SD 71-256
CR-123483

Saturn S-II
Problem Resolution History Report

September 1971

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FOREWORD

This report is submitted by Space Division, North American Rockwell Corporation, to the National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Alabama.

The report provides the results of the "Saturn S-II Problem Resolution History" conducted under Contract NAS7-200, Task Authorization No. 2026-TA-12.

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INTRODUCTION

This document provides a summary of S-II Program problems and the solutions that were implemented. The problems occurred during a period starting with the initial design concepts and continuing through the launch of the tenth S-II flight stage—a period of nine years (1962 to mid-1971). This information is provided for dissemination and use, to the extent practical, on other NASA programs where the extensive Saturn S-II experience can contribute to the avoidance or solution of similar problem areas.

After considering various techniques for presenting the problem information (i.e., film, video tape, briefings, etc.), the published document form was selected as the most useful.

Information is from nine separate disciplines within the S-II Program: design, facilities, logistics, manufacturing, material, program management, quality assurance, safety, and test. If a particular problem is applicable to more than one discipline, it is included in all relevent sections. The basic concept for problem selection by NR was to provide the information that would be useful to other persons and companies facing similar problems in these disciplines. All geographical areas where S-II activities were conducted and where problems occurred were considered in selecting problems for inclusion into this report.

Each problem is presented in a summary form identified by and sectionalized by discipline as follows:

1. Design
2. Facilities
3. Logistics
4. Manufacturing
5. Logistics
6. Program Management
7. Quality Assurance
8. Safety
9. Test

The information presented describes the problem, its effect, and the solutions as they affected that discipline. The two digit code following the discipline name represents the item, operation, or function within the discipline affected by the problem as follows:

01 Documentation
02 Tapes
03 Insulation
04 Welding
05 Fabrication
06 Corrosion
07 Connectors
08 Relays
09 Valves
10 Wiring/Cables
11 Structures
12 Buildings/Grounds
13 Contract
14 Handling/Packaging
15 Management System
16 Color Coding/Marking
17 Contamination
18 Flight
19 Purging
20 Seals
21 B-nuts/Sleeves
22 Component Acceptance
23 Line Assemblies
24 Static Firing
25 Soldering
26 Propellants/Loading
27 Calibration
28 X-ray
29 Commercial Electrical Power
30 Bearings
31 Transportation
32 Electrical/Instrumentation
33 Limited Life/Time Cycle
34 Pressurization
35 Proof-loading
36 Stage/Hardware Protection
37 Vendor Equipment
38 Ground Support Equipment

The last two digits in the summary sheet identification are sequential numbers for each item in the subcategory. For example:

Facilities 12-02

Facilities discipline — Buildings/Grounds — Second facilities problem related to Buildings/Grounds

References indicate sources of additional detail information available from either NR or NASA/MSFC.

CONCLUSION AND RECOMMENDATIONS

Most problems contained in this report would not have developed if they could have been anticipated, permitting corrective action early in the developmental activities of the program. Many valid reasons for action being deferred or unrecognized are apparent. It is hoped that the information in this report may benefit some future program by contributing to corrective action at the appropriate time.

CRITICALITY IDENTIFICATION CRITERIA

PROBLEM STATEMENT AND EFFECT

Early in the Saturn S-II Program development effort, concern existed as to how to achieve initial high reliability, in view of historical data on similar large programs which indicated achievement of high reliability only after repeated failures, redesigns, and schedule slippages. The mission requirement of the Saturn launch vehicle was such as to dictate extremely high reliability since schedule and cost factors were heavy drivers which virtually precluded a "trial and error" approach. A reliability plan, involving a unique criticality analysis and identification methodology, was developed to provide a basis for the attainment of initial high reliability. Subsequent to incorporation of the NR/SD approach, the NASA requested the S-II Program to use an analysis technique for criticality identification which differed considerably (less depth) from the NR method, but which was intended to produce consistency and uniformity with other launch vehicle and payload contractors techniques. The problem existed as to how to accommodate the NASA request for the implementation of the methodology without losing those gains accomplished with the past use of the NR method.

SOLUTION/RECOMMENDATION

The solution resulted in an agreement to utilize both methods and to merge the criticality identifications in failure reports and analysis effort to indicate clearly the mission impact potential.

DISCUSSION

The reliability analysis technique employed from the outset of the S-II Program was directed toward the identification of critical systems and components for the express purposes in: (1) highlighting areas for design redundancy provision considerations; (2) design, development and test controls; and (3) designing an emergency detection system (EDS) to sense critical failures and enable preventive or evasive action. The analysis, known best by the term Failure Mode Effect Analysis (FMEA), was performed in depth taking into account up to, and including third order (three independent failures combining together to produce the undesirable effect) type failures.

Failure modes were defined with respect to time between occurrence and the resultant effect. The definitions were identified as follows:

0 to 500 milliseconds	-	Catastrophic
500 milliseconds to 5 seconds	-	Critical
5 seconds and greater	-	Deferred

In addition, categories of I, II and III were assigned per the criteria listed in Table 1:

Table 1. NR Developed Definitions

Category	Definition
I	1st Order - Catastrophic 2nd Order - Catastraphic 3rd Order - Critical
II	2nd Order - Critical 3rd Order - Catastrophic 1st Order - Deferred
III	2nd Order - Deferred 3rd Order - Critical

The time to hazard identification was designed to enable the development of an emergency detection system (EDS) wherein certain failure modes involving a critical or deferred condition could be detected and displayed in the command module for crew information and appropriate action. The envisioned EDS was never developed because of several reasons, one of which was the difficulty in definitizing the real constituents of the system.

In all, the FMEA effort, was most valuable in highlighting critical areas for either design change consideration or for imposition of controls to assure attainment of the high reliability requirements.

Approximately midway in the S-II development program, the requirements of NASA headquarters Directive No. 26, Saturn V Single Failure Point Control, was imposed on the S-II Program. This directive required an analysis of all S-II systems to determine which components could, with any degree of probability, contribute to a crew loss or mission loss. Single or first order failures only, were to be identified. This directive was imposed upon all launch vehicle contractors and, this with the results obtained, presented to NASA a uniform display of critical areas across the entire launch vehicle.

The accomplishment of this analysis effort, known as the Saturn V Reliability Analysis Model (RAM), placed two methods of failure effects analysis on the S-II Program, each with different definitions of the terms Criticality I, II, and III. A reference to Table 1 and Table 2 will reveal the differences.

Because of differences in the definitions and criticality criteria, and the existence of two methods of effect analysis, consideration was given to deleting the requirements of the analysis per the S-II Reliability Program Plan, SD 62-128. Trade-off considerations indicated that to delete the NR-developed analysis technique, criteria, definitions and the attendant controls, could impact the overall S-II reliability. Both analyses were directed by NASA to continue but with formal document submittals deleted effective S-II-5 and S-II-8 for the NR and NASA analysis methods, respectively.

The use of both analyses techniques created a problem since the definitions of Table 1 and Table 2 for the same criticality category numeric. A solution was needed on how to assign criticality to hardware failures in the failure reporting and failure analysis system, wherein the true impact of a failure would be readily identifiable and understandable for either of the definitions of Table 1 and Table 2.

Table 2. NASA (RAM) Definitions

Category	Definition
I	Single failure (1st Order) points which could result in crew loss
II	Single failure points which could result in mission loss, but not crew loss
III	Failures which would not result in crew loss or mission loss

Negotiations with NASA resulted in a solution to the problem whereby hardware failures would be categorized by Roman numerals I through IV and Arabic numerals 1 through 9. The first categorization covered the definitions of Table 1, and the latter covered the definitions of Table 2. Combinations of these two numerals and the applicability to failures and the associated effects are found in Table 3.

Classes 1, 2, and 5, in combination with the respective category criticalities, comprise all types of failures which have impact potential on the crew and mission.

The combination of these definitions in a common categorization for failure analysis has enabled an accurate display of hardware criticality, and has thus served the purpose of providing the necessary preventive action emphasis in areas where mission reliability could be in jeopardy.

Table 3. Failure/Unsatisfactory Condition Classification

Hardware Criticality Categories	Class	Failure Classification Definitions
Criticality I	1	A failure/unsatisfactory condition that could result in loss of life of any crewmember.
	2	A failure unsatisfactory condition that could result in abort of mission or complete stage/vehicle loss but does not cause loss of life. This includes failures that can cause a definite launch scrub.
	3	A failure/unsatisfactory condition that does not affect Class 1 or 2 classification criteria. This classification includes a failure/unsatisfactory condition that could result in information loss when no significant affect on mission operation is concerned, and conditions that could cause a short launch delay.
	4	Any failure/unsatisfactory condition other than above.
Criticality II	5	A failure/unsatisfactory condition that could result in abort of mission. This includes failures that can cause a definite launch scrub.
	6	A failure/unsatisfactory condition that does not significantly affect mission success. This classification includes a failure/unsatisfactory condition that could result in information loss when no significant affect on mission operation is concerned.
	7	Any failure/unsatisfactory condition other than above.
Criticality III - IV	8	A failure/unsatisfactory condition that does not significantly affect mission success. This classification includes a failure/unsatisfactory condition that could result in information loss when no significant affect on mission operation is concerned.
	9	Any failure condition other than above.

PART NUMBER CONTROL

PROBLEM STATEMENT AND EFFECT

Due to many interpretations (and misinterpretations) of the governing rules for part number identification and reidentification, many parts have been changed without reidentification where new part numbers should have been assigned, and, conversely, configurations have been reidentified where change conditions have not warranted such reidentification, resulting in too few part numbers on one hand and too many part numbers on the other hand, for effective part number control and effective configuration management.

RESOLUTION/RECOMMENDATION

On the Saturn S-II Program at North American Rockwell Corp., a thorough study was made of part number identification and reidentification that resulted in the Company publication (Drawing Requirements Manual, Article 7422A) of part number control instructions. In the Discussion paragraph is a restructure of that publication to describe the fundamental principles of reidentification due to design or requirements revisions; the conditions under which new part numbers should or should not be assigned, as applicable; and the conditions under which component part reidentification should or should not cause higher assembly level reidentification.

DISCUSSION

Part numbers are assigned to component parts, assemblies, and end items to identify in common all configurations which are interchangeable in all applications where used, and to distinguish differing configurations when new or changed designs result in noninterchangeable conditions. The prime function of a part number, as stated in governing NASA and DOD publications, is to control assembly and replacement on the basis of interchangeability or exchangeability.

Certain terms and concepts are employed which are consistent with the governing NASA and DOD directives; certain other terms and concepts are introduced in order to clarify these directives.

The term "exchangeability" is used to describe the capability of two differently numbered parts to be exchanged either completely or conditionally in all applications. Interchangeable parts are capable of being completely exchanged, either one for the other without selection for fit or performance; substitutable parts are capable of being conditionally exchanged, new for old but not old for new without alteration; and replacement or replaceable parts are functionally interchangeable but physically different in that replacement of new part for old requires certain installation operations. When none of these three conditions of exchangeability are met, then the parts are non-exchangeable or non-interchangeable.

A "full effectivity" change is one which is effective on all items on which the affected part is used; a "limited effectivity" change is one which is effective on some but not all of the items on which the affected part is used. A design change is one which affects the hardware or configuration of the affected part; a clerical change is one which affects only the document or drawing, but does not affect the hardware per se. A requirements change is a design change which affects the initial baselined hardware or configuration requirements. A "make-play" change is one that is necessary to make a part meet its initial design requirements and perform in its initial application.

A permanent assembly is one that cannot be disassembled without destruction of one or more of its component parts; a repairable or separable assembly is one which can be disassembled without destruction of its component parts. Either a separable or a permanent assembly may or may not be capable of being "reworked" to accomplish a change.

An installation delineates the attachment of parts in end item position and is not a part per se; therefore, an installation is treated differently from an assembly in certain cases.

A mandatory change is one which must be accomplished; a non-mandatory change is one which is desirable but not absolutely necessary. A mandatory design or requirements change is one which must be accomplished at the specified effectivity point during manufacturing. A make-play change is a mandatory design and requirements change which must have full effectivity application.

The following paragraphs list the rules for component part, assembly identification, and reidentification due to changes. These rules are summarized in Figure 1 which graphically shows the various rules as applied to the noted conditions.

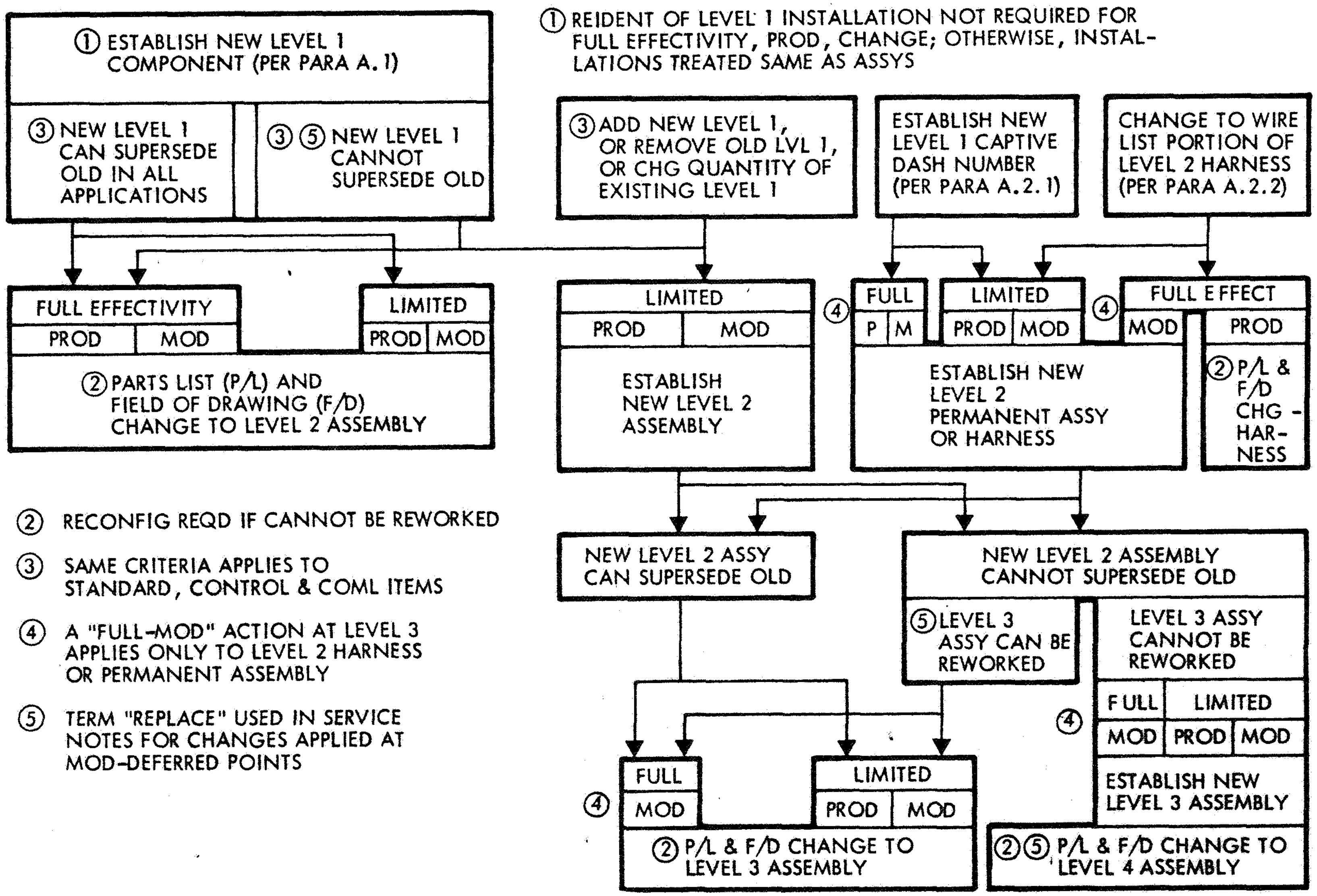


Figure 1. Reidentification Summary

A. Changes Requiring Reidentification

A. 1 Change Level 1 Part Number Requirements (The level to which a requirements change is directed is called Change Level 1.) - A new part number shall be assigned to a component part when a Level 1 requirements change causes any one or more of the following conditions to occur, regardless of whether the change is applied to some or to all of the items on which the component part is effective.

A. 1. 1 When performance or durability is affected to the extent that superseded components must be discarded for reasons of safety, malfunction, or reliability.

A. 1. 2 When superseded and superseding components are not directly and completely interchangeable with respect to installation and performance.

A. 1. 3 When superseded components are limited in use and superseding components are not so limited in use.

A. 1. 4 When a component must be altered or selected.

A. 1. 5 When a material, process, or treatment is changed such that any of the above conditions exist.

A. 2 Change Level 2 Part Number Requirements - A new part number shall be assigned to a Level 2 using assembly when a Level 1 component is reidentified and any of the following conditions occur:

A. 2. 1 A Level 1 requirements change is applied to a captive part. Both the captive part and its parent permanent assembly shall be reidentified.

A. 2. 2 A Level 1 requirements change is applied to the wire list portion of a harness and the change is directed to full effectivity with deferred change points; or if to limited effectivity, the Level 2 harness assembly requires reidentification.

A. 2. 3 The new Level 1 component is applied to some but not all items on which the old Level 1 component was effective, i. e., limited effectivity, and the new Level 1 component cannot supersede the old.

NOTE: This condition also applies when a Level 1 component part is removed from or added to the Level 2 assembly, or when the quantity of a component part is changed; or when an existing commercial control or standard part is replaced by a non-interchangeable part.

A. 2. 4 A new part number shall not be assigned to a Level 2 using assembly when either of the following conditions occur:

(a) The new Level 1 component is applied to some but not all items on which the old Level 1 component was effective (limited effectivity), and the new Level 1 component can supersede the old.

(b) The new Level 1 component is applied to all items on which the old Level 1 component was effective except for conditions in Paragraphs A. 2. 1 and A. 2. 2.

A. 3 Change Level 3 and Higher Part Number Requirements - When a Level 2 using assembly is reconfigured, the Level 3 next higher assembly shall be reidentified if it cannot be reworked to accept the new Level 2 assembly. Reidentification of Level 3 or higher assembly is required whenever rework action cannot be accomplished or is unacceptable. If, for valid reasons, it is desired to reconfigure a Level 3 or higher assembly when such reconfiguration is not required per the above rules, permission to accomplish additional reconfiguration must be obtained from the program Configuration Management function.

B. Changes Not Requiring New Identification

When a part or assembly is changed in such a manner that none of the conditions in Paragraph A occur, the part number shall not be changed. Under no condition shall the number be changed when a new usage is found for an existing part.

B. 1 Examples of changes not requiring reidentification:

(a) Correcting clerical errors

(b) Incorporating outstanding EO's without changes

(c) Adding view and reference data

(d) Revising usage data

(e) Adding information without which it is impossible to complete the part

(f) Correcting P/L changes to detail part material specification

(g) Changes to reference documents

Design 01-03

DOCUMENTATION OF CHANGES TO KSC SPECIFICATIONS AND CRITERIA

PROBLEM STATEMENT AND EFFECT

The change procedure for the KSC Specifications and Criteria document was such that it did not reflect the actual hardware configuration of the stage. In addition, the revised pages did not indicate the changes that had been made to the document. This incompatibility and lack of change traceability caused confusion.

SOLUTION/RECOMMENDATION

The problem was resolved by revising the KSC specifications and criteria change procedure. It now requires the Revision Change Notice (RCN) to be submitted with the ECP to MSFC/NASA for approval on all changes. Approved by MSFC, the RCN's are released as document change pages in a change package. These change pages contain the MSFC-approved requirement changes and the applicable RCN number, which indicates the delta from one revision to the next. The change package also contains a page revision log that identifies the current status of every page in the document by its latest issue.

DISCUSSION

Initially, test requirement changes to the KSC Specification and Criteria document were written and coordinated between Seal Beach Engineering and KSC as problems occurred. These test requirement changes were documented on RCN's and sent as a package to MSFC for approval. If, after two weeks no dissenting comments were received, the package was assumed to be in effect. These RCN's were subsequently incorporated as a revision to the document. Since the revised document did not show the difference from one change to the next, there was no indication of the change status.

Implementation of the present system was supplemented by final NASA concurrence of the changes at KSC through NASA submittal of a Notification of Requirements Acceptance (NORA) form to MSFC to close the change loop.

Design 01-04

DOCUMENTATION OF CHANGES TO AUTOMATIC CHECKOUT PROGRAMS

PROBLEM STATEMENT AND EFFECT

Improper documentation of changes to the automatic checkout programs will result in the need for a complete review after each revision to ensure correctness of changes and to maintain awareness of program details.

SOLUTION/RECOMMENDATION

This was solved for the S-II by attaching computer-generated IS-WAS listing sheets to the software modification sheet (SMS). The SMS is the official program change authorization that defines the changes to be made to the checkout tape. The IS-WAS listings provide the customer with information on what changes were made in the ATOLL and what portions of the program were affected.

For future programs it is recommended that both the SMS and IS-WAS listing for all program changes be attached as an appendix to the released Program Listing Document (PLD). This will make available more information, concerning the checkout programs, to testing personnel.

DISCUSSION

S-II stage changes that affect automatic checkout software programs must be implemented and documented, as they are authorized, in time to support stage checkout. Normally a change only affects portions of a particular checkout program. However, the process of implementation is such that a retranslation of the revised card image tape is required before generating new program listings and checkout tapes. The new program listing is a document of the checkout program in symbolic language (ATOLL).

The following information is contained in an SMS:

1. SMS Number (Program revision number) and date
2. MCR or GO number
3. Revision
4. Priority

Design 01-04

5. Hardware affected

6. Title of change

7. Initiator

8. Program number, old and new

9. Description of change

10. Reason for change

11. References

12. Verification required

13. Program tape change required ____ YES ____ NO

14. Program document change required ____ YES ____ NO

15. Space for remarks

16. Space for engineering, site manager and customer approval, signature and dates.

DOCUMENTATION OF LARGE WIRING INSTALLATIONS

PROBLEM STATEMENT AND EFFECT

Engineering drawings documenting wire harness routing on the S-II are very large because the routing for complete areas, i.e., aft, forward, LH_2 tank, etc., is shown on single drawings. These large multiple-sheet drawings are extremely hard for the various using organizations to handle.

SOLUTION/RECOMMENDATION

The problem was partially solved by breaking the large-area drawings into smaller area segment drawings. Recommendations for further simplifying the documentation are as follows:

1. To eliminate the views showing the differences in installation procedures by creating a ship-by-ship drawing release for each vehicle.

2. To establish ground rules for clamp installations and to utilize a matrix of tabulation blocks and eliminate the pictorial representation. Actually to revise the drawing format.

3. To establish the necessary photographic log books (contractual), to depict the actual installation pictorially, and to fabricate, install, and inspect accordingly.

4. To revise the DRM and specifications to allow more lateral tolerances in depicting detailed items. Those items presently simplified are clamps and connectors shown in box form. Harnesses could be shown as single heavy lines on the drawing in lieu of depicting the actual size and specific enlarged views required.

DISCUSSION

The documentation required to describe large electrical installations are justifiably large. Many pictorial views are required to show wire narness installation location, hardware requirements, and proper identification. Wire harness routing is documented by using information taken from a wiring mockup. The actual vehicles on which the harnesses are installed vary due to dimensional tolerances. This variation causes more views to be added to the drawings to document the differences between vehicles, i.e., the as-installed configuration; thereby the size and complexity of the drawing is increased.

The procedures for documenting large wiring installations, developed early in the S-II program, consisted of using a single multiple-sheet drawing for each major area on the vehicle. These drawings became extremely large and cumbersome as the program progressed.

MAINTENANCE OF STAGE ELECTRICAL SCHEMATICS

PROBLEM STATEMENT AND EFFECT

Early in the S-II Program, each stage electrical schematic book which formed a part of the as-built data package was updated in three increments to correspond to (1) the stage as initially delivered to the static firing site, (2) as initially delivered to the launch site, and (3) to the final flight configuration. This caused concern during in-process modifications and troubleshooting in that it was difficult to ascertain the exact as-built configuration.

SOLUTION/RECOMMENDATION

A schematic change package release system was implemented to allow design changes to be released incrementally and incorporated into the as-built schematic book upon physical modification to the stage.

DISCUSSION

Implementation of the above resolved the problem with the S-II and a modification of this system was implemented for GSE and end-to-end schematics. In each case, periodic reviews during manufacturing and at the test and launch sites are required to verify compatibility of the as-designed master schematic with the as-built master schematic.

AUTOMATIC CHECKOUT PROGRAMS

PROBLEM STATEMENT AND EFFECT

Automatic checkout tests are normally constructed to verify complete stage subsystems performance. Component replacement requires retest to ensure proper system and/or component operation. Improperly constructed automatic checkout programs will require rerunning of entire subsystem tests; thus increasing checkout time unnecessarily.

SOLUTION/RECOMMENDATION

The S-II automatic checkout programs were re-written in modular fashion for checkout of system functions and individual components. For example, the electrical power automatic checkout program has five different parts or procedures that had to be run to verify performance of the six dc bus networks. A repaired failure in one bus network could be verified by selecting the electrical power program and going to the procedure that checks out the repaired bus power network and components.

Adequate program options and program execution flexibility are essential. Display of prerequisite and initial conditions, and warnings of potential hazardous conditions at the beginning of each of the modularized procedures will provide the test personnel with valuable tools.

DISCUSSION

Checkout of the S-II stage at the manufacturing and static firing sites was accomplished by execution of computer software programs written to meet requirements per acceptance test specifications at the system level. Computer programs were written to verify flight readiness of each S-II stage by checkout of the following subsystems: (1) electrical power, (2) pressurization, (3) engine, (4) propellant feed, (5) measurement, (6) propellant management, (7) propellant dispersion and range safety, (8) separation and, (9) engine actuation.

All programs were run and all systems verified prior to running the final simulated flight program at the manufacturing and static firing sites. In the course of running the subsystem programs, a component failure could occur within a system that had previously passed all acceptance test requirements. A component failure in a system which invalidates a prerequisite requirement for testing another system will require corrective action prior to successful checkout of the latter system. Once this corrective action has been taken and the defective component has been repaired or replaced, the problem is performing only that portion of retesting required to verify satisfactory operation of the first system. While the retest requirements are fixed by system design, the amount of retest which must be accomplished is governed by the construction of the checkout program. The checkout programs for the nine S-II subsystems mentioned above were written in a modular form to accomplish checkout of individual components; thus simplifying the task of retest.

FUNGUS CONTROL

PROBLEM STATEMENT AND EFFECT

During functional checkout of the S-II at the Mississippi Test Facility (MTF) the stage was often positioned in the test stand exposed to the elements for periods of up to several months. During these periods, areas of insulation on the sidewall and forward skirt darkened as a result of fungal attack. The degree of discoloration was severe enough to be noticeable at a distance of 100 yards from the vehicle. Visual assessment revealed that the infestation was concentrated on cork insulation ramps coated with a fungus-resistant polyurethane seal coat and fungus-resistant vinyl top coating.

SOLUTION/RECOMMENDATION

The problem was resolved by cleaning the discolored insulation coatings with a solution of trisodium phosphate, chlorine, and water followed by re-application of the white vinyl top coat, when necessary. In addition, periodic inspection of the vehicles was implemented to identify the fungal attack in its early stages and to arrest its growth with the cleaning solution. It was recommended that for future exterior coatings where the material will be exposed to long term, static, outdoor exposure, that periodic cleaning or fungus-inhibiting (not fungus resistant) coatings be resorted to.

DISCUSSION

Laboratory evaluation revealed that the infestation occurred as a result of microbiological organisms present in the Mississippi atmosphere which attached themselves to the ramp areas of the stage. These organisms were nourished not by the coating, but rather by particulate matter (dirt, grease, body oil, etc.) which accumulated on the stage surface.

Rubber, plastic coatings, and paint films serving as physical barriers between materials and microorganisms may prevent deterioration so long as they remain continuous and intact. Once the protective coating cracks, erodes, or becomes damaged or wet, degradation proceeds rather rapidly. Although paint films are seldom broken down by microorganisms, they are frequently splotched and blackened by mildew. Fungi growing on the surface of paint films subject to high humidity cause dirt to adhere to these films, and the fungus then obtains nutrients from the dirt and proliferates. This compounds the problem of discoloration.

Because of the many contacts between the top coating material and humans during operations, and due to ambient conditions and the availability of nutrients, elimination of microbial contamination is virtually impossible. The problem can be minimized, however, through good housekeeping and control measures. The most practical and economical approach to resolution of the present discoloration problem involves the use of a surface-active agent to wash the stages followed by a resurfacing with a top coat containing a compatible fungicide.

Design 03-02

SPRAY FOAM EROSION ON LH_2 TANK SIDEWALL

PROBLEM STATEMENT AND EFFECT

Use of an erodable external insulation resulted in degradation of insulation quality around protuberances in high heating and shear areas. These protuberances contained components, such as LH_2 feed lines and pyrotechnics, which must be protected from boundary layer heating.

SOLUTION /RECOMMENDATION

Erosion barriers were installed to protect the spray foam insulation. In certain critical areas, foam was replaced with a honeycomb foam insulation, with high temperature covers. It is recommended that the use of erodable materials be avoided in areas in which system or component failure could result from material loss. If such use cannot be avoided, protect the erodable material with an erosion barrier.

DISCUSSION

Spray foam insulation was proposed to replace the helium-purged foam-filled honeycomb insulation as the LH_2 tank sidewall insulation. The spray foam provided lower overall costs and weights for a more efficient thermal insulation. Preliminary tests indicated a good resistance to erosion at room temperature, and a good resistance to thermal degradation at very low shear stress.

The simulation requirement for a flight-environment time history of temperature and shear stresses led to a test program on the X-15 airplane. The use of test data (including trajectory information, static and pitot pressure measurements, in-flight photography, post-flight examination, and imbedded thermocouple data) and digital computation programs with detailed thermal models, led to a method of predicting the erosion-time history for panels experiencing the basic sidewall environment and the environment near protuberances. The predictions of erosion near protuberances led to requirements for protection of the foam against those losses which would permit hot boundary layer gas to impinge on temperature sensitive components, such as LH_2 feed lines and pyrotechnics. High-density cork bonded to the spray foam and penetrating the foam to a position close to the tank wall was proposed. Difficulties arose in preventing debond of the cork from the foam, or cracking and debonding of the foam from the tank sidewall.

Thus, in especially critical regions near protuberances, the spray-foam cork barrier is replaced with a foam filled honeycomb with a high temperature cover.

CORK/FOAM DEBOND BACKGROUND

PROBLEM STATEMENT AND EFFECT

Upon S-II propellant detanking the cryopumped gasses expand and build up pressure within the insulation causing cork foam debonds. Attempts were made to seal all potential leakage areas. This solution technique was not successful in eliminating the cork/foam debond problem.

SOLUTION/RECOMMENDATION

The source of the leakage was traced to the fairing standoffs. Isolating the cork from the fairing standoffs has eliminated these as potential problem areas. Testing (Reference 1) has shown no problems around the isolated standoffs and tanking histories on S-II-9 and subs have shown no debonds originating from the isolated fairing standoffs.

DISCUSSION

Cord bonded over foam is used in conjunction with the cork and core rail configuration to protect the underlying foam from excessive erosion during the boost phase of the Saturn V mission. The cork over foam design has been proven adequate through laboratory testing (Reference 2) and stage preflight tests. There have been problems, however, with cork to foam debonds as the result of the cryopumping of condensible gasses through leak paths in the insulation.

A test program with analysis was undertaken to attempt to duplicate the conditions leading to the debond problems. This program did confirm (Reference 3) that, if leaks occur in the insulation and if air is allowed to cryopump, the cryopumped gasses on expansion will result in the debond conditions observed in the S-II insulation.

Various techniques were considered for solving the cork debond problem. These included perforation of the cork with a specific hole pattern to reduce the size of any debond area, grooving the foam surface under the cork to allow for venting of any cryopumped gasses, sealing of all areas which could constitute a potential leak path, and isolating potential leak paths from the cork/foam areas.

The results of the effort to groove the foam or perforate the cork (Reference 1) showed these techniques to be unsuccessful in preventing large debonds from occurring. Sealing of the leakage areas has been successful to some degree as observed from the stage post-test observations. However, it has been shown that 100 percent sealing cannot be achieved and cork/foam debonds will still occur where there are sufficient leakage conditions.

REFERENCES

1. "S-II-12 Cork Debond Investigation and Evaluation of Repair Techniques," Ltr 7685-4553 (May 11, 1970).

2. Structural Verification of Cork Over Spray Foam in Hot-Spot Areas of Saturn S-II Stage, (July 15, 1970) SD 69-96.

3. "Cork Debond Evaluation When Subjected to Entrapped, Vaporized LN_2," Ltr 7159-4540 (February 27, 1970).

HEAT LEAK THROUGH COMMON BULKHEAD

PROBLEM STATEMENT AND EFFECT

The heat transfer through the common bulkhead was found to be higher than predicted because the effective gas heat transfer was greater than predicted due to convective circulation in the 3/8 by 4.75-inch honeycomb cells. The increased heat transfer caused the pressurizing gas in the LOX tank to be chilled more than planned, thus resulting in a GOX pressure decay. The heat rate to the liquid hydrogen was also increased.

SOLUTION/RECOMMENDATION

The heat transfer through the common bulkhead was reduced by connecting a vacuum pump to the bulkhead and reducing the pressure. This reduced the quantity of gas in the honeycomb which therefore reduced the heat transfer by changing the heat transfer mode from convection to conduction. In determining the heat transfer through a honeycomb structure, the convection as well as the conduction of the gas should be included in the original heat transfer evaluation.

DISCUSSION

Prior to liftoff the LOX tank is pressurized with helium gas. Added chilling of the gas during first stage boost caused the tank pressure to drop. Pre-chilling the helium to below 350 F as delivered to the LOX tank was impractical, as was the redesign of the valving and tank structure. During pre-launch, there was a purge of the cavity between the two facing sheets of the common bulkhead. The requirement for a continuous purge was modified and vacuum pumps were utilized to lower the pressure, thus reducing heat leak and changing heat transfer mode from circulation in the individual cells to conduction.

Design 03-05

HONEYCOMB RAIL DEBOND

PROBLEM STATEMENT AND EFFECT

During LH_2/LOX cryogenic tankage of the first S-II stages utilizing SOFI (spray-on foam insulation) at the Mississippi Test Facility, numerous foam debonds occurred. Detailed investigation revealed that an entire honeycomb rail was debonded from the LH_2 tank wall. The rail had been bonded with a 0.0035-inch-thick glass scrim/Lefkoweld adhesive system utilizing vacuum bag pressure to maintain intimate contact. The rail was 8 feet long, approximately 7-1/2 inches wide, and 1.6 inches deep at the heel tapering to 0.4 inch at the toe. The rail was debonded across the width for the full length except for approximately 3/4 inch at the toe. A cursory evaluation brought the thickness of the adhesive system into question. Preliminary measurements revealed the adhesive thickness at the heel to be a nominal 50 mil thickness tapering across the width to 20 mils. The debond had occurred at a time that the stage was subjected to -423 F temperatures at a stress level of around 54000 psi in the base metal. At this time, it was suspected that the thick adhesive had caused excessive shear strains at the bond line. The problem was to prove the cause of debond, determine the allowable adhesive thickness, and modify the design and processing to prevent recurrence.

SOLUTION/RECOMMENDATION

The bonding process was changed to assure rail bond line thicknesses of less than 0.023 inch. The damaged stage rails were reworked and subjected to a second cryogenic proof pressure test. No failures were encountered. All subsequent stages were built by the new process. No further failures were encountered during cryogenic proof tests.

DISCUSSION

Spray foam insulation was partially or totally used on the S-II-4 and subsequent stages to replace the 1.6-inch honeycomb thermal insulation. In the single and multiple shock protuberance areas, it was found that the foam experienced excessive heating and erosion, thereby requiring protection from aerodynamic shear. The erosion mainly occurred in the regions around the LH_2 feedline fairing and the fill-and-drain fairings. The foam erosion was prevented by bonding foam-filled 3/8-inch honeycomb core rails in a rectangular arrangement around the fairings. Sheets of 30-pound-per-foot, 1/4-inch-thick cork were bonded over the foam and rails so that the cork protected the foam from aerodynamic shear.

From previous experience it was known that relatively thick bond lines will fail due to thermal stresses when chilled to cryogenic temperatures. The main question concerned the specific value of the maximum allowable thickness. A test program was initiated to identify the critical bond line thickness. The testing was accomplished by constructing aluminum dogbone tensile specimens 3 inches wide and 24 inches long and bonding a representative cross section of the rail to the aluminum. These dogbone specimens were then subjected to tensile stress of 54, 000 psi, at -423 F. The specimen failed in bond line shear at various tensile stresses depending on the particular adhesive thickness. After testing, each rail bond line was removed and the thickness was measured in a grid pattern. The adhesive thermal strain plus the applied mechanical strain were than calculated as a function of the bond line thickness for each test specimen. The thermal strain increased with thickness, thereby increasing the thermal portion of the bond line shear. The tests revealed that the thicker bond line specimens failed at lower applied mechanical strains. All specimens with a total thermal plus mechanical strain of less than 0. 00105 inch per inch passed with no failures, whereas all specimens subjected to total strains above 0. 0011 inch per inch failed. From these data, it was apparent that the 0. 050-inch stage rails had failed from excessive thermal strain. The calculated stage cryogenic plus mechanical strains were then calculated versus bond line thickness for the cryogenic proof test and superimposed on the test results. The crossing of the 0. 00105 inch-per-inch allowable line and the stage strains revealed the maximum allowable bond line thickness to be 0. 023 inch. The stage rail bond line thickness was mapped and it was found that the areas on the rail toe which did not debond were less than 0. 023 inch while the debonded portions were greater than this value.

INSULATION FLEXIBLE CLOSEOUTS (RUBBER DOUBLERS)

PROBLEM STATEMENT AND EFFECT

During cryogenic testing of the first S-II flight stages, cracking of the insulation rubber doublers occurred. Cause of the problem, and redesign implementation if required, had to be determined in time to support launch schedules; otherwise, launch delays would occur.

SOLUTION/RECOMMENDATION

The rubber doublers (RTV 560 silicon rubber tape) were replaced with nylon/Narmco 7343 wet layups which proved capable of withstanding environmental extremes.

DISCUSSION

The S-II-1, S-II-2, and S-II-3 were thermally insulated with 3/4-inch cell foam-filled HRP honeycomb core 1.6 inches deep with a phenolic nylon outer facing sheet. These insulation panels were bonded to the hydrogen tank quarter panels over the entire surface area except for a 5-inch region around the perimeter. This region was not insulated until all panels were welded into the complete LH_2 tank. The close-out area over the weld lands was then filled with bonded insulation strips to complete 100-percent insulation of the LH_2 tank. Due to structural compatibility requirements, the outer phenolic nylon facing had to be spliced at the butted edges. This was accomplished by using 2-inch-wide RTV 560 silicon rubber tape to bridge the butted joint.

During LH_2 tankage tests at the Mississippi Test Facility these flexible closeouts began to crack due to the cold environment. Since the insulation system was designed for continuous gaseous helium purging, leaks occurred, causing an overload on the ground purge system. There were four longitudinal closeouts 90 degrees apart and six circumferential closeouts with a total length of approximately 19,000 inches. Numerous cracks occurred and in some places long strips of the rubber material fractured. The RTV 560 silicone had undergone a second-order transition and become brittle due to excessively low temperatures even though this material was reported by specification to be usable down to -220 F. The worst outer surface temperature was predicted to be -160 F on a 28 F Florida day with 0.8 inch of frost over the surface. Since the stage would be re-tanked with LH_2 on the countdown demonstration test at Kennedy Space Flight Center in Florida and subsequently on launch it was imperative that the cause of the problem be determined and that the necessary redesign and rework be accomplished prior to countdown demonstration test.

Investigations as to the cause of the problem revealed that the flexible closeouts had become excessively cold. The 3/4-inch cell honeycomb core was designed to be filled with isocyanate foam to prevent convection. In the normal fabrication process, the phenolic facing sheet was first bonded to the HRP 3/4 inch honeycomb core. The panel size was approximately 100 by 300 inches. The isocyanate foam was then pressed into the cells on the open side and recessed 1/8 inch to allow purge circulation under the vented core. It was found that the bonded assembly was later trimmed to size to fit the quarter panels. This trimming operation left cut or partial hexcells which gave little support to the impressed isocyanate foam. On later closeout assemblies the facing sheets had to be spliced for strain compatibility; however, there was no requirement for core splicing since no shear forces existed. Later evaluation revealed that there was no isocyanate foam on the assembled stages in the butted imperfect cells under the flexible closeouts. When the LH_2 tank was later filled with liquid hydrogen, convection occurred in the open cells under the closeout, causing the silicone rubber closeout to reach temperatures as low as -240 F. Since all rubber compounds have a second-order transition at various cryogenic temperatures, the mechanical properties of RTV 560 were determined by tensile tests. The tests revealed that the second-order transition occurred somewhere between -50 F to -100 F. Below these temperatures the rubber compound became increasingly brittle. Evaluation tests indicated that the lowest allowable temperature that the elongation of the rubber could stand under strain application was -160 to -180 F. For this reason, the RTV 560 closeout was eliminated and a phenolic nylon closeout was used with a polyurethane bonding system. On the rework or repair operations for the stages the isocyanate foam was replaced in the core butts prior to bonding the closeouts. Later cryogenic tankages of the reworked stages proved to be trouble free.

Design 03-07

FAILURE OF OUTER LAMINATE FOR 1.6-INCH PURGED INSULATION

PROBLEM STATEMENT AND EFFECT

Early test and flight stages utilized purged insulation for thermal protection of the LH_2. The insulation composite was made of polyurethane foam supported in a heat resistant phenolic (HRP) honeycomb core and sealed on the outer surface by a tedlar-nylon-phenolic laminate. The composite was bonded to the external surface of the LH_2 tank. Channels were cut diagonally through the bottom of each cell in the HRP core to permit the passage of the helium purge gas along the surface of the LH_2 tank structure. The purge gas served the dual function of (1) preventing intrusion of air which could condense along the cryogenic surfaces and (2) providing a capability for identification of structural leaks through analysis of the effluent purge gas. The system was pressurized in the course of manufacturing and installation to ensure structural integrity of the composite. It was also pressurized to operational levels while cryogens were loaded. During these periods of pressurization failures were experienced in the adhesive bond line that joined the outer laminate to the HRP core.

Failure of this type during cryogenic operations voided insulation performance, created hazardous cryopumping conditions, and precluded detection of leaks in the LH_2 tank structure.

SOLUTION/RECOMMENDATION

An extensive program was undertaken to determine the causes of the failures and establish corrective actions. Changes were made to:

1. Strengthen specifications
2. Enhance producibility and improve quality
3. Improve quality assurance
4. Bring fabrication of the basic insulation in-house
5. Expand manufacturing capability and sophistication
6. Develop repair capability.

The principal technical problem was found to be the choice of adhesive for bonding the outer laminate to the HRP core. The HT 424 adhesive was changed from Type I to Type II to increase the bond line thickness.

DISCUSSION

The initial significant defect was the delamination of a large section of the forward bulkhead insulation on the CBTT. This section was approximately six feet long by three feet wide. Failure occurred at low internal pressure. Analysis of this one failure triggered each of the actions listed previously, for example:

1. Areas with little or no imprint from the honeycomb core indicating that the supplier did not apply proper bonding pressure at the time of fabrication.

2. Lack of stubble (small pieces of core) in the imprint which indicates substandard adhesive strength, possibly due to overage adhesive.

3. Inclusion of small pieces of core and foam lying flat across the imprints--no bond to HRP.

4. Wrinkles in the adhesive indicating that the adhesive or core was moved after being put in place and before bonding.

The HT424 adhesive is a modified epoxy supported on fiberglas carrier cloth. It was initially selected based on laboratory demonstration of ability to meet temperature and structural requirements. Type I adhesive was selected because it is approximately 50 percent of the weight of Type II. The change to Type II adhesive approximately doubled the bondline thickness. This provided the advantage of a more generous fillet between the laminate and the HRP core and is more tolerant of mismatches and defects in the core. This change, combined with the improved processing, quality, manufacturing, and test procedures, resulted in elimination of bondline failures due to fabrication.

Design 03-08

INSULATION SYSTEM HISTORY, EVALUATION OF INSULATION ON S-II STAGES

PROBLEM STATEMENT AND EFFECT

On the S-II insulation system, several changes were made during development. Each change was instituted as a result of (1) new knowledge in cryogenic technology generated by NASA/MSFC, or (2) desire for product improvement. The insulation system resulting from each change has met or exceeded the system requirements.

SOLUTION/RECOMMENDATION

The insulation system design as initially proposed was based upon the requirement that it limit the LH_2 boiloff during ground hold to less than 6 percent of tanked quantity per hour. An insulation system using 0.33 inch of foam supported by phenolic glass honeycomb and sealed with glass phenolic laminate was proposed.

Following an extensive investigation of the phenomenon of stratification of LH_2 in large diameter tanks, NASA/MSFC required the insulation thickness to be extended to 0.8 inch. This requirement was later changed to include effective thermal conductivity of 0.7 Btu/in. per $ft^2/hr/°F$ to meet all program missions.

Following an evaluation program, the design was changed to a 1.6-inch-thick foam-filled honeycomb helium-purged system. This design was later changed to sprayable polyurethane foam, which resulted in an improvement in performance and a marked reduction in weight.

DISCUSSION

The chronological evolution of the insulation system is shown in Figure 2. While helium was used to preclude the intrusion of air into the insulation, it also provided for a system to detect defects in the LH_2 tank structure with no weight penalty to the stage by passing the helium through the channels cut in the bottom of the honeycomb.

Although six insulation systems were evaluated on the program, only two were installed on the flight stages.

1. The 1.6-inch honeycomb helium purged insulation was used on stages S-II-1 through S-II-7.

2. Spray foam insulation was employed on S-II-8 through S-II-15.

Table 4 is a matrix which shows the insulation used in individual areas on each stage.

Performance of all stages in flight has exceeded requirements as follows:

1. Ground hold LH_2 boiloff

Allowable	159 lb LH_2 per minute (6 percent per hour)
Prior stages	110 lb LH_2 per minute
S-II-8	49. 5 lb LH_2 per minute (MTF - cold day)
S-II-9	57 lb LH_2 per minute (MTF - hot day)
S-II-10	Not measured

2. Flight, total heat to LH_2 from all sources

Allowable	209, 000 Btu
Prior stages	140, 000-170, 000 Btu
S-II-8	65, 000 Btu
S-II-9	65, 000 Btu (estimate)
S-II-10	65, 000 Btu (estimate)

3. LH_2 temperature at engine inlet at T-22 seconds

Redline	-420. 5 F
S-II-8	-422. 1 F
S-II-9	-422 F
S-II-10	-421. 8 F

4. LH_2 temperature at engine start

Allowable	-416. 3 F (43. 7 psia)
S-II-8	-422. 0 F (T + 165 sec)
S-II-9	-422, 4 F (T + 166 sec)
S-II-10	-422. 2 F (T + 162 sec)

Total cryogenic experience is shown in Table 5.

Design 03-08

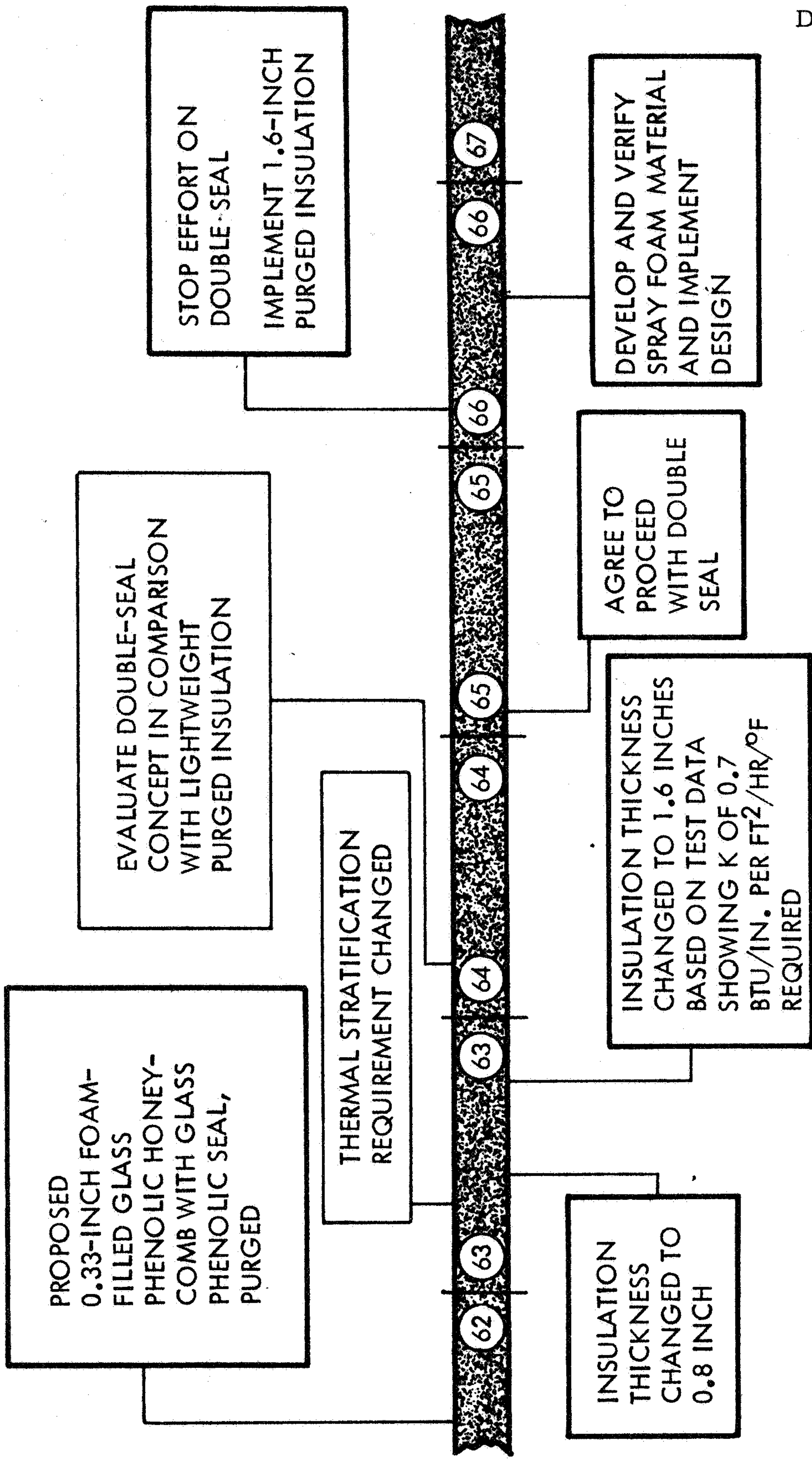


Figure 2. Insulation System History

Table 4. Insulation Matrix

Area	Vehicle									
	S-II-T	S-II-F	S-II-1	S-II-2	S-II-3	S-II-4	S-II-5	S-II-6	S-II-7	S-II-8 through S-II-15
Forward bulkhead	1/2-inch-thick honeycomb, helium purge							Spray foam		
Forward bulkhead uninsulated area	Membrane seal, helium purge							Debris barrier		
Forward skirt	Foam blocks, honeycomb panels, helium purge									Spray foam, foam sheets
LH_2 tank sidewall	0.8-inch thick honeycomb, helium purge (buy item)		1.6-inch-thick honeycomb helium purge (buy item)			1.6-inch-thick honeycomb helium purge (NR make item)				Spray foam
LH_2 tank cylinder 1	Honeycomb, helium purge				Foam blocks, foam sheets, helium purge			Spray foam, foam sheets		
LH_2 tank bolting ring	Honeycomb, helium purge	Foam blocks, foam sheets, helium purge						Spray foam, foam sheets		

Design 03-08

Table 5. S-II Cryogenic Experience

Stage	Total Cryogenic Experience	MTF				KSC			
		Tanking	Cryogenic Proof	Firing	Acceptance Firing	CDDT	Repeat CDDT	Launch	Mission
T	12	3/26/66 3/29/66 4/9/66	4/10/66	4/23/66 5/7/66 5/10/66 5/11/66 5/16/66 5/17/66 5/20/66 5/25/66					
F	2					10/8/66	10/12/66		
1	10	10/17/66 11/23/66		12/1/66 12/22/66	12/30/66	10/4/6	10/11/67 10/13/67	11/9/67	Apollo 4
2	5			3/31/67 4/6/67		3/31/68		4/4/68	Apollo 6
3	7	9/6/67	5/29/68	9/19/67	9/27/67	12/9/68	12/10/68	12/12/68	Apollo 8
4	6	1/16/68	3/22/68	1/30/68	2/10/68	2/18/69		3/3/69	Apollo 9
5	6		4/30/68	7/25/68 8/1/68	8/9/68	5/5/69		5/18/69	Apollo 10
6	4		8/17/68		10/3/68	7/2/69		7/16/69	Apollo 11

Table 5. S-II Cryogenic Experience (Cont)

Stage	Total Cryogenic Experience	MIF				KSC			
		Tanking	Cryogenic Proof	Firing	Acceptance Firing	CDDT	Repeat CDDT	Launch	Mission
7	4		1/15/69		1/22/69	10/28/69		11/14/69	Apollo 12
8	4		3/28/69		4/8/69	3/25/70		4/11/70	Apollo 13
9	4		5/23/69		6/20/69	1/18/71		1/31/71	Apollo 14
10	2		8/15/69		10/1/69	7/13/71		7/26/71	Apollo 15
11	2		10/31/69		11/14/69				
12	2			2/26/70	3/5/70				
13	2	5/8/70			4/30/70				
14	1				7/31/70				
15	1				11/4/70				

WELDED 6061 ALUMINUM FOR AEROSPACE HARDWARE

PROBLEM STATEMENT AND EFFECT

Base metal cracks occur from high frequency arc impingement during manual gas tungsten arc welding of 6061 aluminum alloy. This type of cracking occurs on many fillet weld joints which results in excessive repairs.

Cracking also occurs on manual butt and fillet welds at start and stop areas on material thicknesses of less than 0.050 inch. An investigation of a part number of this type showed that 50 percent of the assemblies required from one to seven rework operations per part.

Heat treatment of 6061 welded assemblies has also been a problem during S-II hardware fabrication. These weld assemblies are extremely crack-sensitive, resulting in numerous repairs and hardware schedule delays.

SOLUTION/RECOMMENDATION

High-frequency cracking is a typical problem associated with the welding of 6061 aluminum material. There is no known solution to this problem except a change in the material to be welded. However, the welding operators were given special training to improve their welding technique which reduced the magnitude of the problem.

The weld "heat treat" problem was solved by a design change to an "as welded" assembly.

A recommendation was made to replace all 6061 material requiring welding with the 5000 Series alloys on any follow-on contract. This change will completely eliminate the high frequency cracking on the parts in question.

DISCUSSION

The 6061 welding problem originates with the development of the alloy by the aluminum producers. Cracking has always been present, but in the past this alloy was the only weldable alloy that could be heat treated after welding. A welding technique for 2014 alloy was developed on the Saturn Program, and 2219 and 2021 weldable alloys are very recent developments.

Although the aluminum companies still list 6061 as a weldable alloy, their technical representatives admit the inferior characteristics of this material. Since the melting practices for the 6061 are not as closely controlled as other structural alloys, the cracking sensitivity appears to be related to the purity of the alloy. In recent years the industry trend has been to eliminate 6061 material from welded assemblies and to replace it with more readily weldable alloy such as the 5000 Series materials.

Design 04-02

WELD INTERSECTIONS AND STRESS RELIEFS

PROBLEM STATEMENT AND EFFECT

A review of the LH_2 tank cylinder welds was performed in 1964 after receipt of new test data concerning weld allowable strength. At this time the stress analysis indicated a marginal condition in the vertical weld joining the circumferential weld (weld crossover). In an effort to reduce the load imposed on the vertical weld juncture, the circumferential weldland thickness was reduced (commonly referred to as "stress relief") in the first bay on each side of the crossover (Figure 3). An inspection performed subsequent to the S-II-7 proof pressure test revealed a crack in each of the two "stress reliefs."

SOLUTION/RECOMMENDATION

Tests were performed on small laboratory specimens which reproduced the plastic deformation of the "stress relief" region and assisted in stress analysis of the weld crossover region. A repair technique was developed for use in the Material Review disposition of the S-II-7 cracked regions and was verified by test of welded panels. "Stress reliefs" were eliminated on S-II-9 and subsequent vehicles. Large gussets were incorporated into the S-II-11 and subsequent designs which improved the crossover design (Figure 3). Subsequent large panel tests were performed which verified the structural integrity of the crossover region for all flight stages. The tests described above are documented in detail in the reference.

Although the addition of "stress reliefs" in the LH_2 tank may have reduced the stress levels at the weld crossover, the discontinuity stresses induced into the "stress relief" area by local notch effects resulted in a marginal condition. Therefore, the overall design of the crossover region was not improved. One solution would have been a "stress relief" without notch effects.

The solution incorporated into the S-II-11 design was to add a larger transition gusset at the weldland intersection. The addition of the larger gusset caused the total load at the weld intersection to be distributed over a larger area thereby reducing the peak stress level at the weld intersection.

Design 04-02

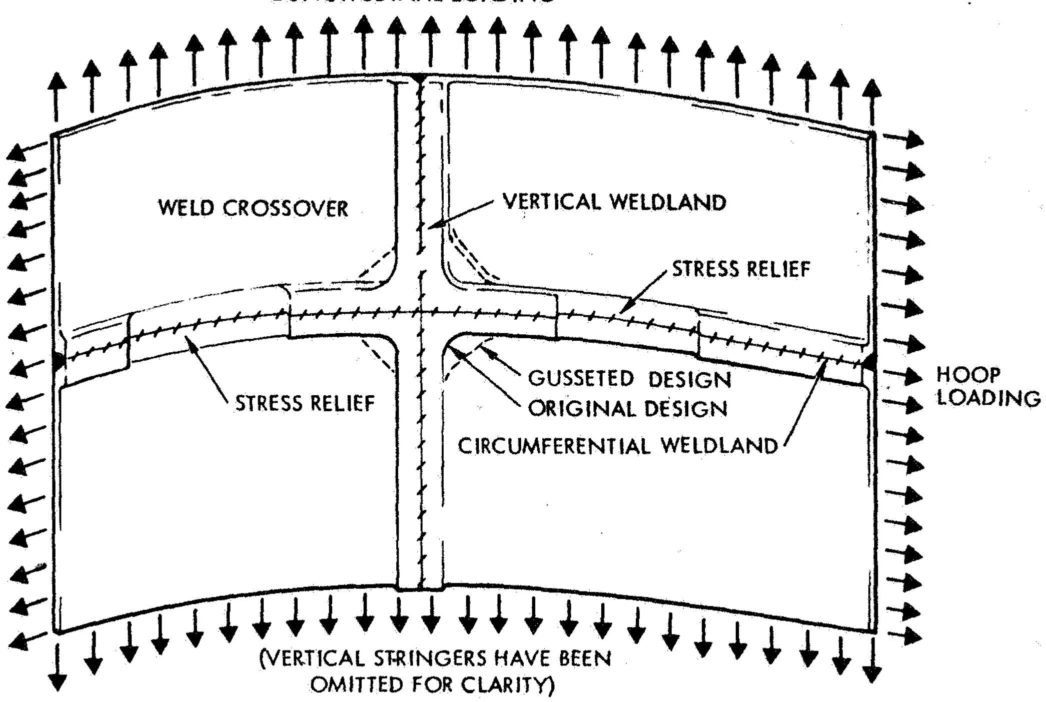


Figure 3. LH_2 Tank Weld Intersection

It is recommended extra attention be given to design improvements which may induce marginal conditions in other areas. Component testing would be recommended to avoid such problems.

DISCUSSION

Weld crossovers in the Saturn S-II LH_2 tank are formed by the intersection of longitudinal and circumferential weldlands (Figure 3). The circumferential weldland thickness causes a "belly band" restraint in and near the land which results in a hoop stress at the land which is about 80 percent of the basic membrane hoop stress. Although the hoop stress is reduced in the circumferential land, the hoop load per inch is increased. This apparent contradiction is due to the fact that the weldland hoop load is the product of the weldland hoop stress and land thickness which is greater than the product of the skin hoop stress and skin thickness. This results in the highest hoop loads (and stress) occurring at the weld crossovers.

Receipt of new test data concerning weld allowable strength and subsequent stress analysis of the weld crossover indicated a marginal condition. In an effort to reduce the load imposed on the vertical weld junction it was first recommended that the circumferential weldlands be reduced in thickness between each stringer boss. However, the considerations of other problems resulted in a design having the reduced weldland thickness only in the first stringer bay on each side of the crossover. The first production article to incorporate these "stress reliefs" was S-II-2. There was no indication that a problem existed until the room-temperature proof pressure test (pneumostat) of the S-II-7 Stage. An inspection performed subsequent to the pneumostat revealed a crack in each of the two "stress reliefs."

Several actions were started soon after the results of the S-II-7 pneumostat were known. Tests were performed on small laboratory specimens which reproduced the plastic distortion of the "stress relief" found on S-II-7 and assisted in stress analysis of the weld-crossover region. A repair technique was developed for use in Material Review disposition of the S-II-7 cracked regions and was verified by test of welded panels. Further inspection was performed on previous production articles, and prior Material Review actions were reappraised. When it became apparent that the "stress reliefs" did not improve the overall strength of the crossover region, the decision was made to revise the design at the earliest possible change point. At this time, the large panel tests had not been performed and the exact amount of interaction between the crossover weld and the "stress reliefs" was not known. Therefore, a conservative design approach was taken. "Stress reliefs" were eliminated at S-II-9 and subsequent models. The S-II-11 design was changed to have a larger gussetted region at the crossover. The addition of the larger gusset caused the total load into the crossover to be distributed over a larger area, reducing the peak stress at the intersection.

Evaluation of the test results found (in retrospect) that removal of the "stress reliefs" was not mandatory. As documented in the reference, an adequate factor of safety exists in any "stress relief" that has passed inspection subsequent to proof test. Also, the larger gussets of the S-II-11 design improved the crossover region.

REFERENCES

1. Vroman, G. A., and Johnson, D. W., "Weld Repair and Defect Simulation, Test Program Structural Evaluation Report," NR STR-SS-69-1, (January, 1969).

Design 05-01

CRACKING OF 2020-T6 EXTRUSIONS

PROBLEM STATEMENT AND EFFECT

Skin-stringer assemblies on the S-II-4 forward skirt, aft skirt, interstage, and thrust cone were found to have many cracked stringers. The cracks were in the vicinity of the stringer foot-sidewall intersection and usually occurred near ring frames. The S-II-4 was the first vehicle using the 2020 aluminum alloy.

An extensive investigation was initiated to determine the cause of the stringer cracking and to recommend the necessary remedial action to be used on the nonpressurized structures of the S-II vehicle. The continued use of 2020 aluminum alloy, and the weight-saving it afforded, was dependent upon the results of this investigation.

SOLUTION/RECOMMENDATION

The cracked stringers were replaced, and new installation procedures were introduced to insure special handling of the 2020 aluminum alloy. All impact fasteners (conventional rivets) were replaced by nonimpact fasteners (screws, bolts, Hi-loks). Also, stringer foot dihedral angle limitations were imposed on the stringer extrusions which, with new shimming requirements, prevented unacceptable built-in stresses in the stringer feet.

DISCUSSION

A redesign of the nonpressurized sections of the S-II vehicle (forward skirt, aft skirt, interstage, and thrust cone) was initiated for the purpose of saving weight, thus increasing the payload capability of the Saturn V booster. In addition to the use of a lower factor of safety (1.3 versus 1.4), a change in stringer material was introduced, with 2020-T6 aluminum extrusions substituted for the 7075 alloy. The S-II-4 was selected as the first vehicle to incorporate the weight-saving changes. The 2020 alloy offered the following advantages:

1. High tensile and compressive strength

2. High modulus of elasticity

3. Low density

4. Favorable elevated temperature performance

However, the alloy also had the following unfavorable properties:

1. Poor ductility, especially in the transverse direction

2. Low resistance to tearing

3. Crack propagation energy is low

4. Notch sensitive

Fabrication experience on 2020 aluminum alloy is very limited. The NR Columbus Division used it in plate and sheet form on the A-5C airframe, but this was the first time the material was used in the extruded form. Only limited knowledge was available concerning its behavior, metallurgical characteristics, the effects of the extrusion processes, and the special provisions required in the design and manufacturing of deliverable items when the material is used in this form. Tests were run on the new material to determine its chemical and mechanical properties, and these tests indicated that all specification requirements were met. Limited tests were also conducted to obtain information on machining, drilling, and riveting of this material, and no problems were disclosed. This led to the erroneous conclusion that the 2020 alloy could be handled by existing shop techniques adapted to high-strength aluminum alloys.

In February, 1966, stringer cracks were discovered in panel assemblies of the S-II-4 interstage. An exhaustive investigation was launched to determine the cause of the cracks, the extent of the problem, and the remedial action required. Technical personnel outside the Company, as well as within, were consulted. Reference 1 describes the plan of action for the investigation, the details and results of the extensive test effort expended, and the conclusions reached concerning the cause of the cracks. Reference 2 delineates the results of a meeting with expert Alcoa laboratory representatives, and a review of their test and manufacturing data. Details and results of a follow-on laboratory test effort, recommended by the initial investigation, are also included. Reference 3 summarizes the test results and conclusions drawn from the completed investigation into the problem of 2020 aluminum extrusion cracking, plus the design and manufacturing changes required for the continued use of this alloy. Reference 4 describes the structural and acoustic tests conducted on panel assemblies and the results obtained.

A complete inspection of the S-II-4 nonpressurized structure revealed that no stringers were cracked before they were installed in panel assemblies. Twenty to thirty percent of all installed extrusions had cracks, and these cracks were in the vicinity of the stringer foot-sidewall intersection. The cracks occurred most frequently in locations where the sidewalls were constrained or near ring frames. All cracks found were associated with the point of impact of a riveting gun. The conclusion drawn from the investigation was that the cracks were mechanical failures due either to static (tensile) overload resulting from overstressing during installation, or to bending resulting from mismatching of the material to the mating parts. There was no stress corrosion cracking.

It became evident that the 2020 aluminum alloy requires gentler care in handling, improved tooling, tighter tolerance on extrusion shape control, more comprehensive quality control procedures, and new joining techniques. The major innovations initiated included the use of non-impact fasteners (hi-loks, screws, and bolts) in place of impact fasteners (conventional rivets), rigid shimming requirements in hard attachment zones to eliminate excessive strain during assembly, and stricter design stringer contour control to minimize stringer to parent structure mismatch. These changes, together with improvements in handling, tooling, machining, and inspection procedures, renewed confidence in the use of this new alloy.

Successful comprehensive testing (acoustic and structural) of panel assemblies fabricated using the revised techniques, completed the clean bill of health given to 2020-T6 extrusions.

The major lesson learned from the 2020 cracking problem is that new materials require more than the usual specification verification tests for chemical and mechanical properties. Additional testing efforts must be expended to provide guidelines for satisfactory handling and fabrication procedures. Materials with adverse transverse properties should be especially suspect and signal a need for special attention.

REFERENCES

1. SID 66T-18, Investigation of X2020-T6511 Aluminum Alloy Stringer Cracking Problem, March 23, 1966

2. Addendum to SID 66T-18, June 21, 1966.

3. SID 66T-15A, Final Report on Saturn II Stringer Cracking Problem, March 16, 1966, revised August 26, 1966.

4. Addendum 1 to SID 66T-15, May, 1966.

STRESS CORROSION SUSCEPTIBLE PARTS ON S-II STAGE

PROBLEM STATEMENT AND EFFECT

Subsequent to initial design release of the S-II stage, approximately 300 components were identified as fabricated from stress corrosion-susceptible materials. Redesign and controls were required to preclude stress corrosion failures on production vehicles.

SOLUTION/RECOMMENDATION

Material changes were made, where feasible, and a corrosion inspection specification (MA0609-009) was written encompassing all the susceptible parts. This specification covered the inspection procedure, part number, actual location of each part, and when each inspection should take place.

In addition to the controls noted in MA0609-009, a recommendation was made to the customer to replace all susceptible materials for follow-on contracts with nonsusceptible materials.

DISCUSSION

Although in the early stages of the S-II design some consideration was given to stress corrosion susceptible materials, the Customer requested a review of all S-II hardware from a stress corrosion standpoint. The Customer also requested that adequate controls be established to preclude and/or minimize the possibility of stress corrosion failures on production vehicles.

When the identification review was complete, an evaluation team composed of Design, Stress, Reliability, and Materials and Processes established the criticality of each item. Approximately one-third of susceptible parts were determined to be critical from a mission loss standpoint and it was deemed necessary to take action to minimize the possibility of stress corrosion failures on production vehicles.

The review of the S-II stage hardware from a stress corrosion standpoint established the necessity of materials, processes, and design action early in a program's conception. Selection of proper materials, heat treatment tempers, and surface protection coatings increase hardware reliability and reduce the program's overall cost. The S-II Program also established that adequate specification control (MA0609-007, MA0609-009 and MA0610-001) does reduce corrosion problems and assures adequate reliability of space vehicles. It should also be noted that MA0609-009 is unique to the "state-of-the-art" and is the only known specification covering this type of corrosion control.

REFERENCES

MA0609-007, Corrosion Control of Metallic Components of Saturn S-II Stage.

MA0609-009, Corrosion Control - Saturn S-II Stage.

MA0610-001, Methods of Cleaning and Cleanliness Requirements for Saturn S-II Fuel and Oxidizer Tanks.

Design 06-02

TORSION BELLOWS CORROSION

PROBLEM STATEMENT AND EFFECT

Moisture entrapped between the external dryfilm lubricated convolutions of the center engine LOX feedline torsion bellows initiated corrosion through the bellows parent metal creating a leak path.

SOLUTION/RECOMMENDATION

Specific supplier processes (Solar) were pinpointed that showed where moisture, resulting from line cleaning operations, was not totally removed from the highly compressed torsion bellows convolutions. The suspect process/operation was revised to insure total drying. Purge ports and heater blankets, as required, were added to the bellows housing to aid the drying after all cryogenic exposure. Also, a new corrosion inhibiting dryfilm was added after it was found the prior dryfilm contributed to the corrosion problem.

DISCUSSION

Leakage was noted on one center engine feedline torsion bellows (the S-II-12 failure), however, rust and water marks were seen on several others that were assessed during the failure investigation. It was found that the supplier, after cleaning and rinsing cycles, was not drying the line assembly at a sufficient time or temperature to totally dry the line assembly. Also, adequate protection was not being exercised in keeping swab passivation media away from the torsion bellows area. Processes were revised to incorporate changes in these areas. Heater blankets were added at Solar and MTF to dry the torsion bellows area post-static firing, and at KSC if subsequent cryogenic exposure is not within 4 weeks. The new dryfilm (ECOALUBE replaced LUBECO 905) inhibits corrosion to the degree that pre-post CDDT leak checks are not required (as is done with the outboard engine inlet ducts, and was done with the center engine lines prior to the change, and after the problem came about). Effectivities for the above changes were: center engine LOX feedline, S-II-9 and subs; and center engine LH_2 feedline, S-II-10 and subs.

BENDIX CONNECTOR RECESSED CONTACT

PROBLEM STATEMENT AND EFFECT

The failure of an S-IV-B LOX control valve on the MDAC S-IV-B 507 flight was attributed to a recessed contact in a Bendix CE connector. The contacts in these connectors are retained by an interference fit between the contact and a rigid plastic disc sandwiched between the front insert and the rear grommet of the connector.

A recessed contact in a connector used in a critical circuit could cause the failure of a component resulting in mission loss and loss of life.

SOLUTION/RECOMMENDATION

Revise all connector assembly specifications to require mandatory performance of a contact retention test on all contacts to verify proper contact seating and locking. Inspect all connectors used in critical applications on completed articles by performing a contact retention test.

DISCUSSION

On January 16, 1970, NASA advised NR that MDAC had experienced an anomaly on the S-IV-B 507 flight. After earth-orbit insertion burn of the S-IV-B, a LOX control valve failed to close. Prior to initiating translunar insertion burn the open LOX valve was discovered and cycled closed manually. It was concluded from the MDAC analysis of this failure that the cause was a recessed contact in a Bendix CE connector. This assessment was satisfactorily substantiated by MDAC by testing a similar connector with a deliberately recessed contact and thereby duplicating the anomaly.

A hardware analysis conducted by NR revealed that the Bendix CE connectors are used only in two places on the S-II. Both applications are non-critical; however, the Amphenol connectors used on the S-II's up to and including S-II-10 are similar in design insofar as the contact retention system is concerned and were therefore suspect.

AMPHENOL CONNECTOR RECESSED CONTACTS, GAGES 4 AND 0

PROBLEM STATEMENT AND EFFECT

During fabrication and installation of the S-II electrical harnesses, many instances of recessed contacts on the Amphenol power connectors were encountered. Most of these problems were found to be associated with the connectors utilizing the larger gages of wire (No. 4 and No. 0 AWG). This connector utilized a plastic retention device for the contacts, and it was concluded that because of the bulk of the harnesses and the loads imparted to this retention disc, the design was marginal.

Since these connectors are used exclusively in power applications such as the power distribution system and as electrical interfaces to the stage batteries, the recessing of one of these connectors could cause a catastrophic failure.

SOLUTION/RECOMMENDATION

From a review of the problem by both the supplier and NR/SD it was concluded that the final corrective action should be a design change that would provide a connector with a metallic clip retention device. This proposal was accepted by NASA and a request for proposal was transmitted to the Saturn connector suppliers. As a result of these proposals, the "Cannon" design was selected and the new connectors were implemented on the S-II's starting with S-II-11.

Recommendations for future connectors:

1. Minimize or eliminate the use of extremely large-gage wires (4 and 0) on future programs.

2. Use connectors with metallic retention devices for power applications requiring large wires.

3. Provide sufficient installation clearance so that severe harness bend radii are not required close to connectors.

DISCUSSION

During the June, 1966 Saturn Quarterly Review Meeting several connector discrepancies associated with Amphenol large power connectors were discussed. Basically these problems were related to the power connectors utilizing both No. 4 and No. 0 gage contacts, and it was determined that these problems were the result of a marginal connector design insofar as the contact retention device was concerned. The contact is retained in these connectors by a molded shoulder of the plastic contact retention disc. This system, when used for very large gage wires (4 and 0) that are harnessed together and subsequently subjected to very small bend radii, was found to be marginal. In order to eliminate the problem of recessed contacts, a supplemental contact retention device consisting of a nylon sleeve installed on the individual wires behind the contact crimp barrel provided a means for positively capturing the contact between the retention disc and the connector rear wire support. This device was used to correct the problem on all Amphenol connectors utilizing No. 4 or No. 0 gage contacts. As a final solution to the problem a new design for connectors employing a metallic clip for contact retention was implemented, to be effective on all S-II's commencing with S-II-11.

Design 07-03

RECESSED INSERT OF CANNON PATCHBOARD CONNECTOR

PROBLEM STATEMENT AND EFFECT

During assembly operations on the Cannon patchboard connector (40 shell size, 81 pin) several cases of insert recession were detected. An investigation of these connectors already installed on stages revealed that the insert assemblies were slightly displaced. Displacement of the snap ring permitted the entire insert assembly to recede, thereby reducing the contact engagement. Loss of contact engagement in critical applications could cause a catastrophic failure.

SOLUTION/RECOMMENDATION

As a result of the above problem, a design analysis was conducted by both the supplier (ITT Cannon) and NR. It was concluded that the snap ring used to capture the insert assembly was not of sufficient cross-sectional area to preclude the possibility of its becoming displaced from its groove in the connector shell. ITT Cannon and North American agreed that the only satisfactory solution would be to redesign the insert retaining ring to provide a larger cross section.

It was further recommended that on connector designs considered for new programs this possible failure mode be reviewed and, if found marginal, the new design should be employed.

DISCUSSION

During rework of the S-II-6 sequence controller, it was noted that two ITT Cannon patchboard connectors on the wire harness exhibited insert recession. This raised the question as to the adequacy of the insert retention device used by these connectors. Subsequent analysis substantiated that the design was marginal. Immediate action was taken to determine the necessary inspection criteria to be used for verifying the condition of these connectors on other S-II stages, commencing with S-II-2. Visual inspections and measurements performed on the S-II-2 confirmed that the connectors in question on the stage were satisfactory for launch. From inspections conducted on the S-II-3, however, it was determined that the measuring inspection did not provide positive assurance that the questionable snap ring was properly seated . It was found that the most satisfactory method of inspection was by X-ray, and this method was used on the S-II-3, S-II-4, and S-II-5 to determine the position of the insert retaining rings. All those found displaced were removed and replaced with connectors of the new design, which were also used on all subsequent stages.

CRYOGENIC CONNECTOR

PROBLEM STATEMENT AND EFFECT

During the early phases of the S-II Program, several problems related to cryogenic connectors were encountered; of these the most significant were:

1. Silicone insert material developed cracks after being subjected to thermal cycling (tanking and static firing)
2. Excess corrosion on plugs encapsulated in stage foam insulation
3. Degradation of connector interfacial seals was observed after thermal cycling (cryoproof tank tests).

The effect of all three of these failures could result in loss of electrical continuity, and system failure, causing loss of mission.

SOLUTION/RECOMMENDATION

The following are the respective solutions for the above problems:

1. The insert material was changed from silicone to teflon.
2. Anti-wicking plugs were installed on harnesses.
3. Interfacial seals were debonded.

DISCUSSION

Engineering analysis revealed that the use of silicone insert material in applications where temperatures ranged below -320 F was not satisfactory. The design change to teflon, as indicated above, solved the problem.

The problem of corrosion of the cryogenic connector plugs encapsulated in the stage foam insulation was isolated to a condition known as "cryopumping." This occurs when wires pass from an extremely cold area through the foam to an area that is closer in temperature to ambient. This thermal cycling permits moisture to flow along the wires into the rear of the connectors and causes corrosion. To eliminate this condition a method of blocking the moisture path had to be developed; analysis revealed the most practical and efficient method of accomplishing this was to install a molded plastic plug on the wire harness under the foam to form a seal around each individual wire. After conducting a series of engineering tests to prove the design, the "anti-wicking" plugs were installed on the harness and the problem was resolved.

The problem of degradation of connector interfacial seals was isolated to the engine cutoff (ECO) connectors that are used to shut the engines down as fuel depletion occurs. It was found that after conducting the cryo-proof tests and static firing the interfacial seals that were bonded to the glass insert of the ECO receptacle were severely degraded (badly cracked), and the seal fragments were found to have flakes of glass from the insert adhering to them (spalling). Analysis of the problem with the supplier revealed that the coefficient of expansion of the silicone interfacial seal and the glass insert were too far apart to tolerate bonding. A recommendation to eliminate the bonding operation was proposed and testing confirmed that this procedure would eliminate the problem of the damaged interfacial seals as well as the spalling of the glass insert.

MISMATED ELECTRICAL CONNECTORS

PROBLEM STATEMENT AND EFFECT

Use of two or more identical electrical connectors in close proximity increases the cross-connection margin of error.

A classic example of such an effect can be noted from an early Saturn V launch when two engines of the S-II second stage shut down when only one engine was commanded. A data review indicated that the connectors to the two engines' prevalves were cross connected.

SOLUTION/RECOMMENDATION

The ideal solution for preventing cross connections is to use electrical connectors of different sizes and clocking arrangements in common areas. However, this is not always feasible or practical, due to vendor component design, physical limitations, and cost considerations.

Solutions include the following:

1. Route harnesses to physically minimize the possibility of making cross connections.
2. Color code receptacles and plugs to aid visually in the making of proper connections.
3. Install full reference designators on each plug and on or near each receptacle to aid in the verification of proper connections.
4. Devise system-level testing to ensure the detection of cross connections. This requires adequate initial vehicle/GSE interface design.

DISCUSSION

Cross connections result from human error and are compounded by vague documentation. A prerequisite to clear, concise documentation is a training course to acquaint the designer and the user with the methods available to prevent misconnections and to establish means for detecting the misconnection if precautionary measures fail.

A mockup is required to adequately determine the optimum harness routing, break-out points, and length. It would be desirable to document the installation of harnesses through photographs to aid in vehicle installations.

Reference designators are the "fingerprints" of electrical/electronic connections. They provide a unique alphanumeric code to each individual component, wire harness assembly, and connector. Once a designator has been assigned to a piece of equipment, it is always identified, located, and referred to by that designator. Plugs and mating receptacles are assigned matching designators. Legibility problems with reference designators on the S-II Program were overcome by increasing the size of the designators to 1/4 inch and by ensuring that the designators were visible after connections were made.

The advantages of match color coding plugs and receptacles are obvious - a plug-receptacle color mismatch indicates a cross connection.

However, in spite of the aids, misconnections can occur. If the ideal solution cannot be used, it is prudent to "design in" methods of detecting cross connections, and to devise test requirements accordingly. It is considered that incorporation of the above will minimize margin of error for cross connections.

Design 07-06

THREADED COUPLING-RING CONNECTORS

PROBLEM STATEMENT AND EFFECT

Loose electrical connector coupling rings were detected after initial connector matings. If this condition were undetected, it could lead to intermittent or total loss of circuit functions.

SOLUTION/RECOMMENDATION

Inspection criteria was developed for verifying engagement of cryogenic connectors, and for the application and inspection of torque stripes and tamper-proof seals on other threaded connectors. Specific mating procedures were also established for the cryogenic connectors.

It is recommended that improved methods and procedures be developed for verifying proper connector engagement. Means are required for positive verification of tightness such as a secondary locking device or "short pins" which have continuity only when connectors are properly tightened.

DISCUSSION

Extensive inspections were performed on stage electrical connectors to verify proper tightness of the coupling rings. During the course of the inspections, it became evident that indiscriminate, unauthorized disconnections were being made without proper reconnection. Controls were established through the use of tamper-proof seals to provide a simple means for verifying that connectors were given proper attention at time of last mating. The tamper-proof seal application included the inspector's identification and date of application.

The cryogenic connectors were used inside the propellant tanks and consequently were not safety wired; therefore, proper coupling ring tightness was mandatory. The threads of the cryogenic connectors are double lead ACME threads which inherently present mating problems. Detailed instructions were devised for the proper tightening of the ACME threads.

RELAY PROBLEMS, MANUFACTURING AND SUPPLIER

PROBLEM STATEMENT AND EFFECT

The two significant manufacturing and supplier problems concerning relays involved (1) diodes and resistors and (2) weldable leads:

1. The S-II originally utilized relays for switching circuits which contained diodes and resistors positioned across the relay coils for arc and transient suppression. The restricted space available for the diodes and resistors in the relay resulted in manufacturing problems pertaining to soldering, mounting of components, and additional wire routings. Also the diodes created a polarized coil and the diodes could fail in a shorted mode, thus creating circuit problems.

2. Leads to the Babcock relay for external weld connections proved not to be weldable; there was too great a variation in pull strength and excessive splatter and expulsion after welding to 100 percent nickel wire. Leads were Carpenter alloy 426 copper-nickel, gold plated, 20 to 50 mils in diameter. The header manufacturer (Airpax) fuses the alloy lead into the glass bead of the header at 1800 F which drives contamination into the lead. A subsequent chemical cleaning did not remove the contamination below the surface of the leads. This residual contamination invalidated the weld setup schedules during relay module manufacturing at NR.

SOLUTION/RECOMMENDATION

The respective solutions for the above problems are:

1. Bifilar relay coil construction utilizing a shorted coil parallel wound with the relay coil accomplished the transient suppression and eliminated the diodes and interconnecting wiring.

2. Stripping the leads by an Electro Suma stripping process to 0.001 inch and replating with gold produced a good weldable lead.

DISCUSSION

The Bifilar Relay and its Advantages

Twenty-eight volts dc is applied to the relay coil. At T_o, coil voltage is removed. The magnetic field around the magnet coil collapses. Instead of producing a high, negative, inductive spike in the direction of the power source, comparable to that of a standard coil, it is transferred to the bifilar coil in a closed-loop circuit having resistance, inductance and capacitance; the power transferred from the magnet coil is dissipated in the bifilar winding. The result is that the inductive spike seen by the power source is suppressed to approximately -50 volts. This spike is reduced to -6 volts at $T_{3.0}$ (3.0 msec after removal of coil voltage at T_o). A slight increase in release time may be expected because of the transformer action setting up another magnetic field around the bifilar coil. This tends to hold the armature in the energized position until the power is dissipated from the bifilar coil.

The main advantages of the bifilar coil method of reducing suppression of inductive spikes (Figure 4) over the conventional diode or resistor techniques are as follows:

1. It has the ability to operate more effectively at temperature extremes (especially at high temperature).

2. It is not polarity sensitive.

3. Foreign materials are eliminated.

4. Outgassing of suppression components is eliminated.

5. The number of manufacturing operations is reduced.

Weldable Leads

The weld problem was discovered at the NR/SD McAlester facility during lot welding tests on relays received from the supplier. The weld pull tests were below the minimum pull tests for Group (b) material specified in NR/SD Specification MA0607-009. Relay lots which failed MA0607-009 were subjected to modified weld schedules with no success and then were rejected as not weldable, and finally submitted for rework at the NR/SD laboratories in Downey, California.

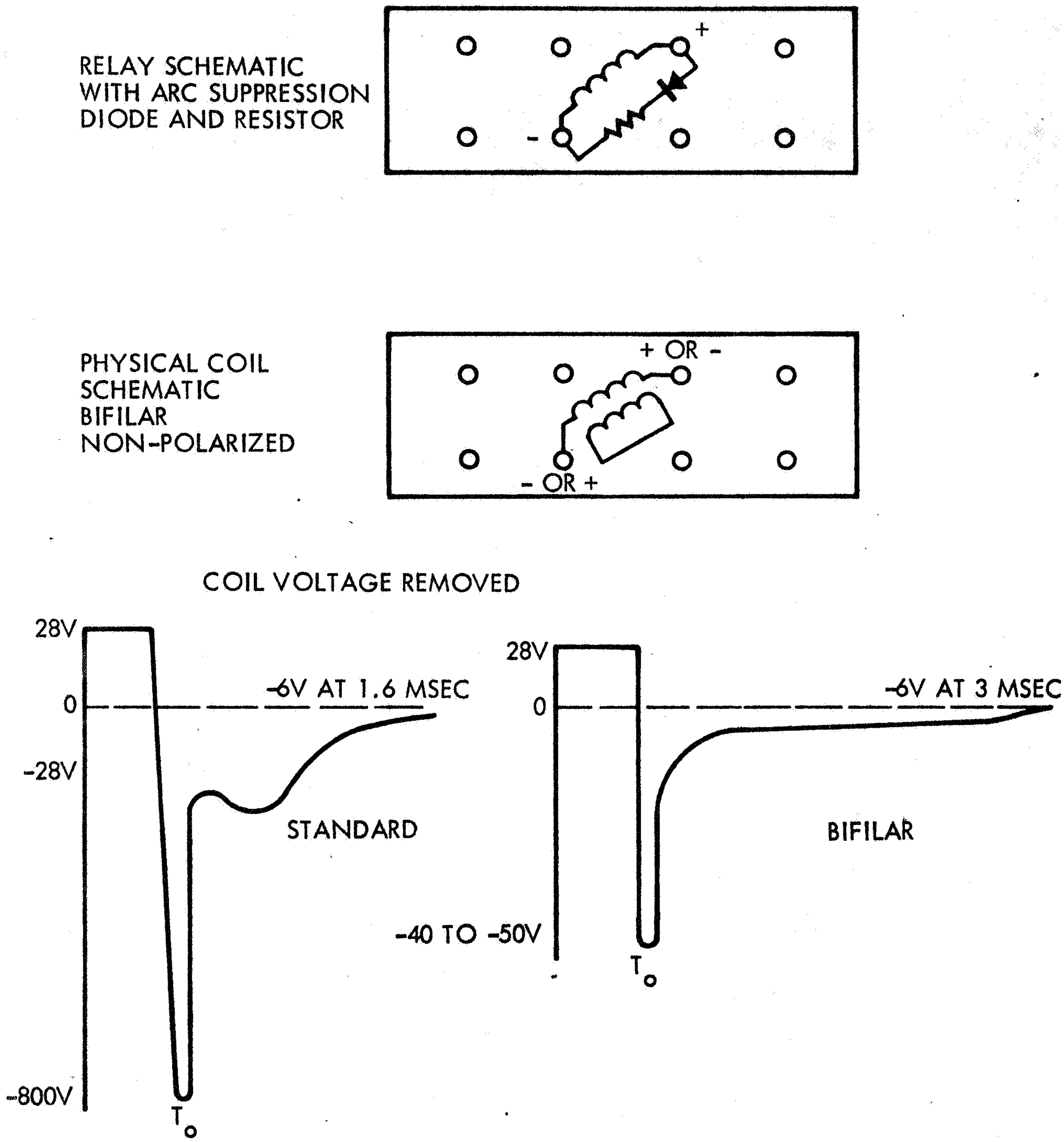


Figure 4. Bifilar Coil Method

The inconsistency of the weld strength during weld qualification testing was identified as resulting from contamination of the leads under the plating. The leads of the relay consist of a copper-cored Carpenter 426 alloy wire 0. 032 inch in diameter. This wire is copper-plated and then coated with tin lead solder (60SN-40Pb) by the hot dip method. When the oxides are not completely removed from the Carpenter 426 alloy prior to copper plating, inconsistent welds result.

These are the factors affecting weldability:

1. Oxide contamination driven into the Carpenter 426 basic metal, which was impossible to remove by the normal state-of-the-art cleaning, i. e., chemical cleaning.

2. Heavy copper undercoat in plating the leads, which varied from lot to lot.

3. Variation of electro-tin plating thickness. Specification requirement was a minimum of 0. 0002 inch. Plating varied from 0. 0002 to 0. 0008 inch.

4. Grain enlargement of lead material, which results from the high oxidation fusing temperature (1800 F) when bonding the lead material through the glass bead of the header.

5. Carpenter 426 lead material. This material is not as easy to weld as are other lead materials; i. e., it is not as easy to weld as 99 percent nickel, Dumont, and Alloy 52. However, Carpenter 426 lead material, when subjected to high temperature bonding into the header glass bead, is the only consistently reliable lead material which will meet the NASA High Reliability Relay Specification leakage and twist test requirements.

It was found that oxide contamination (factor 1, above) was the primary problem, factors 2 and 3 were secondary and should be controlled, and 4 and 5 could not be changed due to requirements. Also, the laboratory tests proved that if 1, 2, and 3 were eliminated or controlled, then consistent welds could be made, i. e., welds were made to conform to a coefficient of variation of less than 0. 4 vs. 9. 6 in the problem relays, and tested above the minimum pull test requirements.

In arriving at a solution to the problem the NR/SD laboratory, with the relay supplier's permission, directly contacted the header manufacturer.

The header manufacturer submitted wire samples both processed and unprocessed, and also described the chemical cleaning process; NR/SD research finally concluded that chemical cleaning of the header leads would not remove the imbedded contamination. It was then determined that reverse electrolytic cleaning was required, followed by electrolytic polishing (Suma process). Then the leads could be replated and processed for welding.

The complete treatment devised by NR for reworking the welding leads included cleaning and polishing. The leads are chemically cleaned, then subjected to a reverse electrolytic action to remove oxides and material to a depth of 0.0005 inch (oxides are driven 0.0003 inch into lead material). Then the leads are subjected to a Suma electrolytic polishing process. After the Suma process, the leads have a shiny bright appearance provided all oxides are removed, but a dull dark appearance if they are not. After a successful Suma process, the leads are gold plated over a nickel flash.

This is a description of the cleaning process:

1. Weld the ends of the relay leads to a nickel ribbon 0.015 inch by 0.032 inch and approximately 6 inches long to facilitate electrical contact for electro-cleaning and plating. Mask the bodies of the relays with lead tape, and coat with micro mask (strippable paint type coating).

2. Strip the solder coating and the copper plate under the solder by immersion in a 50-percent solution of nitric acid at room temperature. The immersion time is approximately 30 seconds.

3. Electro-polish the lead wires for 45 seconds by the Suma process.

4. Gold plate the lead wires of the relays per MIL-G-45204, Type 1, Class 3, to an approximate thickness of 50 micro-inches.

RELAY PROBLEMS, STAGE USAGE

PROBLEM STATEMENT AND EFFECT

The contacts of a Babcock relay used for activating an RF transmitter failed to open on command during the S-II-13 checkout. Analysis and tests showed that the transmitter had a high capactitive input characteristic (approximately 500 μf). The inrush current through the relay contacts varied between 60 and 120 amperes of spike current for approximately 10 microseconds. This results in fused contacts.

SOLUTION AND RECOMMENDATIONS

Conditions which contribute to sticking contacts on 10-ampere relays when switching into capacitive loads include:

1. Inrush current above 50 amperes.

2. High rise current, with sharp peaking at 50 microseconds. This inrush supplies the maximum current during the period that contacts are breaking through the surface film and before maximum contact pressure is developed.

3. Amount of over travel. This varies from contact to contact and involves a slight friction movement of contacts when they meet.

4. Contour of contact "make" area. There is some convex curvature in the contact seating area (where contacts meet) which varies from contact to contact.

5. Contact bounce during contact make period. This increases the time that arcing and fusion can take place.

The conditions listed above explain why some contacts will stick and others will not under the same capacitance loads. Tests indicate that contacts which have stuck as a result of capacitive switching can be, when commanded, opened by vibration, jarring, or repeated turning on and off of the relay. This was the only solution available for the S-II because of the tight schedule and the costs involved.

Two electro-circuit modifications that can be helpful are:

1. Adding inductive chokes in series with capacitive loads to reduce the effect of capacitive switching.

2. Adding resistance in series with the capacitive load to reduce the inrush current to a safe level.

DISCUSSION

Analysis of Stage Operation at Time of Failure

Stage checkout was being performed when the anomaly occurred. During these tests, transmitters BP1, BF1, and BF2 were turned on at once, checked out, turned off, and then turned on individually. The switching anomaly occurred when BF2 transmitter was energized followed by BF1. The relay contact failed to respond to a de-energizing signal, remaining in the energized position for approximately nineteen minutes. The third attempt to de-energize (open) the contact, was successful. The anomaly was repeated during three subsequent tests with the contact failing to respond for periods of from three to ten seconds.

The contacts of the suspected relay were examined and it was determined that one set of contacts was very heavily pitted, showing evidence of having been immobilized by switching into a capacitive load. Similar relays with the same contact material and arrangement were switched into high capacitance, 1000 to 2000 micro-farad loads. (Three transmitters represent approximately 1500 micro-farads, 500 micro-farads each.) Some contacts started sticking after 10 cycles of operation. These contacts were compared with the contact in question and found to be similar under microscopic analysis. A series of tests on contacts switched into capacitance loads (no sticking) and resistive loads was made and compared with the subject contact, and with contacts of a relay which switched the BP1 transmitter without sticking. The visual evidence indicates that the subject contact had all the appearance of having been in a sticking mode during capacitance switching.

It was also determined that there was no evidence of any mechanical or foreign particles inside the relay having interfered with relay operation.

Tests were conducted at NR, switching the three transmitters BF1, BF2, and BP1 in various modes, instrumented by checking current inrush with an oscilloscope, utilizing a battery power source. The following is a synopsis of these tests:

1. One transmitter (BP1) turned on - 62 amperes peak; current peaked (rounded peak) in 50 microseconds, second peak at 200 microseconds.

2. Added 10, 000 microfarad capacitor across power supply and repeated test 1. Current inrush: 80 amperes peak; current peaked in 10 microseconds (sharp peak), second peak 150 microseconds, but oscillatory ringing between the first and second peak.

3. Repeated test 2 turning one transmitter (BF1) on with BP1 still on. Current inrush: 100 amperes peak; current peak in 10 microseconds (sharp peak), second peak 150 microseconds, but oscillatory ringing between first and second peak increased.

4. Repeated test 2 turning BF2 on with BP1 and BF1 still on. Current inrush: 120 amperes peak; peaking and oscillatory ringing similar to that during test 3.

5. Turned all three transmitters on at once (BP1, BF1 and BF2). Current peaks in 3 successful series; peaks building up to 150 amps by 250 microseconds with approximately 80 microseconds between peaks. This is caused by different switch times in closing the relay contacts to each transmitter.

6. Repeating the foregoing tests with a 1 millihenry choke in series with each transmitter significantly knocked down the peaks, rounded them off, and delayed the peaking for 200 microseconds. This delay would benefit the relay switching because it allows the contacts to firmly seat before the peak transient inrush current is reached.

Test 3 above repeated the stage failure mode. Also, tests on relays at the supplier indicated that capacitive switching transients of 100 amperes could freeze the contacts when operated ten times with this type of load. The stage tests indicate this happened the eighth time the relay was switched.

VENT VALVE LOW RESEAT

PROBLEM STATEMENT AND EFFECT

During tests on the S-II-1 prior to static firing, a LOX tank vent valve failed to reseat within the specified pressure range. This was found to be caused by pressure oscillations (organ pipe effect) in the vent valve portion of the pressure-sensing system.

SOLUTION/RECOMMENDATION

The oscillations were eliminated by adding a double-orificed plenum chamber to the valve pressure-sensing system external to the valve main housing.

DISCUSSION

The first vent valve malfunction occurred on the S-II-1 when the valve did not reseat by 39 psia due to valve oscillation. The malfunction recurred on the battleship test vehicle. This suggested a chronic instability problem during the venting mode of operation. Preliminary tests were performed by the supplier, Calmec, on two vent valves. Both valves proved unstable, but the vent valve responded quickly enough to track the frequency of pressure oscillations in the vent line. Uncoupling the vent valve from the line by adding an orifice plenum chamber to the valve-sensing line slowed the valve's response capability.

Design 09-02

VENT VALVE DESIGN

PROBLEM STATEMENT AND EFFECT

Vent valves presently in use on the S-II propellant tanks require a pressure relief band (from valve opening to reseat) of two to three psi. A reduction in the actuation pressure band of the valve will permit a reduction in the structural requirements of the tank and increase the margin between the vent valve cracking pressure and the maximum allowable differential pressure across the tank wall.

SOLUTION/RECOMMENDATION

A test program, utilizing the basic S-II LOX and LH_2 vent valves as test beds to evaluate a 1-psi pressure band design concept, was developed and implemented. The program achieved the desired goal of a 1-psi pressure relief band by modifying the vent valve pilot valve system. It is recommended that this concept be utilized on future space vehicle programs to achieve the desirable effects described above.

DISCUSSION

The pilot valve redesign consists of (1) rearrangement of detail parts within the existing pilot valve housing, (2) Belleville-diaphragm assembly redesign, and (3) incorporation of a bellows seal. The Belleville spring and a diaphragm ring was made into a weldment with the Belleville interface on a ring of circular cross section to reduce operational friction loads. A bellows seal was added to the poppet stem to eliminate leakage-induced error. Rearrangement of the detail parts permitted use of the existing pilot-valve housing space envelope. The resultant configuration meets the requirements of a 1.0-psi pressure-band vent valve.

Design 09-03

SOLENOID VALVE DESIGN

PROBLEM STATEMENT AND EFFECT

The S-II-14 LH_2 vent-valve step-vent solenoid valve failed to actuate (could not shift from low mode to high mode) due to a shorted coil. As a result of performing an insulation resistance test on other stage valves, more coils were found to have unacceptably low insulation resistances. The anomaly cause was found to be twofold. The coil wire insulation, which was of improper quality, degraded as a function of time. The coil enclosure was not hermetically sealed. This allowed moisture to enter, providing a current leak path and causing corrosion.

SOLUTION/RECOMMENDATION

The solenoid enclosure construction had to be revised to provide for a hermetically sealed enclosure. Inspection of the coil wire insulation was implemented to ascertain the proper curing of the wire insulation prior to use for coil winding.

DISCUSSION

A corrective action plan was instituted for S-II-10 and subsequent stages.

All of the vent valve solenoid coils which contained questionable wire were replaced with redesigned coils. The redesigned coils contain wire which has been tested by NR by lot. The new coils are subjected to a complete drying procedure to insure that the coil is free of moisture. The coil enclosure is completely welded. The integrity of the welded hermetic seal is finally verified by the Radiflo leak detection method which utilizes a radioactive tracer gas (Krypton 85-Nitrogen).

A specification and criterion document requirement was added to check coil resistance and insulation resistance on selected stage components prior to launch.

RETEST OF S-II HARNESS ASSEMBLIES AFTER REWORK

PROBLEM STATEMENT AND EFFECT

About the time S-II-3 completed system checkout at Seal Beach, a large amount of wire harness modification and rework was performed by manufacturing. Existing retest methods required extensive time and effort to accomplish and sometimes resulted in unnecessary retest.

While stages were in system-level checkout, the disconnection of connectors to perform continuity and insulation resistance retest invalidated previously run system-level tests. System-level retest was then required. The wisdom of performing continuity and insulation resistance retest is questionable.

SOLUTION/RECOMMENDATION

Negotiations with Manufacturing, Quality Assurance, and NASA resulted in agreement that certain types of harness rework were minor and did not require continuity and insulation resistance retest. Agreement was reached on the definition of minor rework.

Rather than establish a firm requirement for continuity and insulation resistance retest, the responsibility for determining retest requirement was given to the cognizant site test engineering organization.

DISCUSSION

The rework performed on the S-II wire harnesses from S-II-3 on consisted mainly of rerouting, addition and removal of clamps, and shortening harness length. The specification requirement applicable at that time was that after rework retest was required. The requirement did not allow for variation in the complexity of the rework. For example, many times a single clamp was removed and then installed solely for the purpose of access to wire harnesses within the bundle. This is obviously an example of minor rework which probably should not require any kind of retest. In other instances, similar rework was performed but many clamps were removed and reinstalled. Given a sufficiently large number of clamp removals, a continuity and insulation resistance retest would be necessary. In order to specify a realistic and adequate retest requirement, it is necessary to determine how many clamps can be removed without adversely affecting the wire harness.

Consequently, discussions were held by Engineering, Manufacturing, Quality Assurance and NASA to attempt to define minor rework not requiring continuity and insulation resistance retest. It was agreed that a rework involving removal and reinstallation of three clamps or less would constitute minor rework and would not require retest. Also harness rerouting which could be accomplished without disconnecting connectors was defined as minor rework.

Disconnecting connectors to perform continuity and insulation resistance retest is necessary to prevent application of the test voltage (500 VDC) to sensitive stage components. Disconnection also invalidates any system-level checkout which may have previously been performed. The system-level checkout must then be rerun. This can involve considerable testing. It is therefore desirable to examine all aspects of a particular rework to determine the optimum retest. Considerations such as accessibility of the wire harness to visual inspection, whether or not the harness is braided, and the function of the harness must be taken into account.

Since these considerations cannot be anticipated and cannot be generalized, an Engineering Specification requirement was not feasible.

The following requirement was incorporated into the Engineering Specification:

> Insulation Resistance and Continuity Retest Requirements for Rework Performed After Beginning Stage System Unit Acceptance Testing.
>
> These requirements shall be determined by site Test Operations and coordinated with site Quality Assurance and site NASA, or as specified by S-II Engineering on retest E. O. 's.

This requirement gave the organization best able to assess all factors associated with a given situation the latitude to determine retest requirements.

Design 10-02

COAXIAL CABLE INSTALLATION

PROBLEM STATEMENT AND EFFECT

Routing of RF coaxial cables on the S-II through areas of high personnel traffic resulted in cable damage and costly repair and replacement.

SOLUTION/RECOMMENDATION

Temporary protective covers were installed to prevent cable damage. The intent of the initial design was to maintain a separation between the coaxial cables and the electrical harnesses due to electrical interference. However, in routing coaxial cables, other parameters such as accessibility, maintainability, mechanical interference, and human factors should be considered.

DISCUSSION

The majority of the electrical harnesses were routed between Stations Xb 930. 00 and Xb 955. 00 in the Forward Skirt Area. The containers and antennas were located between Stations Xb 894. 00 and Xb 930. 00. A requirement to maintain a separation between the electrical harnesses and coaxial cables was imposed on the installation design to prevent electrical interference. The logical coaxial routing installation was to approach the containers and antennas from below to eliminate the cross-over. The installation maintained the necessary clearance between the containers and the coaxial cables, but the cables are located on the same level and adjacent to the work platform (walkway), making them subject to damage from foot traffic. Significant harness damage was incurred due to this routing. Since some of the cables are part of the Range Safety System RF Signal system, minor damage in some instances resulted in cable replacement. The location of cables also necessitated partial removal of forward skirt containers to accomplish cable replacement.

Close coordination between cable installation design personnel and facilities personnel who design the work platforms should be established early in the program.

COAXIAL CABLE HANDLING

PROBLEM STATEMENT AND EFFECT

A number of failures which resulted in measurement anomalies were experienced with the S-II coaxial cable assemblies used for piezoelectric transducer vibration. An investigation was made to determine the problem areas and to perform corrective action.

SOLUTION/RECOMMENDATION

The solution is to replace the existing connector on the coaxial cable assembly with a connector of a new design. The connector material should be changed from brass to stainless steel; the coaxial cable welded or soldered (high temperature) in place; all joints enlarged and made more rugged; and a workable humidity seal against the transducer connector face must be devised.

DISCUSSION

No problem exists with the coaxial wire; however, the connector and cable-to-connector interface has repeatedly failed. Several design deficiency points in the connector-cable joint were apparent. There is a possiblity that during assembly, the cable could be damaged. The center pin in the connector is, essentially, jammed and crimped in place. The general construction of the connector was rather flimsy and no provision was made for an "O" ring seal. Any seal made was due to the interface of the connector shell with the face of the accelerometer with a flat gasket mounted between.

The knurled portion of the connector was not torqued into place but was attached finger tight. To secure it, a drop of Loctite was placed on the inside of the threads. If this procedure had been followed properly, it would have assured a reliable connection; however, because of the extreme difficulty in controlling the application of the Loctite (too much or too little), short circuit and open circuit conditions resulted in some instances. The Loctite also made it difficult to remove the connector from the accelerometer, in case accelerometer replacement was required, and in some cases, this caused the cable termination to be destroyed.

The new replacement connector resolved most of these problems. This connector is made of stainless steel, has a hermetic glass seal, and is heavier and more rugged than the old design. Assembly includes a welded center conductor and an integral "O" ring seal. The connector design is such that it is much easier to assemble to the cable and is thus less subject to damage during this procedure.

Design 10-04

WIRING INSTALLATION IN CONGESTED AREAS

PROBLEM STATEMENT AND EFFECT

Wiring installations in congested areas on the S-II resulted in a high incidence of wire damage during installation, modifications, and inspections.

SOLUTION/RECOMMENDATION

The problem on the S-II was partially resolved by rerouting certain wire harnesses in the congested areas.

For future programs, it is recommended that close attention be given to component and container locations to avoid such congestion, and that sufficient tolerances be included for growth factors. It is also recommended that a full-scale mockup be maintained to provide visual awareness of potential interferences or congestion.

DISCUSSION

As a result of joint NASA/NR shakedown inspections held on the first three S-II flight articles, a high number of discrepancies were uncovered that required clarification of harness installations. Inspection for damage to wiring was hampered due to poor visibility and accessibility. A set of guidelines were established to aid in the installation and inspection of all S-II wire harnesses.

Concerted action of NASA/NR teams resulted in reaffirmation, with changes, that the overall wiring concepts and practices implemented on the S-II Program met the high standards of design and workmanship required for the program, and that all possible steps were taken to provide a safe and high quality physical installation of stage wiring.

Congested wiring installations can be avoided through careful planning of initial design concepts. Full correction undertaken after an inadequate design is implemented, is prohibitively costly and incurs delays that may prove critical.

Design 10-05

HARNESS MOCKUP PROBLEMS

PROBLEM STATEMENT AND EFFECT

The problem was one of long harnesses, short harnesses, mislocated breakouts, and the variation in harness installations from stage to stage. Its effect was large amounts of rework. Modification kits could not be installed as intended and Engineering drawing changes were made to describe the as-installed configuration.

SOLUTION/RECOMMENDATION

The solution was partially accomplished by the utilization of the electrical mechanical mockup (EMM) initially in the program, the incorporation of station markers on the vehicles as an interim procedure, and the utilization of the systems dimensional simulator (SDS) late in the program.

Use of a full-scale flight-configuration operational mockup is recommended in the initial phase of the program with engineering design control. Point to point dimensions should be logged as depicted on road maps and utilized to preclude the human error in repeated measurements.

DISCUSSION

The harnesses installed on the vehicle became involved in many modification changes which affected the length, diameter and breakouts of the harnesses and their installation. In many cases the installations on the vehicle did not reflect the drawing configuration or the requirements of the installation specification.

This situation existed until the Smash Program was initiated. The purpose of the Smash Program was to clear all discrepancies discovered by the inspection teams, in the most expeditious manner possible. This meant revision of the engineering documentation to reflect the acceptable as-installed configuration. Design changes were written to revise the existing design drawings to effect the necessary rework and clear the discrepancies within engineering documentation. Implementation of this effort required the following revisions: addition or relocation of cable clamps and attaching hardware; addition and relocation and change of g grommets; addition of hardware for mounting connectors (screws, washers, etc.); addition and relocation of support brackets; and the addition of protection from abrasion (add RTV, grommets, reverse HiLoc fasteners, etc.).

The electrical mechanical mockup was constructed in the initial phase of the program to ensure that proper installations could be accomplished. However, the EMM did not reflect the flight configuration of the vehicle, nor was it maintained to current configurations.

The final installation (FI) diagram of each harness was established after the installation was approved by Engineering and Q&RA personnel. These FI's were documented in the Operators General Instruction Manual (OGID) No. 006-009 which was used to instruct the Manufacturing personnel in the proper sequence, procedures, and methods necessary to expeditiously install the harnesses in the S-II stage's aft skirt area.

Identification station markers were added to the harness assemblies to identify specific locations for harness installations within the S-II stage and to provide a more efficient means of operation during the manufacturing and inspection effort.

A plan of action for activation of the S-II-T aft skirt and thrust structure as a systems dimensional simulator (SDS) was established. This control function was headed by an Engineering representative (Spacemaster), Q&RA representative, and Manufacturing representative (Simulator Master) to control mockup activities and satisfy their respective requirements.

Design 11-01

THRUST STRUCTURE LONGERON FAILURE AND REDESIGN

PROBLEM STATEMENT AND EFFECT

During testing of the S-II thrust structure on the S-II-S test vehicle at Seal Beach, the thrust longerons failed as the loading approached the level of 120 percent of limit load. The test objective was to qualify the thrust structure to the ultimate loading of 140 percent of limit load. The test condition was a hard-over gimbaling case which imposed high moments on the thrust longerons. Compressive failure of the unsupported inner cap, at the upper end of both longerons at Engine 3, initiated the general collapse of the thrust cone shell.

As a result of this failure, a redesign of the longerons, and subsequent test verification, was necessary to show fulfillment of contractual requirements.

SOLUTION/RECOMMENDATION

The original thrust longeron design used an allowable cap stress based on the appropriate bending modulus of rupture curves. Lateral instability of the unsupported cap was not considered critical because of the short span and cross-sectional dimensions of the longerons. This proved to be unconservative. The redesign of the longerons was accomplished utilizing a rigorous analytical investigation of lateral stability. This investigation limited the allowable stress in the unsupported cap to the compression yield stress of the material. The longerons were redesigned to include heavier caps and deeper sections. Subsequent testing verified the analytical approach.

DISCUSSION

Four pairs of longerons provide the backup support to the outboard engine attach fittings, accepting the concentrated engine thrust loads and distributing them into the conical shell structure. Beam end reactions are supplied to the longerons by ring frames at Stations 167.5 and 112. The longeron assemblies also provide support for the hydraulic servoactuators that control engine pitch and yaw deflections. The longerons are machined from 7079-T652 hand forgings. Stress-relieved temper and surface protection (by shot peening, anodizing, priming, and epoxy-base painting) are employed to eliminate the possibility of stress corrosion in the heavy machined sections of these members.

On April 30, 1965, during testing of the thrust structure on the S-II-S vehicle, the longerons failed as the loading approached 120 percent of limit load. The test case was Condition VB (control engines at full thrust and at maximum-gimbaled position, with actuator loads on and center engine out), and the test objective was to achieve 140 percent of limit load. This condition imposes high moments on the thrust longerons. Compressive failure of the unsupported inner caps of both longerons at Engine 3 initiated the general collapse of the thrust cone shell. Details of the testing, and the failure, are found in Reference 3.

The failure brought about an intensive review of the structural analysis on the thrust longerons. The design of these members was based on the use of appropriate bending modulus of rupture curves in determining an allowable inner cap stress (Reference 5). Bending in the plastic range is described in Section 2.70 of Reference 4, and is a valid method for arriving at beam stresses above the elastic limit that can be withstood without failure. The shape and the dimensions of the section subjected to the moment loading, as well as the stress-strain curve of the material, enter into the development of these plastic bending design curves. However, because of the short span of the longerons and the large cross-sectional area of the beam, lateral stability of the unsupported cap was not considered a problem. More intensive and rigorous analytical investigation into this type of failure showed that the initial assumption was unconservative. Detailed lateral stability analysis procedure is found in Section 2.60 of Reference 4, (with use of data from Reference 5), providing a reasonably conservative analysis to predict this type of beam failure. The primary instability mode of a beam attached to skin and loaded in compression at the free flange, may be considered as a pure torsional mode with rotation occurring about the enforced center of twist existing at the skin attachment point. A significant reduction in the allowable stress of the unsupported inner cap of the longerons resulted from this lateral stability analysis. The longerons were redesigned using the new criteria.

Retesting of the thrust structure, with the new longerons, was started in August 1965; details of this test can be found in Reference 3. Successful conpletion of Condition VB (140 percent of limit load) was attained, but it was then determined that a second phase of this test condition would be required. The second phase would be similar to the first phase but with the addition of full thrust from the center engine. Failure of the engine attach bolts at 128 percent of limit load, plus the subsequent destruction of the S-II-S Stage, prevented test verification of the redesigned longerons. However, References 1 and 2 contain analyses of the test data with extrapolations to verify that the longerons would easily accommodate ultimate loading. Details of subsequent testing on the high force thrust structure

(MSFC Test No. 404), with results to the 130 percent of limit load test objective, are found in Reference 6. This test verified the stress levels obtained on the S-II-S thereby validating the data extrapolated for design certification.

REFERENCES

1. SID 67-32, Design Certification Review, SA501/S-II-1, Structure Subsystem Report, reissued May, 1967.

2. SD 68-125(B), Volume 5, Saturn S-II-3 Stage Design Certification Review Report, 26 February 1968, revised 23 March 1968, revised 17 June 1968.

3. SID 65-1682, Saturn S-II Major Structural Tests, 1 July 1966.

4. Structures Manual, Space Division, North American Rockwell.

5. Materials Properties Manual, Volume 1, Design Data, October 1969, Space Division, North American Rockwell.

6. S-II-1 Stage Thrust Structure Evaluation, August 21, 1968, prepared for Structures Division, P&VE Laboratory, MSFC, by the Structures Department of Brown Engineering.

J-JOINT THERMAL STRESSES

PROBLEM STATEMENT AND EFFECT

The J-joint — the junction of the common bulkhead, the LOX tank sidewall, and the hydrogen tank sidewall — is a critical area for thermally induced stresses. In addition, there were original requirements that the tanks be capable of being filled independently. These proved impractical and imposed an unwarrantably severe condition on the vehicle.

SOLUTION/RECOMMENDATION

The J-joint structure is pre-chilled prior to LH_2 loading. The design requirements were also revised and GSE systems and procedures modified to reduce the differences in temperature at the J-joint and thus reduce thermal strain.

It is recommended for future systems that the filling requirements be evaluated to make certain that there are no requirements for "fast fill" so that the entire vehicle system can be cooled (chilled) simultaneously. In general, the flow of hydrogen gas for pre-chill must occur during LOX filling. Establishing these requirements early will expedite design and eliminate worrisome problems.

DISCUSSION

The lower (LOX) tank is chilled first and as the joint cools, gaseous hydrogen is admitted through the fill-and-drain valve in the bottom of the forward (LH_2) tank to chill all sides of the J-joint simultaneously. The ground lines from the main storage tanks must also be cooled. By venting the cooling gas through the S-II tank, the tank is purged and chilled with no loss of time and using a minimum amount of gas.

DEFICIENT BRACKET DESIGN

PROBLEM STATEMENT AND EFFECT

Problems encountered with brackets on the S-II occurred in 3 categories:

1. During the early manufacturing period of the S-II it was found that many brackets were functionally inadequate or placed at undesirable locations.

2. Extensive use of welded joints was employed in the original design of many brackets with the material usually being 6061 aluminum alloy. Welding proved difficult, with flange warping and very fine shallow cracks in material adjacent to the weld beads being the major problems.

3. During the early design period, the effect of transmitted vibration on the components being supported by the brackets was not considered.

SOLUTION/RECOMMENDATION

It was found that assignment of responsibility for the design of substantially all brackets to one engineering group (Structures Design) rather than a distributed responsibility among various disciplines was required to assure uniform, good design and coordinated installation.

DISCUSSION

During the early design period of the S-II there was a rapid evolution of design involving changes in line routing for the various systems. Lack of coordination among the design groups involved resulted in some installations which utilized brackets which were less than optimum. Electrical or fluid systems engineers, unfamiliar with sheet metal fabrication, sometimes designed overly complex brackets or brackets unsuitable to the purpose. Coordination and integration of design was greatly aided later in the program with the institution of a full-scale dimensional simulator of the thrust cone and aft skirt area of the stage where the greatest concentration of line routing existed. During the active development phase of the S-II there were numerous changes specifically involving bracket problems. Many other changes, although not specifically chargeable to bracket problems, involved significant bracket changes.

In an attempt to achieve the lightest design for brackets, many brackets were fabricated from sheet metal with welded-in gussets and webs. The welding proved difficult. There was difficulty in maintaining the required size, shape, and dimensional tolerances. Where flanges had to mate with the cylindrical stage mold-line some cracking along weld beads was experienced because of an improper match of the welded flange to the structure. When the attaching fasteners were drawn tight, cracking resulted. A continuing fabrication problem was crazing of 6061 Aluminum alloy welded parts. C-arc welding results in the formation of very fine, shallow cracks in the material adjacent to the weld beads. Although this crazing would not materially reduce the strength of a part, it was considered to be unacceptable for spacecraft quality requirements and had to be polished out wherever detected. This experience with welded brackets led to the conclusion that where integral gussets are required, which cannot be formed into a bracket from a single sheet, a more feasible method of fabrication would be to machine the part from bar or billet or use 2- or 3-part brackets.

Many mechanical or electrical units mounted within the stage are limited as to the intensity of vibration that they can withstand. Usually these components are qualified to specific limits of vibration, such as plus or minus 30 g's for given frequency ranges. When vibration from the structure occurs at the resonant frequency of a bracket, the vibration is amplified in the bracket. Thus a vibration of ±15 g's in the basic structure might be amplified to more than ±100 g's for a component mounted on a bracket whose resonant frequency is being excited. At very high frequencies the amplitudes of vibration become infinitesimal and not destructive to physical elements; the lower frequencies, with larger amplitudes, are more destructive. Generally, to avoid transmitting harmful vibration to sensitive elements, it was found that sheet metal brackets were inadequate. The supporting brackets had to have very high resonant frequencies. Brackets machined from bar stock with relatively thick walls and flanges and with integrally machined gussets were found to be required.

Design 11-04

COMPLIANCE MODE FREQUENCY AND STABILITY FOR THE ENGINE ACTUATOR STRUCTURE

PROBLEM STATEMENT AND EFFECT

Early in S-II control system design (late October 1963), it was recognized the compliance mode frequency for the J-2 engine actuator structure would have a significant influence on control system stability. For this reason an active damping device was incorporated in the engine actuation system design specifications. Recognition of this problem was based on preliminary theoretical considerations, which pointed to the need for

1. A sound theoretical set of equations describing the engine actuator structural system dynamics

2. Reliable estimates of compliance and other physical characteristics for each of the components

3. Prototype and production testing and measurements of the system and its components to confirm the theoretical estimates and data

A course of action was followed to supply these needs, since an unstable control system could not be tolerated.

SOLUTION/RECOMMENDATION

The course of action included theoretical studies, analog simulation of the system and its components, and extensive testing on prototype and production vehicles. These actions covered approximately 36 months terminating when battleship test results confirmed theoretical predictions. Test and analyses activities were later extended to include general and special testing of production vehicles through S-II-12 at the Mississippi Test Facility, MTF.

Several theoretical approaches, or models, were developed to study the problem. One model consisted of a matrix of linear influence coefficients describing the thrust structure, engine, and actuator. These coefficients were theoretically calculated, and a special static test was made on a prototype thrust structure to verify portions of these calculations. This test provided good agreement between the theoretical influence coefficients and those resulting from the test. Test verification of the influence coefficients describing the engine and actuator were obtained from the suppliers.

However, many problems were concerned with obtaining reliable and meaningful data for these components. This model made it possible to obtain linear analyses of the system compliance mode frequency.

Other theoretical models of the system were considered that included nonlinear characteristics such as engine gimbal friction and the dynamics of the DPF (dynamic pressure feedback) active damping device in the actuator. Studies of compliance mode frequency from these models were principally performed by analog computer simulation. A mockup engine actuator structure was available for tie-in with the analog computer. One important result of using a simulation of the system was to provide an assessment of the theoretical range of variance of the compliance mode frequency. In this study the Monte Carlo sampling technique was used to select tolerances of individual parameters. Over 100 analog computer runs were made in this assessment. The theoretical range of variance of the compliance mode frequency was found to include situations where the control system would not be stable. For this reason it was decided to continue to test production stages during static firing at MTF. Variability of the compliance mode frequency could be monitored indirectly from frequency response tests and from compliance measurements. Significant differences between theoretical and test results were considered as indicating a significant variance in the compliance mode frequency.

Two kinds of tests were performed during static firing of production vehicles at MTF. In one test the engines were gimbaled at certain discrete frequencies to obtain frequency response characteristics. Measurements were made of the commands to the actuators, and of the actuator extensions in response to these commands. These measurements were analyzed by auto- and cross-correlation techniques that produced a mathematical transfer function of the engine actuation system. This transfer function was then compared with a theoretical transfer function to determine if significant differences existed. This test was conducted on the battleship, and S-II-1 through S-II-12. However, good repeatability was observed in all cases where a common thrust structure design was used. Differences were expected and noted when a new thrust structure design was being tested.

In the other test, motion picture cameras were focused on engine-mounted targets to record engine alignment changes in two planes as thrust was applied to an engine. Since the alignment change is proportional to the stiffness of the engine actuator structure system, this measurement could be used to assess system compliance. This test was conducted on selected stages, and only on two engines for any one stage. The results compared acceptably with theoretical values. The test could be improved by installing additional reference targets on the stage in the camera field of view, and also by photographing all four engines simultaneously.

The solution as outlined above combines theoretical solutions with actual testing wherever possible. From the experience gained in solving this problem, the following recommendations are made for future efforts involving gimbaled rocket engines used for attitude control:

1. Make adequate allowance in the work statement for testing of components as well as for system testing
2. Do not permit suppliers to perform component acceptance testing
3. Add reference targets on the stage as well as on the engines when photographing engine alignment changes due to thrust
4. Photograph all four engines on each stage selected for photographic compliance measurements

DISCUSSION

Much of the effort described above was concerned with developing or learning new techniques. For example, the Monte Carlo sampling techniques were not previously used to organize data for analog computer runs. The photo-optical measuring system used to measure engine alignment changes in a live thrust environment was developed from scratch. The auto- and cross-correlation analysis techniques were adapted from a Rocketdyne program, but the techniques for producing a transfer function from the correlation functions was developed entirely by Flight Dynamics and Control personnel. (This was accepted by NASA at TU No. SID 92343.)

STRINGER END-FIXITY COEFFICIENT

PROBLEM STATEMENT AND EFFECT

NR and NASA (MSFC) agreed that the method of analysis to be used for determining the critical buckling load of the S-II LH_2 tank wall under axial compressive loading would be that given in NASA Memo 2-12-59L (Reference 1). However, this method of analysis requires that a stringer "end-fixity coefficient" be known in order to accurately determine the critical buckling load. The end-fixity coefficient may vary by a factor of four depending on the degree of end-fixity (pined end versus fixed end).

The effect of not accurately determing this end-fixity coefficient would result in a non-optimum tank design. In order to design a minimum weight structure, it was required to determine the end-fixity coefficient by test.

SOLUTION/RECOMMENDATION

Three LH_2 tank wall quarter panels were tested under axial compressive loading at the University of California and the buckling load determined (Reference 2). The LH_2 tank stringer end-fixity coefficient was then computed from the empirically determined buckling loads.

Although a theoretical expression correlated excellently with small cylinder test data, it was found to be unconservative when applied to the S-II LH_2 tank. Therefore, it is recommended that full-scale tests be performed to determine the end-fixity coefficient for structures which would require large extrapolations from available test data.

DISCUSSION

Methods of analysis for determining orthotropic shell buckling loads generally consist of column and shell curvature effects. One such method selected for analysis of the S-II, is given in Reference 1. The basic equation is:

$$N_{cr} = \frac{C \pi^2 E \bar{t}}{(L/\zeta)^2} + \frac{E}{\sqrt{3}} \frac{t_s}{R} \sqrt{t_s \bar{t}}$$

where the first term on the right-hand side of the equation represents the Euler load of a flat panel having the same cross section as the cylinder wall.

The second term on the right-hand side of the equation represents the buckling load of a moderately long longitudinally stiffened cylinder; that is, a cylinder long enough so that the ends have a negligible effect on the buckling load but short enough to preclude the possibility of flattening the cylinder into an elliptical shape. For the S-II configuration, the Euler portion of the equation predominates. The end-fixity coefficient, C, may vary from a value of 1.0 to 4.0 depending on the degree of end-fixity.

A theoretical expression to evaluate effective column end-fixity had been developed by Langhaar (Reference 3). Correlation between the Langhaar expression and available test data was excellent. However, a lack of confidence in the reliability of the shell buckling equations of Reference 1 as well as in the Langhaar expression for column end-fixity is indicated. The validity of applying test data obtained on model cylinders in the size range covered by the referenced tests to extremely large shell structures such as the S-II tank is questionable. Also, conflict in existing test data and disagreement between various investigators in the field is apparent. It was therefore decided that tests on full-scale curved panels of the LH_2 tank wall configuration were warranted. The end-fixity coefficient for the S-II tank wall was derived from these tests (Reference 4). Comparison of the end-fixity coefficient derived from the full-scale tests and the theoretical coefficient derived from the Langhaar expression found the Langhaar method to be unconservative for the S-II LH_2 tank structure.

REFERENCES

1. Peterson, J. P., and Dow, M. B., "Compression Tests on Circular Cylinders Stiffened Longitudinally by Closely Spaced Z-Section Stringers," NASA Memorandum 2-12-59L (November 1958).

2. Test Data Report LMSC/A704552; Lockheed Aircraft Corporation, Missiles and Space Division, Sunnyvale, California (September 1964).

3. Langhaar, H., "Stability of Semi-Monocoque Wing Structures," Journal-Aero Sciences, Volume 13, p. 119 (March 1946).

4. Stress Analysis of the Saturn S-II Stage Airframe (S-II-S, T, and F); NAA SID, SID 65-1676 (1 January 1966).

MATERIAL AND PROCESS SPECIFICATION APPROVAL

PROBLEM STATEMENT AND EFFECT

New and changed Material and Process Specifications on the S-II Program required MSFC/NASA contractual approval prior to release or implementation. The lengthy approval cycle resulted in hardware processing delays and increased program costs.

SOLUTION/RECOMMENDATION

Certain non-critical specifications were removed from the "Approval Prior to Release" list to reduce the quantity of specifications submitted in an effort to provide an expedient approval cycle. Additionally, special NR/NASA task groups were formed to provide expedited review and approval of the specifications. However, backlogs of specification changes continued to develop, lengthening the approval cycles. An expedient approval cycle was never established.

On future programs, it is recommended that requirements be negotiated with the customer but that specification release and implementation remain contractor responsibilities.

DISCUSSION

Most changes to specifications were in methods and techniques. However, customer approval was required for all specification changes regardless of the technical content. Specification backlogs developed which, at one point in the program, required at least 90 days for approval regardless of the magnitude of the change. This resulted in hardware processing delays whenever an in-process change was required. Concerted efforts by contractor-customer personnel relieved critical areas of concern but never fully resolved the problem.

Design 17-01

PNEUMATIC/FLUID SYSTEMS PARTICULATE CONTAMINATION

PROBLEM STATEMENT AND EFFECT

Malfunction of stage mechanical components during checkout, attributed to particulate contamination, generated a concern for all stage and GSE fluid system components.

SOLUTION/RECOMMENDATION

Because of the fabrication status of the existing program (all vehicles complete) an interim solution was implemented. This solution was to blow down all stage mechanical systems which contained particulate contamination sensitive components, where failure of these components would cause launch abort or mission failure. These systems were identified as critical systems.

The recommended solution for implementation on future vehicles (follow-on contract) was to protect all contamination sensitive components by filtering, etc., and to clean critical systems after assembly prior to component installation.

It was further recommended that the particulate level utilized as the acceptance criterion be reduced. This in turn would reduce the cumulative particulate level which results from the assembly of individually cleaned components.

DISCUSSION

A gas blowdown (high velocity purge) was performed on critical stage systems to determine the existing particulate level and to clean the system. This procedure utilized a stage-certified GSE helium supply attached to the inlet of the system or part of a system being blown down. A Millipore filter holder containing a five micron filter was attached to the outlet of the system. Pressure gages reflected system inlet and outlet pressure.

Flow was established by adjusting the system inlet pressure until the outlet pressure (filter inlet pressure) reached 300 psig, or the system inlet pressure reached operating pressure of the system, whichever was established first. Each purge cycle consisted of three minutes. The subject systems were repeatedly blown down until they met the cleanliness levels of NR detailed cleaning specification MA0110-018. All contamination sensitive components were removed from the system prior to blowdown in order to prevent their damage. Further detail of this procedure is reflected in Reference 1. This blowdown analysis reflected that particulate contamination exceeding the levels allowed by the detailed cleaning specification existed in most stage systems. The type of this particulate indicated that its occurrence was primarily contributable to generation during assembly and induction from the assembly environment.

Testing performed as part of a contamination program conducted by NR verified that particulate contamination is generated during the assembly and disassembly of "B" nut joints of the type utilized on the S-II stage. Test data also reflected that the particulate generated followed a definite size distribution and that the "Gas Blowdown" procedure was effective in removing this particulate. Additional data obtained during this program may be found in Reference 2. Also reflected in this report is the particulate level recommended for incorporation into cleaning specifications MA0110-018 and the MSFC-SPEC-164.

A follow-on program is currently being proposed to continue development in the particulate contamination control field. This program will primarily be concerned with establishing, through evaluation testing, an ultimate cleanliness level (practical cleaning plateau). This data will establish a base line for the establishment of design and control criteria, cleanliness requirements and cleaning procedures for future applications. Advanced methods of system cleaning will also be evaluated including the "Gas Blowdown" method and cryogenic fluid flushing.

REFERENCES

1. Contamination, SD 70-557-5, Saturn S-II Quality Assurance Critical Process Control Manual (October 30, 1970).

2. Contamination Program Final Report, SD 71-247 (April 15, 1971).

Design 19-01

VENTING OF HONEYCOMB INSULATION

PROBLEM STATEMENT AND EFFECT

Analyses and full scale tests indicated that the flow resistance of the honeycomb-insulation purge vent system was too high and that bursting pressures, causing insulation debonding, would result during the atmospheric boost phase.

SOLUTION/RECOMMENDATION

The problem was solved by cutting a network of interconnecting manifolds in the insulation which greatly reduced the pressure lag through the insulation. In addition, vent plugs were added to the upper and lower manifolds; these were closed during ground operations and opened at lift-off to provide additional vent area without introducing losses associated with pipe flow. It is recommended that in-flight venting system designs that use flow paths having undefined high frictional losses should be avoided. Whenever possible, tests should be performed to ascertain these type of losses.

DISCUSSION

The LH_2 tank 1.6-inch foam-filled honeycomb insulation was helium purged during prelaunch operations. It was necessary to provide sufficient venting to allow the purge gas to escape during boost, since insufficient venting could cause the insulation to debond. The original venting concept used a mesh of saw cuts in the insulation next to the tank to transport the purge gas to the manifolds at both ends of the sidewall. The gas flowed through 1/2-inch pipes leading to the umbilical panels. The same system was used for ground purge. These design changes were implemented to provide adequate in-flight venting of the honeycomb purge.

Design 19-02

VENTING OF FORWARD SKIRT AND AFT INTERSTAGE COMPARTMENTS

PROBLEM STATEMENT AND EFFECT

Analysis indicated the S-II forward skirt and aft interstage compartment vent holes were undersized for the Skylab mission. Undersized vent holes could result in excessive compressive and burst loads on the compartment walls during flight.

SOLUTION/RECOMMENDATION

By using external aerodynamic flow field data in conjunction with an in-flight venting program, the vent holes were properly sized and located to satisfy the in-flight venting requirements without compromising the ground purge requirements.

In design of in-flight venting systems, it is recommended that adequate provision be made for trajectory changes which may be required for future missions.

DISCUSSION

The S-II forward and aft interstage compartments are purged during pre-launch operations. Venting provisions must be made to prevent excessive structural loads during boost. The problem was to provide adequate vent area during boost in order to meet structural requirements, without exceeding the maximum allowable area for compartment purging. An additional problem affecting the forward skirt compartment was caused by the external aerodynamic flow field in this region. Compressive loads could exist on the frustum at the same time bursting loads were acting on the forward skirt. The trajectory of the S-II for Skylab is different from the trajectory for LOR missions resulting in a different set of values used for external aerodynamic flow data. Tolerance provisions for venting were inadequate to accommodate both missions.

MOISTURE CONTROL WITHIN SYSTEM COMPONENTS

PROBLEM STATEMENT AND EFFECT

Initial S-II design did not adequately consider the problem of moisture accumulation. Excessive moisture has resulted in slow component response, component failure, and corrosion.

SOLUTION/RECOMMENDATION

Subsequent to initial S-II design, it became necessary to make engineering design changes to add purge provisions; perform additional purging, component cycling, pressure cycling, and vacuum drying; and redesign components. It is recommended that moisture accumulation be considered in initial design so that traps are eliminated, purging provisions made, and procedures written so that all moisture is removed.

DISCUSSION

During the S-II program, a number of component failures occurred which can be attributed to moisture or where moisture is suspect. The failures have been caused by either moisture freezing at cryogenic conditions or by corrosion. The failures and their immediate effect include:

1. An LH_2 prevalve failure during a static firing countdown. The static firing was aborted and the valve replaced.
2. Vent valve position microswitches malfunctioning. No immediate effect.
3. A slow opening of an engine main LOX valve during an S-II static firing. The static firing was cutoff during the start transient and the valve replaced.
4. A leak through a torsional bellows. The line was replaced.
5. A slow opening of a start tank vent and relief valve during CDDT. The valve was replaced.

For each of the failures it was necessary to initiate an Engineering Design Change to prevent recurrence of the problem.

In addition to the design changes made as a result of S-II failures, a number of changes were made on S-II as a result of other program moisture problems.

Design 20-01

MECHANICAL JOINTS SEAL DEVELOPMENT

PROBLEM STATEMENT AND EFFECT

It was necessary to select, design, test, and qualify an adequate mechanical systems tubular joint sealing system. The tubular systems are of various sizes and subjected to severe service conditions and temperature extremes.

An inadequate sealing system, one permitting leakage, would be extremely hazardous, resulting in fire or premature depletion of fuels, oxidizer, or pressurization media.

SOLUTION/RECOMMENDATION

A thorough industry search was made to select candidate seals for testing. Flange designs were prepared, fabricated, tested, and optimized. The test program was successfully completed, resulting in the selection of the seal now manufactured by Megatech.

It is recommended that the seal/flange system as qualified continue to be utilized: its capabilities are known, installation procedures and handling devices are successful, and the supplier is cooperative.

DISCUSSION

Three significant problems were encountered during the development phase of this program.

1. Peeling of the teflon coating on cryogenic seals
2. Oxidation of the copper alloy coating on hot gas seals
3. Warping of the flange

The Navan (Megatech) cryogenic seal was originally coated with teflon tape and it was noted that after exposure to cryogenic temperatures the coating would split and peel off. The problem was overcome by applying the teflon by the dispersion process.

When the hot gas seals, coated with copper alloy, were exposed to LN_2 after exposure to hot gas (air) it was noted that leakage and severe oxidation of the coating occurred. Changing the coating from copper alloy to silver corrected the problem.

The third problem involved the seal and flange combination. Thermal shock tests conducted on the combination (subjection of an ambient seal and flange to LH_2 at -423 F) resulted in permanent warpage of the flange and leakage of the seal. Analysis of the problem led to the conclusion that this was due to the flange material (steel) low strain level, shrinkage at cryogenic temperatures and decreasing thermal conductivity. The problem was eliminated by prechilling the installation to -250 F prior to exposure to LH_2.

REFERENCES

Final Report - Testing of Saturn S-II Cryogenic and Hot Gas Seals, SID 66-294 (April 20, 1966).

Design 20-02

LARGE DIAMETER KEL-F LIPSEALS

PROBLEM STATEMENT AND EFFECT

Internal leakage and timing failures of cryogenic valves occurred due to the dimensional instability of the lipseal.

SOLUTION/RECOMMENDATION

A process must be developed to be used during seal and valve manufacturing to stabilize the seal and prevent distortion during the life of the valve.

DISCUSSION

The following sequence was developed to relieve stress on the seal during machining and fabrication.

The lipseals are machined to a rough ring configuration measuring 10.850 inches (outer diameter) by 7.750 inches (inner diameter) by 3/16 inch thick. These rings are stacked in a jig fixture and placed in an oven with sections of aluminum foil between each ring. The aluminum foil is trimmed on the inner and outer diameters to within 1/8 inch of the Kel-F to remove excess material. A restraining bolt on the jig fixture is then finger tightened to apply a slight compression load to the rings and prevent excessive warping during the stress relieving process. The oven control is adjusted to the desired temperature (250 ± 15 F) and a thermocouple installed near the center of the ring stack is monitored until the temperature is reached. When the temperature has been reached, a timer is set for 24 hours. At the conclusion of the 24 hours the oven is turned off, the oven door remains closed, and the oven is allowed to cool down to a maximum of 100 F before the specimens are removed. During the entire period in which the Kel-F is in the oven, it is extremely important that the oven door not be opened. This can not be over-emphasized.

After the oven has cooled to 100 F maximum, the rings are removed from the oven and machined to drawing dimensions.

Design 20-03

ACCUMULATOR RESERVOIR MANIFOLD ASSEMBLY RESERVOIR PISTON SEAL LEAKAGE

PROBLEM STATEMENT AND EFFECT

The reservoir piston "O"-ring seal has a tendency to spiral (twisting, nonuniform rolling action) during piston cycling. The effect is excessive leakage requiring accumulator reservoir manifold assembly (ARMA) replacement.

SOLUTION/RECOMMENDATION

The "O"-ring seal was replaced with a quad-ring seal specifically designed not to spiral. Future designs should not utilize standard "O"-rings for dynamic application on large pistons.

DISCUSSION

This reservoir is used in a hydraulic system with MIL-H-5606A fluid. The primary cause of spiralling is thought to result from the large diameter (8 inches) of the piston. Other factors considered to compound the problem are the slow speed of stroke (less than 1 inch per 10 seconds), low pressure differential (60 to 110 ΔP), small length of stroke (2.4 inches nominal, 4.2 inches total) and the fact that lubrication is not optimum (back side of piston is vented).

An engineering evaluation test was run to determine spiralling tendencies of the reservoir piston "O"-ring seal versus a quad-ring seal. Several tests were conducted, including piston cycling with no lubrication on the reservoir bore where the "O"-ring spiralled during the first cycle and the quad-ring did not spiral after 5 cycles. The conclusion of these tests (Reference 1) was that the quad-ring seal exhibited no signs of rolling, twisting, or spiralling and that there was no sign of leakage and no indication of seal deterioration as a result of that series of tests.

A design verification test was later conducted with an ARMA reservoir to determine the effectiveness of the quad-ring seal to resist spiralling and leakage under dynamic and static conditions at various pressures and temperatures. These tests (Reference 2) included 4,266 cycles accumulated through a series of simulated duty cycle tests, ground checkout tests, and accelerated aging and storage tests. Results were satisfactory.

After design go-ahead, the ARMA quad-ring configuration was qualified by the supplier.

REFERENCES

1. "Test Report Saturn S-II EAS ARMA Quad-Ring Test", LTR 3306-3401, L&T (January 1970).

2. "Test Report Saturn S-II Design Verification Test, ARMA Reservoir Piston Quad-Ring Seal", LTR 7617-3401, L&T (May 1970).

3. Parker Hannifin, "Qualification Test Report Quad-Ring for ARMA", 3QTR5630087M1 (June 26, 1970).

CRACKED B-NUT SLEEVES

PROBLEM STATEMENT AND EFFECT

MS20819 "B" nut sleeves fabricated of 303 SE Cres material exhibited numerous cracking failures induced by sulphur stringers within the raw material. The sulphur is added to provide free machining characteristics.

The cracking of the sleeve causes torque relaxation in the joint, which could result in excessive system leakage.

SOLUTION/RECOMMENDATION

The sleeve material was changed to 304 CRES. It is recommended that type 304 CRES sleeves continue to be utilized. Experience has proven this material is acceptable and not susceptible to cracking failures.

DISCUSSION

A series of leakage tests were conducted with purposely cracked -4C, -6C, -8C, -10C, -12C and -16C sleeves installed at minimum torque. The tests were conducted at 1500 psi while submerged in LN_2 and at room temperature.

It was found that the leakage rates of the -4, -6, -8 and -10 sleeves did not exceed 0.3 scims. This amount of leakage was not considered significant and is non-detrimental to the reliability of the systems involved. The -12 sleeve leakage was approximately 60 scims and -16 was in excess of 300 scims.

Design 22-01

SERVOACTUATOR PHASE LAG

PROBLEM STATEMENT AND EFFECT

The servoactuator supplier phase-lag acceptance test procedures and requirements were not compatible with the contractor's acceptance test. The effect was that servoactuators could pass the supplier's acceptance test and fail the contractor's static firing acceptance test.

SOLUTION/RECOMMENDATION

A study (Reference 1) indicates that in flight the vehicle reacted to a resultant phase lag which was closely approximated by average phase lag. Accordingly, the static firing acceptance test requirements were revised to specify that the average of the four pitch servoactuator phase lags and the average of the four yaw servoactuator phase lags shall be equal to or less than 34° with no individual servoactuator phase lags of more than 40°. (The original requirement was for all servoactuator phase lags to be less than 34°).

Supplier test equipment requirements and supplier and vehicle acceptance test requirements are provided early in the program. It is recommended that these early requirements be re-evaluated, as test data becomes available, in order to insure compatibility.

DISCUSSION

A static firing acceptance test criteria for the servoactuators was less than 34° phase lag between the input current and the servoactuators output position, when applying a sinusoidal input signal of 6 ma P-P at a frequency of 1 Hz. The supplier's acceptance test requirement at this amplitude and frequency was equal to or less than 33°. A problem existed because of differences in test configuration and method of determining results. The primary difference was in load inertia with the supplier's load inertia (flight configuration) being only approximately 60 percent of the static firing configuration. Other differences thought to have a minor effect were differences in load structure stiffness, bearing friction, and the transfer function (supplier used load position while the static firing data used was servoactuator piston position). Data evaluation indicated an average static firing phase lag increase of 7° over that recorded by the supplier on the same servoactuators. Accordingly, servoactuators could pass the supplier's phase lag acceptance test and fail the static firing acceptance test. This condition actually occurred on the one servoactuator removed for excessive static firing phase lag. When retested by the supplier, the phase lag was almost identical to that recorded during the initial supplier acceptance test (Reference 2).

REFERENCES

1. "Minutes of the Thirteenth S-II Stage Vehicle, Dynamics and Control Working Group Meeting," R-ASTR-BV-709-68, Agenda Item 7 (October 30, 1968).

2. "Minutes of the Twelve S-II Stage Vehicle, Dynamics and Control Working Group Meeting," R-AERO-P-22-S-68, Agenda Item 6 (May 13, 1968).

PRODUCT REPEATABILITY PROGRAM

PROBLEM STATEMENT AND EFFECT

A review of component failures (electrical and mechanical) after the components had been installed on the stage revealed that the failures occurred when the attempt was made to repeat component functions which had recently been passed during a supplier's acceptance test program.

SOLUTION/RECOMMENDATION

A Product Repeatability Program was developed by NR/SD, NASA, and the supplier for improvement of configuration management, planning, tooling and quality assurance functions. This program included the establishment of an in-house Re-acceptance Test Program. This re-acceptance test was performed on all Criticality I and II components and some Criticality III components.

In view of the number of components rejected during this program, it is recommended that a similar component test program be developed and implemented wherever high reliability systems are required.

DISCUSSION

The Product Repeatability Program consists of subjecting the component to an upgraded (more stringent) acceptance test program by an independent user test facility. In this program the testing was performed in an NR/SD laboratory. Detailed test plans were developed and implemented for each component to be tested. Test stands which were equal to or better than the supplier's were designed and built.

Any malfunctioning component was returned to the supplier for corrective measures. Upon completion of this action the component was subjected to the supplier's acceptance test program and upon receipt at NR/SD was again subjected to the Product Repeatability test program.

This test program resulted in a significant reduction of failures of components after installation on the stage.

Design 23-01

S-II CRYOGENIC TRANSFER LINE

PROBLEM STATEMENT AND EFFECT

Early Saturn Program cryogenic transfer line assembly designs were not effectively verified by development tests, because test facilities were not available to test with operational fluid media and flow rates. Many laboratories lacked the experience necessary to fully understand the effects of cryogenic flows. Subsequently, line failures occurred on the Saturn S-II as a result of vibration caused by high propellant flow rates. Flow facilities capable of simulating exact service flow conditions were built. Flow tests performed revealed that line assemblies behaved quite differently with minor changes in flow media or flow rates. The flow-induced vibration phenomena was later the subject of an extensive study by the NASA.

SOLUTION/RECOMMENDATION

The basic qualification test philosophy was changed to include operational flow test for high-flow line assemblies. A comprehensive analysis of all line assemblies was initiated to determine the effects of flow induced vibration. From the analysis, five components were singled out for additional flow testing to complete qualification requirements.

Serious consideration as to the effects of flow induced vibration must be included in the design of future cryogenic transfer lines. Flow tests must be a part of the development test phase using the proper fluid media and instrumentation to verify compliance to design requirements.

DISCUSSION

Test facilities and test techniques were lacking to adequately verify the structural capabilities of early cryogenic transfer line assembly design. Test facilities did not have the knowledge and were not equipped to provide operational flow rates using liquid oxygen or liquid hydrogen as the flow media. The flow techniques employed were the substitution of water or in some cases liquid nitrogen at equivalent flow rates, or short bursts with the actual media (gravity flow). No matter how well these systems performed, they failed to provide the exacting information.

Failures during the tanking operations of a 6-inch-diameter Boeing Saturn S-IC LOX fill and drain line assembly bellows and an 8-inch-diameter North American Rockwell Saturn S-II LOX fill and drain line assembly bellows provided the major impetus into flow characteristic investigations. Boeing's study revealed that flow-induced vibration on their 6-inch-diameter line assembly was significantly increased when the flow exceeded 3000 gallons per minute, and structural failures would occur on unlined single or multi-ply bellows at flow rates in excess of 4000 gallons per minute.

Note: The same conditions will exist at equivalent velocities for larger diameter line assemblies.

The NR failed LOX fill and drain line assembly qualification test program was reviewed to determine cause of failure. From the review, it became apparent that some minor differences in flow characteristics existed between water (used during the initial line qualification program) and LOX, which could be a problem when related to high-flow rates. To substantiate this analysis, a LOX flow system was developed capable of flowing LOX at operational flow rates and extended durations.

The failed bellows in the NR line assembly was replaced with a multi-ply bellows with liner. The remaining bellows were not changed since it was assumed that a valve located near the failed bellows causes turbulent conditions, thus causing the failure. This redesigned line assembly was subjected to an LN_2 flow test and then to a LOX flow test at operational flow rates and duration. The unlined compensator bellows failed one minute into the LOX flow test. This failure influenced the selection and design on many line assemblies such that multi-ply bellows with liners replaced all single ply bellows without liners.

The J-2 engine ASI fuel line flex hose failure initiated a comprehensive study program into the effects of the flow-induced vibration. All Saturn S-II flexible line sections were assessed for potential failure due to flow-induced fatigue. Five of the ducts determined to be influenced by flow-induced vibration were subjected to flow tests following the techniques fostered by Dr. C. R. Gerlach. This program verified the integrity of the Saturn S-II Stage flexible lines and ducting, and established new guidelines for the flow testing.

The approach to line assembly flow tests are now well defined, providing a development tool for actual simulation of system requirements. Flow test results have provided confidence that the transfer line assemblies, designed for various systems, will perform as required.

Design 23-02

EFFECTS OF LOCAL GEOMETRIC IRREGULARITIES ON WELDED THIN-WALL LINES

PROBLEM STATEMENT AND EFFECT

In February 1967 a failure of the LOX tank internal vent line occurred on the S-II-F/D during the longitudinal phase of the Dynamic Test Program being conducted on the Saturn V vehicle at MSFC. The flight dynamic and pressure environments to which this line had been designed and analyzed and for which other specimens had been successfully qualified were considerably higher than the corresponding levels that preceded the failure. Subsequent metallurgical investigation determined that failure began as a high-cycle fatigue fracture in an area exhibiting incomplete weld penetration and large degrees of material offset (mismatch) and peaking (weld joint angularity). Re-examination of inspection radiographs obtained from the line supplier indicated discernable weld discrepancies in the failure area that had not been repaired during line production. Further review of this supplier's weld specifications revealed that, although weld offset was limited to 35 percent of the adjacent material thickness, no limitation existed for joint angularity or peaking. Weld offsets greater than 100 percent of the material thickness and weld peaking of varying degrees were found to exist elsewhere on the failed line and on other lines subsequently examined. Immediate concern developed regarding the structural integrity of this line and all other similarly-constructed thinwall welded line systems employed on the S-II flight stages.

SOLUTION/RECOMMENDATION

A list was compiled of all line systems on the S-II that, because of design or method of support, could prove susceptible to the deleterious effects of weld offset and peaking conditions. All weld radiographs were re-examined to insure the adequacy of line structural welds; discrepancies were noted and the affected parts returned to the manufacturer for repair.

Analysis results were combined with static and dynamic test results to establish the effects of various geometric irregularities on the fatigue strength of this type of welded line system. The results of these efforts were compared to the predicted cyclic load spectra for each structural weld on the listed S-II line systems to determine allowable limits for weld offset and peaking. All applicable welds were then inspected to insure these limits were not exceeded. These limits were incorporated in the applicable weld specifications to preclude future occurrence of the problem.

DISCUSSION

The large number of potential weld peaking and offset configurations as well as the variations in circumferential length precluded any possibility of rigorous structural analysis. For this reason, a more general approach was employed using idealized geometries. Peaking and offset were assumed to be axisymmetric and were analyzed independently. As developed for the aforementioned LOX tank vent line failure, the analysis techniques and assumptions are documented in Reference 1. These same methods (described below) were employed in the analysis of welded thin wall line assemblies on the S-II.

Weld peaking was represented in a longitudinal cross-section of the line wall as two straight slopes emanating obliquely from either side of the weld bead and joining the basic contour at an angle. For a given amount of peaking (expressed as multiples of the material thickness), the magnitudes of the three angles thus formed are functions of the longitudinal separations of the apexes. The various conditions representing symmetrical and unsymmetrical peaking were evaluated by considering the local moment effects to be equivalent to those that would result from the action of three uniformly distributed radial loads V_a, V_b, and V_c (Figure 5). These were assumed to act at circumferences along the line in directions that would tend to produce the particular peaking conditions studied. For several conditions of symmetrical and unsymmetrical peaking, the magnitudes of these radial loads were determined so as to balance the line maximum longitudinal force P resulting from the combination of line axial load and gross line bending. This calculation assumed no bending stiffness existed in the longitudinal discontinuity element at the load locations. Local longitudinal moments resulting from each of the three uniform radial loads were next determined using methods described in Reference 2. These were added algebraically to determine the maximum moment and its location. Because of the rapid decay in moment away from the radial load producing it, the maximum was found always to occur at the weld.

A more general case was considered for weld offsets. An inflection point was assumed to exist at the weld so as to result in a moment arm equal to 60 percent of the total offset in the longitudinal element of the line (Figure 6).

For both weld peaking and offset, the stress resulting from the local moment effects was represented as a stress intensification multiplier for the gross line stress. These factors vary from a minimum value of unity for the case of no discontinuity to maximums in the range of ten for peaking and offset values equalling 200 percent of the material thickness. They have been plotted as functions of the eccentricity ratio (e/t) for the various cases considered.

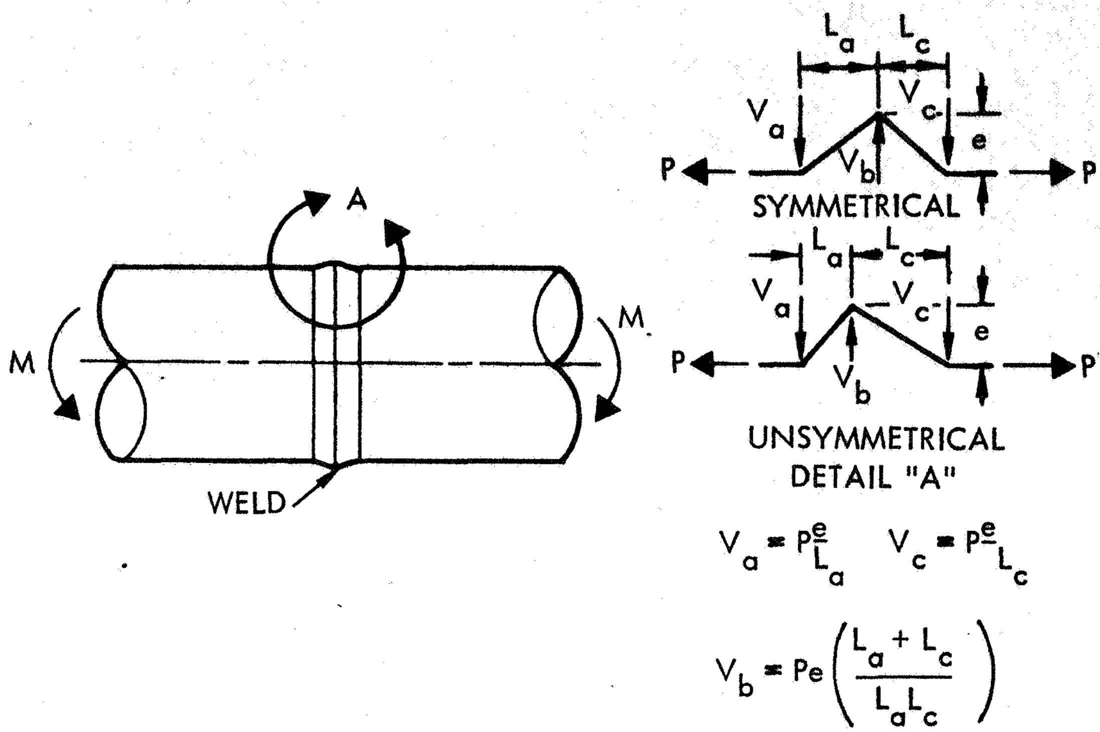


Figure 5. Symmetrical and Unsymmetrical Weld Peaking

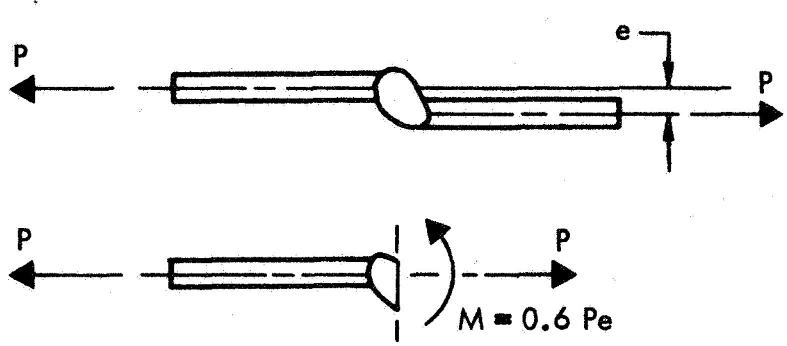


Figure 6. Weld Offset Representation

To obtain actual measurements of the stress intensification factor, a segment of the failed S-II-F/D line was subjected to a static tension test at MSFC. Six weld areas representing various conditions of offset and peaking were instrumented with strain gages. Stresses at the weld center were calculated, based on strains measured adjacent to the welds; these were compared to the gross line stress obtained from longitudinal strain gages located between welds on the duct surface to determine the corresponding intensification factors.

Based on the foregoing analysis and tests, the following observations are made:

1. The analytical approach is conservative; calculated weld stress intensification factors are higher in all cases than those resulting from measured discontinuity strains.

2. For a given eccentricity ratio, weld peaking is more severe than weld offset.

3. For a given peaking eccentricity ratio, the stress intensification factor increases as the slope of the peak increases.

Practical application of the calculated stress intensification factors requires that the cyclic load spectra and material weld fatigue allowables be known. By use of Miner's theory of cumulative fatigue damage and fatigue curves at temperature (Reference 3), allowable intensification factors can be determined for a given load spectrum. (A trial and error process is often required for complex loading spectra.) From this, weld peaking and offset maximum allowables can be determined so as not to exceed a cumulative damage increment of unity.

As applied to lines on the S-II, a weld was classified as "critical" if the allowable offset or peaking calculated as described above was greater than 1.0 t or 0.8 t, respectively. All other welds were classified as "non-critical." Conservative arbitrary limits were established as follows:

Condition	Critical Weld (t)	Non-Critical Weld (t)
Offset	0.35	0.60
Peaking	0.35	0.50
Offset and peaking	0.35	0.50

The primary objective was to provide a basis for assessing flightworthiness of S-II lines. Although intended for application to fabricated hardware, the techniques could be employed to establish design requirements for maximum weld offsets and peaking, provided determination of the cyclic load spectra is possible. Since this is often not possible during preliminary design, a more realistic approach would be to establish rigorous quality requirements for all such line welds and to employ the foregoing analysis techniques as required for Material Review Disposition.

REFERENCES

1. "Internal LOX Tank Vent Line Fatigue Investigation," S-II/STR 67-5, Space Division, North American Rockwell Corporation (June 19, 1967).

2. Roark, R. J., Formulas for Stress and Strain, Fourth Edition, McGraw-Hill Book Company (1965).

3. Cryogenic Material Data Handbook, ML-TDR-64-280, Air Force Materials Laboratory, Research and Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio.

Design 23-03

FLOW-INDUCED VIBRATION ANALYSIS

PROBLEM STATEMENT AND EFFECT

Under certain conditions, gaseous or liquid flow through a convoluted flexible element of a duct or hose (bellows section) may result in a fatigue failure of the element which can cause leakage or premature shutdown of a critical fluid system.

SOLUTION/RECOMMENDATION

As a general rule, liners can be added to prevent resonance of ducting bellows if media flow velocities exceed Mach 0.3. However, flow-induced acoustic resonance can occur under otherwise "safe" conditions, and liners under some conditions may not be required at flow rates exceeding Mach 0.3. It is recommended that a flow-induced vibration/acoustic resonant analysis be made of all bellows sections of a fluid system to determine if a resonance condition exists. Reference 1 includes a technique which has been proven to give valid results with this phenomena.

DISCUSSION

While the J-2 Engine A.S.I. line failure on AS-502 is the best-known instance of flow-induced vibration (Reference 2), two instances of flow-induced fatigue failure have occurred in the S-II program. The first was in a bellows section of the S-II-1 LOX fill and drain line. The solution was to add liners and incorporate multi-ply bellows; analyses such as in Reference 1 were not available at the time.

The second failure was that of a pre-pressurization system flexible hose in S-II-9 that had been identified in a prior test program (Reference 2) subject to a flow-induced vibration condition. Discovery of the failed hose in S-II-9 prompted an immediate investigation and test program (Reference 3). It was found that purge media used during ground maintenance operations (GN_2) created a more severe flow-induced vibration problem than the system's end-use gas (GHe) used during the prior analysis. While the solution to this particular problem was relatively simple (mandatory use of a second source flex-hose which was not susceptible to flow-induced fatigue), this failure points up the conditions that must be evaluated in determining flow fatigue susceptibility.

REFERENCES

1. Gerlach, C.R., et al. "Flow-Induced Vibration of Bellows with Internal Cryogenic Fluid Flows," Interim Technical Report No. 2, Contract No. NAS8-21133, Southwest Research Institute (August 1970).

2. Final Report - Flow Test Program for Stage Flexible Lines, SD 69-97 (March 1969).

3. Henry, R.H. "Flow-Induced Acoustic Resonance in Flexible Hoses: S-II-9 Flex-Hose Failure," NR-Space Division Interdivisional Technology Seminar (February 1971).

Design 23-04

PNEUMATIC CONTROL LINE FAILURES

PROBLEM STATEMENT AND EFFECT

Pneumatic control line failures were experienced early in the program due to failure of the weld joints as a result of vibration. A failure of this type could cause mission loss or abort.

SOLUTION/RECOMMENDATION

Rocketdyne introduced new weld techniques (shot-peened double-weld) to preclude the possibility of line separation during test. It is recommended that welding of pneumatic lines utilize this technique.

DISCUSSION

During early cluster testing of the J-2 engines on the S-II Battleship, weld joint failures experienced on the engine pneumatic lines were found to be due to vibration. Rocketdyne developed a shot-peened, double-weld joint which successfully withstood the cluster environment. In conjunction with the weld redesign, a special inspection of the applicable lines was performed pre-static firing and post-static firing on S-II-1 through S-II-4. No discrepancies were found. The pneumatic control lines rewelded were:

1. Oxidizer turbine bypass valve opening control
2. Oxidizer turbine bypass valve closing control
3. Main fuel valve opening control
4. Main fuel valve closing control
5. Main fuel valve sequence valve inlet
6. Main fuel valve sequence valve outlet

VACUUM JACKETED LINES

PROBLEM STATEMENT AND EFFECT

The fuel and oxidizer propellant, fuel vent, and recirculation lines of the S-II depend on the vacuum in the jacket annulus for insulation to prevent excessive heat leak into the cryogenic liquid propellants. Outgassing contaminants in the annulus, cracked or corroded welds, rupture discs or bellows, cracked or broken thermocouple gage pins, and faulty evacuation valves are all means by which the vacuum insulation has been lost.

SOLUTION/RECOMMENDATION

Initial vacuum losses were attributable to "freezing out" of the primary "0" ring seal which was fabricated of Viton A with a lower temperature limit of -65 F. When stage installed lines exceeded this limit the result was an abrupt pressure rise in the vacuum annulus. Depending on the annulus volume this pressure rise would vary from 140 to 2000 microns. This pressure rise was the result of leakage in the primary seal and the cap's secondary seal maintaining the new higher vacuum level. This condition was resolved by changing the primary seal "0" ring to one fabricated from Kel-F and redesigning the plug and disc assembly to a two-piece construction to accommodate the new Kel-F ring.

Initial rupture discs of the LH_2 recirculation system were of coated aluminum which corroded in the salt-air atmosphere to which the S-II is subjected. These discs were replaced by CRES 321 discs which, with one exception, corrected the problem. Although the material of the rupture discs for the propellant feed and vent systems lines was also CRES 321, through improper processing several discs corroded. The material in these discs was changed to Inconel 600 and processing was strictly controlled.

Pressure carrier bellows which cracked due to improper supplier forming processes caused loss of vacuum by leaking propellant into the annulus area. This was corrected by working with the supplier in implementing new forming methods and bellows re-rolling techniques.

Bent thermocouple pins contributed to loss of vacuum also. The thermocouple gage pins are set in glass and may be bent without loss of vacuum, but when straightened so they will accept the readout instrument cap, the glass cracks and the vacuum is lost.

The evacuation valve plug and disc assemblies have the male threads of the plug silver plated to prevent metal-to-metal galling when the valve is cycled from open to closed. With the changing of the material in the primary seal "0" ring from Viton to Kel-F considerably more torque was required to effect an acceptable seal. In addition, the Kel-F "0" ring had a tendency to cold flow under the loading conditions, thus requiring periodic retorquing to maintain the seal. These conditions caused silver plate flaking from the plug with subsequent migration of the silver to the sealing surface of the "0" ring, thus providing a leak path for loss of vacuum. Engineering tests are scheduled for the purpose of finding a more suitable lubricant and providing this change for the remaining S-II's.

DISCUSSION

Vacuum-jacketed line maintenance technology was a non-existent skill at all NR facilities at the inception of the program; therefore, until sufficient technical skills were acquired by Seal Beach, MTF and KSC personnel, line annulus contamination was a continuing problem. Eventually documentation was written for all facilities to control and regulate annulus entry. The imposition of this documentation and training of technicians brought the contamination under control.

RETEST AFTER REMOVAL OF CHECKOUT DRAG-ON CABLES

PROBLEM STATEMENT AND EFFECT

S-II stage systems checkout was performed at Seal Beach and MTF with drag-on (nonflight) cables installed to obtain the desired instrumentation readouts. This necessitated retest, after return to flight configuration, to verify flight functions. Early in the S-II Program, retesting was inadequate to validate all disturbed flight functions.

SOLUTION/RECOMMENDATION

The systems functions disturbed by cable disconnection and reconnection were analyzed, and tests were defined to provide the required reverification. These tests were incorporated into the simulated flight automatic checkout test (final checkout) that is performed after the vehicle has been returned to flight configuration.

It is recommended for new business that systems be designed to minimize use of nonflight hardware in order to meet checkout requirements.

DISCUSSION

If the reasons for tests performed in the nonflight configuration are justified, define the functional disturbance caused by removing the nonflight hardware (drag-on cables, break-out boxes, pneumatic lines, etc.). Develop test requirements and operations that will retest these invalidated functions when the vehicle under checkout is in the flight configuration.

Example: The engine valves position measurements are routed to continuous recorders via drag-on cables during functional sequence tests. This drag-on cable configuration was required to obtain the engine valve position measurements for continuous monitoring, due to the critical timing requirements of valve positioning, to be verified during the engine sequence tests. A procedure was provided in the simulated flight automatic checkout test to verify all engine valve measurements when the stage harnesses were reconnected in the flight configuration. Individual engine sequences were performed to retest all engine functions that were disturbed by this cable configuration change.

Design 25-01

CRACKED SOLDER CONNECTION ANOMALIES IN S-II INSTRUMENTATION EQUIPMENT

PROBLEM STATEMENT AND EFFECT

Numerous instrumentation equipment failures caused by cracked solder connections have been experienced on the S-II Program during the various phases of S-II vehicle test. Much time and effort have been expended in recycling, failure analysis, and effecting corrective action on each failure occurrence.

SOLUTION/RECOMMENDATION

All affected equipment is being recycled to the supplier for re-inspection of each solder joint and reworked as required. The supplier has incorporated an improved production process for rework of solder joints. New motherboards were fabricated by an improved production process for refurbishing the flow-tach chassis to be used on S-II's -6 through -15.

It is recommended that where reflow of solder is required, such as bifurcated terminal soldering, a 47-watt soldering iron and liquid flux be used. All conformal coating should be deferred until the soldering process has been completed.

It is also recommended that Final Report No. 8402A, "Development of Highly Reliable Soldered Joints for Printed Circuit Boards" (August 1968), by Westinghouse Defense and Space Center should be considered when production processes are prepared for future programs.

DISCUSSION

Due to variation in design of each failed unit of instrumentation equipment, failure analysis and corrective action of cracked solder connections have varied. In general, the major loading mechanism in solder joint failure was entrapped conformal coating and/or contaminants stressing the joint during thermal excursions and/or soldering. The major objective in establishing corrective action was to strengthen solder joints so they can withstand stresses caused by thermal excursions when equipment is in use or during uncontrolled storage. Because of design variations and schedule and cost impact, the established corrective actions taken on the S-II program relative to cracked solder anomalies can be classified into two categories:

Category A

Equipment using pull-out printed circuit boards that can be visibly inspected. Also, schedule and cost impact was seriously considered. Detection of stressed solder joints was improved by revising production process specifications using 30X power magnification glasses rather than the 7X previously used. All stressed solder joints detected were strengthened by improved production processing and quality control. Equipment in this category is recycled for inspection prior to six months of launch date. The following equipment was selected for recycling based on observed failures and laboratory analysis:

Part Name	Part No.	Failure	Percent of Stressed Joints per Unit
PCM/DDAS	ME470-0083	2 units	35% of total joints
TDM	ME456-0027	None*	25% of total joints
RASM	ME456-0031	None*	30% of total joints
RDSM	ME456-0033	None*	20% of total joints
RF Power Assy.	V7-750140	None	10% of total joints

Category B

Equipment in the category have experienced high failure rates but cannot be visually inspected for stressed solder joints due to non-transparent protective coatings such as silicone rubber. Flow-tach signal conditioner chassis, V7-750145, was the only equipment that was in this category. Corrective action for equipment in this category was found to be costly due to packaging design. Various nondestructive detection methods for cracked solder joints were used with little success. Therefore, investigation was concentrated in the production process.

*Unverified failures experienced with this equipment may have been due to stressed solder joints.

It was determined that several discrepancies existed during fabrication. These discrepancies were:

1. Improper swaging tools for bifurcated terminals were used.

2. Cleanliness of production process area was not enforced.

3. Assembly specification allowed conformal coating entrapment in the solder joints.

4. Inspection personnel were not properly trained for inspecting solder joints.

5. Soldering specification did not provide sufficient details in soldering bifurcated terminals where a reflow of solder could take place, thereby causing weakened solder joints to occur. Solder joints were strengthened by use of higher iron-tip wattage and use of liquid flux during reflow of solder.

Thorough review of above discrepancies indicated that the quality of solder joints in the flow-tach chassis was extremely poor. The following failure history of the flow-tach chassis during various phases of S-II vehicle test substantiated the above conclusion.

Facility	Vehicle No.	Test	Failure
Seal Beach	S-II-8	Checkout	Cracked solder
Seal Beach	S-II-8 (spare)	Checkout (retest)	Cracked solder
MTF	S-II-4	Post Static Firing	Cracked solder
MTF	S-II-5	Static Firing	Cracked solder
MTF	S-II-6	Static Firing	Cracked solder
MTF	S-II-7	Static Firing	Cracked solder
MTF	S-II-9	Static Firing	Cracked solder

Because of this high failure rate, all flow-tach chassis from S-II-6 through S-II-15 were recycled to the NR/McAlester facility for fabrication of new motherboards which incorporated an improved production process. This corrected all the above-listed discrepancies. Since corrective action was taken, no further failures have occurred.

CAPACITANCE PROPELLANT-GAGING HARDWARE

PROBLEM STATEMENT AND EFFECT

A number of hardware problems have been encountered with capacitance propellant-gaging equipment on the S-II and other programs. These are the major problems:

1. Coaxial wiring and connectors

2. Electromechanical potentiometers

3. Electronic component reliability

These problems have degraded countdown and flight reliability, threatened launch delays, and caused heavy expenditures of time and money for corrective actions.

SOLUTION/RECOMMENDATION

Stringent quality control and workmanship procedures were instituted to minimize sensitivity of coaxial wiring and connectors to environmental factors (cryogenic temperatures and moisture). Upgrading of numerous components (capacitors, potentiometers, transistors, diodes) was necessary to achieve acceptable reliability of the propellant utilization (PU) computer electronics assembly. Improvements in welding and lubrication of electromechanical potentiometer windings were necessary to correct breakage and noise problems with this component.

It is recommended that the use of capacitance type propellant-gaging equipment be avoided unless a strong requirement exists for a continuous (analog) measurement of propellant quantity. This is because of the extremely low signal-to-noise ratio inherent in capacitance gaging systems and the resultant sensitivity to wiring defects and stray capacitance.

DISCUSSION

The S-II Propellant Loading and PU System is an adaptation of the capacitance system designed for the S-IVB. As such, the electronics were not built to the same high reliability and traceability standards normally imposed on S-II hardware. As a result, numerous failures of components such as capacitors, semi-conductors, and potentiometers have occurred over a 7-year period. These problems were corrected as they occurred by upgrading the particular parts involved, but as of the AS-510 launch (July 26, 1971) new component problems continue to appear. The only positive solution is believed to be a high reliability program for complete upgrading of the PU computer, including replacement of the electromechanical rebalancing bridges with solid-state devices.

To avoid the expense of this change, an open-loop PU system was provided on S-II-9 and subsequent stages which bypassed the PU computer entirely. Open-loop commands from the guidance system are now used to control a pneumatically actuated 2-position MRCV (mixture ratio control valve) on each engine. The capacitance gaging system is now used only for ground loading and inflight instrumentation.

Discrete level sensors are used for redline monitoring of propellant level during steady-state replenishment.

Failures of the coaxial wiring and connectors between the probes and PU computer presented a more difficult problem, due to the low signal-to-noise ratio and inherent sensitivity of capacitance systems to minor influences. This meant that slight damage to the wiring or flaws in assembly of the connectors often caused shifts in the system readout, especially during rainy weather and cryogenic loading. The number of connectors in the system tunnel was reduced and stringent quality control procedures were instituted to reduce these problems, but the element of human error cannot be completely eliminated. This is a serious drawback of capacitance systems since it is not feasible to provide redundancy in the full-length capacitance probes and associated hardware.

OPTIMIZATION OF PROPELLANT UTILIZATION FUEL BIASING

PROBLEM STATEMENT AND EFFECT

Previous methods of selecting fuel bias sought to minimize the 3-sigma S-II PU (propellant utilization) residuals. This did not maximize S-V payload capability since the mean S-II residual (rather than the dispersion about the mean) has the greatest effect on 3-sigma S-V performance.

SOLUTION/RECOMMENDATION

A Monte Carlo statistical simulation program was devised to optimize fuel bias with respect to 3-sigma S-V performance (rather than 3-sigma S-II residual weight). This approach should be used in all cases where payload capability is important.

DISCUSSION

To maximize 3-sigma S-V performance, it is necessary to adjust the S-II fuel bias so as to minimize the mean S-II residual weight rather than the +3 sigma S-II residual weight. This is so because, when statistically combining the various factors which affect S-V performance, the mean S-II residual weight must be combined arithmetically with all other mean factors affecting S-V performance, such as mean dry weight and mean thrust; whereas the random variance or residual weight (about the mean) must be combined in a root sum square manner with all the other random variances affecting S-V performance, such as dry weight tolerances and thrust tolerances. This drastically dilutes the effect of the S-II residual variance on 3-sigma S-V performance. The minimum mean residual and the minimum residual variance do not occur at the same value of fuel bias.

Design 26-03

UNCERTAINTY OF BUBBLE VOLUME IN BOILING PROPELLANTS

PROBLEM STATEMENT AND EFFECT

The volume of bubbles in a tank of boiling cryogenic propellant can vary from near-zero to approximately 3 percent of the liquid volume, depending on tank size, shape, liquid convection, and thermal insulation. The uncertainty in bubble volume assumed for the S-II tanks was ±0.4 percent which substantially degraded the accuracy of gaging and loading propellants.

SOLUTION/RECOMMENDATION

Stillwells were installed in the S-II tanks to isolate the propellant level monitoring point sensors from the effects of bubbles and indicate the effective liquid level (that which would exist in the tank if no bubbles were present). Point sensors were also installed outside the stillwell to measure the actual tank level including bubbles. The difference in measured level inside and outside of the stillwell indicated the volume of bubbles in the liquid. This technique was used in correcting indications from sensors subjected to bubbles.

Sensors used for gaging boiling propellants should be protected from the effects of bubbles by means of stillwells and bubble deflectors, except as noted below.

DISCUSSION

The effectiveness of stillwell compensation for bubbles is 100 percent in a tank of constant cross-section area (assuming a uniform radial distribution of bubbles). For the S-II tanks, which have a varying cross-sectional area, the compensation is less than perfect but still on the order of 80 to 90 percent, which reduces the bubble content error to negligible amounts. For S-II-11 and following S-II's, however, loading is controlled to the overfill sensors which are located outside of the stillwells. The advantage of external point sensors is that they indicate over a broader range of tank level since they are exposed to the wave action caused by normal boiling. (The percent of time that a sensor flashes wet indicates the average surface level if the wave height is known.) When loading to external sensors, it is important to know the absolute value of bubble content. This can best be determined by means of closely spaced point sensors which indicate the difference in liquid level inside and outside of the stillwell.

LH_2 RECIRCULATION PUMP BEARING

PROBLEM STATEMENT AND EFFECT

LH_2 pump Barden bearings with phenolic-micarta retainer failed due to inadvertent pneumatic turbining (pressure differential across pump) and/or excessive electrically powered dry spinning operations during checkout. Pump failure affects engine preconditioning and ability to start engines.

SOLUTION/RECOMMENDATION

The Barden bearings with phenolic-micarta retainers were replaced with MCRC (Marlin-Rockwell Corp.) bearings with teflon impregnated fiberglass (Rulon) retainers. All applicable specifications and detailed operating procedures that could produce a differential pressure across the pump were reviewed and caution notes such as the following, added:

> Caution - Never open pump discharge valves until pressure has been equalized across the recirc pumps.

After experiencing the individual failure and prior to making the bearing change, all electrical dry-spinning operations were deleted. After incorporating the new bearings, electrical dry spins, up to 10 seconds in duration for a total of not more than 24 cycles, were allowed to facilitate electrical checkout.

DISCUSSION

Bearing failures occurred on pumps installed on the S-II Battleship and four S-II stages (S-II-T to S-II-3). Time of failure ranged from one minute of dry spinning to 25 hours of cryogenic operations. Results of failure analysis showed that all bearing failures were similar in that a considerable amount of friction was in evidence between the bearing's rotating parts. Thus, it was concluded that the pumps had been subjected to excessive turbining and/or dry spinning and operations.

The improved lubricity of the Rulon material has increased the allowable electrically powered dry-spinning operations to 10-second durations with up to 24 cycles, and eliminated bearing damage caused by pneumatic turbining overspeed and dry spinning.

Design 32-01

NOISE ON 28-VOLT IGNITION BUS

PROBLEM STATEMENT AND EFFECT

When the spark exciters of the ignition systems in the J-2 engines were operating, noise and transients in excess of the maximum allowable levels appeared on the 28-volt ignition bus.

The ignition interference was coupled into data lines to obliterate some data and to render suspect much data that was not obliterated.

SOLUTION/RECOMMENDATION

The ignition interference resulted in a contract change allowing NR to ignore all PCM data during operation of the ignition system.

Current J-2 engine ignition systems can be vastly improved by the addition of power-line filters which attenuate the ignition noise as much as 50 to 60 decibels. A filter should be installed in the monitor line also. A separate bus, isolated from other busses by twisting and shielding and by distance should be used.

New designs should be integral units comprising the exciter, high voltage cable, and spark plug. This unit should be mounted on the thrust chamber. The power input lines should be current regulated to minimize current fluctuations; this will minimize induction of voltages into adjacent lines.

DISCUSSION

The noise and transients were generated by (1) the operation of the spark exciter, and (2) discharge of the storage capacitor through the spark plug gap. The operation of the spark exciter contributed the higher frequency (600 to 800 Hz), lower-level pulses. The discharge of the capacitor through the spark plug contributed the lower frequency (500 to 80 Hz), higher-level pulses. Both types of pulses had fast rise times and thus contained frequencies as high as several mHz. While the EMI specification does not limit noise in the frequency range below 150 kHz, it is necessary to limit noise in this frequency range for proper operation of adjacent equipment.

Because the ignition systems on the J-2 engines were part of a government furnished equipment (GFE) package, NR/SD made no attempt to physically alter the equipment. Instead, a specification change was requested and approved to allow this higher interference level on the 28-volt bus. Later, a test was performed in the Laboratories and Test department electronics laboratory to determine whether a design change was feasible. An optimum L-C filter configuration was developed. This filter configuration reduced the interference on the ignition bus as much as 50 to 60 decibels. NR/SD requested that the J-2 engine manufacturer install this filter in the ignition system power lines. However, the J-2 engine manufacturer had already received a contract change approval allowing noncompliance with the specification. It was not feasible for NR/SD to install filters in each of the many lines interfacing with the J-2 engine system. Consequently, NR/SD applied for a contract change to allow the deviation from normal data monitoring. Approval of the contract change was granted by MSFC. While this was not the best solution in that data were lost for approximately 4.75 seconds, it appeared to be the most feasible solution.

When new ignition systems are designed, they should be of the integral type of unit recently developed by the Rocketdyne Division of NR, under contract to the NASA Lewis Laboratories. This type has extremely low radiation levels because the spark exciter and spark plug are an integral unit, mounted on the thrust chamber, with no high voltage cable. In addition, the power lines are filtered with a constant-current regulator which allows only milliampere fluctuations in power current rather than ampere fluctuations such as those in the J-2 engine ignition system. This minute current fluctuation limits the induced voltages in adjacent lines to very small values.

RECIRCULATION INVERTER ELECTRICAL NOISE

PROBLEM STATEMENT AND EFFECT

Excessive electrical noise level due to the operation of the LH_2 recirculation inverter was experienced on the EDS measurement system; thereby causing an out-of-tolerance condition on the S-II. The major cause was determined to be poor filtering of inverter noise.

SOLUTION/RECOMMENDATION

A pi input filter with a choke in the return line was added between the bus and each inverter. This reduced the noise to an acceptable level (between 50 and 70 mv). It is recommended that filtering be used for any Avionics system which utilizes power conversion equipment with quasi square-wave switching in order to meet EMI requirements.

DISCUSSION

Without any filter, the system noise levels varied from 100 to 200 mv. Several filter configurations were considered and tests conducted to select the most effective filter for the S-II system.

All noise wave forms showed a damped oscillatory transient with a repetition rate of 2400 Hz and a ringing frequency of 50 to 100 KHz.

The 2400-Hz repetition rate of the inverter was derived by multiplying the fundamental frequency of 400 Hz by 2 because the amplifier is push pull, and then multiplying by three for the amplifier's three phases.

The final filter configuration is shown in Figure 7 . The most effective filter would have used 1000 μf capacitors, but the delivery schedule for these capacitors was not feasible, so 660 μf capacitors were selected. The filters were supplied by Engineered Magnetics and were first installed on the S-II-2. Subsequent tests showed that the filters meet all procurement specification requirements.

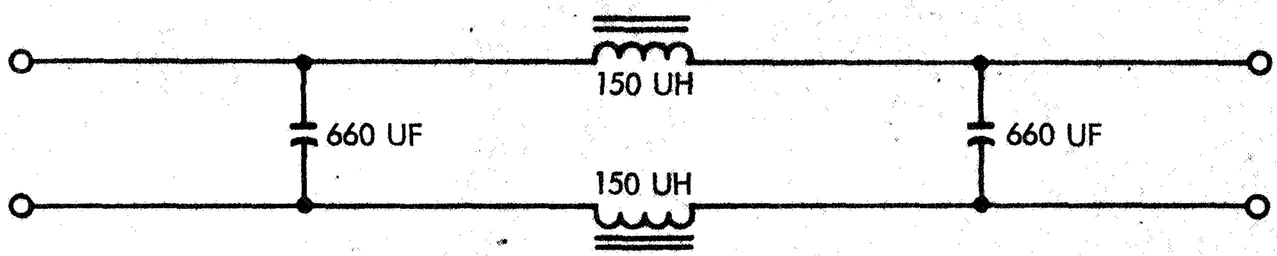


Figure 7. Final Filter Configuration

Design 32-03

FLIGHT MEASUREMENTS FOR ANALYSIS OF LOW FREQUENCY OSCILLATIONS (POGO)

PROBLEM STATEMENT AND EFFECT

The vibration and pressure measurement requirements originally established for the S-II did not provide the capability for analysis of phase and amplitude on low frequency data. Indications of low frequency vibration of the center engine beam were apparent during the S-II boost phase.

SOLUTION/RECOMMENDATION

Three low-frequency vibration measurements were implemented using piezoelectric transducers mounted at two locations on the center engine beam and at one location on the LOX tank sump. Three close-coupled pressure measurements were implemented, two measuring LOX pump inlet pressures on Engine 1 and Engine 5, and one measuring the LOX tank sump pressure. Existing LOX pump inlet and discharge pressure measurements were re-channelized from time-shared to continuous channels.

DISCUSSION

Beginning with S-II-6, a series of instrumentation changes were made that resulted in the data required to complete phase and amplitude analysis of the low-frequency vibration phenomenon on the S-II. Three new low frequency measurements were implemented and transmitted over the FM/FM data link as continuous channels. After the S-II-6 launch, the frequencies of interest became better identified and low-pass filters were added to the stage signal conditioning for these low frequency vibrations on S-II-7 and following S-II's. Three close-coupled pressure measurements were added along with the rechannelization of three existing pressure measurements from 120 samples per second to continuous channels. These measurement changes were made to provide information regarding the source of the driving mechanism of the low frequency oscillations.

During the S-II boost of the AS-508 launch, an early cutoff of the S-II center engine occurred due to a loss of chamber pressure that resulted from excessive low frequency vibrations of the primary structure. Analysis performed for S-II-7 and subsequent S-II's using the new measurement data proved an extremely valuable design aid in the corrective action program, resulting in the installation of the accumulator on the center engine feed line for later vehicles. This data also provided design information for implementation of a backup acceleration switch (G-switch) that would provide center engine cutoff in the event of excessive beam vibration.

Design 32-04

CLOSE-COUPLED VS LONG-LINE INSTRUMENTS FOR BIPHASE PRESSURE MEASUREMENTS IN A CRYOGENIC LIQUID

PROBLEM STATEMENT AND EFFECT

A low-frequency oscillation problem (POGO) occurred on Saturn S-II vehicles which caused difficulties in correlating frequency and phase data from various pressure and vibration transducers.

SOLUTION/RECOMMENDATION

When true frequency, amplitude, and phase information is desired from a liquid pressure measurement, it is essential that the measuring device be flush-mounted as close to the measurement medium as possible. The use of long-line coupling from the medium to a remotely mounted measurement device introduces considerable distortion.

DISCUSSION

As a result of the POGO problems associated with some of the Saturn vehicle flights, a question arose as to the fidelity of long-line pressure transducer installations. Considerable information was available on the frequency loss in a long line with gases but the effect of bi-phase cryogenic liquid in a long line were unknown. A test setup was devised using nine transducers of the same type. A large tank eight inches in diameter and 11 inches high was fabricated. At the lower end of the tank, seven bosses were made to hold two flush-mounted transducers and five plumbed units. Each plumbed unit was different in length but used the same diameter of tube. On top of the tank two instruments were installed to measure gas pressures. The tank was filled with LN_2, and a gas pulse at a varying rate of 1 to 17 cps was introduced. The gas measurements and the flush-mounted liquid measurements followed each other very well; however, there was no fidelity to the long-line measurement readings. The sudden surging of the liquid down the long lines produced such distortion that the data had no meaning. As the lines got longer, the distortion increased. The amount of distortion was dependent upon the surge of the liquid down the line such that a step function produced total distortion, while a slow, repetitive movement suffered loss in amplitude but retained phase and frequency data.

It became apparent that an additional stage measurement was necessary in order to provide meaningful information of flow in the LOX pump inlet line. Prior to this time, an unsuccessful attempt had been made to use the information from a long line (42 inch) transducer without any success.

An investigation disclosed a location on the LOX feed lines that would accept a 1/4-inch fitting. This location was on the same plane as the plumbed long line transducer but was located 90° off center. Basic requirements were that the transducer must be light in weight, small in size, be capable of being mounted from an existing 1/4-inch boss, and must be available off the shelf for immediate delivery. Contact was made with several potential suppliers and one was selected. The unit decided upon was manufactured by CEC, of an unbonded design and was very lightweight. Supplies of these units were available off the shelf at the supplier's facility. These parts were slightly modified by CEC to comply with NR requirements, and delivery and qualification was completed within 2 months. The measurement was first implemented on Saturn S-II-6 and extremely valuable data was obtained from this measurement during the POGO problem on Saturn S-II-8, which allowed correlation in frequency and phase of other pressure and vibration measurements.

Design 32-05

ELECTRICAL COMPONENT REDUNDANCY

PROBLEM AND EFFECT

Electrical component failures resulted in concern that Saturn S-II reliability of electrical circuits might not meet program requirements.

SOLUTION/RECOMMENDATION

Provide selective redundant electrical components wherever possible.

DISCUSSION

When the Saturn S-II program progressed from the design to the manufacturing phase problems arose with electrical equipment which had met program qualification requirements. Even though reliability apportionment requirements could still be demonstrated it became evident that a significant reliability increase would result from selective redundancy in electrical components.

The concept of redundancy was thoroughly covered during the Saturn S-II Phase I and Phase II Design Reviews held by MSFC as well as the various in-house design reviews that were held by Space Division Quality Assurance. During these operations all single failure modes were identified and the various design review boards were satisfied that the Saturn S-II program was in compliance with design requirements.

The present design criteria for the S-II program represents an increase in reliance upon redundancy, and all new design considers redundant components, but across-the-board redundancy is not practical due to cost and weight considerations. Also, redundancy should never be used to justify use of unreliable components.

Design 32-06

BATTERY CELL TABS

PROBLEM STATEMENT AND EFFECT

During initial qualification tests of the S-II batteries, the voltage and capacity performance was adversely affected by the breaking of plate tabs between the cell plates and terminals. This occurred during vibration. The performance was such as to require a redesign.

SOLUTION/RECOMMENDATION

Redesign was accomplished by adding integral, expanded metal grid tabs in place of the wire tabs used in the original design and by using hold-down potting in the corners and bottom of the cells to fix the plates to the cell wall. This allows less motion between the plates and terminals and reduces the tendency for tab breakage. It is recommended that foil tabs be used in the future where high vibrational environments are expected. The tab is less susceptible to breakage and makes a stronger cell pack design.

DISCUSSION

The battery used on the S-II program is a manually activated, primary, silver zinc battery. The positive plates are made of silver peroxide and the negative plates of sponge zinc. The separators are made of Viscone and cellophane. The electrolyte is potassium hydroxide. The ESB battery was originally designed with conventional wires attached to the plates and terminals. Each plate used three wires. When qualification tests severed the wires, ESB attempted to solve the problem by compressing the cell pack so that the plates could not move up and down, thus work-hardening the wires leading to the terminal and breaking them. On subsequent tests wires continued to sever.

A contract was subsequently negotiated with Eagle Picher to produce the S-II battery in support of S-II-1. The advantage of the Eagle Picher design was twofold. One, the tab design used an integral tab and plate expanded metal screen design. The metal screen was attached directly by silver solder to the terminal. This led to a stronger mechanical connection that resisted flexing when the plates attempted to move. Second, an epoxy base potting material was added on the bottom of each cell and along the sides of the expanded metal tabs, which tied the plates, separators, and cell walls together, allowing the batteries to pass all specification requirements in qualification tests.

GSE OPERATING AND TROUBLESHOOTING PROCEDURES

PROBLEM STATEMENT AND EFFECT

During the activation period for Seal Beach and MTF, GSE operational problems were encountered. It was difficult to isolate problems due to inadequate documentation.

SOLUTION/RECOMMENDATION

Requirements documents, overall system schematics, and individual rack schematics must be developed as part of the initial phase of a program.

DISCUSSION

The Saturn S-II Program ground support equipment for checkout and static firing the vehicle for acceptance was designed on an end item basis using interface control documents (ICD's). This type of design control can be utilized effectively if properly implemented on a systems requirements and control basis. This control must be implemented logically and sequentially:

1. Based upon vehicle checkout and operational requirements, develop an overall GSE operational requirement specification which defines the GSE rack level operational requirements.

2. Produce and continually maintain an end-to-end GSE schematic which contains, as a minimum, all interface-to-interface wiring including the vehicle interface. This schematic must show all test points, patching, signal nomenclature, and will preferably contain internal GSE rack circuitry; however, this schematic will not control the configuration of the internal rack circuits. This schematic must be complete and accurate prior to activation of the test site. An inter-rack wiring list must accompany the schematic and will control the wiring configuration. All wiring changes will be incorporated into the wire list by engineering order with the change immediately reflected on the schematic.

3. Produce and continually maintain rack schematics and wire lists. These documents must contain all test points, patching, and signal nomenclature.

The above documentation is required to successfully activate and maintain an operational site for acceptance or development testing.

INSULATION IN WELDING AREAS

PROBLEM STATEMENT AND EFFECT

The insulation material utilized in the weld area stations of the S-II Bulkhead Fabrication Building (BFB), S-02, was exposed and was installed without a surface covering or exterior bond. As a result of traffic and traverse of the overhead crane, and building expansion and contraction, this unbonded material flaked and settled into welding areas. This material was assumed to contribute to weld contamination.

SOLUTION/RECOMMENDATION

In a continuing effort to minimize any source of contamination in the welding operation, vinyl sheet coverings were installed directly to the surface of the insulation. This bonding of vinyl to the insulation, with adhesives, provided an adequate interim means of containing the flaking material. Continual maintenance was required to maintain the vinyl on the insulation due to continual traffic, traverse of the crane, and wind currents through the aisles and doors.

It is the recommendation of North American Rockwell that insulation panels utilized in new facilities, where critical welding operations will be conducted, be installed with either a polyurethane spray finish or covered with a factory-installed vinyl cover that is adequately bonded to insure minimum maintenance costs, and also insure debris containment.

Incorporation of a factory surfaced, bonded, nonflaking insulation or vinyl-bonded material should be included in the initial Facilities criteria, for building installation at the earliest date of design or modification to negate future contamination problems.

DISCUSSION

The BFB, S-02, was of girder and truss, sheet metal-faced construction. To provide a degree of personnel comfort and noise abatement, the interior walls were lined, between the girders, with a composition fiberglass insulation. The insulation face was not finished with sealer or bond and, as a result of heavy traffic from shop flat trucks, overhead crane travel and other related vibrations, the material began to flake and fall. The falling flakes and dust settled on materials to be welded, tool fixtures, and the general area causing a probable weld contamination problem.

Corrective action was initiated by Facilities to contain the falling and flaking debris. This action consisted of applying vinyl sheeting over the face of the insulation, from girder to girder, with adhesives. This measure was not a panacea but did provide a control measure. Continued traffic, crane operations, and wind necessitated continued surveillance of the vinyl to contain the contaminating dust.

RADIOGRAPHIC INSPECTION OF FUSION WELDMENTS

PROBLEM STATEMENT AND EFFECT

Radiographic inspection techniques (x-ray) employed in support of S-II stage bulkhead weld operations were accomplished independently of the welding provisions incorporated in the four, major, bulkhead weld tools. The tooling provisions made for x-ray, while satisfying quality requirements, had numerous potential areas for improvement in both operating time and materials.

Radiographic inspection of the bulkhead meridian welds are made in a series of 16 individual radiographs, each 12 inches in length, along the 16 feet of weld. This method requires an individual set-up for each exposure and, subsequently, individual handling in processing, interpretation, filing, sorting, retrieval, etc.

SOLUTION/RECOMMENDATION

Simplification of x-ray inspection can be accomplished by elimination of the 1-foot radiographs. The utilization of full weld-length film strips will accelerate all steps in handling and processing.

DISCUSSION

The Boeing Company, in conjunction with NASA Huntsville, has developed an automated, radiographic inspection system for S-1C stage operations. This system has proven successful in providing the required quality and can be expected to reduce the S-II method by 15 set-up operations per bulkhead meridian weld.

The Boeing system is built around an automated film-transport cassette, which permits the use of full weld-length film strips. This unit contains, internally, shielded film advance and take-up spools, permitting stop and go film exposures of 12 inches in length. Operating techniques employ the cassette on a tape-controlled skate mechanism which propels the cassette on a fixed track along the weldment in 12-inch increments. The cassette progresses from point to point, stopping for the x-ray exposure. After exposure and during the movement of the cassette to the next point, the film strip within the cassette is advanced to an unexposed section. This action is repeated the number of times necessary to expose the entire weld.

Upon completion of the full weld travel, the total film strip is processed, interpreted, and stored. Film retrieval and flaw locating is accelerated by use of specially designed strip-film readers. Flaw location is enhanced by use of a specific steel tape measure which is attached to the part being x-rayed, adjacent to the weld. The tape measure indications are clearly discernible in the processed film and reveal the exact location of discrepancies

X-ray film data, such as part number, film number, date, etc., are included on all radiographs. This is accomplished by using a standard "Addressograph plate" to emboss information on a lead plate, which is also attached to the part and thus incorporated into the exposed film.

It is recommended that this Boeing system be incorporated in all future tooling design programs for any products requiring "in tool" radiographic inspection.

WELD QUALITY REQUIREMENTS

PROBLEM STATEMENT AND EFFECT

At the time of Saturn S-II contract award, the definition of what constituted required weld quality was subject to various interpretations and subsequent disagreement. What constituted a good weld was agreed upon, but permissible defects, which were allowable in a satisfactory weld, were always points of contention.

SOLUTION/RECOMMENDATION

The problem of "acceptable" weld quality was not resolved. Personal differences of opinion as to what constituted an acceptable, or a rejectable defect along with the recommendation for a "fix" for each point of contention resulted in many meetings, investigations, and even Material Review actions.

A recommended solution follows: by joint action of concerned industry (material suppliers, fabricators, NASA, the Armed Forces, and manufacturers of welding equipment and inspection systems) develop and publish an illustrated description of weld parameters, showing acceptable and unacceptable conditions. This jointly developed and approved manual would then become an authoritative reference baseline. This activity would be conducted independently for any contract or project and could require considerable effort on the part of the participants. The joint committee would also compile necessary reference data, from current and previous programs. There would be no specific completion date, and the document would be reviewed periodically to insure inclusion of the necessary revisions accrued from experience and technological progress.

DISCUSSION

Controversy over what degree and type of weld defects were acceptable arose early in the S-II program. Part of this was due to the limited experience of personnel delegated with the responsibility. Part was due to the lack of existing information on specific materials and their application.

The problem was compounded by the lack of historical data on material usage for systems such as the S-II. There was no baseline or authority of acceptable reference and the task of interpretation fell upon the Material Engineers and Quality Control personnel.

On occasion repair was undertaken on questionable defects. This type of repair often resulted in creating other defects or conditions less desirable than the original offending fault. In a few instances expensive repair and panel replacement was resorted to as a way of insuring agreement. (e.g., cutting an entire cylinder-barrel off an assembly, replacing a panel and then rejoining.) This sort of problem was also responsible for extensive non-destructive testing to insure the capability of an assembly (bulkhead hydrostat and pneumostatic testing of entire tanks) because the contractor and customer had to verify what had already been inspected by dye penetrant and X-ray.

Nobody desires a bad weld, everyone agrees on what a clear one is. The area of borderline controversies result in costly resolutions. The proposed "Defect Document" could reduce the area of disagreement, expedite production, test, and programs, and ultimately result in reduced production cost.

REPEATABLE, CERTIFIABLE WELDING EQUIPMENT

PROBLEM STATEMENT AND EFFECT

The integration of an acceptable assembly process was troublesome early in the S-II program. This was compounded by the inexperience of maintenance technicians in the diagnosis of machine faults and isolation and correction of these problems.

SOLUTION/RECOMMENDATION

The technicians responsible for the performance of the equipment acquired familiarization and knowledge through continued exposure to the welding process. This was helpful but inadequate to meet the requirements of schedule and achieve desired weld quality. To accelerate the learning process, contracts were developed between NR and the two prime suppliers of welding packages — Sciaky Bros., Inc. and the Air Reduction Company (AIRCO) — for on-the-job training (OJT), and assistance in personnel education, maintenance techniques, and qualification of equipment. Any new program should emphasize initial technician capability upgrading by intensive on-the-job and classroom training and should be conducted by the manufacturer of the original equipment.

DISCUSSION

The S-II contains over 2,200 feet of exacting quality weldments. Bulkheads for the hydrogen and LOX vessels required long, tapered welds and step welds. To accomplish such weld joints, programmable controls were incorporated into the system by blending the power supply current requirements with the tool and piece part requirements. Also required was an inert gas envelope to preclude weld contamination; the necessary equipment functions to move the torch along the weld at a controlled rate of speed; and maintaining of the proper weld temperature through an elaborate arc voltage comparison system which regulated the tungsten tip to work piece distance.

Synchronizing all these requirements into a functional operation (tool, power supply, piece part, and programmer) was critical and was accomplished on representative material which simulated the actual part. This test material was then removed for laboratory evaluation and testing to assure weld quality and to establish equipment parameters.

The possibilities for malfunctions during such a critical process was recognized even at the time of conceptual equipment design. The use of time- and process-proven components was emphasized to preclude operational difficulty. However, the system was so comprehensive that malfunctions did occur and the diagnosis of a fault, its isolation and correction, in many instances, was a tedious and time-consuming task.

Maintenance personnel were qualified as electrical/electronic technicians and most of them had previous weld machine maintenance experience. The S-II weld process and equipment, however, was considerably more elaborate than any previous weld equipment assignments at the Space Division. Assistance was required and was requested from the prime suppliers of the welding machines. Sciaky Bros., Inc. provided an instructor for on-the-job training of technicians in the maintenance and functioning of penetration control systems and weld equipment and later provided weld process and equipment instruction to run a class on site for weld equipment technicians. The assistance and training acquired from outside contracted support accelerated NR personnel training.

IN-TANK ENTRY AND UTILITY DISTRIBUTION

PROBLEM STATEMENT AND EFFECT

In-tank entry was required prior to the pneumostat test to finalize certain hardware installations and to perform closeout welding. Entry was also required, following the pneumostat test, to perform dye-penetrant inspection of the stage and to make repairs, as required. Equipment such as electrical units with J-boxes and extension cords, intercom units, and phone lines were required by the craftsman inside the tank for the performance of installation and inspection. Through constant use, and as a result of continual chafing, the electrical cord insulations were damaged at the plug ends and at the equipment casing ends. The exposed wire coming into contact with the stage created arc burns to the product, which created Material Review action, rework, and lost production time.

SOLUTION/RECOMMENDATION

To overcome the inherent dangers of arcing, damage to the stage and injury to employees, new procedures were implemented. These new procedures included the encapsulation of all electrically operated units in the stage; the elimination of J-boxes; the installation of electrical systems on the access ladder; and the installation of a Rucker sentry alarm system. In addition, the S-II Tank Entry Safety Standard procedure was issued.

Aerospace contractors encountering similar confined entry requirements, where utilities are mandatory within the tank, should provide encapsulated receptacles for all power requirements such as: electrical, intercom, and phone lines, prior to the first requirements for tank entry.

DISCUSSION

Entry into the S-II stage was a procedure followed for in-tank installations and for post-pneumostatic inspection. The interior of the stage had to be provided with lighting and power from external sources to provide a means from which to operate power tools, welding equipment, and black lights for inspection purposes. The power sources were long extension cords equipped with J-boxes which became worn and frayed from constant use, handling, and twisting. In the performance of installation or inspection, some of these frayed cords grounded out to the stage interior causing arc burns. Also a minor incident involving an employee was encountered wherein the employee was shocked but not hurt.

To minimize the dangers cited above, corrective action was instituted by Systems Safety, Facilities and Manufacturing. These actions included the elimination of the extension boxes, intercom, and phone lines. The 8EH-5101 entry tank platform was modified to include the following:

1. Floodlights were installed on top of the ladder with lights designed so that they could be plugged into a separate circuit from the rest of the electrical requirements.

2. A plug jack was added for the intercom system at the bottom of the ladder and at the top.

3. Six air outlets were added at the bottom of the ladder for plant air.

4. Six electrical outlets were provided for lights and electrical power equipment.

5. All outlets were tied to a Rucker sentry alarm system.

6. A battery powered emergency light was provided to allow safe exit in the event of power failure.

In addition to these modifications, all extension and power cords used inside the tank were encapsulated and all tools were continuity checked. Twist-lock design connectors were mandatory. These new applications corrected all prior problems except the black light used in the dye-penetrant inspection. Due to size and shape of the light and the heat generated, this unit was wrapped in asbestos sheeting to provide the insulation required.

MULTICONDUCTOR PIN ALIGNMENT

PROBLEM STATEMENT AND EFFECT

Numerous multi-conductor cables were used during Test & Operations checkout of the Saturn S-II. Each of these cables, routed from the Stage to the check-out consoles, was equipped with a large electrical plug containing connector pins set in potting compound. During alignment setups and separation tests many pins were bent or broken due to tension on the cables and misalignment at the connecting points. These damaged or broken pins required extensive rework, incurred added program costs, and caused delays in stage checkout schedules.

SOLUTION/RECOMMENDATION

Following a detailed study of the problem, Industrial Engineering issued a contract funded Job Order for design rework of the Umbilical Station in Building S-15, the Vertical Checkout Facility. The rework consisted of the addition of an access ladder to the east side of the cable disconnect platform; re-routing of all cabling and power lines; installation of a cable carrier rack to align to the umbilical carrier rack; and rework of the umbilical carrier rack to provide a more positive alignment. The re-routing of the multi-conductor cables increased the bend radius of the cables making the connection to the umbilical carrier easier and minimizing the probability of bending or breaking pin connectors. It is recommended that similar installations requiring manual hook-up include human factors evaluation during the design phase. Inclusion of this aspect during design will provide easier cable handling and routing, reduce the exposure of connector pins to damage, and minimize rework and design costs.

DISCUSSION

Following Final Assembly, the Saturn S-II's were moved to the Vertical Checkout Building where each stage underwent system checkout and test. The stage was connected to a fixed umbilical tower interconnected with the check-out consoles. The various systems included multiconductor cables equipped with large potted fixed pin connectors. The alignment of these connectors to the umbilical was difficult due to the limited cable flexibility and limited radius in the cable. As a result of these problems, pins were bent and broken during set-up and separation. To alleviate the condition a design

Job Order to analyze and rework this system was issued. The justification for this release stated:

> "Due to extreme difficulty when connecting electrical cables at the forward and aft umbilical stands to the umbilical interface plate, many connectors have been damaged. This situation has been extremely costly and contributed to many hours of unnecessary downtime. Redesign of the umbilical stands to provide better accessibility at the cable connect points will greatly alleviate this condition."

As a result of a detailed study, modifications to modify umbilical retract mechanisms to allow higher carrier plate installation were approved. The modifications eliminated the previous problem and gave greater flexibility to the connection and separation of the cables to the umbilical carrier rack.

RINSE REQUIREMENTS FOR SATURN S-II STAGES

PROBLEM STATEMENT AND EFFECT

Cleaning requirements for the Saturn S-II stipulated that the interior of the stage be cleaned with heated demineralized water (120 degrees) and detergent. The wash cycle was followed by a rinse flush of the total interior. The rinse cycle was accomplished with water of an ambient temperature which retarded drying time and resulted in a detergent residue clinging to the interior skin and baffles. To remove the residue, the affected areas of the stage were hand-wiped.

SOLUTION/RECOMMENDATION

It is recommended that future cleaning installations for large vehicles, requiring interior rinsing following a detergent wash, incorporate heaters to heat the required rinse water to a temperature compatible to the wash cycle requirements. Heated water will accelerate the drying and reduce the amount of residue clinging to the interior surfaces.

Although this system of heated water for rinsing was not incorporated in the Saturn S-II program, it was evaluated and its costs were studied after the demineralized system was in operation. Installation of a heating system for large volumes of rinse water should be incorporated into the basic Facilities requirements and included in the construction specifications.

DISCUSSION

Specifications for cleaning the interior of the Saturn S-II stages stipulated a detergent, demineralized water cleaning at a temperature of 120 F at the nozzle. This was accomplished by preheating the 300, 000 to 500, 000 gallons of water in the tank-farm holding tank to approximately 180 F. This detergent-water mix was, in turn, pumped through the cleaning boom to provide a detergent wash at 250 gpm and 200 psi. Following the cleaning cycle the stage interior was spot sprayed with rinse water of an ambient temperature (approximately 55 to 60 F, depending on the climate) to reduce the shock to the metal. When the mean temperatures on the skins were attained, a full and final rinse was conducted to remove residue and scums. This rinse, with water at an ambient temperature, slowed the interior drying and did not remove all water spots or traces of detergent. The final residue was removed from side wall and baffle areas by hand wiping.

Based upon the experience gained in the Saturn program, it is the recommendation of North American Rockwell that any contractor faced with a similar problem of cleaning large interior surfaces should incorporate heated rinse water into the process specifications. These requirements should become a basic part of any Facilities criteria at the earliest possible date to minimize installation costs.

DOOR CONTROL DURING WELD OPERATIONS

PROBLEM STATEMENT AND EFFECT

High bay doors in the Bulkhead Building, S-02, were installed without locking devices. During welding operations, if these doors were opened, a weld arc flame-out interrupted the welding. Additionally, dust and dirt, transported by wind through the doorways, created a weld contamination problem.

SOLUTION/RECOMMENDATION

All major exterior doors, leading into areas where critical welding operations are performed, should be equipped with electrical "lock-out" devices and indicator signs noting "Weld-In-Process".

The inclusion of the above controls should be incorporated during the design phase of the facilities installation.

DISCUSSION

Welding operations for the bulkheads of the Saturn S-II were conducted in an area of Building S-02 adjacent to high bay, electrically operated doors. When these high bay doors were inadvertently opened during welding, the wind currents caused the inert gases to drift from the weld line or to flame-out. The wind also caused dust and particulate matter to settle on the product leading to contamination of the welds. To avoid flameouts and contaminations, signs of "Do Not Open During Weld Operation" were installed and the doors secured. In addition, a system of warning lights were installed in Building S-02. These lights were energized when welding operations were in progress, thus alerting all personnel in the area that the doors were not to be opened without permission from those in charge of the welding operations. Further, canvas drop curtains were installed in all weld station access areas. The inclusion of required controls during the design phase of the building will do much to minimize cost and increase product reliability.

SITE DUST CONTROL

PROBLEM STATEMENT AND EFFECT

The first construction specification for the NASA Site, Seal Beach, dictated asphalt covering to be installed on areas of parking lots, road beds, and outside storage. This type of installation left significant unimproved areas between buildings and roadways that created a dust/dirt problem. Swirling dust and dirt flowed through open doorways, service doors and breezeways creating a housekeeping and contamination problem in areas of welding, bonding, etching/cleaning, and processing.

SOLUTION/RECOMMENDATION

To overcome the problems created by the dust and dirt swirling and settling in and around buildings and on deliverable hardware, the site was surfaced with asphalt covering. The action negated dust pockets adjacent to all site locations, improved housekeeping, and reduced contamination of in-process hardware.

For similar activations it is recommended that the total, exposed, ground surface be black-topped or have ground cover installed concurrent with completion of the site as a planned part of the site facilities criteria.

DISCUSSION

The construction specification for site activation called for asphalt coverings of road beds, parking lots, and outside storage areas. With high-velocity winds funneling between buildings, dust and dirt were picked up and moved along, between, and into buildings from the unimproved pockets of exposed ground. Dust settled in breezeways, doorways, and on in-process hardware causing both a housekeeping and a product contamination problem. Fine dust settling on product hardware in welding jigs, and on weld heads and parts had to be continually cleaned before welding to forestall weld failures. Parts already cleaned and etched required extra handling and protection from settling dust. Parts entering and leaving processing areas required extra handling to guard against abrasive dust and dirt on critical edges and finished surfaces.

Dust and dirt created additional maintenance problems in air conditioned areas by clogging filters and entering into ducts, causing extensive maintenance expenditures of time and material.

Costs can be reduced if the site is adequately surfaced with blacktop and/or ground cover as a control measure concurrent with site activation.

CONSTRUCTION LEAD TIME, NEW FACILITIES

PROBLEM STATEMENT AND EFFECT

Joint occupancy by North American Rockwell and construction contractors in critical areas of new buildings was necessary to meet building completion dates and to start production of subassemblies for the Saturn S-II program. Joint occupancy imposed duplication of cost to provide temporary accommodations such as utilities, restrooms, and storage areas. Subsequent demolition and/or removal of temporary accommodations further increased start-up costs.

SOLUTION/RECOMMENDATION

North American Rockwell could not resolve the joint occupancy problem because the contract for the Saturn S-II Program had already been awarded and new construction was necessary. The requirements, as stipulated by the Master Program Schedule, required detail fabrication and subassembly at a very early date.

It is recommended that, in future large aerospace or airframe contracts, the product be defined at the earliest possible date and that the manufacturing methods be identified to allow adequate lead time for major construction. A period of 12 to 18 months is normally required to design, bid, and construct these types of facilities.

If either NASA's "Phased Project Planning Guidelines" (PPP) or the Air Force's "Systems Program Management" are not imposed, it would enhance the contractor's visibility if he implemented a similar program of his own design.

DISCUSSION

The acquisition and construction of facilities has always been a major problem facing airframe and aerospace contractors. Following the capture of a contract, little if any time was allowed for the design, bidding and construction of the new facilities required to support production and testing. Joint occupancy with the builder always means increased costs and duplication of requirements.

New concepts in bidding and awarding contracts have now been implemented and, if properly organized and scheduled, adequate lead time will be incorporated. Adoption of NASA's Phased Project Planning or a contractor's version of a similar planning procedure is recommended for all new facilities acquisitions that require long lead times to construct. Such planning will allow for a Beneficial Occupancy data commensurate with program requirements.

REFERENCES

Figure 8, from NASA Handbook 7121.2.

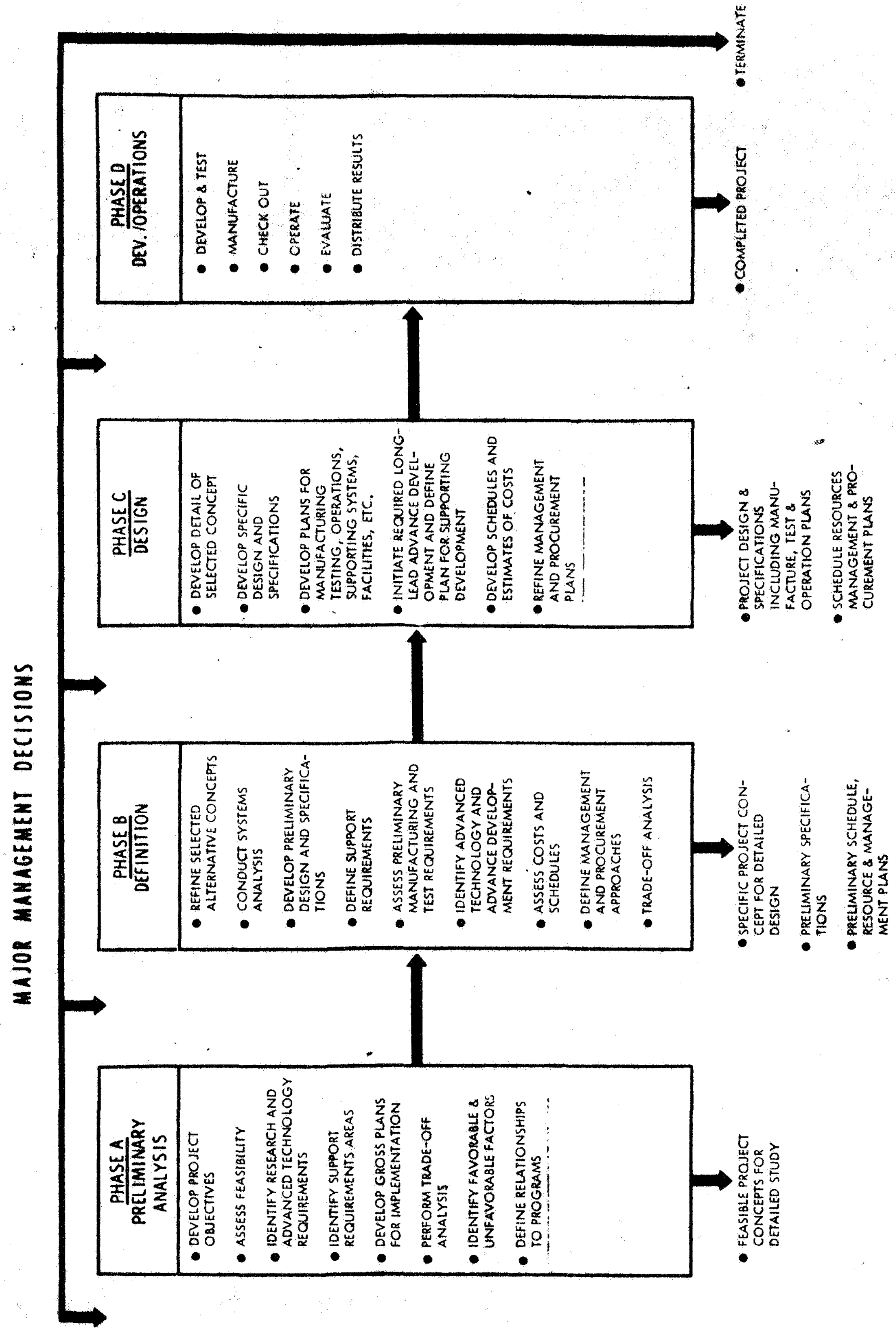


Figure 8. Project Planning Phase Relationships

TEMPERATURE/ENVIRONMENTAL CONTROL FACILITY PLANNING

PROBLEM STATEMENT AND EFFECT

Initial facilities requirements for the environmental and temperature controlled areas required for the manufacture and test of S-II stages were based on existing state-of-the-art methods. Building construction and equipment procurement were initiated as a result of the then current planning to permit facility implementation with adequate lead time to comply with program schedules. Subsequent weather variations, engineering design verification, and validation testing, plus other technological advances, imposed substantial changes in temperature/environmental control requirements. Identification of total requirements was accomplished incrementally after the program was underway. This latent development-growth period precluded incorporation of the ultimate required capacity and flexibility in the Seal Beach temperature/environmental control systems during the facility design and construction phases.

SOLUTION/RECOMMENDATION

The experiences incurred in the S-II Program, as specifically related to the above described problem, reveal the need for total facilities program planning, including personnel comfort. It further identifies that a phased approach to the planning, approval and conduct of major research and development activities must be conducted to effect facility flexibility, capacities and economics.

In 1968, the NASA Organization and Management Offices adopted a policy of Phased Project Planning (PPP). NASA Headquarters Bulletin 7121.2, issued in August 1968, contains the guidelines for implementation of this approach. In summary, PPP will conduct the development of space hardware systems in four distinct phases:

A — Preliminary analysis

B — Definition

C — Design

D — Development/operations

Resources planning, when conducted on the PPP basis, will provide a progressive build-up of knowledge on all aspects of the proposed project. Thus, the implementation can be undertaken with the confidence that comes from a fuller understanding of the program objectives and requirements.

DISCUSSION

Original Vertical Assembly and Hydrotest Building Requirements

Requirements and usage originally established for the Vertical Assembly and Hydrotest Building are defined in Table 6.

Original Chiller System and Air Conditioning System

The original system was designed for a summer ambient condition of 85 F (dry bulb) and 69 F (wet bulb). Chilling capacity was provided by a 163-ton main Chiller No. 1 and a redundant standby 39.4-ton Chiller No. 2 for the computer room.

System Inadequacies

The chiller and air conditioning system has been modified and supplemented. However, it still does not have sufficient capacity to provide the proper environment for S-II Stage manufacturing activities. Two main factors contribute to this condition.

1. Ambient conditions experienced to date exceed those conditions anticipated by the original design. Actual summer ambient conditions are 95 F (dry bulb) and 74 F (wet bulb). This factor alone prevented the originally installed system from providing proper environment for even the original station requirements.

2. Manufacturing sequence changes.

   a. Station IV has been changed from system checkout to insulation bonding and system installation, requiring a station work area control of 65 to 80 F and 70-percent maximum relative humidity. Remedy was provided by adding a third chiller with a 58.5-ton capacity and by installing cooling coils in Station IV air handlers on Levels 1 through 5.

Table 6. Temperature/Environmental Control Requirements

Area	Use	Air Conditioning Requirement
Station I	Circumferential welding	Stabilized temperature only (no cooling required)
Station II	Insulation bonding	In-tank - 140 F (±10) for curing insulation bonding Work area - 65 to 80 F
Station III	Systems installation	Stabilized temperature only (no cooling requirement)
Station IV	Systems checkout	Stabilized temperature only (no cooling requirement)
Station V	Hydrotest and cleaning, in-tank installation	In-tank - 180 F (±15) for drying 73 F (± 5) for installation
Station VI	Bulkhead hydrostat	180 F (±15) for drying
Clean room (Class D clean area)	Component cleaning	72 F (±5) 50-percent maximum relative humidity
Computer room (Class D clean area)	System checkout	70 F (±5) 50-percent maximum relative humidity
Office area	Manufacturing supervision	70 F (±10) 50-percent maximum relative humidity
Station V control room	Hydrostat test control	70 F (±10) 50-percent maximum relative humidity

b. Station II and IV operations were changed from providing heat for insulation bond curing to the inclusion of in-tank installations requiring an in-tank low-humidity air conditioning system to prevent tank wall corrosion and permit human survival. (Insulation bond curing is now accomplished with externally-applied heat blankets.)

A remedy to the situation was attempted by redirecting the Station II in-tank air handler to Stations II and IV and by using the standby 39.4-ton chiller to supply chilled water. However, the air handler was designed for heating and has never been able to provide sufficient cool and dry air for simultaneous Station I and IV in-tank installations.

c. Environment in the J-2 engine shop was too warm during the summer months for comfort. This situation was remedied by the installation of chiller coils in the existing air handler using chilled water from the main chiller.

d. Station work areas of Station V must be environmentally controlled for the application of foam insulation to stage closeout areas.

The first all-foam insulated S-II stage was recently closed out with spray foam insulation in a Station V environment of 75 F (±5) and 50-percent maximum relative humidity. This was provided by temporary ducting and a 65-ton mobile truck air conditioning system with reheat capability. This first insulation closeout was accomplished under favorable wintertime ambient air conditions. Closeouts on subsequent stages under summar ambient air conditions required additional air conditioning equipment.

Summary

The effects of the ambient temperatures and manufacturing requirements lead to the following conclusions.

1. Total chilled-water requirements to support the current station exceed the available capacity by 269 tons

2. Chilled-water supply and return lines are not large enough to handle the required additional chilled-water capacity

3. Present air handler cooling coils are not large enough to handle the required chilled water

4. Some air handlers do not have sufficient cfm capacity.

To resolve the above critical situation, Appendix "A" to the NAS8-14016(F) contract was prepared and submitted to NASA. This submittal recommended the installation of a central chiller plant, chilled-water distribution system, and new or modified air conditioning equipment.

Remedial action taken to improve temperature conditions on the upper floors of the VAB/VCO included the provisioning of side wall vents and roof exhaust. This action provided improvement but does not afford a permanent fix to the excessive temperature variations experienced during peak heat wave conditions.

REFERENCES

NHB 7121.2 Phased Project Planning

IP 68-1422 (S-8-J) Appendix "A" NAS8-14016(F), April 19, 1968, Central Environmental Control System, Vertical Assembly and Hydro-test Building, Seal Beach, California.

PAINT AND CHEMICAL STORAGE

PROBLEM STATEMENT AND EFFECT

Site activation and design criteria planning for the Saturn S-II stages did not incorporate a separate building to house sizable quantities of paints, chemicals, solvents, and acids. The intent of the contractor was to utilize an existing structure designed and used for this type of storage at the main plant in Downey and two separate rooms designed for chemical/paint storage adjacent to the multipurpose Paint and Package Building, S-04, at Seal Beach.

The growth of Saturn program, and production changes in processing techniques increased the demand for materials of the types noted above. This, in turn, created logistical and materials handling problems. To be assured of adequate materials on demand, departments ordered and received large quantities, storing them within and around the Manufacturing areas.

SOLUTION/RECOMMENDATION

Major production requirements should be analyzed and criteria prepared for the safe storage of paints and chemicals in a suitable structure. The inclusion of such a facility at the time of site planning will negate unsafe conditions being created as production requirements increase and as production and processing techniques are modified or changed.

DISCUSSION

Early production planning requirements showed a minimum quantity of paint and chemicals support. Chemicals used in the processing of bulkhead gore sections were delivered as required and mixed in the tanks; the remaining limited chemical and storage requirements were accommodated in a small structure adjacent to but separated from Building S-04.

As production accelerated, increasing quantities of chemicals, paint, acids, and solvents were requisitioned and stored adjacent to production facilities. To alleviate these unsafe conditions, the contractor fenced in a section of outside yard area, away from the production facilities, for chemical and paint storage. The area was equipped with a safety shower, eye wash, sump, control berm, and grounding rods. All excess quantities of paint, chemicals, acids, and solvents not immediately required for production and stored in proper cans and cabinets were removed from the production area to this new location.

This new location provided limited safety and reduced the previous hazardous condition but it was not a completely adequate solution. To provide for the complete and adequate storage of paint and chemicals, the contractor submitted an Application for Industrial Facilities. This submittal detailed a specific building for paint and chemical storage as follows:

> "Construct a one-story building, 40 feet by 150 feet, of clear span prefabricated-type structure with ribbed metal sides and roof. This structure to have lighting, special retention curbs, sump, 2-hour fire rated walls for the flammable liquid dispensing and gas bottle storage area, and a 10-foot concrete apron on the front side of the building for loading and unloading."

The submittal was received and evaluated by the NASA, however, for various reasons, outside storage of chemicals was continued by the contractor.

REFERENCES

Appendix "A", Industrial Facilities, Saturn S-II Program, NAS 8-14016(F); SD 67-1135, December 8, 1967, Item 1102.

FLOOR COVERING FOR STAGE PROTECTION

PROBLEM STATEMENT AND EFFECT

The raisable floor decks in the Vertical Checkout (VCO) building were installed with open-faced metal grating. The open grating allowed small parts (such as washers, nuts, bolts, rivets, and tools) to drop between floor openings, creating potential damage to stage insulation and a hazard to employees.

SOLUTION/RECOMMENDATION

To alleviate the cited situation above, plywood covers were installed over all open grating. This installation, in turn, caused other problems that are covered in the discussion which follows; however, the primary aim of product and personnel protection was achieved.

An alternate recommendation would be that all raisable floors in new facilities construction be installed with solid-type, skid-proof, lightweight, aluminum decking. The basic building criteria and design should be planned to accommodate this additional dead-load weight and ventilation problem.

DISCUSSION

The VCO was originally planned to be utilized for Systems Installation and Checkout with no provisions for rework or work-around situations. The open grated floors were designed to serve two purposes: reduce structural costs and to provide ventilation.

On August 16, 1967, a design change was released to rework and change certain portions of the stage insulation. The VCO had to be utilized for this effort because all other vertical stations were occupied in accordance with the Manufacturing Sequence Plan. The rework to be accomplished required that part of the insulation on the stage be opened and exposed. The potential damage from dropped nuts, bolts, washers, and small hand tools falling through the open grating became a problem. To forestall damage to the product and to protect personnel, plywood was cut, shaped and secured to the deck plates. This was an emergency "fix" to correct the problem and was accomplished by means of an Expense Job Order.

This corrective action created a secondary problem that must be noted. The installation of the plywood diverted the orderly up-draft of air through the building, as established in the original design. The new upward air flow was diverted to the open spacing between the stage and the floor causing a high-velocity funneling effect. Further, the wood floors had to be replaced continually because of damage sustained from equipment moves.

The installation of solid, skid-proof, lightweight, aluminum deck plates, coupled with adequate ducts and registers at the outboard areas of the floor levels would negate having to make temporary flooring installations, eliminate ventilation problems, and make the facility more general purpose.

BRIDGE CRANE ACCESS CATWALKS

PROBLEM STATEMENT AND EFFECT

The bridge crane installations in all stations (I through VI) of the Vertical Assembly Building (VAB) were completed without catwalks. Without catwalks it became necessary, in the event of power failure, for the crane operator to evacuate the cab by means of a dropped rope and Sky-Genie, which he slides down, or to walk the rails back into the building. Both of these constituted a hazardous situation for the employee.

SOLUTION/RECOMMENDATION

The hazardous situations noted above were corrected by the installation of:

1. 150-foot catwalk with handrails between Stations II and IV
2. 150-foot catwalk with handrails between Stations I and III
3. 190-foot catwalk with handrails at Station V
4. 190-foot catwalk with handrails at Station VI

This installation was accomplished with NASA funds in response to the contractor's application to NASA for Industrial Facilities, Saturn S-II Program, SID 64-1034, dated June 1, 1964.

It is recommended that bridge crane installations of this span and height include catwalks in the initial design criteria. It is further recommended that applicable State Safety Codes be researched and implemented at the time of construction. The time of implementation should be concurrent with the basic installation of the bridge cranes to reduce total cost and to make the catwalk installation current with the building design for the doors, ladders, and platforms required to conform to the applicable safety codes.

It is also recommended that for future installations the Williamson-Steiger Occupational Safety and Health Act of 1970 (Public Law 91-596) be investigated and applicable sections be included in design and construction criteria.

DISCUSSION

The Vertical Assembly and Hydrostatic Test Building was designed with four independent bridge crane systems to service six assembly and test stations. These bridge cranes had capacities of 10 tons, Stations I and III, 20 tons, Stations II and IV; 50 tons, Station VI; and 70 tons, Station V, and were located approximately 100 feet above ground level. These bridges were not equipped with catwalks that could be utilized by the operator in the event of loss of motive power or by maintenance personnel to make inspection and required repairs. This lack of safe ingress/egress to the bridge crane was noted to be in violation of the California General Industry Safety Orders, which describe catwalks in Article 5, Section 3262, which states:

> "Every permanent inaccessible elevated location, where there is machinery, equipment, or material which is customarily operated or frequently repaired, serviced, adjusted, or otherwise handled, shall be provided with a safe platform or maintenance runway which shall be made accessible by means of either fixed ladders or permanent ramps or stairways."

The catwalk requirements were further detailed in Article 62, Section 3926, which states:

> "Access to the cage, cab, or machinery house shall be afforded by conveniently placed stationary ladder, stairs, or platforms."

The bridge cranes experienced heavy utilization based on the Saturn S-II Manufacturing Sequence Plan and on station utilization. Any lock-up or malfunction over the transfer table pit, for an extended period of time, could have tied up all operations in Stations I through IV. The cranes in Stations V and VI handled major assemblies and the completed stage outside the building. These handling operations were accomplished night or day during low-velocity or zero-velocity winds. If the cab controls on one of these cranes became inoperative during the outside traverse operations, immediate access to the area of the malfunction was required. The installation of catwalks provided this access to the rail, bridge, and cab facilitating repairs and recovery. Without immediate access and repair, any change in wind velocity, while the stage or assembly was suspended, could have resulted in heavy damage or total loss of these units.

REFERENCES

Application to NASA for Industrial Facilities, Appendix "A", SID 64-1034, Item 608, June 1, 1964.

A&E Design Criteria for Crane Access Catwalks - Vertical Assembly-Hydrotest Facility, January 15, 1965.

Construction Specification for Crane Catwalks, Vertical Assembly-Hydrotest Facility, Seal Beach Facility.

DUST CONTROL, PHENOLIC MILLING

PROBLEM STATEMENT AND EFFECT

Contour milling of bulkhead honeycomb materials prior to the final fit of the aluminum bulkhead facing sheet within the same enclosed area created a dust problem detrimental to final bonding of the honeycomb to the facing sheet. The dust created problems in adhesive bonding operations, in personnel environment and in maintenance of clean facilities.

SOLUTION/RECOMMENDATION

An existing building exhaust system was modified and reworked to provide increased face velocity exhaust to the trim tool used in the contour milling. This increased exhaust removed the dust generated by cutting, and reduced personnel hazards and improved adhesive bonding operations.

In similar situations, it is recommended that cut and trim tools be equipped with an exhaust system sized with adequate face velocity for the product being milled and tied into a central evacuation dust collector.

Further, it is recommended that in the design for a new installation where cut and trim, bond, layup and cure are to be accomplished, separate rooms be utilized. These separate rooms should be sized to accommodate the movement of the tool and/or part and should be serviced from a common exhaust system with a high face velocity.

This problem should be considered during preparation of the facilities design criteria.

DISCUSSION

Phenolic honeycomb materials utilized in the bulkhead manufacturing process were pre-faced by the vendor for immediate installation. Manufacturing plans called for the use of a technique known as "Putty Pads" for the installation required minimum trim after layup. This proved to be inadequate due to the diameter and height of the bulkhead and the contours required. New techniques were devised wherein the honeycomb was faced and bonded to the base material, a vacuum drawn on the material and approximately 1700 measurements were made of the honeycomb in this condition. These measurements were then programmed and fed into a computer. The computer results were then analyzed by Materials Development Laboratory personnel who, in turn, established all of the areas that required milling.

To accomplish the removal and collection of the phenolic dust from the trim cutting, the trim tool was equipped with an exhaust tube running to a portable vacuum cleaner. Due to the high volume of dust from cutting, this exhaust system proved to be inadequate because dust settled on the product which, in turn, created problems in the adhesive bonding process. The fine powdered dust was very difficult to remove.

This method was improved by connecting the tooling exhaust tube into a central building exhaust system in order to provide a higher face velocity at the cutting head. This increased capacity reduced dust in the product insuring a better bond, improved housekeeping, and contributing to safer environmental conditions for employees.

MODULAR OFFICE INSTALLATIONS

PROBLEM STATEMENT AND EFFECT

During peak growth periods on large programs, office rearrangements and relocation are continually required to accommodate the increasing departmental headcounts. These rearrangements and relocations require constant area planning, facilities modification, and resource investments.

SOLUTION/RECOMMENDATION

Establish a mathematical model for housing personnel based upon established company standards for offices and office furnishings. This standardized area should incorporate adequate office areas for levels of supervision/management, "bull-pens" for support personnel, file areas, and fixed utility installations to minimize rearrangement costs.

DISCUSSION

Common practice is to plan and implement rearrangements/relocations on an as-required basis. As a result, each relocation requires new area planning, the construction of offices to meet requirements for functional organizations, and rearrangements of areas to accommodate increasing head count levels. This is particularly true during those peak growth periods of program buildup which contribute to higher overhead costs.

The establishment of a modular office layout plan for variable office requirements was instituted by North American Rockwell and proved to contribute substantially to lower relocation/rearrangement costs. The plan as implemented provided for:

1. Perimeter management offices, complexes, and conference rooms

2. Low office profiles for first level supervision and secretaries adjacent to working groups

3. Standardized office layouts with utility rail separation between desks

4. Standardized aisle patterns

5. In-place electrical and telephone outlets
6. Minor rearrangement impacts
7. Provided for "box moves" of personnel
8. Minimized lost move time
9. Lower costs to maintain
10. Uniformity of similar areas throughout the facility

Planning for such modular installations should be instituted at the earliest possible date in the program buildup.

PROTECTION OF FEMALE EMPLOYEES AT NIGHT IN GENERAL PARKING AREAS

PROBLEM STATEMENT AND EFFECT

Female employees entering or leaving the plant at night have been accosted in the "general" parking areas adjacent to the plant. When these incidents were broadcast by word of mouth, all female employees refused to work at night without adequate protection in the general parking areas.

SOLUTION/RECOMMENDATION

To prevent further occurrences, all female employees scheduled to work at night were assigned reserved parking spaces immediately adjacent to the guard's shack at the well-lighted main gate. No further incidents of this nature occurred.

It is recommended that the parking area closest to the lobby or main gate be lighted to 50 foot-candles and made available to all female employees for night parking. This is a practical solution to the problem since 80% of these reserved spaces (normally occupied by management personnel during the day shift) are unoccupied at night.

When planning for the construction of a new site or at the beginning of a new program on an existing site this problem should be considered as a part of the facilities criteria package.

DISCUSSION

During the month of July 1968, about midnight, a female employee was attacked by a man in the general parking area, approximately 300 feet from the main gate on the NASA Seal Beach site. Fortunately, two male employees heard her scream and came to her assistance. Again, during the month of January 1971, at 1:30 AM, another female employee was molested by a male exhibitionist in the general parking area east of Building 80 on the NR Seal Beach site. Soon after each incident occurred the offender was apprehended by the Seal Beach police. Nevertheless, to avert any future incidents, all female employees who plan to enter or leave the site at night have been requested to park in the reserved parking space close to the lobby or main gate.

HELIUM MANIFOLD SYSTEM FOR LEAK CHECKS

PROBLEM STATEMENT AND EFFECT

During the early stages of Saturn S-II production, helium leak-checks of weld joints on the tank were performed using K-bottles, containing helium, to pressurize the S-II subassemblies and completed stages. These bottles were located on the floor adjacent to the assemblies and used one at a time as the gas was depleted. This resulted in a high-helium loss factor because of recurring connecting and disconnecting of the bottles when tests were underway, as well as the residuals of gas remaining in each bottle. Controlled helium flow into the tanks was highly critical and, if not maintained, resulted in the loss of effective test results because of the doubtful accuracy manual handling provided.

SOLUTION/RECOMMENDATION

To provide helium in sufficient quantities at the proper pressures, a helium manifold system was installed. This installation included a bank of bottles manifolded together, outside the Vertical Assembly Building (VAB), with related controls, gauges, indicators, and piping distributed from the bottle manifold into the test control room. The installation provided a helium source from which helium leak-checks could be conducted with efficiency, reliability, and greater speed.

It is recommended that testing requirement for leak-check of welds in critical subassemblies be identified as a first priority in the manufacturing test plan. Based upon requirement of the test plan, the design criteria for building installation would then incorporate such requirements.

DISCUSSION

In accordance with the Manufacturing Plan for the Saturn S-II stage, it was stipulated that helium be used to perform leak-checks on the S-II assembly and subassembly. This plan required leak-checking of all tank welds by first pressurizing the unit with helium, and then, scanning with a helium leak detector for determination of the helium flow rates through the weld joints.

Early leak-checking was performed on the station floor, adjacent to the article under test, by K-bottles filled with helium. This manual system involved the distribution of helium bottles throughout the VAB. Test results were doubtful due to the high helium loss encountered through the constant connect and disconnect from bottle to bottle. This distribution system also created a housekeeping problem in areas densely populated with personnel and equipment. Further, the system created a continual logistics problem of supply and return of bottles, and presented product and personnel safety hazards due to constant handling.

To overcome the shortcomings of the manual system, the Contractor proposed and received approval to install a helium bank with the necessary gauges, related controls, indicators, and plumbing. The system consisted of a bank of 144 storage bottles, with manifold, set on a concrete pad at ground level, and routed through the building to the control room on the fifth floor. This storage capacity was sufficient to provide a supply of helium gas delivered at 300 scfm at 800 psig for 45 minutes. The installation provided a continuous source of helium at the required pressure for the stipulated times required to perform the leak tests.

RATIOS FOR PARKING LOTS

PROBLEM STATEMENT AND EFFECT

The original criteria for site parking stipulated a standard accepted A&E ratio of 1.5 employees per car. This ratio proved to be invalid in respect to total employees, and cars that had to be parked during peak shifts.

SOLUTION/RECOMMENDATION

A study of available parking stations and the number of cars used by employees dictated that a ratio of 1.1 was necessary to provide adequate parking during high shift periods.

In-depth studies should be taken at the time of the preliminary site planning to insure adequate parking facilities. This study should include site location in relation to public transportation; frequency of public transportation to support employees at shift changes; and forecast of employment by shifts and the planned available parking stalls.

DISCUSSION

The parking lot utilization area planned was based upon a standard A&E factor of 1.5 employees per car. Due to the lack of public transportation, limited car pooling, and the divergent areas from which people drove to work, it later proved that a more acceptable ratio would be provision of 9 parking stalls for every 10 employees.

PNEUMOSTATIC TEST SAFEGUARDS

PROBLEM STATEMENT AND EFFECT

Two of the original requirements in the Saturn program were hydrostatic and pneumatic testing. Provisions to incorporate these requirements were included in site planning with hydrostatic testing being accomplished at Station V and pneumatic testing at Station VII.

In early 1967 the Manufacturing Working Plan 67-A was revised to delete hydrostatic testing of the structural assembly on S-II-4 and subsequent stages. At the same time the pneumatic pressures were increased from 20 to 62 psi. The new requirement was to certify the structural integrity of the tank and weldments. The increased pressure requirements dictated a new site for testing. This was predicated on the explosion and burst pressures that would endanger other site buildings and the surrounding business and residential areas.

SOLUTION/RECOMMENDATION

Negotiations between NR, NASA, and the United States Navy resulted in an agreement to utilize an isolated area within the confines of neighboring Naval Weapons Station, Seal Beach. All pneumostatic testing was conducted at this site for the remaining Saturn S-II stages.

Other contractors encountering similar problems for high pressure testing face one of two options:

1. Location of facilities in an isolated area with adequate perimeter boundaries to prevent damage liability.

2. Construction of an explosion-proof structure and control room designed to protect surrounding structures and environs.

These options must be analyzed and a determination made as early as possible during program definition.

DISCUSSION

The test plan initially implemented to verify the structural integrity of S-II structural assembly and major stage components utilized hydrostatic testing. Leak testing of weldments was accomplished with the helium leak detection method by internal pressurization and external mechanical leak detection. These testing techniques were successfully employed through S-II-3 in the Seal Beach work stations specifically established during the initial facility implementation. While these tests basically accomplished the intended purpose, methods and techniques were investigated for reducing overall activities.

The test method investigation responsibility was assigned to a special joint MSFC/NR task team and resulted in the issuance of a Memorandum of Agreement. The recommended action provided for changes in S-II testing to reduce assembly time and provide schedule improvement.

Events that followed this recommendation were consummated in the normal change board activities, terminating with a contract change order. Facility planning did not commence until commitment on the revised testing techniques had been made.

Initial facilitization of a pneumostatic test site was accomplished on a temporary basis at the adjacent Naval Ammunition Depot in order to accommodate the S-II-4 schedule requirements. This activity was ultimately established at the present location on the Navy site.

HEAVY-DUTY CRANE SHOES

PROBLEM STATEMENT AND EFFECT

The electrical trolley ducts, which provide power for the bridge crane in the Bulkhead Fabrication Building, were installed without heavy-duty contact shoes. Constant use of the cranes created excessive wear on the shoes. Additional wear was created by crane cross-over gates employed in the interlocking bridge crane system employed in Building S-02. The lack of heavy-duty contact shoes resulted in frequent breakdowns and related delays.

SOLUTION/RECOMMENDATION

Several alternate solutions were investigated by the contractor in an effort to correct the deficiencies noted above. The solution most readily implemented was to double the number of rollers used in conjunction with the shoe. The original factory designed and installed shoes were mounted with two pair of rollers, one in front and one in the rear. To maintain a straightforward thrust at the cab crossover point and to reduce frictional wear on the rail, two rollers were added, one in front and one in the rear. The new installation on 3-inch centers thus reduced the flex load on the spring-loaded bayonet contact shoe.

Another alternate evaluated was to double the length of the contact shoe so that electrical contact was constant over the length of the enlarged shoe in contact with the power rail even at the cab crossovers.

It is recommended that all crane utilization be critically analyzed and that the contact shoes be sized to twice the required capacity to reduce wear and down time. This criteria should be a basic portion of the specification for overhead crane acquisition.

DISCUSSION

The power shoes, ducts, and rails provided with the bridge crane in the Bulkhead Fabrication Building were standard off-the-shelf components. In a normal installation with no breaks in the rails, these components would prove adequate and very effective. However, due to the crossover gates and the high level of use of the bridge crane system, the contact shoes were inadequate. The problem does not concern the contact shoe only, but also the rail alignment. Constant preventive maintenance is required to minimize rail misalignment.

The solution as implemented by North American Rockwell is one of several approaches that material-handling engineers should consider in acquiring and maintaining heavily used bridge crane systems embodying crossover systems.

CONTINGENCY PLANNING—MANUFACTURING FACILITIES

PROBLEM STATEMENT AND EFFECT

With the rapid growth of the S-II production program it became evident that additional high bay building area was necessary for storage of in-process hardware and to accommodate new stations for changes in manufacturing processes. Off-site manufacturing and warehousing presented logistical and transportation problems.

SOLUTION/RECOMMENDATION

NR submitted an Application to NASA for Industrial Facilities Saturn S-II Program, SID 63-449, dated 15 May 1963, for a 30,000-square-foot warehouse. The justification for this additional building included all aspects of the problem based upon the handling and storage of 207 parts per month. This analysis included the size per part (50 to 860 square feet); configuration and weight which precluded parts stacking; and an estimated cost of $200,000 for material and labor, including inspection, to provide surveillance of parts stored outside the facility.

Authorization for construction of the warehouse was received in May 1964 and construction completed in August 1965. This additional building provided the necessary flexibility to rearrange work stations and to accommodate changes in the manufacturing processes.

To preclude this problem on a similar future major program, on-site warehousing for large components and contingency provisions for technological advances in manufacturing should be considered as an early program requirement with justification and approval receiving a high priority in the Facility/ Manufacturing Plan.

DISCUSSION

Original manufacturing planning of the S-II Stage assembly was based on an optimized series of sequential operations. This operating premise did not require "off-line" storage of major subassemblies in process. Planning was also based on the then-current state of the art of manufacturing processes. This philosophy influenced the facility planning criteria and, ultimately, construction of the NASA Seal Beach site.

Part of the stated problem arises from the requirement for inside storage area for major subassemblies (33-foot diameter) awaiting the next assembly operation. The material in the subassemblies, essentially 2014 aluminum, is highly susceptible to corrosion when exposed to humid salt air for short periods of time.

The problem manifested itself as these subassemblies began to accumulate in 1963 and all production stations were taken up with work in process. At the same time, it became impractical to store these units in off-site warehouses because of the transportation difficulties and the additional handling operations involved. Transportation problems involved wide load permits, restricted hours of operation, and the relocation and rearrangement of public utilities to allow the loads to pass without damage. Off-site storage required additional handling operations and protective devices, both costly in time and money.

Further, outside storage presented corrosion problems because of the humid salt air. This, in turn, required additional Q&RA surveillance and reporting. Additional parts protection was envisioned and susceptibility to hardware damage was heightened in an unguarded environment.

Welding problems incurred were further compounded by the requirement for parts in process storage. In some instances, these problems, plus the lack of rework stations, caused schedule problems by preventing timely access to weld stations. Resolution of the flow process problems and station constraints was achieved with the implementation of additional stations.

REFERENCES

Appendix A SID 63-449 (May 15, 1963).

CATHODIC PROTECTION

PROBLEM STATEMENT AND EFFECT

Utility piping (black iron, steel, and aluminum) was installed on the NASA site in accordance with normal construction standards. Shortly after installation it was noted that electrolytic action was destroying some of these installations.

SOLUTION/RECOMMENDATION

North American Rockwell submitted an Application to NASA for Industrial Facilities, Saturn S-II Program, Appendix A, IP 1379, dated July 1, 1965, Item 908, requesting funds to provide cathodic protection for the underground piping systems. This submittal covered the first of two phases for corrective protection. The project was not funded.

At the time of site preparation, a soil survey should be made to determine the possible electrolytic effect of the soil on metals such as black iron and aluminum. The results of this survey should be incorporated into the A&E Design Criteria for all underground piping installations which will service the facility. Early identification of soil conditions and specifications for piping protection and the implementation of protection systems will negate the more costly remedial installations, at a later date. Further, it is recommended that polypropolene piping be utilized where high electrolytic action is evident in the soil.

DISCUSSION

Standard black iron, steel, and aluminum piping were utilized in underground utility installations at the NASA site at Seal Beach. These installations were covered with protective wrapping which did not, in all instances, provide adequate protection from the hostile soil conditions in the Seal Beach area. Electrolytic action with the soil caused piping damage which resulted in line leaks and the need for piping repair.

The earliest significant occurrence of underground piping leaks was early in 1965. During checkout of the fill and drain systems for the cleaning and hydrostating operations in the Vertical Assembly Building (VAB), leaks occurred in these piping systems. The underground system was abandoned and the piping was run overhead from the water conditioning plant to the VAB.

The decision to go overhead was made to avoid the adverse schedule impact which a leak in this system would have created during production operations.

The most recent failure of underground piping occurred late in April 1971. An air line that served the sewage lift station eroded away causing loss of air service to the station. The excavation to uncover and locate the corroded pipe required the removal of 1400 square feet of asphaltic concrete and the exposure of 66 feet of air line piping because the site could not be determined by a visual inspection of the surface. After replacement of the corroded section of pipe, a protective coating was applied to the 66 feet of exposed line and the trench was refilled.

When the first problem occurred, NR had a soil survey conducted by a qualified A&E firm, Bechtel Corporation, Power and Industrial Division, Vernon, California. Their report classified the soil as "severely corrosive to corrosive."

REFERENCES

Appendix A, IP 1379, dated 1 July 1965, Item #908.

FUNDING CYCLE FOR REQUIRED FACILITY MODIFICATIONS

PROBLEM STATEMENT AND EFFECT

Normal procedures for the acquisition of Facilities funds for modifications, alterations, or repairs, required the preparation of the Application for Industrial Facilities submittal to NASA, and a waiting period of from 6 to 8 months for approval. In emergency situations such as a power failure, this procedure for obtaining new or modified facilities, in such situations, was unrealistic with respect to maintaining production schedules.

SOLUTION/RECOMMENDATION

To expedite the approval of minor modifications, alterations or repairs, the basic contract, NAS8-14016(F), dated May 12, 1965, was modified by Supplemental Agreement No. 11, dated September 27, 1966. This modification provided for local approval of specific projects, providing the costs did not exceed $10, 000. Submittal of requests to expend facilities funds were documented by a Task Order, prepared in Appendix A format with its own numbering sequence.

It is recommended that future basic contracts for large aerospace or airframe contracts contain similar provisions, such as the Task Order, to allow for flexibility in the administration of contract funds to meet emergency or unforecasted requirements. It is further recommended that these terms and conditions be implemented at the time of the basic contract negotiations.

DISCUSSION

The approval of Facilities funds, for projects proposed by the Contractor, is a process which takes about one year from preparation to approval and implementation. Normally, there is little flexibility to cover emergency situations that may arise. To overcome this void and to provide a degree of flexibility, the Saturn S-II/North American Rockwell Task Order system was implemented. Following meetings and discussions, the contract was modified to allow local approval for emergency projects not to exceed

$10, 000. The original ground rules for defining items or tasks under the Supplemental Agreement were specified by NASA representatives as follows:

"1. No single item or task exceeding $10, 000 will be approved.

2. Items of work, or tasks, estimated to exceed $10, 000, cannot be subdivided to meet the $10, 000 limitation. Related tasks must be classified as a single project and, if the estimated value exceeds $10, 000, a normal Appendix A submittal must be made."

The submittal of the Task Order followed the format of an Appendix A, but in a simplified form. The Task Order was numbered in a different sequence to negate confusion with an Appendix.

Subsequent agreements with NASA modified the original intent of "emergency items only," and allowed for the submittal of any unforecasted item providing they followed the original ground rules.

REFERENCES

Supplemental Agreement, Modification No. 11, to Contract NAS8-14016(F), dated August 24, 1967.

BUILDING LOCATIONS FOR STAGE MOVES

PROBLEM STATEMENT AND EFFECT

The modified Manufacturing Plan for Saturn S-II created the need for a separate building for Test and Operations. This resulted in the construction of the Vertical Checkout Building (VCO). The original site planning did not contemplate such a requirement and, as a result, additional land was acquired upon which the VCO was constructed. The new facility was sited 150-feet south and 500-feet east of the Vertical Assembly Building (VAB) (see Figure 9).

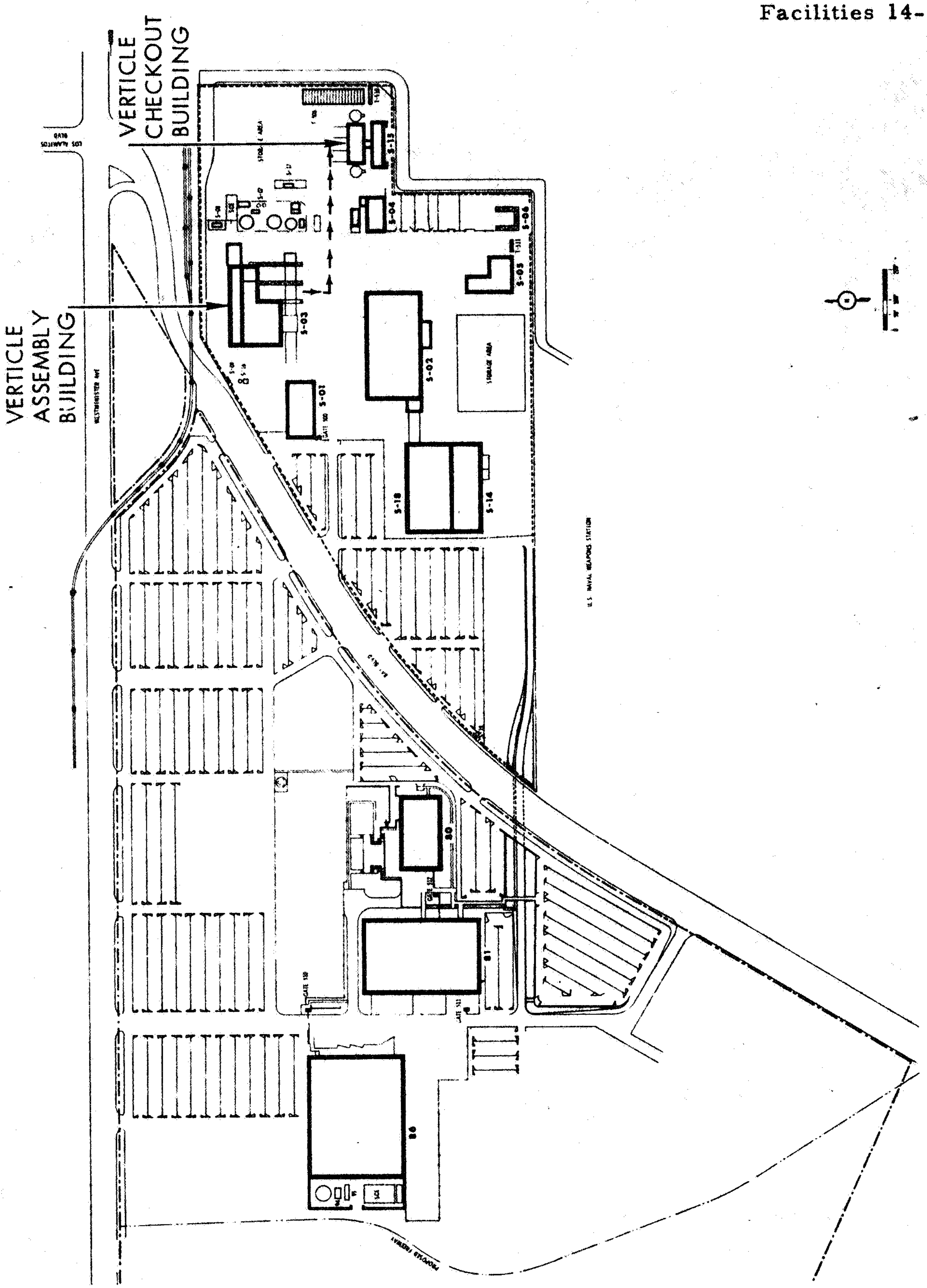
The distance between these two buildings imposed additional stage handling operations including a vertical-to-horizontal rotation of the stage by attachment of slings and handling fixtures, horizontal transportation on the transporter, and subsequent horizontal-to-vertical erection at the VCO. This was a time consuming and critical operation taking many manhours to complete.

SOLUTION/RECOMMENDATION

North American Rockwell used the described system for the full duration of the Saturn S-II program. Material Handling Procedures were revised as required to incorporate the latest and safest methods of handling, transporting, and erection although the site itself did not permit cost effective improvement. It is recommended, however, that if other aerospace or airframe contractors are faced with similar types of handling, planning should consider placement of assembly and test buildings opposite each other. Transfers between buildings could then be accomplished on interconnecting railroad-type tracks upon which the stage could be moved without resorting to the additional operations previously described. This type of planning should be undertaken before site development, if possible.

DISCUSSION

The original site planning for Saturn S-II utilized one building, S-03, with four stations, for the manufacture and test of all stages. Three stations were for manufacturing assembly, systems installation, engine installation, etc. and one station was for combined systems test and checkout. The evolution of program changes and the manufacturing flow process brought about the requirement for one additional assembly station and one additional



Figure, 9 . Seal Beach Complex

checkout station. A decision was reached whereby the NASA would provide a new facility, the Vertical Checkout Building S-15, which would contain two identical combined systems checkout stations, thus devoting the VAB to assembly operations only. This decision, in turn, required the acquisition of an additional building site consisting of five acres of land adjacent to the existing S-II Assembly Site.

The offset location of these buildings required additional material handling procedures for moving the stage from building to building. In these procedures the stage was removed from the assembly tool and stage dolly in a vertical position, rotated to a horizontal position, and placed on the transporter for transfer to the Vertical Checkout Building. Placement of the stage in the VCO was accomplished in the reverse order. These multiple tasks required a minimum of 18 personnel to affix the handling cones, lifting rings, tag lines, and tools, and to transport the stage into the VCO. Wind velocities were an additional factor.

The Material Handling Procedures used to support and implement these moves are submitted as reference material.

REVIEW BOARD FOR FACILITIES INSTALLATION

PROBLEM STATEMENT AND EFFECT

The Facilities department is chartered with the prime responsibility to forecast, justify and provide new facilities, facility modifications, and rehabilitation of facilities. The implementation of approved projects was coordinated with the affected production operations and related functions through a coordination letter of notification which requested comments, approval or disapproval of the design, the modifications, and time schedules established. In addition to the letter, construction/installation times were coordinated with Manufacturing Scheduling to utilize the available "window times" in the production schedule, which would allow facilities work to be accomplished on a noninterference basis.

This letter did not always provide the desired results for a number of reasons and resulted in delays encountered in re-design, re-scheduling and delays in construction.

SOLUTION/RECOMMENDATION

To improve the scheduling and implementation of all major facilities projects, a Facilities Control Board (FCB) was established under the cognizance of the Facilities & Industrial Engineering Manager with the direct approval of the Saturn S-II Program Manager. The FCB consisted of permanent members and alternates from the organization representing:

Facilities & Industrial Engineering
Manufacturing
Quality & Reliability Assurance
Test & Logistics
System Safety
Engineering

This control board established, published, and had approved by Management, a charter of responsibilities which said in part:

> "The function of the board will be to review and evaluate all proposed facilities work activity in order to categorize the criticality and to establish the inspection and/or surveillance levels required."

Based upon the timely results achieved by North American Rockwell Seal Beach Facility in the creation of such a unit, it is recommended that a Facilities Control Board, or equivalent, be created with the beginning of construction of facilities and carry through the total production cycle. Favorable coordination results were realized in construction and cost savings, in addition to having all functional areas aware of and a part of Facilities activation and improvements.

DISCUSSION

During production operations it is necessary to implement certain facility changes or modifications. The implementation of these design changes or modifications requires coordination between various functional organizations for approval, and of Manufacturing to work in or around the product. Typical projects included such items as: capital type rehabilitation projects for overhead handling devices; rehabilitation of processing tanks and feed lines; or the installation of new facilities. These types of construction projects require surveillance and "buy-off" by a responsible cognizant organization. The decision as to the category of surveillance and determination of the responsible organization for surveillance assignment was established by the FCB. The criticality categories were established as follows:

Category A	Extremely Critical, requires full surveillance
Category B	Critical, requires full surveillance except for items specifically designated as exempt
Category C	Semicritical, requires surveillance only on items designated as critical
Category D	Safe, requires only normal surveillance

The creation of the FCB minimized prior problems and instituted an orderly dispostion of assignments. Guidance for the FCB was included within a charter granted to the Board. A guideline was issued as Implementing Instruction SS11-F14, dated January 1970, Performing Facilities Control Board Operations, and distributed to all functional departments.

Meetings were scheduled on a weekly basis, at which time the Board established the criticality for current and pending Facilities projects. After being firmly established and operating procedures formalized, the Board met on an as-needed basis.

REFERENCES

Implementing Instruction SS11 F-14, Performing Facilities Control Board Operations, dated January 1970.

COLOR CODE MARKING FOR PIPING SYSTEMS AND CONTAINERS

PROBLEM STATEMENT AND EFFECT

Internal contractor surveillance by a safety audit disclosed that the color coding of fixed piping systems for gases, fluids and containers was incomplete. Without a complete color coding of all hazardous lines and containers the contractor could encounter a problem of shutdown in case of an emergency or malfunction because of his lack of ability to trace back to the shutdown point quickly. The ability to shut down quickly is highly desirable to confine the hazard or damage into a small area.

SOLUTION/RECOMMENDATION

Corrective action was taken by the contractor to complete the color coding of piping carrying fluids and gases, in accordance with MIL-STD-1247. The primary corrective effort was concentrated in critical areas such as the fluid distribution systems.

Additionally, the contractor ensured that all future installations would be per MIL-STD-101A, Color Code for Pipeline and for Compressed-Gas Cylinders. It is recommended that all aerospace contractors investigate and use the applicable MIL standard at the time of facilities installations to minimize costs and reduce the potentially hazardous environment of unmarked lines and containers.

DISCUSSION

During the facilitization and construction periods, some critical areas of color coding were overlooked. During a contractor-directed safety tour, these areas were identified and corrective action taken. At about this same time, Marshall Space Flight Center issued Apollo Program Directive No. 38-A stipulating that all contractor-operated NASA facilities comply with the color coding/marking of piping systems by government or other equivalent standards. NR used Corporate Standard RM 8010-001 and MIL STD's 1247A and 101A.

The intent of APD 38-A states:

"This Program Directive establishes the requirement for piping system identification and encompasses a standard MSF code for identification of materials conveyed in piping systems. The use of this code will promote greater safety and will decrease the risk of error, confusion, or inaction in times of emergency by providing a uniform color code and written identification to warn personnel of the hazards associated with the materials involved."

To comply with Memo I-I/IB-E-525-68, December 3, 1968, Subject: Color Coding/Marking of Piping Systems at Contractor-operated NASA Facilities, and the MSFC letter that transmitted APD 38A, NR submitted a Budgetary and Planning Estimate per MSFC-STD-146, September 16, 1968. This estimate excluded the identification of ground support equipment. All facilities installations completed after the receipt of APD 38A were installed to an applicable standard.

REFERENCES

Corporate MRO Standard RM 4710-001 RW 3, March 1965.

MIL STD-1247A, August 17, 1964.

MSFC STD-146, September 16, 1968.

MERCURY CONTAMINATION EXPOSURE

PROBLEM STATEMENT AND EFFECT

Mercury vapor lamps/fluorescent tube fixtures were utilized in and around the NASA S-II assembly site to provide illumination. Fluorescent tubes were also used during in-tank entry for cleaning and inspection of the S-II fuel and oxidizer tanks.

This in-tank use of fluorescent lamps presented a problem in that the fluorescent tubes contained mercury, and the presence of mercury was in violation of NR Specification MA0610-001, Revision D, dated February 1, 1968, which states:

> "With the exception of mercury vapor ultraviolet lamps, any equipment which contains Mercury or uses Mercury in its operation, shall not be used in or attached to the LOX or LH_2 tanks at any time."

SOLUTION/RECOMMENDATION

To overcome the possible mercury contamination problem from a broken fluroescent tube, and to provide adequate illumination, incandescent floodlights were added to the 8EH-5101 entry tank platform to provide the primary light source. Particular areas of the tank, requiring additional lighting for cleaning and inspection, were provided with encapsulated fluorescent fixtures and the tube was covered with a clear, high-impact plastic facing. Battery-powered lights of 6- and 12-volt capacity were also utilized.

Studies and evaluations were also made to utilize fiber optics, light tubes and other light sources, none of which proved to be of adequate foot-candle power to support the needs for product inspection and cleaning.

It is recommended that incandescent lighting be utilized in all areas, where possible, in the internal inspection and cleaning process of aluminum tanks to negate the possibility of mercury contamination.

The incorporation of internal lighting needs should be a consideration of the basic design for ladder or platform entry into the tank or product.

DISCUSSION

The fuel and oxidizer tanks of the Saturn S-II stage required both cleaning and inspection prior to the next assembly operation. To accomplish these tasks, the inside of the tank was illuminated with standard fluorescent fixtures and tubes. This presented two problems: (1) the ungrounded two-wire fixture presented a problem of a possible "arc burn" to the stage; and (2) a broken fluorescent tube would contaminate the stage. Mercury and aluminum are not compatible, and exposure to mercury could destroy the molecular structure of the aluminum tank.

To provide illumination of the desired foot-candles required for inspection and cleaning, incandescent floodlights were added to the entry tank platform. Fluorescent light units that were required in specific areas of the tank were encapsulated over the wire, the frame and the end plates, and were provided with high-impact plastic tube covers. These encapsulated lights were inspected, cleaned and bagged after every use, and stored in the tool crib to insure proper cleanliness and control.

REFERENCES

NR Specification MA0601-001, Rev. D, dated February 1, 1968, Methods of Cleaning and Cleanliness Requirements for Saturn S-II Fuel or Oxidizer Tanks.

LOX/GOX COMPATIBILITY OF GSE COMPONENTS

PROBLEM STATEMENT AND EFFECT

LOX/GOX compatible materials are normally considered mandatory for use in aerospace vehicle LOX/GOX systems. However, for the associated GSE systems many compromises in material selection are made because of considerations such as high pressure requirements, economics, and availability. As a result of such factors, several S-II GSE systems contained materials which were noncompatible with LOX/GOX. Some of these were considered to represent safety hazards because of the possibility of combustion if these materials came into contact with LOX or GOX in the presence of a sufficiently high energy source.

SOLUTION/RECOMMENDATION

Ground rules were established to govern the utilization and selection of materials contained in GSE circuits which service LOX/GOX systems. All systems which did not comply with these criteria were modified as necessary.

It is recommended that firm and comprehensive ground rules be established for material compatibility prior to designing any system.

DISCUSSION

MSFC-SPEC-106B establishes the basic compatibility requirements for the selection, testing, and control of materials to be used in S-II systems subjected to LOX/GOX. The basic problem exists in determining which materials and components will be exposed to LOX/GOX. Obvious areas such as GSE systems servicing LOX/GOX as the primary fluid medium for vehicle fill, pressurization, and tank venting are readily defined. Less obvious areas include GSE systems normally processing inert fluids which may, through operational sequences, be made susceptible to a backflow of LOX/GOX from stage systems as a result of stage component allowable leakage. Assessments must be made for components not in the direct fluid flow path, or located at the end of static, dead-ended lines. Static seals located outside the direct fluid flow path, lubricants, and sealants such as plating should also be considered for compatibility.

As a basis for making the above determinations, the following ground rules were established to govern the use of materials in GSE circuits which service LOX/GOX systems or components.

1. Combustible material in GSE components can be exposed to LOX/GOX by either a particle of the material breaking off and migrating to the downstream LOX/GOX system being serviced, or by LOX/GOX from a downstream system backflowing into a GSE system normally containing an inert gas.

2. The 25-micron absolute filters utilized in LVGSE or the S-II will prevent migration of particles larger than this size to the LOX/GOX systems downstream of the filters. Particles less than 25 microns, even if detonated, will not produce sufficient energy to be of concern. (A failure of the filter which allows a larger particle to migrate downstream was considered a second-order failure since a previous component failure would be required to introduce the particle into the system.)

3. Components requiring one or more failures before becoming exposed to LOX/GOX, and those which by the nature of the system design or system operating modes could not become exposed to LOX/GOX were not given further consideration.

4. Only NR/SD LVGSE equipment used with the S-II at KSC was considered. (Fluid distribution and facility lines and components must be verified as LOX/GOX compatible by the customer or contractor.)

5. Since data indicates there has never been a LOX/GOX leak into the S-II common bulkhead, and the confidence level for this system was high enough to have eliminated the need for a leak detection capability in the GSE, a GOX leak into the GSE from this circuit was not considered.

6. Lubricants utilized in components upstream of the last system filter are not considered to be a potential compatibility problem unless it is possible to backflow LOX/GOX to these components.

7. If components are located at the end of a long static line that has contained an inert gas before the opposite end of the line is exposed to low pressure GOX, the system should be evaluated for GOX diffusion. If it is determined that the required diffusion time is

much greater than the time that the system was exposed to GOX and the components do not contain an energy source, then GOX compatibility for the components is not a requirement.

WELD WIRE CABINETS

PROBLEM STATEMENT AND EFFECT

Some of the weld defects that occurred in the production of the Saturn S-II Stages were attributed to oxidized or dirty weld wire.

SOLUTION/RECOMMENDATION

To protect weld wire from contamination and oxidation, North American Rockwell purchased sealed, humidity controlled cabinets. Utilization of these cabinets for storage of the wire sustained the validity and chemical purity of the wire.

It is recommended that humidity controlled cabinets of this type be provided for production operations prior to the acquisition of the weld wire. This early acquisition will minimize any exposure of weld wire to oxidation and contamination.

DISCUSSION

Early production requirements did not specify environmental control for the protection of weld wire used in the production of Saturn S-II components. The wire was, therefore, stored in open line supply racks and standard cabinets. The wire was not totally protected from dust, dirt, changing temperatures and salt air, prevalent in an area adjacent to an ocean. This condition of storage resulted in a suspicion that the wire was contributing to some weld defects early in the Program.

To prevent continued contamination and oxidation, the contractor acquired special cabinets for the storage of spools of weld wires and welding rods. These cabinets were of metal all welded frame construction with glass door fronts and included a 75 watt heater with thermostat control and an automatic dehumidifier. These units provided a positive environmental condition for the storage of welding wire and rods used in critical production operations of the Saturn S-II.

REFERENCES

KEDCO, Inc., Dust-Tight Spool Storage Cabinet Drawings and Specifications.

POWER SUPPLY OVER-VOLTAGE FAILURE

PROBLEM STATEMENT AND EFFECT

An over-voltage spike was applied to the S-II-12 during checkout at Seal Beach, Station IX, due to a momentary primary AC power failure which caused the output of the 28 vdc Inet-Sprague facility rectifier, supplying instrumentation bus power, to rise to 56 vdc and damage stage electrical components. The spike existed for approximately 75 milliseconds, at which time the rectifier internal over-voltage protection circuit shut down the unit.

SOLUTION/RECOMMENDATION

Specifications for facility equipment which interfaces directly with vehicle hardware should be thoroughly reviewed for completeness and accuracy by vehicle program engineering. In the particular case of rectifiers (power supplies), the over-voltage protection circuitry must provide absolute protection to the load regardless of input power fluctuations, internal component failures, and transients due to load switching.

Therefore, the procurement specification must be explicit in describing the over-voltage protection requirements, and the detailed test specification must determine the capability of the unit to meet these requirements.

DISCUSSION

On December 1, 1969, an over-voltage spike was applied to the S-II-12 during checkout at Seal Beach, Station IX. This anomaly was the result of a rare momentary primary ac power failure caused by a car hitting a Southern California Edison Company power line pole. Because of the design of the facility 28 vdc rectifier (Inet-Sprague Model SCR-36-250) which was supplying power to the S-II-12 instrumentation bus, the output voltage rose to 56 vdc upon loss of primary power. This spike existed for approximately 75 milliseconds (at which time the rectifier internal over-voltage protection circuit shut down the unit) and resulted in damage to a number of stage electrical components including the power supplies in a remote analog submultiplexer and a remote digital submultiplexer.

The Inet-Sprague rectifier uses a full-wave, three-phase, rectifier and filter capacitor on the output of a step-down transformer. This raw voltage (60 vdc) is applied to a combination of SCR's which do the regulating. These SCR's are operated in a controlled duty cycle oscillating mode. As the ac power began to fail, the on time of the SCR's was increased since the control circuit sensed a decrease in rectifier output voltage. This continued until the SCR's were fully turned on. The ac power then began to recover, but since it is difficult to control (turn off) SCR's with dc voltage applied to them, the rectifier output voltage went to approximately 56 vdc (normal failure mode). At this same time, the over-voltage protection circuit began to shut down the rectifier but this requires approximately 75 milliseconds due to the drop-out time of the power contactor.

As a result of this problem, the Inet-Sprague rectifiers were removed from service where they were being used to supply stage power and replaced by Cal-Power rectifiers which do not exhibit the above failure mode. In addition, the stage switch selector was replaced as a precautionary measure.

FACILITIES REQUIREMENTS FOR SUPPORT EQUIPMENT

PROBLEM STATEMENT AND EFFECT

Ground Support Equipment (GSE) and Systems Measuring Devices (SMD) are basic program requirements which have sizable cost impacts upon facility floor space, environmental requirements, and utility requirements.

SOLUTION/RECOMMENDATION

During the life of the Saturn II program, solutions to minimize the facility costs related to systems installations (GSE/SMD) were investigated and analyzed for future requirements.

It is recommended that designs for new program GSE and SMD consoles and support requirements be analyzed to utilize the very latest or newest technology, such as solid state circuitry, transistors, and miniaturization to minimize facility costs. These recommendations and utilization of Phased Project Planning (Reference 1) should be included as early as possible in the program plans to minimize the facilities support requirements.

DISCUSSION

In general, facilities planning is based upon the product size, the number of manufacturing work stations, the support operations, and the test and checkout requirements. This planning is based on current product visibility, quantity, and product design. Based upon these same general criteria, SMD and GSE are designed and fabricated to support and check out the product.

Facility requirement to support SMD and GSE installations generally consists of raised plenum floors upon which the equipment is placed and underneath which cabling and ducting are routed to the equipment. This underneath area often serves also as cooling chambers for the equipment items. This type of installation currently costs approximately $75 per square foot. These costs would be minimized through self-contained fan and vent systems in an equipment unit, or by designing the equipment with solid state circuitry to reduce unit size, and to obviate the use of vacuum tubes, which generate much heat and require extensive cooling equipment. The total effect would be to reduce the size and cost of facilities required to house the equipment.

Total integration of all the latest technological changes can be attained only through a detailed interface of all functional organizations. A positive approach to the integration of all the latest technological changes and facilities requirements to support this type of program can be attained through the "Integrated Program Management Process" NR Publication 2547 B-13, dated September 1970. The adoption of this planning is further identified in Reference 2, which depicts the broad management approach to program plans.

REFERENCES

1. Phased Project Planning - NASA Handbook NHB 7121.2, dated (August 1968).

2. Space Station Program Definition (Phase B) SD 69-200-2.

TASK AND RESPONSIBILITY IDENTIFICATION FOR SITE ACTIVATION

PROBLEM STATEMENT AND EFFECT

During site activation at the Mississippi Test Facility (MTF), serious problems were encountered because of the lack of a baseline operations plan and contractor interface criteria.

SOLUTION/RECOMMENDATION

Personnel familiar with activation tasks were sent to MTF to develop a site activation planning document. Original program requirements should define the need for and scope of activation plans.

DISCUSSION

Logistics support document personnel went to MTF and developed a site activation planning document through the use of raw data, PERT charts, personal contacts, and a basic understanding of the site activation tasks. This document defined, in text and matrix form, all tasks with prime and secondary responsibilities for all contractors and functional organizations. The document was approved and used by NASA in managing the activation tasks.

REFERENCES

MTF Site Activation Plan, July 1965.

SIGNAL FLOW DIAGRAMS FOR STAGE AND GSE

PROBLEM STATEMENT AND EFFECT

The lack of stage signal flow diagrams and specific provisions to update GSE signal flow diagrams caused delays in troubleshooting and circuit analysis.

SOLUTION/RECOMMENDATION

GSE signal flow diagrams, which were prepared by Logistics, Test Operations activity in tracing out stage problem circuits, and extensive training of technicians eventually solved the problem. Future programs should include the requirement for originating and updating signal flow diagrams.

DISCUSSION

During the integration and functional testing of the Seal Beach automatic checkout equipment and other related GSE, Test Operations personnel drew signal schematics to supplement the Logistics-originated signal flow diagrams which were not specifically covered contractually and were not adequately funded for updating. To avoid future duplication, all documents were monitored and retained.

During the checkout of the first S-II stage, an identical problem existed. Test Operations traced problem circuits and submitted requests for drawing changes, as applicable. This supplemental documentation also was monitored and retained for future use.

COMMON HARDWARE FOR MULTIPLE EFFECTIVITIES

PROBLEM STATEMENT AND EFFECT

Hardware requirements existed which were common to multiple vehicle effectivities. The hardware was installed on the vehicle at various points, including preparation for launch. Events such as shipment, transportation, and testing were supported by these hardware installations. After completion of the event being supported, the hardware was to be removed and discarded per drawing requirements. This created a potential waste of highly expensive material.

SOLUTION/RECOMMENDATION

Hardware requirements having multiple vehicle effectivity were analyzed. The program schedules were evaluated to determine the number of hardware packages required to support program milestones. Drawings were revised to specify the number of hardware packages required with accompanying notes specifying retention. The logistics functions at the sites were responsible for the original issue of the hardware packages, a review of the hardware returned after removal, the rework or replacement of damaged hardware, and packaging for the next requirement.

DISCUSSION

To ensure that the S-II stage was qualified for flight, it was necessary to control the required flight configuration by engineering drawing. To support the launch, it was necessary to install nonflight loose equipment and test hardware in support of various preceding events. This installation had to be controlled to ensure subsequent removal. To accomplish this control, Engineering utilized a loose equipment drawing (V7-000025) with individual loose equipment drawing callouts, plus other drawing requirements (J7) which were used specifically for test installations. These controls were adequate; however, the assignment of effectivity and utilization of the multiple release system resulted in multiple (common) like packages of support hardware until corrective action was implemented.

ILLUSTRATED PARTS BOOK

PROBLEM STATEMENT AND EFFECT

There was a lack of common reference that could be utilized by functional groups to identify part numbers, common nomenclature, cleaning codes, and traceability requirements.

SOLUTION/RECOMMENDATION

Logistics originated and implemented an illustrated parts book (IPB) which defined and configured all significant S-II stage maintenance items.

DISCUSSION

Because of the lack of an easy reference hardware identification document, extreme difficulty was encountered by personnel at the sites and home plant supporting functions during conference phone calls, meetings, problem analysis, and troubleshooting. Use of drawings for this effort is extremely cumbersome and open to interpretation. The creation and subsequent use of the IPB supported this effort by a highly effective ready reference to figure and index number, and cross-reference data at the systems or part level.

REFERENCES

NASA support documents: MSFC-MAN-051-1 through -5.

LIMITED LIFE HARDWARE CONTROLS

PROBLEM STATEMENT AND EFFECT

Original limited life hardware requirements (age sensitive, shelf life, time service, and time cycle) were not sufficiently detailed nor were they established early enough in the program to adequately control production and spare hardware.

SOLUTION/RECOMMENDATION

Limited life hardware procedures were generated and imposed as required to remedy problems throughout the program. Engineering control of limited life hardware should be instituted as part of the original engineering criteria at program inception, even though the original program life span may fall within defined specification limitations.

DISCUSSION

Limited life controls, much the same as good preventive maintenance procedures, can complement the design reliability of components and systems. The circumstances encountered on the Saturn Program, due to the lack of limited life controls, could have created false statistics on spares utilization. Late definition of requirements did establish control for that hardware in or awaiting production; however, delivered hardware which malfunctioned at the component level was supported from spares on an attrition basis. Those malfunctions which should have been controlled by limited life requirements should not have been supported from a spares inventory which was stocked to support true failures. The end result could have been the potential overstocking of spares items due to the use of wrong statistics.

COMMONALITY IN FUNCTIONAL TEST REQUIREMENTS

PROBLEM STATEMENT AND EFFECT

A high rate of rejection of purchased spares was experienced due to incompatibilities between supplier's acceptance test procedures (ATP) and in-house functional test requirements.

SOLUTION/RECOMMENDATION

Design Engineering reviewed test specification data and made compatibility corrections between functional test requirements and supplier ATP's to meet actual design performance criteria. Compatibility requirements were also established for the test equipment.

DISCUSSION

Many items of hardware (spares) accepted at the vendor's facility by NR representatives were functionally retested in-house and subsequently rejected and returned to the vendor as defective. A review of the rejections showed criteria incompatibilities between the vendor's ATP's and equipment and the in-house test specifications and equipment. This problem and its solution also shows a need exists for compatibility in qualifications of personnel witnessing tests at a vendor facility and those performing the in-house retests.

CONTRACTUALLY SPECIFIED DOCUMENTATION

PROBLEM STATEMENT AND EFFECT

Affected or using organizations will not always recognize contract specified documentation for use by personnel at the working level.

SOLUTION/RECOMMENDATION

All logistics, vendor, and engineering manuals and operational data should be listed on an end item/system control data drawing.

DISCUSSION

Many contractually specified documents, such as operational and Maintenance Manuals, are not themselves recognized by using organizations. Functions such as Quality Assurance, Test, and Site organizations will not always recognize documents which are not officially released by Engineering. In this event, these functions generally rewrite the information into organization or site work documents, procedures, or directives for use by the respective function. This redundant effort creates a potential cost impact, generation of errors, or use of outdated information.

MANUFACTURING/SITE REPAIR OR REWORK TECHNIQUES

PROBLEM STATEMENT AND EFFECT

Engineering defined and specified production techniques which can also apply to future manufacturing/site repair or rework requirements should include acceptable technologies for utilization by site personnel.

SOLUTION/RECOMMENDATION

All original drawings and specifications should specify production and field acceptable repair or rework methods at the first release.

DISCUSSION

Original drawing requirements were totally centered around production requirements relative to techniques for accomplishing special efforts. As an example, silk screening is an acceptable production method for original repair or rework items while the hardware is in the production area and unassembled. However, this same technique is painstaking and time consuming for utilization by site personnel where the process itself and the disassembly requirements are not conducive to supporting tight schedules. The end result of the latter condition was not to incorporate required changes.

Logistics Engineering developed a dry transfer process for implementation of silk screening requirements by site personnel. This process was negotiated with Engineering and implemented incrementally by drawing change for authority.

Repair or rework technologies suitable for site implementation are not included on the drawings at the first release because potential impact to hardware configurations, cost, and schedules could occur.

MANDATORY REQUIREMENTS ON COMPONENT PART NUMBERS

PROBLEM STATEMENT AND EFFECT

Established mandatory requirements which did not affect form, fit, or function did not always result in component re-identification.

SOLUTION/RECOMMENDATION

In negotiated instances, Engineering changed the component part number on drawings; however, the general tendency was to identify the component by a decal or tag that could be easily lost. All mandatory requirements (contractual or otherwise) imposed on hardware after initial deliveries have been made should require Engineering to record the requirement on the respective component drawing and re-identify the component by part number change.

DISCUSSION

On several occasions on the Saturn Program, mandatory requirements for both contractual and engineering criteria were imposed on component hardware after initial deliveries had been made. Some requirements affected partial inventories with a limited effectivity while others affected the full component inventory with full effectivity. An example of such an imposed requirement was the product repeatability program (PRP). The object of this requirement was to fully retest hardware in the inventory to assure a no-failure mode due to handling and storage over a period of time. To record this retest, a tag or decal was attached to the component. At the same time, a specific effectivity was assigned to the component. If this tag/decal identification was lost, a repeat of the PRP requirements would be mandatory. The loss of a tag/decal created a potential impact to cost and schedules.

CONTROL OF PATCH BOARD CONFIGURATIONS AND CORD LENGTHS

PROBLEM STATEMENT AND EFFECT

Hardware changes installed on an incremental basis created difficulties in defining, much less controlling, patch board configurations and patch cord lengths.

SOLUTION/RECOMMENDATION

It is suggested that acquisition of extra patch boards for configuring at the home plant on a rotational basis with patch boards from the sites would minimize the difficulties associated with providing patch boards and patch cords for hardware changes.

DISCUSSION

The installation of several changes incrementally and in no particular sequence made it impossible to define patch cord lengths. This resulted in a need to stock larger quantities of patch cords of various lengths. Further, random installation of changes did not lend itself toward neatness and minor changes for troubleshooting were quite difficult to accomplish.

MANAGEMENT OF STAGE-ORIENTED GSE

PROBLEM STATEMENT AND EFFECT

Stage-oriented GSE (equipment assigned to and traveling with a stage) was not consistently available in a timely manner to support stage deliveries from Seal Beach because of poor recycle schedule techniques and extensive refurbishment turnaround efforts.

SOLUTION/RECOMMENDATION

The program manager reassigned the responsibility for management of stage-oriented GSE which included maintenance, end item assignment, scheduling of the repair/modification/refurbishment effort, and cost controls to the Logistics organization.

In future programs, any equipment having an interface with and transferred between several functions should be immediately assigned to a single function for full responsibility and control of maintenance requirements, original and recycle scheduling, end item assignment, and repair/refurbishment.

DISCUSSION

Logistics developed a system for managing the stage-oriented GSE which included a delivery sequence for returning GSE, a marine transportation schedule for the stage transportation ship (AKD) and barges, and GSE allocation data used to update the allocation of stage-oriented GSE documentation. Display charts also were made to depict the total position of stage-oriented GSE which provided management with visibility and a means to evaluate schedule changes and GSE allocations.

The field sites performed only minimal preventive maintenance to the type of GSE under their jurisdiction. In an effort to minimize this problem and lessen the refurbishment time, due to the lack of maintenance per the S-II Preventive Maintenance Manual (SD 67-77), a plan was established whereby the sites were given advance notification of end item preventive maintenance requirements. This notification established a date by which the maintenance was to be performed with a need for a feedback verifying the task completion. A program status report was issued monthly which identified the location of all stage-oriented GSE and their scheduled maintenance periods. Visual charts were prepared and updated which displayed the status of preventive maintenance tasks pending and completed for utilization by management and the customer as insurance of compliance with maintenance requirements.

A system also was implemented for controlling and minimizing repair/modification/refurbishment costs. A single department was established as the rework department for all stage-oriented GSE. An average time span for the recycle of each end item was established and the next organization needing the end item identified realistic need dates to identify to NASA the dates for the return of GSE via marine transportation.

CHANGE PACKAGE DEFINITION

PROBLEM STATEMENT AND EFFECT

Program Change Control did not have sufficient visibility of engineering change package releases to identify when total release had been achieved.

SOLUTION/RECOMMENDATION

The modification kit drawing system was implemented on the Saturn Program.

DISCUSSION

Engineering documentation is released incrementally by functions within Engineering. In some instances, it is possible for a partial release to be made with the final release held temporarily pending coordination with another design function in Engineering.

In the earlier phases of the program, the latter situation could have resulted in partial change installation and equipment incompatibilities. Although engineering schedules were monitored, it was possible to confuse a partial release for the total release. The modification kit drawing system was implemented. A V7 or G7-88XXXX drawing number was assigned to each end item affected. This drawing was scheduled and monitored as the 100 percent release date. Once this drawing was released, additional engineering releases created new dash-numbered kits, which established new 100 percent release dates and revisions to the design change documentation.

CHANGE INSTALLATION CONTROLS

PROBLEM STATEMENT AND EFFECT

It was possible to install more than one modification ahead of schedule, resulting in potential hardware functional incompatibilities.

SOLUTION/RECOMMENDATION

The Modification Kit Summary Drawing (MKSD) was implemented. This drawing listed all the modification kits applicable on a single end item and the configuration change point (CCP) being supported. Specific drawings were listed in the modification instruction, including revision letters and the attached engineering orders. A data package of applicable drawings was put together at the time of their release and included in the modification kit.

DISCUSSION

Because of the multiple release system, scheduled implementation of Mississippi Test Facility (MTF) modifications at Seal Beach and multiple events scheduled at MTF, it was possible to install many changes over several change points. This defect in the system was possible because the blueprint cribs carried the latest drawing which could, as an example, include post-static firing changes. Because of tight schedules, the technician would not wait for the modification kit, but rather, draw hardware from stock to support the latest drawing requirement. After installation of this hardware at Seal Beach, potential vehicle incompatibilities were created at final Seal Beach checkout or at MTF during tests prior to static firing. As an added feature to the solution of this problem, the modification kit drawing listed the modification instruction (MI) as a line item, which made it mandatory for the MI to be included in the kit. Further, the drawings included in the kit data package were color-coded to show hardware to be removed as well as hardware to be installed.

REFERENCES

SID 64-1577, "Detail Guide for Preparation of Saturn S-II Modification Instructions."

BULK HARDWARE CONTROLS

PROBLEM STATEMENT AND EFFECT

Bulk hardware costs can become excessive when the hardware is issued in bulk quantities rather than measured requirements.

SOLUTION/RECOMMENDATION

Set up a single control/issue source for all bulk hardware requirements supporting planned modifications. Cut, count, or measure the quantity required for the concurrent issue with the modification kit.

DISCUSSION

Bulk items such as safety wire, paint, chemicals, and glue cannot be economically included in modification kits at the home plant because many items are lot-controlled or have shelf life limits. Unless kits can be utilized immediately, which is not reasonable when production quantities are involved, bulk items with these characteristics would be costly to handle. The cost is associated with throwaway and recordkeeping.

A simple solution is to set up a single site issue point for all bulk hardware to be issued concurrently with the modification kit when it is scheduled for installation. The amount to be issued would include reasonable mortality quantities.

A section of the modification instruction includes a listing of hardware requirements not included in the modification kit. This listing could be used as the bill of material to make up the bulk hardware issue requirements.

CONTROL OF DRAWING COMPLETENESS AND SCHEDULES UPON ORIGINAL DRAWING RELEASE

PROBLEM STATEMENT AND EFFECT

Because of overscheduling tendencies, incomplete documentation of the design parameters existed at the time of original drawing release.

SOLUTION/RECOMMENDATION

A limit of five attaching engineering orders per drawing was established. A schedule change board function was established and a 100 percent design/review/release participation by Logistics Engineering was recognized as a requirement.

DISCUSSION

During the initial phases of a program, there is a tendency for functional groups to overschedule (pad) related responsibilities. The accumulated effect of this practice is to impose unrealistic demands on the design engineers to meet release schedules, resulting in incomplete designs at the time of original drawing release. To offset this problem, the designer attempts to complete his design incrementally by individual EO. This creates the unwieldy situation of many EO's (in some cases over 100) being attached to a single drawing.

On the Saturn Program this problem was overcome by imposing a five EO limit per drawing. This required the drawing vellum to be revised by EO to support minor changes and clarifications as originally intended rather than have the EO system support drawing changes of great magnitude.

Further, program recognition of the merits, decisions, and authority of its schedule change board gave realism to required scheduling responsibilities.

Logistics Engineering participated in design reviews and final reviews prior to drawing release, and therefore could identify release priorities to lower drawing levels for the design groups. This enhanced the on-time delivery of end items, modification kits, and spare hardware.

DEFINITION OF TEST SITE'S FUNCTIONAL CAPABILITIES

PROBLEM STATEMENT AND EFFECT

In many instances, capabilities existing at a site were duplicated by associate contractors and were not planned for utilization.

SOLUTION/RECOMMENDATION

Future contracts should include provisions for a comprehensive and concise maintenance plan. These provisions should include a definition of site, contractor, and vendor capabilities.

DISCUSSION

During the development and activation phases of the various Saturn test site facilities, the permanent or planned test site functional capabilities available to associate contractors were not adequately defined. The definition of these capabilities would include such items as site repair capabilities, levels of repair, cleaning/clean room facilities, cryogenic/vacuum line checkout capabilities, nondestruct inspection, and calibration facilities. Because of the lack of this information, redundant capabilities are created at the contractor home plant or vendor facilities. In addition, delays are encountered due to time lost in unnecessary shipment to and from the site. An adequate maintenance concept or plan, if recognized and properly coordinated with the appropriate levels of contractor and customer management, would preclude this situation. A plan of this type would provide a better baseline for planning design, support, training, personnel, and equipment requirements.

RETENTION OF REPAIR CAPABILITIES

PROBLEM STATEMENT AND EFFECT

During the decline and stretchout phase of the program, considerable difficulty was experienced in sustaining adequate repair capability at subcontractor and supplier facilities for reparable hardware.

SOLUTION/RECOMMENDATION

A plan was developed to review and select in-house functions as alternate sources to support repair of supplier items. On future programs, consideration should be given to including a central overhaul and repair facility as a program requirement.

DISCUSSION

In some instances, the loss of supplier certification and repair capability occurred because of company liquidation, merger, cessation of product line, or loss of key personnel. In other instances, exorbitant costs would have been required for suppliers to maintain skills, capabilities, and equipment on standby to support potential repairable activity. As a result, in-house functions concerned with failed/defective hardware participated in the selection of supplier items to be repaired by in-house organizations. Steps were taken to ensure that this repair activity would not infringe on subcontractor or vendor proprietary and warranty agreements.

PART NUMBER CONTROL

PROBLEM STATEMENT AND EFFECT

Part numbers were not controlled to the lowest drawing level of hardware in the controlled inventory.

SOLUTION/RECOMMENDATION

Each part number control problem was solved individually by negotiation of the released engineering documentation or by manually tracking the part under question. Future programs should consider establishment of a part number controls system which would define and execute part number changes during definition and scheduling phases of the hardware change.

DISCUSSION

The Saturn Program had an adequate part number control system to support the manufacturing of the hardware through launch provided there was no need for a spares inventory. However, the Saturn S-II Program had an extensive spares inventory. Hardware was stocked by part number to drawing levels lower than covered by the system. As a result, modifications affecting the lower part numbers had to be individually negotiated for engineering documentation coverage. When this was not possible, a manual system was used to ensure proper update of hardware in the spares inventory. The manual system was controlled by a spares analyst, who kept the composite history of events on scrap paper. It is evident that other official records were kept, such as DD250 s, DD1149 s and Purchase Orders; however, without a part number change, the verification of a change installation after several months was a tedious and extensive operation.

UNIFORMITY OF QUALITY ASSURANCE PROCEDURES

PROBLEM STATEMENT AND EFFECT

The lack of a fast-reacting procedural change system and uniform interpretation for Quality Assurance procedures could potentially impact the flow of hardware.

SOLUTION/RECOMMENDATION

All known change requirements which could possibly affect hardware flow were given the personal attention of direct coordination among the Central Quality Assurance function and the responsible interfacing functions.

Future programs should consider establishment of a central control agency which would devote full attention to coordinating, interpreting, administrating, and resolving procedural conflicts on a timely basis and in concert with contractor requirements.

DISCUSSION

There were instances when the flow of hardware was held up due to misinterpretation, slow change processes, or conflicts in the Quality Assurance procedure system. In some cases, division procedures are supplemented by program procedures and further supplemented by a desk or working level instruction from the Quality Assurance function. A choice of vocabulary in each separate procedure could create conflicts.

The resolution of procedural change problems on a single piece of hardware could be accomplished in a timely manner; however, due to the lag in making procedural changes, subsequent identical problems created another hardware under-support condition. Further, some procedural changes were made without coordination with all affected functions which created additional problems. Having a central function singly responsible for the release, control, and coordination of all levels of procedures would eliminate misinterpretation, speed the flow of changes, and avoid conflicts between procedures.

LOGISTICS INVENTORY MANAGEMENT SYSTEM (LIMS)

PROBLEM STATEMENT AND EFFECT

The computer program for LIMS did not provide sufficient flexibility in record or status reports to allow visibility of hardware in the repair/refurbishment process.

SOLUTION/RECOMMENDATION

A simple mechanized (EDP) card system, operated independently of the computerized LIMS, was developed. This card system had the capability of providing the required level of status on reparable hardware.

Future programs, utilizing computerized inventory management systems, should provide for flexibility in the data field and include on-line and/or off-line report capabilities in the computer program to satisfy various phases of hardware support.

DISCUSSION

The S-II LIMS computer program could not be economically revised to status hardware in the repair/refurbishment cycle. The original intent of the system was to status the hardware in the inventory; in this regard, the system proved adequate. When a large volume of the hardware was in a recycle process, it became obvious that manual statusing was much more costly than a mechanized system; therefore, a simple mechanized card system was developed. This card system effectively replaced the costly manual statusing method. The most cost effective approach however would have been to include these requirements in the original LIMS program.

SOURCE MAINTENANCE RECOVERABILITY (SMR) CODES

PROBLEM STATEMENT AND EFFECT

The SMR codes which identify the reparable and recoverability status of hardware, as reflected in maintenance analysis documentation, were not updated in a timely manner.

SOLUTION/RECOMMENDATION

A manual and mechanized system was established to supplement the existing system. This system accelerated the dispositioning process of reparable and recoverable hardware.

Future programs should consider a cost effective, fully mechanized, maintenance analysis which would include the most current requirements based on actual program experience or redefined capabilities.

DISCUSSION

The system for updating of the SMR codes in the maintenance analysis documentation was not responsive. As a result, dispositioning of failed defective hardware returned from test sites was delayed. Without specific and immediate action to remedy the situation, program mission schedule could have been impacted. The manual/mechanized system used to solve this problem was not the most cost effective method, due to the excessive paperwork and coordination involved; however, it was not feasible to provide a fully mechanized system at the time a solution was required.

HAND TOOLING CONTROLS

PROBLEM STATEMENT AND EFFECT

Technicians were assigned or acquired more than one set of tools without justification.

SOLUTION/RECOMMENDATION

As a pilot exercise at the Mississippi Test Facility (MTF), an inventory was performed on all tool boxes and work areas. All excess tools were confiscated and manual issue/reissue controls were updated.

Future programs should consider use of a data processing system with a deck of cards by name and serial number for each technician. Updated printouts could be maintained at all tool cribs to verify assigned tools, to avoid unnecessary duplication of tools, or to identify individual requirements if more than one set of tools is actually required. Scheduled audits of these records would be maintained by Quality Control.

DISCUSSION

Due to tight schedules, spur of the moment assignments to various locations at a site, outlying tool crib issue points, and a slow reacting expensive manual record control system, tools were issued to technicians by type and in quantities they requested rather than by controlled authorization. The result was a hypothetical lack of sufficient quantities of common and certified types of hand tools.

TECHNOLOGY COORDINATION

PROBLEM STATEMENT AND EFFECT

Advanced technologies are not properly coordinated between organizations.

SOLUTION/RECOMMENDATION

Organizations expanding their responsibilities to include established technologies should be required to substantiate coordination with knowledgeable organizations.

To assure adequate coordination of a specific technology by an organization expanding its responsibilities, a member of management, such as, the Chairman of the Change Control Board, should review all coordination effort for compatibility and completeness.

DISCUSSION

Rocketdyne was advanced in the technology of LOX cleanliness in 1964. The Space Division sent a team to Canoga Park to negotiate cleanliness requirements with Rocketdyne personnel. Specific differences in requirements were made clear to the Space Division team, as related to flight and facility hardware; however, the team members were strictly flight hardware oriented, which resulted only in the adaptation of flight hardware requirements at the Space Division.

Subsequent to these negotiations, the Space Division took control of the Battleship facility at Santa Susana and started activation at two other test sites. The lack of a lower level facility LOX cleanliness requirement caused a potential impact to vendor, construction, test and activation schedules.

PREVENTIVE MAINTENANCE OF GROUND SUPPORT EQUIPMENT (GSE)

PROBLEM STATEMENT AND EFFECT

The lack of a defined preventive maintenance plan for GSE and a single discipline to control its implementation.

SOLUTION/RECOMMENDATION

The S-II Program Manager appointed a single discipline (Logistics) to prepare a preventive maintenance plan (SD 67-677) which defined all maintenance requirements. Early implementation of this plan could have provided the technical and administrative requirements and controls necessary to reduce equipment deterioration and corrective maintenance actions.

Generate a preventive maintenance plan for GSE early in the program. Establish a GSE maintenance team staffed by personnel from the home plant who would periodically perform site equipment maintenance and report on all corrective action requirements.

DISCUSSION

GSE was not being properly maintained at any of the test sites. The major problem was the lack of an adequate maintenance program which included funding, planning, followup, and documentation requirements. Although this problem was generally resolved by direction of the Program Manager, major implementation deficiencies still existed. Seal Beach, as a test site, with its close proximity to the home plant, did comply 100 percent with program direction. The Mississippi test site, on the other hand, complied with all requirements except established documentation and reporting media. Finally, the KSC test site complied to its own criteria.

REFERENCES

Saturn S-II Program Preventive Maintenance Plan, SD 67-677.

INSULATION PURGE TEST SCHEMATIC DRAWINGS

PROBLEM STATEMENT AND EFFECT

Because of continual changes to S-II insulation and related circuits, it became increasingly difficult to define insulation purge test requirements and techniques.

SOLUTION/RECOMMENDATION

Insulation purge system schematic diagrams reflecting the operating manuals to be used were prepared. These schematics formed a basis whereby all insulation changes could be noted, and manuals could be changed accordingly. This solution should be implemented when manufacturing test procedures are initially prepared. Thereafter, the procedures should be continually updated as test requirements change.

DISCUSSION

The Special Test Equipment (STE) Engineering group is responsible for preparing the insulation purge test procedures to be used by Manufacturing. There were several applicable assembly drawings and test specifications involved in determining test requirements and techniques.

As an aid to visualize the scope of the purge test and the effect of changes to the specifications and drawings, the STE Engineering group prepared insulation purge system schematic diagrams. This effort reduced the time required to make changes to the manufacturing test procedures.

DEVELOPMENT AND USE OF A STANDARD COMMERCIAL PRACTICE PROCESS SPECIFICATION

PROBLEM STATEMENT AND EFFECT

Nonflight items and equipment were being fabricated to unnecessarily stringent requirements of flight specifications.

SOLUTION/RECOMMENDATION

A standard commercial practice process specification was established which would be applicable to nonflight items fabricated by processes requiring minimum controls and inspection. Considerable time and cost can be saved by use of this specification in procurement of noncritical equipment.

DISCUSSION

Specification MA0113-002 applies to all equipment not classified as Criticality Category I or II. This specification outlines the general requirements for mounting electronic components and hardware on terminal boards, etched or printed circuit boards, and console panels. In addition to these requirements, the specification refers other stringent specifications. However, these requirements are not mandatory on certain equipment, and provisions are never made to relax the requirements on nondeliverable equipment required by the contractor in the performance of a development or production contract for checkout and servicing of the product during the manufacturing process. Since this in-process test equipment did not fall within Criticality Category I or II, it was assumed that the MA0113-002 specification was applicable; thus many items of satisfactory and available equipment were eliminated and special procurement was required.

REFERENCES

1. Standard Commercial Practice Specification (ST0113MA0001)

2. Installation of Aerospace Ground Equipment Wiring (MA0113-002)

ELECTROMECHANICAL FLUID SCHEMATICS

PROBLEM STATEMENT AND EFFECT

The Drawing Requirements Manual (DRM) recommended the complete separation of fluid and electrical schematics. This philosophy, although adequate for system fabrication, proved cumbersome and difficult to use in troubleshooting problems during system operation.

SOLUTION/RECOMMENDATION

Certain of the electromechanical systems fluid schematics were modified to include electrical energizing components associated with the mechanical components. This improvement resulted in combined electromechanical fluid schematics which could be readily used to troubleshoot systems problems. Additionally, these schematics were of significant value in training test personnel in the operation of the systems and related equipment.

DISCUSSION

In compliance with DRM recommendations, the fluid and electrical schematics for an electromechanical system were prepared separately with major consideration given to use during the fabrication cycle. It was found during checkout and operation of these systems that the schematics were somewhat difficult to use for troubleshooting problems. It was necessary to consult both schematics when attempting to isolate a problem which proved to be not only impractical, but also cumbersome. The addition of electrical reference information for applicable mechanical components on the fluid schematics facilitated troubleshooting of system problems and aided in the training of test personnel.

RECAPITULATION OF UNACCOMPLISHED S-II STAGE WORK

PROBLEM STATEMENT AND EFFECT

Manufacturing had the responsibility of informing Test Operations of unaccomplished work before turnover of the stage. These data were required to determine constraints on test requirements and to allow scheduling of the work during the test phase. Consolidation of these data required the screening of numerous Fabrication and Inspection Record (FAIR) books located throughout a six-story complex.

To gather and consolidate the necessary data, personnel were assigned to the task commencing approximately 30-days before turnover. To maintain the quality standard required many manhours were needed to perform the task.

SOLUTION/RECOMMENDATION

Manufacturing Planning introduced a low-cost data processing system which produced daily tabulation runs depicting all unaccomplished effort. System capability included sorting techniques to reflect that effort attributed to a supervisor, test constraints, specific design changes, etc.

DISCUSSION

Manufacturing started a system of accumulating all applicable documents immediately before turnover. Each document was temporarily out of use while negotiation with Test Operations took place. This procedure resulted in a mass of data to search in a short period of time to establish stage status for turnover to Test Operations.

The new open-item status reporting system included an initial input of planned work sequences extracted from manufacturing orders before issuance, and unaccomplished effort obtained from transfer documents written by areas not controlled by the system. Assigned personnel transferred the necessary data to Data Processing Transmittals. Additional data were added for system control which consisted of applicable codes for shop supervisor, tests affected, completion dates, etc. Manufacturing Planning personnel were assigned to screen shop areas on a daily basis for the addition or deletion of work effort; thus an up-to-date listing was maintained.

Before turnover to Test Operations, a final tabulation was run depicting the total remaining effort, listed by functional categories.

Program Schedule required that Manufacturing begin final installation effort on another unit before turnover of a previous unit. The advantages gained by using the new system allowed for concurrent accumulation of work items applicable to the new unit without restriction to turnover proceedings.

PLANNING RESIDENT ORDERS (PRO'S)

PROBLEM STATEMENT AND EFFECT

Numerous fabrication and assembly processes used on the Saturn S-II program required in-depth specification interpretation so that efficient and positive control could be maintained during manufacturing operations. This need caused a constant search of specifications and installation drawings, thereby creating schedule and cost problems.

SOLUTION/RECOMMENDATION

A procedure was developed whereby Manufacturing Planning Resident Orders (PRO's) were prepared and issued which described the sequential fabrication and assembly processes, techniques, and methodology for accomplishing selected major manufacturing tasks (see Figure 10). These documents provided Manufacturing personnel with specific bench-level instructions and assured positive controls for specification and engineering document interpretation.

DISCUSSION

Because of the complexity of the operations (i. e., spray foam insulation, structural welding, engine installation, major structural component assembly, etc.) and the necessity for ensured product repeatability, it was essential that detailed instructions be provided to describe the operations. Inclusion of detailed instructions in the Manufacturing Order documents was undesirable because of the excessive time and cost involved for preparation and control. Development and use of the Planning Resident Orders contributed significantly in providing instructions to Manufacturing personnel.

Figure 10. Typical Planning Resident Order Sequence (Sheet 1 of 3)

Oper. No.	Operation Description	Tool, Gauge, Spec Fixture, Vis Aid
	RESTRICTIONS: Use of this procedure is limited to Seal Beach welding operations on the Saturn II LOX and LH_2 tank fabrication. NOTES: a. During pre-weld cleaning and all subsequent operations, until completion of the weld, all personnel inside the weld station shall wear clean white nylon, cotton or paper smocks or coveralls and hair covers. (Sta. 1-A and all VAB weld stations). b. Clean, lint-free, white nylon gloves must be worn by all personnel performing pre-weld cleaning operations and subsequent operations prior to weld (handling pre-cleaned tools, equipment and/or parts). Gloves are to be used for their intended purpose only and are not to be used in lieu of cheesecloth, etc.	
	c. All tools required for pre-weld cleaning must be "tool" cleaned prior to this operation.	MA0107-016 MA0610-001
	d. The following procedure must be performed in the sequence outlined and in conjunction with special cleaning requirements specified in applicable weld schedule.	

Figure 10. Typical Planning Resident Order Sequence (Sheet 2 of 3)

Oper. No.	Operation Description	Tool, Gauge, Spec Fixture, Vis Aid
	e. In event of conflict between this procedure and applicable weld schedule, the applicable weld schedule shall take precedence.	
1.	Remove all contaminants from surface of material using clean cheesecloth moistened with acetone (do not "wet" surface with acetone).	
2.	Remove all visible traces of chem-film coating (or other coating) from surfaces adjacent to the joint (2" minimum). NOTE: Do not re-clean weld joint or surface adjacent to weld joint with solvents after the above operation. If such cleaning is necessary, the entire procedure must be repeated in the area which was solvent wiped.	Air Motor Bear-Tex Wheel
3.	The cleaning operation is basically a draw-file operation. The following ground rules must be observed during draw filing operations: 3.1 The file must be "tool" cleaned with acetone prior to beginning the draw file operation. 3.2 All chips must be progressively removed from the draw file gullets with a small stainless steel wire brush.	Vixen File Stainless Steel Wire Brush

Figure 10. Typical Planning Resident Order Sequence (Sheet 3 of 3)

Oper. No.	Operation Description	Tool, Gauge, Spec Fixture, Vis Aid
	3.2.1 The wire brush must be "tool" clean. If it becomes contaminated it must be cleaned in acetone before re-use.	
	3.2.2 The wire brush must not be handled by the bristles or placed on a dirty surface.	
	3.2.3 In a "draw" file operation, the file must contact metal in the cutting direction only. If the file is dragged back across the metal in preparation for the next cutting stroke, it could cause contamination entrapment.	
	3.2.4 Do not blow chips or dust from the metal surface with the breath. It will contaminate the metal.	
4.	Take particle count. The count of a given weld area must not exceed 3500 particles, 5 microns in size and larger, per cubic foot of air when measured approximately 5 feet from the weld joint and joint prior to initiation of final cleaning operations.	
	NOTE: Particle count shall not be taken during contaminant generating operations such as machine cutting and fit-up trimming. Clean-up subsequent to fit-up trimming and cutting operations must be completed in sufficient time (at least one hour) prior to pre-weld cleaning to permit particle counting operation to be performed. Do not attempt to take	

CORRELATION OF NOMENCLATURE AND IDENTIFYING NUMBERS

PROBLEM STATEMENT AND EFFECT

Many stage components were referred to by three or more different names and identifying numbers. This situation created a communication problem among the various groups when referring to the same stage component.

SOLUTION/RECOMMENDATION

The various identifying names and numbers were correlated into a single well-indexed booklet.

DISCUSSION

Use of multiple names and identifying numbers created a communication problem between Engineering, Inspection, Manufacturing, and other groups. An example is shown below:

Part Number: V7-480328
Stage Reference Designation Number: F5A-F5E, F6A-F6E, F10
Product Repeatability Program Number: Item 1
Nomenclature: Recirculation valve, return valve, bypass valve
pump valve

The booklet correlates these various identifications. In addition, the quantity per stage is specified, and comments on their usage and history are recorded.

ADAPTER CABLE CROSS REFERENCE

PROBLEM STATEMENT AND EFFECT

Duplicate cables with different part numbers were being fabricated for signal breakout boxes and test equipment.

SOLUTION/RECOMMENDATION

An adapter cable cross-reference list was developed listing the interfacing connectors in alpha-numeric order for quick reference to existing cable adapters. This type of listing should be established during initial design and updated continually.

DISCUSSION

One of the phases in which manufacturing costs increase substantially is in the design time and quantity of interconnecting adapter cables required and fabricated by the contractor for use during the manufacturing process. During the Saturn S-II program, special test equipment adapter cables were designed and fabricated; and in order to reduce this cost, an adapter cable cross-reference list (see Table 7) was developed in which every adapter cable drawing number was listed and cross-referenced to an alpha-numeric listing of all connectors which appear at either interfacing end of the adapter. This list facilitated analysis and checkout of equipment and minimized fabrication of duplicate adapter cables.

Table 7. Adapter Cable Cross Reference List

Connector Part No.	Length (ft)	Connector Part No.	Dwg No. SMD8-	Model 8FC-	Remarks
MS3126F10-6PW	1	MS3126F16-26P	0050	5446	
MS3126F10-6S	1	MS3126F16-26P	0043	5446	
MS3126F10-6S	1 1/2	MS3126F24-61S	0531	0027	
MS3126F12-10P	1	MS3126F16-26P	0127	5446	
-10P	1 1/2	MS3126F24-61S	0538	0027	
-10S	1	MS3126F16-26P	0044	5446	
-10S	1 1/2	MS3126F24-61S	0555	0027	
-10S	3	PT06SE-24-61S (SR)	6725	5444	
-10PW	1 1/2	MS3126F24-61S	0547	0027	
MS3126F12-10SW	1 1/2	MS3126F24-61S	0537	0027	
MS3126F14-5P	1	MS3126F16-26P	0042	5446	
-5P	1 1/2	MS3126F24-61S	0561	0027	
-5P	3	PT06SE-24-61S (SR)	6723-11	5444	
-5S	3	PT06SE-24-61S (SR)	6723-21	5444	
-12P	1	MS3126F16-26P	0107	5446	
-12P	1 1/2	MS3126F24-61S	0546	0027	
-12S	1	MS3126F16-26P	0119	5446	
-19P	1	MS3126F16-26P	0077	5446	
-19P	1	MS3126F16-26P	0045	5446	
-19P	1 1/2	MS3126F24-61S	0558	0027	
-19P	3	PT06SE-24-61S (SR)	6718-11	5444	
-19PW	1	MS3126F16-26P	0040	5446	
-19PW	1 1/2	MS3126F24-61S	0540	0027	
-19PX	1	MS3126F16-26P	0124	5446	
MS3126F14-19PX	1 1/2	MS3126F24-61S	0569	0027	

PROOF AND LEAK TEST TRAINING MANUAL

PROBLEM STATEMENT AND EFFECT

Training and coordination of effort relating to three-shift coverage for S-II stage proof and leak test operations were difficult because of the complexity of S-II systems and the "piecemeal" type of testing required.

SOLUTION/RECOMMENDATION

A booklet was prepared showing stage systems, subsystems, components, electrical tie-ins, and associated data related to proof and leak test operations. These data were presented so as to clearly show test personnel which operating manual was to be used for each stage subsystem/system.

DISCUSSION

The complexity of the numerous stage systems, and subsystems thereof, encountered during proof and leak testing created difficulties relating to training engineers and technicians to facilitate three-shift coverage of testing operations. In addition, since testing was accomplished in "piecemeal" fashion to support manufacturing installation schedules, there were necessarily many operating manuals required to facilitate inspection acceptance of partial systems. The problem, therefore, was one of correlating and organizing applicable information into a readily usable form for engineers not completely familiar with the S-II and related testing activities.

REFERENCES

STE Engineering Proof and Leak Test Booklet

CONTROL DIMENSIONAL TOOL LOCATION AND MOVEMENTS

PROBLEM STATEMENT AND EFFECT

Individual manufacturing departments were required to control the location and movement of the tools used. A variety of minor systems were employed, which frequently resulted in lost or misplaced tools.

SOLUTION/RECOMMENDATION

Manufacturing developed the Transaction Record and Accountability Control System (TRACS), which consisted of on-line equipment capable of accepting and processing data with respect to the location, fabrication status, type, effectivity, disposition, etc., of all dimensional tools. The system was further expanded to include those data pertinent to contract closeout preservation, condition codes, storage location, periodic inspection requirements, discarding, etc. These codes were applied to all types of tools and equipment, both on and off site.

DISCUSSION

The results of the 1967 triennial inventory instigated the investigation for improved control of tooling items. To determine the availability and condition status of a tool, required manual screening of various departments records. Departments were not consistent in format and accuracy of record keeping which contributed to lost tooling. TRACS was developed to provide a single up-to-date source of tooling information. This information, some of which was not previously available, included the capability to determine tool costs, hours expended, and common factors, such as location, part number, and general order.

A feature subsequently added was the capability to process storage data. The Saturn program requirements included the storage of tools for possible follow-on usage. Retention codes for location preservation requirements, inspections, etc., were applied to each tool. Also included is a listing of those changes to tools which would be incorporated in the event of follow-on use. This feature has proven itself during many of the customer-requested studies for cost data and follow-on proposals.

SPRAY FOAM INSULATION MACHINING AND FINISHING

PROBLEM STATEMENT AND EFFECT

Spray foam insulation on the S-II bulkheads required special tooling and facility support for machining and finishing the insulation to required thickness.

SOLUTION/RECOMMENDATION

The following were designed and built:

1. A special air-conditioning supply and return duct to provide temperature and humidity control in the bulkhead fabrication building.
2. An arched half-round access platform to follow the spraying and machining tool.
3. A machining dust exhaust system to pick up and remove the spray foam dust during machining operations. The system retained the dust in a hopper for disposal.

Also, installed were required air, vacuum, and electrical facilities at the need points in the fabrication building.

DISCUSSION

Spraying and maching of polyurethane foam insulation presents the problem of fume and dust removal, access to the areas, support facilities, and collection of the dust for disposal. The system described here satisfactorily performed the functions required. Specification requirements were met.

SPRAY FOAM MACHINING

PROBLEM STATEMENT AND EFFECT

A diamond impregnated machine cutter inadvertently contacted the LH_2 bulkhead during a spray-on foam trimming operation. The resulting damage required foam removal, metal bulkhead repair and reapplication of spray foam.

SOLUTION/RECOMMENDATION

This problem was solved at Seal Beach by developing phenolic foam cutters and an electronic sensing device to be used together with the foam trim machine. It is suggested that before machining foam on a metal base, these innovations should be incorporated in the trim machine.

DISCUSSION

The incident of damage to the bulkhead was caused by operator error. The operator failed to recognize the hard spots on the bulkhead that are used as reference marks for machining the foam. This incident resulted in the change of cutter composition (phenolic instead of impregnated nickel) and provisions for an electronic sensing device to give the operator better visibility during the machining operation.

REFERENCES

SK-017287, Spray Foam Phenolic Cutter

OFFSET-VERSUS-WELD-PEAKING INSPECTION TECHNIQUE

PROBLEM STATEMENT AND EFFECT

No positive means of identifying the true offset/peaking condition of a weld joint existed. Unnecessary Material Review action resulted.

SOLUTION/RECOMMENDATION

To aid in precisely establishing the condition that existed and the degree of its severity, Manufacturing Engineering developed an electromechanical tracer known as a profilometer.

It is recommended that the training of personnel in the use of this tool be in the initial production phase of a program.

DISCUSSION

In circumferential welding of large 33-foot-diameter cylinders on Saturn S-II program, offset and peaking were constantly under question by Quality Control. Offset is the result of joint mismatch, and peaking is the result of excess longitudinal and transverse weld shrinkage. An excess of both conditions impacts joint efficiency.

To aid in precisely establishing the condition that existed and the degree of severity, the area in question was traced with an electromechanical tracer and the data were transmitted to a strip chart recorder. The points plotted were then drawn by using conventional curve development techniques. The results showed the exact profile of the suspect area and its differential from the part mold line. Direct measurements were taken of the exploded view and compared to the tolerance allowables dictated by specification. Out-of-tolerance findings were then submitted to Material Review for disposition.

REFERENCES

T-7204193, Electromechanical Tracer

UNIQUE J-SECTION WELD

PROBLEM STATEMENT AND EFFECT

The J-area of the S-II forward common bulkhead requires welding from both inboard and outboard sides. Improper chill will cause lack of penetration, suckback, or blow holes.

SOLUTION/RECOMMENDATION

On Saturn S-II this problem was solved by developing copper interlocking backup bars, precisely machined to maintain 100-percent contact with parent metal. Stringent process controls were also imposed.

The time to impose these solutions on a program with unique welds similar to the S-II J-weld would be in the early tool design/fabrication stages. The concept could be tool-proofed during weld certification.

DISCUSSION

The forward facing sheet of the common bulkhead on the Saturn S-II vehicle contained an area known as the J-section. Many problems were encountered in producing a quality weld in this area, in that the backup tooling was not of the proper configuration to allow for a constant, repeatable weld on each machine pass. On the initial test vehicles, there was a history of lack of penetration, suckback, and blow holes. Extensive rework and loss of schedule position resulted.

FILLER WIRE INCOMPATIBILITY FOR WELDING DISSIMILAR ALUMINUM ALLOYS

PROBLEM STATEMENT AND EFFECT

The J-section of the forward common bulkhead (2219 aluminum alloy) was welded to the bulkhead gores (2014 aluminum alloy) by using 2319 aluminum filler alloy. After the gore panels were trimmed for bulkhead meridian welding, cracks would appear in the ends of the weld. Before any subsequent meridian welding could be performed, these cracked areas had to be repaired (welded) to assure that the cracks did not propagate.

SOLUTION/RECOMMENDATION

During repair efforts, it was noted that rewelding the defective area with 2319 filler alloy caused additional crack propagation. Therefore, it was necessary to use 4043 filler alloy to eliminate this problem.

As a result of these findings, in-depth analysis was conducted to determine the compatibility of the 2319 filler alloy to the combination 2014 and 2219 aluminum alloys. Test welds were made in numerous quantities until the defects could be reproduced at will. These tests proved that the dilution of the 2319 filler alloy in the welded joint of 2014 and 2219 aluminum alloy base metals produced a crack-sensitive condition, and the slightest notch effect propagated cracks. Conversely, when 4043 filler alloy was used in welding these base metals, the dilution provided a sufficient ductility to eliminate the cracking problem. A slight degradation was noted in the tensile strength, but it was well within the process specification allowables.

WELD MACHINE CONFIGURATION VERSUS WELD SCHEDULE INTERCHANGEABILITY

PROBLEM STATEMENT AND EFFECT

Modifications and part substitutions made to equipment without print updating resulted in identical weld machines having different configurations. This method of weld machine maintenance made it necessary to maintain separate weld schedules for each machine.

SOLUTION/RECOMMENDATION

A configuration control program was established by Plant Services and Manufacturing Engineering, whereby all welding machines were completely updated and all electronic configurations were duplicated and recorded on the schematic diagrams. The machines were then locked and sealed to assure the control of the established configuration. The seals and locks were opened only in the presence of the responsible Manufacturing engineer and a Plant Services technician. This control improved the reliability and repeatability of the equipment and allowed weld schedules to be interchangeable.

It is recommended that controls similar to those described here be implemented from the start of any new program using welding machines.

DISCUSSION

Approximately 22 fully automatic direct-current, gas tungsten arc welding machines were used on the Saturn S-II program. Quarterly calibration by the metrology laboratory was a standard method of an established preventive maintenance program. Also, just before every production weld, a complete calibration check was made by Plant Services electronic technicians. , During this check, if a particular parameter was off, the technician would correct the error by changing, adding, or removing the necessary components. These changes were never red-lined on the schematics; consequently, after several such changes, each machine became a special case requiring specific weld schedules which were not interchangeable.

IMPROVED STUD WELDING

PROBLEM STATEMENT AND EFFECT

The welding of studs on the forward LH_2 and aft LOX bulkheads was a constant source of rework. The studs are grouped in sets of three and straddle a meridian weld. Because of the weld peaking encountered in the meridian weld, the surface to which the studs attach is not normal to the centerline of the studs. This surface variation results in degraded weld values because of poor alignment of the stud to the bulkhead surface and creates variations in the stud-to-bulkhead pre-weld gap.

The effect of these variations is studs that will not meet the specification requirement of 45 inch-pounds of torque.

SOLUTION/RECOMMENDATION

A new welded-stud locating tool (Figure 11) was fabricated that could be secured to the bulkhead by vacuum cups. This tool established the stud pattern and the surface from which the spotfacing and gap adjustment are performed.

A special micro-stop spotfacing unit (Figure 12) was made. This unit was indexed for location by the locating tool previously mentioned. This device is used to machine a minimum depth spotfaced surface normal to the desired stud centerline.

The stud welding gun (Figure 13) was modified by replacing the fixed tripod support with an adjustable gap control support (Figures 14 and 15). This support unit along with its accompanying gap adjustment adapter provides the capability to measure the depth from the locating tool to the bulkhead surface and to adjust the pre-weld gap accordingly.

These refinements were not certified in time to be used in production on the S-II but should be considered for other applications.

DISCUSSION

The welded-stud locating tool with its vacuum cup support provides a stable surface from which the bulkhead surface is spotfaced. This spotfacing provides a clean surface normal to the stud centerline which provides the proper relationship at the weld interface during the weld cycle.

The adjustable gap control support simplified considerably the task of adjusting the gap before each stud weld. The previous method set the stud gap to a flat surface, but the bulkhead surface is not flat because of weld peaking and variations in the gap setting resulted.

The result of these changes was an increase in stud torque values to the 70-inch-pound range.

REFERENCES

Tool Designs T-7205002 and T-7205005

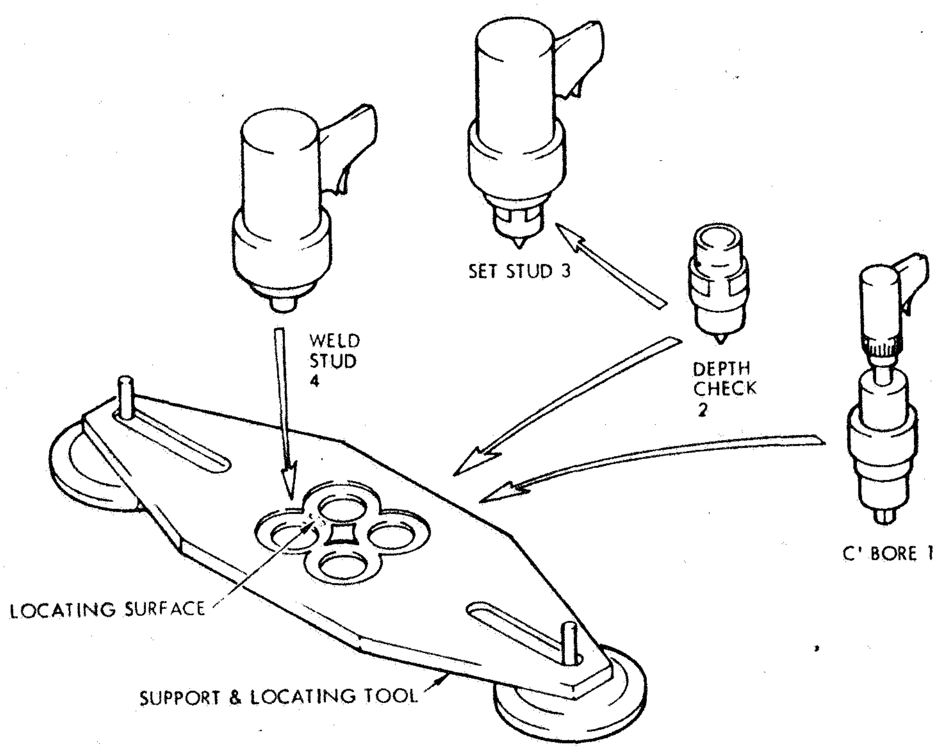


Figure 11. Welded-Stud Locating Tool

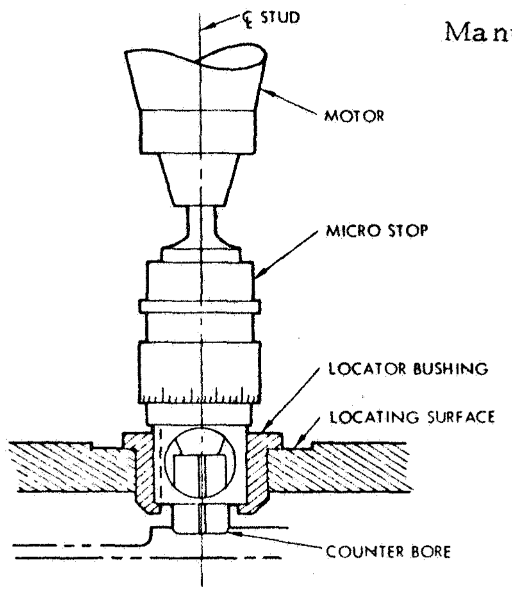


Figure 12. Micro-Stop Spotfacing Unit

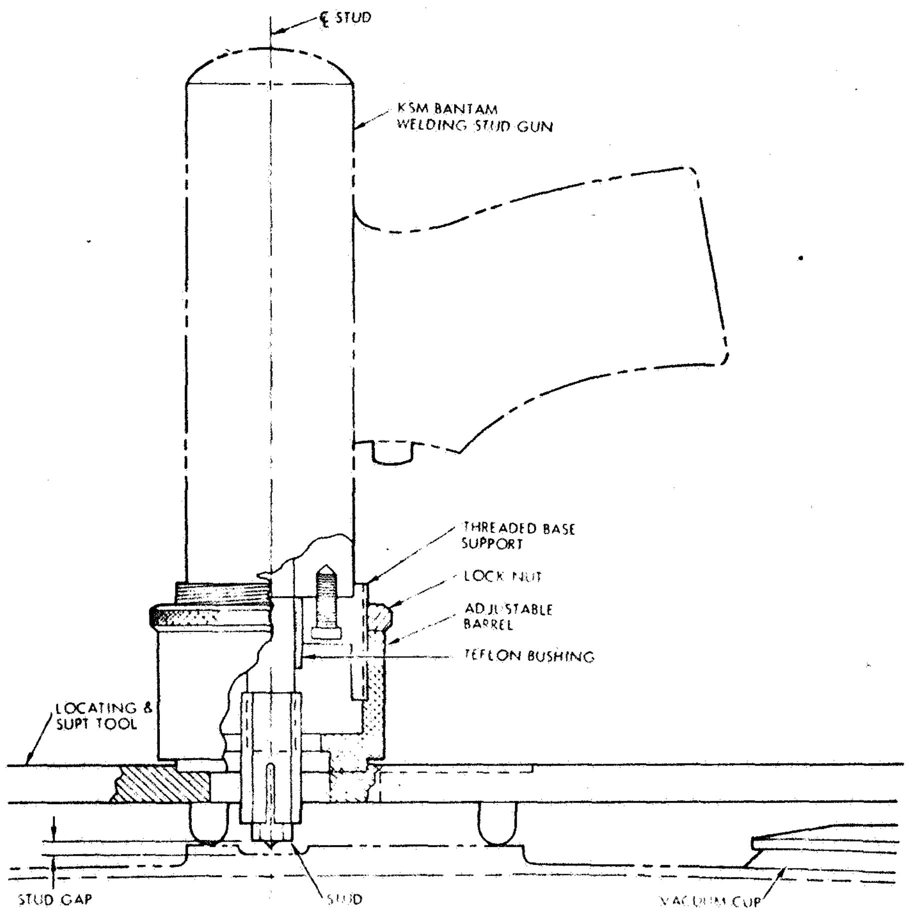


Figure 13. Stud Welding Gun

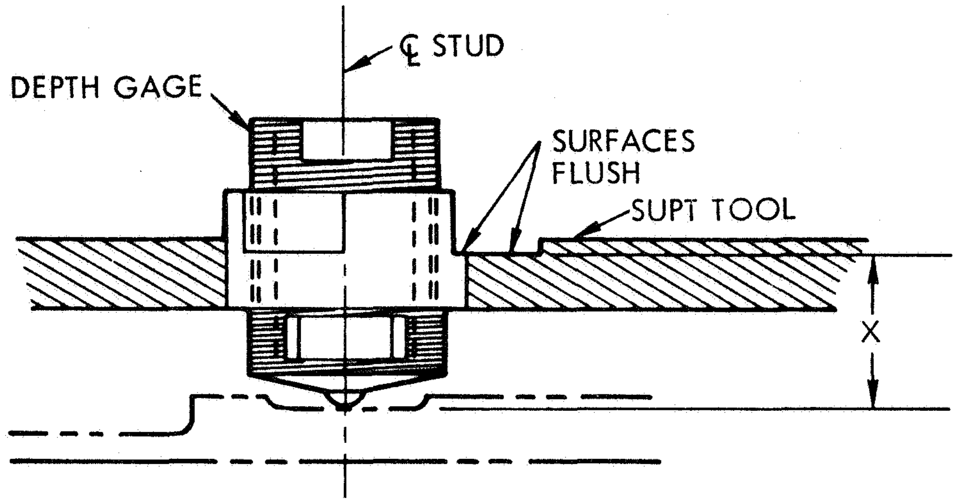


Figure 14. Adjustable Gap Supporting Tool

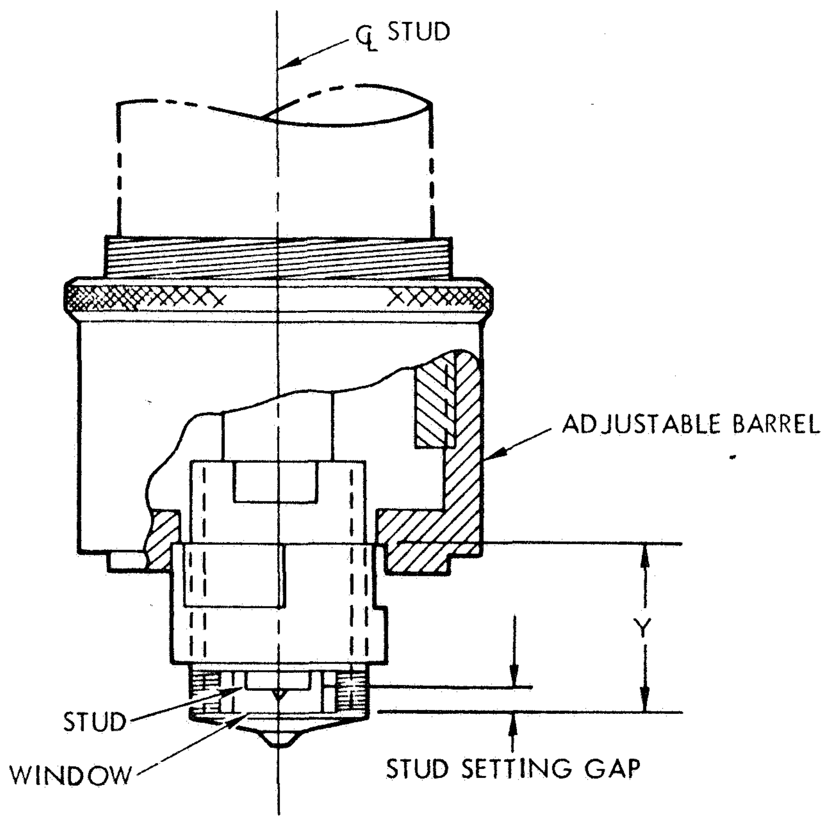


Figure 15. Adjustable Gap Control Support

ELECTRODE CONFIGURATION CONTROL

PROBLEM STATEMENT AND EFFECT

Precision fusion welding dictates that all parameters be strictly controlled to assure repeatable weld quality. The manufacturing process specification details these controls with the exception of electrode configuration.

SOLUTION/RECOMMENDATION

The tungsten electrode shapes, used in the DCSP/GTA welding process on the Saturn S-II program, were determined during the weld certification effort. All sizes, shapes and finishes which were proven for specific weld operations were established as standard and recorded on tool design drawings.

The following steps were started in September 1968 to control this valuable welding parameter:

1. For tungsten electrodes, configuration and identification shall be specified on SK-017352 provided by the Tool Design Department.

2. The welding schedule, Form 971-D, shall specify the tungsten electrode to be used. The electrodes will be identified by numbers with a configuration sketch on the face of the 971-D weld schedule.

3. Stock electrodes shall be procured by the using department. Procurement will be in accordance with standard practice.

4. Vinyl envelopes and labels used for electrode storage and identification, as shown on SK-017352 (refer to -109 and -110), may be obtained by Internal Letter request, by the using departments, from Central Manufacturing. Detail numbers will be added to the labels by the using departments.

5. Electrode machining to the required configuration may be accomplished by Internal Letter request to the Quality Assurance Laboratory machining group. The request shall be accompanied by an SK-107352 drawing. Quantities will be specified for each

configuration required. Sufficient vinyl envelopes, labels, and electrodes shall be supplied by the using departments.

6. The Quality Assurance machining group shall request inspection of the completed electrodes. The Inspection Department shall date and inspection-stamp the label (SK-107352-110). The label and electrodes shall be inserted in the vinyl envelope (SK-017352-109) and stapled closed in accordance with the SK-017352 drawing.

7. The inspected and packaged electrodes shall be returned to the using departments for storage and dispensing in accordance with standard practice.

8. The Inspection Department will verify the packaged electrode identification in accordance with the 971-D weld schedule and witness its installation in the weld torch.

9. Used electrodes will be accumulated by the using departments and may be salvaged by re-machining according to the outlined steps.

DISCUSSION

Precise control of the electrode shape and finish was proven to be a valuable requirement for guaranteeing repeatable arc plasma consistency that provides the established arc force necessary for proper penetration.

REFERENCES

SK-017352, Saturn Welding Electrodes

WELDING MACHINE GROUND SPIDER

PROBLEM STATEMENT AND EFFECT

The 104 feet of periphery of every circumferential weld made on the Saturn S-II vehicles required the use of two welding machines diametrically opposed. The location of the grounds and signal trace leads was critical. Improper location or attachment meant the difference in maintaining a consistent voltage drop across the work piece, which subsequently affected the established weld parameters.

SOLUTION/RECOMMENDATION

To assure constant control of both welding machines and reduce the possibility that one machine's malfunction would not influence or affect the other, a weld ground spider was designed and developed. The ground spider, fabricated of electrolytic copper, was attached to the tank walls at 12 equally spaced attach points. The welding machine ground cables and signal trace leads were then bolted to a common bus which tied all 12 straps together.

DISCUSSION

The uniform distribution of the ground system provided assurance of consistent circuit control and reduced the possibility of weld defects occurring because of malfunctioning welding equipment or affected welding parameters.

REFERENCES

R-376465. Detail Drawing of Ground Spider

INTERNAL WELD DEFECTS

PROBLEM STATEMENT AND EFFECT

Internal weld defects caused by surface oxides, oils, and moisture required welds to be repaired.

SOLUTION/RECOMMENDATION

The following actions were instituted on the Saturn S-II program to aid in resolving the internal weld defects problem:

1. Procedures in pre-weld joint preparation were meticulously controlled; i. e., scraping and draw-filing in one direction only, bare hands never to touch the part, and no air hoses to be used for cleaning the part surfaces.

2. White nylon gloves and garments were used instead of cotton to reduce lint factor.

3. Liberal vacuum cleaning of the area and part surfaces was a continual operation during pre-weld clean and during welding.

4. Weld stations were environmentally controlled — temperature, humidity, and dust count.

5. Reactor grade helium was used for the torch shielding gas to assure high purity.

6. As an additional precaution, the reactor grade helium was subjected to a chromatograph analysis. The results were then compared to Quality Assurance Acceptance Standards for maximum allowable constituents.

7. Before any weld, either certification or production, was started, a hygrometer was attached to the torch and a moisture check was made to verify that no leaks existed in any gas lines (maximum allowable moisture content was set at 25 ppm).

8. After final cleaning was completed under bright lights, a black light inspection was performed on all surfaces of the weld joint to reveal traces of oxide film, lint, or dust which could not be detected under bright lights. All suspect areas were recleaned and vacuum-cleaned.

DISCUSSION

These controls and improvements were progressive efforts which started with the first S-II flight stage (S-II-1) and were completed in 1966 during the fabrication of Saturn S-II-6. Results of the effort showed a continuous quality improvement to a level of perfection where the final (S-II-15) vehicle required only 1/2 inch of weld repair in approximately 25, 000 inches of welding.

OFFSET CONTROL — CIRCUMFERENTIAL WELDING

PROBLEM STATEMENT AND EFFECT

The Saturn S-II consists of stacked bulkhead and ring assemblies. In order to complete the assembly, eight 33-foot-diameter circumferential welds were required. These welds were made in the horizontal attitude by using the free-fall welding technique. The only tooling involved was an eight-segment, internal, circumferential sizing ring. Since the tank sections were not built as concentric entities but rather to matched circumferential sizes, it was necessary for the internal sizing ring to force the segments to concentricity. Because of the limitation of the solid segments of the sizing ring to overcome local offset, it was necessary to install "bottle jacks" at all points where excessive offset occurred. These jacks were placed between the part and the pressurized sizing ring.

Limited success in offset control was notable, but the process was very time consuming.

SOLUTION/RECOMMENDATION

In order to overcome the offset problem and reduce costly fabrication time, the internal sizing ring was redesigned to provide individual, 1-inch increment adjustments over the entire top and bottom periphery of the sizing tool. Preadjustments were made over the entire surface area before any welding was done, and progressive adjustments followed, as required, during the tank welding operation. This newly designed tool provided a reduction in tank welding time by approximately 60 percent and a considerable improvement in offset control.

The first S-II to employ the use of this tool was S-II-7. Future programs should take into consideration circumferential welding offset problems in initial tool design.

REFERENCES

Planning Resident Order (PRO) TOS-556-0005, Circumferential Weld Backup Tooling.

UMBRELLA PLATFORM TOOL

PROBLEM STATEMENT AND EFFECT

No work platforms were available to perform in-tank rework – removal and replacement of the forward LH_2 bulkhead.

SOLUTION/RECOMMENDATION

The lack of suitable platforms for in-tank rework was solved at Seal Beach by developing an umbrella-type, collapsible platform that could be inserted into the LH_2 tank through a 36-inch opening in the forward bulkhead and suspended in the tank.

DISCUSSION

On two Saturn S-II stages, it was necessary to remove the forward LH_2 bulkhead from Cylinder 6 because the juncture weld offset and pearing were out of specification. Just the act of removing a 33-foot-diameter dome was a complex operation, compounded by the fact that there was no way, at that time, to position tools and personnel inside the tank at the Cylinder 6 and bulkhead level. The sequence of stacking the vehicle dictated that joining of Cylinder 2 to Cylinder 3 would be the closeout weld, with platforms to support that station. The 20-foot span between the closeout weld and the desired work area was bridged with the umbrella tool (see Figure 16).

REFERENCES

1. Umbrella-Type Platform Drawings, T-7204145 J-1 through J-11

2. Operation Sequence, SK-017243

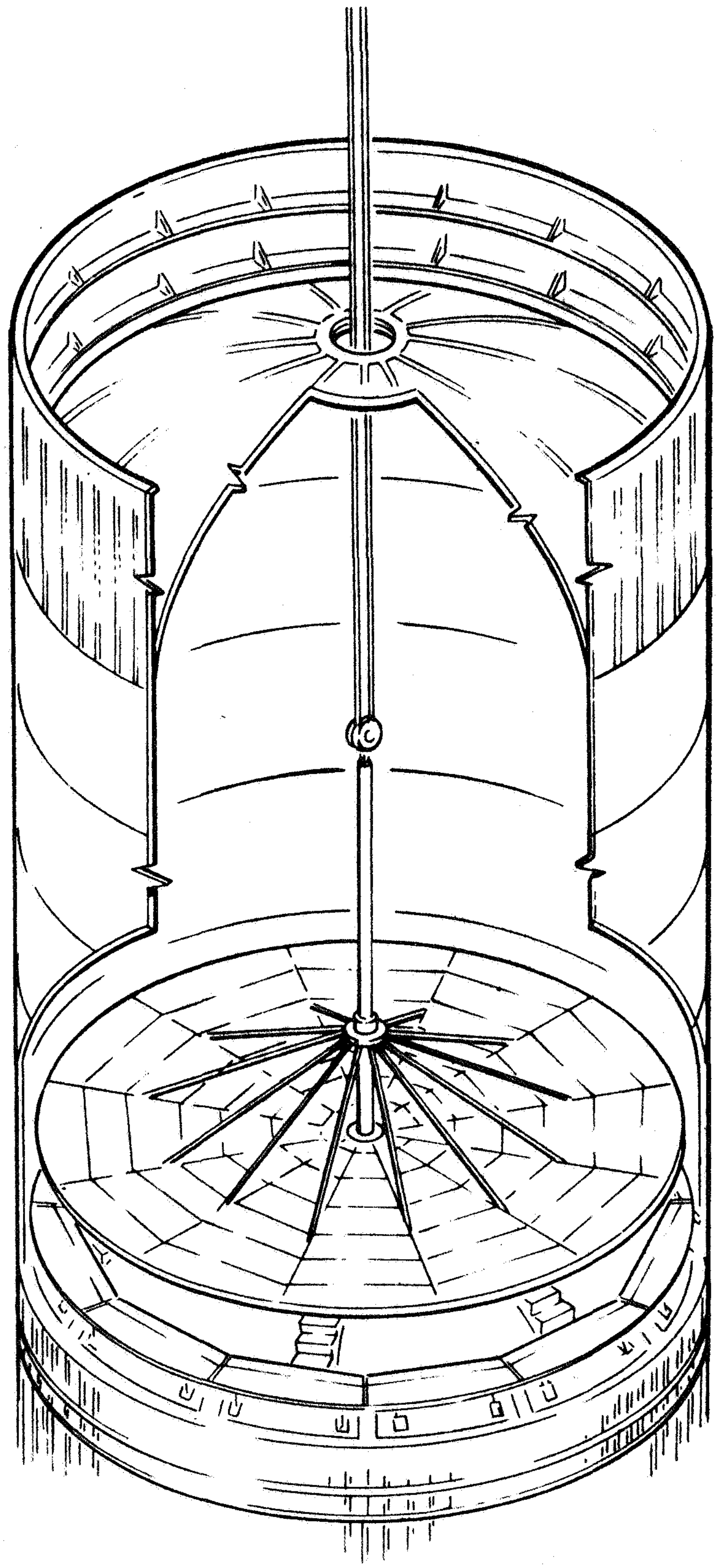


Figure 16. Umbrella Platform Tool

THICKNESS MEASUREMENT OF SPRAY FOAM INSULATION

PROBLEM STATEMENT AND EFFECT

Thickness of the Saturn S-II insulation was being measured by penetrating the foam with hypodermic needles and other thin-line instruments and measuring the depth of penetration. Holes left by such instruments had to be repaired and were difficult to fill with foam.

SOLUTION/RECOMMENDATION

The problem was resolved by developing a hand-held RF proximity measurement tool. The self-contained device is capable of measuring foam insulation when backed by a metallic plate. (Refer to the Attachment A for detailed tool description)

DISCUSSION

The hand-held RF proximity measurement tool has two measurement ranges: 0. to 1.2 inches in the low range and 1.3 to 3.0 inches in the high range. After a short familiarization period, accuracies of ±0.031 inch on the low range and ±0.062 inch on the high range can be expected. The tool can be expected to operate continuously for 24 hours after the batteries have been fully recharged.

ATTACHMENT A
HAND-HELD RF PROXIMITY MEASUREMENT TOOL

INTRODUCTION

Thickness measurements were being made on the Saturn S-II foam insulation with hypodermic needles and other thin-line instruments which are detrimental to the insulation properties of the material. Holes left by such instruments had to be repaired and were difficult to fill with foam. Experience gained with the addition of recent effort expended on an RF proximity alarm sensor indicated that an RF electronic measurement device could be fabricated using similar circuits to measure the foam thickness without degrading the insulation material.

DEVELOPMENT PRESENTATION

Objective

The objective of this development program was to design and construct a rugged hand-held metal-detecting device. The device was to be self-contained and capable of measuring foam insulation thicknesses when backed by a metallic plate.

Design Criteria

While the instrument should always be handled with care, construction of the unit was to be rugged enough to withstand accidental mistreatment with a minimum of repair. The device was to be self-contained, operated with rechargeable batteries, capable of measuring 0.750-inch thickness within a tolerance of ±0.062, and was to maintain calibration over long periods of time.

Design Consideration

The newly developed proximity alarm sensor had several qualities that were desirable for a hand-held measuring device. It contained an advanced use of circuitry for electronic measurement of distance, the measurements were maintained accurately for long periods of time with few calibration problems, and the equipment showed excellent stability and repeatability.

It was determined that the basic principle of the alarm sensor would be used to obtain these qualities. (Reference Letter Report No. PAP 68-0016). However, other aspects like battery operation and packaging would present different problems during development of the hand-held proximity measurement device.

System Description

A 455 Kc crystal oscillator was used to feed several stages of amplification with the gain of one controlled by the impedance change in a tank circuit. The AC output was fed into a conventional bridge circuit and the DC output read on a meter. For measurement purpose, the impedance is changed by the proximity of metal to the "sense" tank circuit and represents a DC voltage which can be read on a meter. This voltage can then be calibrated on the meter to represent the distance between the metal surface and the forward contacting face of the instrument.

Nickel cadmium batteries were selected for the power source over conventional batteries for their constant voltage output over a longer period of time and are good for an infinite number of recharging cycles. As development of the system progressed, a voltage regulator was added to ensure a constant voltage to the circuit essential for stability and repeatability, and a second range was added to make the unit more versatile (see Figure A-1).

The prototype gun-shaped case was fabricated from high-impact plastic and phenolic materials with the meter mounted at the back for easy reading. If quantities warranted, however, the cases should be of molded construction for cost saving and appearance purposes.

CONCLUSIONS

The completed hand-held RF proximity measurement tool has measurement ranges: -0 to 1.2 inches in the low range and 1.3 to 3.0 inches in the high range. The accuracy is somewhat dependent upon the ability of the operator to position the gun properly; however, after a short period of familiarization, accuracies of ±0.031 inch on the low range and ±0.062 inch on the high range can be expected. The tool has been operated continually during test for 4-hour periods with no deterioration of the above accuracies. The tool can be expected to operate continuously for 24 hours after the batteries have been fully recharged.

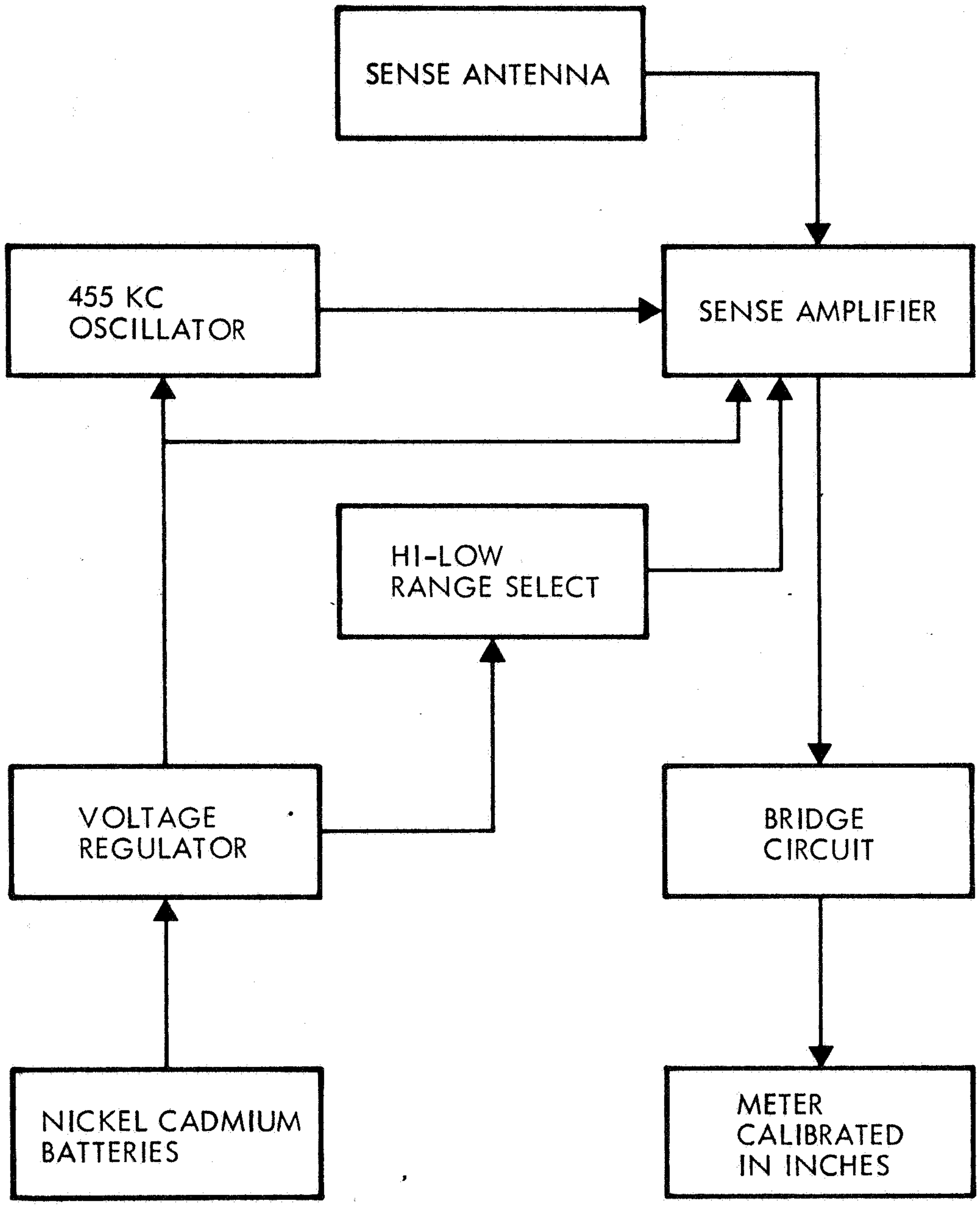


Figure A-1. Hand-Held RF Proximity Measurement Tool

AFT LOX BULKHEAD PEAKING

PROBLEM STATEMENT AND EFFECT

The cross-sectional configuration of the weld lands on the gore sections of the aft LOX bulkhead was of a double-reverse taper. Material thicknesses varied in ranges from 0.250, 0.375, 0.550, and 0.625 inch. The heaviest gauges were at the apex and at the equator. Welding of these gore panels from the outboard side caused peaking conditions to occur in the heavy areas which exceeded specification allowables. Subsequently, these peaking conditions induced offset problems when matching bulkheads for the girth weld of the LOX tank and when attempting the fitup of the 111-inch-diameter dollar ring into the welded bulkhead.

SOLUTION/RECOMMENDATION

The first solution to this problem was the establishment of welding parameters which provided a 75-percent penetration from the inboard side. This system aided in reducing the peaking, but was time consuming because the welded area had to be repositioned from under the beam of the tool to an area where an internal track was installed. This method also induced a high-risk factor of possible damage to the weld due to equipment malfunction or crater cracks caused by improper weld initiation.

In order to remove the damage risk and improve schedule position, a second system was developed. This method was a mechanical pre-peaking capability built into the hold-down bars of the tool.

Specifically, the pre-peaking system employed a series of adjusting screws the entire length of both sides of the meridian and at a location where they produced a cantilever action when the hold-down pressure was applied from the inboard side of the part. This bending moment changed the square butt condition to a "V" condition with the opening on the torch side. Since the weld bead geometry normally includes a shrink differential between the penetration side and the drop-through side, the pre-peaked groove reduced the configuration to a near parallel-sided nugget. The results nullified all peaking from the weld operation, and the part remained in contour.

This system was first used on the S-II-4 bulkhead, and all subsequent bulkheads welded were acceptable without the necessity of rework.

New programs should take into consideration the peaking problems inherent in welding and make allowances in all tool designs.

REFERENCES

T-7201800, Assembly Weld Jig

WELD STATION UTILITY POSITIONER

PROBLEM STATEMENT AND EFFECT

Vacuum positioners and hydraulic jacks were used to hold the S-II Cylinder 6 and the forward bulkhead in position and retain configuration mold lines during the weld operation in the weld station. A continuous supply of vacuum and high and low hydraulic pressure was needed to support these tools.

SOLUTION/RECOMMENDATION

A unique utility support fixture was designed and built which could continuously supply vacuum and high and low hydraulic pressure to the tooling fixtures. This fixture consisted of a cantilevered swing arm which rotates about a fixed central axis. The vacuum and hydraulic pressure are supplied through a slip ring assembly at the axis and carried to the ends of the arms to the tooling fixtures through hose assemblies with quick disconnects at the tools. The fixture was completed and put into operation in June 1967.

DISCUSSION

The welding operation to join the forward bulkhead to S-II Cylinder 6 was accomplished in Weld Station 1A at Seal Beach. The tooling that supports the cylinder and bulkhead was designed to rotate the product through a fixed weld head. The cylinder and bulkhead were held in position by internal vacuum positioners, and hydraulic jacks were used to obtain configuration mold lines. It became apparent that a fixture was required to provide a continuous vacuum and hydraulic supply to the vacuum and hydraulic tooling fixtures as they rotated with the bulkhead and cylinder through the weld head. A concept for a fixture was initiated, and a design and specification were prepared to provide a rotating fixture to meet the requirements. The fixture was fabricated and put into operation in June 1967. (See Figure 17.)

REFERENCES

Job Order 561-67016-120, F&I Utility Positioner 1A 0852

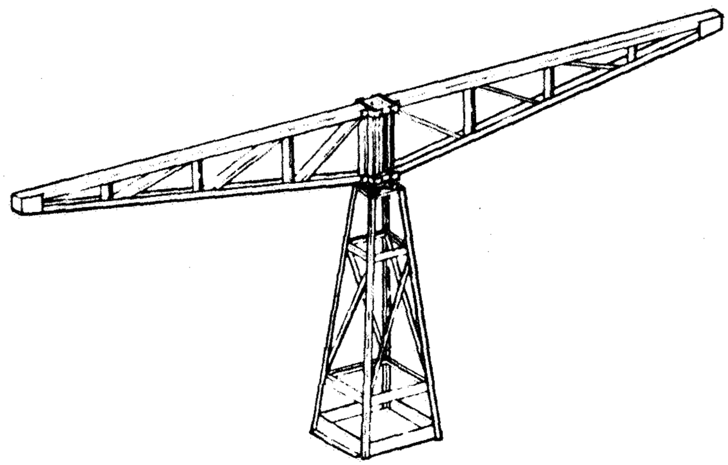


Figure 17. Support Assembly Positioner

DOLLAR WELDING S-II AFT LOX BULKHEAD

PROBLEM STATEMENT AND EFFECT

Because of the thickness of material (0.625 inch), the welding of the dollar section (aft apex of the LOX tank) became one of the major weld problems on the program. Control of offset and peaking in the weld necessitated procedures not normally used in other tungsten inert gas welding processes.

SOLUTION/RECOMMENDATION

The problem of welding the dollar section of the LOX tank was solved at Seal Beach by setting up stringent process controls and specifying that the dollar section would be welded from the forward and aft sides. This method produced an interlocking weld nugget. The NASA (Hawthorne) strap clamp was used for positioning and controlling offset.

DISCUSSION

In the initial effort to perform the dollar weld, tooling was provided with backup chill bars. This method was never successful in producing parameters for a quality weld. Difficulty was encountered in centering the backup tooling. As a result, there was a lack of penetration in one area, and the other extreme of overheat or blow holes in another.

REFERENCES

1. Planning Resident Order (PRO) MW565-008, Standard Welding Operating Procedure — Aft LOX Bulkhead
2. 971D Weld Schedule 00503
3. Job Instruction Manual T-7200077

WELD – BEAD TRIM TOOL AND OPTICAL VIEWER

PROBLEM STATEMENT AND EFFECT

Milling and viewing the weld bead at the junction of the S-II domed common bulkhead and Outside Cylinder 1 (referred to as the J-groove) is extremely difficult, and the milling must be done by hand.

SOLUTION/RECOMMENDATION

The solution to this problem was to develop a tool that could be placed in the limited space between the bulkhead and cylinder which would mill and view the weld bead as it travels around the periphery of the J-groove.

DISCUSSION

The specification governing welding dictates that welds will be crack-free. At times a weld will develop minute surface cracks which must be removed. The removal of these surface defects in the confined J-groove area of the S-II was very difficult and time-consuming. The mechanics had to position themselves in very awkward and unsafe positions to allow hand filing of the area. In order to inspect the area, mirrors and flashlights were used.

SPRAY FOAMING PANELS 1-INCH-THICK BY 4 FEET BY 6 FEET

PROBLEM STATEMENT AND EFFECT

In the early phase of the S-II program, no acceptable method was available to spray a consistent thickness of foam on insulation panels.

SOLUTION/RECOMMENDATION

A motor-driven conveyor was developed which moves a boxed panel tray at various speeds under an oscillating panel of spray foam application guns. This method was used to spray repair panels of foam insulation for S-II stages.

This method of spraying polyurethane foam panels could have many other commercial and industrial applications and should be considered in the initial planning of the insulation system.

DISCUSSION

Consistent forming of spray foam insulation panels required a method of moving the frame during oscillator spraying from two or more spray guns; the motor driven conveyor was designed and has worked very well for large insulation panels. This method of application could be applied to many spray foam uses.

REFERENCES

1. M/PHE Design Drawing for 8EH-0918 Conveyor, Drawing SK-1007 (29 March 1968)

2. Process Specification MA0606-050 for Polyurethane Foam Application and Materials

INFLATED SKIN POSITIONING FOR CONTROLLED CORE MACHINING

PROBLEM STATEMENT AND EFFECT

Producing a common bulkhead consisting of two aluminum domes (facing sheets) bonded to a varying thickness honeycomb core presented a difficult problem because of surface variations produced during fabrication and residual stresses caused by welding. To achieve a successful bond joint, the contours must have matched within 0.010 inch. Because of the flexibility and variations in both forward and aft facing sheets, considerable hand fitting and uncertainty of tolerance were experienced.

SOLUTION/RECOMMENDATION

The standard technique used in industry to match surfaces of the honeycomb core to the aluminum bulkheads was hand sanding. While this technique was satisfactory for smaller vehicles, it was not considered acceptable for a bulkhead the size of S-II. The area involved on S-II was approximately 1400 square feet, of three different contours (elliptical, torodial, and conical). A system to produce an acceptable method was established and became known as the inflation technique. This system was to inflate, at low pressures, the forward and aft skin assemblies of the bulkhead into smoothly faired contours. The aluminum domes were individually traced by dial indicators at 7920 points during the tracing operations. From the trace information, computer readouts supplied the data for machining the core for a precise match to both surfaces. A skate machining technique was developed to machine the honeycomb core as defined by the computer data. The skins were then bonded to the core in a preload condition. The bulkhead assembly so fabricated was free of slack and non-working membrane zones usually associated with non-preloaded structures.

On future programs, such techniques should be considered in the early design phases in the initial study so that engineering coverage can be provided prior to production.

DISCUSSION

The common bulkhead is composed of a tapered honeycomb core sandwiched between, and bonded to, two aluminum facing sheets. The facing sheets are made up of 12 sections called gore panels and a center cap known as the dollar panel. The fabrication of these aluminum details involves stretch or explosive forming, chemical milling, machining, and fusion welding, the operation that joins them into an assembly. The most critical aspect in the manufacture of this assembly is to obtain the required fit of the core to the facing sheet surfaces, because, to obtain a successful bond joint, the core contour must match the bulkhead within ten thousandths of an inch, the maximum gap which the adhesive can bridge and still maintain structural integrity. Since the honeycomb core surface is approximately 1400 square feet, or the size of an average house, and the surfaces are composed of three different contours, the problem was extremely complex. The problem was further complicated by the fact that fabrication of the aluminum facing sheets resulted in some localized distortion caused by uneven residual stresses.

The process previously used in the industry to fit the honeycomb core and facing sheets involved hand sanding the core to match contour templates. This process was not considered satisfactory so that Engineering and Manufacturing joined forces and developed the inflation technique. Briefly, this technique employs either air pressure or vacuum to inflate the assemblies into smoothly faired contours. The inner surface of the forward facing sheet and the outer surface of the aft facing sheet are accurately measured at approximately 15,000 points, and deviations from true contour are recorded. With the aid of a computer, this information is used to develop core cutting tables. Thus, the core thickness and profile are closely controlled.

The first step in the process is to inflate the aft facing sheet with air pressure to 1/2 psi. This pressure causes the facing sheet to expand like a balloon into a smooth contour. The tool for this purpose is especially designed to hold the facing sheet and to seal the undersurfaces so that this inflation can be accomplished and maintained. By using the rainbow beam and work platforms, 43 dial indicators are employed to measure the bulkhead contour at each 2-degree increment of bulkhead circumference. This method results in a measurement of 7740 points for the aft facing sheet. These measurements are made and documented by certified mechanics, and verified by Quality Control. Engineering converts these measurements to core cutting tables for use by Manufacturing in establishing the honeycomb core machining parameters.

Before adhesive is applied the core blocks are fit checked to the facing sheet contour by using a layer of polyvinylchloride (PVC) both to simulate the adhesive thickness and to provide an impression check. When this operation verifies that the core matches the facing sheet within 0.010 inch, the bonding operation can commence.

A compartmentized vacuum bell is placed over the forward facing sheet and secured in place. A vacuum is applied to the lower vacuum bell compartment; later, vacuum is applied to the upper compartment. The slack in the facing sheet skin is eliminated as the skin area is moved into its normal contour. When the facing sheet is drawn smooth, precise contour measurements can be made.

The forward facing sheet contour tracing is taken in a manner similar to that utilized for the aft facing sheet, except that the contour measured is on the inside of the facing sheet. This tracing requires 7560 measurements to be recorded by Manufacturing and verified by Quality Control.

The aft facing sheet with core panels bonded in place is fixed to the machining tool; the internal surface is pressurized to 1/2 psi; and core material is removed in ten thousandths of an inch increments around the core panel's periphery. This operation continues until the core panel contour matches the forward facing sheet contour. The airborne minute dust particles caused by milling the nylon fabric core make it mandatory for employees in the machining area to wear respirators. Before this operation is started, equipment is inspected to assure that each component is securely attached and is in working order. The 43 adjustments for controlling cutting contour are set to data computed by Engineering from the aft and forward facing sheet tracings, and a test cut is milled across the honeycomb core panel. Cutting machine head is re-adjusted for the next 0.010-inch cut after each 360 degree milling sweep.

The forward facing sheet is transferred to the location of the aft facing sheet and core panel with an overhead bridge crane and a vacuum bell. The forward facing sheet is lowered onto the core, making certain that the preset facing sheet indexing targets align and that the assembly is level. One hundred thirty special turnbuckle-type load cells are installed hand-tight. The assembly is slowly drawn over the core panel like a beanie cap by incrementally tightening the load cells. This procedure continues until each load cell is indicating 1000 pounds. Then the vacuum bell is removed and stored.

BULKHEAD CIRCUMFERENCE CONTROL

PROBLEM STATEMENT AND EFFECT

The 33-foot-diameter welded bulkhead assemblies used on S-II must be fabricated to a specific equatorial circumferential dimension within a tolerance of ±0.078 inch (which is theoretically ±0.025 inch on the diameter). Because of the apparent variations encountered in trimming and weld shrinkage of the 12 meridian welds, the tolerance was quite hard to maintain. The effect of exceeding the ±0.078-inch tolerance is an increased mismatch with the circumference of the mating bulkhead or cylinder. This mismatch compounds the task of effecting a proper weld joint alignment, which requires that the smaller assembly be stretched to match the larger.

SOLUTION/RECOMMENDATION

In order to minimize the variation of the bulkhead circumference, an assembly sequence was instituted that required incremental circumference measurement. These measurements were accomplished with a Pi tape and were taken after every second meridian weld was completed, starting after weld six. This procedure allows for any required corrections to be performed during the subsequent two gore trim operations. The implementation of this procedure should be undertaken on first-article fabrication.

DISCUSSION

The use of this procedure has resulted in bulkheads of quite consistent circumferential quality. One future advantage of this more precise circumferential control is that any new circumferential backup bars (an apply-type weld joint alignment fixture) can be designed much lighter because much less force is required to effect proper weld joint alignment.

REFERENCES

Saturn S-II Production Operation Techniques, Production Welding, Volume I, Bulkhead Welding, SD 70-559-1, pages 20-28, 92-103.

COMMON BULKHEAD HONEYCOMB MERIDIAN MACHINING CUTTER

PROBLEM STATEMENT AND EFFECT

The machining of the common bulkhead honeycomb core, a phenolic impregnated nylon material, presented the problem of producing a finished surface cut cleanly and without edge fray while using very little cutting contact pressure due to the fragility of the material.

The change in the anti-profile (the profile perpendicular to the meridian and normal to mold line at a given point) curvature from the center of the bulkhead down to the bulkhead equator represents approximately a 2:1 ratio (401 to 198 inch radius). This change in curvature presented a problem theoretically with regard to whether more than one cutter face profile must be used to machine the entire core surface. If more than one cutter profile were required, this would necessitate cutter changes for machining different elevations of the core which would further complicate the operation.

The machining of the core also presented another problem, that of machining the wide, hard bond lines present between individual core sections.

SOLUTION/RECOMMENDATION

The design of the honeycomb core cutter represented several variables, e.g., diameter, face width, face concavity, revolutions per minute and cutting medium. The diameter was determined by what seemed to be a reasonable proximity of the skate-mounted cutter drive motor shaft center line to core. This dimension was 4 inches, which obviously results in an 8-inch diameter.

Because of the known abrasiveness of phenolic-nylon honeycomb core, a diamond-coated cutter was tried. Testing proved that diamond-coated cutters would work satisfactorily if the cutting surface speed exceeded 6000 surface feet per minute.

The concavity of the cutter face was made to the larger aforementioned radius. This calculated out as creating a theoretical error of less than 0.0015 inch when cutting in the 198-inch radius area based on a 2-inch cut width increment. The face of the cutter was made 3 inches wide but cut-width increments were kept at 2 inches or less.

The implementation of this machining approach is most advisable during tooling conception phase.

DISCUSSION

The design of this cutter has proven to be quite successful. Both the diamond coating longevity and the finish produced have been excellent. The cost for this cutter could be considered reasonable when the cost of other types of special form cutters and the probable difference in longevity are considered.

REFERENCES

Tool Design T-7200415, Sheet G-10, Detail 1001

HIGH ENERGY FORMING OF BULKHEAD GORE SECTIONS

PROBLEM STATEMENT AND EFFECT

Because of their extreme size, approximately 10 x 22 feet, the bulkhead gore thin sections could not be formed by conventional means within a reasonable distance of the Los Angeles area. Likewise, the fully machined bulkhead gore waffle sections (which have a diagonally oriented, egg-crated standing rib stiffener pattern on what is, after forming, the concave surface) could not be formed properly by standard techniques.

SOLUTION/RECOMMENDATION

In order to meet this forming requirement, a high energy forming facility was established at El Toro, California. This facility included water-filled forming pits up to 25 feet in diameter by 15 feet deep and a crane capacity of 80 tons. Likewise, a series of high energy form dies were fabricated to accommodate the various bulkhead sections.

Briefly stated, high energy forming is the use of explosives for forming ductile metals to a die surface. This was done by clamping the sheet to be formed onto a female die and drawing a vacuum between the part and die. The explosive charge is then installed a predetermined distance above the workpiece. Then the die, workpiece, and charge are submerged in a pit of water. The explosive charge is detonated, and the resulting shock-wave forces the workpiece into the die cavity producing a formed part.

The decision of whether or not to use high energy forming or more conventional methods should be made at the pre-design stage so that the part design might be more compatible with the selected forming technique.

DISCUSSION

The use of high energy forming has resulted in a practical method of forming oversize and unique parts such as the bulkhead gore thin and waffle sections. This type of forming has many advantages over conventional methods, e.g., reduced springback, unlimited forming pressure, nearly any thickness and/or size of part can be formed, only a female die is required, close tolerances can be obtained on any size part, and otherwise difficult or impossible shapes can be formed readily.

REFERENCES

1. NR Document NA-64-170, Explosive Forming.

2. NR Document NA-69-531, High Energy Forming, Saturn II, Technical Manual, Section C - Bulkhead Gore Panel Forming.

3. NR Document NA-69-531, High Energy Forming - El Toro, Saturn II, Technical Manual, Section B - Waffles.

LH_2 CYLINDER ROTATING FIXTURE FOR CIRCUMFERENTIAL WELDING

PROBLEM STATEMENT AND EFFECT

Because of manufacturing schedule requirements, it was necessary to establish a new circumferential weld station. At the time, opposed arc, opposed nugget TIG welding and pulsed arc MIG welding were being considered for circumferential welding. It was desired that this new station be designed with these types of welding in mind.

Each of these types of welding requires welding from both sides of a panel. At the time, the only capability to weld externally was by using an apply-type vacuum cup supported weld skate track. The opposed arc welding presented an additional problem in that two torches are used simultaneously and must remain directly opposed to each other. If this were done by using internal and external skate tracks, there would also be a problem of slaving one skate to the other to maintain the direct opposition of the torches.

SOLUTION/RECOMMENDATION

The basic solution to this problem was to rotate the cylinders and mount the weld torches on stationary pedestals. This effort was accomplished by fabricating a precision turntable driven by a dual-drive position Sciakydyne drive with precision speed regulation controlled through the weld pack.

DISCUSSION

The precision turntable simplified the internal and external weld torch positioning requirement and eliminated the need for vacuum cup supported skate tracks. This solution resulted in a weld station with increased versatility and reduced the probability of accidentally damaging any hardware because of the reduction of apply-type tooling involved.

The concept of rotating the part resulted in a convenient and efficient operation even though it was decided that straight TIG welding would best serve this station's purpose.

REFERENCES

Tool Design T-7204224, Circumferential Welding Turntable

SINGLE LAYOUT FOR DOUBLE-SIDED PRINTED CIRCUIT BOARD

PROBLEM STATEMENT AND EFFECT

Separate art work was required for front view and rear view for a double-sided printed circuit board.

SOLUTION/RECOMMENDATION

An S-II original art work was prepared by applying all tape and pads on one view – red transparent tape to depict far side circuitry, blue transparent tape for near side circuitry, and black tape for pads and circuitry appearing on both sides. By applying all tape and pads on a single view, absolute rear-to-front registration was accomplished and a light table was not required to align or check registration of terminal pad holes. The positive and negative manufacturing tool (actual size) was obtained directly from the printed circuit original by using a photographing system. This system uses a camera loaded with orth-chromatic film, a filter over the lens (red or blue filter), and blacklighting to achieve desired results. This method should be incorporated during initial design.

DISCUSSION

In a double-sided printed circuit board, it was required that a four times size printed circuit original (art work) be prepared for the front view and a second separate original be prepared for the rear view. A coordinate grid and a light table were used to assure close tolerance (rear-to-front registration terminal hole pads). Shortcomings to this method were as follows:

1. Absolute registration from rear to front on terminal holes cannot be accomplished.

2. Design and drafting time is increased.

3. A light table and stringent checking are required to assure good registration.

SUBSYSTEM HARDWARE INSTALLATION INTERFERENCE

PROBLEM STATEMENT AND EFFECT

Personnel working in the area of the aft skirt and thrust structure of the S-II were constantly interrupted due to the harness changes and tubing routing fit checks in this congested area. Sometimes, because of reconfiguration to an existing system, an interference problem resulted. These problems created design problems and schedule delays due to multiple rework and fit check operations.

SOLUTION/RECOMMENDATION

The systems dimensional simulator (SDS) was developed. The SDS, a full-scale replica of the vehicle aft skirt and thrust structure, is used for development purposes, early problem identification, design analysis, and evaluation of harness, tubing, and mechanical routing and mounting interfaces without interference on stage fabrication. Aside from the primary development aspect of the simulator, the intangible benefits (i. e., training, special studies, experimentation, proposals, etc.) derived from the program are numerous.

DISCUSSION

The aft skirt and thrust structure area, which is the most congested of all areas on the space vehicle, contains about 70 percent of all mechanical and electrical systems. This area is subject to complex routing of tubing and harnesses and positioning of components. In the past, the problem of physical interference has caused revision to design changes after formal release of documentation. To eliminate the possibility of interference is paramount if cost effectiveness is to be realized in modification of an existing system, or implementation of a new system. Because these changes occurred during the course of the program, personnel installing these systems were interrupted by fit conflicts or verification checks and manufacturing resulted.

The SDS program was therefore implemented, and methods of configuration control were instituted. To assure the best possible design, Program Design Engineering, Manufacturing, and Quality Control jointly review the change as it has been made on the SDS, before formal release of engineering documentation. All specifications regarding bracketry design spacings must be met as well as the general routing and placement of components to satisfy the interfaces of the system and ensure that the installation in question does not create a possible interference with another system. Once an agreement is made that all avenues of design and quality are as optimum as possible, formal documentation for production can be processed from the design group and interference-free installation can be accomplished.

STANDARDIZATION OF WIRE HARNESS INSTALLATION CRITERIA – STATION AND STRINGER MARKERS

PROBLEM STATEMENT AND EFFECT

Various types of identification markers had been installed on stringers and stations to facilitate installations. Lack of standardized procedures resulted in incorrect positioning and installation of wire harnesses.

SOLUTION/RECOMMENDATION

A station marker method was developed and implemented on S-II to preclude unnecessary problems during installation. Station and stringer location markers are attached to wire harnesses during fabrication. During installation of trunk wire harnesses, the harness is aligned with the location depicted on the station or stringer marker, thereby correct wire harness positioning is assured.

DISCUSSION

Various types of identification techniques were devised by Manufacturing personnel to mark stringers and station planes (e.g., masking tape, dyna-tape, colored paper, and pencil marks) to identify specific locations in the S-II. Mislocated or incorrect markings resulted in incorrect installations, short wire harnesses, and misrouted wire harnesses. Numerous such discrepancies necessitated implementation of an efficient and reliable system to ensure correct positioning of wire harnesses.

During development activities on the systems dimensional simulator, proper installation of each wire harness is verified. Station marker locations are forwarded to Wiring Analysis personnel for inclusion in assembly instruction documents. Dimensioned locations of markers are specified in the harness assembly procedure, and the markers (Ty-wrap type) are installed on the wire harness by utilizing an operator's general instruction document. Station and stringer locations are also depicted in the stage final installation document. Alignment of the previously installed markers on wire harnesses to locations specified in the stage final installation procedure assures that harnesses are installed correctly.

CLAMPING OF PHENOLIC HONEYCOMB CORE FOR PERIPHERAL MACHINING

PROBLEM STATEMENT AND EFFECT

The clamping of compound contoured phenolic impregnated nylon honeycomb core presented a problem because of the honeycomb's extreme fragility and the infinite number of sizes. Mechanical means of clamping were undesirable due to the fragility of the honeycomb and the expense of accommodating the number of sizes involved.

SOLUTION/RECOMMENDATION

A tool was built with a perforated surface duplicating the desired male compound contour. The underside of this surface was enclosed, creating a plenum connector to a large squirrel cage blower. This blower creates a high-volume, very-low-quality, negative pressure in the plenum chamber. When a section of honeycomb core is positioned on the tool's perforated surface and a sheet of plastic is placed over the exposed surface of honeycomb core, except for the edge to be trimmed, sufficient clamping of the core is provided by the negative pressure to allow for accurate trimming.

DISCUSSION

This approach allows for an infinite number of core sizes, which fall within the tool's dimensional capacity, to be trimmed. The even distribution of clamping force and use of a simple sheet of plastic rather than special clamping components for each size and shape of core have proven to be quite effective.

This particular application uses a skate beam swung above the core material to achieve one direction of trim. A trim skate moves along the skate beam, effecting the second direction of trim.

NON-COPPER-CLAD PRINTED CIRCUIT BOARDS

PROBLEM STATEMENT AND EFFECT

Copper-clad glass epoxy or copper-clad phenolic material used for fabrication of printed circuit boards requires extreme care and inspection operations in the process of removing the excessive copper to form the required circuit image. Delamination usually results if this extra care is not exercised.

SOLUTION/RECOMMENDATION

In order to accelerate design and fabrication of printed circuit boards and also reduce cost and the rejection rate, the existing stock of epoxy glass board or phenolic material (without copper clad) was utilized. The punching, blanking, and drilling operations were performed without the problem of weakening the laminate bond. The required circuitry was then applied by using a silk screenable conductive silver epoxy compound.

DISCUSSION

The copper-clad glass epoxy or copper-clad phenolic material used in the fabrication of printed circuit boards always requires extra operations in removing the excessive copper to form the required circuit image. Some of the main problems encountered when using copper-clad materials are as follows:

1. Copper-clad stock must be inspected when received from the vendor or laminate surface pinholes, which will cause lack of ink adherence when silkscreening is performed.

2. Copper-clad laminate will vary in color.

3. Laminate bond is usually weakened by punching, drilling, or piercing, causing portions of pads to lift.

4. During punching, drilling, or piercing if the oils used are not properly removed, there will be a lack of ink adherence when silkscreening is performed.

5. Discoloration or permanent staining sometimes occurs. The organic resist used for etching operations must be removed.

TRIMMING OF EXCESS FOAM INSULATION FROM FOAM-FILLED HONEYCOMB CORE SHEETS

PROBLEM STATEMENT AND EFFECT

The manufacture of foam-filled honeycomb core sheets presented a problem of removing the excess foam buildup which resulted during fabrication. This buildup removal required an excessive amount of hand labor to whittle off.

SOLUTION/RECOMMENDATION

A standard 14-inch woodworking band saw was modified by removing the table and increasing the throat opening to 34 inches and then rigging into a throat-down attitude above a conveyor table. The structure that supports the saw was designed to provide counterbalanced vertical adjustment. By adjusting the saw to the desired height and running the foam-filled honeycomb through the saw by using the conveyor table, the excess foam was removed with one saw cut.

This approach of modifying a band saw was dictated by an immediate specific need. In the future it is recommended that a commercially available horizontal band saw be used. A commercial band saw would result in a more sophisticated and efficient unit.

DISCUSSION

A dust collection system was installed to preclude any safety hazard from the foam dust produced during band saw cutting operations. Saw motor stop buttons were also installed on both sides of the conveyor table for improved accessibility in an emergency.

ALUMINUM ALLOY CORROSION

PROBLEM STATEMENT AND EFFECT

Corrosion of 2014 aluminum alloy components on the S-II was a continuing problem during fabrication and assembly. It resulted in repair or scrapping of hardware as well as a consequent impact on cost and schedule.

SOLUTION/RECOMMENDATION

A new corrosion control specification was released for components made from aluminum alloys. Additionally, Manufacturing Order Planning documentation was initiated that included improved operational and verification sequences, as defined by the process specification.

DISCUSSION

The problem of corrosion has been recognized since 1963. Investigation of the problem started in December 1966 and continued through March 1967. The results of the investigation are documented in SID 67-533.

REFERENCES

1. Corrosion Investigation of Aluminum Components of the Saturn S-II Stage, SID 67-533

2. Process Specification MA0609-007

SIMPLIFIED CONNECTOR KEYING

PROBLEM STATEMENT AND EFFECT

Flight article connector requirements are such that connectors in the same vicinity required a different key arrangement to prevent mismating of interconnecting harnesses. This requirement was so greatly emphasized that it was carried over to in-process special test equipment (STE).

SOLUTION/RECOMMENDATION

A connector was developed that can be re-keyed without disassembly from STE adapter cable. It is recommended that deliverable equipment continue to be designed such that any interfaces within the same vicinity should have different keying arrangements, but that STE interconnecting adapter cables be designed utilizing this clockable connector (Figure 18), which allows the use of the same adapter cable to interface with all the different keying arrangements.

DISCUSSION

One of the phases in which manufacturing costs increase substantially is in the design time for, and quantity of, interconnecting adapter cables required and fabricated for use in checking out deliverable equipment. The numerous designs and quantity of cable adapters required are the result of S-II Engineering complying with good design practices.

A universal type of special test equipment is usually designed to check out the different types of deliverable equipment. Interconnecting adapter cables are then designed to hook up with these different pieces of deliverable equipment, which may or may not be installed in the same vicinity; thus a different key arrangement is required to prevent mismating. Because of this requirement, a different STE cable adapter is designed and fabricated for each different interface.

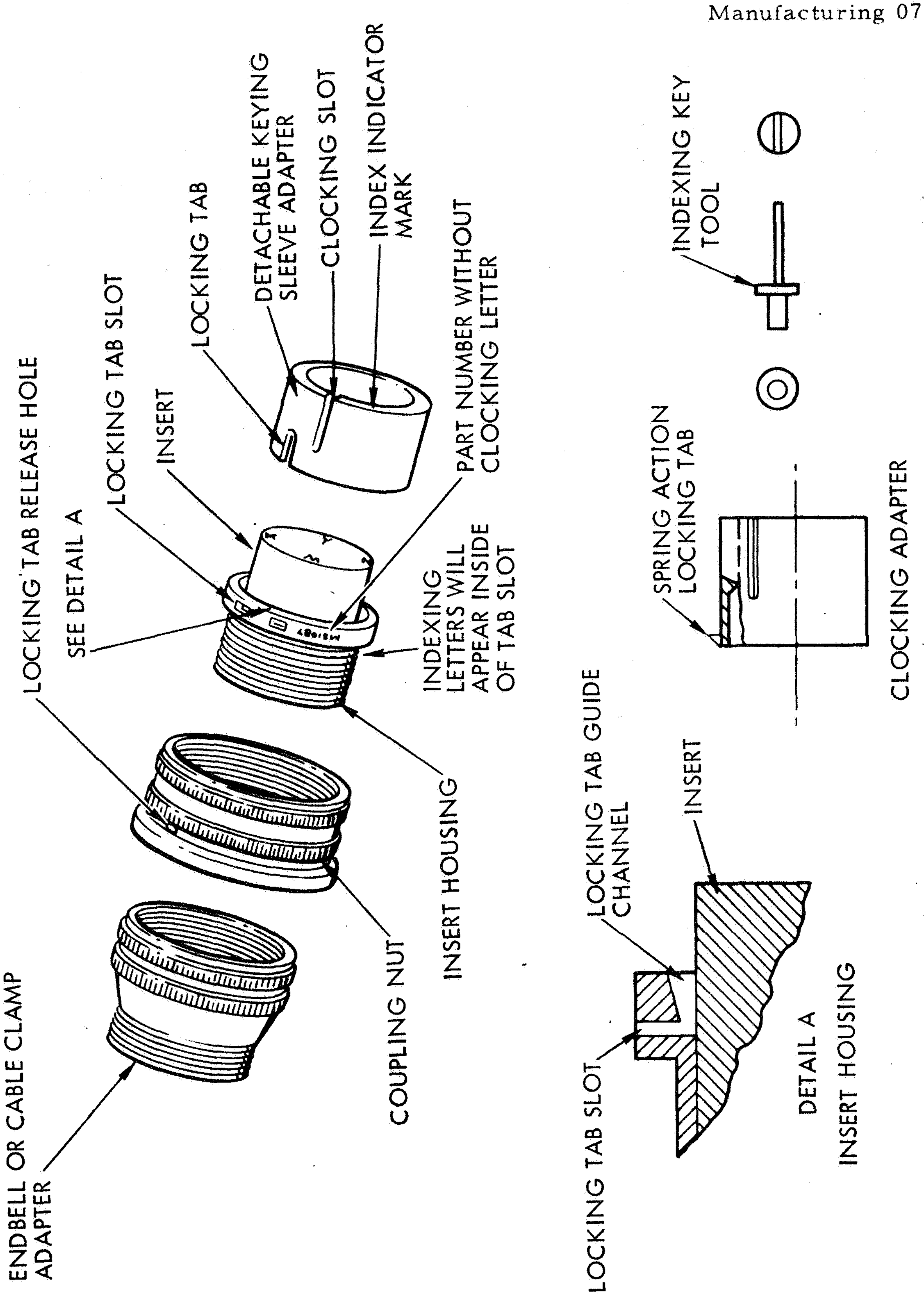


Figure 18. Clockable Connector

CONNECTOR PIN BENDING

PROBLEM STATEMENT AND EFFECT

Damage to connector pins during mating caused short-circuit and system malfunctions.

SOLUTION/RECOMMENDATION

On future programs, an improved type of connector should be used such as amphenol 270 series shown in Figure 19.

DISCUSSION

Because of the size and complexity of the S-II, the multiple harness concept was used to interconnect all the different subsystems. This multiple harness concept consisted of 16 cryogenic, 25 interstage, 235 aft skirt, 59 forward skirt, and 83 tunnel trunk harnesses in addition to 117 container J-box and miscellaneous black-box harnesses. During the processes of bench checking, installing, and testing, the harness connector pins are sometimes bent, shorting out or causing system malfunctions. In order to prevent these hazardous conditions on future programs, it is recommended that an improved type of connector such as amphenol 270 series be incorporated into harness designs. This type of connector has pins and sockets recessed in respect to the plug and receptacle shell, eliminating the possibility of the pins or sockets coming in contact with any part of the connector when a plug is inadvertently cocked while mating. The pin contact is shrouded by the insert instead of the socket contact being shrouded by the insert. The exposed socket contact is approximately four times more resistant to bending than the pin because of its larger diameter.

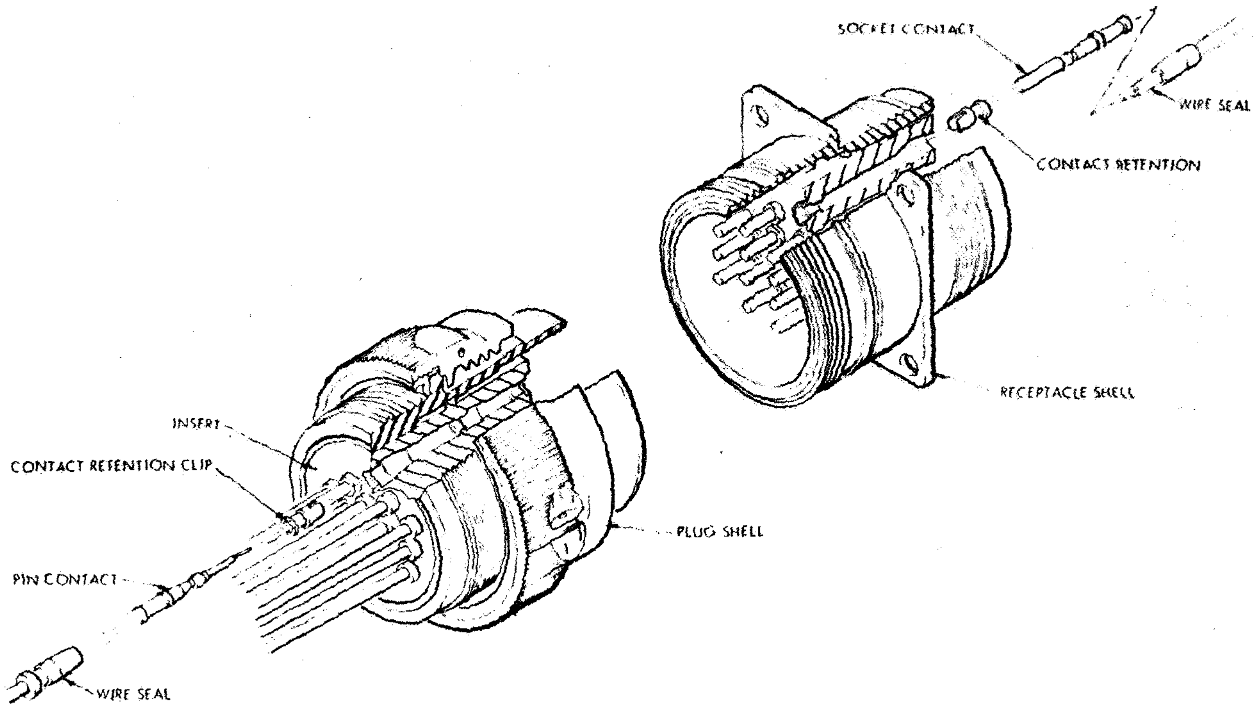


Figure 19. Wiring Connector

RF COAXIAL CONNECTOR JAM NUT TORQUE RELAXATION

PROBLEM STATEMENT AND EFFECT

The coaxial cable shield braid, when secured to the coaxial connector by compression, "cold flows" with the resulting degradation of the jam nut torque values.

SOLUTION/RECOMMENDATION

To determine the necessary corrective action, sample cables were subjected to a series of tests. The changes to manufacturing processes resulting from these tests are as follows:

1. Coaxial connector jam nuts will be torqued to the specified values and re-torqued after 24 hours.

2. Whenever a jam nut is suspected of being loose or if the torque strip has been disturbed, the jam nut will be considered properly torqued when the jam nut cannot be moved by hand.

3. When the jam nut is considered to be loose, the jam nut will be tightened by hand only.

Another approach is to bond the coaxial cable to the coaxial connector. The process for performing this task is as follows:

1. Tighten the jam nut to a specified torque value.

2. Perform electrical integrity checks.

3. Remove the jam nut, making sure all components remain in their proper position.

4. Apply adhesive to the area of the connector where the jam nut is normally installed.

5. Replace the jam nut and tighten to the specified values.

DISCUSSION

Several discrepancies related to RF coaxial connectors were noted on various S-II stages. The problem was relaxation of the fabricated torque value and, in a few cases, complete loosening of the connector jam nut. The time elapsed between cable fabrication and observance of the discrepancy was from one day to many months.

To determine the necessary corrective action, an evaluation was made of the assembly procedures and subsequent use of all S-II stage RF coaxial connectors. Concurrent with this investigation, 14 sample cable assemblies were fabricated and subjected to a series of tests.

All the mechanical tests, torquing, re-torquing, and measurement of jam nut rotations clearly show that RF coaxial connectors are subject to torque relaxation. In no case, however, did the torque decrease to a value which permitted the jam nut to be turned by hand. The relaxation was due to compression within the connector rather that rotation of the jam nut. After each re-torquing, the amount of torque relaxation and subsequent jam nut rotation decreased. One connector did exhibit maximum torque relaxation consistently. This connector was the only one in the test samples that used a compression gasket; all others used a type of gasket that is cut in two during connector fabrication.

The electrical characteristics (VSWR) are essentially unaffected by repeated torquing, and a megger test performed on each cable set with all cables connected in series showed the resistance to be far in excess of the specification minimum. A vibration test, performed on two cable assemblies at levels greater than expected during flight, also confirmed the electrical and mechanical integrity of the assemblies. Although the jam nuts were loosened to a finger-tight condition before the start of vibration testing, neither cable malfunctions nor jam nut rotations were observed.

Based upon the results of the various tests described here, it was concluded that the existing torque problem was not due to improper assembly or usage but rather to an improper assumption that cable assembly level torque values should apply at any time after stage installation. All the forgoing tests indicate that the post-installation torque requirements can be reduced without compromising the mechanical and electrical integrity of the cable assemblies. This conclusion is substantiated by the vibration test and also by an evaluation of the various stage installations. The cables are either very short and connected to two rigidly mounted components or, in the case of long cables, are clamped at sufficient intervals to prevent movement.

ELECTRICAL CONNECTOR, ASSEMBLY OF END BELL AND BUSHING

PROBLEM STATEMENT AND EFFECT

When "0" and larger gauge wire is used in the connector, the force required to compress the insert and engage the gland nut threads is greater than the force an assembler can physically exert.

SOLUTION/RECOMMENDATION

The problem was resolved by the development of a small hand-operated press suitable for use on the assembly line and in the field.

DISCUSSION

Electrical connectors of the circular MS type employing insertable and removable contacts rely on compression of the resilient rear grommet to provide environmental sealing at the point of wire entry. This is accomplished by drawing a conical-shaped nylon ferrule over the insert. When "0" and larger gauge wire is used, compression of the insert and engagement of the gland nut threads require a force beyond the capability of the average assembler. Thus, a hand-operated press was developed to close the connector and to assure pin alignment.

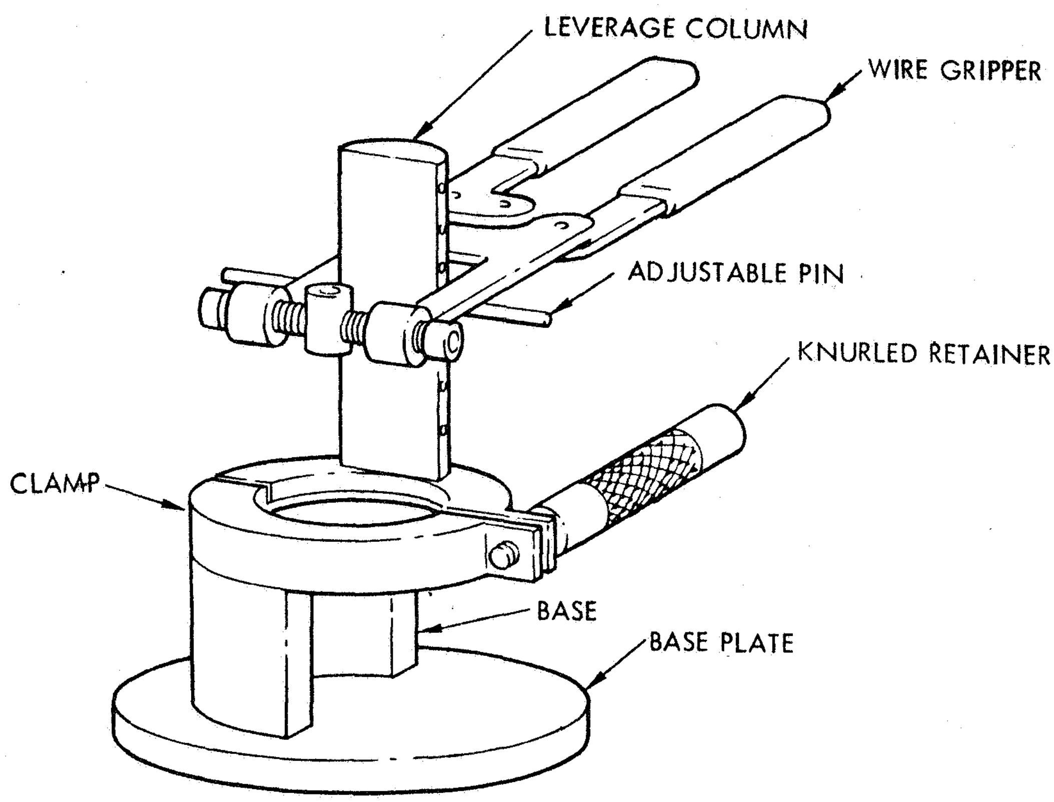


Figure 20. Astro Insertion Tool

CONNECTOR, CLEANING AGENTS

PROBLEM STATEMENT AND EFFECT

Inspection of electrical connectors revealed that there might be possible deleterious effects or damage to electrical connector hardware through the use of some common cleaning agents that were called out in S-II process specifications. The effect of this problem caused Quality Assurance to question the quality of the product.

SOLUTION/RECOMMENDATION

Laboratory tests were performed to determine what cleaning agents were causing the problem. On the basis of the test results, engineering process specifications were changed, eliminating the suspect cleaning agents.

DISCUSSION

The full impact of connector degradation by cleaning agents was difficult to determine; hence, the laboratory tests were performed. Other problems created by cleaning agents were reported when the silicone rubber swelling restricted the assembly of the connector. This problem was more prevalent with large-gauge wires, 4 gauge through 1/0 gauge. Freon TF caused the greatest damage; therefore, it was eliminated from connector specifications.

It was brought to the attention of the Saturn S-II Engineering Department that there might be possible deleterious effects and/or damage to electrical connector hardware through the use of some common cleaning agents. An investigation was conducted by Space Division personnel on cleaning solvents that are in fairly common use and called out in certain North American Rockwell specifications (primary and sub tier) for cleaning operations of electrical connectors.

The following cleaning agents were investigated: Freon TF, MEK (methyl-ethyl-ketone), primary alcohols (methanol and ethanol) and secondary propyl-alcohol. Connector materials included the connector shells with Alodine 1200S and Iridite 8 finishes, silicone rubber, teflon (FEP and TFE), sealing plugs, gold-plated contacts, and the adhesive bond of the insert to the shell.

Results of the tests indicate that Freon TF solvent causes severe swelling and degradation to the silicone rubber compound of connector assemblies and its use in cleaning connectors with silicone rubber should be discontinued.

MEK had no serious affect when used in sparing amounts, e. g. , a cloth saturated and used for wiping. Caution should be exercised, however, as excessive use of MEK can damage the adhesives used in connector assembly.

Any of the three alcohols investigated are suitable and recommended for cleaning all the various connector composites itemized above. Of the three, isopropanol is recommended because it has a higher flash point than either ethanol or methanol. In addition, methanol vapors are potentially harmful to personnel.

If Freon TF solvent is used for cleaning electrical connectors, the effect on the sealing materials should be investigated. In addition, consideration should be given to the possible out-gassing of Freon during potting or foaming operations in the vicinity of electrical connectors.

CONNECTOR LOCATION

PROBLEM STATEMENT AND EFFECT

During rework or test cycles, locating a particular connector was a time-consuming situation. The reason was that some wire harnesses consisted of many connectors routed through structure areas, thereby necessitating an extensive search of drawings to determine locations.

SOLUTION/RECOMMENDATION

A system was devised to pictorially define the exact location and routing of each wire harness, including the stringer and station of each connector.

DISCUSSION

The increase in the change activity by engineering orders made locating connectors a very important item. The size of the S-II also contributed to the problem of locating a connector quickly. Some installation drawings consisted of 15 or more sheets. Manufacturing Engineering released final installation documents for each critical area; i.e., aft-skirt, forward skirt, etc. These documents were used very extensively by Manufacturing, Test Operations, and Quality Assurance and during continuity and insulation resistance testing.

ELECTRICAL CONNECTOR, REAR SEAL AND GROMMET DAMAGE

PROBLEM STATEMENT AND EFFECT

The wiring seals of electrical connectors with insertable and removable crimp contacts and resilient rear grommets are susceptible to damage during fabrication of wire harnesses, etc. This damage is cause to suspect the reliability of the connector even though the damage is superficial.

SOLUTION/RECOMMENDATION

On the Saturn S-II Program, this problem was not recognized until the design was fixed and hardware was being produced. Thus, the solution at that time was to continue to use the existing design and hardware. Subsequent study of the problem was limited to investigation of damage and its relationship to the reliability of the connector, the methods employed for installing the contacts into the connector, the tools used in the installation of the contacts into the connector, and the personnel skills training requirements. The solution proved to be a combination of acceptance criteria, methods training, and tool modification.

To preclude this problem from recurring, connectors with resilient rear grommets should be candidates for exclusion from the design. This approach, although desirable, is not always practical. Thus, if a connector of this type is to be used, a selection process with the emphasis on testing should be employed; also, consideration should be given to the lubrication of insertion tooling.

DISCUSSION

The S-II uses approximately 300 electrical connectors. The primary connector selected for the task was of the MS circular type meeting the requirements of specifications MIL-C-5015D and/or MIL-C-26482. Because of the nickel-plated copper wire employed and its resistance to joining by the solder technique and the number of changes anticipated, the connector design also incorporated insertable and removable crimp-type contacts.

At the onset of the program, it was recognized that the connector selected represented a drastic departure from the fixed-contact solder-type connector employed on previous programs. Therefore, extensive training and quality programs were instituted. The training program included indoctrination and certification for each employee assigned connector assembly tasks and required periodic recertification.

The quality program identified damaged rear grommets on connectors as a major contributor to the rejection of wiring assemblies. As a result, the training program was augmented with a section emphasizing procedures for the insertion and removal of connector contacts. Specifically, the employee was shown the proper technique and the consequences of not following the prescribed method: That is, insertion tools shall be in acceptable working condition; they shall be inspected by Quality Control before and after completion of each connector; to avoid internal damage to the connector, do not twist or tilt the insertion tool, etc. Training was not the complete answer for the quality program continued to identify damaged rear grommets as a major problem.

Engineering reviewed and analyzed the type of damage that was occurring. This study included an environmental test of damaged connectors, and the results were compared with supplier-established criteria. As a result of this review, visual standards were recommended and were adopted by Quality Control.

Manufacturing Engineering together with the responsible Design Engineering organization investigated the methods and tooling used to assemble the connector. The study concluded that insertion tool drag was partly responsible for torn grommets. The process specifications were then modified to allow lubrication of the tool with fluorinated grease.

HIGH VELOCITY GASES IN FLEX HOSE

PROBLEM STATEMENT AND EFFECT

During venting of the S-II propellant tanks, high velocity discharge of the gas through a flex hose created high frequency vibrations that could have resulted in a rupture.

SOLUTION/RECOMMENDATION

An additional (redundant) vent valve of a smaller size was installed to vent the tanks at a slower rate to reduce the discharge velocity to acceptable levels. The larger vent valve was opened later when the tank pressures dropped to a point where a high velocity discharge would not result.

DISCUSSION

The discharge of high velocity gas occurred in the pneumostat system. The stage LOX tank was pressurized to 76.7 psia and the LH_2 tank was pressurized to 49.7 psia. Both tanks were vented through 6-inch diameter flex hoses.

Empirical data shows that the maximum vent rate occurred in the LH_2 tank when the pressure dropped from 44.7 psia to 39.7 psia in a period of 1.2 minutes. Neglecting the effects of temperature, the vent rate was computed to be 179 cubic feet per second. This volume exhausted through a 6-inch diameter hose would result in a discharge velocity of 900 fps. This is equivalent to Mach 0.83. The use of the smaller vent valve reduced the velocity to about Mach 0.3.

VACUUM RELIEF VALVE FOR OPERATION UNDER A LIQUID PRESSURE

PROBLEM STATEMENT AND EFFECT

An internal negative pressure greater than -0.1 psig was created during hydrostatic tests resulting in the collapse of a forward LH_2 bulkhead on the S-II (S-II-3).

SOLUTION/RECOMMENDATION

Modifications were implemented to adapt the normal type vacuum relief valve so that it would operate against the water head conditions invoked during the hydrotests.

DISCUSSION

Due to the lack of an opening at the top of the LH_2 bulkhead, a normal vacuum relief valve could not be employed to prevent negative internal pressures. See Figure 21 for hydrostatic test setup.

The bulkheads and other large component parts of the S-II tank structure are of extremely thin-walled construction. The reaction of these assemblies resembles to some extent that of a balloon filled with water, in that they "grow" under pressure.

The bulkheads are hydrotested in an uninsulated or unreinforced condition and are especially vulnerable to collapse due to negative internal pressures. Vacuum relief valve leakage occurs during filling operations due to bulkhead deflection, created by the increasing water level head exerted against the sides of the bulkhead. The preset vacuum relief valves, because of the extremely low allowable negative pressure settings, are necessarily quite sensitive and will leak due to the above-mentioned downward deflection of the bulkhead. As a result of this leakage condition, and since the vent valve is open during the filling operation, the vacuum relief valves are not placed in service until after closure of the vent valve and the application of a positive internal pressure on the assembly. A standard vacuum relief valve is shown in Figure 22; a typical installation of such a valve is shown in Figure 23.

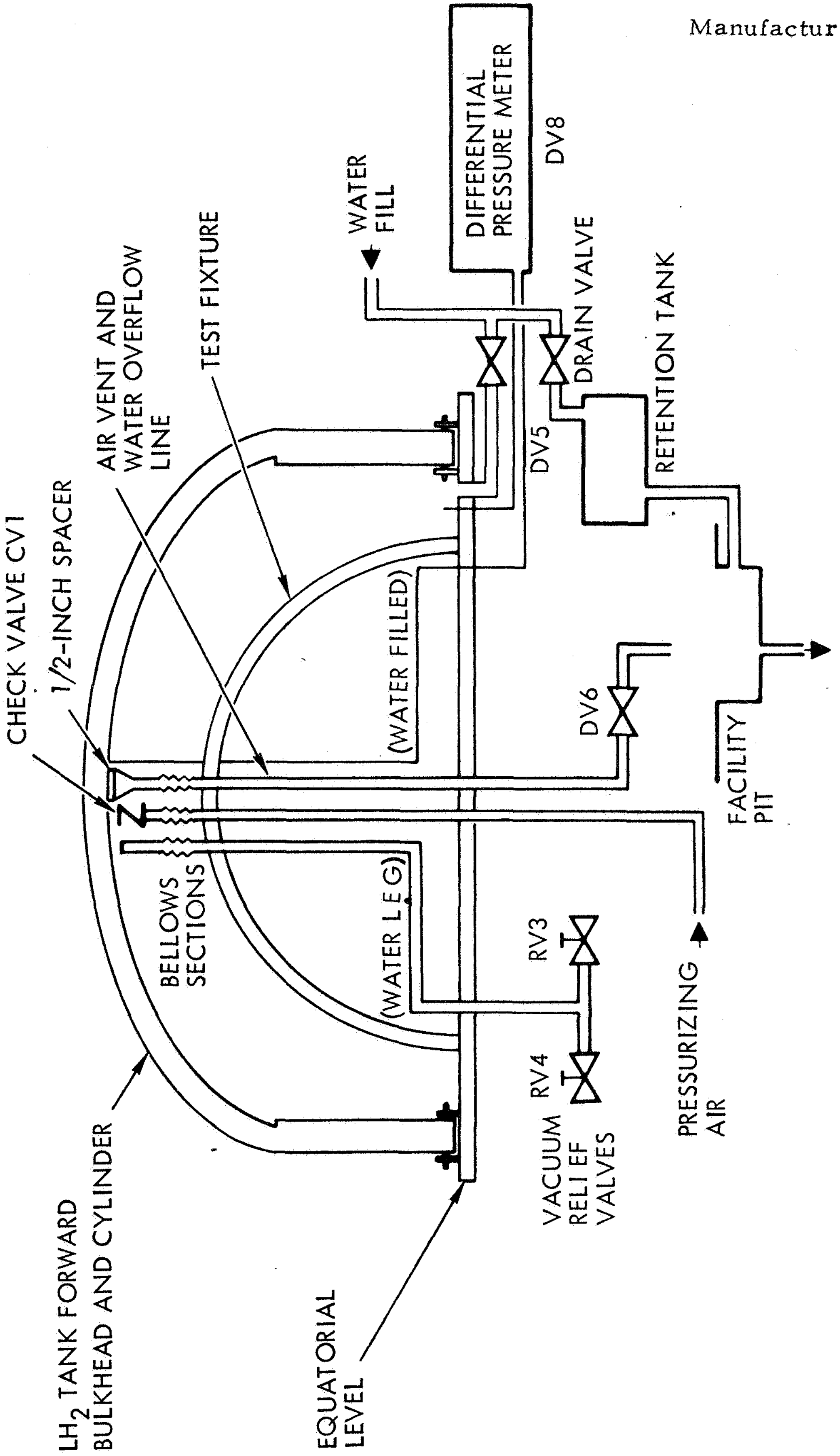


Figure 21. Hydrostatic Test of Tank's Forward Bulkhead Assembly

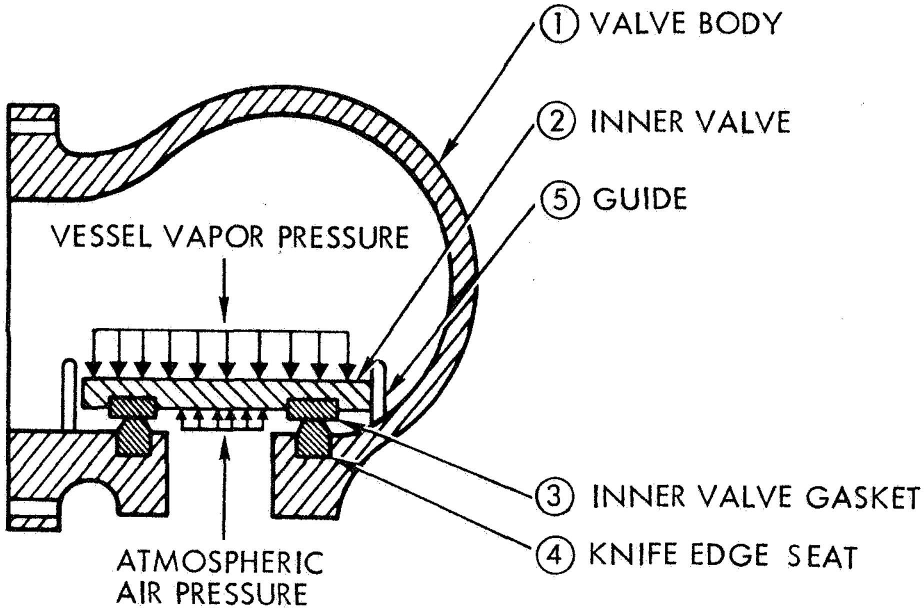


Figure 22. Standard Vacuum Relief Valve

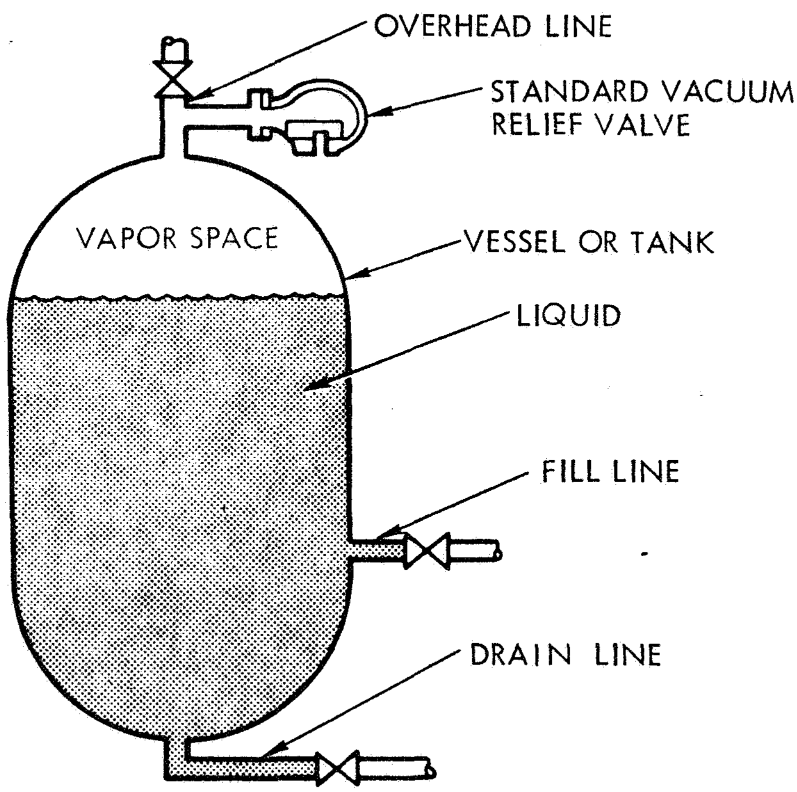


Figure 23. Typical Installation of Standard Vacuum Relief Valve

A greater margin between valve setting and bulkhead failure pressure (if accurately known) has not been found to be practical. The combination of requirements to withstand the hydrostatic pressures involved and to sense the minute values of allowable negative pressures has reached the state of the art in the existing vacuum relief valve: it therefore became necessary to develop a modified vacuum relief valve.

This modified vacuum relief valve (Figure 24) installed in a typical application (Figure 25) is described as follows:

> Lever 7 is raised to allow inner valve 2 to rest on knife edge seat 4. The vacuum relief line is filled with liquid, lever 7 is lowered to contact rod 8, and weights 10 and 11 are added to compensate for the liquid head.
>
> Vacuum valve is calibrated to the proper opening pressure by the adjustment of weights 10 and 11. With the vessel full of liquid and all valves in the closed position, the vacuum relief valves will operate in the following manner.
>
> In the event of liquid leakage from the vessel or vessel rupture, the liquid surface at the top of the vacuum relief line is exposed to a reduction in pressure created by the lessening in vessel liquid level. Weights 10 and 11, previously balanced by the liquid head in the vacuum relief line, exert a greater downward force on lever 7, causing upward movement of rod 8 and unseating inner valve 2. This results in concurrent drainage of liquid from the vacuum relief line and the entrance of atmospheric air pressure into the vessel with resultant breaking of the vacuum and prevention of the collapse of the vessel's upper bulkhead.

The following brief test description shows Saturn S-II use of the modified vacuum relief valve. The bulkhead assembly is securely installed in the test fixture and a small quantity of water admitted in order to detect any leaks in the seal. Air is bled from instrument lines and all instruments calibrated.

Water is then admitted to the space between the test specimen and the test fixture in accordance with the following schedule:

100 gallons per minute to 10% full level
1000 gallons per minute to 90% full level
300 gallons per minute to 95% full level
25 to 50 gallons per minute from 95% full level

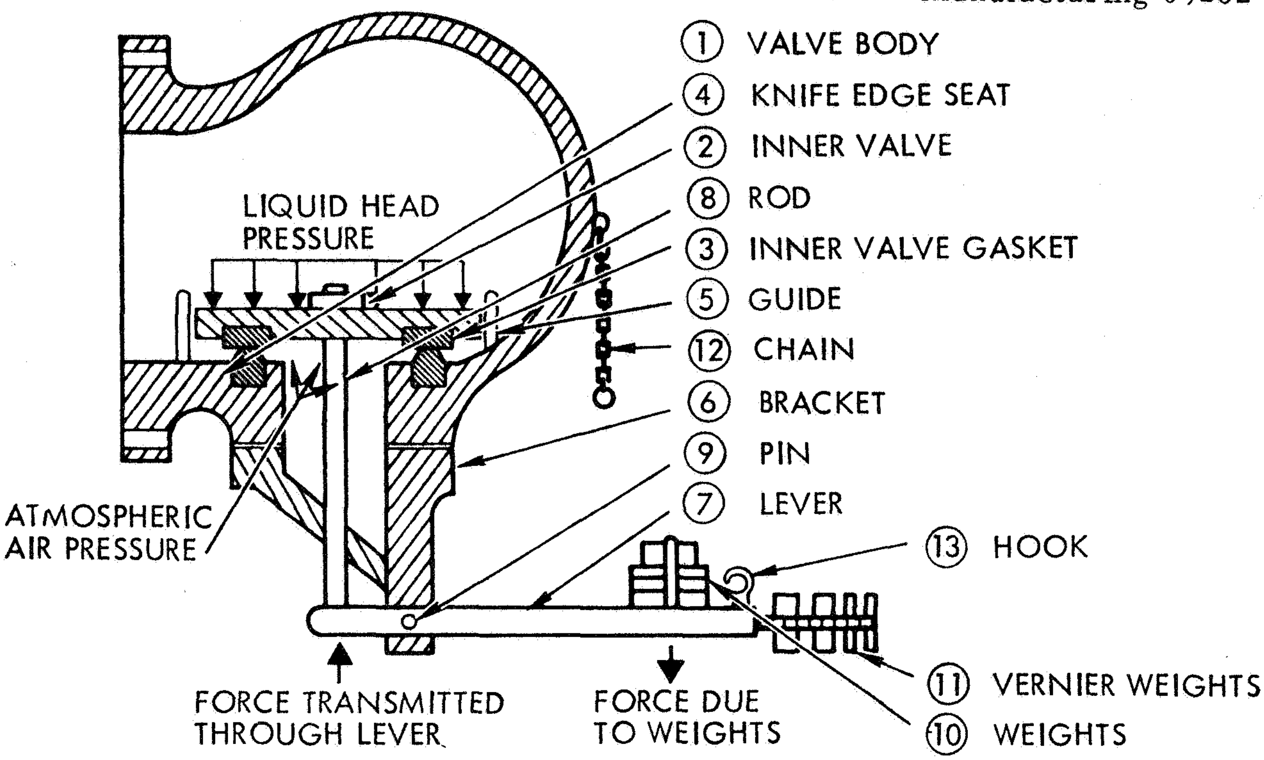


Figure 24. Modified Vacuum Relief Valve

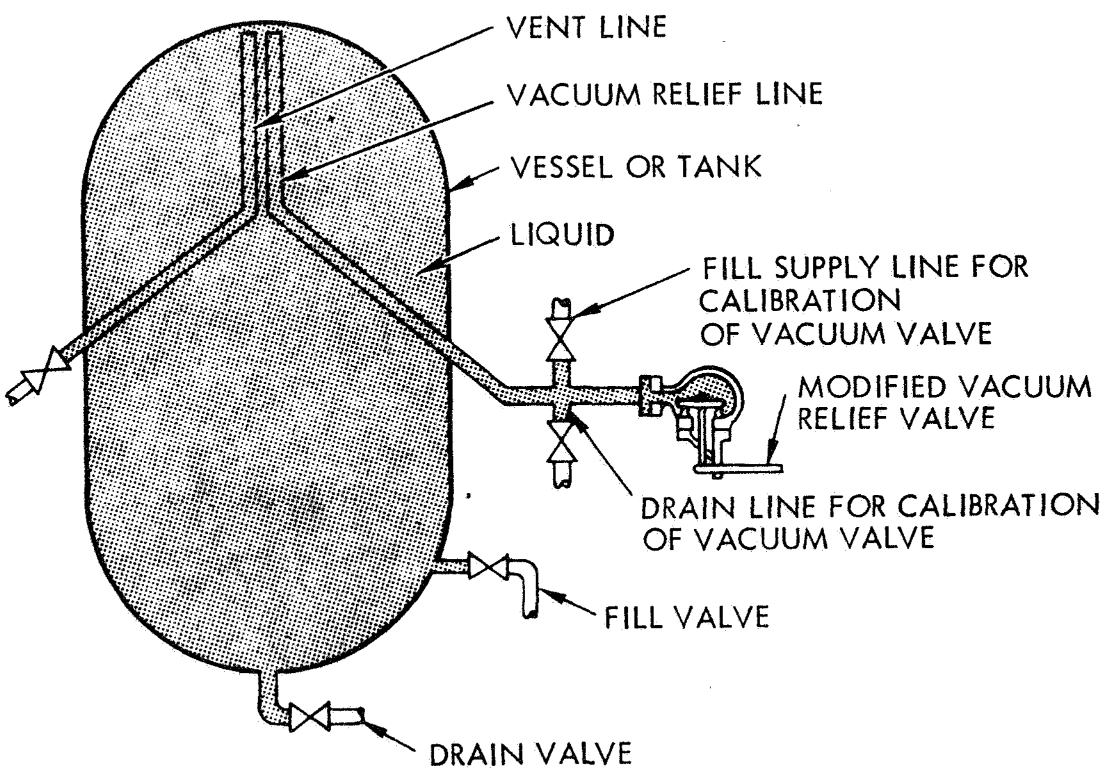


Figure 25. Typical Installation of Modified Vacuum Valve

The last, or "topping," rate requires 20 to 30 minutes to reach the shut-off stage. At 99.5 to 100% of the filling level, the vent valve is closed manually.

At this point, air is admitted through valve CV1 under manual control, until the pressure reaches 3 psig. The locking levers of the vacuum relief valves are removed, if still in place. The pressure is increased at a rate of 0.5 to 1.0 psi/minute by adding water with stops for checking at 5 psi intervals. This is continued until a pressure of 28 psig is reached at the equatorial level. The indicated pressure includes a head of 19.7 feet of water, which means that the pressure at the apex at this time is 19.5 psig.

After reaching 28 psig at the bulkhead assembly equator, pressurization is continued in steps of 2 psi to 33 psig. A pause is made after each increment of 2 psi to permit visual inspection of the assembly for leakage. Pressure is then increased slowly to 35.5 psig at the equator reference point, or 27.0 psig at the bulkhead apex. This pressure is maintained for a period of 10 minutes. Pressure control is maintained by remote operation from the fifth floor control room throughout the entire filling and draining procedure.

The water is drained from between the bulkhead assembly and the test fixture while the pressure inside the bulkhead assembly is controlled by the manual manipulation of the drain valve and the air admittance valve. The pressure is not permitted to go below 5 psig at any time. The vacuum relief valves are operative during this period as well as the pressurizing period, and will open automatically to admit atmospheric pressure should the bulkhead pressure decrease to 1.5 oz/sq in (0.094 psi) of negative pressure. The draining process requires about 1-1/2 hours and is followed by a half-hour drying period in which heated air is blown into the space between test fixture and bulkhead.

DAMAGE TO IN-FOAM WIRE HARNESSES

PROBLEM STATEMENT AND EFFECT

During removal of foam insulation to rework wire harnesses, the harnesses were damaged by cutting tools. The effect was additional rework and degradation of the product.

SOLUTION/RECOMMENDATION

The final solution to this problem was to wrap teflon tape around the harness and connectors prior to spray foaming.

DISCUSSION

Several methods were tried to solve the problem of damage to wire harnesses embedded in foam when removal of foam was necessary to perform rework. The teflon wrap was approved because it is easier to handle than sleeving. In addition to the protection of wire harnesses, another problem was resolved with the teflon tape wrap; it eliminated the foam "creep" into the connectors.

WIRE IDENTIFICATION

PROBLEM AND EFFECT

In regard to wire identification, drawing requirements manuals specify that wire segment letters be used to differentiate between wire segments in a common circuit. Due to this requirement, if engineering makes a circuit path design change, manufacturing is obliged to change more than one wire or group of wires which otherwise need not be changed. Rework of wiring becomes very costly, particularly in the case of special test equipment which is functionally compatible with variable circuit configurations.

SOLUTION/RECOMMENDATION

Wire identification requirements for special test equipment (STE) were modified by having every wire identified in a numerical sequence and utilizing the letter "A" to separate the wire sequence number from the wire size number. Example: 1A20, 2A20, 3A16

DISCUSSION

According to drawing requirements manuals, wire identification requirements for the preparation of a wiring diagram and wire lists specify that the wire segment letter shall be used to differentiate between wire segments in a common terminal or connection.

Due to the nature of in-process test equipment, any stage changes by S-II Engineering, caused circuit path interface changes in STE. Thus, instead of having to change one wire in the stage due to this Engineering change, all wires in the test equipment had to be changed only because they no longer were identified correctly for that particular flow in the circuit. STE Engineering established the method of identifying wires in a numerical sequence and utilized the letter "A" for all wires in place of segment letters as shown in the following excerpt from the SMD wire list:

2.5 Wire Segment Letter - The wire segment letter shall be used to differentiate between wire segments in a common circuits. Wherever practicable, wire segments shall be lettered in alphabetical sequence, and the letter "A" shall identify the first segment of each circuit starting at the power source. A different letter shall be used for wire segments having a common terminal or connection. Double letters AA, AB, etc., shall be used when more than twenty-four segments are required. The letters "I" and "O" shall not be used as segment letters. See Figure 26 Wire segment letters have been underlined for illustration purposes.

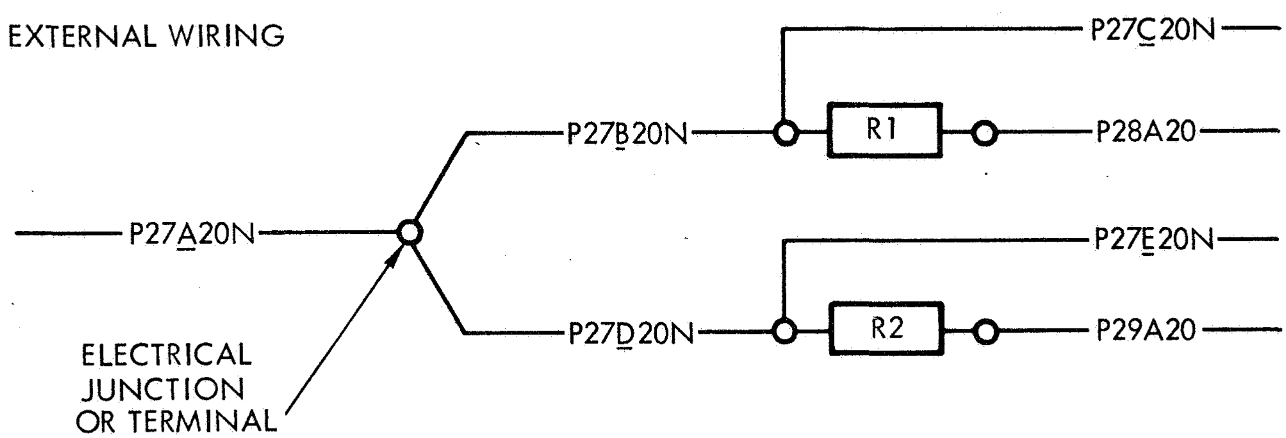


Figure 26. Use of Wire Segment Letter

LOCATION OF WIRE HARNESS IDENTIFICATION PLATES

PROBLEM STATEMENT AND EFFECT

Wire harness identification plates were installed at the center of the wire harness, thereby creating a problem in trying to locate the ID plate to verify a wire harness part number after the harness was installed in the stage.

SOLUTION/RECOMMENDATION

Standard procedures were revised to designate location of harness identification plates within 12 inches of the lowest alphanumeric numbered connector in the harness. To assist in locating the identification plate after a harness was installed, additional procedure is provided that locates each connector within a harness by stringer and station number.

DISCUSSION

The problem of wire harness identification became critical with the increase of change engineering orders. The congested condition of wiring in the aft-skirt, forward skirt, and Station 196 areas also contributed to the problem. The location of the ID plate 12 inches from the lowest alphanumeric connector worked fine for the smaller harnesses. The larger harnesses, those with 15 or more connectors, required more precise definition. This was taken care of by the final installation document that locates each connector by stringer and station.

CRITICAL HANDLING EQUIPMENT FOR INSPECTION AND CERTIFICATION

PROBLEM STATEMENT AND EFFECT

A Material/Personnel Handling Equipment (MPHE) ladder broke during retraction from the S-II. The resulting damage caused the removal and replacement of the forward LH_2 bulkhead.

SOLUTION/RECOMMENDATION

Breakage and similar problems associated with MPHE were solved at Seal Beach by stricter adherence to specifications, design, fabrication, and inspection pertaining to safety-critical MPHE equipment.

It is recommended that initial program planning identify critical MPHE and insure the adequacy of inspection and proof-loading requirements.

DISCUSSION

The welds on a retractable aluminum ladder used in Station VII, Seal Beach, for access to the LH_2 tank of S-II-3 failed. This failure permitted a section of the ladder to drop and strike the forward LH_2 bulkhead. Damage consisted of two cracks which destroyed the structural integrity of a gore section.

Personnel had completed their work in the tank. All personnel had climbed the ladder and exited through the tunnel. Removal of the retractable aluminum ladder was begun by use of the hand operated winch. When the ladder reached a position approximately 90% raised, welds at the flanges used to bolt the two sections of the ladder together gave way, permitting the lower 12 foot section of the ladder to drop away and strike the bulkhead.

PATCHBOARD CONSOLE

PROBLEM STATEMENT AND EFFECT

Ground support equipment changes and vehicle engineering changes were so numerous on the S-II that rework time on special test equipment interphasing adapter cables was a continuous project.

SOLUTION/RECOMMENDATION

A console with patchboard capabilities and fully wired test harnesses was devised to provide the capability of making wire changes within seconds. It is recommended that special test equipment be initially designed with patchboard capabilities.

DISCUSSION

One of the phases in which manufacturing costs increase substantially is in the design time and quantity of interconnecting test cables fabricated and reworked by the contractor for checkout and servicing of the product during the manufacturing process. On the S-II program, engineering electrical design wiring changes were numerous, causing much rework to deliverable equipment and to special test equipment used for checkout and servicing of these deliverable items. This rework was chiefly performed on the unit under test and the adapter cables interconnecting the unit under test with the special test equipment. In order to reduce rework time on these adapter cables, a patchboard console was devised to serve as a junction point in which re-connections would be performed on patchboards, thus allowing the use of the fully wired adapter cables without having to rework them. Any rewiring to the patchboards was made as part of the operating manual procedure for the test equipment model in question. This procedure outlines the requirements to be followed in accordance with the applicable process specification.

DISPOSAL OF TOXIC POLYURETHANE SPRAY FOAM FUMES DURING APPLICATION

PROBLEM STATEMENT AND EFFECT

During spraying of polyurethane foam insulation, a toxic gas is generated which is harmful to the respiratory system of man.

SOLUTION/RECOMMENDATION

The problem of spray foam fume disposal during S-II manufacturing was resolved by purchase and installation of exhaust fan units capable of removing the fumes at the source and exhausting them to the atmosphere outside the area. Neoprene flex ducting was used between blower and spray area for flexibility and mobility.

It is recommended that the fume disposal system be installed at the time of facility construction.

DISCUSSION

Exhaust of toxic or corrosive fumes is always a problem, often endangering both personnel and equipment. Positive removal of such fumes to atmosphere is permissible at certain levels of contamination (Air Pollution Control District). Excessive levels can be decreased through filter systems, water wash, or afterburner units.

The SD requires personnel present during spraying of polyurethane foam to wear airtight breathing masks connected with a filtered air supply.

REFERENCES

1. Process Specification for Polyurethane Foam Application and Materials, MA0606-050.

2. General Industrial Safety Orders, Article 81, Group 9.

PARTS PROTECTION

PROBLEM STATEMENT AND EFFECT

Repeated instances on the S-II program of improperly packaged and protected component parts resulted in excessive disassembly and recleaning due to contamination. In addition, critical sealing surfaces on detail parts were being damaged during subsequent stages of assembly or installation due to lack of protection. The effect of this problem was to create schedule delays and excessive costs.

SOLUTION/RECOMMENDATION

Entries were included in all manufacturing planning documentation (manufacturing orders, parts replacement requests, etc.) for packaging and protection requirements. Implementation of this method required that adequate protective measures be verified and established prior to operations.

DISCUSSION

Investigation of the contamination problem revealed that the protection applied at the detail level was removed and not re-applied during assembly operations. It was imperative that procedures be implemented to ensure contamination-free components and damage-free detail parts in order to preclude systems contamination and costly schedule delays.

CENTRAL FACILITY FOR THE HELIUM SUPPLY SYSTEM

PROBLEM STATEMENT AND EFFECT

Helium required for proof and leak testing of the S-II systems was supplied by portable "K" bottles. The use of K bottles required time for handling, sampling, and analysis in addition to the considerable floor space required for the bottles in the testing area and for the hoses and equipment used for the test setup, which resulted in a generally untidy appearance.

SOLUTION/RECOMMENDATION

A central helium supply system was implemented in the Vertical Assembly Building (VAB) which eliminated the use of K bottles in 80 percent of tests. It is recommended that the helium supply problem be evaluated early so that when the use of K bottles arrives at a point where if is no longer cost effective, a central supply system can be instituted.

DISCUSSION

Special Test Equipment Engineering designed a central helium supply system for installation in the VAB. The system included the reactivation and modification of an existing helium distribution system, the use of an existing helium tube trailer, and a high pressure gas booster for high pressure tests. One tube trailer contains a volume of helium equivalent to approximately two hundred 2000-psi K bottles.

The central system resulted in a significant reduction in the cost of proof and leak testing.

LH_2 TANK SPECIAL INGRESS LADDERS

PROBLEM STATEMENT AND EFFECT

Repairs and inspection had to be performed inside the LH_2 tank while the vehicle was in the stacked configuration. This condition provided minimal access clearance and imposed certain hazards to the LH_2 tank bulkhead insulation and S-IVB engine.

SOLUTION/RECOMMENDATION

The solution was to design and fabricate ladders utilizing a vacuum system for attachment.

This system could be utilized for any area where a vacuum could be maintained (within large tanks, silos, etc.) in order to gain access to an otherwise inaccessible area.

DISCUSSION

A study was conducted to determine the need and feasibility of entering the S-II LH_2 tank when the stage was in the stacked configuration. The study revealed that entry was feasible and that there was a need. The type of effort requiring entry in the LH_2 tank included:

1. Inspection of LH_2 tank secondary structural elements for cracks and other suspected potential secondary failures.

2. Repair or replacement of malfunctioning hardware items.

3. Configuration updating or modification to eliminate potential problem areas.

Due to the minimal access clearance between the S-IVB engine and the S-II forward bulkhead while the Saturn stages are in the stacked configuration, the S-II forward bulkhead insulation and the S-IVB engine were subject to damage. This small clearance also prevents the use of an umbrella type platform which could have been lowered into the LH_2 tank in the closed position and then opened inside. It was therefore necessary to design a relatively simple supporting structure which minimized the hazard of damage to the LH_2 forward bulkhead insulation and S-IVB engine and allowed the lowering of men inside the LH_2 tank in a basket together with a set of "bat" ladders. These bat ladders were designed with a vacuum system which utilized suction cups as a means of attachment to the inside wall of the tank. These ladders were designed with controls to allow workman inside the tank to detach and relocate the ladder while standing on another ladder; thus enabling him to move around without having to step on the LH_2 common bulkhead.

IMPROVED LOAD-LIFTING HARDWARE

PROBLEM STATEMENT AND EFFECT

A four point lifting bar used on the S-II program appeared to cause strain on cylinder, thrust, and skirt structures during mating, lifting, and moving operations. Excessive manhours were used in rigging a hoisting bar with sand bags to equalize loads.

SOLUTION/RECOMMENDATION

A six-way spreader bar provided a better distribution of load and reduced the strain on hardware structures. Two spreader bars were designed with six points and three equalizing arms in pairs to do the lifting. The 8EH-0811 model can lift a maximum of 4200 pounds. The 8EH-5016 model has the capacity of a 10-ton lift. Both units were built with 33-foot arms to facilitate lifting, moving and mating of cylinders, thrust structure assembly, firing skirts and interstages where leveling of loads is required.

DISCUSSION

Maneuvers requiring that assemblies or hardware remain level were performed by utilizing sand bags to balance the unit while it was being moved with the four-way spreader bar. To mate an item such as a thrust structure assembly to the firing skirts, personnel were stationed around the skirt to facilitate alignment. However, some damage resulted to rivets and after a review of the method a special equalizing spreader bar was designed to perform the moving function.

REFERENCES

NASA Tech Brief 69-10514.

LH_2 TANK ENTRY EQUIPMENT

PROBLEM STATEMENT AND EFFECT

Personnel, tools, and equipment were required inside the LH_2 tank to perform the final closeout weld. Personnel were lowered and removed on a boatswain's chair. Tools and equipment were lowered and removed by rope slings, make-shift wire baskets, etc. These means of transporting personnel in and out of the LH_2 tank created a high potential of tank damage and was unsafe for personnel.

SOLUTION/RECOMMENDATION

A steel framed, wire mesh enclosed, cylindricaly shaped device (8EH-0760) was provided. The cylinder is 3 feet in diameter and 14 feet long. This device is strong enough to accommodate personnel safely. It also accommodates tools and equipment to 12 feet in length. The door in the side of the cylinder has a positive lock to prevent accidental opening during ingress and egress.

DISCUSSION

In order to perform the closeout weld on the LH_2 tank, personnel, tools, and equipment had to be lowered into and removed from the tank. This operation was accomplished through the use of a boatswain's chair for personnel and slings for tools and equipment. It became evident to personnel working on the S-II-3 during this in-tank operation that a high potential for stage damage and personnel injury was present. A design and specification were prepared to provide a safe means by which to perform this operation. The cylindrical device was fabricated by Tooling, and put into operation in September 1967.

INSTALLATION AND REMOVAL OF PINS SECURING LARGE STRUCTURAL HANDLING FIXTURES

PROBLEM STATEMENT AND EFFECT

Saturn S-II required numerous large handling fixtures for fabrication and transportation. A particularly hazardous condition arose from the flexibility of the stage forward hoisting cone which allowed for mismatch in mating to the stage forward hoisting spider. A lead mallet was used to drive the connecting pins through the spider and cone assemblies.

SOLUTION/RECOMMENDATION

This problem was solved at Seal Beach by the design and fabrication of hydraulic pin positioners that allowed the installation of pins without manual hammering. This eliminates the possibility of damage to the hardware.

It is recommended that this hydraulic unit be used on large handling fixtures where it is necessary to force mating alignment.

DISCUSSION

The matching holes for mating the spider to the clevises of the forward hoisting cone are not in alignment. The connecting pins are driven in by force with a lead hammer.

This operation is not only time consuming and damaging to hardware, but also is a safety hazard for the riggers, who work off a 20-foot Tel-Hi-Scoper when the stage is in the horizontal position. Damage to the stage could also result if the hammer or pins were dropped during installation.

MANUFACTURING INFORMATION CENTERS

PROBLEM STATEMENT AND EFFECT

Program Management was not provided sufficient visibility on Manufacturing Operations to surface problems in a timely manner so as to reduce or minimize impact to production schedules.

SOLUTION/RECOMMENDATION

In August, 1967, manufacturing information centers were established to provide manufacturing management with the necessary tools to visualize the total production task, and thus free them to concentrate upon their area of responsibility.

This program gives direct support to the Director of Manufacturing, project administrators, managers, supervisors, and leadmen.

DISCUSSION

A control room in each of the three manufacturing areas has provided for display and visual surveillance of the facilities, schedules, work plans, and history of each manager's total task.

The Director of Manufacturing is provided with daily status reports (both visual and oral) and special exercises as required to weigh alternate plans or methods in problem areas.

Support is provided for the manager's task through charts, graphs, and a breakdown of the master schedule on a departmental and task basis through the use of a master plan which complements the master program schedule. The plan will provide visibility of stationization, tooling, and overtime requirements on a departmental basis.

The supervisor is supported by providing coordinated standards and operational sequences for each tool or station in the form of an hourly work plan which will complement the manager's work plan. Constraints and additional functions such as Engineering Changes, Hardware Repair, and shortages will be incorporated through "work arounds" into the plan.

Support at the leadman level will be provided by visual aids for the leadman's visibility and to aid him in providing interdepartmental coordination as required.

Support of the program in general is provided through issuing a daily manufacturing status report and history file on each assembly or task.

WIRE HARNESS MODIFICATION STATUSING

PROBLEM STATEMENT AND EFFECT

A method was lacking to systematically fabricate and accumulate components for wire-harnesses to support modifications.

SOLUTION/RECOMMENDATIONS

The problem was resolved by assigning an MK-1 suffix to the new harness part number and by utilizing the Manufacturing wire harness survey and planning tickets. Parts accumulation and harness pre-processing was accomplished under this one part number.

It is difficult to track wire harness modifications and to maintain an accurate status account of configurations. This problem becomes more apparent where a multiple release drawing system is used and more difficult where changes with contingency aspects are processed.

A producibility analysis should be performed early in the program to preclude this type of problem. A procedure for handling this problem should be developed prior to the first modification requirement.

DISCUSSION

Early in the definition of the Saturn S-II Program modification requirements, both hardware and software were identified, accumulated, shipped, and installed utilizing a logistics form called a kit accumulation list (KAL). All requirements, i.e., purchased parts manufactured parts, and documentation were listed on this KAL. In the area of wire harnesses, since there was a manufactured part number affected, each wire termination and end fitting was listed separately. This procedure was costly and time consuming. In addition, under this method, minor preassembly, i.e., wire end finish or connector wiring could not be done thus creating unnecessary work for the test sites.

By utilizing the wire survey and planning tickets, all wire harness details, i.e., wire, terminals, I.D. bands, connectors, etc., were preassembled to a point, accumulated, and shipped under one part number (new harness part number with the MK-1 suffix).

If subsequent design changes affect the same harness, an MK-2, MK-3, etc. is established satisfying these requirements.

CONTROL OF REQUEST FOR DRAWING CHANGES

PROBLEM STATEMENT AND EFFECT

Early in the S-II program, problems consisting of incorrect Request for Drawing Change (RDC) formats, RDC's written without resolutions, duplicate RDC's (more than one group making parallel requests or investigations), and requests for expensive design changes to save nominal manufacturing hours were prevalent.

The effect of this condition was costly for various reasons: Engineering, for instance, had to answer more than one RDC for a particular problem, and manufacturing costs were increased due to dual investigations.

SOLUTION/RECOMMENDATION

A centralized manufacturing control group was established to eliminate incorrect overlapping or conflicting requests from reaching Design Engineering and to provide a focal point for changes requested by Manufacturing.

RED ANODIZING OF BLANKING PLATES USED FOR IN-PROCESS TESTS

PROBLEM STATEMENT AND EFFECT

During the proof and leak test of an early S-II, a bellows was deformed when the system was overpressurized. The reason for the overpressurization was traced to a blanking plate remaining in the system after completion of a previous test.

SOLUTION/RECOMMENDATION

Blanking plates were anodized (red) to facilitate identification when installed in a stage system. In addition, inspection points were included in proof- and leak-test operating manuals to verify removal, as well as installation, of test blanking plates.

DISCUSSION

During the final systems installation operations on early S-II's, a multitude of concurrent activities were normally in progress. System proof and leak in-process tests were also being accomplished, and were performed in a piecemeal manner to enable inspection buy-off of partial systems. As a result, blanking plates were required to isolate these partial systems for testing purposes. The use of red anodized blanking plates, and inspection points for installation and removal in the operating manuals resolved the problem.

LABELING OF CONSOLE CONTROLS

PROBLEM STATEMENT AND EFFECT

Console controls and instrumentation were identified with functional descriptions, per established procedure but difficulty was experienced in training console operators and test personnel in relating console controls to components actuated.

SOLUTION/RECOMMENDATION

Consoles of recent include silk-screened schematic reference designations in addition to the functional descriptions (e. g., "Chart DRIVE (SW8)") to identify console controls. Reference designations of components actuated by each console control were also silk-screened on the console (i. e., Function - UF Com BHD, SCH Designation (SW1) Actual Function - (Actuates - D11)).

DISCUSSION

During the preparation of acceptance checkout and operating procedures, and during subsequent training of operating personnel, it was found that functional descriptions of console controls were difficult to use. The wordiness of these descriptions hampered training of operators and, in addition, made operating procedures voluminous, as well as difficult to use.

The identification of console controls with schematic reference designations of both the control and component actuated, simplified training of personnel and console operation. Each control was therefore more easily recognized and its function better understood (Figure 27). This labeling also allows operating procedures to be abbreviated.

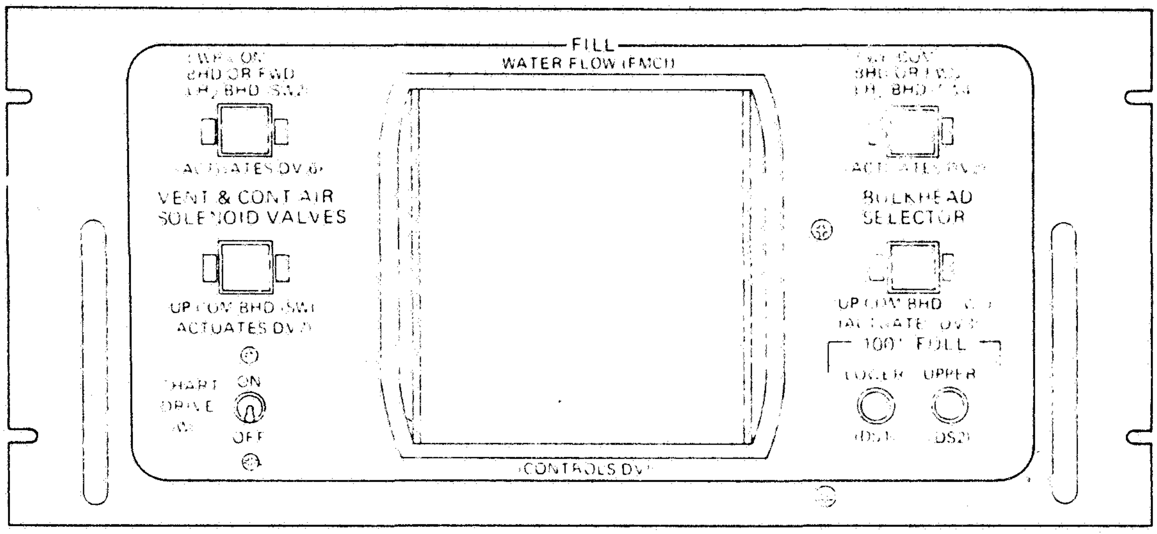


Figure 27. Identification of Console Controls

LEAKAGE THROUGH PIPE THREAD FITTINGS

PROBLEM STATEMENT AND EFFECT

Teflon tape was used to seal pipe thread fittings in facility LOX clean systems. The tape would shred when the connection was tightened. Particles of teflon tape would then contaminate the system.

SOLUTION/RECOMMENDATION

The fittings were changed to AN type connections and the use of teflon tape discontinued. Implementation of this solution should be considered during the initial design phase of LOX clean systems.

DISCUSSION

A large number of mechanical components are available off the shelf with pipe thread fittings. Many of these components were ordered for installation in LOX clean systems.

Teflon tape was used to prevent leaks through the pipe thread. However, in the process of tightening the connection, the teflon tape would shred and enter the system. Pieces of teflon tape were subsequently detected during a particle count and caused the system to fail to meet LOX clean requirements.

The fittings were changed to AN type connections. The AN fittings are machined to a closer tolerance and made of a harder material than regular pipe thread fittings. The use of the AN fittings resulted in a better fit, eliminated the problem of galling, and made possible leak-free connections without the use of teflon tape.

ACLAR FILM CONTAMINATION

PROBLEM STATEMENT AND EFFECT

ACLAR film used to protect open flanges from contamination was left on the flange when the part was incorporated into the stage system. During stage tests, several pieces of 2 mil film were found in the engine systems.

SOLUTION/RECOMMENDATION

Manufacturing procedures were implemented to check for ACLAR film on flanges prior to hookup into stage systems.

In addition, the ACLAR film was cut into square pieces to facilitate its detection. Prior to that the ACLAR was cut to the same outline as the flange. The film, being transparent, is very difficult to detect when it adheres to a highly polished surface.

DISCUSSION

ACLAR is a flexible thermoplastic film made from fluorinated-chlorinated resins. It is highly transparent in the visible region of the spectrum; it transmits over 95 percent of the incident light. This optical property, together with the fact that the film was cut to the shape of the flange, made it very difficult to detect if one were not looking for it.

During pressurization of the stage systems, the ACLAR film ruptured and was distributed throughout the system.

The corrective procedures implemented by manufacturing solved the problem.

FAILURE OF NATORQ SEALS

PROBLEM STATEMENT AND EFFECT

NATORQ stainless steel bulkhead seals failed to prevent helium gas leaks.

SOLUTION/RECOMMENDATION

Silver-plated NATORQ seals were substituted for the stainless steel seals. In addition, manufacturing procedures were changed to require retorquing the fitting twice after installation. Implementation of this solution should be considered the initial design of hydrogen helium systems.

DISCUSSION

The relative softness of the silver plating, together with the retorquing procedures, resulted in leak-free connections.

ADDITION OF CRUSH WASHER REQUIREMENTS TO TUBE ASSEMBLY DRAWINGS

PROBLEM STATEMENT AND EFFECT

Many leaks were found in tube assembly fittings during manufacturing leak tests of S-II systems. This required that the tube assemblies be disconnected to permit installation of crush washers.

SOLUTION/RECOMMENDATION

The requirement for installation of crush washers was added to assembly drawings. Addition of the crush washers reduced the leak problem significantly. It is recommended that consideration be given to crush washer requirements during initial design when engineering drawings are being prepared.

DISCUSSION

Vehicle assembly drawings did not call out the installation of crush washers on tube assembly fittings. The tube connections were secured by torquing the fittings to a value specified on the assembly drawing.

This method of making tube connections resulted in many leaks, which were discovered during manufacturing leak tests. The drawings allowed the use of crush washers where leaks were found; however, this required that the tubes be disconnected to permit installation. The leak tests then had to be repeated.

On the earlier stages, most of the tube assemblies did not pass the leak test and crush washers had to be installed eventually at a much higher cost. One helium actuation system had over 150 recorded leaks. To resolve this problem, the requirement for installation of crush washers was added to the assembly drawings and the leak problem was reduced significantly on subsequent stages.

FUNCTIONAL DRAWING OF NAFLEX SEAL LOCATIONS

PROBLEM STATEMENT AND EFFECT

The determination of the location, size, and test parameters for Naflex seals used throughout the S-II was difficult and time consuming since the information was spread over a number of drawings and specifications.

SOLUTION/RECOMMENDATION

Engineering documents were evaluated and a single reference drawing was prepared showing all seal locations, sizes, applicable installation drawing, and operating manual to be used. This solution is also recommended for AN/multiple use hardware requiring special functional testing.

DISCUSSION

Manufacturing was required to perform leak tests of Naflex seals installed throughout the S-II systems and tank attach points. The information required to determine the locations, sizes, and test parameters appeared on 17 separate installation drawings.

It was difficult and time consuming to read all the drawings to obtain the necessary information for each leak test. Special test equipment Engineering evaluated the applicable engineering documents and prepared a single reference functional drawing summarizing all necessary information.

The locations of the seals are shown on isometric views of the stage. Reference is made to station numbers, stringer numbers, position numbers, engine numbers, fin numbers, and hardware to clarify the location of each seal.

Each seal location is coded to a table specifying seal part numbers, quantities, and installation drawing numbers. In addition, the seal locations are coded to test numbers in the leak-test operating manual.

FLOWMETER CALIBRATION

PROBLEM STATEMENT AND EFFECT

Flowmeters for the S-II manufacturing operation were calibrated in the laboratory using pressure readings which did not duplicate the working conditions in the consoles in which they were to be installed. These pressure differences resulted in inaccurate calibration flow curves.

SOLUTION/RECOMMENDATION

The solution to this problem is to calibrate the flowmeters while they are installed in the using console.

DISCUSSION

The method used to calibrate flowmeters in the laboratory is shown in Figure 28.

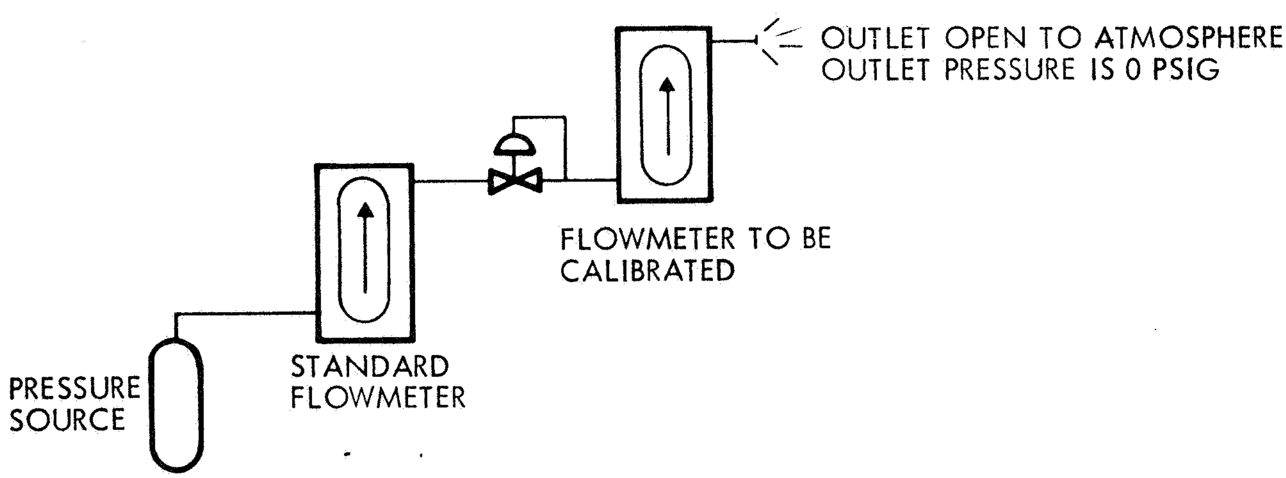


Figure 28. Calibration Setup

The data taken was used to make a calibration chart (Figure 29). Under actual working conditions, the flowmeter was used in the console as shown in Figure 30.

The problem is evident when the laboratory calibration setup is compared to the console setup. In the laboratory calibration setup, the outlet pressure is measured directly at the outlet of the flowmeter while in the console setup, the outlet pressure is measured after the gas has flowed through the console tubing. The calibration setup does not take into account the pressure drop in the console tubing, thus making the calibration chart inaccurate.

This problem is overcome by calibrating the flowmeter while it is installed in the console. In this way, the pressure drop in the console tubing is taken into account and maximum accuracy of calibration is obtained.

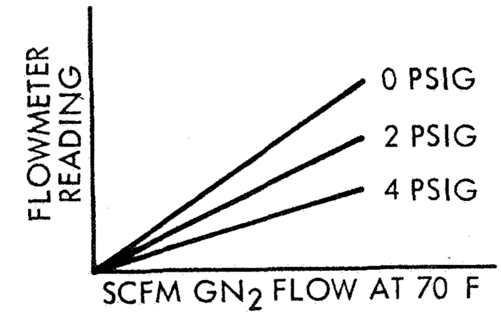


Figure 29. Typical Calibration Flow Chart

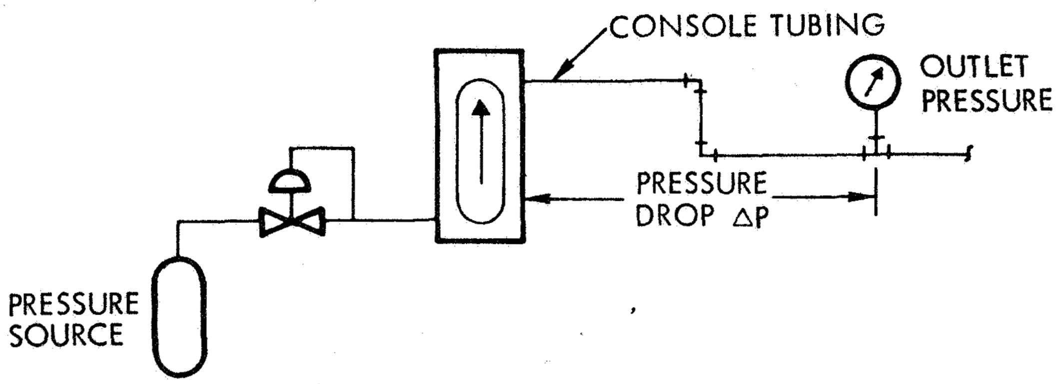


Figure 30. Console Setup

EMERGENCY ELECTRICAL POWER SYSTEM

PROBLEM STATEMENT AND EFFECT

Failure of facility electrical power during critical S-II hydrostatic proof tests could result in damage to stage components and injury to personnel.

SOLUTION/RECOMMENDATION

An emergency electrical power system was installed at each S-II hydrostatic proof test facility. This system was designed to "cut in" automatically on failure of primary power (Figure 31). The system operates as follows: facility power energizes the relay coil, which actuates relay contacts on and emergency power off. On failure of primary power, relay coil is de-energized, contacts close, and emergency power is routed to system electrical components. The emergency 12 volt dc battery power is changed to 115 volt ac by means of an inverter.

DISCUSSION

For critical operations, such as the S-II hydrostatic proof tests, it was impractical to depend solely on fail-safe modes of system components. In the event of primary electrical power failure during proof-testing operations, electrical components would cease to function. An automatically actuated emergency electrical power system allows continued control of critical test components.

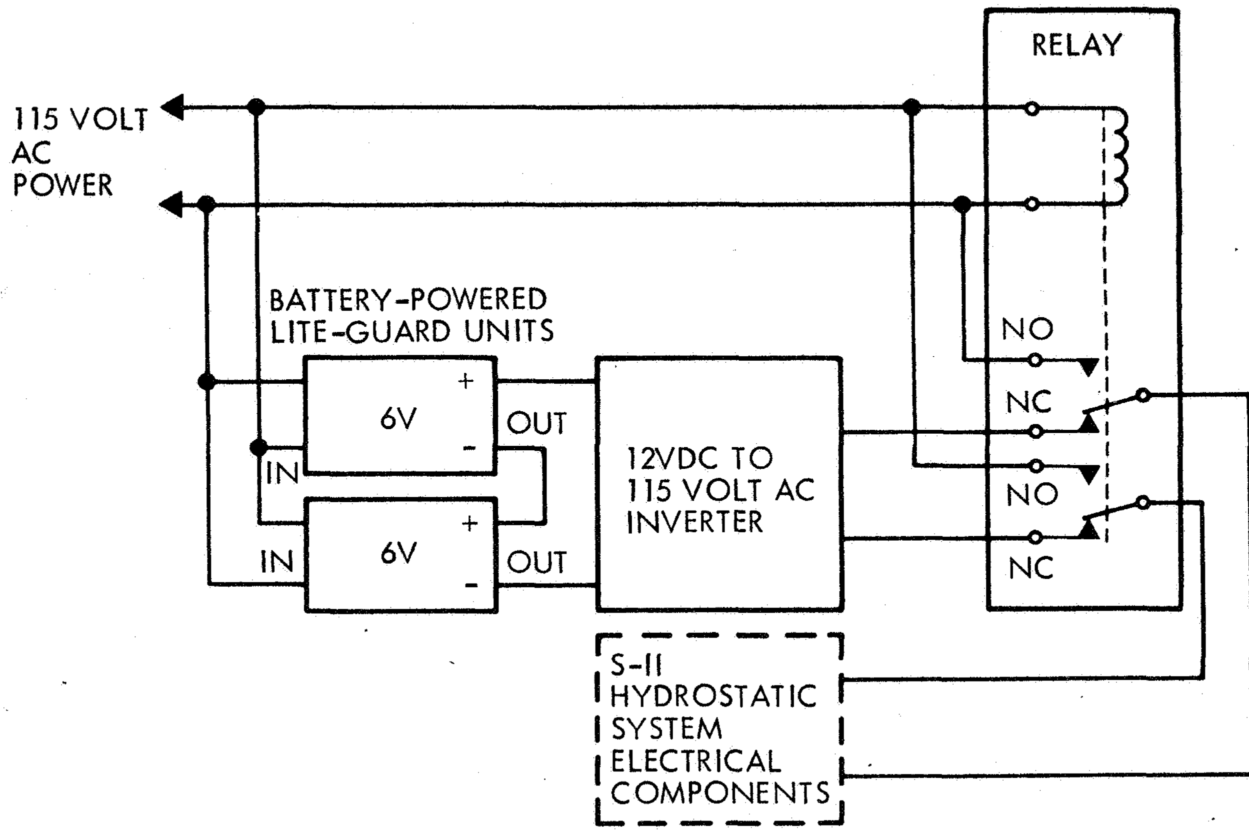


Figure 31. Emergency Electrical Power System

AUTOMATIC EMERGENCY INSTRUMENT AIR SYSTEM

PROBLEM STATEMENT AND EFFECT

Failure of primary gas supply (plant air or other gas) employed for the S-II to operate critical pneumatic instrumentation and control components could result in damage to equipment and injury to personnel.

SOLUTION/RECOMMENDATION

A bottled gas supply, regulated and automated, to "cut in" on loss of primary pressure source, was installed in the safety critical S-II pneumostatic and hydraulic test systems (Figure 32). The system operates as follows: primary pressure source, set at a higher pressure than the emergency pressure source, forces emergency pressure source check valve closed, and provides supply pressure to system instrumentation and pneumatic controls. On loss of the primary pressure source, the emergency pressure-supply check valve will open, the primary-supply check valve will close, and the emergency gas supply will pressurize the system instrumentation and pneumatic controls. Supplementary components, such as a pressure switch, lights, alarm, and solenoid valve may also be added should further sophistication be desired.

DISCUSSION

In cases of critical operations, such as the S-II pneumostatic and hydrostatic proof tests, it was impractical to depend solely on fail-safe modes of system components. In the event of primary instrument supply pressure failure during proof-testing operations, the pneumatic instrumentation and controls would cease to function effectively. An emergency instrument pressure supply system, set to automatically operate on failure of the primary system, would allow continued control and recording of test pressures.

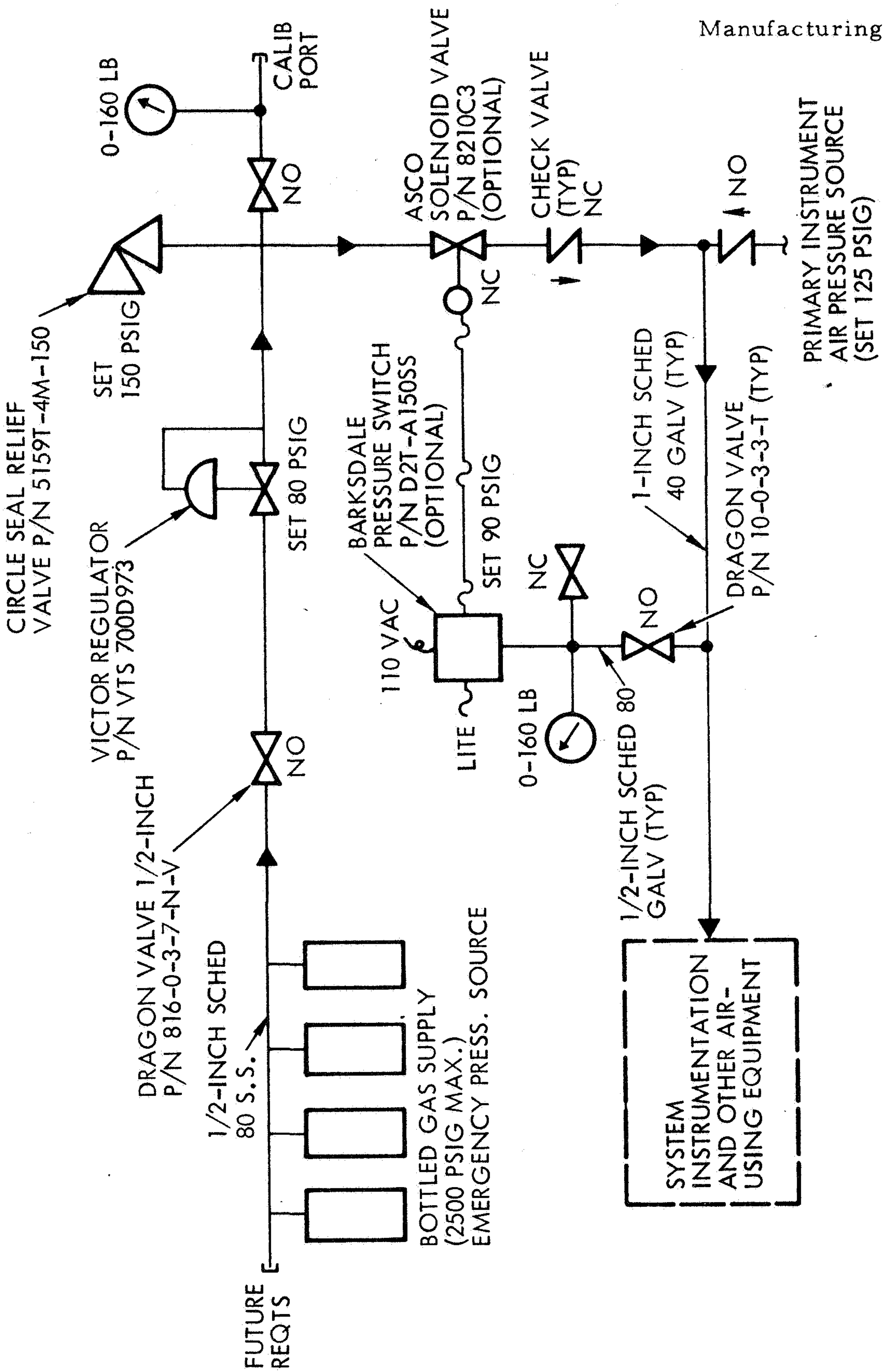


Figure 32. Emergency Instrument Air System

RAPID PRESSURIZATION OF POLYETHYLENE HOSES

PROBLEM STATEMENT AND EFFECT

Rapid pressurization of polyethylene hoses with helium gas resulted in the temperature rising above the melting point of polyethylene. This condition led to the development of longitudinal cracks and splits in the hoses after a very short service life.

SOLUTION/RECOMMENDATION

The use of polyethylene hoses for pneumatic testing was discontinued and teflon hoses were substituted with excellent results.

DISCUSSION

Several polyethylene hoses developed longitudinal cracks and splits after a very short service life. Visual inspection confirmed that the polyethylene appeared to have been softened by an over-temperature condition.

The supplier conducted an investigation of the problem and concluded the hoses had been pressurized at a rate exceeding 20,000 psi per minute, causing the temperature inside the hose to rise above the design temperature.

The formula for determining the approximate temperature of gases under instantaneous compression as in compressors is:

$$T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{N-1}{N}}$$

Where T_2 = compression temperature of gas ^oR
T_1 = initial temperature of gas ^oR
P_2 = compression pressure psia
P_1 = initial pressure psia
N = specific heat ratio

A sample calculation using typical values for the formula above demonstrates how high the compression temperature can rise.

Assume: $T_1 = 75^oF = 535^oR$
$P_2 = 4500$ psia
$P_1 = 15$ psia
$N = 1.4$ for nitrogen; 1.6 for helium

$$T_2 = 535 \left(\frac{4500}{15}\right)^{\frac{1.4-1}{1.4}}$$

$$= 2730^oR$$

$T_2 = 2270^oF$ for nitrogen

$T_2 = 4090^oF$ for helium

In this application, the pressurization rate will be less than that in a compressor, therefore the temperature will be lower (about half the computed value).

Since the melting point of polyethylene is approximately 275F, it is obvious that the rapid pressurization rate can damage the hose without exceeding its pressure rating.

S-II PARTS PROTECTION

PROBLEM STATEMENT AND EFFECT

S-II tubing and harness damage was incurred due to inadvertent blows with tools by personnel working in adjacent areas or by being stepped upon by personnel working in close quarters.

SOLUTION/RECOMMENDATION

Protective covers were designed and fabricated to protect selected components and areas from inadvertent damage. Protective covers were installed on S-II-3 S-II's following. A significant reduction in the number of "Ding" type rework squawks resulted. It is recommended that stage component handling protection be implemented during initial design.

DISCUSSION

Damage was incurred to S-II thrust structure installations during subsystems installations, final systems installations, stage checkout and troubleshooting procedures.

Protective covers were designed and fabricated to provide protection of specific components and structure. The applicable manufacturing working documents required that protective covers be installed, thus insuring parts protection from inadvertent damage. Inspection verified that the protective covers were installed as part of the job buy-off requirements.

REFERENCES

"Parts Protection," Specification MA0616-002.

DEVIATIONS TO SOLDERING SPECIFICATION

PROBLEM STATEMENT AND EFFECT

MSFC-PROC-158A had many soldering requirements that were difficult to attain.

SOLUTION/RECOMMENDATION

Deviations to the soldering specification were requested from NASA and granted. These deviations were then passed on to the requesting supplier. Approved deviations should be extended to all suppliers using MSFC-PROC-158A as soon as possible after receipt of the deviation.

DISCUSSION

Throughout the Saturn program, deviations to MSFC-PROC-158A were granted to Space Division as a result of:

1. Requests from NR suppliers
2. NR Manufacturing Department requests
3. NASA extending to NR certain deviations requested by other prime contractors

All deviations were received and accumulated in SID 61-367C. Only those for which specific deviations have been requested by a supplier were disseminated and then only to that supplier. It must be assumed that in granting a deviation, the customer was satisfied that quality would not be compromised, the requirement was too stringent and a cost savings could be achieved.

On future programs, all specification deviations should be passed on to all operational divisions performing on the program as well as all suppliers who hold the specification as a requirement of the procurement specification to permit them to use the modified specification when appropriate. In some cases, high cost and slipped schedules resulted from requiring suppliers to meet more stringent specifications than permitted by deviations.

REFERENCES

MSFC-PROC-158A
SID61-367C

STANDARDIZATION OF REQUIREMENTS FOR ELECTRIC WIRE AND CABLE

PROBLEM STATEMENT AND EFFECT

Various requirements for different types of wire created material shortages, long lead time, and higher costs to satisfy design specifications.

SOLUTION/RECOMMENDATION

At the outset of a new program, a standard for all wire requirements should be established that keeps the number of configurations to an absolute minimum. It is preferable that a determination of requirements be made after the industry has been canvassed for advancements, availability, lead time, and price.

DISCUSSION

Difficulty in meeting delivery schedules was experienced at the outset of the S-II Program when wire requirements were made known to Purchasing. This was due to the greatly differing specification requirements which created overloads at the suppliers and extended delivery lead times. To alleviate the schedule problem, the buyer, S-II Quality Engineer and S-II Design Engineer jointly reviewed the Apollo and S-II specifications and negotiated standard wire requirements for use on both programs. Cost savings of approximately 1.5 million dollars resulted from standardizing wire requirements for both the Saturn and the Apollo programs.

STRINGENT SPECIFICATION REQUIREMENTS

PROBLEM STATEMENT AND EFFECT

During the course of design, development and fabrication of a confined detonating fuse (CDF) pyrogen initiator for the Saturn program, extremely stringent requirements resulted in costly qualification test failures, development of second source suppliers, and production lot rejections. Both the primary and secondary suppliers experienced failures in trying to maintain an impervious bulkhead with a leak rate allowance of 1 cc per minute tested at 2500 psi of nitrogen gas.

SOLUTION/RECOMMENDATION

Although the technical problem was eventually solved by the suppliers through qualification testing, the cost effectiveness of maintaining the stringent specification leak-rate requirement during design, development, and fabrication phases and during development of second sources is questionable. Subsequent events showed that it would have been advantageous to obtain experimental data on the risks associated with porous initiator bulkhead and relieve the specification requirements accordingly.

DISCUSSION

Through bulkhead initiators are used for ignition of the solid propellant motors on the Saturn V vehicle. Thirty-six initiators are used on each launch vehicle. Problems have been encountered by the two suppliers during the last five years in maintaining a completely impervious bulkhead after use (firing). Since the expended initiator bulkhead is subjected to motor pressure during motor firing, structural integrity in this area is essential. The concern has been that the hot, erosive motor gases would quickly enlarge small, bulkhead, leakage paths sufficiently to allow catastrophic venting. Since the maximum safe leak rate was not known, extremely stringent specification requirements were established. The present specification allows only 1 cc per minute leak rate when tested with 2500 psi nitrogen gas. This stringent requirement resulted in qualification test failures at Link Ordnance (1965) and at McCormick-Selph Associates (1968). Link Ordnance production lot 005 (1969) was also rejected because rates of excessive post-firing bulkhead leakage (up to 43 cc/minute) resulted during lot acceptance testing.

A special test program was conducted by NR in July 1969 to obtain experimental data on the risks associated with porous initiator bulkheads. This program consisted of the exposure of artificial leak specimens to simulated S-II ullage-motor internal burn environments. Comparison of pre-firing and post-firing leak rates indicated that combustion products of an aluminized propellant tended to seal leak paths. No detrimental effects were noted when specimens having pre-fire leak rates up to 23 liters per minute were exposed to internal motor burn environments.

Since aluminized propellants are known to deposit combustion products on internal motor surfaces, the observations noted above may not apply to a nonaluminized propellant such as used in the S-II retro motor. Therefore, another test program was conducted by NR in October 1970 utilizing S-II retro motor (Thiokol Recruit) propellant to verify safe, bulkhead leak levels for all motors on the Saturn V.

This test program was conducted for the purpose of obtaining data which will (1) provide greater confidence that small bulkhead permeability under exposure to nonaluminized propellant does not jeopardize mission success and (2) establish the maximum tolerable post-firing leakage rate to permit relaxation of present stringent specification leak requirements.

The test concluded that (1) the present CDF pyrogen initiator's specification post-fire maximum-leak requirement is much more stringent than necessary, (2) damaging erosion from motor gases can occur only if the bulkhead leakage rates exceed the present tolerance by more than a factor of ten thousand and (3) recommends that in the event minor bulkhead leakage is encountered in future initiator acceptance testing, the procurement specification be revised to allow 100 cc per minute (nitrogen at 2500 psi) maximum leak rate.

TELEMETRY SPARES

PROBLEM STATEMENT AND EFFECT

As a result of design changes on telemetry equipment for stages S-II-1 through S-II-10, three configurations were identified. These different configurations would normally have required spares procurement for all three configurations.

SOLUTION/RECOMMENDATION

Since certain telemetry equipment was one-way-interchangeable, excessive cost would have resulted from procurement of all configurations.

All interchangeable configurations were identified and where delivery schedules permitted, the S-II-4 and S-II-5 configurations were procured in lieu of the S-II-1, S-II-2, and S-II-3 configurations.

The use of higher configurations for spares should be considered whenever configuration differences are planned in advance for various vehicles. When configurations are changed as a result of design changes, spares should be modified to the latest configuration and interchangeability notes added to the drawings.

DISCUSSION

Normally, spares are procured for all configurations shown on drawings. Three major configurations were identified for Saturn S-II telemetry. The first was effective on vehicles one through three, the second configuration was effective on vehicles four and five and the third was effective on vehicles six and subsequent. Three test sites had to be supported.

By normal methods, three complete sets of each configuration would have been required. This situation occurred in April of 1966.

CONFLICT OF NR-IMPOSED PROCESS SPECIFICATION REVISIONS

PROBLEM STATEMENT AND EFFECT

Automatic distribution of revised process specifications to all suppliers conflicts with S-II baseline.

SOLUTION/RECOMMENDATION

As a possible solution, it is suggested that the program approval status of each process specification be denoted on the specification faceplate. This action has been accomplished for the various precision cleaning specifications.

DISCUSSION

Contractual process specifications for the S-II program are baselined to a specific revision by SD-61-367. Material Operations, however, transmits copies of the latest specifications to all approved processors upon release. This transmittal directs immediate implementation of the latest specification for all Space Division projects. In cases where the latest specification is not approved for S-II program use, Configuration Management disciplines are obviously undermined.

CORROSION PREVENTION FOR ALUMINUM DISCONNECTS

PROBLEM STATEMENT AND EFFECT

Aluminum castings for S-II 8-inch propellant fill disconnects were incurring extreme corrosion during use at the Kennedy Space Center test site.

SOLUTION/RECOMMENDATION

The problem was solved through the development of a detailed corrosion treatment.

DISCUSSION

This treatment was established by NR for use under NR supervision at the supplier's facility prior to refurbishment of the disconnects.

The corrosion treatment procedures are outlined in Letter 099-303-68-125, October 23, 1968. Using this procedure, four disconnects were conversion treated, refurbished, and submitted for Material Review Board disposition. The units so treated passed acceptance testing and have since successfully supported launches. Use of the corrosion treatment eliminated procurement of four new 8-inch propellant fill disconnects worth approximately $25,000 each. The four units which underwent corrosion treatment had been declared uneconomical to repair by the supplier due to corrosion.

REFERENCES

Procedure for Hand Removal of Corrosion from A356 Aluminum Alloy Castings and Beryllium Copper, attachment from Letter 099-303-68-125 (see following pages).

Materials 06-01

Letter 099-303-68-236

PROCEDURE FOR HAND REMOVAL OF CORROSION FROM A356 ALUMINUM ALLOY CASTINGS

The following procedure is for removing by nonimmersion methods, localized corrosion from A356 castings. This method should not be applied to assembled parts because of the danger of trapping chemicals in faying surfaces. The operations listed below should be done under the direction of S-II Materials and Processes Laboratory (D/098) personnel.

1. Remove loose residue with a soft, stainless steel wire brush

2. Apply with brush or swab, Turco 5361 paste for ten to fifteen minutes

*3. Rinse with tap water for two to three minutes

4. Apply with brush or swab a nitric-hydrofluoric acid solution (15-20 percent by weight HNO3 and 3 (±1) percent by weight RF) for one to three minutes

*5. Rinse with tap water for two to three minutes

6. Inspect for corrosion removal. Verification of removal to be by NR representative

7. Repeat steps 2 through 6 as required

When the corrosion residues are removed, hand apply a chemical film finish to the reworked areas as follows:

1. Deoxidize by applying the nitric-hydrofluoric acid solution (reference step 4 above) for one to three minutes

*2. Rinse with tap water for two to three minutes

3. Apply Type I chemical film per Table IV, step 2, of MA0109-003

*Note: The rework area may be rinsed under flowing water, immersed in a tank, or wiped with a wet sponge or cheesecloth.

4. Rinse with high purity water per step 3, Table IV, MA0109-003

5. Air dry

PROCEDURES FOR REMOVAL OF CORROSION FROM BERYLLIUM COPPER

I. For Disassembled Parts

1. Remove loose corrosion residue with a soft, stainless steel wire brush

2. Bright dip per Table IV of MA0110-019

3. Rinse in flowing water

4. Air dry

5. Inspect for corrosion removal. Verification of removal to be by NR representative

6. Repeat steps one through five as required

II. For Assembled Parts

Remove corrosion residues by mechanical methods only (no chemicals) such as with a stainless steel brush, an abrasive pad, or crocus cloth.

SUPPLIER ON-SITE REPAIRS AND MODIFICATIONS

PROBLEM STATEMENT AND EFFECT

Supplier technicians were handcarrying components to sites to make repairs and modifications. This practice led to inspection problems in that handcarried components had not been routed through Receiving Inspection. When handcarried components were eventually re-routed through Receiving Inspection rejections were common and led to delays and rescheduling of repairs and modifications.

SOLUTION/RECOMMENDATION

A procedure was initiated to provide for normal shipment, delivery, and receiving inspection of components prior to scheduling of supplier technician on site. Upon arrival of the supplier's technician, the components were handed over and rework or modification performed.

It is recommended that the above procedure be used in all cases where time permits. In the case of urgent repair requirements, where time does not permit the delivery of parts prior to scheduling of the supplier's technician on-site, the components can still be handcarried, and receiving inspection performed while the technician stands by.

DISCUSSION

In order to effect on-site repairs and modifications to equipment installed on an S-II stage, or in laboratories, supplier personnel were handcarrying the components required to effect the repair or modification. In many cases, the supplier's technician would immediately initiate repair or modification and be partially or completely finished, only to have the rework rejected when it was realized that the components used had not been routed through Receiving Inspection.

In other instances, the supplier's technician would deliver the components and then stand by, while the components were routed through Receiving Inspection. This led to excessive standby time for both the supplier's technician and NR personnel, particularly when the components were rejected or when the purchase order or supplier's data required correction. In many instances, it meant that after a 2- to 4-hour standby, the supplier's technician would have to return to his plant and the on-site effort rescheduled.

COMPONENT CLEANLINESS AFTER REWORK

PROBLEM STATEMENT AND EFFECT

Parts were returned for minor rework and then required extensive recleaning to meet Specification MSFC-SPEC-164.

SOLUTION/RECOMMENDATION

Minor rework was allowed on site and specification deviations were granted to allow parts to be returned at the same level of cleanliness as received for rework.

DISCUSSION

Major equipment items were being returned to the supplier for minor rework or modification. In the process, the cleanliness level was lost and in the case of a vent valve, it was necessary to completely disassemble the vent valve to ensure the specification requirement of MSFC-SPEC-164. The cost of the cleaning operation ran as high as $20,000.

Under the surveillance of government and NR source inspection personnel, deviations were granted to:

1. Have supplier technicians perform minor rework or modification while the vent valve was installed

2. Remove the vent valves, immediately install end caps, and perform the minor rework in an on-site clean room.

3. Remove the vent valves, install end caps, place in clean bag, and ship to the supplier with certification of the cleanliness level. Rework was performed and supplier verified that the level of cleanliness was maintained.

This deviation permitted the down time to be reduced from six weeks to as little as three days and reduced the rework costs from as high as $20,000 to as low as $1,000.

REFERENCES

MSFC-SPEC-164

LOX CLEANING OF PARTS AT SUPPLIERS' PLANTS

PROBLEM STATEMENT AND EFFECT

Requirements in procurement specifications for cleanliness in accordance with MSFC-SPEC-164 are interpreted by government and source inspectors as being applicable prior to shipment of the equipment by the supplier. This equipment cleaning is also done after final calibration in the NR test laboratory.

SOLUTION/RECOMMENDATION

On future programs, the cleanliness requirements should read similar to the following: "After final calibration or test, all parts of the transducer which come in contact with media shall be cleaned in accordance with requirements of MSFC-SPEC-164 prior to installation into the system."

DISCUSSION

Numerous purchased equipment items such as transducers and accelerometers are LOX-cleaned following acceptance testing and prior to shipment. When these parts are received at NR, they are calibrated, bench tested, and recleaned. This duplication of effort caused unnecessary monetary expenditures as well as delays in delivery. When it has been determined that in-house effort will be required of an item of equipment which will destroy LOX cleanliness, the procurement specification should be so worded as to remove this requirement from the supplier's effort.

LOX COMPATIBLE DYEPENETRANT REQUIREMENTS ON TEMPERATURE SENSORS

PROBLEM STATEMENT AND EFFECT

Transducer procurement specifications allowed the supplier to use dyepenetrant materials which were not compatible with LOX. Some dyepenetrant materials have a residue which could have adverse results if installed in LOX systems.

SOLUTION/RECOMMENDATION

The dyepenetrant requirements were changed in the procurement specification to require LOX compatibility.

DISCUSSION

It is essential that dyepenetrant materials be LOX compatible. However, the supplier could find no source to certify LOX compatibility through impact testing. NR solved that problem by furnishing LOX compatible materials which had been impact tested and certified by NR. Further, NR trained and certified supplier personnel in the use of the new dyepenetrant procedures.

ACCEPTANCE TESTING OF CRYOGENIC DISCONNECTS

PROBLEM STATEMENT AND EFFECT

The airborne and ground support disconnects for cryogenics were acceptance-tested separately with a dummy disconnect at the supplier's facility.

SOLUTION/RECOMMENDATION

Space vehicles require the use of disconnects for various applications involving airborne and ground support equipment. On new programs, procurement releasing documentation should be worded to require release of the requirements at the same time so that schedules will be established to permit delivery of both disconnects concurrently.

DISCUSSION

In the early part of the Saturn II program, the airborne production requirements were released considerably in advance of the ground support equipment requirements, with schedules calling for delivery of the airborne several months before the GSE. As a result, it was necessary for the supplier to fabricate test setups to permit testing of the airborne first and later, the GSE. This resulted in unnecessary duplication of acceptance test costs.

When follow-on requirements were placed, this excessive acceptance testing cost was recognized, and the buyer then arranged for all ground support equipment requirements, as well as airborne requirements, to be released and scheduled for delivery concurrently. A considerable cost savings resulted.

LINE ASSEMBLY LEAK DETECTION

PROBLEM STATEMENT AND EFFECT

Minute leaks in the main line of vacuum jacketed lines could not be located without disassembly.

SOLUTION/RECOMMENDATION

A tool which would locate leaks without destroying good welds was developed.

DISCUSSION

Throughout the line assembly production program, Solar had a difficult time meeting delivery schedules for the long, complex, vacuum-jacketed line assemblies. It was almost impossible to locate slow, pin-hole type leaks. A test device was developed using two inflatable doughnut type seals to isolate a section of line. A needle extended through one seal and could be rotated to scan the inside surface of the line. As the needle device was rotated, helium was released in a very small quantity into the vacuum jacket. When the needle approached the leak, helium was pulled into the vacuum which was connected to a very sensitive mass spectrometer. This would pin point the leak and allow the supplier to make the repair without destroying good welds on assembled components.

REFERENCES

Tool T7322858, MS Sealer Plug CD90420B, used with ME271-0011 Feed Lines

Tool T7402669, MS Sealer Plug CD90252-D, used with ME271-0021 Vent Line

Materials 23-02

STRUCTURAL INTEGRITY OF WELDED LINE ASSEMBLIES

PROBLEM STATEMENT AND EFFECT

Changes in peaking and offset requirements created a problem for reassessment and remeasurement of both critical and noncritical welded line assemblies. Undetected weld anomalies could result in cracks which would permit leakage of hazardous media (such as LOX) or further propagation to the point of line fracture with a possible launch delay or failure.

SOLUTION/RECOMMENDATION

Critical measurement areas were the inner line surfaces at weld joints for which no standard measuring tools or techniques existed. Sectioning and rewelding were the only known techniques - these were costly, hazardous, and still did not assure that peaking and offset would not occur upon rewelding. The solution was to develop nondestructive techniques and tools which would provide assurance that internal finished surfaces would be free from structural flaws or defects.

DISCUSSION

NR developed an instrument identified as a proficorder - a device which would permit visual inspection as well as mechanical recording for height, width, and offset and peaking of all inner welds. The device consisted of a recorder, TV camera, TV screen, video monitor, measurement head and flex cable, mirror, recorder arm, bladders, power supplies, etc. Two devices - one a 7 inch and the other with an adjustability feature to 8 inches. Through development and use of these units, possible damage to lines and the high cost of cutting and rewelding were avoided.

REFERENCES

SD71-468, March 22, 1971.

Offset profile tool (T-7204193); Inspection Check Fixture (T-7204339)

MATERIAL REVIEW BOARD (MRB) DELEGATION

PROBLEM STATEMENT AND EFFECT

As required by certain suppliers, purchase orders were negotiated with the understanding that the selected supplier would be granted MRB authority.

SOLUTION/RECOMMENDATION

At the time specifications are released a determination should be made as to whether Material Review Board authority should be delegated to the selected supplier. The customer should be requested to approve a candidate list of appropriate items. The actual delegation would be extended when the source has been selected and it has been determined that they have an approved quality control system and qualified personnel.

DISCUSSION

During the period of both initial and follow-on procurement of the Saturn S-II Program, delegation of MRB authority to selected NR subcontractors was historically a lengthy process. In many instances, two to six months were lost awaiting a decision on supplier delegation, even though a number of these subcontractors were also prime contractors on other programs with this same customer.

NR documentation requirements now invite subcontractors to request MRB authority. In many cases suppliers propose with the understanding that they will be granted this privilege whenever the need arises. Resulting delays in obtaining customer approval has an adverse effect on negotiated schedules and purchase order prices. Some suppliers have indicated program losses were caused by their inability to obtain approval of their request for MRB authority. The net result invariably ends in increased cost and relaxation of schedules.

CONSOLIDATION OF PROCUREMENTS

PROBLEM STATEMENT AND EFFECT

It was discovered that the Space Division was using several procured items common to other Divisions. Separate purchases of the same item result in higher procurement costs.

SOLUTION/RECOMMENDATION

A consolidation of requirements was effected where practical.

DISCUSSION

In those cases where common usage was discovered on equipment (specification controlled items), individual buyers coordinated with the other NR divisions, the supplier, and the requestor to effect price reductions through a larger procurement. In some instances, this required the early release of requirements to allow one-lot manufacture.

For usage items; such as O-rings, nuts, bolts, etc.; common to more than one division, corporate buying agreements were used. In addition to combining requirements from all using divisions, purchases under corporate buying agreements also save costs through (1) the avoidance of separate negotiations for each buy within each division and (2) the protection of prices against inflation during the agreement period.

Additionally, in the production of S-II systems/components, certain efforts were transferred to other divisions under Interdivisional Work Authorizations (IDWA). The procurement of many parts required for these IDWA's and Space Division Manufacturing was retained by Space Division. This avoided a separation of requirements/purchases.

Space Division was also awarded procurement responsibility for all Saturn V common ordnance. This common ordnance management program was a valuable tool in reducing S-II costs.

The reduction of procurement costs through consolidating requirements should be an inducement to strengthen and expand consolidated procurement plans for subsequent programs.

WELD X-RAY INTERPRETATION

PROBLEM STATEMENT AND EFFECT

Inconsistent interpretation of radiographic x-rays by supplier inspectors and Government and NR source inspectors caused a high rejection rate, increased costs, and delayed delivery of critical line assemblies.

SOLUTION/RECOMMENDATION

A certification program for all personnel associated with interpretation of radiographic x-rays was established. It is recommended that on future programs all suppliers and source inspectors associated with radiographic x-rays be required to undergo training and certification similar to that used on the S-II program.

DISCUSSION

During calendar years 1966 and 1967, all welds on line assemblies required radiographic x-rays. The need for this requirement resulted from the failure of a line assembly in a critical application. The cause of the failure was found to be a faulty weld. Acceptance of the weld was by supplier in-process inspection and Government and NR source inspectors. Because of the lack of experience, welds were inconsistently accepted and rejected, separately and collectively, by the various inspectors. This caused considerable delay in delivery and additional cost overruns on the CPFF-type subcontracts.

This condition was corrected by a training course established at NR. All inspectors were trained to read and interpret radiographic x-rays to uniform standards. Manpower Development then imposed the requirement that all personnel doing source inspection which required the reading of radiographic x-rays be recertified each year. Recertification accounting is accomplished by an automated tab run which is distributed monthly and lists the name of the individual, and the date when his present certification expires. This provides time for management to schedule each source inspector for recertification prior to expiration of the current certification.

REFERENCES

NR Training Course 782 AE Radiographic Film Interpretation

NR Training Course 782 AF Radiographic Film Reading Recertification

CONTRACTOR NONCONFORMANCES

PROBLEM STATEMENT AND EFFECT

Many unnecessary contractor nonconformances (CNC's) were written against S-II stages due to

1. Lack of understanding of contract requirements

2. Lack of knowledge of criteria for generating CNC's

3. Improper preparation of CNC's

Unnecessary expenditure and time were spent for cancellation of unnecessary CNC's or revision to improperly prepared CNC's.

SOLUTION/RECOMMENDATION

Familiarization meetings were held to acquaint the personnel of NR and government agencies associated with the problem with contract requirements, criteria for CNC's, and proper preparation of CNC's.

It is recommended that the above action be taken early in a program to avoid unnecessary expenditure and time.

DISCUSSION

During a review of nonconformances on S-II-5, it was found that a total of 107 CNC's were written against S-II-5 while at a test site. Many of the CNC's were revised more than once and in two occasions as many as four times. To write a nonconformance, an average of 32 hours of technical and support personnel are expended by the contractor. In the case of S-II-5, approximately one man/year was expended.

As a result, the Manager, S-II Contracts, met with members of management at the test site for the purpose of developing a better knowledge of contract requirements on the part of site personnel. The following actions were taken to resolve the problem:

1. NR nonconformance procedures in effect at the test site were rewritten

2. Seal Beach contracts support was provided to the test site

3. Contract familiarization meetings were held with the MSFC Contracting Officer, the test site Contracting Officer, NASA/MTF, NASA management personnel, and Air Force Quality Management personnel.

As a result of the above action, the number of CNC's on S-II-6 and subsequent stages were reduced significantly as follows:

Stage	No. of CNC's
S-II-6	72
S-II-7	17
S-II-8	18
S-II-9	22
S-II-10	30
S-II-11	27
S-II-12	12
S-II-13	19
S-II-14	16
S-II-15	8

APPROPRIATE ECP REVISION SYMBOL ON AFFECTED NR DOCUMENTATION

PROBLEM STATEMENT AND EFFECT

All affected NR change accounting documentation did not reflect the current engineering change proposal (ECP) revision symbol. This condition created identification problems for the Configuration Control Master Record (CCMR) of the current approved/submitted ECP revision. It was also difficult to relate other documentation to the appropriate ECP revision.

SOLUTION/RECOMMENDATION

The implementing instructions and the contract (SID 65-1516) were changed to establish criteria and ground rules to require application of the appropriate ECP revision symbol on all affected documents. It is recommended that this system be implemented on new programs at the time of initial engineering release.

DISCUSSION

Validation of end item configuration as performed in accordance with contract obligations via comparison of NR documentation to NASA MSFC documentation (Configuration Identification Index and Modification Status Report - CM-017-003-2H) was a cumbersome, time consuming, costly effort. By establishing criteria, ground rules, and rebaselining end item ECPL's, validation of the end item is now accomplished accurately and at less cost with a minimum of effort, and configuration of the end item may be obtained at any given milestone.

[illegible] HARDWARE DESIGN CHANGES AND TEST CRITERIA DOCUMENTS

PROBLEM STATEMENT [illegible]

SID 61-366, "Saturn S-II [illegible] Documentation Requirements," established the requirement to provide [illegible] documents: (1) KSC Prelaunch Checkout and Launch Operations Documentation (Test Requirements, SID 66-1484), and (2) KSC Prelaunch Checkout and Launch Operations Documentation [illegible] 66-1485). These documents [illegible] stage applicability by a dash number [illegible] maintained by revised pages. Changes to these [illegible] criteria for class 1. This condition created a problem at KSC in identifying the relationship between documentation changes and the related hardware changes and in assuring that the approved [illegible] was incorporated into the document.

SOLUTION/RECOMMENDATION

The [illegible] (SID 61-366 and SID 65-1510) [illegible] S-II-7 and subsequent and to require [illegible] document be submitted to NASA MSFC via the test ECP. [illegible], the change to be incorporated into the document by revised [illegible] approach should be implemented prior to delivery of [illegible].

DISCUSSION

The inability [illegible] and expediently relate hardware changes to checkout criteria documentation resulted in an excessive expenditure of manhours for [illegible] all hardware changes at the test site for their effect on the checkout criteria and could result in schedule delays and overlooking a changed or new checkout requirement. By placing the checkout criteria documentation within the contractual Class 1 change definition, a requirement was established for the identification of the documentation change with the same number as the hardware Engineering Change Proposal (ECP) number, submittal, and disposition of both hardware and documentation aspects of the change concurrently. This assured compatibility of hardware and checkout criteria documentation.

ADDED ENGINEERING CRITICAL COMPONENTS

PROBLEM STATEMENT AND EFFECT

After NASA and S-II Engineering's initial identification of stage engineering critical components (ECC's), NASA changed the criteria for selection of ECC's. This new criteria added approximately 135 new ECC's and occurred subsequent to completion of first-article configuration inspection (FACI). Contractually, the S-II Program was obligated to FACI the added ECC's which were procured from 65 different suppliers.

SOLUTION/RECOMMENDATION

Contractor personnel verified that of the 65 suppliers involved, 54 had provided ECC's to the S-II Program that had previously been FACI'd. On this basis, the contractor recommended, and NASA approved, a change to the contract that would require baselining rather than FACI of "old" suppliers of "new" ECC's. This approach can be utilized on any new program where FACI of procured items of hardware is a contractual requirement.

DISCUSSION

By contract definition, a FACI of S-II hardware would not be considered a design review and would consist of a NASA/NR FACI team review of the engineering definition (i.e., drawings, specifications, processes, etc.) and verifying by the review of manufacturing and quality planning/buy-off documentation that the hardware "as-built" configuration conformed to the engineering "as-designed" requirements. During the FACI of hardware at a supplier's facility, the FACI team reviewed the supplier's manufacturing planning, engineering release, and change processing systems to assure that approved articles met engineering requirements and the supplier exercised a positive internal change control system. Subsequent to FACI, formal change control was imposed on the supplier and required NR Configuration Control Board (CCB) approval of all design changes prior to incorporating the design change into released engineering documentation and hardware. NR and NASA agreed that once a supplier's internal systems were validated and that supplier was acclimated to formal change control, that the S-II Program could obtain from the "old" supplier an indentured parts list (IPL) of the new ECC, freeze the design as defined on the IPL, and place the design under formal change control. This approach would provide an effective baseline and preclude a FACI.

REVISION OR CORRECTION OF AN ENGINEERING CHANGE PROPOSAL

PROBLEM STATEMENT AND EFFECT

The requirement to submit a completely revised Engineering Change Proposal (ECP) to affect all changes to an ECP, other than minor editorial changes established by contract (SID 65-1516, S-II Program Engineering Change Proposal Requirements), made nontechnical changes to an ECP costly and time consuming and produced unnecessary paper work. This criteria is normally used on all DOD contracts.

SOLUTION/RECOMMENDATION

This problem was resolved by changing the contract (SID 65-1516) to redefine the criteria applicable to revisions/corrections of an ECP to permit submission of nontechnical changes (i.e., change point for incorporation, etc.), in addition to minor editorial changes as a correction ECP. It is recommended that this criteria for changes to an ECP be used on future programs.

DISCUSSION

The requirement to submit a completely revised ECP to affect all changes other than minor editorial changes to an ECP caused expenditure of excessive cost and man hours of effort. By changing the criteria applicable to revisions/corrections of the ECP in the contract, the problem was minimized to require resubmission of only those pages of nontechnical ECP changes/corrections affected with a cover page.

INCORPORATION OF APPROVED SPECIFICATION CHANGE NOTICES

PROBLEM STATEMENT AND EFFECT

The requirement established by SID 65-1516A was to insert each approved SCN to a specification in front of the page it modifies, causing these documents to become cumbersome and difficult to read and understand. Complete revision was required periodically to incorporate the approved changes.

SOLUTION/RECOMMENDATION

The problem was resolved by changing the contract (SID 65-1516A) to eliminate this requirement and use a page revision technique. It is recommended that the page revision technique of specification maintenance be a requirement on new programs.

DISCUSSION

Maintenance of specifications via insertion of the approved SCN in front of the page it revised, over a period of time, resulted in documents that were difficult to read and understand and required complete revision to incorporate approved changes. By adoption of the page revision technique, maintenance of these documents resulted in specifications that were easier to read, understand, and keep up to date.

VALIDATION/VERIFICATION OF CHANGE INTO THE CONTRACT END ITEM

PROBLEM STATEMENT AND EFFECT

Validation/verification of changes for incorporation into the contract end item (CEI) at contractually prescribed milestones presented a difficult and unwarranted effort. It required validation/verification of accomplishment of a random selection of the ECP's listed in the engineering change proposal log (ECPL) for the CEI.

SOLUTION/RECOMMENDATION

Changing the contract (SID 65-1526A and SID 65-1516A) to require the ECPL's in the CEI specifications to be divided into an active and a closed section with only the active section to be used for selection of ECP's for validation/verification minimized the effort to meet this requirement and presented a more realistic validation/verification technique. It is recommended that this approach be taken on all future programs.

DISCUSSION

The requirement to validate/verify incorporation of approved ECP's in a random sample from the CEI's ECPL presented a problem because the ECPL contained all approved ECP's from the time the CEI specification was placed on contract. Many of these changes have since been incorporated into the basic engineering, thus making identification/documentation a very difficult and redundant effort. This requirement has been minimized and validation/verification has become more realistic and meaningful by changing the baseline of the ECPL and listing in a closed section the completed ECP's (all engineering released, all mod kits installed, and one or more incorporated in-line/field installation). The active/new ECP's are also included in the active section and the contract is changed to show the new requirements.

DESIGN CHANGE EFFECT ON CONTRACT END ITEM SPECIFICATIONS

PROBLEM STATEMENT AND EFFECT

Contract NAS7-200 contained contract end item (CEI) specification CP621M0001A for S-II-1 and addenda specifications CP621M0002A through CP621M0010A for S-II-2 through S-II-10 stages respectively. A design change with a multiple effectivity required a specification change notice (SCN) for each addenda specification affected.

SOLUTION/RECOMMENDATION

Changing the contract (SID 65-1515A) to require one specification (CP621M0014A) for S-II-3 and subsequent stages to define the stage configuration, negated the preparation/submittal of numerous SCN's to addenda specifications for the same design change. It is recommended that this be a requirement on future programs for two or more similar CEI's.

DISCUSSION

The requirement to prepare and submit for approval an SCN for each CEI specification and addenda specification affected by a design change, required up to 12 SCN's for a multiple effectivity design change. This requirement was fulfilled by preparation/submittal of only one SCN for a multiple effectivity design change. This was done by combining the CEI specification and addenda specification into one CEI specification (CP621M0014A) for S-II-3 and subsequent stages making S-II-3 the criteria for stage configuration definition and using alpha-sub paragraphs to define the delta requirements for subsequent stages.

SPECIFICATION PREPARATION FOR NR FABRICATED ENGINEERING CRITICAL COMPONENTS

PROBLEM STATEMENT AND EFFECT

Initial configuration management (CM) requirements required the contractor to prepare and maintain by specification revision notices (SCN's) the specifications for some 300 NR-fabricated ECC's.

SOLUTION/RECOMMENDATION

NR requested a change to the contract (SID 65-1515A) to permit using the ECC top drawing/part number as the contractually controlling element for NR-fabricated ECC's in lieu of detail specifications. This approach should be considered during initial negotiation of CM contractual requirements but only if the program has a positive change control and part-number control system.

DISCUSSION

During the initial negotiation of CM requirements, the program identified only 11 NR-fabricated ECC's. Some two years subsequent to this negotiation, the customer, through failure-mode effect analysis, identified some 289 additional NR-fabricated items that would be identified contractually as ECC's. This action would have caused NR to prepare individual specifications for each of these items. Because of the positive change/part number control system implemented on the program, the contractor was in a position to convince the customer that he could exercise a comparable degree of control on these ECC's by identifying the ECC by part number within the stage CEI specifications, thus avoiding the cost of preparing individual ECC specifications.

FIRST-ARTICLE CONFIGURATION INSPECTION (FACI) AT SUBCONTRACTOR FACILITIES

PROBLEM STATEMENT AND EFFECT

When NASA/NR FACI team conducts first-article configuration inspections (FACI) of engineering critical components (ECC's) at subcontractor facilities, it generally resulted in the FACI team devoting the first two to three days of a scheduled five day FACI explaining FACI requirements and identifying specific data to be reviewed by the FACI team. This was an unnecessary expenditure of the FACI team effort.

SOLUTION/RECOMMENDATION

The NR members of the NASA/NR FACI team arrived at the subcontractor's facility and spent the first three days explaining the FACI methodology, accumulating data, and assembling the data in a presentable format. The NASA team members would arrive on the fourth day and an orderly FACI would be conducted during the fourth and fifth days. This approach should be followed on all subcontractor FACI's.

DISCUSSION

The initial approach selected by NR and NASA for conducting FACI of ECC's at subcontractor facilities required that:

1. An NR team would visit some 100 subcontractors and brief the subcontractor on: the purpose of FACI, FACI team complement, subcontractor documentation requirements, and change control requirements

2. Subsequent to the briefing by NR (sometimes three to six months due to schedule), the NASA/NR FACI team would conduct the FACI at the subcontractors facility

This approach proved totally unsatisfactory for the following reasons:

1. During the time between the briefing and the FACI personnel, changes were effected within the subcontractor's facility

2. New subcontractor personnel did not know what to expect of the FACI team

3. All required documentation was not available and subcontractor personnel were not aware of other types of documentation that could suffice

4. Because of subcontractor unfamiliarity with requirements and methodology, the costs negotiated prior to FACI were high

5. The NASA members were unnecessarily detained while documentation was accumulated and formatted.

The new approach of having the NR FACI team members proceeding to the subcontractor's facility three days prior to the NASA team members resulted in:

1. All required data being accumulated and placed in the proper format

2. NR team members were conversant with subcontractor systems and documentation at time of FACI

3. Subcontractor personnel became conversant with FACI requirements

4. A total atmosphere of cooperation existed at the time of FACI.

5. Costs were reduced since the NR buyer could, in some instances, negotiate a level of effort and cost plus a lower fee versus a fixed price contract.

CRITICAL PROBLEM REPORT SYSTEM

PROBLEM STATEMENT AND EFFECT

In the early phases of the Saturn S-II Program there was no formal closed-loop problem resolution system in effect. Thus, several potential and actual critical problems that had program effect were not identified in a timely manner for program and functional management attention and resolution.

SOLUTION/RECOMMENDATION

The Saturn S-II Program resolved this problem in March 1966 by implementing the S-II critical problem report system. The system provides for early problem identification, action assignment, visibility of the problem by all members of management, effective coordination and communication, and the documentation of resolution and closeout actions. It is recommended that on future programs that a critical problem reporting system be implemented in the first phase of the program.

DISCUSSION

It was recognized by S-II program management in March 1966 (the S-II Program was at its zenith of development and production) that management was not receiving timely notification with adequate visibility and status of critical program problems. At that time, the critical problem report system was implemented to identify problems critical to the S-II Program on the basis of schedule, cost, and technical performance, to focus program and functional management attention on the problem, and to accelerate the development and use of optimum corrective action.

The Critical Problem Report, Form 984-N-2, is used as an aid in accomplishing this objective. It contains a statement of the problem, its major effects, analysis of the problem, recommendations, and an action assignment. During the period the problem remains critical, the action assignee prepares a weekly status report. This report indicates actions which are being taken to identify the problem cause, results of tests and special studies, choices of alternative solutions, final management selection of the optimum corrective action, and implementation of the correction. Form 984-N-2 is also used to close out the critical problem when management is satisfied that the optimum solution has been implemented and that criticality no longer exists.

REFERENCES

SSII M-200. 3 Reporting Critical and Potentially Critical Problems

THE PLANNING AND ACCOUNTING OF ENGINEERING CHANGES

PROBLEM STATEMENT AND EFFECT

The planning and accountability of approved Engineering Changes during approximately the first two years of the S-II Program were not systematically organized and controlled. The system was under the jurisdiction of one of the functional departments which utilized the change implementation plan (CIP) document to control the system. However, the CIP was not an official/authoritative schedule, had no reboard system for the modification of initial planning, and had no accountability or statusing system.

SOLUTION/RECOMMENDATION

In June 1964, the problem was resolved by transferring responsibility for the planning and accountability of engineering changes to S-II Program Management for the development and implementation of new procedures to provide the desired control and accountability for all engineering changes. It is recommended that a configuration management system similar to the S-II system be implemented in the first phase of future programs.

DISCUSSION

As the S-II Program approached its peak of development and production, it was recognized by S-II Program Management that the system for planning and maintaining accountability of engineering changes was no longer adequate. In June 1964, the responsibility for planning and accountability of approved engineering changes was transferred to S-II Configuration Management, a functional unit of program management. The name of the function was changed from manufacturing schedule change board (MSCB) to schedule change board (SCB). The previously employed change implementation plan (CIP) was superseded by a change commitment schedule (CCS). To formalize the engineering change control system, the S-II Program released implementing instructions (C-100 series) that completely define the detail requirements and methodology for the performance of the S-II Change Management system.

REFERENCES

SSII C-100.3, Planning and Accountability of Approved Engineering Changes.

PLANNING IMPLEMENTATION OF ENGINEERING CHANGES

PROBLEM STATEMENT AND EFFECT

In the early phases of the program, hardware changes to Saturn S-II stages were planned and implemented at the most convenient change point. Although this technique maintained the schedule, numerous improvement changes were deferred to test sites rather than incorporating them in-line at Seal Beach. This procedure resulted in costly additional requirements for modification kit drawings, modification instructions, data packages, modification kit accumulations, and shipments to field sites. In addition to higher cost, changes could not be implemented in the field as efficiently as they could at Seal Beach during the manufacturing and checkout processes.

SOLUTIONS/RECOMMENDATION

In July 1968, the S-II Program Manager issued a directive containing revised ground rules for planning and implementing changes. The new ground rules stipulated that the Program Schedule Change Board (SCB) would plan the incorporation of as many changes as possible for in-line Seal Beach, rather than deferring them to test sites. It is recommended that program management emphasize in-line incorporation of changes on all future programs.

DISCUSSION

NASA and NR agreed that costs could be reduced by refining schedule change board (SCB) planning to accomplish a much higher percentage of changes in-line at Seal Beach and significantly reduce the percentage deferred to test sites.

The first flight stage affected was S-II-9, which was turned over from manufacturing to test operations at Seal Beach in February, 1969, and was scheduled for shipment to a test site in March, 1969. Hardware changes (48) had been approved for this stage and through a variety of tradeoffs and work-around plans, the schedule change board (SCB) successfully planned implementation of 42 of the 48 changes at Seal Beach, without schedule impact. This compared favorably with 16 deferred changes on S-II-8, 59 on S-II-7, 60 on S-II-6, and 41 on S-II-5. The action resulted in both identifiable cost savings from eliminating shipment of extensive data to the field, and intangible cost savings through improved efficiency and reduced constraints on field sites.

REFERENCES

SSII C-100.3, Planning and Accountability of Approved Engineering Changes.

DD FORM 250 PREPARATION FOR SATURN S-II GSE

PROBLEM STATEMENT AND EFFECT

A total of 47 end items of ground support equipment (GSE) were required to support shipment of each S-II stage. Individual DD Form 250's were prepared to document configuration, open work items, deferred changes, etc. This caused the expenditure of excessive manhours in preparation and negotiation effort, and often resulted in constraints to established acceptance data package (ADP) submittal schedules.

SOLUTION/RECOMMENDATION

Negotiations with NASA resulted in a contractual change to allow the initiation of a single DD Form 250 listing of all GSE end items applicable to a specific stage shipment. This reduced preparation and negotiation hours considerably, and was a great contribution in meeting established schedules. This method is highly recommended on future programs where multiple end items of GSE are required.

DISCUSSION

At the beginning of the S-II program, many problems existed relative to stage/GSE acceptance data package preparation (ADP). These problems included DD Form 250 preparation requirements, ADP accumulation/submittal methods, operating time accumulation, and the processing of contractor nonconformance data. Major contributing factors were insufficient and improper data recordings of FAIR/TAIR documents, failure to properly document inspections, and the untimely processing of the paperwork needed to facilitate ADP preparation. These problems were attributed to several factors; inexperienced personnel, procedural deficiencies, and lack of proper functional coordination.

Since these problems had far reaching effects on the end product, expeditious solutions were mandatory. Through coordination meetings, training sessions, and procedural/contractual changes, methods of data accumulation, reporting, and submittal were established or revised to assure a significant, error-free ADP for the delivered end item.

S-II ACCEPTANCE DATA PACKAGE

PROBLEM STATEMENT AND EFFECT

S-II acceptance data packages (ADP's) were accumulated during the fabrication and testing of the individual stages. Upon completion of the effort, the fabrication, test, and inspection documents were reviewed and data applicable to the ADP were extracted, entered on applicable ADP forms, and submitted to NASA as a total package for review. Due to the volume of data, definite hardships were imposed on NASA and NR personnel in completing the review prior to the scheduled signing of the DD Form 250.

SOLUTION/RECOMMENDATION

A closeout schedule was imposed on the various manufacturing, test operations, and inspection functions related to their documentation and records. As these records were received by quality information personnel, the various data were extracted and incorporated into the applicable ADP increments. Submittal of the ADP to the NASA for review was scheduled incrementally and coincided with the documentation and records closeout schedules, thereby allowing approximately 95 percent of the total review effort to be complete upon receipt of the final documentation and records. A final ADP update and NASA approval was effected through the review of the final records, thereby precluding any schedule constraints. This method of data preparation and submittal is recommended for future programs where ADP's are required.

DISCUSSION

See discussion in Quality Assurance 01-01.

Quality Assurance 01-03

PROCESS CONTROL LIMITATIONS DUE TO MOISTURE DURING BONDING OPERATIONS

PROBLEM STATEMENT AND EFFECT

Process control test coupons representing Saturn S-II production structural-bonding operations exhibited extremely high "data scatter." One key factor was the variation in ambient moisture levels allowed by process specifications. Operational parameters for both temperature and relative humidity were established as maximums and minimums. When the maximum allowable temperature was encountered simultaneously with the maximum allowable relative humidity, extremely high absolute moisture levels were present. During these time periods rejection rates due to test coupon failure were extremely high.

SOLUTION AND RECOMMENDATIONS

Specifications governing the processing of bonding materials known to be moisture sensitive were reviewed from the standpoint of absolute moisture levels allowable. This information was extracted from psychrometric curves in terms of grains of moisture per pound of dry air at various temperature and relative humidity conditions. The process specifications were then revised to provide a "processing permitted" window in which the maximum allowable relative humidity decreased as the temperature increased. Substrate temperatures were also controlled to prevent the possibility of moisture condensation due to a lower substrate temperature then ambient temperature.

It is recommended that all specifications governing the use of moisture sensitive organic materials contain this type of environmental requirements for processing (Figures 33 and 34).

DISCUSSION

The problems encountered due to excessive moisture levels in the structural bonding areas were not immediately apparent on the Saturn S-II production program. The primary reason was that production at Seal Beach, California seldom encountered conditions of high temperature and high relative humidity simultaneously. The need for structural bonding environmental processing parameters did occur at both the Mississippi Test Facility and the Florida launch facility where climatic conditions were simultaneously hot and humid.

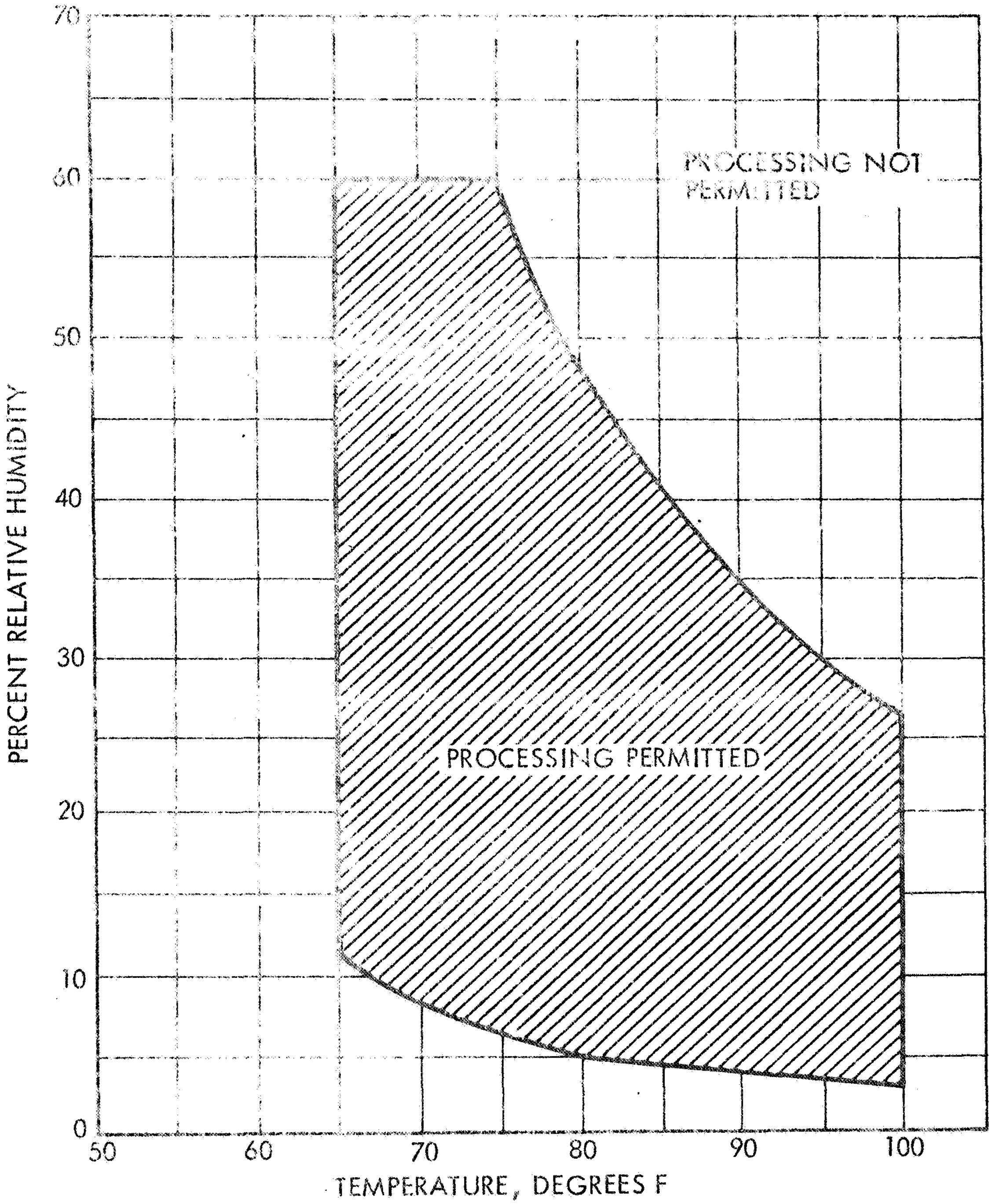


Figure 33. Temperature and Relative Humidity Requirements

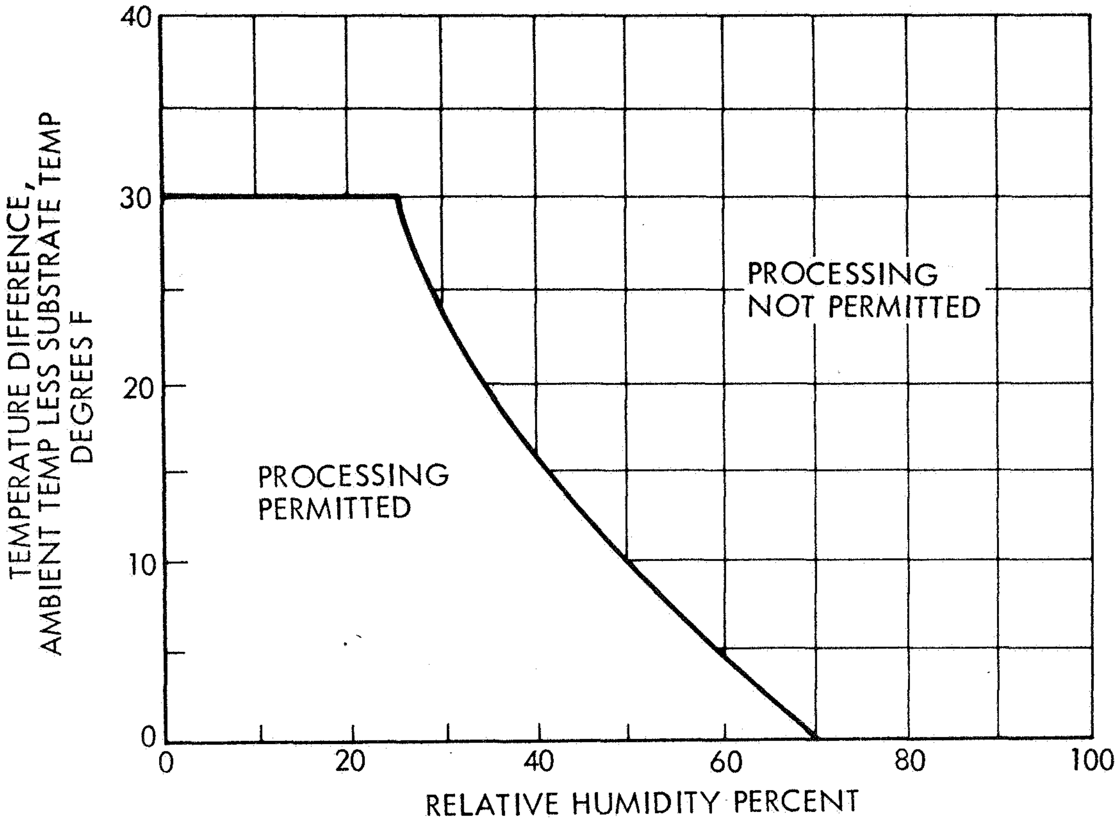


Figure 34. Substrate Temperature Control

RECORDING AND ACCUMULATION OF OPERATING TIME/CYCLE DATA

PROBLEM STATEMENT AND EFFECT

Operating time/cycle data were recorded on appropriate forms, verified by inspection, and inserted into the applicable test and inspection records (TAIR) book. Since approximately 35 TAIR books were utilized to document test activity for each stage, problems in statusing and data extraction were encountered resulting in a loss of data and constraints to acceptance data package (ADP) preparation.

SOLUTION/RECOMMENDATION

An Operating Time Record (OTR) log was initiated by Quality Information for each S-II Stage. The log was delivered to Inspection personnel, and contained sufficient pre-planned forms to satisfy total recording requirements during the test and checkout of the stage. This eliminated the individual TAIR Book requirements and, in addition to reducing the manhours expended on book issue, increased the overall Quality Assurance efficiency, and eliminated any schedule constraints. This method of operation proved very satisfactory on the S-II Program, and is recommended for future programs imposing Operating Time/Cycle recording requirements.

DISCUSSION

See discussion in Quality Assurance 01-01.

DD FORM 250 SHORTAGE

PROBLEM STATEMENT AND EFFECT

At the beginning of the S-II Program, DD Form 250 preparation requirements included the listing of actual shortages and held up items that were accomplished at time of Stage delivery. Since the applicable Contractor Nonconformances (CNC's) and Government Nonconformances (GNC's) that authorized shipment were also required to be listed, the listing of actual shortages/ held up items was redundant, causing an expenditure of unnecessary manhours.

SOLUTION/RECOMMENDATION

Negotiation with the NASA resulted in procedural changes to delete the requirement of listing actual shortages/held up items on the DD Form 250. The applicable CNC/GNC is listed on the DD Form 250 and crossed references to a shortage report. This method reduced the DD Form 250 by approximately 25 percent, and resulted in a cost savings in manhours and materials.

DISCUSSION

See discussion in Quality Assurance 01-01.

TRANSFER OF OPEN WORK BETWEEN STATIONS/DEPARTMENTS

PROBLEM STATEMENT AND EFFECT

Work authorization documents, which provide detailed sequence of operation for part and assembly fabrication, are preplanned and released to the manufacturing areas in book form (fabrication and inspection records (FAIR) and/or test and inspection records (TAIR) books). During manufacture of an end item, the parts and assemblies are processed through a series of departments and/or stations where numerous FAIR and TAIR books are applicable. At time of transfer of an assembly or partial end item between departments and/or stations, one or more sequence of operations may be open in several FAIR or TAIR books. In order to accumulate incomplete work and eliminate a gross amount of paperwork, each FAIR/TAIR book is reviewed and open operations are transcribed to shortage reports which accompany the assembly or partial end item to the next work station or department, while the FAIR and TAIR books are transferred to a bonded file area. The shortage reports are integrated as a section of the FAIR and TAIR books applicable to the next station and/or department.

The transcription of open operation from FAIR/TAIR books to shortage reports creates a loss of information or incomplete instructions. This results when such extracted information is taken out of context with related sequences which have been previously completed and signed off.

SOLUTION/RECOMMENDATION

Representatives of Manufacturing, Test Operations and Quality Assurance were appointed as members of a FAIR/TAIR book recap (closeout) team. This group of personnel performed an assessment of the type of problems created during recap operations on assemblies and end items previously completed. Upon completion of the assessment, the recap team was assigned the responsibility of FAIR/TAIR closeout on future assemblies and end items.

An alternate solution which provides for less transcription of data during recap and transfer of assemblies and end items between stations/departments is warranted. On future programs, if magnitude and complexity mandates the release of large quantities of preplanned work authorization documents, it is recommended that initial Manufacturing planning incorporate work descriptions (Manufacturing sequence of operations) within the FAIR/TAIR systems which cannot be transcribed out of context to other documents.

Each operational description would provide an adequate definition of what work was to be performed, locations within assembly or end item, and the applicable drawings and/or specifications.

Further economies and/or improvements should be incorporated into the FAIR/TAIR system through implementation of an automated release system which would allow for transfer of open FAIR/TAIR documents between stations/departments in lieu of recap and closeout. In order to status open FAIR/TAIR documents to reflect latest design changes, the physical location of the records must be known. The current automated systems (POLAR/MADRE), with minor program changes, would provide the required visibility of document location.

DISCUSSION

Work authorization documents, as preplanned and released to the Manufacturing areas, contained operational sequences that were dependent upon information embodied in other sections (Parts List, General Notes, Operational Sequences, etc.) of the same document. When work defined in the operational sequence could not be completed due to shortages or behind schedule conditions, internal procedures required that open items be transferred to Shortage Reports, and FAIR/TAIR books be closed. Operational sequences, when transcribed verbatim from the FAIR/TAIR book to the shortage report, were not accompanied by other supporting information which was required by other departments. In order to complete the required work, the next department/station was required to perform extensive research to assure accurate interpretation of the listed shortage item. Quality Assurance in conjunction with Manufacturing and Test Operations formed a task team that was delegated the responsibility to perform all FAIR/TAIR recap operations on major assemblies and/or end items. This group reviewed all FAIR/TAIR books and transcribed incomplete operations to shortage reports along with required information extracted from other sequences or sections of the same document. This method, although not 100 percent effective, eliminated the major problem and reduced documentation research time. However, the aforementioned alternate method of resolution provides a more consistent approach for open work transfer.

LOSS OF TRACEABILITY/RETRIEVAL CAPABILITY FOR HARDWARE/HISTORICAL DATA

PROBLEM STATEMENT AND EFFECT

The S-II Program's identification and traceability (I&T) system was established upon concepts which provided a capability of tracing materials/ parts history from the inception of manufacturing through current status or from current status backward to the point of manufacture. This process required disciplines for recording and retention of data at each level of manufacture and physical application of unique serial/lot numbers to both hardware and software. However, due to human error, system imperfections and/or conflicting requirements, serial/lot numbers were omitted, transcribed incorrectly or recorded on nonretrievable documents, which prevented recovery of part histories and/or acquisition of questionable material/parts for assessment and disposition.

Loss of traceability affected the capabilities of Engineering and Quality Assurance during performance of failure analysis when the physical hardware had been expended. In addition, material/parts which were of a suspect series could not be located for evaluation and/or disposition.

SOLUTION/RECOMMENDATION

Identification and traceability problems, as encountered during manufacture of the S-II Stage, were resolved through employee training, revision of Manufacturing planning techniques, publication and distribution of specific I&T problems, and physical reinspection of hardware. Problems created because of conflicting requirements and system imperfections were not satisfactorily resolved for all conditions, and more economical work around solutions were devised.

Traceable Parts Used in Exempt Applications

In order to circumvent accountability problems the use of traceable parts in exempt application should be discontinued. Since alternate resolutions would degrade the capability of recovering questionable parts/materials, the above solution is the only recommendation to be made. Disciplines should be implemented during the design phase on new programs.

Surplus of Traceable Parts

Accountability for traceable parts/materials, which are disposed of through the excess property control system (Surplus Inventories), requires implementation of an automated control system. The Inventory Schedules Record, and other forms used to surplus excess property, should be revised to provide direct keypunch capability to circumvent additional transcription cost. Current automated programs would provide input/output capability with minor system revisions. Alternate resolutions would require listing of one part number on each surplus document and establishment of a manual file. The control system should be functional prior to date of parts manufacture on new programs.

Traceable Parts in Spares Inventory

Accountability of traceable parts/materials stored in Logistic's inventory should be shown by serial/lot number in the mechanized Logistics Inventory Management System (LIMS). This system currently reflects the part number, quantity, site location, reparable status, etc., and only minor programming changes would be required to incorporate the serial/lot number. An alternate solution could be implemented by limiting one traceable part number on each Material Inspection and Receiving Report and establishing a manual file. Spares accountability should be implemented during development of spares requirements.

Rework of Space Division and Supplier Manufactured Parts

Historical data related to internal and/or supplier-manufactured items should be updated through automated systems to reflect modifications performed at the Space Division or suppliers facility. Fabrication and test inspection records (FAIR and TAIR) documents generated internally to modify parts/assemblies, for both manufactured and procured items, should be inserted into their appropriate system book. Purchase orders which are prepared for return of supplier items for modification and/or repair should specify acceptance data package update with copy distribution as required on original purchase order. When parts are reworked from one part/dash number to another, the latest acceptance documentation (FAIR, TAIR, or Supplier ADP) should show the old part/serial number and new part/serial number even though the serial number may not change. No alternate solution to this problem is justified. Implementation should be accomplished during inception of manufacturing and/or procurement activity.

Exempt Parts Requiring Traceability

Specific categories of parts which require control for reasons other than criticality must be designated as traceable to assure retrievability of generated histories. These components are categorized as requiring data elements relative to operating time/cycle, age control, periodic maintenance, pressure vessel, etc., and include the next higher assemblies containing such items. No alternate method of control is warranted and implementation on new programs should be accomplished at inception of the design effort.

Loss of Traceability Through Human Error

Resolution of total problems created through human errors are most difficult due to lack of visibility. However, anomalies created can be minimized through preparation of detailed system descriptions, training aids, specific planning operations, and employee counciling upon identification of initial error. Training aids should be maintained current to type of errors being inserted within the system. System descriptions should be prepared and distributed to personnel working at the shop level.

DISCUSSION

Since I&T problems are varied, recommendations are provided for each type of problem detailed within this paragraph.

Traceable Parts Used in Exempt Application

In order to reduce cost, Engineering revised the S-II Stage drawings to permit use of traceable items procured to Specification Control Drawings in exempt application. Traceable parts used in exempt applications were reidentified by addition of an "E" instead of the last dash in the part number. This practice permitted procurement to buy in larger volume at reduced cost. However, when a defect/failure was isolated to a specific serialized series of parts, and recovery action was necessary, only those used in traceable application were retrievable. The remaining parts could not be verified as being used in exempt application or located in stock. This condition prevented closeout of the anomaly and created requirements for extensive research.

Surplus of Traceable Parts

Manufacturing and Logistics' parts which were disposed of through the excess property control system (surplus inventory) were documented on a

Material Transfer Order, and listed on the series Inventory Schedule Records for final disposition. The forms were filed by an assigned serial number. Cross-reference of part/serial number to transfer disposition document was not available. Questionable materials which were to be recovered and were not located as active program items could only be verified as surplus through review of total excess property files. This effort was costly and sometimes ineffective.

Traceable Parts in Spares Inventory

Traceable parts in spares inventory could not be accounted for except through physical inspection of all warehouse areas. This effort is only effective if visibility is maintained over several days to assure accountability of spares in-transit between warehouse locations. When questionable material/parts are to be recovered, the portion retained in spares inventory is costly to locate and disposition. The spares quantity is often in doubt because of fluctuation in total parts count due to the in-transit condition.

Rework of Space Division and Supplier Manufactured Parts

Space Division documentation generated to rework in-house or supplier-manufactured components was inserted in FAIR/TAIR books unrelated to the stage system being reworked. This resulted in problems during preparation of the acceptance data package and created requirements for excess data research during failure investigations. In addition, purchase orders processed to components returned to the supplier for modification/repair failed to identify acceptance data package (ADP) update requirements. Failure to update the supplier data, on file at Space Division, was costly in research time when performed in support of the failure investigation.

Exempt Parts Requiring Traceability

S-II Program components (stage/GSE) that are controlled because of operating time cycle, age control, periodic maintenance, pressure vessel log, etc., requirements were not designated as traceable on engineering drawings. Difficulty was encountered during periodic evaluation of items in this category due to serial numbers not being recorded on all transaction documentation.

Loss of Traceability Through Human Error

Traceability was lost on program hardware due to omission of requirements on FAIR/TAIR planning, incorrect serial numbers recorded, parts identified with incorrect serial/lot numbers, and failure to record data. This impaired the capability of retrieving hardware histories and/or recovery of questionable materials.

QUALITY DISCREPANCY DATA

PROBLEM STATEMENT AND EFFECT

Customer requirements specify that each contractor will have a method of recording discrepancies, rework, scrap, etc. This requirement is established for the purpose of measuring the quality level of the product, process, work area, and workmanship. The data may be presented in various formats for corrective action or motivation. Many people are involved in the process of counting, reporting and posting discrepancies and each may use different methods of establishing ground rules for counting discrepancies and the assignment of responsibility. The absence of a definitive procedure for ground rules resulted in reporting a minimum count that the customer erroneously interpreted as inability to detect discrepancies.

SOLUTION/RECOMMENDATION

Establish a procedure with forms for daily inspection reporting of discrepancies. This procedure should define ground rules as to the method of counting and coding of type and cause of each discrepancy. A plan should be established for transmittal, analysis, type and level of reporting. Personnel at all levels should be trained in the operation of the system.

DISCUSSION

Government specifications require records to be maintained and utilized for economical and effective operation of a quality program. Records are considered one of the principal forms of objective evidence of quality. Records should, as a minimum, indicate the nature of the observations, number of observations, and the number and type of deficiencies found. The quality program shall provide analysis and use of records as a basis of management action. Corrective action shall include as a minimum:

1. Analysis of data and examination of products scrapped or reworked to determine extent and causes.

2. Analysis of trends in processes or performance of work to prevent nonconforming products.

3. Introduction of required improvements and corrections. A system to measure and monitor the effectiveness of corrective action taken.

Data was maintained such as Material Review Dispositions, and the resulting rework, scrap, and OK to use. The defects were noted on the squawk or disposition sheet in the fabrication, test and inspection records books, but the method of reporting was not standardized and reported to a central area for analysis and charting in order to measure the trends in processes and work. Standards did not include the counting of defects such as: one assembly might have 300 bracket installations of which 170 were mislocated. One inspector or supervisor would include the 170 mislocated brackets in one squawk and count it as one defect against the manufacturing department or group. Another inspector or supervisor would report the 170 mislocated parts as 170 defects. This same problem existed in reporting such items as drilled holes, scratches, spot ties, safety wire, etc.

The customer has inspectors surveying work completion at various points of in-process fabrication. The customer inspectors list each defect as a single item, each hole out of tolerance being a defect. The systems used by the Company and customer must be compatible.

In addition to reporting a defect, the following minimum information is required for analysis and reporting.

- Defects by department/work station
- Defects by station/leadman
- Defects/inspections by leadman
- Defects by responsibility
- Defects by part number
- Defects by disposition code
- Defects by department/quantity
- Defects by assembly serial No. or completed article sequence number

CONTRACTOR AND GOVERNMENT NONCONFORMANCES (CNC/GNC)

PROBLEM STATEMENT AND EFFECT

Prior to inclusion in the acceptance data package (ADP), CNC/GNC data must be reviewed and approved by the NASA. At the beginning of the S-II program, these data were accumulated and submitted after all fabrication, test and inspection records were closed and returned to quality information. Due to the volume of data and the limited time span between review and scheduled stage delivery, "around the clock" effort by NASA and NR personnel was often required to meet delivery schedules.

SOLUTION/RECOMMENDATION

A method was established whereby weekly status meetings were conducted for the purpose of tracking CNC's/GNC's. The meetings began with stage acceptance by Test Operations from Manufacturing and continued until stage delivery. Each open item was discussed and CNC's/GNC's were initiated for those items expected to be unaccomplished at time of delivery. Preliminary reviews were conducted with NASA and CNC/GNC documentation approved incrementally, thereby eliminating the total effort after book closure and precluding possible delivery constraints. This method could be adopted to future programs with a minimum effort and would facilitate preparation of the ADP and DD Form 250.

DISCUSSION

See discussion in Quality Assurance 01-01.

POUR FOAM RAW MATERIAL STORAGE

PROBLEM STATEMENT AND EFFECT

A large portion of field repair of Saturn S-II foam insulation is accomplished with pour foam. Pour foam is procured in 10-gallon kits (two 5-gallon cans make one kit). One of the two pour foam components (isocyanate) is extremely sensitive to moisture. The other component (polyol) is sensitive to elevated temperatures (above 74 F). During certain times of the year, the test sites are subject to extremely high temperatures and relative humidity conditions. In addition, the vehicle under repair is quite often located in the uncontrolled outside environment of the test stand or launch pad. Since most pour foam repairs require relatively small amounts of raw material, repeated opening of the containers is required in this adverse environment. These conditions make quality control of this raw material extremely difficult.

SOLUTION/RECOMMENDATION

The problem was never fully resolved on the S-II Program. Field site quality control personnel were required to perform relatively high-level material validation tests to assure continued raw material quality. In addition, the raw material would be scrapped and replaced as required.

An improved, raw material handling technique was developed in the laboratory, and is the subject of this writeup.

A storage and dispensing system was developed consisting of two stainless steel tanks. Each 10-gallon capacity tank was insulated with approximately one inch of pour foam and was identified with respect to the foam composite to be stored in the tank. Each tank was equipped with the necessary siphon tube, relief valve, pressure gauge, and quick-disconnect fitting for pressurization. It was critical that all metallic components be fabricated from stainless steel. Other metals were found to chemically react to the foam components resulting in greatly accelerated reaction rates (20 seconds down to 5 seconds). A portable cart, equipped with a high-pressure bottle of dry nitrogen to be used as a dispensing gas, was designed to carry the foam tanks.

The foam storage and dispensing system provided the following features:

1. Due to insulation on the dispensing tanks, the system could be allowed to stand in the hot sun at elevated temperatures for

extended periods of time without the foam components exceeding the 74 F allowed by the specification.

2. Material could be stored without fear of loss of the freon blowing agent, since a positive pressure head of GN_2 was maintained at all times.

3. The potential for contamination by ambient moisture was eliminated.

4. The possibility of component contamination during sample removal was eliminated.

DISCUSSION

When Freon-blown foam systems were procured for use on the S-II Program, extensive testing was performed to verify the proper chemical balance of the two components and associated mechanical properties. In order to assure repeatability of mechanical properties to meet design requirements, it was necessary to assure that proper chemical balance was maintained when the two components were mixed together.

It was necessary to control two critical elements to assure proper chemical balance; heat and moisture. If the polyol component was exposed to temperatures in excess of 74 F, the Freon blowing agent would vaporize thus reducing the quantity present if the container were either open or leaked. If the isocyanate component was exposed to moisture, the isocyanate would react with the moisture forming crystalline urea compounds. If either or both of these conditions were allowed to occur, the proper chemical balance could not be achieved by a predesignated proportional mixing of the two components.

SELECTED PROBLEM AREAS ASSOCIATED WITH SPRAY FOAM INSULATION

PROBLEM STATEMENT AND EFFECT

During the development of spray-on-foam insulation (SOFI) for application on the Saturn S-II, numerous problems were encountered. Three problems which were not identified prior to commencement of production operations have been selected for discussion herein. Specifically, the problems were as follows:

1. SOFI Divots. During detanking of cryogens from the S-II at MTF, numerous small plugs (2 to 6 inches in diameter) of foam insulation would pop off the tank wall at random locations. The phenomenom was caused by minute leak paths which had gone undetected during production operations. The leak paths led from the external surface of the insulation down to the LH_2 tank wall proper. In many cases small pockets, or voids, were found at the tank wall along the leak paths. When the structure was loaded with liquid hydrogen (-423 F), ambient air would enter the leak paths and liquefy in the pockets at the cold tank wall. During warmup of the structure following detanking, the pockets of liquid air would essentially explode when the boiling point of the liquid air was reached, thus causing the divoting phenomenon to occur.

2. SOFI Rind. The ability of foam insulation to remain structurally sound during cryogenic operations is directly related to the low modulus of elasticity of foam at the foam/cold tank wall interface. The foam insulation, when properly applied, does have the ability to withstand the strain and shrinkage levels encountered on the S-II structure during cryogenic operations.

   During some spray foam operations rework, on the S-II-7 vehicle in the test stand at MTF, an extremely high density rind layer was encountered at the foam/tank wall interface. Had the condition gone undetected, the foam insulation would have become debonded during cryogenic operations. A subsequent investigation revealed that all specification processing requirements (temperature, humidity, etc.) had been met during the spray operations that led to the rind formation.

3. Corrosion. When the SOFI concept was originally implemented on the S-II Program, there were two different primer systems used with the foam composite. The majority of the aluminum structure was primed with heat-cured phenolic primer. Weld closeout areas were primed with room temperature curing polyester primer. It was subsequently discovered that all aluminum surfaces were corroding under the SOFI where the polyester primer system was employed. All such areas were redesigned and reworked with considerable program impact relative to schedule and cost.

SOLUTION/RECOMMENDATION

SOFI Divots

A comprehensive design review was conducted to determine those regions of the SOFI which would be most susceptible to the formation of leak paths that would lead to the divoting phenomenon. Those areas were generally determined to be:

1. All foam to foam joints

2. All hardware penetrating the SOFI (hard spots, wire bundles, hard lines, etc.)

3. SOFI containing buried protuberances

4. Areas requiring multiple spray operations during initial production

A redesign was initiated to re-seal all SOFI areas prone to divoting. The rework resulted in a large reduction in the number of divots following cryogenic operations. In addition to the sealing rework, all insulated areas were mapped out and rated based on insulation criticality and allowable heat leak. Zone numbers were assigned, and allowable divot areas were established for each zone. This was accomplished specifically for divoting that occurred as a result of final tanking tests just prior to launch of the vehicle.

SOFI Rind

It was verified that the rind condition occurred even though all specification processing parameters were met. The investigation of the phenomenon led to the discovery that the rind layer formed because of immediate loss of the exothermic heat internally generated during the foaming reaction.

Lacking the necessary internal system heat to expand the freon blowing agent contained in the foam reactants, the cellular structure failed to form, thus producing the rind layer.

The process specification in effect at the time of the rind problem established environmental parameters only for the immediate area being processed (foamed). To preclude rind formation in subsequent spray foam operations, the specification was revised to require a temperature equilibrium for the entire stage structure prior to commencement of spray operations on any portion of the stage structure. The requirement for temperature equilibrium is critical and mandatory for all spray foam operations on structures designed for cryogenic operations.

Corrosion

It was determined by an extensive laboratory investigation that the Freon 11, used in the foam system as a blowing agent, entered into a corrosive reaction with the 2014 aluminum tank structure in all areas where the sole primer system was polyester. A laboratory program was initiated for selection of a room temperature curing primer that could replace the polyester system and act as an adequate corrosion barrier. Koropon 515-701, a modified epoxy primer, was ultimately selected and applied to all affected surfaces.

DISCUSSION

SOFI Divots

The divot phenomenon was first experienced in July 1967. NR insulated a Thor Delta LOX tank with spray foam insulation for LH_2 testing at the McDonnell Douglas Sacramento facility. Divoting occurred following each cryogenic cycle, primarily along the foam/foam joints in the closeout areas. The basic cause of the divots was attributed to pockets of cryopumped air which had been formed at the cold tank wall from a leak path connecting the tank wall to the outer foam mold line.

It was determined that the leak paths were usually caused by one of two factors. Either the leak path was the result of a porous foam to foam joint or was the result of a foam joint that had cracked to the tank wall during cryogenic operations.

The Thor test tank program was used to optimize the foam to foam joint configuration, which was finalized as a straight vertical butt joint, perpendicular to the tank wall. The cut surface of the joint was sealed with a polyurethane adhesive prior to spraying the closeout. If the seal coat was even slightly porous the joint would invariably leak, resulting in foam divots. If the polyurethane adhesive was allowed to flow from the foam onto the tank wall, the joint would probably crack during cryogenic operations, also resulting in foam divots during warmup following cryogenic testing.

Optimization of the foam joints greatly reduced the problem on the Thor tank; however, some divoting did occur on the first foam insulated flight articles tested at MTF. A design modification was finally implemented which required a coat of polyurethane adhesive on the outer joint mold line. This final seal coat reduced the occurrence of foam divots to a relatively insignificant level. This seal coat was also applied to hard lines, etc., protruding through the outer foam mold line.

SOFI Rind

The rind on spray foam was the noncellular layer that was formed immediately adjacent to the substrate. On nominal foam, the layer was only 2 or 3 mils thick, looking very much like a thin skin. Immediately above the rind was a region where the foam density was somewhat higher than the nominal 2 pounds per cubic foot.

The actual thickness of the rind and the actual thickness and density of the high-density layer were a function of the amount of exothermic reaction heat absorbed by the substrate during the foaming reaction. For this reason it was undesirable to spray foam on cold surfaces, especially large heat sink zones such as the Bolting Ring assembly on the S-II vehicle.

The high-density foam layer, including the rind, was undesirable from the standpoint of cryogenic strain compatibility. The modulus of elasticity of the rind layer was considerably higher than that of the nominal foam. Laboratory tests verified that foam samples containing severe rind conditions would not meet the cryogenic strain compatibility requirements for the S-II Stage.

The presence of an excessive rind condition was never encountered on any spray foam applied to an S-II Stage during normal production operations. Excessive rind (approximately 1/8 inch thick) was found only once during the application of spray foam to the LH_2 feedlines of the S-II-7 at the Mississippi Test Facility (MTF). The spray foam operation was performed while the vehicle was located in the static firing test stand. A check of Quality Control records verified that all environmental parameters in the spray foam area were within specification requirements at the time the spray foam operation was accomplished. The ensuing investigation resulted in a change to the specification requirements relative to temperature conditions during spray foam operations at field sites.

The conditions that led to the severe rind formation were as follows:

1. The S-II-7 vehicle was in the static firing test stand. Ambient temperatures were low, i.e., 40 to 60 F.

2. A portable cubicle with internal heating capability was built around the spray foam repair area for the purpose of controlling temperature and humidity.

3. Ground support equipment was used to heat the inside of the LH_2 tank during spray operations.

4. At the time of commencement of spray foam operations, the tank wall temperature and the temperature in the cubicle were in the mid-70 F range. The relative humidity was less than 60 percent.

5. All equipment checks (ratios, cup densities, etc.) were within specification requirements.

6. Test coupons sprayed on 1/8-inch-thick aluminum, in the portable cubicle immediately prior to repair spray operations, did not contain the severe rind condition.

7. The spray foam repair of the LH_2 feedline cavity was completed. Subsequent dissection of foam samples from the metal substrate revealed the presence of the severe (1/8-inch thick) rind condition.

The explanation for the rind formation was that at the time of spray operations the total vehicle structure—except for the immediate area within the portable cubicle—was at a lower temperature than the spray foam repair area. Therefore, heat dissipation was in a direction away from the repair area in all directions. This heat flow pattern resulted in an accelerated dissipation of the exothermic reaction heat as the foaming reaction commenced. The required amount of heat was, therefore, not available for blowing the Freon in the foam system. After formation of the 1/8-inch-thick ring layer, the substrate became sufficiently insulated to allow the remainder of the foam to be of nominal 2-pounds-per-cubic foot density. Since the test coupons had achieved a temperature equilibrium, heat flow was not a factor on the test coupons sprayed simultaneously within the cubicle. No rind formation occurred.

As corrective action, the NR/SD process specification was revised to include the following requirement:

> When spray foam operations are performed at field sites, the work area environmental conditions must be critically controlled during the application of spray foam. In addition, the environmental temperature surrounding the entire stage during the preceding 3 hours is to be 77 F mimimun. The substrate must be at a stable temperature of 80 F, minimum, during spray foam application.

There was no recurrence of excessive rind formation on spray foam insulated structures processed within the revised environmental parameters.

Corrosion of the aluminum structure under spray-foam insulation was discovered to be a major problem in August and September of 1968. The problem was solved prior to delivery of any affected flight hardware to MTF. The problem was limited in scope to those areas of the vehicle not primed with heat-cured primer. The structural areas affected were essentially the weld closeout zones of the vehicle. The weld closeout areas were primed with a solvent-based polyester primer used as a structural tie-coat for the foam.

A laboratory investigation led to the following conclusions:

1. Freon-blown polyurethane foam insulation in contact with the aluminum employed on the S-II vehicle (primarily 2014 and 6061) would result in corrosive attack.

2. Necessary ingredients for corrosive attack are Freon, aluminum, and external moisture. It was verified that the minute traces of moisture within the foam system would not produce corrosion.

3. Under conditions of accelerated aging, the seal coat employed on the outer foam surface would not prevent moisture permeation in sufficient quantities to generate corrosion.

Corrosion

NONDESTRUCTIVE INSPECTION FOR SHEET CORK DEBONDS

PROBLEM STATEMENT AND EFFECT

Cork sheet stock (1/4-inch thick) was bonded over spray foam insulation in certain heat-affected zones on the Saturn S-II. The cork was designed to prevent erosion of the foam insulation and the attendant loss of thermal efficiency during the S-I-C boost phase of the Saturn V launch. A problem arose at MTF and KSC in that following detanking of cryogenics (static firing and CDDT), cork debonding occurred in random locations due to cryopumped entrapped air under the cork. No inspection technique, other than visual, was available for detection of the discrepant areas. Analysis indicated that any cork/foam debond greater than 3 inches in diameter was unacceptable for flight.

SOLUTION/RECOMMENDATION

A nondestructive inspection technique was developed. The principle of operation was based on the fact that structurally sound cork sheet will deflect less under a given tensile load than will a debonded area of cork sheet. The test device, a "vacuum plate," was fabricated from one-inch-thick Lexan polycarbonate. The plate (approximately 7 inches square) was fitted with standoff legs approximately 1/8-inch deep. A soft rubber seal was located adjacent to the legs to provide a positive seal during application of the vacuum. A hole was drilled through the plate to provide a hookup to the vacuum source. A dial deflection indicator was located in the geometric center of the plate. During an inspection, the vacuum plate was placed upon the cork sheet. A vacuum of 5 inches of Hg was applied and regulated by a relief valve incorporated into the vacuum source. When the vacuum had stabilized, the dial indicator was set at zero. The vacuum was then increased to 20 inches of Hg, and the amount of cork deflection was read off the dial indicator. Deflection as a function of debond size was determined by a laboratory investigation. (Reported in Laboratories and Test Report, LR 6491-4568, dated September 3, 1970.) On the particular cork zone inspected on the S-II Stage, the maximum void allowable was established as 3 inches in diameter. Therefore, the applicable cork zone was inspected on 2-inch centers.

DISCUSSION

The vacuum plate inspection technique was highly efficient but extremely time consuming. Even after the development of the inspection technique, Quality Assurance at the production level continued to rely on process control. During production operations, the cork sheet was bonded to the foam insulation using vacuum as a pressure source. The relatively permeable nature of the cork sheet coupled with the extended period of time under vacuum resulted in void-free production bonds. It is emphasized that the debond conditions detected between the cork sheet and the foam substrate, following cryogenic operations, resulted from entrapped cryopumped gases and were not original production defects.

The sequence of events resulting in the debond conditions were as follows:

1. The vehicle was fueled with liquid hydrogen (LH_2) at -423 F.

2. Cryopumping would then occur at any point in the insulation composite where even a minute leak path existed to the cold tank wall.

3. Depending on the length of time at -423 F, small pools of liquid air would collect at the tank wall.

4. Following detanking, the stage would slowly warm up to ambient temperature. When the boiling point of the liquid air pools was reached, an extremely rapid expansion of gases took place.

5. If these areas were located under zones insulated with sheet cork, the rapid expansion of gases would invariably result in a debond of the cork from the foam substrate.

INCIPIENT CRACKS IN INCONEL 718 WELDMENTS

PROBLEM STATEMENT AND EFFECT

Leakage through the wall of a stage pressurization duct in a stage was discovered during production leak check. Leakage was in the area of a circumferential weld and was not detected during fabrication/checkout of the duct section.

SOLUTION/RECOMMENDATION

Improve the inspection techniques used by the duct manufacturer during the manufacturing build-up of the line and revise the acceptance test procedure to assist in the detection of leaks.

DISCUSSION

During the investigation of the cracking problem it was determined the cracks occurred as a result of stops and starts during the welding process producing uneven stresses in the forged Inconel 718 material. The most successful method to eliminate the starts and stops was to change to machine welding. This was not feasible as a solution for the immediate problem since all hardware for stages on the existing contract were already fabricated and delivered. However, test ducts were fabricated and the machine welding techniques determined along with an improved forging process for the Inconel 718 rings.

The solution was to improve the quality of X-rays taken during duct manufacturing by increasing the number of shots per weld, by controlling the film, X-ray machine, distance from machine to duct, and by using single wall shots and other X-ray process techniques. These methods assisted in the detection of cracks during the welding inspection. Along with the X-ray technique improvement, the acceptance test procedure was resequenced to perform the pressure leak checks during the time the duct was readily visible to increase the possibility of detection.

RUNNING WELD STOP TECHNIQUE

PROBLEM STATEMENT AND EFFECT

No definite cause could be given for the crack conditions which occurred in the S-II aft common bulkhead horizontal weld crossover after repeated weld repairs. The aft common bulkhead had been repaired after the 3-cycle hydrostat test.

SOLUTION/RECOMMENDATION

The defective areas in the aft common bulkhead were grooved to approximately 60 percent. The defects remained. The grooves were manually welded with penetration to push the defects into the drop through weld metal. Both manual-welded areas were X-ray acceptable but contained microporosity. Tests were conducted to determine the machine weld techniques. The weld was the deposited transverse meridian weld along the waffle to sheet weld with a ball up stop. Angled X-ray views taken after the repair showed linear indications adjacent to the weld stop area which were interpreted as cracks. It was decided the stop technique (ball up stop) caused the crack indication. Weld tests were conducted to determine a better weld stop technique. The running stop was determined to have the best possibilities. This technique was refined to allow a reliable crack-free stop and included in a weld schedule. An alternate solution to preclude occurrence is to groove to 50 percent from either the weld face or root side, and reweld through the groove.

DISCUSSION

The defects remaining in the aft common bulkhead weld repair were dispositioned to continue into the three-cycle hydrostat test and would remain acceptable as is, provided the defects did not propagate during the hydrostat test. X-ray inspection after the hydrostat test revealed that one 0.085-inch porosity defect had propagated to a 0.10-inch pore with tail which was unacceptable. The cause was determined to be the ball up stop weld technique.

THICK TO THIN WELD

PROBLEM STATEMENT AND EFFECT

A thick-to-thin weld performed on the S-II Stage gore panels, exhibited peaking which caused microfissuring when the meridian weld passed through this area.

SOLUTION/RECOMMENDATION

The thick-to-thin welds are to be depeaked by using an Enerpac tool prior to loading into the meridian welding tool.

An alternate solution was to minimize the backing and hold-down fixture pressure.

DISCUSSION

The thick-to-thin weld performed at the Los Angeles Division has peaking in the gore panel configuration. When the gore panel is held in the tool for meridian welding into aft common bulkhead configuration, the peaked area tends to straighten due to the backing and hold-down fixture pressure. The resulting stresses in the weld caused microfissuring when the meridian weld passed through this area. Nondestructive testing could not often reveal these microfissures prior to hydrostat testing. During hydrostat testing, the microfissures could propagate into cracks which are then detectable by nondestructive testing methods.

WELD LAND DIMENSION

PROBLEM STATEMENT AND EFFECT

Weld land dimensions were discrepant and caused excessive rework.

SOLUTION/RECOMMENDATION

The solution used on the S-II Program was issuance of engineering changes expanding the weld land dimension.

DISCUSSION

Due to the excessive amount of oversize weld land dimensional discrepancies, Design Engineering and Quality Engineering investigated the problem. It was found that LH_2 quarter panels and bulkhead components had slight width variations which exceeded allowable drawing tolerances. These width variations caused squawks to be written and an excessive amount of hand filing rework to be performed. This rework being slow and tedious caused delay in schedules and programming. The Design Engineering investigation resulted in expanding the weld land dimension.

WELD LAND MEASUREMENT - IN-PROCESS FABRICATION VERIFICATION

PROBLEM STATEMENT AND EFFECT

Two-inch plate stock was machined, Chem-milled, formed, and trimmed leaving excess material for pre-weld trim. The design tolerance for the material thickness at the weld land was critical in order to obtain a proper butt-weld joint and minimize peaking. Each measurement was taken at the discretion of the individual inspector with no index points established. Repeatability of measurements at different stations did not occur. Variations in measurement caused excessive hand work at time of the weld setup.

SOLUTION/RECOMMENDATION

Measurement systems on large surfaces should be standardized for repeatability.

Development parts and first articles should be reviewed to establish and standardize measurements in a formal manner that will reduce the variations in reinspection measurements. The standardization of measurements, on large panels with critical weld land thickness, was accomplished by establishing procedure and matrix forms of the part showing the weld land area. Specific types of measuring equipment and the method of usage was established. Specific start point for the first measurement, with incremental points for subsequent measurements, was established and the actual readings recorded on the matrix form that traveled with the part and became part of the inspection records.

DISCUSSION

Initial inspections of the weld land thickness were the responsibility of the inspector using measuring devices. The problem existed when, during the manufacturing sequence, an additional weld land inspection was conducted by the same or another inspector. The resulting readings varied and out-of-tolerance readings found were not found on the first inspection. A Quality Engineering review of five inspectors resulted in the findings that each inspector would start his measurements at different points. In addition, a variation was found when inspections were made in small increments inboard or outboard the surface of the weld land. By controlling the start point index, distance between measurements, approximate weld scrib line area of the weld land, and listing the actual measurement on a matrix sketch of the part, a close measurement repeatability could be maintained.

EARLY REDUCTION OF DISCREPANCIES -- FIRST ARTICLES DELIVERED AGAINST PRE-DELIVERY ARTICLE

PROBLEM STATEMAND AND EFFECT

A thorough shakedown inspection is established for each major assembly and each completed article upon manufacturing completion prior to test, post-test, and pre-shipping. Some discrepancies (defects) are not evident until after final article usage.

SOLUTION/RECOMMENDATIONS

Firm shakedown procedures and methods should be established for each point of transfer and receival. A method established for feedback of documentation, including photographs, and each reported discrepancy reviewed and corrective action documented when indicated. A task team (company and customer) should be established to inspect the first article delivered to the customer, document the results and perform the same shakedown against their findings on the second, third, etc., article backstream to the test sites and manufacturing facility. The effect would be to surface the largest number of defects possible for detection and correction, eliminate opinion problems, and furnish engineering design evidence of problem areas where changes might be required. A quality product, on time and at a minimum cost, will be realized at an early point.

DISCUSSION

New programs push the state-of-the-art on initial design and, as design drawings are released for fabrication, changes occur. Schedule is tight, and in some cases due to circumstances such as parts shortage, a behind schedule condition exists. The frequency of repeating specific fabrication events is infrequent, causing various operations from becoming shop practice. Personnel training becomes a problem due to a rapid buildup of personnel. Some requirements are accomplished, but not to the intent of the designer. Many initial program problems may result in numerous discrepancies in early production, test, and usage.

It is necessary that special effort be concentrated in the area of critical inspection reviews by specialized teams of technical personnel. The teams should review the end product and usage to locate, document, and notify all concerned personnel, and monitor corrective action and corrective action results.

On a complex functional item it is best to establish more than one team and divide the tasks into product systems. A comparison of the findings on the first delivered item against the same articles in preparation for delivery, test and fabrication, will aid in a rapid decrease of discrepancies and assure the quality and reliability of the product.

INSULATION SLEEVING

PROBLEM STATEMENT AND EFFECT

Wire insulation was damaged from the high temperature required to shrink insulation sleeving.

SOLUTION/RECOMMENDATION

The Saturn S-II Program changed their engineering specification to use sleeving that shrinks at 271F instead of the former high temperature of 400 to 600F. Engineering updated applicable drawings.

It is recommended that future programs evaluate compatibility between materials and processes prior to production.

USE OF BREAKOUT BOX FOR HAND CONTINUITY VERIFICATION OF ELECTRICAL HARNESSES

PROBLEM STATEMENT AND EFFECT

Two technicians were used to check harness continuity, subsequent to stage installation modification, by each placing a multimeter probe to a connector pin and calling out the pin identification. This sometimes led to wrong pins erroneously being probed or called out with two errors (installation and testing) resulting in a miswired cable. Also, direct probing or the use of a socket pin could result in marred, scratched, or bent pins or sockets.

SOLUTION/RECOMMENDATION

The S-II Program used mating receptacles which were connected to a simple interconnect box which one operator could use. This breakout box required a switch for operation, and reduced the operator error to wrong pin or socket identification and testing. This method of test resulted in several miswired cables being detected, and avoided rejection of acceptable cables.

Recommend that all future programs provide simple breakout boxes for technician use.

Quality Assurance 10-03

SUBSTANDARD QUALITY ELECTRICAL WIRE AND CABLE

PROBLEM STATEMENT AND EFFECT

During the initial production phase of the S-II Program, detection of discrepancies in electrical wire and cable were occurring at an alarming rate. Due to the criticality of the S-II Stage wire and cable requirements, it was necessary that immediate action be taken to reduce the rejection rate.

Defective wire and cable exhibited defect conditions such as: burned spots, splits in the insulation, longitudinal striations, bulges, and foreign material. The aforementioned conditions could result in dielectric failures, open circuit conditions, and loss of environmental seal.

SOLUTION/RECOMMENDATION

The solution to the problem was in three phases. The first phase defined specific criteria for accomplishing the reinspection of assemblies in work. Phase two set forth the re-test parameters for all unprocessed wire and cable in stock. The third phase was revising the procurement requirements for future orders and the establishment of a limited source capable of producing high quality wire and cable.

DISCUSSION

The procurement of high quality wire and cable for use in sophisticated aerospace vehicles presents a formidable problem to the vehicle manufacturers. The problem arises from two principal factors: (1) the nature of the domestic wire and cable manufacturing industry, and (2) the requirements peculiar to aerospace vehicle wire and cable.

The domestic wire and cable manufacturing industry is highly competitive. Firms whose primary source of revenue is the manufacture and sale of wire must product at minimal cost and sell in large quantity to realize acceptable returns on investment. In order to operate in this manner, most wire manufacturers are geared to high speed production of commercial and telephone-type wire and cable where cost rather than quality is of primary concern. While the total conductor footage required to produce a single aerospace vehicle may be formidable (it is estimated to be in the order to 2,000,000 feet for one Apollo-Saturn V vehicle) because so few units are produced, total footage required for one program is quite small when compared to the production capacity of even a small mill. Thus, the earnings potential for supply of aerospace wire for any one program does not warrant the expenditures required to initiate special production and quality control procedures necessary for the manufacture of the very high quality material needed in some aerospace programs. This would be true even if all the procurement of one type of material required for one program were made from the same supplier. This situation is further compounded by the necessity of making buys based upon competitive bidding. This requires the approval of a number of suppliers (there are nine presently approved to supply Saturn stage wire and cable) which results in reducing the quantity of material procured from any one source to a trivial level.

There is no quick and easy solution to the problem of consistent procurement of high quantity wire and cable. The measures outlined in this summary should assure better quality material if they are fully implemented. Beyond this, perhaps basic concepts must be examined. Among the concepts which should be examined are: (1) procurement of wire and cable intended for critical aerospace applications like any other raw material, (2) handling, storing and distributing of wire and cable like any other raw material, and (3) classification of wire and cable as a raw material.

STAGE DIMENSIONAL ALIGNMENT

PROBLEM STATEMENT AND EFFECT

Variations and inconsistencies in performing precision optical and mechanical stage alignment measurements resulted in incorrect or questionable data required to meet stage alignment requirements. Measurements reflecting NASA, MSFC requirements were performed in various stations utilizing noncontrolled measurement techniques, and with varying tool setups. The result was missing or inaccurate stage dimensional configuration measurements.

SOLUTION/RECOMMENDATION

Definitive stage alignment plans and requirements documents that specified the location of tool setups, measurement techniques, and data recording of all stage alignment requirements to assure accuracy and repeatability of measurements were provided.

DISCUSSION

Precision optical and mechanical measurements may vary considerably depending on the type of measurement technique and tool setups used. The time periods between stages and changes in personnel performing the measurements emphasize these variations. In order to definitively control contractually required stage alignment data, Quality Engineering and Manufacturing Engineering provided a five-phase plan and sets of requirements documents. These documents, implemented during the specified fabrication cycles, result in the accumulation of all required data in a controlled manner and of known accuracy. Quality Engineering provided stage alignment inspection instructions specifying required inspections and data reflecting the MSFC interface control document (ICD), and stage alignment specification. Manufacturing Engineering prepared tool drawings specifying all tool and measurement setups with measurement instructions. The inspection instructions and measurement documents were cross-referenced with all measurements requiring inspection verification of setup and technique.

RIB STRINGER CRACKS ON LARGE MACHINED SURFACES (LH_2 PANELS)

PROBLEM STATEMENT AND EFFECT

The LH_2 tank skin after machining has a wall thickness of 0.125 inch with three machined horizontal stiffener stringers and 19 longitudinal stiffeners, 1.375 inch in height and 0.125 inch in width. Large quantity of material cracks occurred during machine and forming operations. Cracks were found in the radius at the start of the stringers and at the base of stringers adjacent to the tank skin. Each crack resulted in material review action for repair or scrap of LH_2 tank quarter panel.

The effect of this problem was high cost of machine time, man-hours, and schedule impact for rework and remake. Material cost and procurement time were also affected.

SOLUTION/RECOMMENDATION

The development of adequate machine tapes, machine capability studies, machine cutting rate should be established at an early period in the development program and controls established to prevent variations to proven methods. Adequate personnel training and specific task assignments should be used. The machine forming should also be developed and controlled in the early stages of development.

Strain and stress analysis are required to more adequately establish thickness and radius tolerance for producibility.

DISCUSSION

Panels of this size with ridged machined stringers had not been previously fabricated and subjected to forming operations. New equipment, automated tape machine programs, inspection controls, and handling methods had to be developed by Manufacturing. The schedule need dates were too tight for adequate development and standardization. Engineering tolerances were in some cases beyond the capability of the machines and many hours of hand work were required. As the schedule became more critical, machine settings and speeds were changed to speed up the fabrication process. These changes resulted in more defects and loss of panels due to scrap action. Any change should have been coordinated with a team comprised of Manufacturing Engineering, Tooling Engineering, and Quality Engineering prior to implementation.

ACCIDENTAL DAMAGE AND WORKMANSHIP PROBLEMS DURING PRODUCTION

PROBLEM STATEMENT AND EFFECT

During the initial phases of production of Saturn S-II stages at Seal Beach, an extremely high percentage (21 to 39 percent) of material review actions were caused by accidental damage and workmanship. During early production activities as many as 200 material review actions of this type were processed per month. Disposition and rework of these discrepancies consumed countless man-hours and added considerable costs to the program.

SOLUTION/RECOMMENDATION

Workmanship and accidental damage discrepancies are problems that will exist on any production contract involving complex space hardware. A significant reduction of these types of discrepancies was accomplished, however, on the S-II program by concerted effort in four separate areas:

1. Personnel training
2. Implementation of Pride programs
3. Departmental competition and awards
4. Increased utilization of protective devices

DISCUSSION

On production programs such as the Saturn S-II, much of the design and of the fabrication processes represent advancements in the state-of-the-art. This is further complicated by the problem of designing a minimum weight structure. The result is an end product, built from new materials, using new procedures and techniques. The end product also contains hardware that is subject to accidental damage. In addition, the production labor force must develop new skills on the job as often occurs during initial production of such equipment.

PRODUCT REPEATABILITY - ITS CONCEPT PROBLEMS AND RESOLUTIONS

PROBLEM STATEMENT AND EFFECT

The Product Repeatability Program was initiated when the customer expressed concern about the functional capabilities of high reliability hardware. NR had an inspection program where Source Inspection representatives monitored the suppliers' in-process testing, cleaning, and packaging. Inspection representatives were assigned to the suppliers' plants to eliminate the duplication of complex expensive test equipment for reinspection after receipt. This control was not deemed adequate by the customer. The original inspection plan would have resulted in the inability of supplier high reliability functional hardware to perform to designed criteria after final installation on Saturn S-II stages.

The necessity to replace high reliability components during stage checkout operations at Seal Beach, Mississippi Test Facility, and Kennedy Space Center, contributed to schedule slippage and/or complete redesign of the units. Subsequent effort required a partial retest of either individual components or stage integrated testing.

The reacceptance program produced the following results:

	1827 Components presented
	117 Rejected upon receiving inspection
	1711 Components subjected to test
(18.6%)	319 Components failed to meet test requirements
	Failure Categories
(8.6%)	147 Hardware malfunction
(4.2%)	72 Test equipment
(3%)	52 Test requirements
(1.5%)	27 Unknown/unassigned
(1.2%)	21 Test operator

SOLUTION/RECOMMENDATION

This reacceptance program was initiated upon receipt of the hardware from the supplier for in-house retest to verify that the parts would function properly prior to installation on the Saturn S-II stage.

This type of program should be incorporated into the proposal package on future programs and negotiated as part of the initial contract.

Those items selected for a reacceptance test program should be phased to fulfill manufacturing and installation schedules. Approximately a six-month lead time should be planned prior to the need for installation and/or test in the end product.

DISCUSSION

To obtain a high degree of reliability for selected items, the Product Repeatability Program was initiated. It was found during the reacceptance test phases of the program that there was some incompatibility of the parts to perform to their designed criteria.

1. Physical Discrepancies upon Receival (ID and Damage). Units were found to be contaminated, scratched, etc., upon receipt from the suppliers. Coordination through source inspection and packaging engineering was initiated. Materials review dispositions (MRD's) were initiated for those discrepancies resolved in-house and/or returned to the supplier. In both instances, to preclude a recurrence, corrective action requests (CAR's) were initiated for follow-up corrective action to be taken at the suppliers.

2. Test Specification Clarification. During testing phases, numerous instances arose where the specifications and detail test procedures (DTP's) were not clarified sufficiently pertaining to test parameters and equipment configuration. Task teams reviewed and updated specifications and test procedures, for example, part cleanliness verification was incorporated within the DTP.

3. Test Equipment Compatibility. During testing, numerous instances arose where the in-house test equipment would not produce the (desired) results previously recorded by the supplier's test data. This was due in part to the different test equipment configurations utilized in-house and at the supplier's facility.

Task teams reviewed the supplier's test systems and associated equipment for compatibility with the laboratories and test equipment, and the vehicle systems checkout equipment. The reviews resulted in changes to the test systems in-house and at the suppliers. These changes were initiated by engineering design change proposals (EDCP's), and specification revision sheets (SRS's), etc.

4. Functional Failures. During the reacceptance testing of the selected, highly critical hardware, numerous occasions arose where the units would not perform to the parameters of the specifications or DTP's.

The task team evaluated the anomalies and isolated the problems. In some instances, the failure analysis revealed internal part failures or damage which caused a complete design review. These reviews resulted in component design changes or a complete redesign of the unit. Further testing was delayed until a resolution had been established for the next part.

TEST PROGRAM FOR DETECTION OF COMPONENT DEFICIENCIES

PROBLEM STATEMENT AND EFFECT

The procurement of S-II components required specialized incremental production. The special processing and assembly techniques involved in this type of production required considerable attention to detail to maintain consistency. An extension of the S-II production schedule for five additional vehicles caused concern that component quality could erode to a degree which would affect performance. Due to the potential stage impact from component failures, a comprehensive test program was initiated to detect latent defects.

SOLUTION/RECOMMENDATION

The qualification certification test program (QCTP) was initiated to verify that the performance and quality of qualified S-II components had not degraded subsequent to the achievement of reliability goals. A total of 26 different components were selected for the QCTP. Selections were based on accumulated failure histories from qualification tests, quality maintenance tests, the PAR system, and acceptance data.

The program was successful in isolating problems with 35 test specimens out of the 68 specimens utilized for the test. Corrective and preventative actions were initiated to resolve all problems while minimizing the impact on all similar delivered components.

Fourteen of the anomalies were detected during environmental exposure. Since these problems would have escaped detection by normal acceptance testing, potential stage impacts were prevented by early action. Incremental production sampling tests are recommended for any future space programs where production schedules are similar to those of the S-II.

DISCUSSION

The reliability of a component is influenced by the ability of a manufacturer to continually reproduce the item to a prescribed set of standards. Maintaining the quality of a product becomes more difficult when production covers a lengthy time span. The qualification certification program was instituted to verify the long term repeatability of component performance.

Quality Assurance 22-02

The results of the qualification certification test program indicated a predominance of anomalies attributed to lack of attention to good workmanship practices. The anomalies were classified as either workmanship oriented, engineering oriented, or unsatisfactory conditions as follows:

	Specimens	Problems
Workmanship	26	8
Engineering	7	3
Unsatisfactory conditions	2	2

Although there were more problems than anticipated, the results were understandable. Components were selected for the program because they were particularly susceptible to quality-oriented problems. Further, each of the selected components was purchased for follow-on stages after an interruption in production. This created an atmosphere which caused individuals responsible for fabricating and assembling components to relax their attention to detail.

As a result of the qualification certification program, the following actions were implemented to improve component workmanship.

1. Reinspected and reworked tooling
2. Added mandatory inspection points
3. Increased quality surveillance by source inspectors
4. Reviewed and updated procedures and processes
5. Increased control of suppliers

Results of the program have been transmitted to the NASA in 18 individual test reports.

Report Number	Originator	Component Name	Part Number
51309	Wyle	LOX feed line	ME271-0010-0009
SD 69-346	NR	Manifold assembly (GOX)	ME272-0005-0019 ME272-0005-0021 ME272-0005-0023
2QTR5630087M1	Parker	ARMA	ME282-0028-0002
SD 69-343	NR	Vent valve	ME284-0030-0034
SD 68-356	NR	Check valve	ME284-0074-0003
1QTR5640011 1QTR5640012	Parker	Regulator	ME284-0161-0009 ME284-0161-0010
193831A	W.O. Leonard	Relief valve	ME284-0270-0001
5450-00-1869-1	AETL	RF coupler	ME413-0008-0002
12-4916	Bendix	Separation plane connector	ME414-0042-0001
F-30741	Ogden	Cryogenic connector	ME414-0046-0001 ME414-0046-0002 ME414-0046-0016
PX1-69	Cannon	Umbilical connector	ME414-0055-0004 ME414-0055-0008
F-30672	Ogden	Quick disconnect connector	ME414-0082-0555 ME414-0082-2550
664	Electronic Resources	RC-band pass filter	ME447-0004-0002
7410 REN 2	Durkee Lab	Power transfer switch	ME452-0026-0011
2347	Engineering Magnetics	Inverter/ filter	ME495-0006-0004 ME495-0006-0006

Report Number	Originator	Component Name	Part Number
ER1 663	Electronic Resources	Hybrid junction	ME901-0043-0002
SD 70-177	NR	Recirculation valve	V7-480328
SD 69-331	NR	Engine cutoff assembly	V7-540503

FEED AND VENT LINE ASSEMBLY X-RAYS

PROBLEM STATEMENT AND EFFECT

X-ray film reviewed by NR disclosed defects in feed and vent line assemblies previously accepted by the supplier. Effect of the problem was a lack of confidence in X-ray acceptance at the supplier's facility.

SOLUTION/RECOMMENDATION

NR coordinated with the supplier in preparing weld characteristics sheets depicting acceptance criteria to be used at the supplier. The recommendation was a weld standards manual with physical X-ray examples of acceptable and unacceptable weld defects utilized by both NR and the supplier.

DISCUSSION

The film X-ray interpreted by NR of welds on feed and vent line assemblies disclosed defects previously accepted by the supplier. The supplier's welding specification did not reflect acceptance criteria for peaking as the supplier was not measuring for off-set as required by specification. NR engineering reviewed drawings and designated critical weld areas for peaking. A method of measuring and acceptance criteria was established.

HEAVY PLATE STOCK - SHIPPING PROTECTION AND PRESERVATION, RECEIVING, INSPECTION AND WAREHOUSE STORAGE

PROBLEM STATEMENT AND EFFECT

Heavy plate stock, 10 feet x 18 feet x 2 inches, for the S-II tank structure was ordered from the mill and delivered to the SD and LAD in a crated condition. The crates were assembled with nails that penetrated the wood and caused damage to the plate stock. The multiple plate stock sheets were separated with heavy paper which absorbed moisture and caused surface corrosion on the plate stock thereby causing rejection and scrap of long lead-time material.

SOLUTION/RECOMMENDATION

Define method of preservation, packaging and handling at the supplier's mill. Upon receipt, transfer the material immediately from outside dock to indoor protection. Perform an early inspection of each sheet, conduct re-preservation, and store in a controlled warehouse condition.

DISCUSSION

Plate stock in larger sizes than normally used was procured without detail specified packaging requirements with consideration of the potential problems that would occur during shipment due to handling and weather conditions. After receipt of the material and unloading, the packaged material was sometimes left in outdoor dock areas because of size, weight, and preparation of warehouse storage area. At the time of uncrating, the size, and weight of each plate made it difficult to handle and turn over each panel for inspection of each surface. Special handling equipment with suction cups had to be designed and procured in order to handle without damage for inspection and storage of the plate stock. Inspection revealed that the original crating was not satisfactory as the protective wood crating was damaged during transportation leaving exposed sections of the metal plate and sometimes damage to the exposed plate stock. The wood crate was secured by nails which penetrated the wood crating causing gouges on the metal sheet surfaces. This had to be changed to clamps. The exposure to atmosphere (rain, moisture) caused corrosion. The heavy protective paper between plates absorbed moisture which also caused corrosion.

A review of the events from the mill supplier to the point of storage in the warehouse resulted in an established requirement of preservation, handling, packaging, inspection upon receipt, re-preservation storage, and periodic inspections during storage and prior to release to the shop for fabrication.

HYDROGEN LEAKAGE CONTROL REQUIREMENTS FOR SPRAY FOAM APPLICATIONS

PROBLEM STATEMENT AND EFFECT

The application of spray foam insulation to the LH_2 stage tank eliminated the sidewall purge and hydrogen leakage detection system formally used with the foam-filled insulation.

As a result of the insulation changeover, a new system was required to inert and dispose of the hydrogen leakage to a place approved for dumping of gaseous hydrogen.

SOLUTION/RECOMMENDATION

A new sidewall drain system tapped helium from the LH_2 fill valve actuation system. This helium purge was manifolded past each NAFLEX seal within each engine feedline proximity area. Any hydrogen seepage from a NAFLEX seal was diluted with the helium (inert gas), and carried off in the helium-purged drain manifold and deposited (vented) within the nitrogen purged engine LH_2 feedline fairing. A check valve was located at the discharge point to prevent the possibility of a backflow (cryopumping) of contamination back up the purge system manifold drain line.

DISCUSSION

Application of spray-on foam insulation eliminated the purged honeycomb insulation into which the leakage from NAFLEX seals was drained. An investigation was made to determine the damage which might occur as a result of leakage from NAFLEX seals under foam insulation.

It was determined that a seal drain system was desirable:

1. To prevent failure of the foam insulation by over-pressure

2. To prevent foam from becoming flammable by hydrogen saturation

3. To prevent any damage due to fire from hydrogen leaking through the foam or openings in the foam

As a result of the potential damage to the insulation as a result of leakage from the NAFLEX seals, a system to collect seal leakage and dispose of the leakage was designed.

When the system as designed was evaluated it showed the potential for a hazardous operational mode if cryogenic leakage was dumped into the air-filled lines.

The system was then re-designed to inert the lines with helium before on-loading of cryogenics.

DESIGN OF CRITICAL TOOLING

PROBLEM STATEMENT AND EFFECT

A cutting tool was manufactured with an aluminum shaft and during use, the cutting section separated from the shaft damaging insulation on the stage and causing slight injury to an employee.

SOLUTION/RECOMMENDATION

The tool was re-designed to use a steel shaft on the cutting head. All other cutting/rotating tools used were inspected to determine type of shaft material. No other tools with aluminum shafts were found.

Designs of rotating cutting tools should consider the forces applied to rotating shafts and cutters, and material that will provide the safety factors required should be specified.

DISCUSSION

During the machining (using an air motor and cutter tool) of spray foam on the forward S-II skirt, the aluminum shaft sheared at the base of the phenolic cutting tool, the rotating phenolic tool struck and damaged the insulation, and then ricocheted, striking an employee on the left leg causing a minor laceration injury.

TECHNIQUE FOR VERIFYING STRUCTURAL INTEGRITY OF SHEET CORK INSULATION

PROBLEM STATEMENT AND EFFECT

Capability was needed to detect cork or foam debonds in the vicinity of LH_2 feedlines on the S-II vehicle, as a result of static firing of the stages at a test site.

The inspection technique had to be of a nondestructive nature.

SOLUTION/RECOMMENDATION

A tool was developed whereby the inspection technique consisted of the application by vacuum of a tension to the cork or foam composite while measuring the amount of induced deflection of the cork. Cork debonds as small as 2 inches in diameter will display a marked increase in deflection compared to structurally sound areas.

DISCUSSION

The objective was to provide assurance that the cork insulation was structurally sound prior to a countdown demonstration test (CDDT) at a test site. The general construction details were as follows:

1. Standoff height was approximately 0.125 inches.

2. The seal was constructed from 1/4-inch-diameter surgical tubing held in place with neoprene-base adhesive.

3. A "vacuum control" unit was located between the vacuum plate and a vacuum pump consisting of two bleed valves and a vacuum gage.

4. A 1/4-inch-diameter hole was drilled through the vacuum plate to provide for rapid vacuum relief between inspection points. An elastomeric "flap" was provided to readily cover and uncover the relief port.

5. A standard quick-disconnect fitting was provided in the vacuum plate for attachment to the vacuum source.

CRACKING OF 2020 ALUMINUM STRINGERS IN FABRICATION

PROBLEM STATEMENT AND EFFECT

Cracks were found in the 2020 aluminum stringers in the aft skirt and aft interstage assemblies.

The cracking problem is estimated to have caused a slip of 6 to 8 weeks in delivery of S-II-4 assemblies to Seal Beach.

SOLUTION/RECOMMENDATION

No impact riveting was permitted to be used on any 2020 material.

Nonimpact type fasteners were used to attach 2020 aluminum stringers in and near all hard point areas; i.e., attachment of all 2020 aluminum alloy stringers and frames.

Defined allowable extrusion contour tolerances for attaching the stringers and frames with nonimpact fasteners.

Permitted limited use of shims to provide a snug fit of 2020 extrusion to skin, or between extrusion and end fittings installed therein.

DISCUSSION

In the interest of weight saving, it was decided to replace 7075 aluminum with 2020 aluminum on the thrust cone, aft skirt, and interstage of the vehicle.

With the start of fabrication, cracks were noted which had been caused by impact of the rivet gun upon the stringers. These cracks were visible externally.

This problem appeared to be solved by putting the manufactured head on the skin side; however, additional cracks were found between the hat section and skin. Standard inspection procedures; i.e., dye penetrant, X-ray, did not bring out the cracks in other areas until a caustic etch method was tried. This method isolated more cracks than had previously been detected.

As the result of an investigation of the causes of cracking, it was determined that low ductility of 2020 aluminum extrusion used as stringers did not permit impact riveting at or near joints involving more than skin and stringer or where tooling would back up skin, making a hard point attachment.

It was also determined that tolerances on extrusion shape control were not adequate to eliminate excessive strain by fasteners on stringers during assembly.

Lack of experience in impact rivet fabrication with 2020 aluminum extrusion contributed to the problem.

LEAKAGE OF TORSIONAL BELLOWS AS THE RESULT OF CORROSION

PROBLEM STATEMENT AND EFFECT

Leakage due to corrosion has been found in the torsional bellows used in the LH_2 and LOX feedlines on the stage engines.

Bellows showing signs of leakage had to be replaced to prevent a launch scrub or last minute delay.

SOLUTION/RECOMMENDATION

It was determined that corrosion of the bellows material was responsible for holes in the material through which the leakage was occurring.

The following action was taken:

1. Improve dry lubricant application to the bellows by assuring good pre-cleaning and coverage.
2. Use more corrosion inhibiting dry lube.
3. Assure drying torsion bellows cavity after exposure to moisture and cryogenic fluids.
4. Investigate use of a more corrosion-resistant bellows material.
5. Purge ports were added to the LOX and LH_2 torsional bellows for the center engine.

DISCUSSION

The initial indication that a problem existed on the LOX and LH_2 torsional bellows was leakage of the center engine feedline during a LOX tank leak test. The line was returned to the manufacturer where it was determined that the leakage was the result of corrosion through the bellows ply.

The suspected cause was nonuniform dry-lube coverage. Further investigation determined that this type of corrosion was due to chloride introduced into the bellows by various fluids used to clean the bellows such as: tap water, trichloroethylene, perchloroethylene, and solutions containing chlorine. Inadequate drying procedures and the inability to inspect the bellows after installation contributed to the problem.

As a result of the manufacturing investigation, recommendations were made to extend the bellows to 8.50 inches in an extension fixture for the clean and dry cycle, and to increase the time and temperature during the dry cycle.

After cryogenic exposure, recommendations were also made to use the ports in the center engine bellows for purging.

Recommendations were made to use a superior, corrosion-resistant material in place of CRES 321 (e.g., INCO 600) for the bellows.

ADDITION OF STRAIN RELIEF CLAMPS TO CRITICAL ELECTRICAL COMPONENT CONNECTORS

PROBLEM STATEMENT AND EFFECT

All connectors used on critical electrical components must provide strain relief to the wire harness to prevent damage to contacts of connector inserts.

Failure of components to operate when required during flight could result in mission loss.

SOLUTION/RECOMMENDATION

Design Engineering added the requirement for use of connectors with a strain relief clamp to the specification control drawing. The requirement for use of a strain relief device should be included in the procurement specification when sent to the supplier furnishing the connector.

DISCUSSION

During manufacturing cycle of the harnesses the strain of the harness on pins or contacts during electrical testing caused by the weight bending action, torsion, associated with handling, will damage the mechanical characteristics of the inserts of the connector unless the strain is transferred to the connector body through the strain relief clamp.

CONNECTOR DISCREPANCIES DUE TO MISHANDLING

PROBLEM STATEMENT AND EFFECT

Various recurring problems with electrical connectors on the S-II Stage were determined to have resulted from mishandling by technicians.

SOLUTION/RECOMMENDATION

Upgraded connector training courses.

Renewed emphasis was placed on workmanship relative to connector handling in the technician meetings.

Established a requirement that only technicians trained and certified could work on connectors.

Provided improved (modified) insertion tools for installing pins in connectors and verified their use.

Developed and implemented backshell tightening criteria.

Implemented the use of contact pin alignment gauges to verify that the pins were not damaged prior to connector mating.

DISCUSSION

Many problems were encountered during the assembly of electrical connectors to harness installation, and mating of harness connectors on the stage and demating of connectors for test or checkout. The following is a list of some damage resulting from mishandling:

- Torn grommets
- Bent pins
- Dinged contacts
- Corroded contacts
- Contact recession
- Insert recession
- Scratched, chipped finish
- Cracked contacts (due to crimping)
- Scratched or scarred pins

Bent pins, torn grommets, pin recession, and insert recession were generally the type of damage resulting from poor workmanship during removing and replacing electrical pins in a connector. This operation required the use of the proper insertion tool. As a result of using incorrect tools, connector grommets were damaged and parts of contacts were broken or deformed so that electrical contact with mating parts was degraded or lost completely.

Another instance of connector mishandling occurred prior to and during S-II-7 static firing when anomalies were noted with the LOX engine cutoff (ECO) sensors. They were flickering "wet" and "dry" intermittently, indicating a possible open circuit condition. Subsequent investigation revealed the in-tank connector coupling ring to be loose resulting in intermittent open circuits. These sensors were used in a two out of five voting network to shut down the engines in flight. A premature shutdown could result in possible mission loss.

To preclude the recurrence of a loose-in-tank connector, a specific requirement to verify "tight" (bottomed out) coupling rings was established as a mandatory inspection point (MIP), prior to closeout of the LH_2 and LOX tanks in-line and during tank entry.

An evaluation of records indicated that connector discrepancies were increasing to the point that significant action was mandatory.

A connector task team was established to review the total problem and recommend actions required for correction. Those determined to be appropriate are listed under Solution/Recommendation.

STAGE SYSTEMS RETEST REQUIREMENTS AFTER SYSTEMS DISTURBANCE AND REWORK

PROBLEM STATEMENT AND EFFECT

During the AS-502 flight, Engine 2 inadvertently shut down and was followed by the closing of the prevalve for Engine 3.

Closing of the Engine 3 prevalve resulted in the shutdown of Engine 3 which created an underthrust and control problem for the vehicle due to a two-engine out condition.

SOLUTION/RECOMMENDATION

A cross of electrical connectors to prevalve solenoids was determined to be the condition responsible for shutdown of the second engine.

Retest requirements of systems broken into or modified were revised to require individual testing of the system for operation in a manner that would show up any deficiencies, or failure of a system to perform as designed.

DISCUSSION

Investigation into the inadvertent shutdown of the second engine, as a result of the loss of the first engine, determined that the connectors to the control solenoids for the Engines 2 and 3 LOX prevalves had been installed in reverse.

Normally, this would have been detected during individual engine system checkout and shutdown sequence testing. However, the engine shutdown sequence testing was deferred and then accomplished for all the engines together which did not reveal the crossed signals to the prevalve solenoids.

In support of the revision to the retest requirements, studies were conducted to establish means for identifying connectors to prevent mismating with the wrong component.

Wire harnesses to components were also re-routed to the prevalve solenoids so that the right connectors to each component would just reach the connector attach point on the solenoid.

ELIMINATION OF POTENTIAL SOURCES OF MOISTURE FROM LOX AND LH_2 PREVALVES AND ASSOCIATED SYSTEMS

PROBLEM STATEMENT AND EFFECT

During the first static firing countdown of the S-II-2 Stage at MTF, the prevalve on Engine 1 failed to close at recirculation start. This resulted in the countdown being terminated.

SOLUTION/RECOMMENDATION

As a result of finding water in the vent port cavity of the prevalve, which froze and prevented operation of the prevalve during the static firing, the following precautions and requirements were recommended to eliminate the potential source of water to the prevalves:

1. A positive pressure should be maintained in the recirculation actuation system during transportation.
2. Enforce existing purge requirements with backup dew point checks of gas during each blowdown.
3. Provisions were made to purge and/or apply vacuum to the GH_2 internal cavity exhaust system/flange seal leak detection system and propellant tank pressurant system, and perform moisture checks prior to propellant loading.
4. Purge the GSE prevalve latch supply lines prior to stage hookup. Perform periodic checks to ensure that lines are free of moisture, and ends are properly capped to preclude the entrance of moisture.
5. Established the criteria for actuating gas to meet MIL-P-27407 Specification.
6. Established prevalve check and purge and/or evacuating procedure for the vent port cavity.

DISCUSSION

A countdown was terminated when a prevalve failed to close at start of recirculation. When the valve was disassembled, approximately 10 to 15 cc's of water was poured out of the vent port cavity.

As a result of this problem, an investigation was conducted to determine the origin of the water found in the LH_2 prevalve. All other systems associated with the LOX and LH_2 prevalves to determine sources of moisture were investigated.

As a result of the first two investigations, recommendations and changes were made to preclude water from the systems by eliminating the source of the moisture, and providing the means to remove and check for indications of moisture.

A series of tests proved the feasibility of using a vacuum to extract water from a valve. It was concluded if a vacuum of no less than the vapor pressure of water at the existing ambient temperature can be maintained (approximately 0.73 inch of Hg absolute) by the vacuum pump, the valve cavity can be made free of water.

It was also determined that the protective covering, used over the work area at the test site during the time of the installation of the valve that failed, was not adequate to preclude moist air or water from the valve. Therefore, the recommendation was made that a properly constructed and adequately maintained work structure for protection from rain and other detrimental environmental conditions be mandatory for operations involving replacement of such critical components as the prevalves.

CONTROL OF SUPPLIER MATERIAL AND PROCESSING

PROBLEM STATEMENT AND EFFECT

Marginal operation and failure to pass electrical tests were the first indications of problems with stage vent valve solenoid valves. Disassembly of the valves indicated that the solenoids had failed electrically due to shorting across the windings. Further investigation showed the enamel insulation to be peeling from the coil wire leaving the bare wire exposed.

SOLUTION/RECOMMENDATION

The investigation indicated that coil wire utilized in the solenoid coils of 1967 and 1968 wire-type solenoid coils had the potential for failure. Those utilizing 1966 wire types were of known integrity and were acceptable.

Those valves utilizing 1967 and 1968 wire types in the coil windings were re-worked with coil wire acceptable by testing, and wound to new requirements and processes.

DISCUSSION

During S-II-14 special testing, stage vent solenoid valve became inoperable resulting in the vent valve cracking pressure exceeding its relief pressure limit.

The coil was found to be shorted, winding to winding, due to cracked coil wire insulation.

Tear-down inspection of seven solenoid valves, from three stages, and eight test solenoids established "cracked coil wire insulation." Specific wire order manufactured in 1966 was established as acceptable. Wire manufactured in 1967 and 1968 was established as not acceptable.

Parallel efforts with coil tear down inspection were NR Materials and Processes Lab tests of the solenoid materials of construction including various coil wire lots. No major incompatibilities were demonstrated except those wherein H_2O, alcohol, and acid flux were introduced in the grouping to simulate inadvertent processing retention or post-closeout moisture leakage. All three liquids noted caused the wire insulation to crack.

The following revisions were made to the design and/or processing, and were required down to the subsupplier who manufactured the coils and the supplier who assembled the coil into the valve.

1. Required receiving inspection of coil wire to NR requirements

2. Required machine winding for precision tension control

3. Required coil winding using varnish to result in "wet wound coil"

4. Changed coil closeout wrap to teflon tape in lieu of glass tape

5. Replaced closeout plug and solder with pinch tube

6. Revised potting procedure

7. Required leakage test of electrical connector by receiving inspection

8. Added dehydration procedure before closeout of coil cavity

9. Added post-closeout leak test to verify acceptability of hermetic cavity sealing using "tracer gas" method

10. Add requirement for hi-temp solder for solder plug closeout

All of the above changes were required to correct and control design and processes down to the subsupplier level in order to guarantee the integrity of the S-II Program vent valve solenoid valves.

TEST OPERATION REQUIREMENTS FOR LH_2 TESTS

PROBLEM STATEMENT AND EFFECT

An accident occurred on a test tank while the unit was undergoing an LH_2 chilldown preparatory to starting a scheduled test.

As a result of the accident, the test article was totally destroyed.

SOLUTION/RECOMMENDATION

As the result of the total destruction of the test article, the following solutions are recommended:

1. Ensure rigid enforcement, by periodic monitoring, of work activity acceptance procedures and hazardous operational procedures.

2. Provide continuous multiple tape video camera coverage with a minimum 5- to 10-minute loop recording from initiation of a hazardous test including pre-test operations (such as transferring fluids, gases, pressurization, etc.).

3. Perform a review of all major S-II test programs to ensure proper instrumentation and/or video coverage.

4. Review present test procedures to ensure that all LH_2 propellant tanks are sampled, top and bottom, and are within specification limits for O_2 and/or other incompatible gas before transfer.

5. Perform a Saturn S-II review of all conditioning, transferring, and tanking procedures, including safety.

6. Review procedures for vent stack operation and standby conditions to ensure their adequacy including safety.

7. Initiate action to continually monitor and record all critical instrumentation during chilldown LH_2 transfer or pressurization.

8. Ensure that changes on a working GH_2 system or operational procedure are systems analyzed to ensure that no detrimental side effects will result from the change.

DISCUSSION

A test vehicle was destroyed by a relatively low-level explosion at the Santa Susana Test Facility COCA IV Test Stand. The incident occurred immediately after the initiation of system chilldown during the countdown operation prior to loading propellant for application of structural loads.

Damage to the test vehicle was total and the structural loading fixtures were severely damaged. Several fires were observed simultaneously with the explosion report and were extinguished several minutes later through action of stand firex and site firemen.

The facility LH_2 storage tank had been vented to 3 psig to start system chilldown, and the stage was vented through the smaller of two vent valves in order to maintain back pressure in the stage during chilldown. Approximately one minute later, the explosion and fire occurred.

Tests conducted on the Battleship vehicle, duplicating the procedures used on the test vehicle, indicated the possibility that the oxygen content of the test vehicle had stratified in the bottom of the tank and in combination with the chilldown hydrogen gas, set up the mixture responsible for the low-level explosion. Sampling of the tank oxygen level subsequent to the purging or prior to chilldown was not performed.

The investigation of the incident required the implementation of the eight items noted above. These were accomplished to provide the positive control needed to assure no reoccurrence of the incident in future testing.

TOLERANCE RELAXATION FOR ALIGNING AND POSITIONING SECTIONS OF TANK STRUCTURE FOR WELDING

PROBLEM STATEMENT AND EFFECT

Drawing tolerances for indexing position markers on the forward LH_2 bulkhead and the position markers on Cylinder 6 were listed on the drawing as ±0.010. Manufacturing initiated a drawing change request to change the tolerance to ±0.030 because the drawing tolerance would not permit a proper fit-up between the two assemblies.

RESOLUTION/RECOMMENDATION

An investigation into the problem indicated that ±0.030 tolerance of the circumferential alignment coincided with that of Manufacturing tooling.

A general note was added to the assembly drawing changing the position marker 1 of the forward LH_2 bulkhead to be aligned to position marker 1 of Cylinder 6, allowable tolerance for alignment of these components not to exceed ±0.030.

Coordination should be completed between Engineering and Manufacturing to establish reasonable engineering requirements for tolerances of this category that will permit tooling to be designed and used to acceptable design requirements. As a result of the difference between design tolerances and ability of the positioning tool to control alignment of the tank assemblies, MRD action was required to clear the squawks generated.

DISCUSSION

Design engineering investigated the circumstances responsible for the requested drawing change in tolerances from ±0.010 to ±0.030 for circumferential alignment of forward LH_2 bulkhead and Cylinder 6.

It was determined that the manufacturing tool used to position the assemblies for welding could not locate the parts to closer than ±0.030 tolerance.

An engineering evaluation of the possible effects of granting the tolerance relaxation was performed. No effect on the structural integrity of the stage was found; therefore, the requested tolerance change was incorporated into the drawings.

DAMAGE TO STAGE STRUCTURE RESULTING FROM UNSAFE ELECTRICAL EQUIPMENT

PROBLEM STATEMENT AND EFFECT

A portable floodlight shorted against the interior tank wall causing damage to the tank.

SOLUTION/RECOMMENDATION

All electrical equipment to be used inside the stage tanks will be subjected to testing by tool crib personnel using the Rucker Safety Sentry, a device for detecting electrically shorted equipment.

The existing method of running extension cords and air hoses from the building, through the tunnel, down the ladder, and into the tank will be replaced with a permanently attached outlet on bottom of the ladder.

The stage will be grounded from the facilities power panel and a second ground attached to the stage transporter.

DISCUSSION

During the in-tank cleaning operation on the S-II-7, a portable floodlight shorted out causing four arc burns. The two deepest burns were 0.026 and 0.025.

The floodlight was a hand-held type with an aluminum reflector. The arcing occurred between the edge of the reflector and the tank surface.

POST PROOF-PRESSURE TESTING INSPECTION REQUIREMENTS FOR PROPELLANT TANKS

PROBLEM STATEMENT AND EFFECT

Structural weld inspection requirements for testing of the LH_2 and LOX tanks were required in four separate accounting systems.

As a result a degree of inconsistency existed between documents which could have resulted in inspection discrepancies.

SOLUTION/RECOMMENDATION

All of the inspection requirements for post-hydrostat and post-pneumatic tests were transferred to the propellant tank proof-pressure testing drawing.

These weld inspection requirements were previously called for on tank component drawings.

The requirements for inspections must be kept current and revised as the results of the data from the inspections dictate. The basic inspection requirements should be called out on the applicable engineering drawings at the beginning of the program before initial release to Manufacturing.

DISCUSSION

S-II structural weld inspection requirements for testing of the LH_2 and LOX tanks were established in specifications, internal letters, Quality and Assurance documents, and on several drawings. Because of the diversity of requirement sources a degree of inconsistency existed between these individually established requirements. Post proof-pressure testing inspections, for instance, were not completely identified on the engineering drawings.

Another example was the requirement for the forward LH_2 bulkhead inspections. The penetrant inspection was called out on the drawings and the radiographic inspection was required by Quality Assurance documents.

The problem of updating and revising requirements can only be accomplished and controlled to the degree required by revisions to the drawing.

As indicated by the information listed relative to the preceding problem, it is suggested that all requirements for inspection criteria for pre- and post proof-pressure weld inspections (or similar inspection requirements) be incorporated within the framework of engineering drawings.

RECOMMENDATIONS RESULTING FROM S-II-T TANK RUPTURE

PROBLEM STATEMENT AND EFFECT

An S-II Stage tank ruptured while being pressurized in the test stand at the Mississippi Test Facility.

The tank rupture totally destroyed the stage and resulted in the injury of six men.

SOLUTION/RECOMMENDATION

Redesign was done on the LH_2 feedline elbow, integral boss of the feedline elbow, stringers, and rib splices to eliminate stress concentrations and provide stronger parts.

Design changes provided separate sensing sources for monitoring tank pressure and tank control pressure switches.

The fill link coupling length was increased 3 inches and support legs added for load distribution.

The facility vent system from the tank was changed to provide automatic relief and fail-safe-open provisions for the blocking valves.

Procedures and Implementing Instructions were revised to control the performance of test operations, and preparation and control of test procedures.

Responsibilities were established for system test engineers.

Requirements were established for crew qualification for critical tests.

The instructions for cryogenic system installation and operations were up-dated.

The Safety Manuals and Procedures were revised and new Standard Operating Procedures were established.

Required instrumentation to record all critical valve positions on event recorder.

DISCUSSION

During attempts to pressurize the LH_2 tank on the S-II Stage at the Mississippi Test site, the LH_2 tank failed. Both propellant tanks and associated systems were destroyed. Six men were injured.

The preliminary investigation showed the probable cause of tank failure to be the result of overpressurization due to the absence of pressure indications. Previous incomplete testing of the LH_2 tank pressure regulator involved disconnection of the pressure switches. All Test Control Center pressure indications being monitored at the time of the failure were connected to transducers on the pressure sensing line, common to the line from which the switches were disconnected.

This resulted in zero pressure indication at the Control Center where they attempted to pressurize the tanks to 8 psig, the pressure at which leak checks were to have been made.

The LH_2 tank rupture occurred at a tank pressure well below the design pressure limits.

The investigation after the incident determined that the facility blocking valves, in the LH_2 tank vent line downstream of the LH_2 tank vent, were closed before the last five attempts to pressurize the tank were made.

The lack of a relief provision or fail-safe device in this vent system was considered to have contributed to the tank failure.

It was concluded that the origin of the structural failure was localized in the region of the LH_2 tank feedline outlets. Dye penetrant tests on a following stage revealed cracks in the same location as the failed area of the S-II-T.

It was determined that it was necessary to forcibly stretch and position the flexible fill line to permit attachment to the stage fill and drain coupling. This was a result of deviations between planned and actual location of the facility interface with respect to the stage.

As a result of bending stresses combined with tensile stresses, calculations indicated maximum surface stress of 46,000 psi was possible in the localized area of the fill and drain coupling.

The investigation resulted in recommendations for changes in stage structure management, procedures, safety requirements, facility systems, instrumentation, and inspection requirements.

USE OF ARROW-TYPE DECALS TO CLARIFY FIND NUMBERS

PROBLEM STATEMENT AND EFFECT

Incorrect mating of systems between the ground half and stage half of the disconnects on all aft and forward umbilical lines can occur due to find number location, and when an actual umbilical carrier plate is not being used.

Misinterpretation is possible because the find numbers cannot always be located directly adjacent to the disconnects.

SOLUTION/RECOMMENDATION

Decals with arrows were provided and placed adjacent to the find numbers, and pointing to the disconnect that the find number was to identify on the stage half-disconnect.

Identification of single connect/disconnect points should appear on the drawing, particularly if the disconnect cannot be sized or designed to preclude inadvertent misconnection.

DISCUSSION

During checkout operations of individual systems requiring hookup of lines to the disconnects on all aft and forward umbilical locations, the find numbers were found to be located such that the disconnects were not readily identifiable. To preclude the inadvertent cross-connection of systems and the possible resultant damage to the system, the use of decal "arrows" was used in conjunction with the find numbers.

CONTAMINATION CONTROL OF STAGE SYSTEMS AND FUEL TANKS

PROBLEM STATEMENT AND EFFECT

Contamination of various types has been found in the fuel tanks and in components in the systems of the S-II stages.

There have been repeated component failures due to hard contamination and some objects removed from the tanks which subsequently could cause an engine abort, malfunction, or performance shift during a static firing.

SOLUTION/RECOMMENDATION

Parts to be assembled into the tanks were kitted so accountability could be established. All tools were checked in and out of the tanks. Torque callouts were added to fabrication, assembly, and inspection (FAIR) tickets during in-tank installations.

Black-light inspections were implemented to show up contamination.

Rotation of the stage (tinkle test) was implemented to detect loose objects in the tanks.

The stage systems were subjected to blow-downs after installation of a micron milliport filter in the system to catch the contaminants.

A conical-type filter element was added to the LOX and LH_2 fill and drain flex hoses at the GSE/stage connection.

A Saturn contamination control team was established to look into the total picture of contamination sources and control.

DISCUSSION

Various forms of contamination have been removed from the tanks and systems of the stage.

The "tinkle test", used to ascertain the condition of the tanks relative to foreign objects, has produced many items of loose hardware that inspections have not disclosed.

The inspection performed in the LOX tank disclosed bolts that were not torqued to the required values. Corrective action was taken to add a torque callout to FAIR tickets during in-tank installations.

Some components that had been installed had been cleaned and accepted to specification; however, when inspected by black-light, they showed contamination sensitive to LOX.

This condition was determined to be residue from tape used during the installation of rivets in the component. Specifications were changed to eliminate the tape and require black-light inspection after in-house cleaning of all LOX-cleaned system components.

Numerous particles of a teflon material were found in an LH_2 tank during a routine post-cryoproof inspection of the tank. The material proved to be 80 percent of a teflon gasket from the flapper on a check valve downstream from the filter in the LH_2 transfer system. The flapper valve source of the contamination was modified for the LH_2 and LOX transfer systems, and a screen added to the stage interface on both LH_2 transfer systems.

The problem of contamination from an overall standpoint was studied by a contamination control team. This team investigated associated facility systems, manufacturing procedures, shipping procedures, quality control procedures, and made recommendations to control or eliminate sources of contamination.

REQUIREMENTS FOR SAMPLING OF FACILITY FLUID SYSTEMS

PROBLEM STATEMENT AND EFFECT

Specific requirements for the quality of fluids supplied to the GSE/facility interface, if not available when the GSE is tied into the facility, could result in contamination of GSE, stage, and facility systems.

SOLUTION/RECOMMENDATION

Specific requirements for fluids should be negotiated with the customer at the beginning of the program. These should include those applicable to helium, nitrogen, missile grade air, hydrogen (liquid or gas) and oxygen (liquid or gas).

The specifics should list the impurities by name, and maximum allowables in parts per million by volume or purity shall not be less than a specific percent by volume for each and to any other fluids or gases added to the above list. Particulate count permitted shall also be listed.

The requirements established above should then be listed on drawings, specifications, and in all documents where fluids are used as part of a design, in test, or furnished to a facility for use during system tests or end item use.

Sampling requirements should also be established on a periodic basis and the location specified from which the sample shall be taken for certification purposes. Gaseous hydrogen should be certified at the storage bottle, provided the GHe or GN_2 purge for the facility hydrogen system is sampled at the GSE/facility interface and meets the established requirements for helium or nitrogen. Verification of particulate count shall be made of purge gas only and shall meet the requirements for hydrogen.

Liquid oxygen and hydrogen, if furnished by barge, should be sampled at the barge.

DISCUSSION

There were no requirements established in specifications or on drawings for quality of fluids supplied to the GSE/facility interface. Although a number of documents listed fluid quality requirements, none applied to facility systems. Requirements must be established to assure that fluids/gases entering the GSE/stage are of sufficiently high quality to enable the GSE to meet stage/GSE fluid requirements.

Unless the requirements are established in the negotiated contract, and required in all associated engineering documentation, confusion will result in selecting criteria suitable for certification of fluid samples. This situation could result in rejection of fluid sample and test delay. In addition, contamination of stage systems could result if unqualified fluid is supplied from the facility.

LOX CLEANLINESS OF TEST EQUIPMENT

PROBLEM STATEMENT AND EFFECT

A stainless steel hand valve exploded when a K-bottle containing oxygen was introduced into the test system. The detonation was followed by sparks and flame.

SOLUTION/RECOMMENDATION

The cause of the explosion was determined to be contaminated trichloroethylene used in the cleaning process of the test components.

Cleaning procedures were changed to start the process with trichloroethylene as an initial rinse of the test equipment components followed with a rinse of Freon, and finally purged dry with gaseous nitrogen.

DISCUSSION

Apollo materials and components had been undergoing oxygen humidity tests over a 3-year period in the Engineering Development Laboratory. During a series of events required to start a test, an explosion occurred in an oxygen hand valve that was part of the test equipment.

The general cleaning procedure, previous to the incident, was to clean tubing, fittings and valves with trichloroethylene followed with a purge of nitrogen.

At the start of the test the test chamber was evacuated to 80,000 feet and the valve on the K-bottle containing oxygen was opened, and as the next valve in the test sequence was about to be opened in the manifold, the explosion occurred.

The investigation of the valve revealed that spontaneous combustion had occurred internally. The valve was made of stainless steel and rated at 3,000 psi. Special precautions had been taken to preclude incidents due to the use of the valve with oxygen by installing a teflon valve seat, and using KEL-F or Flurolube as a lubricant on the valve stem.

Investigation determined that contaminated trichloroethylene trapped in the valve was ignited when the oxygen supply was turned on.

PROCEDURES FOR CONTAMINATION CRITERIA

PROBLEM STATEMENT AND EFFECT

Check valves subjected to pretest cleanliness verification have shown contamination in excess of the LOX cleanliness requirements imposed on the supplier by specification.

Those valves which do not meet the specified cleanliness requirements require additional blowdown checks that consume 6 1/2 hours each.

SOLUTION/RECOMMENDATION

Higher flow rates were established as criteria for the supplier.

DISCUSSION

During pretest cleanliness verification in the Product Reliability Program test program, 21 out of 37 engine isolation check valves were contaminated in excess of the LOX cleanliness requirements in the as-delivered condition. The existing cleanliness verification tests imposed on the supplier facility were in accordance with the specification requirements. The specification required only a flow rate of 7±1 standard cubic foot per minute which did not establish a sufficient velocity to maintain larger particles in suspension. By imposing a higher velocity on the supplier's facility, all the check valves delivered would meet the cleanliness level required. Those valves not meeting the cleanliness requirements require additional blowdown checks of up to 6 1/2 hours each.

VERIFICATION OF CRYOGENIC SEALS BY LEAK CHECKS, NAFLEX TYPE

PROBLEM STATEMENT AND EFFECT

Early in the S-II Program problems were encountered with seal leakage due to installation difficulties and lack of experience in the handling of seals.

As a result of the possibility of LOX/GOX concentration in the presence of non-LOX/GOX compatible materials, positive checks were required as to the integrity of the seals during cryogenic conditions to prevent a hazardous concentration which could result in an explosion or fire.

SOLUTION/RECOMMENDATION

Checkout specifications were written for use during manufacturing, test and operations, and test operations at test sites.

Allowable seal leakage is based on total seal circumferential inches and is imposed on that basis by the procurement specification when written. Hazardous concentrations of cryogenic gas in specific areas can be controlled when the total seal leakage of all the seals is within specification limits and purge flows into the area have been designed based on anticipated permitted maximum total seal leakage.

All drawings, procurement specifications, and checkout specifications for individual seals and systems should require leak checks at specific points during procurement, installation and checkout of cryogenic seals and systems, and purge systems which are designed to control and neutralize hazardous cryogenic gas concentrations.

DISCUSSION

Engineering response to LOX/GOX compatibility inquiry, pertaining specifically to external leakage from seals, reviewed the leakage history and the conditions responsible for the leakages. The review listed 80 seals but failed to list LOX sump to tank leakage information.

The failure to include the LOX sump leakage in the list required a re-evaluation of the purge requirements for the boattail area of the stage when the maximum LOX sump permissible leakage was added to the total seal leakage being dumped in the area.

Although the problem presented above was concerned with only one seal in one area, other areas have been investigated relative to suspected concentrations of hazardous gases such as the tunnel area on the outside of the S-II Stage.

Unless positive requirements exist for periodic leak checks to be made at specific times for seal leakage and the data available for review when needed, the problems of suspected accumulation of hazardous gases in specific areas cannot be answered to any degree of accuracy.

DESIGN OF COMPONENTS TO PREVENT REVERSE ASSEMBLY

PROBLEM STATEMENT AND EFFECT

A turbine wheel of an engine fuel pump was found to have been assembled in reverse. This condition was responsible for a J-2 engine failing to start.

SOLUTION/RECOMMENDATION

Mechanical design criteria were updated to include a design approach which would preclude the design of a part which could result in the reverse installation of a component during assembly.

DISCUSSION

A problem developed during the attempted firing of a J-2 engine at the Rocketdyne Test Facility. The symptoms of the problem were stated to be that an engine had stalled twice and a hot gas generator temperature indication had been received.

Inspection of the turbine determined that the first stage turbine wheel of the fuel pump had been installed in reverse.

The corrective action recommended was to update the Mechanical Design Criteria Manual to require designing of component parts so that it would be impossible to assemble the part in any other except the as-designed configuration.

BELLOWS DAMAGE

PROBLEM STATEMENT AND EFFECT

Damage to stage line bellows occurred approximately 116 times in the period of 1965 to the end of 1968. As a result of these bellow discrepancies many of the lines had to be removed from the stage and re-cycled back through the supplier.

SOLUTION/RECOMMENDATION

The flange bolt installation drawings were revised to require installation of bolts so that torqueing could be accomplished on the side of the flange away from the bellows.

Provide and require protective bellows covers to be used from the time the bellows leave the supplier's facility and removed only as required for installation, and then replaced until removed for flight.

Special skills qualifications were defined for the technicians doing the installation of the bellows.

Planning ticket procedures were revised to require callout of special skills trained technicians to do the installation. The planning ticket procedures were then revised to call out procedures for removal of bellows protective devices as required by the planning ticket work requirements, and replacement will follow verification by an inspector.

Material Dept. procedures incorporated a maintenance procedure for records of protective covers from re-cycle through the supplier of bellows through final removal at the test site.

Inspection procedures were revised for source inspection at the supplier and receiving acceptance testing of protective covers at NR facilities.

All desk instructions for inspectors were updated to reflect the change to documents relative to correction of the bellows problem, and to the special skills requirement for technicians installing lines.

DISCUSSION

Damage to stage line bellows in the 1965 to 1968 period incurred the loss of time as well as dollars. Investigation revealed that the damage occurred during transportation, installation on the stage, and from other causes as a result of work in the area of the bellows with protective devices removed from the bellows. System Safety made a complete analysis of the background of the bellows problems from the beginning of the first reported damage to a bellows and, as a result, recommended changes to drawings, specifications, procedures in the responsible areas of Engineering Material Manufacturing, Quality Assurance, and Logistics. These are listed above under Solution/Recommendation, and contributed to a very high percentage reduction in bellows damage incidents.

BACKUP CONTROLS FOR EMERGENCY SHUTDOWN OF CRITICAL EQUIPMENT

PROBLEM STATEMENT AND EFFECT

A fire occurred around a feed duct during static firing and destroyed the wires in the harness controlling the engine cutoff system and solenoid used for venting the start tanks.

Due to damage to wiring, the start tanks could not be vented down to a safe pressure to permit technicians to work in the area.

SOLUTION/RECOMMENDATION

As an immediate solution for the condition a temporary pneumatic line was attached to the vent valve and operated to drop the high pressure in the start tanks.

As a permanent solution, redundant start tank vent control system was designed and installed so that actuation pressure to control the vent solenoid could be applied from an off-stage source if the normal system was damaged or malfunctioning. The relief devices were also manifolded and vented out of the area.

Redundant controls to shut down and safe critical equipment should be designed into facilities as a normal facilities design safety requirement.

DISCUSSION

During a static firing of an S-II engine at Santa Susana Test Facility a leak of LH_2 into the annular space of the vacuum-jacketed line resulted in a hydrogen fire around the LH_2 feed duct which burned some stage electrical harness near the duct.

When an attempt was made to reduce the pressure in the engine start tanks the vent valves would not actuate due to damage to the wire harness which contained the control wires to the solenoid which in turn, controlled the pneumatic pressure required to operate the vent valves.

A jury rig was used to bring pressure directly to the vent valves so the engine start tanks could be relieved of their high pressure.

A redundant start tank vent control system was designed and installed so that actuation pressure could be applied from an off-stage source if the normal control systems were damaged or malfunctioned.

The overpressure device which relieved gaseous hydrogen into the atmosphere and was responsible for the fire was manifolded with other relief devices and vented out of the area.

CRACKED SOLDER CONNECTIONS ON PRINTED CIRCUIT BOARDS

PROBLEM STATEMENT AND EFFECT

Cracked solder connections on etched circuit boards have resulted in instrumentation equipment failures.

The equipment failures caused loss of critical data, failure analysis of each board, corrective action on each board, and re-cycling of the boards.

SOLUTION/RECOMMENDATION

As a result of instrument failures, the following solutions are recommended:

Use proper swaging tools for bifurcated terminals.

Enforce cleanliness in production process area.

Defer all conformal coating until all soldering has been completed.

Where re-flow of solder is required, such as bifurcated terminal soldering, use a 47-watt soldering iron and liquid flux.

Change assembly specification so conformal coating can not be trapped in solder joints.

Train inspection personnel in the proper methods and criteria for inspection of solder joints.

Provide sufficient details in the specification for the soldering of bifurcated terminals where a re-flow of solder would occur so as to prevent weakened solder joints.

DISCUSSION

The S-II Program has experienced numerous instrumentation equipment failures caused by cracked solder connections during the various phases of the S-II vehicle test.

Considerable time and effort have been expended in re-cycling, failure analysis, and effecting corrective action on each failure occurrence.

Due to variation of each failed printed circuit board, the failure analysis and corrective action of cracked solder connections varied. In general, the major loading mechanism in solder joint failure was entrapped conformal coating or contaminants stressing the joint during thermal excursions and/or soldering. The major objective in the establishment of corrective action was to strengthen solder joints such that the joints could withstand stresses caused by thermal excursions during equipment usage or during storage. Detection of stressed solder joints was improved by revising production process specifications to call out the use of 30X power magnification glasses in place of 7X power. All stressed solder joints detected were strengthened by improved production process and quality control. The above was accomplished for the pullout printed circuit boards that could be visibly inspected.

The equipment that could not be visually inspected for stressed solder joints due to non-transparent protective coating such as silicone rubber, but had experienced high failure rate, was determined to be too costly to re-work due to the packaging design; therefore, the correction was concentrated in the production processes on follow-on units.

As a result of equipment failures, a refurbishment re-cycle was set up for PCM telemetry components installed in the stage at time of launch. The components required re-work to requirements specified within a period no greater than 6 months prior to a scheduled launch.

SAFING HAZARDOUS EQUIPMENT FOR MAINTENANCE OR REWORK

PROBLEM STATEMENT AND EFFECT

The power to a substation was turned off before clean-up was to be accomplished in the immediate area by electrical technicians. However, there was a second source of power into the substation that was not known.

The two technicians were injured as a result of coming in contact with one leg of a 12,000-volt 3-phase feeder, fed from an unknown source that did not show up on the schematics.

SOLUTION/RECOMMENDATION

Drawings were revised to reflect the actual configuration of the electrical system, and posted in each main and substation to show all 12 kv breaker and distribution systems.

A lockout procedure was prepared and implemented which conformed to the requirements of the System Safety Manual.

The 12-kv power indicating lights were installed on the feed side of the transformer disconnect switch in each substation to indicate power status between the substation and the main switchgear cubicle.

Instruction manuals were prepared for issue to each department electrican to inform them of the service and operation of each main station and substation. This manual will include copies of the single line diagrams of the lockout procedures.

A lock-controlled properly equipped tool cabinet was installed in each main and substation to ensure that all tools and safety equipment required are always available. All technicians were given a refresher course on proper operating procedures.

DISCUSSION

Two technicians received an electrical shock when coming in contact with an energized 12,000-volt feeder line while cleaning insulators in a substation. The basic causes for the accident can be summarized as follows:

1. Primary power schematic diagrams were not up-to-date to show modifications as new buildings were added to the Seal Beach complex.

2. A test for the presence of voltage on the primary feeder line was not made as a doublecheck before beginning work on the equipment.

3. A switch lockout procedure using individually assigned padlocks was not in effect.

4. Power indicating lights on the front panel of the substation equipment do not exist.

REQUIREMENT FOR LH_2 RECIRCULATION PUMPS CAPABLE OF WITHSTANDING ALL TESTING AND LAUNCH CONDITIONS

PROBLEM STATEMENT AND EFFECT

LH_2 recirculation pump bearing failures were due to inadvertent pneumatic turbining (pressure differential across pump) and/or excessive electrically powered (dry spinning) operations.

Because of bearing failure on four stages and without backup test data as to speed and duration of overspeeds on installed pumps prior to launch, many pumps had to be replaced in order to guarantee integrity of the pumps for flight.

SOLUTION/RECOMMENDATION

The supplier was required to test the pumps and determine the cause of the bearing failures. Procedures were reviewed by design engineering to ascertain the cause of pump overspeed and make changes, as required, to the test procedures to preclude a recurrence of the conditions responsible for overspeeding the pumps.

Design engineering should be cognizant of the total test and service conditions that the pump will be subjected to from time of supplier tests through test operations, launch, and flight.

Procurement and Process Specifications should contain the requirements to design to the eventual service environments and sufficient development testing completed to prove that the pump is qualified for production and service use.

DISCUSSION

LH_2 recirculation pump bearing failures occurred on pumps installed on S-II Stages. The pump bearing failures were due to inadvertent pneumatic turbining (pressure differential across pump) and/or excessive electrically powered (dry-spinning) operations. Time to failure ranged from one minute of dry-spinning to 25 hours of cryogenic operation. The bearings contained phenolic-micarta retainers.

The analysis of the bearings after failure indicated a considerable amount of friction between the bearing rotating parts as a result of turbining which caused chatter of the micarta retainer against the bearing outer race. This action caused fatigue failure of the retainer rivets, separation or breaking of the retainer, and/or failure of the aluminum side retainers resulting in damage to bearings and races.

The probability of pump failure was determined to be a function of the frequency and/or duration of unscheduled pump operations.

A failure of a pump during flight would cause loss of recirculation on the affected engine, no engine start, and resultant loss of mission.

A design change was approved to replace the Barden bearings, with reinforced-phenolic (micarta) retainers, with teflon-impregnated fiberglass (Rulon) retainers.

All applicable process specifications and detailed operating procedures which could produce a differential pressure across the pump were reviewed, and caution notes added where required.

The improved lubricity of the Rulon material increased the allowable electrically powered (dry-spinning) operations to 8 cycles per 40 minutes total time and, together with a change in retainer design, eliminated bearing damage caused by pneumatic turbining overspeed operations.

In addition to the bearing change and updating of the procedures, the capability of monitoring the LH_2 recirculation pump output in revolutions per minute has been incorporated at the test site for use during dry spin tests. The LH_2 recirculation pump dry spin test is performed as required following either unscheduled dry spin of the pumps or replacement to validate pump integrity.

CONTROL OF TRANSPORTATION HARDWARE

PROBLEM STATEMENT AND EFFECT

A transportation bolt, one of 203 used to ship the interstage, was found to have been overlooked and still in place.

If a transportation bolt was inadvertently left in place, the end result would be a failure of the stage to separate and a probable mission abort.

SOLUTION/RECOMMENDATION

Controls were established whereby the bolts would be color coded and removed and accounted for by a fabrication, assembly, and inspection record (FAIR) ticket.

A second inspection was recommended prior to stacking.

DISCUSSION

A transportation bolt, which is one of 203 bolts used to ship the interstage from the Tulsa Facility to Seal Beach, was found still in place on the interstage. Even one bolt could cause a mission failure if left in place. As a result of discovery of the bolt, action was taken to color code the transportation bolts and account for each bolt shipped with the interstage. This was accomplished by a FAIR ticket. The bolts were then processed back to the shipping point for re-use.

A second inspection was included for re-inspection of the holes to assure they had not been filled by a technician assuming that the holes should have a bolt. This was to be accomplished prior to stacking the stage.

SAFETY HAZARDS ASSOCIATED WITH STAGE TRANSPORTATION EQUIPMENT

PROBLEM STATEMENT AND EFFECT

The S-II stage transporter electrical system malfunctioned during a move of the stage to a new location. As a result of the investigation that followed, it was determined that the system did not have an electrical ground from the facility power supply (480-volt 3-phase ac) to the transporter and from the portable remote control unit (115-volt single-phase ac power) to the transporter.

A potentially hazardous condition existed which could have resulted in injury or death to personnel working on or operating the transporter.

SOLUTION/RECOMMENDATION

Replaced 3-wire cable connecting to facility power with a 4-wire cable. Connected the fourth wire between the transporter frame and facility ground.

Replaced 4-conductor cable with a 5-conductor cable and connected the fifth wire between ground and drive control case.

Added protective covers over the terminals of control switches exposed to operator contact.

Added protective covers to the microswitch terminals of stabilization circuits exposed to working personnel and not protected from environmental conditions.

DISCUSSION

During troubleshooting activities resulting from malfunctions of the stage transporter, conditions were observed which required corrective action to prevent injury or death to personnel or malfunction of the transporter electrical system.

A shock hazard existed in the stage rotation system through lack of an electrical ground from the facility primary power supply (480-volt 3-phase ac) to the transporter, and from the portable remote control unit (115-volt single-phase ac power) to the transporter.

A shock hazard existed in the operator cabs (forward and aft) of the transporter because the terminals of control switches on the dashboard in the cabs were exposed (115-volt ac potential) to the operator's legs or hands.

A shock hazard was present during operation and adjustment of the transporter stabilization system because the microswitch terminals of the stabilization circuits were exposed to working personnel (115 volts ac).

The microswitches were directly exposed to rain and other environmental conditions.

HAZARD PREVENTION FROM CAPACITORS

PROBLEM STATEMENT AND EFFECT

Radio noise filters were inadvertently placed in a circuit ahead of the noise circuit breakers.

This is technically correct but creates a potentially hazardous condition for people.

SOLUTION /RECOMMENDATION

Circuit re-wired to put the radio noise filters on the load side of the circuit and behind the circuit breakers and bleeder resistors in the load side of the circuit to discharge the capacitors.

DISCUSSION

Technical and operating personnel had received electrical shocks when working around a piece of ground support equipment. The equipment was a vacuum pump, and had a three-wire system with a 480-volt input to the pump from the facility source through three circuit breakers. The radio noise filters (capacitors) were in the lines between the facility power supply and the circuit breakers. Whenever the circuit breakers were opened, the capacitors were still connected to the 480-volt power source and stored an electrical charge capable of giving a severe electrical shock to anyone coming in contact with the circuit.

The circuits were re-designed to put the capacitors on the load side of the circuit so that power would be disconnected from the capacitors whenever the circuit breakers were opened. Also, bleeder resistors were added to each line to bleed off the capacitor charge to ground, thereby getting rid of the potentially hazardous condition responsible for the electrical shock to people.

GROUNDING REQUIREMENTS FOR EXPLODING BRIDGEWIRE FIRING UNITS

PROBLEM STATEMENT AND EFFECT

The eight exploding bridgewire (EBW) firing units on the S-II flight stage were found to be unbonded to the stage structure.

In their unbonded condition the firing units could have produced radio frequencies, and could have been hazardous to personnel working around them if they were charged to their flight-working voltage of 2300 volts dc.

SOLUTION/RECOMMENDATION

The faying surfaces of the EBW firing units support assemblies and interstage structure were prepared to provide a metal-to-metal contact with a low resistance of less than 0.1 ohm to structure.

DISCUSSION

Review of the electrical bonding requirements ascertained that the requirement to bond the eight EBW firing units on the S-II flight stage had not been complied with. The requirements were delineated in the MA0303-025 Specification which was applicable for S-II airborne systems. These units in the unbonded condition could have produced undesirable radio frequencies and, from a personnel hazard standpoint, could be a shock hazard if charged to their flight-working voltage of 2300 volts dc. A requirement was added to documentation to assure the required bonding between units and stage structure.

Safety 32-03

MALFUNCTION SENSING AND INHIBIT FOR RANDOM ACCESS SWITCHING SYSTEM

PROBLEM STATEMENT AND EFFECT

During a checkout station verification, the test results indicated that noise was being developed across current-limiting resistors causing out-of-tolerance measurements and rendering low-level signal measurements with any degree of accuracy virtually impossible.

SOLUTION/RECOMMENDATION

Malfunction sensing circuits were added in a random access switching drawer to monitor the three coordinate solenoid/relay drivers. Simultaneous outputs from any two solenoid/relay drivers in one coordinate will inhibit the coil excitation in less than ten microseconds.

DISCUSSION

The test results during a GSE station verification indicated that without malfunction sensing and inhibit circuits, inadvertent application of power to otherwise de-energized circuits on the stage and in GSE can occur due to the stacking of test points.

Safety 32-04

EXCESSIVE ELECTRICAL STATIC BUILDUP AND DISCHARGE

PROBLEM STATEMENT AND EFFECT

Static buildup and discharge has been responsible for electrical shock to technicians working on stages. The shock has been of sufficient magnitude to cause momentary loss of muscle control.

Insufficient grounding of equipment to adjacent grounded structure contributes to the problem.

SOLUTION/RECOMMENDATION

Ground strap requirements were added to the drawings and to the installation procedures. After installation of the equipment into the stage and installation of ground straps, specific resistance testing of the ground strap grounding verification was required as part of the procedure.

DISCUSSION

There have been incidents of electrical shock to technicians working on the stages. These are the result of static electrical buildup charges on stage equipment that have not been grounded through the stage structure.

One instance concerned protective pads used on the stage forward bulkhead. A maximum voltage was generated when the pads were installed on the stage forward bulkhead as the result of dragging and sliding the protective pad into place.

Revisions to the installation procedure were made requiring the technicians to wear clothing not subject to static buildup. The pad installation also required the pad to be rolled into place rather than dragging or sliding. Grounding could not be required in this installation since no attach points or methods of grounding the pad to the structure was possible.

Another static problem involved the heat shield protective platform. This unit required static straps to be installed when assembled into the stage; however, provisions for the straps and points of attachment were not provided. In this instance, the drawing for the platform was revised to require the straps to be a part of the heat shield protective platform and provide specific grounding studs for ground strap attachment.

Additional documentation changes required resistance checks after installation of the grounding straps.

PACKAGING MATERIAL FOR ORDNANCE ITEMS

PROBLEM STATEMENT AND EFFECT

Packaging material used for shipping ordnance items to a test site (KSC) was found to have a static charge.

Static electricity discharge could cause an explosion of ordnance items, ignition of flammable material, or shock to personnel.

SOLUTION/RECOMMENDATION

Do not permit the use of static generating packaging materials for explosives.

Use all safety precautions necessary when presence of a static electrical charge is evident or suspected. Bleed off static charges by using a ground wire.

DISCUSSION

When a shipping container used to ship a single bridgewire Apollo standard initiator (SBASI) to NASA/MSC was opened, the packaging material (styrofoam) was found to contain a static charge of 4500 volts dc. The problem was detected because the packing material stuck to the side of the container.

A problem similar to this was reported by Andrews Air Force Base, Maryland.

It was stated that during unpacking, ignition of the styrofoam lid occurred due to static discharge.

CONTROL OF ELECTRICAL BACKUP SYSTEMS

PROBLEM STATEMENT AND EFFECT

During a field test checkout of a stage, lightning struck the test stand and caused the primary source of power to the facility to fail.

The secondary backup power source failed to come on the line.

SOLUTION/RECOMMENDATION

A procedure was written to require that the electrical backup system be checked out for operation and that the system is on the line before start of testing.

Verification that the system is operational and on the line is required by Quality Control.

DISCUSSION

A test was in progress at the Mississippi Test Facility when the test stand was struck by lightning and all power to the facility, GSE, and stage was immediately lost. The normal backup system, consisting of generator and batteries, failed to come on the line as designed to do in such cases as loss of primary power.

An investigation determined that the control switches were in the off position and, therefore, could not back up the test operation as the secondary source of power.

INADVERTENT ELECTRICAL STRESSING AND OPERATION OF LIMITED LIFE COMPONENTS

PROBLEM STATEMENT AND EFFECT

Limited life electrical components can inadvertently and unknowingly be energized and damaged by continuous operation during stage checkout.

SOLUTION/RECOMMENDATION

All limited life items were identified on the drawings and in the design engineering checkout specifications. The detailed operating procedures were expanded to list the switch and circuit positions to be used for supporting, monitoring, and/or partial testing of other stage systems while the GSE is in standby periods. Cautions and Warnings were added for all alternate switch and circuit breaker positions used during stage monitoring and/or partial testing of stage systems.

Redesign the control circuits in the GSE to preclude the possibility of their inadvertent energizing and/or provide a warning light on the console whenever the circuits are energizing the limited life components. Limited life components must be identified, monitored, and controlled early in a program.

DISCUSSION

During a stage checkout the stage and GSE were interfaced electrically and pneumatically with the GSE operating on a standby status. Meanwhile, the technicians were accomplishing modifications to the stage thrust structure and conducting line leak checks.

The GSE had been configured according to a section of the Stage Checkout Operating Procedure manual. After 91 hours and 22 minutes of GSE standby operation, it was discovered that the main hydraulic pump solenoids had inadvertently and unknowingly been in an energized condition for this full period of time.

REQUIREMENT FOR OPERATING TIME/CYCLE MEASUREMENT AND RECORDING REQUIREMENTS

PROBLEM STATEMENT AND EFFECT

A helium tank of the Saturn V disintegrated during a static firing after system pressure had been brought up to operating pressure. The stage was lost as a result of the tank disintegration.

The number of high pressure cycles that the tank had been subjected to before disintegration had taken place was determined.

NR did not have a record of the number of cycles that S-II tanks had been subjected to during test and checkout operations and, since the tanks were from the same supplier as the helium tank that had exploded, all testing on the S-II Stages was stopped until the cause of tank failure could be determined.

SOLUTION/RECOMMENDATION

A requirement for monitoring and recording all high-pressure cycles applied to the helium tanks from acceptance testing through checkout and launch operations was added to the pressure vessel drawings. This was done by referencing the procurement and specific process specifications which detailed the methods of logging and recording pressure cycles.

This requirement should be listed on all pressure vessel drawings while in vellum stage before release, so the requirement will be established early in the program.

DISCUSSION

During a static firing an explosion occurred to one stage of the S-V stack that was traced to the disintegration of a helium sphere on the stage. The investigation indicated that the shrapnel from the helium sphere resulted in loss of the stage by penetrating the fuel tank. Since the S-II Program used helium spheres from the same supplier, all testing that required pressurizing the spheres above 50 percent of operational pressure was stopped.

The supplier of the tanks, after a careful investigation, determined that the wrong titanium welding wire was used for a certain series of tanks manufactured in their facility. NR was able to ascertain that the tanks on the S-II Stages were not any of those assembled with the incorrect welding rod. This was accomplished through the traceability system in effect on the S-II Program.

The verification of the acceptability of the tanks for use was done by taking samples of weld material from each of the tanks and making a material determination and verification that the weld rod used was that specified on the supplier's drawings.

Immediately after the loss of the stage, tests on duplicate helium spheres showed that cracks appeared in the welds of helium tanks welded with an incorrect weld rod after a specific number of high pressure cycles, and that after additional high pressure cycles the tanks disintegrated. It was at this point in time that it was necessary to know the exact number of high pressure cycles that each tank on the S-II Stages had been subjected to. It was revealed that the requirement had not been imposed by Design Engineering on the drawings.

Design Engineering then changed the drawings and imposed the requirement to record pressure cycle data in terms of psi and time duration.

AUXILIARY PRESSURE REDUCING PANELS FOR SYSTEM PROOF-PRESSURE TESTING

PROBLEM STATEMENT AND EFFECT

The existing ground support equipment, used to supply pneumatic pressure to the stage at the field sites, was not adaptable for use in pressure and leak-checking stage systems.

The capability to reduce pressures and relieve overpressure to meet the safety requirements for people working in the area was not available and, therefore, was unacceptable to the Safety Department.

SOLUTION/RECOMMENDATION

Pressure reducing panels with the capability to reduce system pressures to "people safe" ranges and relieve any overpressures above "people safe" pressures were provided and temporarily installed in a system as required for specific tests.

DISCUSSION

The requirement to field proof-pressure and leak test "isolated components" within stage pressure systems to industrial safety standards brought out the fact that the existing ground support equipment was not readily adaptable to the configuration needed to perform to safety standards. Industrial safety requires that there be a relief valve in the test system set at 10 percent above the maximum "people safe" pressure which is 25 percent of the design burst pressure of the system to be tested. Due to a wide variation of pressures used in the ground support equipment, it was an almost impossible task to readjust regulators and relief valves, within each console, to the lower pressure and relief requirements established for testing.

As a result of the lack of capability of ground support equipment to be adapted to a usable configuration for proof-pressure and leak testing of stage pressure system, individual pressure reducing panels were manufactured and made available to the test sites.

MINIMUM DESIGN SAFETY FACTORS FOR FACILITY AND GROUND SUPPORT PRESSURE SYSTEMS

PROBLEM STATEMENT AND EFFECT

Pressure systems containing a gas or liquid, and compressed to a pressure exceeding 150 psig around which people are in close proximity, must be designed to a minimum safety factor of 4 to 1. The requirement is mandatory by local, State and Company safety standards; and applies to lines, fittings, valves, tanks, regulators and gages.

Failure to comply with the requirement could result in injury to personnel and damage to equipment, or red tag of equipment until compliance is complete with resultant loss of schedule.

SOLUTION/RECOMMENDATION

Design Engineering established the 4 to 1 safety factor on the drawings for all components on the S-II Program. The requirement should also be specified in procurement specifications and for all off-the-shelf items that are standard commercial components.

Data which establishes the satisfactory results of burst pressure tests of supplier components and proof-pressure tests of production units should also be required in procurement specifications which are referenced on the drawings.

DISCUSSION

Two instances which occurred on the S-II Program point up the consequences of failing to provide the minimum 4 to 1 safety factor.

The first problem concerned a warning horn system (S7-44). This system is used to provide pressure to the S-II LOX and hydrogen tanks during the times the S-II was being transported.

The problem was discovered during a drawing review. It was determined that the relief valve used to relieve an overpressure in the warning horn tank did not meet the ultimate tensile strength of 4 to 1. The warning horn system pressure was 2200 psig and the design burst of the valve body was 5000 psig. In order to meet the minimum safety factor of 4 to 1, the valve design burst should have been 8800 psig.

The operating pressure of the S7-44 units was lowered to 1250 psig in order to comply with a safe environment until the relief valves were replaced with new units meeting the required design burst pressure of 8800 psig.

The second problem associated with design of a part to less than a 4 to 1 safety factor in a component occurred when the weld on a regulator separated at 8700 psi during receiving inspection in the Quality Control laboratory. The working pressure of the valve was 6000 psi, proof pressure 9000 psi, and the burst 24,000 psi. The inlet port of the component was welded into the body of the part, and the weld failed during the proof pressure test at 8700 psi.

The investigation that followed determined that over 300 valves and regulators were suspect of having undersized welds that would not meet a 4 to 1 safety factor. These 300 valves and regulators were only those on the S-II Program. The valve weld fillets were measured, and valves with undersize weld beads were returned for rework. Weld fillet sizes were added to supplier drawings.

MAINTENANCE, INSPECTION, PROOF-LOAD REQUIREMENTS FOR HOISTS

PROBLEM STATEMENT AND EFFECT

A wire rope separated from its wench drum resulting in damage to the insulation covering the hatband of an engine.

SOLUTION /RECOMMENDATION

Corrective action was to paint the wire rope for the last seven turns on the drum, and to maintain at least 5 turns of wire rope on the drum during hoisting operations.

Additionally swaged balls were added to all termination ends of the wire rope on all cables.

Inspections of all hoisting and lifting equipment to assure correct cable termination (prior to next usage) were required.

Reviewed proof-loading and preventive maintenance procedures to assure that specific callouts with mandatory inspection points were included for correct cable termination.

The proof-load requirements were expanded to include both a static and dynamic proof load of the assemblies.

Test checkout procedures were reviewed for adequacy.

DISCUSSION

In the low-bay checkout cell of the Vertical Assembly Building, the center engine was struck by the engine compartment work platform. One of the four hand hoists used in this operation failed which allowed the platform to swing against the engine. The insulation covering the engine was damaged. The basic cause was determined to be an improperly secured cable on the hoist drum. Subsequent investigation revealed that the ball end swage fitting was missing from the drum end of the cable.

Military and Federal specifications do not clearly define the exact method of termination of wire ropes to drums. However, there are standards for cable-to-drum diameter ratios which should be followed whenever possible. This will help to preclude cable slippage on drums with too small a diameter.

All requirements for termination of wire rope should use swaged balls at the hoist end of the cable to provide the factors of safety required by safety standards and criteria.

PROOF-LOAD TESTING OF PERSONNEL ACCESS EQUIPMENT

PROBLEM STATEMENT AND EFFECT

Access equipment used by personnel during manufacture, checkout, and test operations is required by Federal and State codes to be designed to a 4 to 1 safety factor, and to be proof-loaded to 1 1/2 times the maximum load the unit is designed to be subjected to.

Unless the required safety-factors are designed into the equipment and the proof-loading is accomplished after manufacture, the equipment would be considered unsafe and in violation of safety codes which would negate usage of the equipment.

SOLUTION/RECOMMENDATION

All top assembly drawings for end items were up-dated to specify a requirement for proof loading, loads required to meet the 1 1/2 times maximum use, methods of application of proof-loads, and requirement for records to substantiate acceptable proof-loading of the equipment.

DISCUSSION

A review of records at the test site (KSC) indicated that several pieces of personnel access equipment had not been subjected to proof-loading tests to prove that the equipment did "in fact" meet the 4 to 1 safety factor, required by the design on the drawings in compliance with the Federal and State Safety Codes.

An investigation determined that the top assembly drawings did not call out a requirement for proof-loading, method of applying the proof-load, the load required to be applied for the proof-load, or a requirement for records to show accomplishment of a proof-load.

Since the designer of the access equipment is the most knowledgeable of the equipment and its use, his requirements for proof-loading (frequency and weight) should appear on the drawing.

PROOF-TEST REQUIREMENTS OF ON-SITE VENDOR EQUIPMENT

PROBLEM STATEMENT AND EFFECT

A one-inch inside diameter flexible pressure hose burst at 2000 psig, causing violent whipping of the remaining portion of the flexible hose and bending and kinking of the hard line to which it was attached. The flex pressure line was vendor equipment.

The failure of this line created a hazard to the S-II Stage that was adjacent to the burst line and to personnel within 100-feet of the incident.

SOLUTION/RECOMMENDATION

Use of flexible hose was required to be kept to a minimum. Hard lines were to be used if possible.

All high-pressure hard lines used in the system were required to be proof-pressure tested before use.

Flexible hoses were required to show evidence of proof-test identification and approved restraints on each end, as required by the SD Safety Manual.

The high pressure hard line re-installation required concrete "deadmen" or lead ingot-type restraints over the hard line.

Changes were made in procedures that controlled the preparation of the test site for use. These changes consisted of Quality Control verification of compliance with the requirements noted above before testing could proceed.

DISCUSSION

Shortly after start of the pneumostat retest of the S-II Stage, an 8-foot-long flexible line broke from the fitting connecting it to a converter unit. Since the line was not restrained, the force bent and kinked two sections of rigid piping which runs about 75 feet to a GN_2 tube trailer, used as a gas accumulator.

The operator of the converter stated that there was a line pressure of about 2000 psig when the line broke. The pressure in the tube trailer, which was being recharged at the time of the incident, read between 1800 and 1850 psig.

The flex hose parted first where the convoluted interior metal of the flex line is welded to the connector at the converter end.

The investigation determined that the flexible line was not properly supported or restrained at the time of the incident.

There was no evidence of proof-pressure prior to the start of the test of the flex line, hard line, or assembled system.

The sandbags which had been laid over the hard line had burst open, showing rotted burlap which rendered them ineffective in restraining the hard line from flailing and whipping.

One piece of the hard line had been thrown about 100 feet, and could have damaged the stage or caused injury to personnel.

PREVENTION OF DAMAGE TO VEHICLE COMPONENTS DURING MANUFACTURE AND TEST OPERATIONS

PROBLEM STATEMENT AND EFFECT

Several incidents have occurred during the manufacture and test operations of aerospace vehicles which have resulted in damage to large structural components of the vehicles.

The damage to the components has been due to falling objects which inadvertently become detached from facility equipment used in support of a manufacturing process or from access equipment used by personnel to reach areas not accessible by normal means. The repairs required, as a result of these incidents, were costly and affected manufacturing and test schedules adversely.

The investigation of incidents that fall into this category require customer and contractor teams, and are time consuming in ascertaining cause or causes responsible for the incident.

SOLUTION/RECOMMENDATION

An analysis of one of the objects which fell and caused damage indicated that a rotating part in a piece of cleaning equipment had been assembled in reverse. During operation, the assembly backed out of its supporting structure and fell with force sufficient to damage an LH_2 tank being cleaned.

Receiving inspections were instigated which included tests to verify required operational performance. Additional backup was provided by the use of safety wire to assure that the equipment would not come apart during use.

Analysis of a second part that caused damage revealed that a ladder assembly had come apart at welded joints while being removed from a tank. A section of the ladder fell with resultant damage to the tank.

Analysis of welds that failed disclosed that all operational modes of the ladder were not considered as part of the criteria requirements that dictated the design of the failed joint.

As a result of the investigation all material handling, access, and nondimensional tooling equipment was reviewed and inspected for conformance to design requirements for use, and Quality Control requirements imposed on all drawings for future manufacture.

DISCUSSION

The interior of an LH_2 tank, in the Vertical Assembly Building, was being cleaned when a washer spray head became detached from the adapter on the spray arm assembly and fell from an elevation of 49 feet 6 inches above floor level striking two gores of the forward bulkhead. Damage consisted of a skin fracture on one gore and five scratches on the second gore. Investigation disclosed that the rotor, on the spray head that fell, rotated in a counterclockwise manner which tends to loosen the threaded joint holding the spray head to the cleaning assembly adapter.

Action was taken to verify correct rotor assembly by functional tests at receiving inspection, and safety wire added to provide backup integrity for all threaded connections.

The ladder assembly of the horizontal tank entry platform failed while being retracted on completion of work in the LH_2 tank of an S-II Stage. Weld failure of two weld joints of the ladder permitted a section of the ladder to fall causing damage to the forward LH_2 bulkhead.

The weld joints consisted of channel stringers butt-welded to plates that were bolted for disassembly purposes. The joint was designed for a safety factor of 5 to 1, predicated on the down position usage. Subsequent investigation disclosed that all operational modes of the ladder were not a part of the criteria requirements that dictated the design. The ladder was used at different elevations, from horizontal to a fully lowered position.

The use of the ladder in a horizontal position caused an increase in stresses and a reduction in safety factor below the 5 to 1 originally considered in the design.

The welds were not fabricated per the drawings and no Quality Control inspection was made of the joint after manufacture.

The proof load of the ladder was conducted to the full down position and did not take into consideration any other operational modes of the ladder.

SURVEILLANCE OF VENDOR EQUIPMENT USED ON COMPANY-CONTROLLED FACILITIES

PROBLEM STATEMENT AND EFFECT

Vendor equipment used to support work being accomplished on Company-controlled facilities has been in violation of safety standards with resultant damage to the facilities.

SOLUTION/RECOMMENDATION

Criteria was established to require equipment coming into Company facilities to be scrutinized for optimum working condition and safety.

All contracts going to outside vendors should include a clause requiring that vendors meet the safety standards required by local, State, and Federal codes.

DISCUSSION

A vendor's vehicle was stationed in the water conditioning tank area, of the NASA site at Seal Beach, pumping liquid. During the process of pumping, a considerable loss of fluid was taking place at the pump (approximately one gallon of hydrochloric acid a minute). The operation was stopped and the acid runoff diluted with water. The leak was repaired and the operation completed.

The vendor was advised that all future equipment brought into Company property would be scrutinized for optimum working condition and safety.

Test 01-01

CONTROL OF NONFLIGHT HARDWARE

PROBLEM STATEMENT AND EFFECT

Nonflight, stage mounted hardware was not controlled by a single official document.

SOLUTION/RECOMMENDATION

Although multiple documents may be utilized for the installation or removal of stage mounted hardware, the top stage drawing should be the document that controls or specifically lists the control documentation for this type of hardware.

DISCUSSION

In the early stages of the program, the identification of nonflight, stage mounted hardware, was gradual and complicated. As the program picked up momentum, Engineering was unable to issue Engineering Orders (E.O.'s) and change drawings rapidly enough. In an effort to accomplish the requirements on schedule, manufacturing and test utilized their in-process documentation to supplement engineering documentation. At the same time, engineering listed hardware requirements in a specification without the specification being called out on a drawing. The end result of the above described situation was that hardware removed subsequent to manufacturing completion and controlled by manufacturing documentation was not reinstalled; because, manufacturing documentation does not control configuration nor was it recognized, during in-process effort by the test organization, at Seal Beach or at the sites. Further, hardware listings defined in specifications were only partially implemented; usually, only upon hardware availability.

This problem faced the tedious task of drawing EO changes until final resolution was attained prior to the shipment of the final vehicle from Seal Beach.

GROUND MEASUREMENT PROGRAM (GMP)

PROBLEM STATEMENT AND EFFECT

No single locally controlled document was published containing NR's ground measurement and data recording support requirements for S-II testing at the Mississippi Test Facility for use by NASA and the Site Support Contractor (GE). This problem caused numerous difficulties in government-furnished property (GFP) hardware and recording facilities installation and use. The worst case was measurement data not obtained during stage testing.

SOLUTION/RECOMMENDATION

A Ground Measurements Program was published and controlled by the site. The GMP contains all ground measurement, GFP hardware, and recording facility requirements to support stage testing. It is recommended that for all future programs using government-operated/controlled ground measurement facilities for vehicle/engine testing, use of a local site-controlled requirements document, such as the S-II GMP's, be considered.

DISCUSSION

Confusion resulted due to lack of control documentation on the hard-wire instrumentation (ground measurement) system. The site support contractor was responsible for maintaining GFP transducer stocks, test stand-to-data acquisition facility (DAF) interface, closed-circuit television (CCTV) system, film photographic system, and the data acquisition facility for ground measurement recording. NR was responsible for maintaining test-stand signal conditioning, stage and test control center (TCC) to test stand signal-conditioning interfaces, and TCC data recorders. NASA and NR had to develop a control document to ensure that all data requirements necessary for proving the S-II stage flightworthy were met.

The S-II GMP, controlled and published by local MTF NASA, is basically the measurement requirements document for use of government facilities in support of S-II acceptance testing. The document is divided into three sections. Section I, containing NR's requirements, included the following information:

1. A measurement list for each acceptance/critical S-II stage test containing the measurement number, measurement title, range, and recording system to be used.

2. A list of required local site stocked GFP transducers by measurement number and transducer part number.

3. Ground measurement system recording requirements, such as oscillograph paper speeds and digital system sampling rate, including CCTV and 16-mm film coverages.

All additions, deletions, and corrections to Section I of the GMP are submitted by NR in the form of a change notice. The change notice is approved and distributed by MTF NASA. It constitutes local authority for instance, for a transducer to be issued from government stocks by the site support contractor to NR for use in stage testing.

Section II of the S-II GMP contains inputs from the site support contractor - for instance, facility system measurements to be recorded for his use during S-II testing, such as LOX transfer system temperatures at incremental monitoring points.

Section III of the S-II GMP contains inputs from NASA on measurements to be recorded for NASA use during S-II testing.

Test 01-03

ACCEPTANCE TEST REQUIREMENTS DOCUMENTATION

PROBLEM STATEMENT AND EFFECT

Post-manufacturing and static firing checkout of the first six flight stages was performed to the requirements established by numerous acceptance specifications. The specifications required an excessive amount of time to maintain, led to confusion due to monitoring the changes, and often created redundant checkout requirements. Confusion also existed in determining if the detailed operating test procedure prepared by the test group fulfilled the acceptance specification requirements.

SOLUTION/RECOMMENDATION

All post-manufacturing and static-firing requirements were consolidated into three acceptance specifications. Each detailed operating procedure incorporated an engineering requirements section which contained the acceptance requirements for that test procedure. The specification consolidation along with the incorporation of engineering requirements in the test procedure, permitted better control of the changes to the requirements and eliminated the confusion that previously existed on the validity of the procedures test.

The method of making engineering requirements part of the detail test procedure should be implemented from the start of any program. This ensures accuracy of the test operating procedures and eliminates confusion. This will also allow acceptance requirements to be gathered together in a minimum number of documents.

DISCUSSION

The original S-II stage acceptance requirements were contained in numerous subsystem specifications. The test group prepared a detail test procedure for each requirement document. The maintenance of all these documents required a tremendous amount of time, test procedures often had to encompass portions of several different requirements to accomplish one subsystem test, and keeping track of all requirement tasks contained in separate documents were often confusing. The requirement documents were incorporated into three specifications: test requirements (mechanical); manual static firing test requirements; and test requirements (electrical). The acceptance requirements documents were maintained by a central engineering group and all changes were coordinated through them. The detail test procedures were changed to eliminate redundant operations and to incorporate an engineering requirements section to establish the test procedure requirements baseline. Changes were easily made as engineering would send the test group a specification revision sheet indicating the requirements change (engineering requirements section) and the test group would make the necessary changes to the detail procedure on the same revision sheet. Subsequent approval of the revision sheet ensured all changes were incorporated.

REFERENCES

Manual Acceptance Specification, MA0201-4369

Pressurization System Checkout, MA0706-1046-118

SIGNAL FLOW DIAGRAMS FOR GSE MALFUNCTION ANALYSIS

PROBLEM STATEMENT AND EFFECT

GSE schematics, drawn to the rack drawer level, did not indicate system signal flow. Without system signal flow diagrams, Test Operations troubleshooting personnel had to spend considerable time tracing through numerous drawer-level schematics, rack wiring lists, and facility cabling diagrams to determine a function's signal routing and thus locate and correct the indicated malfunction in the GSE.

SOLUTION/RECOMMENDATION

A solution was implemented in the form of the end-to-end static firing GSE schematics. These schematic diagrams did show signal flow through the GSE from the command generation source to the vehicle and back to the response displays. It is recommended that systems-type engineering should be used to develop and maintain signal flow diagrams on GSE. The development and maintenance should be based on the stimuli generation source through the response displays throughout the entire program.

DISCUSSION

To achieve system signal flow diagrams of their respective ground support equipment (GSE) systems, Test Operations personnel used training manuals and hand-drawn flow schematics from engineering sources. These information sources were not updated by any formal release system and had the same status as the engineer's personal notes. While this means sufficed on the S-II test program, considerable time was lost in developing personal knowledge of GSE signal flow by, in many cases, trial and error. The static firing schematics were produced to avoid this problem; and since hold times during cryogenic operations were generally limited, test personnel could not afford excessive time in searching through various separate schematics and interface diagrams to trace out a signal, list the test points, and then start troubleshooting.

AUTOMATIC CHECKOUT DATA REDUCTION

PROBLEM STATEMENT AND EFFECT

Considerable time was required to reduce the data acquired during an automatic test to verify system acceptance. Data from three different sources were manually correlated for this verification on the first two flight stages.

SOLUTION/RECOMMENDATION

A data reduction system was developed that reduced processing time, eliminated most operator errors, increased data accuracy, relegated correlation activities to the computer, and improved data format for a higher degree of readability. The data reduction system, called merge and correlate recorder output (MACRO), reduced the manhours required to verify system acceptance by one-half.

The MACRO system is highly recommended for use where an events trail (a complete listing of all events that occurred during a test) from more than one source is an output of a computer checkout and must be verified for system acceptance.

DISCUSSION

The events trail obtained during automatic checkout of the S-II stage came from three different sources. The requirements for stage acceptance established a need to verify and compare the three data sources. The verification required methodically checking each data source for the proper sequence of events and the elimination of extraneous events. The three sources were then compared to verify the proper sequence of events. This analysis required extensive effort to perform due to the amount of tests that were accomplished and data obtained. This manual reduction was performed on the first two flight stages.

The MACRO data reduction system was established for use with the third flight stage and all subsequent stages. MACRO merged and correlated S-II test data from the computer complex conducting the automatic testing, the digital events recorder, and the pulse-code modulation (PCM) data telemetered from the stage. The program processed data events from the input sources in a time-sequential manner. If an event could not be correlated, a discrepancy message would appear. The confidence level in the final data was very high because better than 90 percent of those discrepancies not detected during the real time test would be flagged by the messages. The remaining ten (10) percent would be present in the data but would not be detected directly by MACRO. The printed single listing obtained from MACRO provided for expeditious test engineering analysis. (Refer to software operations procedure SOP-SOX-Z019 for a detail explanation of the MACRO data reduction system used on the Saturn S-II program.)

S-II AUTOMATIC CHECKOUT PROGRAMMING

PROBLEM STATEMENT AND EFFECT

The following problems were encountered in developing automatic (computer controlled) checkout for S-II:

1. A complete computer tape evaluation program was not conducted before the tapes were used on the flight stages. Many automatic program timing problems resulted. The stage subsystems and automatic checkout equipment (ACE) were not allowed enough time to react after a stimulus had been applied.

2. The automatic checkout programs were written to accomplish subsystem tests, but they did not check for interactions between subsystems or initialize the stage before a particular test was performed.

3. After acceptance testing, the complete automatic program, requiring many manhours, had to be conducted to retest when a component had been replaced due to a failure or modification. Several automatic tests required the same preparations and utilized some of the same subsystems during testing. Redundant effort and testing resulted.

4. Program tape changes made at the Mississippi Test Facility and subsequent engineering approvals required processing the paperwork through the California facility. This procedure meant delays to the test facility in clearing discrepancy reports.

SOLUTION/RECOMMENDATION

The following solutions/recommendations are directly relative to each problem statement:

1. The computer checkout tapes were evaluated during the checkout of the first flight stage. The tapes were to be evaluated on the electrical-mechanical mockup (EMM), but due to several problems the final evaluation was not performed. Because the evaluation was performed on the flight stage, the checkout schedule was affected and premium time was expended in order to evaluate and correct the tapes.

Future programs that use automatic checkout should evaluate the tapes on a test vehicle or allow sufficient time to perform the evaluation on the production vehicle.

2. Common sub-procedures were developed for use with all subsystem checkout tapes. These sub-procedures were utilized throughout the subsystem tapes to check for interactions between subsystems and to initialize the stage at the start of each tape.

   The common sub-procedure method is most efficient where several subsystem tapes are used. Each sub-procedure can be used as necessary, and the programming is limited to one procedure.

3. The automatic checkout programs were modularized to provide the capability to check out partial subsystems. This method of programming was especially effective for partial subsystem checkout after a component failure or a subsystem modification and for an evaluation test. The subsystem tests were also re-evaluated, where preparations for the tests were the same or the tests were redundant, the tapes were combined into one test.

   The modular method of programming is beneficial for partial testing. The preparations for the test are usually minimal, and the time required for testing is considerably reduced. The method is recommended for applications where component failure or subsystem modification is a consideration.

4. When the automatic tests were scheduled, an engineering programmer was sent to the Mississippi Test Facility to process any necessary changes. The engineer was responsible for authorizing changes and assisting in identifying program errors. Errors occurred throughout the program due to stage modifications requiring changes to the checkout tapes.

   It is recommended that engineering representatives be on site where automatic checkout will be performed and authorization is required for any test changes.

DISCUSSION

The problems and solutions previously noted are discussed in the following paragraphs. Each item is directly related to the previous item:

1. An EMM was designed for the S-II program to perform subsystem fit check and manual and automatic test verification. The automatic checkout tapes were to be evaluated in the EMM, but several problems developed; therefore, the schedule did not permit the verification. A late delivery of automatic checkout equipment, station activation problems, and an early deactivation of the EMM were the contributing factors to the problems. The evaluation, therefore, had to be performed on the first flight stage. The checkout schedule did not allow for this extra effort, so the schedule had to be changed and premium time had to be expended to accomplish the work. This problem should be taken into consideration when planning a test program where automatic checkout will be used.

2. The initial release of the automatic checkout programs required ten separate subsystem tapes for test. Each tape activated the systems (applied stage electrical power, activated ACE, and checked for hazardous conditions) required for the particular test. Because there was no standard procedure, it was necessary to program and maintain ten separate activation procedures. Each tape was also programmed to verify only the responses which would result if a particular stimulus was applied. This method did not allow for responses that may react to the stimuli which were unrelated.

   A system of common sub-procedures was developed to be used with all subsystem tapes. Each common sub-procedure was developed by an engineer who was most familiar with the particular stage or ground support equipment in coordination with the subsystem engineers responsible for the checkout tapes. The most common of the sub-procedures was the stage initialization and the stage discrete response evaluation. The stage initialization procedure provided a standard method for stage electrical power activation, stage reset conditions, and ACE readiness; established an initial conditions discrete reference profile; and verified the overall stage-ACE readiness for automatic checkout. The stage discrete response evaluation was used for all discrete measurements after a stimuli had been applied. This evaluation would indicate any discrete that did not respond to the stimuli, plus any discrete that responded erroneously. Using common sub-procedures limited the programming effort, ensured quality with use of specialized system engineers, and reduced the program listings which presented a cost savings.

3. The automatic checkout tapes were first programmed to perform subsystem tests from start to finish with program halts only if a problem developed or a manual action was required. The first two flight stages were checked out in this manner. A problem developed; When a component failed and subsequently was replaced, the retest required repeating the complete automatic test. The same problem also developed when a modification had been performed after the acceptance test. This time-consuming method of retest resulted in excessive workloads. The original checkout tapes were also developed with each subsystem test on a separate tape. This method often presented redundancy in testing and pretest preparations.

   The checkout programs were revised to provide a modular subsystem program testing philosophy and to combine tests that were redundant in testing and preparation. By using the modular concept, the subsystem test was divided into a series of component tests. For example, the engine subsystem test consisted of a spark system test, an engine cutoff system test, an engine sequence test, etc. Therefore, any of these tests could be conducted without performing the complete engine subsystem checkout. The combining of subsystem tests into the same tape also resulted in reducing the number of the separate tapes from 10 to 7, which resulted in cost savings because of the reduced manhours required to perform the tests.

4. The automatic checkout program tapes were developed and released by Saturn S-II Engineering. All changes that were made had to be authorized by Engineering. A problem developed early in the program, at the Mississippi Test Facility, in making and approving changes because processing through the California facility was required. The changes were documented by a discrepancy report, and in order to clear the report, an Engineering Change Release was required. The amount of time required to process the authorization through the California facility often caused delays in clearing the paperwork before shipping the stage. The problem was solved by sending an engineering representative to the test facility at the time the automatic tests were scheduled. The engineer was responsible for authorizing changes and assisted in identifying program errors.

Test 03-01

LH_2 TANK ACCESS HATCH, INSULATION REMOVAL

PROBLEM STATEMENT AND EFFECT

The original engineering design of the LH_2 tank access hatch on the forward bulkhead of the S-II stage utilized a "permanent" application of insulation. Circumstances (such as new inspection requirements, foreign objects in the tank, and malfunctions of in-tank installations) established the need for tank entry. The removal of the permanent insulation was a tedious, time-consuming manual operation. Reinstallation of the insulation was a potential schedule constraint, due to the requirement for three days of chemical cure time.

SOLUTION/RECOMMENDATION

Engineering reassessed the heat loss through the access hatch and determined that it was feasible to change the design to leave the bolting ring for the hatch uninsulated.

During preliminary design review and maintainability evaluation, prior to the original design release, consideration should be given to the segment foam insulation on access hatches or covers.

DISCUSSION

Although it was not the original intention to enter the LH_2 tank after completion by manufacturing, it was soon determined that the requirement to enter the tank was in excess of that originally scheduled. Tank entry for the modification of in-tank installations should have been considered. This requirement did not cause the original problem but accentuated it. The most significant requirements for tank entry were pointed out by foreign objects in the tank and by new incremental inspection requirements.

FIELD REPAIR TECHNIQUES FOR SPRAY FOAM INSULATION

PROBLEM STATEMENT AND EFFECT

The S-II program development and use of spray foam insulation included a requirement to develop field repair techniques. Without such techniques, comples and costly manufacturing facilities would be required at test sites.

SOLUTION/RECOMMENDATIONS

Spray foam insulation repair techniques and procedures were developed and certified to support S-II-6 and subsequent vehicles for static firing and launch activities. Of particular importance was the development and certification of Cook pour foam as a suitable repair material; thus the need for spray foam equipment and facilities at the test and launch sites was eliminated.

DISCUSSION

NR first used spray foam on the S-II-6 and S-II-7 stage forward bulkhead, bolting ring, and Cylinder 1 areas, and totally foam insulated S-II-8 and subsequent vehicles. The spray foam not only saved considerable stage weight, but also proved to be a much better thermal insulator than the previously used foam-filled honeycomb insulation.

The external spray foam insulation proved to be much more rugged than the previously used foam filled honeycomb, but still insulation damage and minor debonds were continuing problems during manufacturing, field site testing, and launch operations. To assure timely and adequate insulation repair, specifications were written and the repair procedures were verified by application and inspection at the static firing test site. The development and proving out of the procedure for repairing damaged spray foam insulation by using Cook pour foam was particularly significant since it eliminated the need to procure equipment and facilities for spray-foaming operations at test sites.

REFERENCES

1. Repair Procedures for Saturn S-II Foam Insulation at Field Sites, MA0606-057

2. Foam-In-Place Application of Two-Pound Density Polyurethane Foam, Saturn S-II, MA0606-060

UMBILICAL ELECTRICAL CONNECTOR EXTENSION ADAPTER

PROBLEM STATEMENT AND EFFECT

The S-II and ground support equipment (GSE) umbilical connectors were damaged during mating because of the weight of the cables, which eliminated the feeling normally associated with electrical connector engagement.

SOLUTION/RECOMMENDATION

A cable extension (adapter) was designed to facilitate the mating operation. The adapter was positioned and mater with the stage connector, and bolts were installed to maintain the proper positioning to the stage connector. The GSE umbilical was then connected to the adapter (see Figure 35).

An adapter of this type should be used in applications where bulky cables are used and visibility is limited during the mating procedure. The use of adapters should be given consideration in the initial design of carrier plates.

DISCUSSION

The mating of the stage and GSE umbilical connectors required extreme care because of the bulky cables used. Bent pins and damaged keys were a major problem in connecting these umbilicals. Limited visibility resulted from the ruggedness of the carrier-plate design dictated by the forces required to disengage all of the umbilical connectors simultaneously. The use of the extension adapter eliminated the connector damage problem. The adapter was utilized successfully at the California and Mississippi S-II Test Facilities.

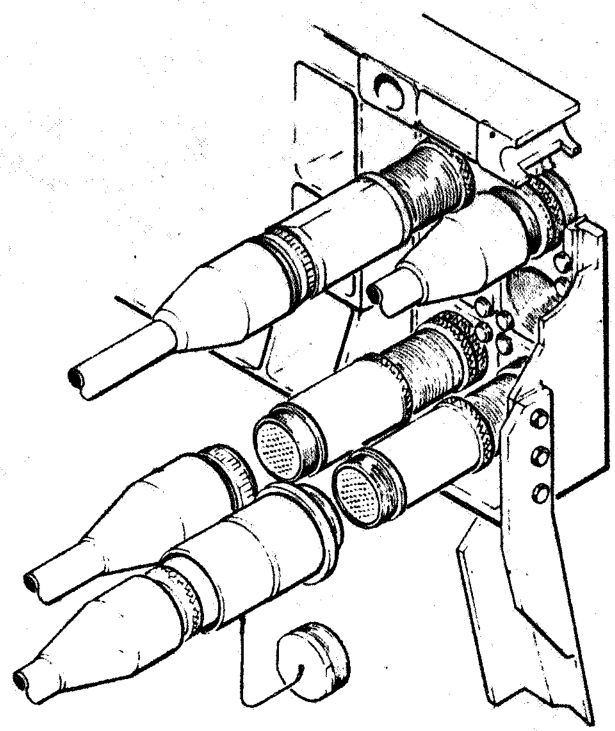


Figure 35. Carrier Plate Assembly With Adapter

STAGE MOVEMENT

PROBLEM STATEMENT AND EFFECT

Initially, movement of S-II stages between stations at Seal Beach caused many problems including:

Damage to vehicles

Support equipment inoperable

Support equipment not available

Functional groups not in a support posture

Functional responsibilities not coordinated

SOLUTION/RECOMMENDATION

A specification for the control of stage movement was generated and plans of action for the definition of responsibilities and schedules were established for both equipment and personnel.

DISCUSSION

After initiation of control procedures, whenever an S-II stage was in a station, the vehicle was under the control of a test conductor. To give the test conductor full station/vehicle visibility, a floor sentry was appointed for each level of the station. The floor sentries observed the vehicle during preparations for a move and enforced the disciplines of control and safety as described and defined in the move controlling specification.

The move conductor and associated functions that were planned and scheduled all required move events. The resultant plan was signed by all responsible participating functions.

The stage-oriented GSE and other related support equipment requiring modification, maintenance, or other scheduled effort was listed and scheduled on the master move schedule, as an effective means to ensure schedule compliance.

S-II TEST CREW QUALIFICATION PROGRAM

PROBLEM STATEMENT AND EFFECT

Due to the high degree of test complexity and the necessity to deliver defect-free S-II's, personnel knowledge and skill had to be developed far in excess of normal requirements. Failure to have anything less than fully competent and dedicated personnel conducting stage tests could cause catastrophic failures.

SOLUTION/RECOMMENDATION

A test crew qualification program was implemented, with primary emphasis on accurately defining test crew position task descriptions. Personnel were trained through formal classroom, formal "On-The-Job" (OJT) and informal OJT to fill the required test positions. The program was administered effectively and records were maintained to assure that only qualified test teams conducted stage tests.

It is recommended that a formal test crew qualifications program be instituted at the start of any future vehicle development program, and the test crew member records used actively during a specific test program be data banked for continuous availability.

DISCUSSION

All test operations sites involved with checkout of the Saturn S-II had the requirement to develop highly skilled personnel to perform the functions of post-manufacturing verification, captive static firing, and launch operations.

A program was set up to assure personnel qualifications at all job levels (technician and engineering) and at test sites by developing and presenting S-II and GSE systems training courses; developing and presenting skills certification courses, such as soldering, scott air-pak use, bridge crane operation; and both formal and informal OJT training under the supervision of qualified personnel. An additional factor was realized on the S-II program by using personnel as a cadre for the test sites who had gained experience by working in the developmental test areas.

Manufacturing verification was performed at the NR Seal Beach facility, stage checkout stations 8 and 9. The testing performed at these stations did not involve the use of cryogenic liquids and was, therefore, not categorized as hazardous.

Seal Beach used a Mechanical Excellence Assessment Sheet which recorded task assignments as well as training requirements and completion dates (formal and OJT) as evidence that personnel are qualified to participate in critical tests.

These assessment sheets were available to the system test conductor and were located with departmental records. It was the responsibility of each individual test supervisor to ensure that identification of test team positions and qualified personnel were maintained within the "S-II Team Personnel Book" located in the S-II Test Project Engineer's office.

Seal Beach testing encountered many cases of improperly installed seals and electrical connectors, damage to vacuum-jacketed line bellows assemblies caused by installation errors, and lost time due to lack of technician system knowledge.

The solution was to implement an informal OJT program during down-time between stage testing, using test engineers as instructors and the assessment sheets for record keeping.

Static firing testing was conducted at NASA's Mississippi Test Facility. Both critical tests (non-cryogenic) and hazardous tests (cryogenic) were performed, and a stringent test crew qualification program was established.

The "Team Position Description & Criteria Sheet," "Team Position Requirements Analysis," and Test Performance and Evaluation Records were maintained by Mississippi Test Operations (MTO) personnel department for use in selecting test crews.

Critical test crew personnel were selected by the test conductor, and the list of crew members and alternates were submitted to Personnel. Personnel screened the test crew records of each crew member selected to assure position qualification, and released a formal crew letter denoting each member by position. This letter was processed by Quality Control as a part of the test records.

Personnel for hazardous test crews required formal review board action for selection. Two weeks prior to the test, an internal test operations crew coordination board meeting was conducted to review qualifications and availability of each individual proposed. This list was submitted to the crew qualification board for final approval at least one week prior to test. The board approved test crew members and their positions were published as a letter by the NR/MTO director, and was a part of the test records.

Two days prior to the test, a redline observer meeting was held to ensure each observer understood his redline parameter and required reaction.

Each hazardous test team member was position qualified through a three phase-out program conducted during actual testing. In-Training Phase I (IT-I) was the development phase, during which the potential crew member gained background knowledge, such as formal training required to perform his task. IT-II was the observation phase during which the potential crew member observed a qualified crew member performing the position task. IT-III was the supervised performance phase during which the potential crew member performed the position task under close surveillance of a qualified crew member. Satisfactory completion of the in-training phases, as approved by the crew qualification board, certified the potential crew member as qualified to perform his specific task in support of stage testing.

Test 15-02

WORK STATUS TABULATION RUN SYSTEM

PROBLEM STATEMENT AND EFFECT

All open work items had to be identified before a particular test or scheduled work at the S-II test sites was performed. In order to identify these items, all open paperwork was scanned to determine test constraints and to schedule work. This time-consuming method resulted in wasted manhours.

SOLUTION/RECOMMENDATION

A status tabulation run system was established to provide visibility into all open work items on the stage. The tabulation run was established at the receipt of a stage in the station. It was updated daily by the night shift, and made available at the beginning of the day shift. This document provided the visibility necessary to establish priorities for work items and thus ensured the best use of personnel to perform the work.

The tabulation run system is recommended for all applications where the work volume is controlled by open paperwork that can change daily. The system aids management with constant insight into problem areas and provides an orderly method of scheduling work.

DISCUSSION

The status tabulation run system was established on the Saturn S-II program after testing of the first production stage. The system required keypunching the data into IBM keypunch cards and printing the document with a line printer. Each item was listed with the responsible supervisor's name, an action block (for comments), and a code for establishing which test the item constrained. Assignments were made to update the tabulation run daily. This updating enabled supervision to schedule all work items on a 24-hour basis, and all disciplines (Test Engineering, Quality Assurance, and the NASA representative) were made aware of any constraints against a particular test. The comment portion was especially important to management in foreseeing problems that could impact schedules. This same system was used for the ground support equipment to document discrepancies and configuration control.

IN-PROCESS INCREMENTAL INSPECTION PROCEDURE

PROBLEM STATEMENT AND EFFECT

The inspection procedure initially used for the S-II resulted in an extensive work load at the conclusion of post-manufacturing test due to accumulation of discrepancies. The S-II was presented to Quality Control for total shakedown inspection after testing and before shipping. The time required to correct discrepancies resulted in schedule problems.

SOLUTION/RECOMMENDATION

An in-process incremental inspection procedure was established in which Quality Control inspected areas as they became available (tests complete in that area) and inspection personnel were instructed to identify discrepancies as testing progressed. This procedure allowed personnel to correct deficiencies incrementally; thus the large workload at the completion of testing was eliminated.

The progressive in-process inspection procedure is recommended where the end item is as large or complex as the S-II stage and an acceptance type of inspection is required. Most of the discrepancies were minor, but they created excessive workloads when allowed to accumulate.

DISCUSSION

A total inspection of the S-II was required after post-manufacturing test and before shipment to the static firing test site. The inspection procedure for the first two production articles was to perform the inspection all at once and then clear the discrepancies. The accumulation of all the discrepancies required days to correct. An agreement between Test Operations and Quality Control resulted in establishing the progressive in-process inspection. Inspection personnel were instructed to document any defects that were found (through visual inspection), and test personnel corrected the defects as time allowed during test. Test Operations notified Quality Control when testing was complete in a particular stage area and when the area was ready for inspection. The area was then inspected; the discrepancies were corrected; and the area was closed. This method resulted in more efficient use of personnel by providing work during slack periods and eliminated the large workload at the end of test.

STATIC FIRING TERMINAL COUNTDOWN PROCEDURE

PROBLEM STATEMENT AND EFFECT

The countdown for the first static firing of the Saturn S-II Battleship (a heavy weight stage designed for experimental testing) was performed as a command and response type of operation under manual control. The test was a single-engine rather than a cluster (all five engines) firing. Significant difficulties in the command and response method were encountered in the countdown for the single-engine operation. It was considered that these difficulties would be magnified in the cluster operations; therefore, the need for improvement of the countdown, particularly in the terminal portion, was clearly indicated.

SOLUTION/RECOMMENDATION

The terminal portion (final 3 minutes) of the Battleship countdown was changed from a command response type of operation to a false time-keyed operation. The last seven seconds of the countdown was also changed to an automated procedure. Commencing with T-3 minutes, all operations were performed by the console operators when the countdown time was called out by the assistant test conductor. The operations were arranged to prevent any detrimental consequences regardless of which operation was performed first on the same count. The response of the console operators on a false time-keyed countdown, combined with the automated T-7 second portion of the countdown, proved very successful in conducting the operation efficiently and smoothly.

The false time-keyed countdown procedure is recommended for applications where numerous simultaneous operations are being performed; many parameters are being monitored; and automatic (computer-controlled) procedures are not practical or possible.

DISCUSSION

The initial Battleship static firing countdown procedures were written for the test conductor to conduct the tests by issuing a command to perform the step required and the console operators answering when the response occurred. The terminal portion of the countdown presented many difficulties due to the number of operations occuring at this time (simultaneous operations, multiple responses, etec.). Since the initial test was a single-engine firing, the procedure was acceptable. The forthcoming cluster firing presented a more complex problem. The procedures were rewritten to eliminate wherever possible the congestion encountered during the last few minutes of countdown. The terminal portion (T-3 minutes) was revised to perform a false time-keyed operation in which the test conductor would announce the time as each step was to be performed. The console operator concerned with that function would send the command and verify the response, and would only contact the test conductor if the response did not occur. The procedure was arranged to prevent any detrimental consequences of simultaneous operations. A panel was used, with indicator lights, to inform the test conductor of the sequence of major functions to keep him abrease of the countdown. The last seven seconds of the countdown was automated by using a stage sequencer. The sequencer used a system of relay interlocks to perform the terminal countdown.

PERSONNEL CERTIFICATION PROGRAM FOR TANK ENTRY

PROBLEM STATEMENT AND EFFECT

Propellant tank entries had to be accomplished for inspection and maintenance after manufacturing closeout. Test Operations personnel were initially not prepared for the hazards and precautions required for working in propellant tanks. Personnel not experienced in working in confined spaces and using breathing equipment could incur serious or possibly fatal injury. Also, personnel not briefed in special precautions (for instance, precautions to ensure that no foreign objects, such as safety wire cuttings, were left in the tank, precautions on where to stand or place ladders, etc.) could cause physical conditions or damage leading to a worst-case failure mode of total stage destruction.

SOLUTION/RECOMMENDATION

A training program was established and implemented to qualify personnel for entry into the stage propellant tanks. Graduates of this program received formal certification records and recertification was required and accomplished annually. Only currently certified personnel were allowed to participate in tank entries.

DISCUSSION

Personnel working in closed, confined areas, such as propellant tanks, generally encounter unique conditions for which they must be prepared. As an example, breathing air must be supplied; if this supply is interrupted, what emergency procedures are taken by the man? The area must also be maintained in a low-humidity condition. Long exposure will adversely affect personnel (i.e., nose bleeds, chapped lips, eye irritation, etc.). Other considerations, such as previously listed, are numerous and point out the fact that a qualification program is a mandatory requirement for personnel working in these areas. The program must include a comprehensive medical examination, use of emergency breathing and communications equipment, use of specialized rigging and handling equipment, and special precautions involved with clothing, tools, etc., used in the confined area.

REFERENCES

MA0701-1181-210, LH_2 Tank Horizontal Entry

IDENTIFICATION OF STAGE TEST CRITERIA AND STAGE MODIFICATIONS

PROBLEM STATEMENT AND EFFECT

No single document existed at the Mississippi Test Facility (MTF) to fully identify stage test criteria and modifications to be incorporated while the stage was at the test site. Lack of this type of information created conflicts in scheduling stage activities and contributed to poor definition of certain range activities required to support stage processing.

SOLUTION/RECOMMENDATION

A catalog of program requirements (COPR) document was prepared which completely delineated stage testing, inspection, and modification requirements. The COPR document served as a tool in monitoring and statusing the noted activities and thereby allowed stage work schedules to be planned and implemented with a minimum of work conflicts.

DISCUSSION

A contract change directed that the S-II contractor at MTF compile and submit to NASA/MTF, eight weeks before end item (stage) arrival at MTF, a catalog of program requirements (COPR). The COPR was to contain the following data:

1. Tests and checkouts to be implemented at MTF.
2. Performance criteria to be met for each acceptance demonstration.
3. Measurement and data requirements to prove performance criteria, including acceptance, operational, and special measurements for end item, GSE, and facilities.
4. Configuration of end item at time of shipment to MTF.
5. Configuration of end item at time of demonstration at MTF.
6. Configuration of end item at time of departure from MTF.
7. Dwell time at MTF with arrival and shipment dates.

Requirements specified in the COPR were validated through a review by site and home plant engineering personnel. The review encompassed the following elements:

1. The technical intent of a design change was examined from a systems analysis standpoint.

2. Engineering drawings, engineering orders (EO's), specifications, and specification revision sheets (SRS's) were examined for correctness and clarity.

3. Test action requirements (TAR's) were examined and rewritten as required for correctness and clarity.

4. Test Operations procedures were reviewed to ensure proper incorporation of all engineering and acceptance requirements.

5. All engineering design changes were examined for conflicts.

Because processing of the COPR was automated, updating, deletion, or addition of line item entries could be accomplished rapidly; COPR revision notices were published daily and a total document revision was puslished weekly.

TEST PROCEDURE REVISION PREPARATION

PROBLEM STATEMENT AND EFFECT

The detailed test procedures to check out the Saturn S-II required periodic revision due to changes of stage configuration and test philosophy. Delays were encountered resulting in time losses and schedule impact due to the time required to type, proof read, and review the revisions after a rough draft had been submitted.

SOLUTION/RECOMMENDATION

The problem was solved by establishing a system to prepare the procedures on IBM punch cards using a keypunch machine and printing the documents using a line printer. In addition, the test site stored the information on magnetic tape and used the computer with a line printer for procedure printout. Revisions to the test procedures were accomplished by changing the applicable cards (each card representing a line of text) and keypunching new cards for the necessary change. The document was then printed and it was only necessary to proof read and review the text that had been changed. The line printer is also capable of producing vellum or multilith masters for reproduction. This method represented not only an efficient and expeditious method of preparing revisions but also resulted in cost savings and the more efficient method of storage using magnetic tapes.

If a system of this type is established, it should be initiated at the beginning of test procedure preparation when the baseline documents can be prepared and revisions can be easily implemented. This method of revision can be utilized in any application where a baseline document has been established and revisions are expected.

DISCUSSION

The problem of document revision first developed on the Saturn S-II Battleship (a heavyweight stage designed for initial systems testing). The procedures were typed using conventional methods. The development program required many configuration and test philosophy changes and therefore required a more expedient method of test procedure revision. Tests were often delayed until the revised document was available. This problem was also prevalent during testing of the first two production stages. The time required to type, proof read, and review a revised document caused many delays.

The system was developed to keypunch each test procedure. The cards were then placed in a line printer (or on magnetic tape) which printed the procedure in page format. The line printer had special patchboards to print the title on each page, number each page, and automatically number, sequentially, the subparagraphs. The print-outs were made on ordinary paper for proof reading, on four-part paper for review, or printed on vellum or multilith masters for reproduction.

Revisions were made to each document by keypunching the cards required to make the change and inserting them in the card deck to replace the old cards. The line printer automatically renumbered the procedural steps and it was only necessary to proofread the test that was changed. A revision page was included in each procedure which listed the changed paragraph numbers so it was necessary to only review the listed paragraphs to verify the changes that were made. This procedure required a minimum of time for the disciplines (engineering, quality assurance, safety, and NASA) to review the procedures.

SPECIAL TEST AND INSPECTION REQUESTS

PROBLEM STATEMENT AND EFFECT

Special tests, inspections, and other tasks on the S-II and GSE were being requested of test sites by various organizations. These requests imposed problems on the test sites with respect to overall scheduling and configuration control of the end items, retest requirements, and data coordination.

SOLUTION/RECOMMENDATION

A procedure (Test Action Requirements) was established to control requests dealing with special tests and inspections at test sites. The procedure required explicit definition of the tasks and the data required. Of prime importance in the procedure was the need of approval by the necessary disciplines (Engineering, Quality Assurance and Test) before the requests could be honored. The procedure also insured that the end item configuration was not affected, that the proper retest was accomplished, that the task was properly scheduled, and that all disciplines were fully coordinated.

Such a procedure is recommended for any program in which special tasks must be performed on a production article. If these tasks are not properly controlled, the effect can be detrimental to test site operations.

DISCUSSION

Early in the S-II Program a need developed for a method to regulate special tasks on the stage and GSE. These special tasks often required disassembly of systems and subsystems. These tasks were generally initiated to collect data for evaluation of design criteria, problem areas and safety factors. The requests were submitted by different disciplines without formal documentation to prevent a possible change of end item configuration, the necessary retest to revalidate the system or subsystem, or the necessary coordination to prevent possible schedule impact on the checkout schedule. A procedure was developed to allow these tasks to be performed with the concurrence of Engineering, Quality Assurance, and Test. Involvement of these disciplines ensured a positive method of control. The procedure requires preparation of a form to provide detailed instructions to perform the task, return the system or subsystem to design configuration, and retest to the original criteria. The form requires approval of the Chief Program Engineer, the Director of Quality Assurance, and the Director of Test and

and Logistics. A central coordinator was appointed from the central test group. The coordinator was responsible for coordination with the sites to establish feasibility of the requested action, coordinate schedules for implementation, maintain pending and completed task files, and publish a weekly task status report.

Test 18-01

PROPULSION PREDICTION PROGRAMS

PROBLEM STATEMENT AND EFFECT

Performance of the S-II stage, when compared to predicted flight performance, resulted in the S-II stage being at a lower altitude and velocity than that predicted. Because of this, it was necessary for the upper stage to use more of the flight propellant reserve than was desired.

SOLUTION/RECOMMENDATION

1. Flight thrust tag values be based upon engine acceptance tests and biased by -3100 pounds thrust as established from a statistical history of comparison of engine acceptance tests and flight

2. Specific impulse tag a low engine-mixture ratio to be calculated from a nominal specific impulse curve derived in engine acceptance testing and referenced to the high engine-mixture ratio's tag value

3. Engine trend characteristics exhibited on the vehicle static test data of specific vehicles be utilized in the flight prediction of the respective stage

4. Trend influence coefficients be further evaluated to decrease their magnitudes and dependence upon trend bias factors

5. Mixture-ratio control valve (MRCV) excursions be predicted assuming a change in mixture ratio of -0. 700 units in conjunction with the two sigma variations observed on S-II vehicles of ±0. 100 mixture ratio and ±6000 pounds thrust

6. Propellant utilization (PU) excursion data and vehicle acceptance be evaluated to determine any relationship that may allow prediction of the MRCV excursion response characteristics of individual engines

7. PU influence coefficients be evaluated for possible revision to improve predictability with the MRCV

DISCUSSION

The procedures of selection and determination of flight tag values for thrust, specific impulse, and mixture ratio have been evaluated. It was found that the prediction of thrust was susceptible to significant variations due to the occurrence of run-to-run resistance shifts in the GG oxidizer. Comparison of the flight of S-II vehicles 3 through 9 to their respective vehicle static tests indicated that thrust cannot be predicted closer than ±6600 pounds on a two sigma basis. Between flight and engine acceptance, it was determined that 37.1 percent of the engines exhibit run-to-run thrust shifts of which over 90 percent were negative and averaged 2000 pounds. Consideration of the last four flights showed that vehicle thrust could be predicted to within ±3800 pounds (two sigma) using engine acceptance as a baseline and subtracting a bias of 3100 pounds thrust.

Specific impulse as given for individual engines during vehicle acceptance and/or flight is an assumed value from the respective engine acceptance tests and variations are attributable to errors in prediction of independent variables (inlet conditions, pressurization flows, etc.) or selection of the tag value. Differences were noted in prediction of specific impulse at low engine-mixture ratios due to instrumentation variations between the Rocketdyne facility's engine acceptance data and vehicle telemetry data. To rectify this error, a procedure was devised utilizing nominal specific impulse excursion data from engine acceptance as referenced to the tag value at high engine-mixture ratios.

Prediction tag values of engine mixture ratio were found to exhibit good repeatability between static test (both engine and vehicle acceptance) and flight.

In-run, J-2 engine, performance trend characteristics for individual engines are considered and accounted for in flight predictions utilizing bias factors in conjunction with a set of nominal trend-defining influence coefficients. A procedure was devised for determining these bias factors based upon the vehicle acceptance test data and the run-to-run repeatability of engine trend characteristics.

MRCV performance during S-II flight has shown significantly greater variations than predicted by Rocketdyne. Data from S-II vehicles 9 and 15 have concurred the prediction of an average mixture-ratio excursion of -0.700 mru but with two sigma variations in thrust on the order of ±6000 pounds rather than the original predicted of ±3000 pounds. Variations in engine response characteristics to a MRCV excursion (i. e. , variations in oxidizer flow as a function of delta mixture ratio) were shown to be significant and a reason for errors in predicted performance at low engine mixture ratio. Effort is continuing to ascertain whether these engine characteristics may be definable from engine and vehicle acceptance PU demonstration data.

PURGING OF LOX AND LH_2 PROPELLANT TANKS AND LINES

PROBLEM STATEMENT AND EFFECT

Investigation into the causes of a structurally damaging explosion of a small scale LH_2 propellant tank (shape of S-II LH_2 tank but 100 foot diameter) identified many purging procedures which could be improved.

SOLUTION/RECOMMENDATION

Improved procedures minimize the potential for additional explosions similar to the one experienced on the small scale tank. These procedures follow.

1. Vent half of the propellant tank pressure/vent cycles out the top of the tank and half out the bottom
2. Hold pressure in tank for 5 minutes before venting
3. Flow-through LH_2 tank from top to bottom
4. Increase engine feed line (8-inch diameter) pressure vent cycle pressure from a maximum of 15 psig to 20-25 psig. Decrease number of cycles from 20 to 13
5. 30-second flow-through of feed lines after pressure/vent cycles

Recommended is a minimum of 3 volume changes by the flow-through method to reduce the hydrogen concentration to <1 percent and a minimum of 13 pressure/vent cycles to purge deadended lines and cavities. Also recommended is the provision of access points to the tanks and connecting systems to facilitate flow-through purges and monitoring capability and to minimize deadended lines and cavities.

DISCUSSION

The "mini B" stage accident was caused by the 3 pressurizing/venting cycles used to purge the tank not being sufficient to reduce the oxygen concentration in the tank to less than 1 percent. In addition, gas samples were not taken subsequent to the purging operations and hazardous gas concentrations were not detected. After the "mini B" accident, a complete investigation evaluated all of the existing S-II purging procedures, revising and updating them as necessary.

Both the cyclic purge and the flow-through purge approaches were evaluated. The result of this investigation clearly showed that the flow-through purge was the better of the two procedures. To reduce contaminant concentration from 100 to 1 percent, it takes 12.5-volume changes for cyclic purging of the S-II while only 4.6-volume changes are required if flow-through techniques are used. However, on the S-II, due to lines and components having deadended cavities, the flow-through purge had to be augmented with cyclic purging. As a point of interest, the present 1 percent GH_2 level used on the S-II was arrived at by dividing the lower explosive limit of hydrogen by a safety factor of 4. Purging times can be reduced considerably if the allowable GH_2 concentration level is reduced to 2 to 3 percent.

Flow-through purging effects a reduction in hazardous gas concentrations by the continuous expulsion of residual gases in a tank by an action similar to a piston effect. To facilitate the piston effect, the purge gas is admitted at the top of the tank when the purge gas is lighter than the residual gas and at the bottom of the tank when the purge gas is heavier than the residual gas. Venting being accomplished at the opposite end of the tank from the point where the purge gas is entering the tank. The requirement for flow through purging is shown by the relationship $Co/C_F = Vp/Vt$ where Co is the initial concentration of the residual gas, C_F is the final concentration of the residual gas, Vp is the total volume of purge gas required to purge the tank and Vt the volume of the tank being purged.

The most significant consideration for cycling purge is the delta pressure of the purging gas over the initial gas in the tank, keeping in mind that the higher the delta pressure, the greater the usage of purge gas. If the delta pressure is increased, fewer cycles are required for purging as shown by the equation $C_1/C_2 = (P_1/P_2)^N$ where C_1 is the initial gas concentration, C_2 the final gas concentration, P_1 initial tank pressure, P_2 elevated pressure caused by purge gas and N the number of pressure cycles required. During every pressure/vent cycle, a pressure hold should be instituted to benefit from the effects of diffusion. Diffusion rates are determined experimentally but "Fick's Law" generally applies.

It is highly recommended that all purging operations should use the pressure/blowdown cycling purge combined with flow-through purging (piston effect with top or bottom of the tank). In addition at least two gas samples at the top and the bottom of the tank should be taken.

WATER SPRAY HEAT SHIELD

PROBLEM STATEMENT AND EFFECT

During sea level static firing of the S-II stage engines, it is necessary to shield the inoperative center J-2 engine nozzle and components from high levels of incident radiative heat flux. Failure to do so could result in severe damage to the engine.

SOLUTION/RECOMMENDATION

A water spray system was installed in the base of the S-II-8 stage during static firing such that the center engine was effectively shielded from the incident radiative flux. No damage resulted to the engine during static firing which was subsequently flown on the AS-508 flight.

Based on the static firing results, it was concluded that water spray was an effective means of blocking 95 percent of incident radiative heat flux in the infrared spectrum.

DISCUSSION

In order to reduce the longitudinal vibrations experienced during S-II boost on AS-501 through AS-504 flights, it was proposed that the center J-2 engine of the S-II stage 5 J-2 engine cluster be shut down during the latter part of S-II stage boost on the AS-505 flight. The effectiveness of this procedure was to be verified by a static firing test on the S-II-8 stage. Since the J-2 exhaust plume radiation levels are considerably higher at sea level than at altitude, the inoperative center engine would be subjected to high levels of incident radiative heat flux. Also, since the inoperative engine is no longer regeneratively cooled by LH_2 circulation, severe damage to the engine nozzle was possible. Therefore, it was necessary to shield the center engine from the high levels of incident radiative heat flux during static firing.

VORTEXING AT LOX TANK OUTLET

PROBLEM STATEMENT AND EFFECT

During early static firings of S-II vehicles at the Mississippi Test Facility, signs of LOX pump cavitation consistently occurred on one engine earlier than the other four engines, indicating premature gas ingestion in that engine. This condition was attributed to small localized vortexing between the radial-vane antivortex baffles in the LOX sump area caused by eddies around the edge of a brace used to support the antivortex baffles. This condition can require earlier shutdown of the engine cluster and result in an increase of trapped propellant weight.

SOLUTION/RECOMMENDATION

For static firings, engine cutoff was initiated several seconds early to avoid gas ingestion. No action was taken in flight since premature gas ingestion only hastened the start of chamber pressure decay but did not greatly affect the level at which the maximum allowable decay occurred.

In the design of propellant tanks, care should be taken to streamline all internal hardware near propellant outlets to prevent the formation of flow eddies and localized vortexing which could cause premature gas ingestion. This recommendation applies even though antivortex baffles may be present, since localized vortices may form between the baffles.

DISCUSSION

Scale model vortex tests of the S-II LOX tank indicated that the S-II antivortex baffle design is adequate to prevent gross vortex action in the LOX sump. It is believed, however, that minor, localized vortices were generated between the radial antivortex baffles by flow around the edge of braces used to support the baffles. The location of these braces corresponds with the position of the sump outlets feeding the engines which first showed evidence of gas ingestion.

Test 26-01

EFFECTS OF BUBBLES ON CAPACITANCE PROBE READOUT

PROBLEM STATEMENT AND EFFECT

During various S-II countdown demonstration tests and launch countdowns, sudden decreases of LH_2 capacitance (CAP) probe readout occurred both in fastfill and/or steady-state replenish operations. It was concluded that this phenomena was the result of a sudden increase in the volume of vapor bubbles entering the coaxial probe (through its open bottom or through perforations in the outer element).

The decrease in probe readout lasts up to 20 seconds and could cause the automatic loading system (PTCS) to temporarily overload the LH_2 tank. If this occurs at the end of loading, it could violate the loading redlines and result in a launch delay.

SOLUTION/RECOMMENDATION

No action was taken to redesign the cap probe since the problem did not occur frequently and the probability of causing a launch delay was small.

On future designs, means (such as baffles and stillwells) should be provided to prevent vapor bubbles from entering cap probes.

DISCUSSION

Extensive trouble shooting of the problem revealed no electrical causes for the sudden changes in probe readout. Since the shifts were always in a negative direction and of a temporary nature, it is reasoned that they were caused by bubbles introduced between the electrodes of the probe. This explanation is supported by the phenomenon of "geysering" which often occurs in large tanks of cryogenic fluid when warm slugs of liquid rise toward the surface and evolve large quantities of vapor bubbles under the reduced static head.

LOX TANK ULLAGE PRESSURE DECAY

PROBLEM STATEMENT AND EFFECT

S-II-1 LOX tank ullage pressure decay during S-IC boost was such that near-zero NPSH margin was reached. Further decay could prevent the J-2 engines from starting, causing mission abort.

SOLUTION/RECOMMENDATION

The problem was resolved by evacuating the common bulkhead to 3 psid maximum before flight to minimize heat transfer across the bulkhead.

DISCUSSION

The ullage pressure decay was experienced during static firings of the first three flight stages as well as during the first flight. Analysis revealed the ullage pressure decay was caused by high heat transfer across the common bulkhead resulting from the temperature differential between LH_2 at -420 F on one side and GOX at about -300 F on the other side. For the initial design concept, purged insulated common bulkhead was used, which was vented in flight. Re-evaluation of thermal characteristics revealed an error which when corrected confirmed the probability that ullage pressure decay had occurred.

The most feasible design correction was determined to be evacuation of the common bulkhead to increase insulation characteristics. The bulkhead vacuum was assured with self-sealing disconnects. Flightworthiness of the design correction was demonstrated during tanking and static firing tests of the S-II-3 and S-II-4 vehicles, and from countdown demonstration tests and flight of the AS-502 vehicle.

HYDROGEN FIRE DETECTION

PROBLEM STATEMENT AND EFFECT

A need was established early in the experimental testing of the Saturn S-II Battleship (a stage designed for initial systems testing) for a means of detecting fires caused by hydrogen leaks. Hydrogen fires are difficult to detect with the naked eye during daylight hours due to the transparent flame.

SOLUTION/RECOMMENDATION

Television cameras with infra-red vidicon tubes were obtained which detect hydrogen fires, and were used for monitoring the battleship stage during static firing.

The use of the infra-red television camera is recommended in any application where the possibility of fires caused from hydrogen leaks exist.

DISCUSSION

The Saturn S-II Battleship engine area was vulnerable to fires from hydrogen leaks due to the use of hydrogen as a propellant. The transparent flame from a hydrogen fire precludes the use of normal visual means to detect, therefore, infra-red vidicon television cameras were used. The use of this sytem was very effective in pin-pointing hydrogen leaks during firing.

PROPELLANT FEED SYSTEM FILTERING SCREENS

PROBLEM STATEMENT AND EFFECT

Foreign particles were found in the battleship stage engines during propellant tanking tests early in the S-II program. The particles proved to be lip seal material from the facility prevalves that had entered the propellant tanks during tanking. Problems were also encountered with contaminants from within the tanks during first tanking of some production stages.

SOLUTION/RECOMMENDATION

A filtering screen was installed in each propellant feed line to prevent contaminents from entering the engines. The screens were installed as non-flight hardware and were removed prior to static firing. They were very effective in protecting the engines as was indicated during first tanking tests of the production stages. Several instances occurred where particles were found on the screens. In most instances these were found after work had been performed in the tanks after initial closeout.

The temporary installation of filtering screens in propellant feed systems is recommended where the possibility exists for contaminants to enter the propulsion system. Critical damage could result if certain contaminants entered the engines and were not detected prior to firing.

DISCUSSION

The initial problem of contaminants in the propulsion system of the S-II was discovered during propellant tanking procedures of the battleship stage. The problem developed as a result of the facility ball valve lip seal failure. The material entered the engine and caused contamination of the fuel injector. The resultant corrective action was to install screens in the engine propellant feed lines and establish a periodic inspection of the screens to ensure system cleanliness. Subsequently, the screens were installed in the production stages to prevent propulsion system contamination.

The contamination within the LH_2 tank of production stages derived from personnel traffic and from equipment and materials used to install in-tank modifications. For production stages, the screens were removed after the tanking tests and prior to static firing. In some cases particles were found on the screens which could have resulted in damage to the engines.

STAGE PROTECTION AGAINST IMPROPER GSE-GENERATED COMMANDS DURING AC POWER FAILURE

PROBLEM STATEMENT AND EFFECT

The automatic checkout equipment (ACE)/ground support equipment (GSE) was not designed to prevent random command generation which could result from a facility ac power failure at test sites. However, this lack of capability was not considered of concern at the Mississippi Test Facility (MTF), since there were adequate backup power sources, and at the Seal Beach test site no hazardous testing was being conducted. During checkout, a momentary dropout occurred on the facility ac power system at MTF. It was noted that the digital events recorder (C7-77) did record discrete status changes, including indication of the presence of extraneous stimuli. Special testing revealed a delay in the facility ac power transfer system. Random command generation had occurred. The delay in transfer indicated an inadequacy in the facility backup ac power system.

SOLUTION/RECOMMENDATION

An automatic master reset function capability was incorporated into the stage command generation GSE. The reset function became operation upon loss or application of ac power.

During initial design, the incorporation of power failure master reset circuitry should be considered in any GSE which generates commands to an operational system.

DISCUSSION

Design of ACE/GSE did not prevent random command generation for an ac power failure. This GSE was used at two locations: the Seal Beach, California, manufacturing complex and the Mississippi Test Facility (MTF) static firing complex. At each location were two ACE/GSE stations for S-II checkout.

At MTF, ac and dc backup power sources were provided as part of the facility. This facility power backup system was considered adequate and, therefore, further power failure protection was considered unnecessary. At Seal Beach no backup power sources were provided, since no damaging or hazardous conditions could be envisioned for the low pressure checkout conducted there.

Test 38-01

During a checkout at MTF, prior to a LN_2/LH_2 tanking test, a momentary ac power interruption occurred. No specific details were noted or available except on the digital events recorder (C7-77). This recorder indicated discrete status changes had occurred, including the appearance of extraneous stimuli. NASA/MTF test operations personnel decided to perform a special test to ascertain the characteristics and effectiveness of the facility automatic power transfer equipment. The test revealed that autotransfer between Louisiana and Mississippi main ac power required approximately 1.4 seconds; dc power was not lost nor did the transfer to backup battery sources occur during this period; random GSE command generation to the stage did occur during both ac power on and off cycles.

In order to ensure that improper commands were not generated to the stage as a result of ac power interruption and/or failure during tanking or static firing tests, the command generation GSE was modified to automatically master reset, thus removing all ACE/GSE commands from the stage. This GSE modification was also implemented in the Seal Beach automatic checkout equipment for use in emergency shutdown procedures.

OPERATIONAL FAILURE OF NEON BLOWN FUSE INDICATORS

PROBLEM STATEMENT AND EFFECT

Neon blown fuse indicators failed to operate when used with fuse-protected high impedance circuits.

Neon blown fuse indicators are installed on GSE fused circuits to allow for visual quick-look statusing during troubleshooting. Failure of these indicators to operate forces the technician to remove the suspected fuse and check continuity, or else to conclude, perhaps erroneously, that the fuse is not blown, and look elsewhere for the malfunction.

SOLUTION/RECOMMENDATION

Install mechanical (pop-out type) fuse status indicators in high impedance circuits.

It is recommended that operating parameters of fuse status indicators be considered during initial design so that blown fuse statusing can be reliably and quickly accomplished.

Test 38-03

MODIFICATION OF THE AUTOMATIC CHECKOUT EQUIPMENT FOR IMPROVED DATA EVALUATION

PROBLEM STATEMENT AND EFFECT

The time required to accomplish manual comparison and evaluation of stage data was causing excessive delays in stage data reviews.

It was determined that the major portion of this data could be processed by the automatic checkout equipment (ACE) into a comprehensive tabulation, thus reducing data evaluation time from days to hours. However, investigation revealed that GSE synchronous timing was not present in the ACE computer and without synchronized timing throughout the data recording and processing equipment, the automatic data evaluation program could not be implemented.

SOLUTION/RECOMMENDATION

The ACE computer was modified to operate on either its internal clock or synchronize on an external clock supplied from the ACE time code rack, thus allowing a data merging and correlating automatic program (MACRO) to be implemented. In addition, a second automatic checkout station was modified to be used as a real time pulse coded modulation (PCM) data station. The modification of the second checkout station not only eliminated time-consuming PCM data reduction and manual evaluation, but also increased the comprehensiveness of the ACE processed data merging program.

DISCUSSION

Stage systems automatic checkout was a stimuli-generated response-verified (go no-go) type of test. Real time data recording systems on line were the ACE computer-generated test results magnetic tape (C7-105 events trail), a digital events recording system (C7-77) and a stage flight telemetry recording station multitrack wideband magnetic tape (C7-516).

Due to the many measurements (in excess of 1000), detailed level of testing, and three completely separate data listings, it required an excessive amount of time for test engineering to manually merge and correlate each recorded stage event status change to ensure it was a proper occurence, and not a malfunction. The decision was made to attempt to automate the merging and correlation functions into a single data listing with all stimuli and responses properly noted for validity.

Two major hardware problems had to be overcome to allow for performance of the MACRO program. First, the problem of common time base synchronization had to be considered. Since the merged program was based on time of day (AMR-D5 Code), as recorded on the C7-77 and the C7-516, it was necessary to provide a synchronization pulse (1 kc) from the time code rack (C7-48) to the ACE computer (CDC-924A). Modification of the computer was required to use this external clock. This modification ensured accurate data correlation with regard to real-time event occurrence in merging the data from three separate data recording systems (C7-77, C7-516, C7-105) into a single test evaluation document. The second problem to be met was actual use of the C7-516 data. Since both Seal Beach and the Mississippi Test Facility contained two identical automatic checkout stations, provision was made to use the second computer and digital data acquisition station (C7-400) as a real-time PCM data recording station. This resulted in elimination of post-test processing of the C7-516 data tape into a computer format suitable for data correlation.

Test 38-04

GROUND SUPPORT EQUIPMENT SAFETY INTERLOCKS

PROBLEM STATEMENT AND EFFECT

The ground support equipment (GSE) used for checkout of the S-II was capable of dual control of the functions of the stage: manual (personnel controlled) and automatic (computer controlled). The pneumatic console could control certain functions to perform leak checks and the electrical station had control over the same functions. The electrical control station was also required for automatic checkout.

The problem developed while the stage systems were pressurized under control of the pneumatic console and two commands were simultaneously sent from the electrical station. This was the result of two engineers performing two different tests at the same time. Injury to personnel or damage to stage systems could have resulted.

SOLUTION/RECOMMENDATION

An interlock circuit was installed in the GSE to prevent any commands from being executed from the electrical station when the pneumatic console was being used for leak check. A three-position selector switch was installed on the test conductor's console to control the interlock. The switch positions allowed selection of the pneumatic console, the electrical station, or a combination of both. The requirement was established that when leak checks were being performed, the switch position had to be selected which eliminated the possibility of commands being executed from the electrical station.

A vehicle as complex as the S-II dictates parallel testing in order to complete checkout expeditiously. It is recommended, therefore, that during initial design of GSE for such a vehicle, interlock circuits be incorporated into the dual control equipment. This is especially essential where pressures (fluid and gas) are utilized to operate systems through these controls.

DISCUSSION

The S-II checkout consisted of approximately 27 subsystem tests. In order to accomplish these tests in a reasonable length of time, it was necessary to perform the tests in parallel. The dual control of certain functions was also necessary as the same GSE was used for manual and automatic tests. All testing was coordinated through the station test conductor but it was impossible for each engineer to know what another engineer's test performed in detail. The greatest hazard existed when pneumatic pressure was applied to the stage subsystems and the possibility existed of operating a control valve out of sequence. This possibility was eliminated with the installation of the interlock circuit.