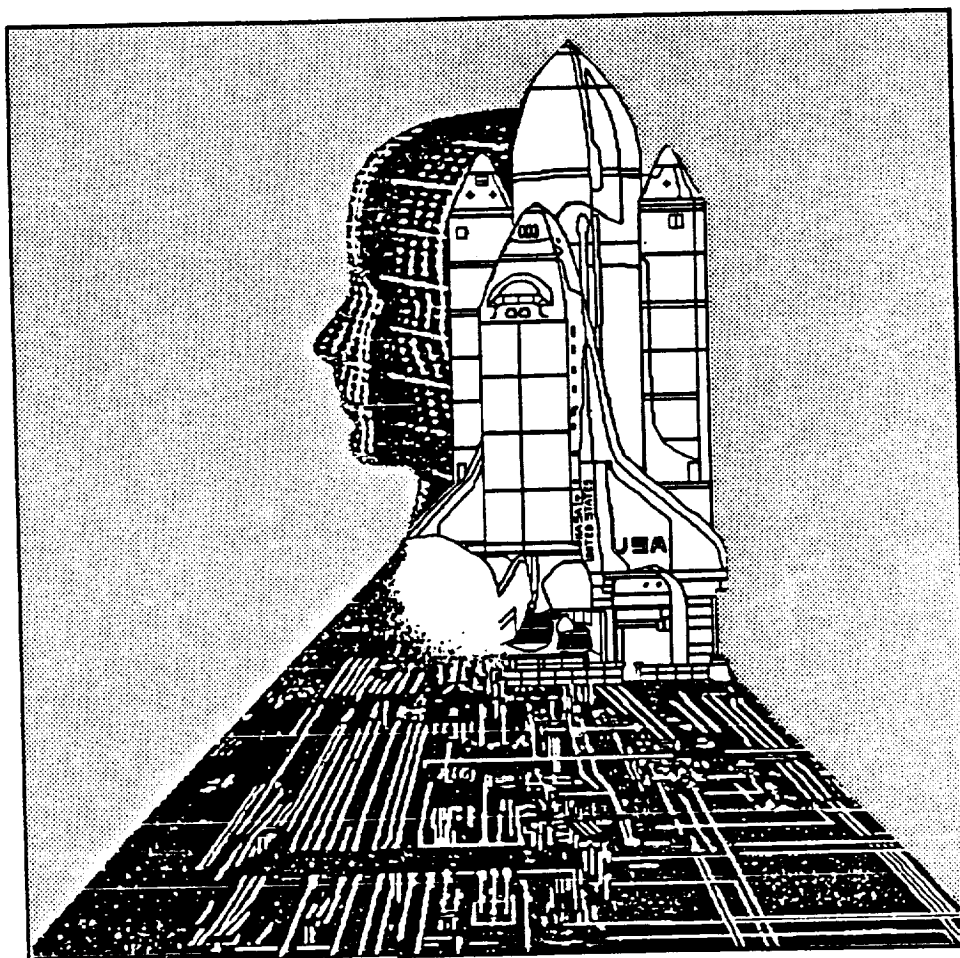# Shuttle Ground Operations Efficiencies/Technologies Study

BOEING

AEROSPACE OPERATIONS

GROUND OPERATIONS EVALUATION
VOLUME 2 of 5

FINAL REPORT - Phase 1

KENNEDY SPACE CENTER

NAS10-11344

May 4, 1987

SHUTTLE GROUND OPERATIONS
EFFICIENCIES/TECHNOLOGIES
STUDY

GROUND OPERATIONS EVALUATION

FINAL REPORT - VOL 2
- PHASE 1 -
MAY 4, 1987

KENNEDY SPACE CENTER
NAS10-11344

BOEING

NASA

A.L. Scholz
    Study Manager
M. T. Hart
    Dep. Study Manager

W.J. Dickinson
    Study Manager

SPACE SHUTTLE GROUND OPERATIONS
EFFICIENCIES/TECHNOLOGIES
STUDY
PHASE 1 FINAL REPORT

The final report for the Shuttle Ground Operations Efficiencies/Technologies Study is made up of five volumes.

Volume 1	Executive Summary
Volume 2	Ground Operations Evaluation
Volume 3	Final Presentation Material
Volume 4	Preliminary Issues Database (PIDB)
Volume 5	Technology Information Sheets (TIS)

Volume 1

The Executive Summary volume provides a brief overview of the major elements of the Study, reviews the findings, and reflects the development of the recommendations resulting from the Study.

Volume 2

The Ground Operations Evaluation volume describes the breath and depth of the various Study elements selected as a result of an operational analysis conducted during the early part of the Study. Analysis techniques used for the evaluation are described in detail. Elements selected for further evaluation are identified; the results of the analysis documented; and a follow-on course of action recommended. The background and rationale for developing recommendations for the current Shuttle or for future programs is presented.

Volume 3

The Final Presentation Material volume contains the most recent version of the charts used in the Final Phase 1 Oral Briefing at KSC on April 6, 1987, and to the STAS (Space Transportation Architecture Study) IPR-5 (Interim Program Review) held at MSFC on April 8, 1987. The KSC, April 6 notation in the title block was used for both packages because the reviews were held so closely together. This volume contains all charts in their final form and any differences from charts presented are minor.

Volume 4

The Preliminary Issues Database (PIDB) was assembled very early in the Study as one of the fundamental tools to be used throughout the Study. Data was acquired from a variety of sources and compiled in such a way that the data could be easily sorted in accordance with a number of different analytical objectives. The system was computerized to significantly expedite sorting and make it more usable. This volume summarizes the information contained in the PIDB and provides the reader with the capability to manually find items of interest. How that information was used in this Study is explained in greater detail in Volumes 2 and 3.

Volume 5

The Technology Information Sheet volume was assembled in database format during Phase 1 of the Study. This document was designed to provide a repository for information pertaining to 144 OMI (Operations and Maintenance Instructions) controlled operations in the OPF, VAB and PAD. It provides a way to accumulate information about required crew sizes, operations task time duration (serial and/or parallel), special GSE required, and identification of a potential application of existing technology -- or the need for the development of a new technology item.

i

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

ACRONYMS and ABBREVIATIONS

AFD	Aft Flight Deck
AH	Ampere-Hour
AI	Artificial Intelligence
APU	Auxiliary Power Unit
ATE	Automatic Test Equipment
ATKB	Automation Technology Knowledge Base
ATPG	Automatic Test Program Generation
BIT	Built-In-Test
BITE	Built-In-Test-Equipment
CDF	Confined Detonating Fuse
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAI	Computer Aided Instruction
CALS	Computer Aided Logistics System
CAM	Computer Aided Manufacturing
CG	Center of Gravity
COMM	Communications
CPV	Combined Pressure Vessel
CVD	Chemical Vapor Deposition
DAS	Data Acquisition System
DBT	Design Build Team
DFT	Design For Testability
DOD,DoD	Department of Defense
DPS	Data Processing System
DTC	Design to Cost
DR	Discrepancy Report
ECLSS	Environmental Control & Life Support System
ECS	Environmental Control System
	Executive Control System
EIU	Engine Interface Unit
EPD&C	Electrical Power Distribution and Control
ES	Expert System
ESS	Energy Storage System
E/T	External Tank
EVA	Extra Vehicular Activity
FCM	Fuel Cell Module
FMS	Flight Management System
FRCS	Forward reaction control system
FY	Fiscal Year
GH2,GH_2	Gaseous Hydrogen
GN&C	Guidance Navigation and Control
GO2,GO_2	Gaseous Oxygen
GSE	Ground Support Equipment
HPFTP	High Pressure Fuel Turbo Pump
H/W	Hardware
HYD	Hydraulic(s)
IDSS	Integrated Design Support System
IMIS	Integrated Maintenance Information System
IFA	In-flight Anomaly
IMU	Inertial Measurement Unit

INEL	Idaho National Engineering Laboratory
INS,INST	Instrumentation
IOC	Initial Operational Capability
IPR	Interim Problem Report
IPV	Individual Pressure Vessel
IUS	Inertial Upper Stage
JSC	Johnson Space Center
KSC	Kennedy Space Center
KW	Kilowatt
LCA	Launch Control Amplifier
LCC	Life Cycle Cost
LH	Left Hand
LH2,LH_2	Liquid Hydrogen
$LiSOCL_2$	Lithium Sulphur Oxygen Chlorine
LO2,LO_2	Liquid Oxygen
LPS	Launch Processing System
LRU	Line Replaceable Unit
LSC	Linear Shaped Charge
ME	Main Engine
	Maintenance Expert
MCC	Main Combustion Chamber
MCR	Modification Change Request
MDM	Multiplex/DeMultiplex
MPM	Manipulator Positioning Mechanism
MPS	Main Propulsion System
MSFC	Marshall Space Flight Center
NaS	Sodium Sulphur
NASA	National Aeronautics and Space Administration
NDT	Non-Destructive Test
NiCad	Nickel Cadmium
NiH_2	Nickel Hydrogen
NiTi	Nickel-Titanium
Nitinol	Nickel-Titanium-Naval Ordnance Laboratory
NIH	Not Invented Here
NLG	Nose Landing Gear
NSI	NASA Standard Initiator
OMI	Operations and Maintenance Instruction
OMP	Operation Maintenance Plan
OMRSD	Operational Maintenance Requirements and Specifications Document
OMS	Orbital Maneuvering System
OPF	Orbiter Processing Facility
OPS	Operations
OV	Orbiter Vehicle
PAM	Payload Assist Module
PCBS	Printed Circuit Boards
PCR	Payload Changeout Room
PDI	Payload Data Interleaver
PIC	Pyro Initiator Controller
PIDB	Preliminary Issues Database

ACRONYMS AND ABBREVIATIONS
(Continued)

PLB   Payload Bay
PR   Problem Report
PRSD   Power Reactant Storage and Distribution
PSA   Payload Support Avionics
PSP   Processing Support Plan
PV&D   Purge, Vent and Drain
QA   Quality Assurance
QC   Quality Control
RADC   Rome Air Development Center
R&D   Research and Development
RAMCAD   Reliability and Maintainability through Computer Aided
            Design
R&R   Remove and Replace
RCC   Reinforced Carbon Carbon
RFCS   Regenerative Fuel Cell System
RFP   Request For Proposal
RH   Right Hand
RMS   Remote Manipulator System
RSI   Reusable Surface Insulation
RTOMI   Repetitive Task Operations and Maintenance Instruction
RTV   Room Temperature Vulcanizing
SAFT   Semi-Automatic Flight line Tester
S&A   Safe and Arm
SCAPE   Self-Contained Atmospheric Protective Ensemble
SDIO   Space Defense Initiative Office
SIP   Standard Interface Panel
            Strain Isolation Pad
SIT   System Integrated Test
SMA   Shape-memory alloy
SMCH   Standard Mission Cable Harness
SME   Shape Memory Effect
SS   Space Station
SSME   Space Shuttle Main Engine(s)
SSMEC   Space Shuttle Main Engine Controller
SPC   Shuttle Processing Contractor
SPDMS   Shuttle Processing Data Management System
SPI   Standard Practice Instructions
SRB   Solid Rocket Booster
SRSS   Shuttle Range Safety System
SS   Space Station
STAS   Space Transportation Architecture Study
STS   Space Transportation System
S\W   Software
TARS   Turnaround and reconfiguration Simulation
TDRS   Tracking and Data Relay Satellite
TIS   Technology Identification Sheet
TPS   Thermal Protection System
            Test Preparation Sheet
T/S   Test Setup
TSM   Tail Service Mast
TVC   Thrust Vector Control
ULCE   Unified Life Cycle Engineering
VAB   Vehicle Assembly Building

ACRONYMS AND ABBREVIATIONS
(Continued)

VC1	Visual Clean 1 (standard)
VC1A	Visual Clean 1A (sensitive)
VC2	Visual Clean 2 (highly sensitive)
VHSIC	Very High Speed Integrated Circuit
VLSI	Very Large Scale Integration
VPF	Vertical Processing Facility
WAD	Work Authorization Document
WEM	Water Electrolysis Module
WCCS	Window Cavity Conditioning System
WCS	Waste Conditioning System
WSB	Water Spray Boiler
XTKB	Expanded Technology Knowledge Base

1.0 GROUND OPERATIONS EVALUATION

INTRODUCTION

STUDY OBJECTIVES: The overall objectives of this Study are to determine high payoff, innovative methodologies and technologies to reduce the cost of STS ground processing and manpower; and, thereby reduce life cycle costs. These objectives shall be accomplished through an overall analysis of the current shuttle ground operations functions including but not limited to: assembly, test and checkout, logistics, recovery, refurbishment, servicing, payload integration, launch operations, operations management, and ground systems operations and maintenance.

OVERALL STUDY CONCLUSIONS:

SHUTTLE

Analysis of the massive amount of ground processing-related information; and documented information and reports generated after the Challenger (51-L) loss; and management of those activities provided the basis for the conclusions reached during this Study. Those conclusions involve both the Shuttle ground processing operations and the management of those activities. All the reviewed issues and related problems were ultimately determined to be the result of either a "design" or a "management" deficiency.

Management: While it may be beyond the intended scope of this Study, the basic Program problems and the idealized future solution became evident to the Study participants. These conclusions are described graphically in Figures 1 and 2 below.
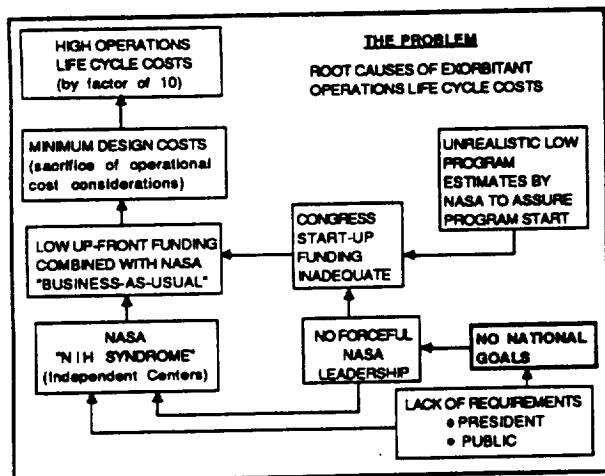
Figure 1
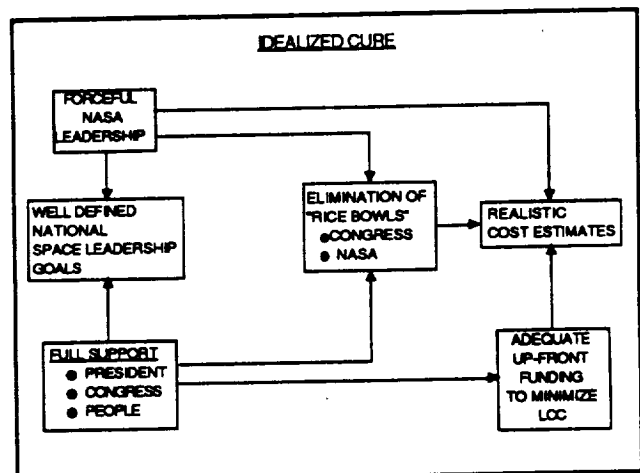
Figure 2

1.0 GROUND OPERATIONS EVALUATION
Continued

Ground Operations: There is no easy answer for streamlining
Shuttle ground operations. The Shuttle was not designed for ease
of operations -- by limiting front-end design costs, the vehicle
turned out to be a proof-of-concept vehicle that is not designed
to be operationally efficient. This is a fact that is generally
conceded by most everyone today. The realistic, full cost per
flight, based on 10 flights per year, is over $246 million in
1985 dollars. It is only by forecasting 24 flights per year that
the "full cost per flight" could even approach the advertised
$100 million cost figure in 1985 dollars. Since the best flight
rate achieved to date (FY-85) was 8 and with a maximum
improvement of 10% in ground operations without very major block
modifications to the orbiter systems, it is unrealistic to quote
a full cost of $100M in 1985 dollars, much less in 1987 dollars.

Analysis shows that major block modifications to make the three
Orbiters operationally efficient does not appear to be cost
effective.   Only those efficiency mods that could be worked in
parallel with mandatory safety mods appear practical.
Implementation of the IMIS (Integrated Maintenance Information
System) portion of the ULCE (Unified Life Cycle Engineering)
system could, by simplifying the paperwork processing systems
used on Shuttle, potentially reduce life cycle costs on Shuttle
by better than 4%. This would, of course, require a significant
up-front investment.   The investment can be shown to pay for
itself in three years at a flight rate of ten flights per year.

Section 1.4 details the analyses and recommendations for Shuttle
and they are summarized in Section 1.5.2.

FUTURE PROGRAMS

The operations and management lessons learned from the Shuttle
Program, if used in conjunction with technology advances, can
significantly reduce the operational portion of life cycle costs
for new vehicles.   If maximum use is not made of all these
lessons and improved technology, program costs will continué to
rise -- life cycle costs could prevent this Country from
regaining the space leadership it once held.

ULCE/CALS (Unified Life Cycle Engineering/Computer Aided
Logistics System): The most important finding of this Study is
the requirement for NASA to immediately require some form of the
ULCE system to be included along with the new DoD standards for
data interchange (MIL-STD-1840A). Individual Centers must not be
allowed to develop data formats that are unique. Systems must be
developed that will allow full communications with other NASA
Centers, Air Force, or Contractors: for example, the "new"
Shuttle Processing Data Management System (SPDMS) currently under
development at KSC. NASA should insist that it conform to the
new standards that have been developed for data interchange. DoD
is in the process of funding approximately $685 million (for
FY-87, 88, & 89) to research and provide standards for the
ULCE/CALS mentioned above. NASA could easily participate in the
Standards committees for that development. Full use of ULCE/CALS
in future programs can bring about a six percent reduction in
total life cycle costs -- a VERY large dollar value ($1.82B for a
100 flight Shuttle Orbiter, for example).

1.0 GROUND OPERATIONS EVALUATION
Continued

Management Issues: A major issue stressed during the Study was the need to accept new management concepts and practices. The increasing demand by both NASA and DoD to drastically reduce the cost of operations can only be met if the designed and fabricated hardware, as delivered to the operational site, has had supportability and maintainability designed into it from the beginning of the conceptual study development. Advanced management techniques are an essential part of the "new look" required for future vehicles. The use of Design/Build Teams and Build-to-Cost concepts, along with the use of new design tools like ULCE (Unified Life Cycle Engineering) systems, will be required if one is to stay in business. It may require a change in mindset about what constitutes "good management" but cost figures for new programs are getting so huge that inefficiencies, of any nature, can no longer be tolerated. This subject is discussed in more detail in Sect. 1.4.12.

Anomaly Resolution: Full implementation of the automated anomaly resolution capabilities described in Section 1.4.6 could reduce life cycle cost by an additional five percent.

Section 1.4 describes in detail the other recommendations and they are summarized in Section 1.5.1.

1.1 STUDY TOOLS AND EVALUATION PROCESS

The Study Flow Diagram, Figure 1, shows the management scheme used to track progress of various tasks associated with the main thrust of the Study. It shows the data sources inputing to the Study the inter-relationship of various parts of the Study; and Study products.
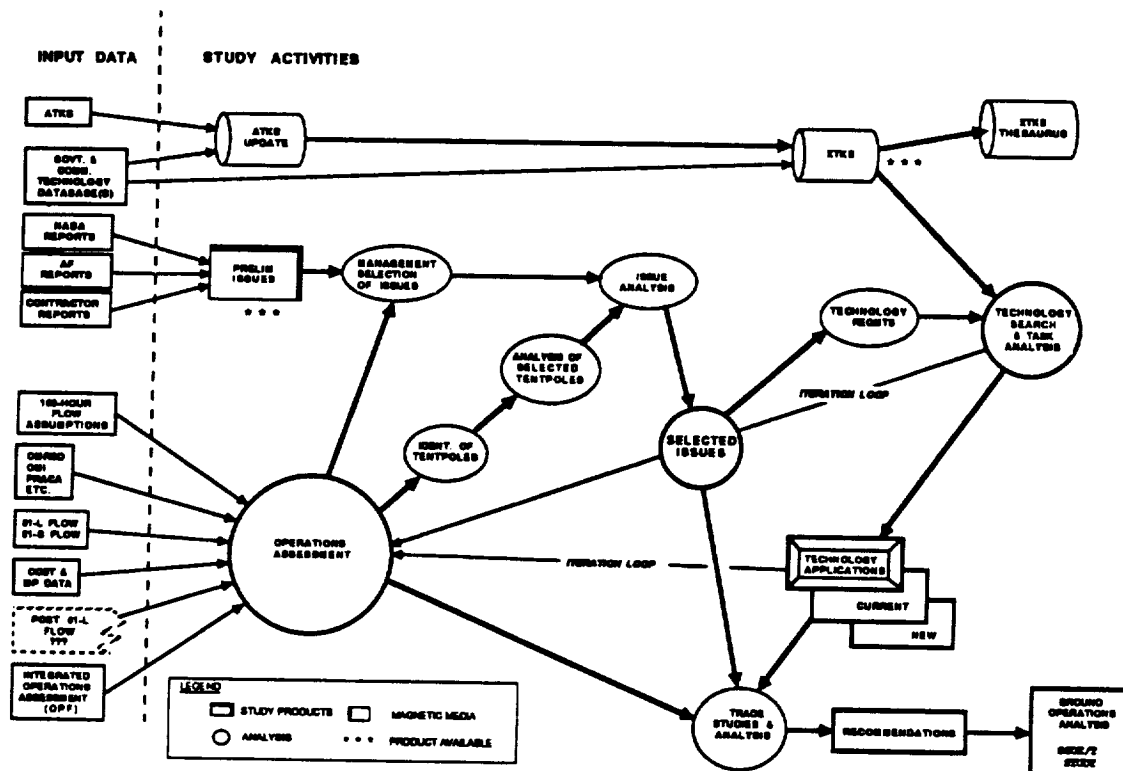
STUDY FLOW
Figure 1

ORIGINAL PAGE IS
OF POOR QUALITY

1.1.1 ENGINEERING TOOLS

Data Processing: In order to survey the very broad scope of the Study and select material for detailed analysis in a very short period of time, it was necessary to provide a comprehensive computer network for the Study personnel. The network shown in Figure 2 allowed us to access NASA and commercial databases; transfer text between work stations; allow personnel to simultaneously work in the same database; and to do presentation quality graphics. The Mac-XL and the Mac-512 provided good graphics capability, while the AT&T 6300+'s with a Xenix operating system provided superior data processing and database management.
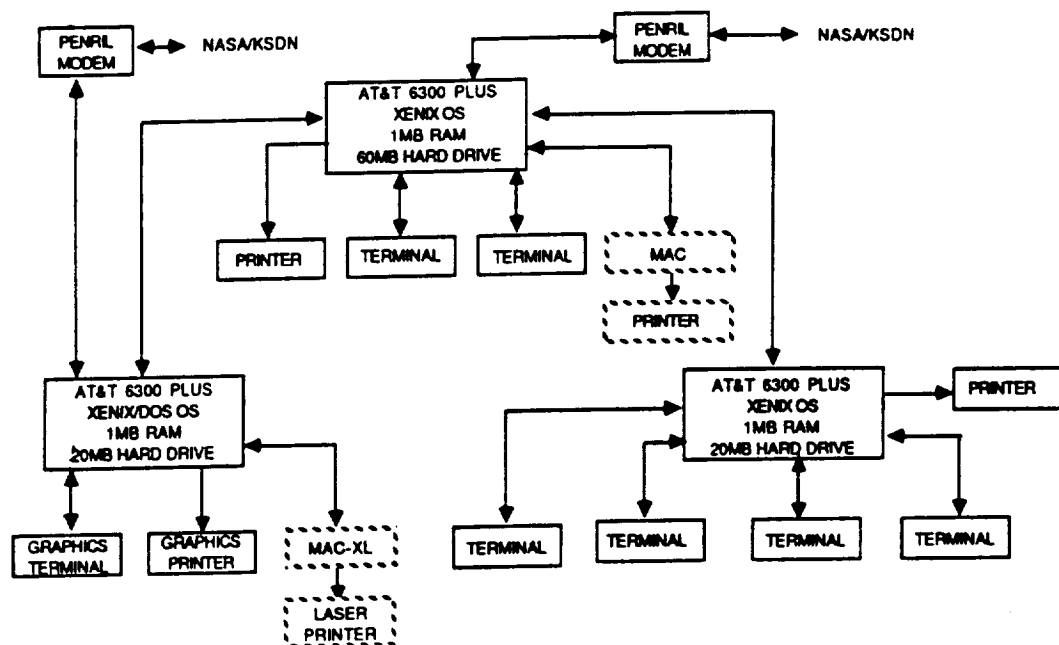
STUDY DATA PROCESSING SYSTEM
Figure 2

Preliminary Issues Database (PIDB): is described at length in Section 1.2 and a 600 page printout is included as Volume 4 of this Report. It includes over 2000 different descriptions of issues or data pertinent to the Study.

_____

Expanded Automation Technology Knowledge Base (XTKB): is the
expansion of the Automation Technology Knowledge Base (ATKB)
brought to this Study from the OTV Launch Operations Study. It
includes some 23000 records of papers and documents related to
Study subjects such as automation, expert systems, artificial
intelligence, fault detection, safety, etc.

PRACA and OMRSD: arrangements were also made to access the NASA
PRACA and OMRSD databases.

Database Relationship: Figure 3 illustrates the relationship of
internal and external databases utilized during the Study.

OTHER COMPUTER DATABASES

PRACA	RECON	COMMERCIAL	OMRSD
107,818 RECORDS	2.4×10^6 RECORDS	6.9×10^6 RECORDS	RECORDS

STUDY COMPUTER DATABASES

REFERENCE FILE SYSTEM	PRELIMINARY ISSUES CATALOG	TECHNOLOGY IDENTIFICATION SHEETS (TIS)	PRACA EXTRACT	XTKB	160-HOUR ASSUMPTIONS
243 RECORDS	3,260 RECORDS	143 RECORDS	RECORDS	22,750 RECORDS	572 RECORDS

ANALYSIS SUPPORT

HARDCOPY DATA

ISSUE SOURCE DOCUMENTS	OMI's	MH/MP/COST DATA	KSC HISTORICAL SCHEDULES	KSC LIBRARY FICHE' HARDCOPY INTER-LIBRARY

LEGEND: ELECTRONIC QUERY   KEYBOARD ENTRY   ELECTRONIC TRANSFER -13-   HARDCOPY

STUDY ANALYSIS SUPPORT
Figure 3

1.1   STUDY TOOLS AND EVALUATION PROCESS
   (Continued)

1.1.2   TECHNICAL SURVEY TRIPS

Four technical survey trips were made in direct support of the Study during Phase 1:

* Boeing Seattle

* Wright-Patterson AFB (WPAFB)

* Rome Air Development Center (RADC)

* Naval Surface Weapon Center (NSWC)(ex NOL)

The survey trip to Boeing Seattle provided us with insight in new management techniques being implemented for the next generation of airplanes where worldwide competition is making the protection of corporate rice bowls suicidal. Section 1.4.12 describes the pertinent management techniques. Technical subjects surveyed during this trip included NDE technology including backscatter X-ray (see Section 1.4.9); integrated fault-tolerant avionics (Section 1.4.6); 767 integrated testing (Section 1.4.6); manipulative robotic systems (led to potential use of Nitinol for ordnance systems (Section 1.4.11); optical sensors and processors (Section 1.4.6).

The trip to WPAFB was a result of an XTKB search which surfaced extensive Air Force activity on ULCE (Unified Life Cycle Engineering). Results of this trip and the additional research done on this and related topics account, in large part, for our conclusions and recommendations in the area of birth-to-death computerized paperwork systems (Section 1.4.12).

The Rome Air Development Center trip provided an update on Air Force research projects of Built-In-Test (BIT) techniques and the status of recommendations to DoD on various aspects of anomaly resolution (fault detection, fault isolation, and fault resolution), see Section 1.4.6.

Our trip to the Naval Surface Weapons Center was for the purpose of investigating feasibility of using Nitinol-type devices as a substitute for certain ordnance devices. Results of this trip were positive and are referenced in Section 1.4.11.

1.2 ISSUES

Issues are items impacting operational areas such as accessibilty, cannibalization, or safety which surfaced from our source documentation or operational analysis.

Forty different issue topics were defined at the beginning of the Study and all issue descriptions were placed in one of these categories in the Preliminary Issues Database (Volume 4 of this Study). The number of description entries range from a low of 3 to a high of 750. The number of entries is indicative of the degree of documented attention. Figure 1 lists the 40 different issues used and the number of description entries in the database.

	NO. ENTRIES		NO. ENTRIES
ASSESSABILITY	104	METHODS	17
AUTOMATION	27	MISSION	30
CANNIBALIZATION	14	MODULARIZATION	8
CHANGE CONTROL	30	PAPERWORK	104
COMMONALITY	45	PLANNING	39
CONSTRAINTS	18	PROCEDURE	94
COST/MANHOURS	101	QA	107
DESIGN	750	REDUNDANCY	33
DESIGN CRITERIA	298	RELIABILITY	51
DISCIPLINE	125	REQUIREMENTS	167
DRAWING SYSTEM	30	SAFETY	250
EFFICIENCY	30	SECURITY	20
EXPERT SYSTEM	16	STANDARDS	33
FAULT DETECTION	54	SURFACE TRANSP.	15
INTEGRATION	11	TECHNOLOGY	91
INTERFACE	42	TIME/CYCLE	3
ISOLATION	24	TIME/OFF-LINE	8
LOGISTICS/SPARES	81	TIME/ON-LINE	22
MAINTAINABILITY	226	TRAINING/CERTIF	31
MANAGEMENT	82	WAIVERS	10

ISSUES
Figure 1

The prime source of issues was documentation resulting from the loss of 51-L. There were also numerous other sources of documented problems independent of 51-L. These sources are listed below in Figure 2 with the associated block of identification numbers in the PIDB, Volume 4.

INDEX NO. SERIES	TOPIC
100	EXCERPTS FROM PRESIDENTIAL COMMISSION REPORT (VOLS. I & II)
200-400	COMPLETE 51-L FINDINGS
500	EXCERPTS FROM AEROSPACE SAFETY ADVISORY PANEL
600	EXCERPTS FROM AIR FORCE OPERATIONS & TEST EVALUATION CENTER REPORTS (AFOTEC)
700	EXCERPTS FROM NATIONAL SPACE TRANSPORTATION STRATEGY
900	COMPLETE DR. LUCAS LETTER TO NASA HQ ON "OPERATIONAL EFFECTIVENESS (MAY '82)
1000-1600	COMPLETE ROCKWELL MAINTENANCE TECHNOLOGY STUDY
1700	EXCERPTS FROM AFSC/NSIA SPACE TRANSPORTATION PANEL WHITE PAPERS ON "COST REDUCTION & COST CREDIBILITY"
1800-2800	COMPLETE DE AND NE-PED "RETURN TO FLIGHT STATUS MOD LIST"
3000	EXCERPTS FROM "SPACE STATION MAINT. PLNG. & ANALYSIS STUDY" (BOEING)

PRELIMINARY ISSUES DATABASE CONTENT
Figure 2

1.2 ISSUES
(Continued)

Figure 3, PIDB Information Sources provides a quantitative look at source documentation origination.
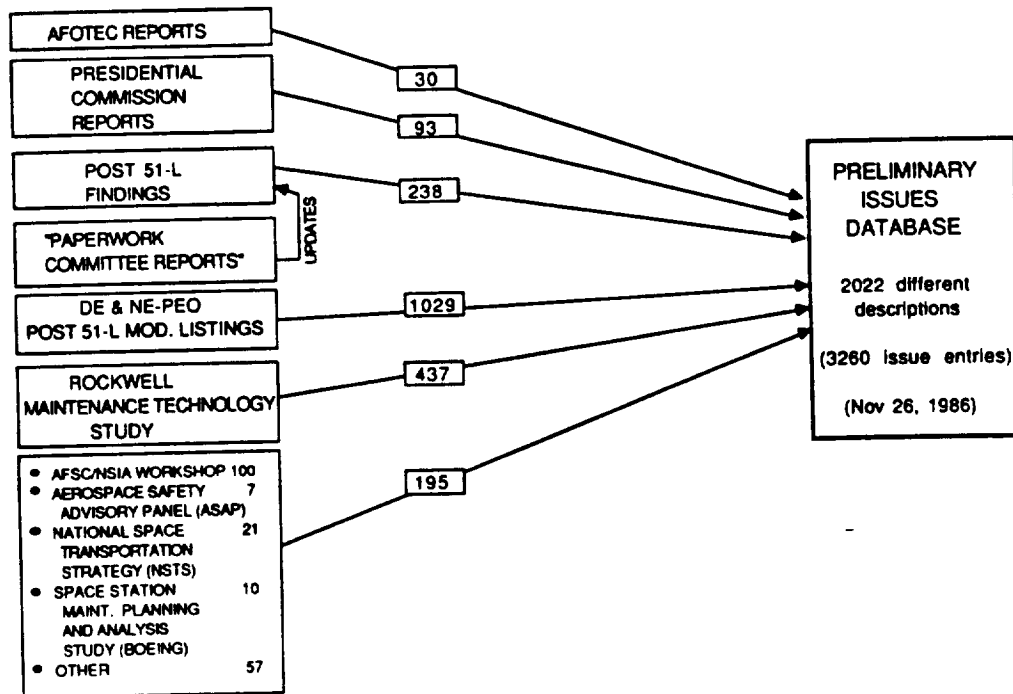
PIDB INFORMATION DATA SOURCES
Figure 3

A complete of the sort capability description of the PIDB is provided in Volume 4.

1.3 STS OPERATIONS ANALYSIS

1.3.1 INTRODUCTION

<u>Objective</u>: The objective of the operations analysis was to first identify current Shuttle operations that historically require excessive time to complete; then to analyze these operations to evaluate suitability as candidates for reduction by applying new technology. The candidates selected have been identified as "tentpoles".

<u>Approach</u>: The entire ground operations spectrum of the current Shuttle system was reviewed to identify operations causing the time between flights. It was immediately apparent that the Orbiter operations was the area of greatest potential reduction in turnaround time. In all flows studied, both the SRB's and the ET was stacked on the MLP; awaiting orbiter mate. Each Orbiter operation was investigated, and timelines evaluated to see if the time required had the potential of reduction through application of technolgy. Note that the emphasis of this study was on technology in order to avoid duplicating the concentrated effort of the Shuttle Processing Contractor on straightforward flow improvement after the 51-L incident.

There were several prime sources of information was used to make the "tentpole" determinations. These sources were:

1. 160-hour Ground Operations Plan

2. As-Run schedules from previous flows with emphasis on the 51-L(the latest) and 61-B (the shortest) flows.

3. STS-XX OPF flow (a composite flow reflecting the best-to-date performance).

4. OMI's used to perform all operations.

5. Discussions with personnel from NASA, the SPC and Rockwell International.

6. Personal experience of Study participants in Shuttle processing.

<u>Rationalization</u>: The 160-hour turnaround was used as a comparison baseline because it is still the NSTS 07700 design goal for the program. This 160-hr turnaround goal is recognized, at all technical and management levels of the program, as unobtainable (by a factor of several times) with the current hardware. Nevertheless, it provided a stable baseline for the study against which all ground operations growth could be measured. As a reference, the best composite turnaround time is 1040 hours.

1.3 STS OPERATIONS ANALYSIS
(Continued)

High Payoff Technology Potential: Figure 1 depicts the growth of processing time from the original 160-hr design goal to the pre-51-L goal of 680 hours and the pre-51-L capability of 1040 hours which combined the best as-run vehicle times for the OPF, VAB, and PAD. It should be noted that this capability will be significantly impacted by additional safety-related test and inspection requirements resulting from 51-L. High potential payoff examples from the OPF and Pad processing provide a total of 1085 hours of potential serial or parallel time improvement (through the use of technology) to meet the initial design goals.
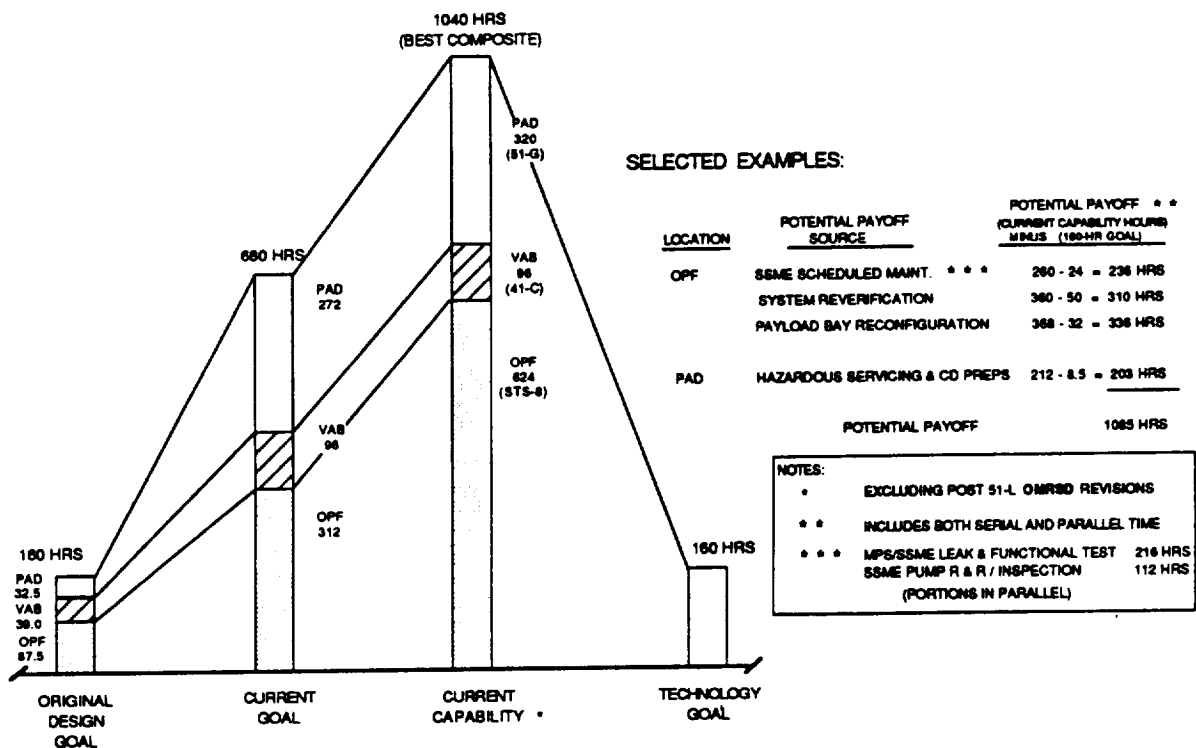
HIGH PAYOFF TECHNOLOGY POTENTIAL
Figure 1

1.3.2 160-Hour Turnaround vs 51-L As-run

This is a comparison between the 160-hr turnaround and the actual processing schedule for the 51-L mission. This includes both the timelines and functions for processing of the Orbiter from Roll-in at the OPF to Launch.

Level I directed that the Shuttle be designed so that it could be launched within 160 working hours after landing of the previous mission. This would be on a two-shift workday, five-days a week. Level II then divided this 160-hrs into time to be spent in the OPF, VAB, and at the Pad. All designs were to support these requirements, but due to both money and weight constraints, the operation times have been lengthened by several times. Figure 2 is the original Level II Schedule with the time allotted to perform each task. Following are sheets giving the 51-L comparison.

Letters A through W are used for each operation identified on the Level II Schedule. The Title of the block on the original schedule, with time originally allocated is used for the heading. A list of the actual operations, with timelines, will show what was required (by the ORMSD and equipment failure, repair and retest) to process 51-L.

TURNAROUND TIME (HRS.)

	Time scale: 0 – 160 hrs	Facility
A	LANDING AREA/TOW TO OPF (1)	ORBITER PROCESSING FACILITY (OPF)
B	SAFING AND DESERVICING (8)	
C	PAYLOAD REMOVAL PREPS (8)	
D	PAYLOAD REMOVAL/MISSION UNIQUE PAYLOAD ACCOMMODATION EQUIPMENT; REMOVAL AND RECONFIGURATION (27)	
E	ORBITER SCHEDULED MAINTENANCE (24)	
F	SSME SCHEDULE MAINTENANCE (24)	
G	UNSCHEDULED MAINTENANCE & SYSTEM REVERIFICATION (50)	
H	TPS REFURBISHMENT (40)	
I	ORBITER INTEGRATED TEST (12)	
J	PREPS FOR MATING (10)	
K	TOW ORBITER TO VAB	VEHICLE ASSEMBLY BLDG. (VAB)
L	(TRANSFER AISLE) ORBITER PREMATE OPS (5)	
M	ORBITER MATE AND INTERFACE VERIFICATION (16)	
N	SHUTTLE INTEGRATED OPS (19)	
O	MOVE TO PAD (7)	
P	MLP MATE TO PAD & LAUNCH PAD VALIDATION (3)	LAUNCH PAD
Q	PAYLOAD INSTALLATION IN PCR (13)	
R	FUEL CELL O2E DEWAR LOADING (16)	
S	POWER ON / SHUTTLE LAUNCH READINESS VERIFICATION (8.5)	
T	PAYLOAD INST & LAUNCH READINESS VERIFICATION (9.0)	
U	CABIN CLOSEOUT OPS (1.0)	
V	HAZARDOUS SERVICING/SERVICE DISCONNECTS (8.5)	
W	LAUNCH FROM STANDBY (2.0)	
	LIFT-OFF	

**160-HR. TIMELINE ALLOCATION
(PAYLOAD INSTALLATION AT PAD)
Figure 2**

1.3 STS OPERATIONS ANALYSIS
(Continued)

A. LANDING AREA   1.0 HR

WAD	TITLE	HOURS
V5001	SLF OPS/TOW TO OPF*	10.5 hours total

* Previous mission landed at DFRF and was
ferried to KSC.

B. SAFING AND DESERVICING   8.0 HRS

WAD	TITLE	HRS
V5001	TOW ORB INTO OPF/JACK & LEVEL/POWER UP PREPS	17.5
V1184	SAFING PATCHES/LOAD MMU	3.0
V1091	PRSD CRYO VENT	40.0
V1158	OMS TRICKLE PURGE & OMS/RCS DESERVICING	96.0
V5012	NOSE LANDING GEAR THRUSTER REMOVAL	8.0
V5012	PYRO WIRE HARNESS R&R RESISTANCE CHECK	48.0
V1078	APU LUBE OIL DESERVICING	24.0
N/A	MPS/SSME PROCESSING (ENGINE DRYING)	71.0
V1018	WATER SPRAY BOILER DESERVICING	24.0
VII96	APU POST FLIGHT FUEL SYSTEM OPS	85.0
	TOTAL	416.5

C. PAYLOAD REMOVAL PREPS.   8.0 HRS

WAD	TITLE	HRS
V3512	INSTALL PAYLOAD ACCESS	8.0
V5006	PAYLOAD STRONGBACK INST/OPEN PAYLOAD BAY DOORS	17.0
	TOTAL	25.0

D. MISSION UNIQUE PAYLOAD ACCOMMODATION EQUIPMENT
REMOVAL/INST.   24.0 HOURS

WAD	TITLE	HRS
N/A	AFT FLIGHT DECK/PAYLOAD BAY DECONFIG/RECONFIG.	240.0
V1175	RMS TURNAROUND VERIF.	16.0
V5R03	PRSD H2/O2 TANK SET 4 REMOVAL	120.0
N/A	PCP/CIU INSTALLATION	48.0
N0533	PCP/CIU CHECKOUT	5.5
	TOTAL	429.5

E.   ORBITER SCHEDULED MAINTENANCE   24.0 HRS

WAD	TITLE	HRS
V6002	ORBITER POST FLIGHT INSPECTION	24.0
V1026	REMOVE WASH & WASTE FUNCTIONAL	16.0
V5017	DESTOW FCE	16.0
V1084	CAUTION & WARNING SYS VERIFICATION	8.0
V5056	REMOVE GAS SAMPLE BOTTLES	8.0
V1134	WATER DRAIN (HORIZONTAL POSITION)	8.0
V1007	PV&D VENT FILTER/INSTL.	104.5
V1076	WCCS FUNCTIONAL CHECKS	176.0
V1062	AIR DATA SYSTEM	8.0
V1008	MSBLS TESTING	8.0
V1200	RECORDER DUMP	8.0
V6005	STARTRACKER CLEAN/INSPECT	8.0
V6018	CABIN AIR/RECIRCULATE MAINTENANCE	120.0
V6012	HYD INSPECTION	16.0
V1217	ECLSS ARPCS FUNCTIONAL TEST	12.0
V1178	KU BAND TURNAROUND C/O	8.0
V1184	LOAD MMU	12.0
V1005	VTR C/O	4.0
V1086	MEC PIC TEST	44.0
V5069	TRANSFER TO AFT 999 JACKS	3.0
V1016	VENT DOOR FUNCTIONAL	11.0
V1097	ET DOOR FUNCTIONAL/LATCH FOR FLIGHT	8.0
V5069	TRANSFER TO AFT 570 JACKS	3.0
V1026	REMOVE WASTE COLLECTION SYSTEM & WASTE FLUSH	24.0
V1153	APU WATER SERVICING	48.0
V1099	STARTRACKER DOOR FUNCTIONAL	5.0
V1042	SMOKE DETECTION & FIRE SUPPRESSION FUNCTIONAL	4.0
V5010	INSTALL B/C/ELBOW CCTV	8.0
V1003	POWER SYSTEM VALIDATION	23.0
V1180	FRCS FUNCTIONAL C/O (LPS)	14.0
V1080	MULT CRT DISP SYS C/O (LPS)	4.0
V1098	LANDING GEAR FUNCTIONAL	4.0
V6034	CREW MODULE SEAT FUNCTIONAL	8.0
V1005	CCTV SYSTEM TEST	3.0
V1183	ORBITER ELECTRICAL SYSTEM VALIDATION (LPS)	12.0
V1078	APU LUBE OIL SERVICING	66.0
V1041	N2 SERVICING	8.0
V9023	CLOSE/OPEN PAYLOAD BAY DOORS	11.0
V1180	AFT OMS/RCS FUNCTIONAL	96.0
V1037	NH3 SYSTEM SERVICING	24.0
V1055	POTABLE WATER SERVICING	24.5
V1017	WATER SPRAY BOILER SYSTEM LEAK & FUNCTIONAL	25.0
V9002	BRAKE FILL & BLEED	4.0
V1048	NOSE WHEEL STEERING	5.0
V1065	BRAKE/ANTI-SKID CONTROL SYSTEM TEST (LPS)	8.0
V1060	AEROSURFACE CHECKOUT	5.5
V6034	GALLEY FUNCTIONAL	8.0
V5050	FLIGHT CREW EQUIPMENT STOWAGE/CEIT/DESTOWAGE	19.0
TPS	FLIGHT CREW EQUIPMENT INFLIGHT MAINT. WALKDOWN	3.0
V9001	STOW KU BAND ANTENNA	8.0
V1131	HYDRAULIC ACCUMULATOR CHECKS	8.0
V1161	ORBITER BUS REDUNDANCY	19.0

	TOTAL	1132.5

F.   PROPULSION SYSTEM SCHEDULED MAINTENANCE   24.0 HRS

WAD	TITLE	HRS
V9002	HYDRAULIC POWER UP PREPS & POSITION SSME'S	49.0
V5043	REMOVE HEAT SHIELDS	20.0
V1009	MPS LEAK & FUNCTIONAL	176.0
V1011	SSME LEAK & FUNCTIONAL	176.0
V5058	REMOVE SSME #2	5.5
TPS	NOZZLE WELD INSPECTION (VAB)	* 240.0
V5E06	SSME #1 HIGH PRESSURE FUEL TURBOPUMP R&R	37.0
V5E06	SSME #2 HIGH PRESSURE FUEL TURBOPUMP R&R (VAB)	* 40.0
V5E29	SSME #2 GIMBAL BOLT R&R	* 32.0
V5057	DISCONNECT SSME TVC'S/INSTALL STIFF ARMS	4.0
V5005	INSTALL SSME #2	20.0
V1063	SSME TVC FLIGHT CONTROLS	3.0
V1011	SSME FLIGHT READINESS TEST	13.0
V1001	SSME ELECTRICAL INTERFACE VERIFICATION	8.0
V9019	MPS VJ LINES CHECK	4.0
V5057	REMOVE STIFF ARMS/CONNECT SSME TVC'S	8.0
V5043	HEAT SHIELD INSTALLATION	57.5

	TOTAL	893.0

* These operations were accomplished in the engine shop in the VAB.

G. UNSCHEDULED MAINTENANCE & SYSTEM REVERIFICATION 5.0 HRS

WAD	TITLE	HRS
N5230	ORBITER POST FLIGHT TROUBLESHOOTING	64.0
V1053	REMOVE CABIN SENSOR	8.0
V7253	WINDOW POLISHING	112.0
N/A	ORBITER POST FLIGHT TROUBLESHOOTING	32.0
IPR	TANK #1 H2 CRYO CONTROL HEATER TROUBLESHOOTING	48.0
V5R01	FUEL CELL #1 REMOVAL	64.0
IPR	MSBLS TROUBLESHOOTING	3.0
PR	REMOVE MSBLS	1.0
V1165	LANDING/BRAKE INSTALLATION	24.0
PR	R&R LAUNCH CONTROL AMPLIFIER	3.0
V5U01	REMOVE APU #3	31.0
V5011	R&R RH OMS POD	29.0
V5079	OMS ENGINE HEAT SHIELD REMOVAL	16.0
V1164	ELEVON LOWER COVE SEAL PRESS LEAK RATE	24.0
V5U01	REINSTALL APU #3	16.0
V5016	TRANSFER RIGHTHAND OMS POD TO HMF	2.0
PR	R&R HEADS UP DISPLAY UNIT	8.0
TPS	AMMONIA TANK PURGE	16.0
V1165	LANDING GEAR BRAKE INSPECTION & BRAKE R&R	23.0
TPS	NH3 LEAK & FUNCTIONAL	16.0
V1225	RIGHT OMS INTERFACE TEST	32.0
V5R01	INSTALL FUEL CELL #1	11.5
V1165	INSTALL NOSE LANDING GEAR TIRES	8.0
V1177	HEADS UP DISPLAY CHECKOUT	3.0
TPS	MATE APU FUEL LINES	13.0
IPR	LEAK IN APU FUEL LINE "B"NUT	16.0
V5079	LEFTHAND OMS ENGINE HEAT SHIELD INST'L R/T & LK CK	16.0
V1180	AFT OMS/RCS FUNCTIONAL	4.0
PR	INSTALL THRUSTER & RETEST	8.5
V1226	OMS POD MATING	16.0
V1053	CABIN SENSOR INSTALLATION & RETEST	8.0
IPR	REMOVE BREAK OUT BOXES	2.0
PR	LEFT OMS CROSSFEED LINE PROBLEM	22.5
V5011	R&R LEFTHAND OMS POD	26.5
V1224	OMS POD ELECTRICAL CONNECT & RETEST	12.5
V1226	LEFTHAND OMS CROSSFEED CONNECT	5.0
V1161	BUS REDUNDANCY LEFTHAND OMS POD	9.0

                                        TOTAL   753.5

H. TPS REFURBISHMENT   40.0 HRS

WAD	TITLE	HRS
V6028	ORBITER POST FLIGHT TPS INSPECTION	N/A
V9024	ORBITER TPS MAINTENANCE/OPERATION	N/A
N/A	ORBITER TPS WATERPROOFING	N/A
V9022	ET DOOR CYCLES/TPS OPERATIONS	120.0
V6035	RSI PRE ROLLOUT INSP & UPPER SURFACE WATERPROOFING	71.0
	TOTAL	191.0+

NOTE: The 51-L as-run schedule shows the first three above operations starting as soon as the orbiter is rolled into the OPF, but does not identify how long they continue. The STS-XX schedule allows 60 hrs for both the inspection and maintenance operation and 168 hrs for waterproofing.

I. ORBITER INTEGRATED TEST   10.0 HRS.

NOTE: The requirement for this test has been deleted from the OMRSD.

J. PREPS FOR MATING   10.0 HRS.

WAD	TITLE	HRS
V5012	AFT SEP HARNESS/ET UMB GSE & PLUG INSTALLATION	8.0
V5012	FWD ET BEARING & YOKE INSTALLATION	32.0
V5012	PRE-OPS SET UP	16.0
V5012	POWER DOWN ORDNANCE INSTALLATION	8.0
V5012	POWER ON PIC TEST	8.0
V6034	PAYLOAD BAY SHARP EDGE INSPECTION	4.0
V1032	ORBITER CLOSEOUT	104.0
V1032	ORBITER AFT CLOSEOUT	85.5
V6003	PAYLOAD BAY CLOSEOUT/INSPECTION	20.0
V9021	DEACTIVATE TRICKLE PURGE	8.0
V1176	PAYLOAD BAY CLEANING	27.5
V5018	CLOSE PAYLOAD BAY DOORS & REMOVE STRONGBACKS	16.0
V9002	HYD OPS/POSITION AEROSURFACES FOR ROLLOUT	4.5
V3555	DISCONNECT ORBITER PURGE AIR	5.0
V3515	REMOVE LH2/LO2 CARRIER PLATES	5.0
V5101	JACKDOWN WEIGH & CG/PREP TO TOW	8.0
	TOTAL	359.5

1.3 STS OPERATIONS ANALYSIS
(Continued)

K. TOW ORBITER TO VAB   NO TIME ALLOTTED

WAD	TITLE	HRS
S0004	ORBITER TOW & MATE	.5

	TOTAL	.5

L. TRANSFER AISLE ORBITER PREMATE OPS   5.0 HRS

WAD	TITLE	HRS
S0004	ORBITER TOW & MATE	18.5

	TOTAL	18.5

M. ORBITER MATE AND INTERFACE VERIFICATION   15.0 HRS

WAD	TITLE	HRS
S0004	ORBITER TOW & MATE	103.0
S0008	SHUTTLE INTERFACE VERIFICATION	36.5
S0020	SRB TESTING	5.5

	TOTAL	144.0

N. SHUTTLE INTERFACE TEST   19.0 HRS

NOTE: The requirements for this test have been removed from the OMR and is no longer being accomplished.

O. MOVE TO PAD   7.0 HRS

WAD	TITLE	HRS
A5214	TRANSFER & MATE TO PAD B	13.5

	TOTAL	13.5

P. MLP MATE TO PAD & LAUNCH PAD VALIDATION   3.0 HRS

WAD	TITLE	HRS
S0009	LAUNCH PAD VALIDATION	9.5
N/A	POWER UP PREPS	30.0

	TOTAL	39.5

Q.   PAYLOAD INSTALLATION IN PCR   13.0 HRS

WAD	TITLE	HRS.
NO133	CARGO INSTALLATION IN PCR PAD B	35.5
N/A	WIND DELAY IN INSTALLING CARGO IN PCR	33.0
N/A	IUS SCU PROBLEM	32.5
N1533	TDRS PROPELLANT LOAD	33.5
N/A	IUS POWER UP/DOWN TEST	21.5
N/A	IUS STANDALONE TEST	18.0
		TOTAL 174.0

R.   FUEL CELL DEWAR LOADING   10.0 HRS

WAD	TITLE	HRS
V2303	DEWAR LOAD	6.5
		TOTAL 6.5

NOTE: The 160-hr Turnaround Schedule has this activity to occur prior to the arrival of the vehicle at the pad. During the 51-L flow, it was accomplished just prior to hyper load which caused another pad clear in the pad operation.

S.   SHUTTLE LAUNCH READINESS VERIFICATION   6.5 HRS

WAD	TITLE	HRS
S0009	LAUNCH PAD VALIDATION WITH APU HOT FIRE *	40.0
V1202	HE SIGNATURE TEST	17.5
		TOTAL 57.5

* This time includes 4.5 hrs. for emergency power down if the orbiter cooling was lost to the vehicle.

1.3 STS OPERATIONS ANALYSIS
(Continued)

T. PAYLOAD INSTALLATION AND LAUNCH READINESS VERIFICATION 9.0 HRS.

WAD	TITLE	HRS
N0133	CARGO PAYLOAD BAY OPERATIONS	80.0
S0017	TERMINAL COUNT DEMONSTRATION TEST	55.5
V9023	OPEN PAYLOAD BAY DOORS	1.5
S0009	1ST MOTION CHECKS & SRSS HOLDFIRE CHECKS	6.0
N/A	HOT GAS SYSTEM TROUBLESHOOTING	15.0
V1202	HOT GAS POI'S	7.5
V1149	AFT CAVITY PURGE	9.5
PR	PDI R&R AND RETEST	5.0
B1500	R&R SRB AFT IEA	8.5
N0433	IUS TDRS IVT/ETE	25.0
IPR	R&R HIM 6893	2.5
PR	IEA ELECTRICAL CONNECT & RETEST	12.5
N/A	POD TOTALIZER CONNECT & RETEST	13.0
PR	UPS 40 TROUBLESHOOTING/CARD CHANGE/RETEST	8.5
N/A	CHARGE CARGO BATTERIES	15.5
V1077	FUEL CELL #1 SERVICING	8.0

		TOTAL 273.5

U. CABIN CLOSEOUT   1.0 HR

NOTE: No serial time was allotted during pad operations to close the crew cabin prior to propellant loading.

V. HAZARDOUS SERVICING/SERVICE DISCONNECTS   8.0 HRS

WAD	TITLE	HRS
S0024	PRE LAUNCH PROPELLANT LOAD	202.5
T1401	ET BLANKING PLATE REMOVAL	5.5
N/A	PAYLOAD DISCONNECT/ PLB CLOSEOUT/PLB DOORS CLOSE	7.0
PR	R&R RJDA #2 & RETEST	9.5
PR	R&R QD & RETEST OMS REG. LOCK UP TEST	8.0
S0009	ORDNANCE INSTALLATION	37.0
N/A	CARRIER PANEL INSTALLATION	37.0
S5009	ORBITER AFT CLOSEOUT	75.0
S1005	ET PURGES	12.0

1.3 STS OPERATIONS ANALYSIS
(Continued)

V. HAZARDOUS SERVICING/SERVICE DISCONNECTS (Continued)

The following operations were performed during this block of time but were part of the original timelines.

N/A	CARGO STANDALONE OPS	88.0
V1103	EMU INSTALLATION & TEST	16.0
V9002	SSME VALVE CYCLES/FRT'S	32.0
V1184	MMU FLIGHT LOAD	14.0

		TOTAL 543.5

W. LAUNCH FROM STANDBY   2.0 HRS

WAD	TITLE	HRS
S0007	LAUNCH COUNTDOWN	121.5

		TOTAL 121.5

NOTE: The length of countdown for the 51-L mission was much longer due to several delays caused mainly by weather. The first one was bad visibility at the transatlantic landing site (dust storm in North Africa). Possible adverse weather at the launch site then caused a 24 hour delay, and on the third attempt, high cross winds caused a scrub at T-9 minutes. A normal countdown is now scheduled for 56 hours.
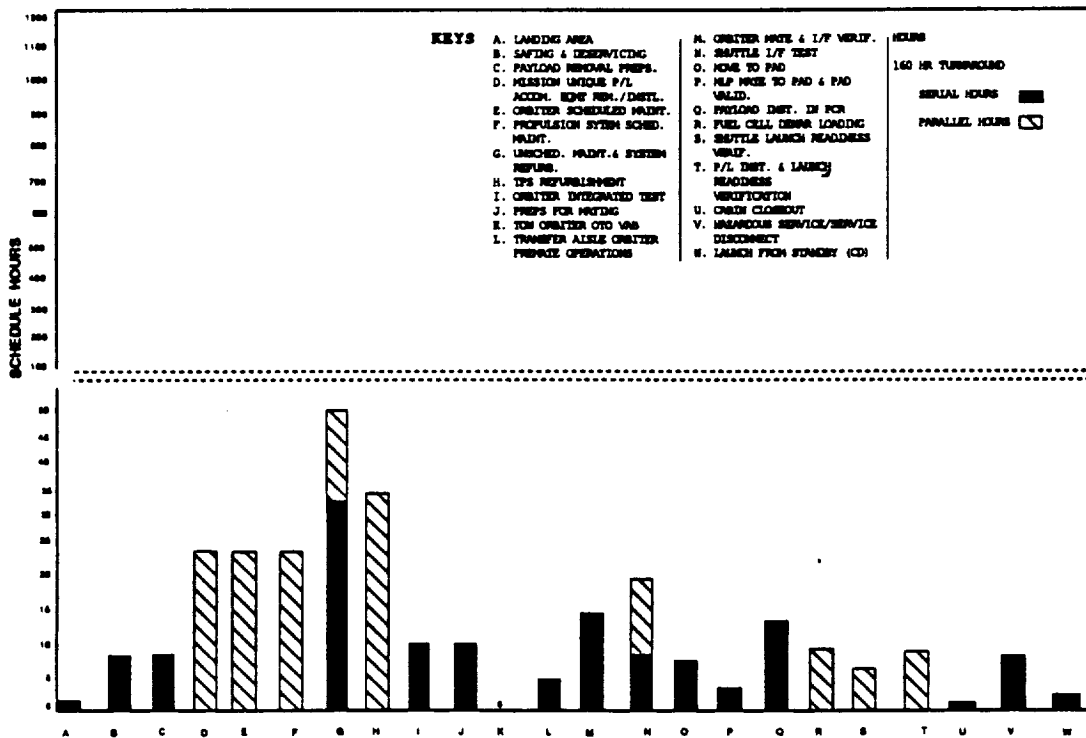
1.3 STS OPERATIONS ANALYSIS
(Continued)

1.3.2 SUMMARY

The following summarizes the results of this timeline analysis.
These are:

1. A comparision of the allocated 160-hour timelines (in
   24 categories) of the actual time required to
   complete all the tasks included under each of these
   categories for the 51-1 flow (preceding list).

2. A chart showing the time allotted in the 160-hour
   Turnaround Ground Operations Plan broken down into
   serial and parallel operations. (Figure 3)

3. The 51-L As-Run Schedule with tasks included under
   the different categories of the 160-hour turnaround
   broken down into serial and parallel operations.
   (Figure 4)

4. A comparision of the 160- hour timelines vs the 51-L
   operations, per 160-hour categories, showing both
   serial and parallel operations. (Figure 5)

The analyses summarized on Figures 3 through 5 served to
highlight the operations timeline growth by procedural/hardware
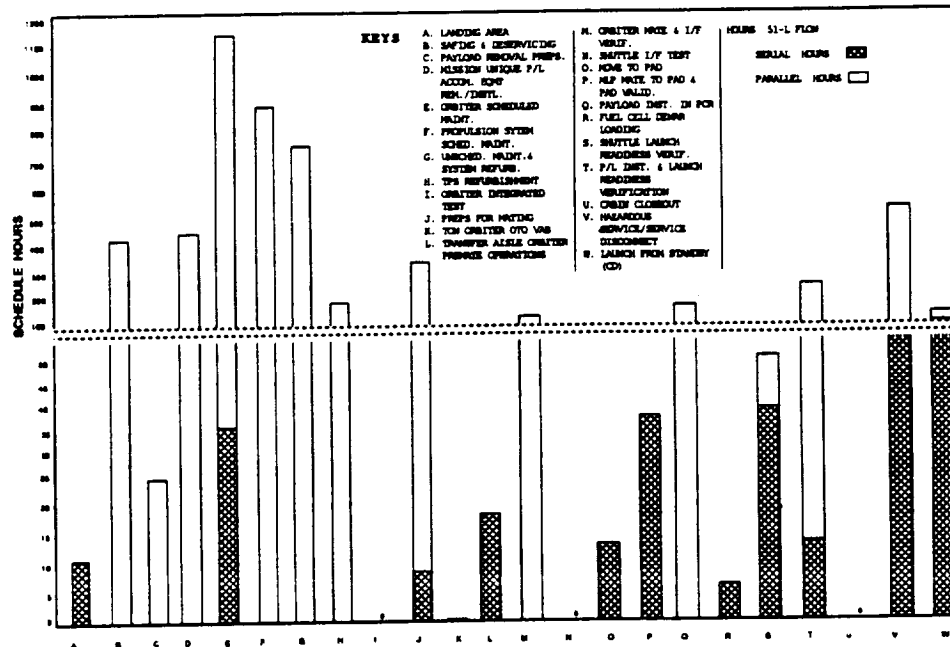areas. This enabled selection of high potential savings areas by
OMI.

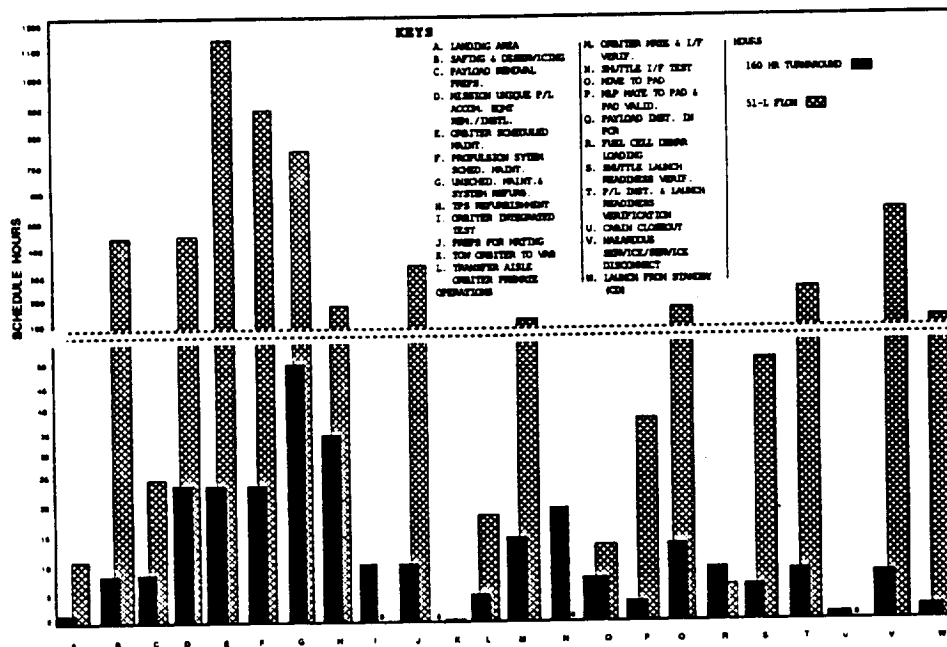**160-HOUR TURNAROUND TIMELINE ALLOCATIONS**
Figure 3

51-L AS-RUN SCHEDULE
MAJOR OPERATIONS ACTIVITY
Figure 4

160-HOUR TURNAROUND vs. 51-L AS-RUN SCHEDULE
MAJOR OPERATIONS ACTIVITY
Figure 5

1.3 STS OPERATIONS ANALYSIS
(Continued)

This resulted in the identification of seven tentpoles that were candidates for investigation for improvement by applying new technology and five candidates for improvements by incorporating operational efficiencies. When the Preliminary Issues Database was queried and the operational issues matched with the tentpoles, the following new technology candidates evolved:

A. Orbiter systems that could be redesigned to include fault detection and anomaly resolution

B. Window Cavity Conditioning System (WCCS)

C. Window Polishing

D. TPS Inspection

E. Fuel Cell Operations

F. Ordnance

G. The paper system used to control the ground operations

The timeline improvements using existing technology and operational efficiencies evolved the following candidates. Those selected are considered representative and popped out of our analyses eventhough they were not a targeted goal as explained previously.

1. SSME Repair Shop

2. Payload Bay Deconfiguration/Reconfiguration

3. Crew Cabin Air Recirculation System

4. Orbiter Weight & C.G. Determination

5. Payload Bay Cleaning

1.4 TENTPOLE AND RELATED ISSUES ANALYSIS

SUMMARY

The tentpole and related issue analysis uses the Operations Analysis and Preliminary Issues Database to define the selected efficiency/technology study targets. Figure 1 is a "funnel chart" which shows pictorially how the Ground Operations task was managed. The scope of the Study was so broad, and the information available so vast, it was necessary to quickly funnel the information, using computerized methods, into pertinent specific buckets (issues). Simultaneously, the Operations Analysis was conducted using KSC data elements shown in the figure. The resultant high-payoff operations issues were then researched for potential technology to increase efficiencies as shown in Figure 2.
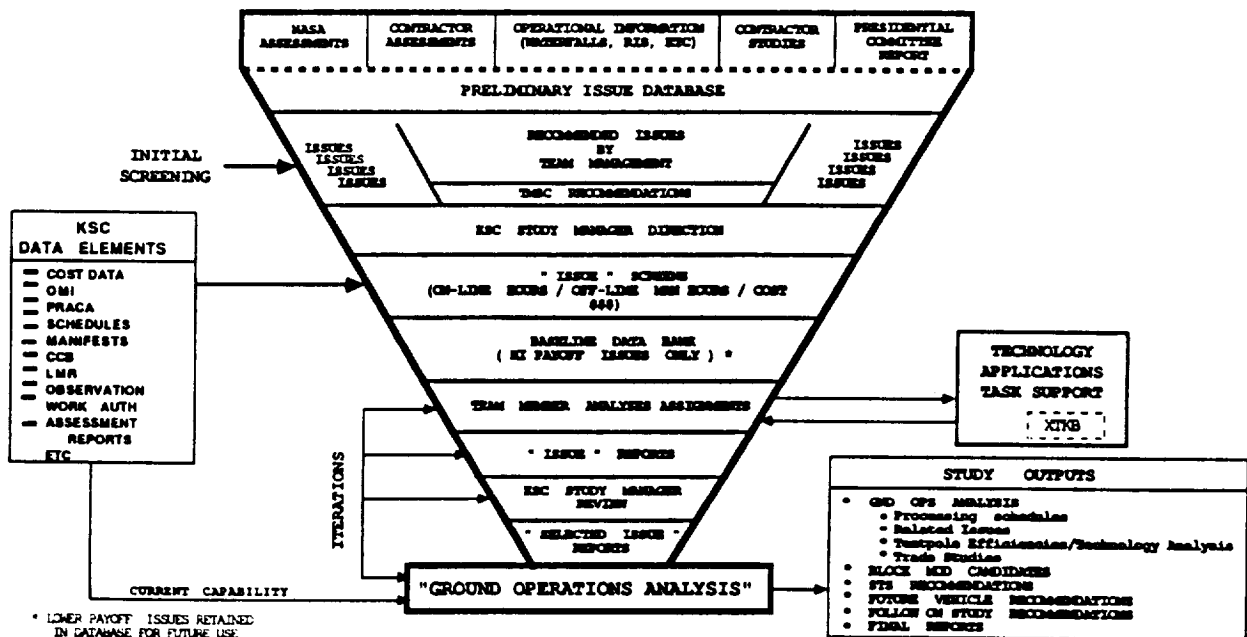
GROUND OPERATIONS TASK MANAGEMENT
Figure 1

-25-

1.4 TENTPOLE AND RELATED ISSUES ANALYSIS
(Continued)
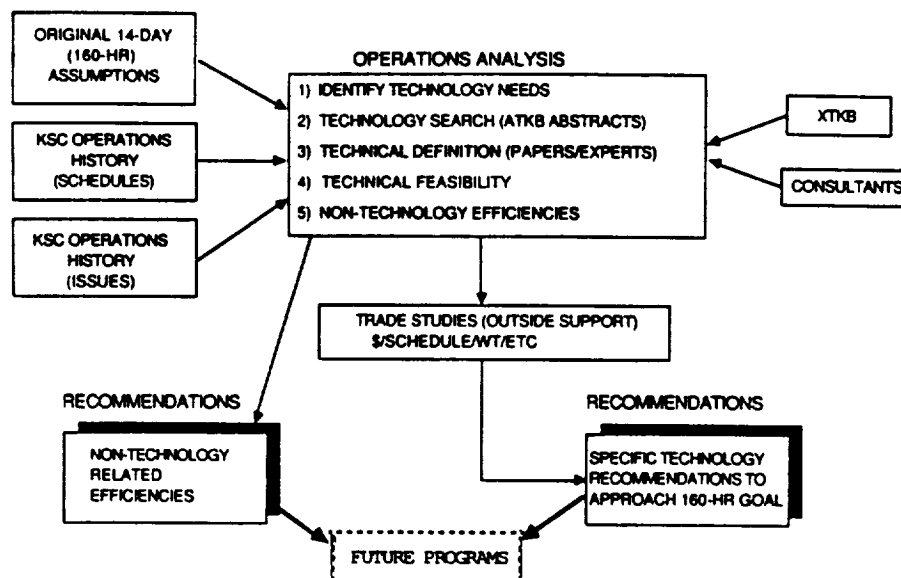
OPERATIONS ANALYSIS
Figure 2
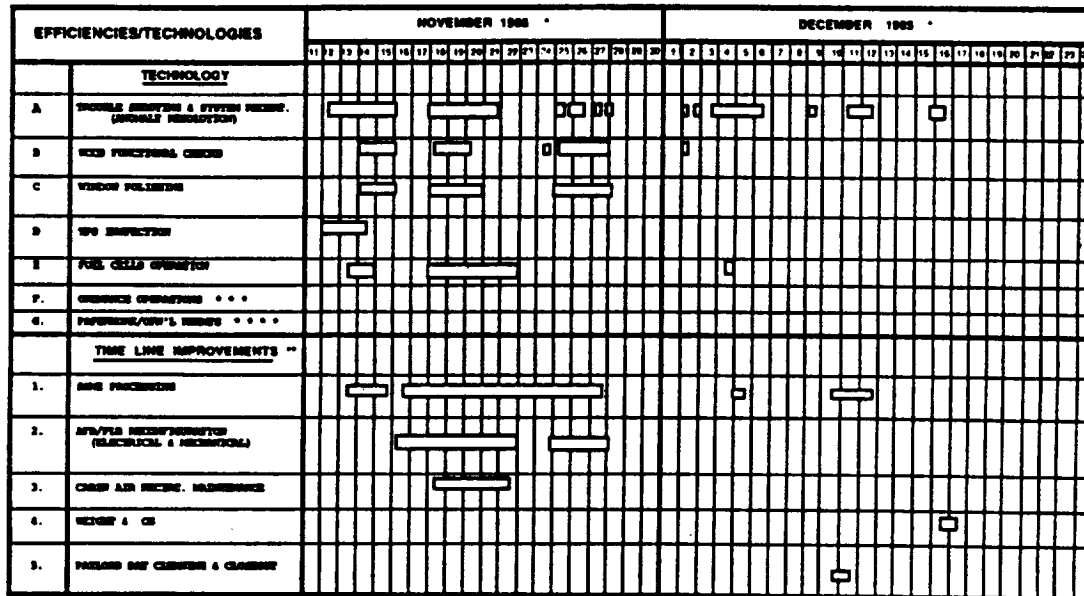
* All timebars indicate 3 shift/day operations
** Does not require new technology - but goes beyond the bandaid fix
*** Tentpole "F", Ordnance operations in the VAB and at the Pad
**** Tentpole "G", Paperwork and Operational Requirements, occurs throughout STS

51-L OPF PROCESSING
Timelines to Support Identified Tentpoles
Technology & Efficiencies Candidates
Figure 3

1.4 TENTPOLE AND RELATED ISSUES ANALYSIS
(Continued)

TECHNOLOGY AND EFFICIENCY CANDIDATES

The Operations Analysis surfaced five tentpoles (Figure 3) in the area of "timeline improvements"; that is, efficiency items that do not require new technology to implement. Because this type of improvement is being vigorously pursued by NASA and the Shuttle Processing Contractor with literally hundreds of people, we directed our prime study effort to new technology. Nevertheless, we have included several serendipitous items as timeline improvement not related to new technology, but which need an extra push.

The main thrust of our effort centered around tentpole activities that could be made more efficient through the use of new technology. Our Operations Analysis identified seven tentpoles (A - G), Figure 3, which, when matched with related issues, provided promising candidates for technology improvement. Tentpoles A through E occur in the OPF. Tentpole F, Ordnance Operations, occurs in the VAB and at the Pad. Tentpole G, Paperwork & Operational Requirements, occurs throughout the total vehicle processing; in fact, throughout the entire life cycle.

The Tentpole Issue Summary, Figure 4 below, provides a matrix of timeline improvement, tentpoles, and technology application tentpoles versus the major issues, shifts of work, and technician manhours. This provides a quick look at the scope of each tentpole selected for detailed investigation.

		TENTPOLE	ISSUES				SHIFTS ①	TECH MHRS ②③	ENGR/ QA/ETC MHRS
			Design	Access.	Maintain.	Cost			
TIMELINE IMPROVEMENTS	1	SSME Processing	X	X	X	X	47	3792	N/A
	2	AFD/PLB Reconfiguration	X	X		X	30	1680	
	3	Cabin Air Recirc.	X	X	X	X	12	384	
	4	Weight & CG	X			X	1	128	
	5	Payload Bay Cleaning	X			X	3.5	112	
TECHNOLOGY APPLICATIONS	A	Anomaly Resolution	X	X	X	X	48	964	
	B	WCCS Functional Checks	X	X	X	X	23	920	
	C	Window Polishing			X	X	24	384	
	D	TPS Inspection			X	X	7	632	
	E	Fuel Cell Operation	X		X	X	21.5	N/A	
	F	Ordnance Operations	X	X	X	X	N/A	N/A	
	G	Paperwork	X		X	X	N/A	N/A	N/A

① OTHER OPERATIONS MAY BE BEING KEPT IN PARALLEL
② DOES NOT INCLUDE TROUBLESHOOTING OR RETEST NOT ASSOCIATED WITH AN OMI
③ MANHOUR DATA NOT COMPLETE
④ NOT VEHICLE DEPENDENT DEPENDS ON GSE AVAILABILITY

▭▭▭ SHORT-TERM MANHATD   ▬▬ BLOCK CHANGES   FUTURE PROGRAM PROBLEM AVOIDANCE

TENTPOLE ISSUE SUMMARY
Figure 4

1.4 TENTPOLE AND RELATED ISSUES ANALYSIS
(Continued)

TENTPOLES CONSIDERED, BUT NOT INCLUDED IN STUDY

There are four significant tentpoles that are not analyzed in this study. They are SRB Processing, Facilities, Adverse Weather, and Weather Forecasts.

SRB Processing

SRB processing is not addressed because of the intensive effort being expended by others in this arena as a result of the Challenger loss. This has not been a significant on-line tentpole since it is primarily an off-line effort. However, from an efficiency manhour and cost standpoint, there is substantial improvement potential. Nevertheless, an efficiency study of expendable vs recoverable, recoverable refurbishment at KSC, etc. would be a superficial duplication of effort already underway.

Facilities:

While the subject of facilities was not addressed in Phase 1 of the Study, they provide a significant contribution to the "operational" portion of the overall life cycle costs for a program. Facilities are one of the significant "tools" provided to the workforce at the launch site. Initial facility costs may be kept low by modifications to old facilities; however, any inefficiencies forced on the operators is not a "one time thing". It is repetitive in every flow for the entire life of the program so even a relatively small item can become large from an LCC standpoint.

The Shuttle program, for example, has had to modify available facilities at KSC. Only recently has solid rocket booster processing been moved from the VAB so that those hazardous operating conditions do not have to be imposed on other VAB located operations. Many of the Shuttle workers remain in improvised office facilities (boxcars) located a considerable distance from the VAB. Workers located in close proximity to their work stations are happier and more productive than workers that have to "check in" at one location and then go some distance to get to their work station. Facilities involved with the various operations at KSC are widely separated so any joint operations requires that at least management personnel have to travel between facilities.

Operationally efficient facilities, designed to provide the right support capabilities at the right location for the processing crews, must be provided if processing costs are to be lowered.

Adverse Weather

Modifications have already been made at the Launch Pad to minimize effects of adverse weather. Literature searches were made using the XTKB for advances made in weather control (i.e., silver iodide cloud seeding, etc.), but to no avail. Further potential does exist at this time for improvement in the area of facility design for future vehicles. This should be considered in follow-on study effort.

Weather   Forecasts

It has been suggested that weather forecasting should be used in the processing scheduling to provide additional efficiency in routine work schedules. No evidence has been found that current weather forecast capability can improve current scheduling techniques.   This also applies to capability in the foreseeable future.   For example, the schedule of the launch of 51-1 was affected several times due to weather forecasts. The following is a list of schedule changes and the reason for the changes. Each of the weather forecasts is assessed for accuracy:

Tuesday, January 14, 1985 Launch date set for January 25

Wednesday, January 22
At 1330 hrs Launch slipped to January 26 due to dust forecast at the TransAtlantic Landing site. Forecast was accurate.

Saturday, January 25
At 2200 hrs Launch slipped to January 27 due to possible adverse weather at KSC.   Forecast was inaccurate because weather at previously scheduled T-0 was excellent.

Monday, January 27
1230 hrs Launch attempt was scrubbed with the count holding at T-9 minutes due to crosswinds at the Secondary Landing Facility being out of launch commit criteria. This condition was not forecasted (inaccurate).

Tuesday, January 28,
1138 hrs 51-1 Launched even though the temperature had been below freezing for several hours and the temperature was in the high thirties at launch. The forecast for that morning was for freezing temperatures, clear skies and light winds. This forecast was accurate.

TENTPOLE ANALYSIS SUMMARY

The Tentpole Analysis Summary, presented below in tabular format, is divided into two parts: Timeline Improvements Summary and Technology Applications.

Timeline Improvements: The Summary presents a brief description of each element evaluated for the Tentpole-Related Issues, Issue Sources, Related Schedule Data, Todays Methods, Timeline Improvements, Operational Evaluation, and Recommendations.

Technology Applications: The Summary presents a brief description of each element evaluated for the Tentpole-Related Issues, Issue Sources, Related Schedule Data, Todays Methods, Technology Requirements, Cost Trades, and Recommendations.

TIMELINE ANALYSIS SUMMARY (TIMELINE IMPROVEMENTS)

04/30/87

RELATED ISSUES	ISSUE SOURCE	SCHEDULE DATA	TODAY'S METHODS	TIMELINE IMPROVEMENTS	OPERATIONAL EVALUATION	RECOMMENDATIONS
SSME SSME PROCESSING--TENTPOLE 1 • OPERATIONAL STATUS OF THE SSME'S • ACCESSIBILITY OF THE SSME WHEN INST. IN THE ORBITER • SERIAL SCHEDULE TIME TIME DURING OPF PROCESSING • COST OF MANHOURS REQUIRED TO INSPECT MAINTAIN AND MODIFY SSME'S	SHUTTLE GROUND OPS EFFICIENCY STUDY, OPERATIONS ANALYSIS, 12/15/86 — ROCKETDYNE OPERATION SPC SUPPORT, SSME SHOP STUDY	160 HOUR TURNAROUND ALLOWED 24 HOURS FOR SSME MAINT. — 51-L FLOW USED 863.0 SCHEDULE HOURS-581.0 IN THE VEHICLE AND 312.0 IN THE SSME SHOP — 61-B USED 394.5 HOURS	MOST WORK ACCOMPLISHED WITH ENGINES INSTALLED ON THE VEHICLE — ACCESSIBILITY IS VERY POOR — LCC SUPPORT AND SEVERAL ORBITER SYSTEMS ARE REQUIRED TO SUPPORT ANY ACTIVITY ON THE SSMES — SPARE COMPONENTS ARE INADEQUATE FOR FAST CHANGE OUT — PRESENT SSME SHOP NOT DESIGNED TO ADEQUATELY SUPPORT ENGINE ACTIVITIES	AN IMPROVEMENT IN THE EXISTING ENGINE SHOP WOULD ALLOW MUCH OF THE ENGINE WORK TO BE DONE OFF THE VEHICLE. — THIS WOULD REQUIRE NO SUPPORT FROM OTHER SYSTEMS AND WOULD ELIMINATE SERIAL WORK IN THE AFT SECTION OF THE VEHICLE.	AN ENGINE SHOP WITH THE CAPABILITY TO PROVIDE FULL ACCESS AND TEST EQUIPMENT IS ESSENTIAL TO REDUCING VEHICLE FLOW TIME — FURTHER REDUCTIONS CAN BE MADE BY PROVIDING SPARE ENGINES THAT COULD BE MAINTAINED IN THE READY CONDITION FOR INSTALLATION IN A VEHICLE	1. APPROVE THE 16 ESR'S SUBMITTED BY ROCKETDYNE TO UPGRADE THE PRESENT ENGINE SHOP — 2. PROVIDE SPARE ENGINES TO SUPPORT ANY CHANGE OUT REQUIRED FOR ENGINE MAINTENANCE, REPAIR OR MODIFICATION — STATUS: CELL 5 UPGRADE APPROVED. BOD SCHEDULED FOR MID-OCT '87. REMAINING $8000 MODS PLANNED FOR FY '88 AND '89.
AFD & PLB RECONFIGURATION AFT FLIGHT DECK & PAYLOAD RECONFIG RECONFIG--TENTPOLE 2 • ON LINE TIME TO RECONFIGURE PAYLOAD BAY • MANHOUR COST TO SUPPORT RECONFIGURATION OPERATION • DESIGN CRITERIA THAT DICTATES AMOUNT OF WORK REQUIRED TO RECONFIGURE PAYLOAD BAY • DESIGN OF THE PAYLOAD BAY & AFT FLIGHT DECK THAT REQUIRES RECONFIGURATION & RETEST BETWEEN EACH FLIGHT	SHUTTLE GROUND OPS EFFICIENCY STUDY, OPERATIONS ANALYSIS, 12/15/86 — ASAP ANNUAL REPORT JAN, 1985 — AFSC/MSIA COST REDUCTION AND CREDIBILITY WORKSHOP 9/18/86 — AFSC/MSIA OPPORTUN- ITY LIST, 5/6/86 — KSC-GO-MFD, M. MILEY OCT. 1985	FOR CARGO INSTALLED AT THE PAD-32 HOURS WERE PLANNED TO REMOVE THE DOWN P/L IN THE OPF & 9 HRS. TO INSTALL & TEST AT THE PAD — 51-L REQUIRED 454.4 HOURS IN THE OPF & 273.5 HOURS AT THE PAD — 13.0 HOURS WERE PREDICTED TO PUT THE CARGO IN THE PCR AND IT TOOK 174.0 HOURS DURING 51-L	MUCH FLEXIBILITY IS PROVIDED FOR DIFFERENT CARGOS — PAYLOAD ATTACH FITTING CAN BE LOCATED EVERY 3.933 INCHES — ELECTRICAL INTERFACES ARE AVAILABLE TO SUPPORT THE DIFFERENT LOCATIONS — A VARIETY OF FLUID SERVICES ARE PROVIDED TO SUPPORT DIFFERENT CARGOS — MUCH TIME IS SPENT BETWEEN EACH FLIGHT TO RECONFIGURE THE PAYLOAD BAY FOR DIFFERENT CARGOS	MAJOR REDESIGN OF THE PAYLOAD BAY WOULD BE REQUIRED TO EFFECT THE CURRENT TIMELINES — PROVIDE SPARE GSE TO SUPPORT MORE THAN ONE OPERATION — DESIGN GSE SO THAT A GANG INSTALLATION COULD BE ACCOMPLISHED — CONTROL THE MANIFEST TO ELIMINATE THIS OPERATION. — DESIGN FUTURE VEHICLES SO THAT CARGO INTERFACES ARE STANDARDIZED ON ELIMINATED.	THIS COULD BECOME THE LONGEST TENTPOLE WHEN OTHER PROBLEMS ARE SOLVED ON THE ORBITER — ONLY A MAJOR REDESIGN OF THE PAYLOAD BAY COULD TOTALLY SOLVE THIS SITUATION — NEW GSE THAT WOULD SUPPORT GANG INSTALLATION & REMOVAL COULD CUT CURRENT TIMELINES — SPARE CARGO FITTINGS WOULD ALLOW SET UPS TO BE MADE PRIOR TO REQUIRED SCHEDULED USE	1. DESIGN NEW GSE TO PROVIDE THE CAPABILITY TO INSTALL ALL THE PAYLOAD ATTACH FITTINGS AT THE SAME TIME — 2. FOR FUTURE VEHICLES REQUIRE THE CARGO TO DESIGN TO STANDARD INTERFACES AND SERVICES AND BE CONTAINERIZED

TECHNICAL CREW VEHICLE SUMMARY (CONTINUED)   04/30/87

RELATED ISSUES	ISSUE SOURCE	SCHEDULE DATA	TODAY'S METHODS	TIMELINE IMPROVEMENTS	OPERATIONAL EVALUATION	RECOMMENDATIONS
CABIN AIR RECIRCULATION • CABIN AIR RECIRCULATION SYSTEM MAINTENANCE--TENTPOLE 3• • VERY POOR ACCESS TO DEBRIS SCREENS AND FILTERS • MAINTAINABILITY NOT INCLUDED IN DESIGN • CONTAMINATION CONTROL PROCEDURES IN CREW MODULE	SHUTTLE GROUND OPS EFFICIENCY STUDY, OPERATIONS ANALYSIS, 12/15/86 KSC-GO-NFO R. WILEY MAY, 1986 STS MAINTENANCE TECH STUDY, RI, 5/30/86	24 HOURS ARE THE TOTAL TIME ALLOTTED FOR MAINTENANCE IN 168 HOUR TURNAROUND IT REQUIRED 120 HRS JUST FOR THE AIR RECIRCULATION SYS. MAINTENANCE ON 51-L MOST OF THIS OPERATION IS DONE WITH THE POWER OFF THE VEHICLE MAKING IT A SERIAL OPERATION	DEBRIS SCREENS & FILTERS IN THE CABIN AIR RECIRCULATION SYSTEM ARE CLEANED AFTER EVERY FLIGHT ACCESS PANELS MUST BE REMOVED TO GAIN ACCESS POWER MUST BE REMOVED FROM THE VEHICLE PHOTO'S ARE TAKEN BEFORE AND AFTER CLEANING LINT & DEBRIS IS COLLECTED & SENT TO JSC FOR STUDY	REDESIGN THE INSTALLATION OF THE DEBRIS SCREENS AND FILTERS TO ALLOW ACCESS PROVIDE SPARE PARTS SO THEY CAN BE CHANGED WITH OUT BEING CLEANED IN SERIAL ON LINE TIME REDUCE THE AMOUNT OF LINT IN CREW CABIN BY CHANGING THE FABRIC OF THE ASTRONAUT'S SUITS	PROVIDING BETTER ACCESS TO THE DEBRIS SCREENS AND FILTERS AND PROVISIONING SPARES WOULD REDUCE THIS OPERATION TO A REASONABLE LEVEL THE PREFERRED SOLUTION WOULD BE TO REDUCE THE CONTAMINATION LEVEL IN THE CREW MODULE SO THIS OPERATION WOULD NOT BE REQUIRED FOR EVERY FLIGHT	1. REDESIGN THE INSTALLATION OF THE CABIN AIR RECIRCULATION SYSTEM TO PROVIDE ACCESS TO THE DEBRIS SCREENS AND FILTERS. INSTALL NEW MODULE DURING FIRST BLOCK PERIOD. 2. CHANGE THE MATERIAL OF THE ASTRONAUT'S SUITS TO A LINT FREE MATERIAL.
WEIGHT & CG • WEIGHT AND CENTER OF GRAVITY DETERMINATION--TENTPOLE 4• • SERIAL TIME TO DETERMINE WEIGHT AND C.G. OF ORBITER • MANPOWER REQUIRED TO SUPPORT THE OPERATION • GROUND SUPPORT EQUIPMENT DESIGN • INADEQUATE METHOD OF MAINTAINING A WEIGHT LOG THAT CAN BE VERIFIED BY ACTUAL WEIGHT DATA	SHUTTLE GROUND OPS EFFICIENCY STUDY, OPERATIONS ANALYSIS, 12/15/86	CLOSE OUT OF THE VEHICLE WAS TO TAKE 10 HOURS 51-L REQUIRED 359.5 HOURS, 8.8 OF WHICH WERE REQUIRED TO PERFORM THE WEIGHT AND BALANCE TASK	WEIGHT LOGS ARE MAINTAINED & ACTUAL WEIGHT DATA ARE COLLECTED TO VERIFY THE LOGS ACTUAL WEIGHTS & LOGS HAVE NOT AGREED PORTABLE SCALES ARE PLACED ON DPF JACK STANDS FOR WEIGHING JACKS ARE SENT TO THE WEST COAST FOR CALIBRATION	TIE THE WEIGHT LOG TO THE NEW SYSTEM THAT THE SPC IS DEVELOPING TO TRACK REQUIREMENT CLOSE OUT TO PROVIDE A MORE ACCURATE LOG REDESIGN THE DPF JACK STANDS TO INCLUDE LOAD CELLS PROVIDE TEST WEIGHTS TO ELIMINATE THE NEED TO SHIP THE SCALES FOR CALIBRATION	ELIMINATION OF THIS OPERATION IS THE DESIRED GOAL AND CAN BE ACCOMPLISHED AS SOON AS AN ACCURATE METHOD IS VERIFIED INCORPORATION OF THE LOAD CELLS IN THE JACK STANDS SHOULD BE CONSIDERED AS A STOP GAP MEASURE	1. INCLUDE WEIGHT DATA IN THE NEW COMPUTER CONTROLLED PAPER CLOSE OUT SYSTEM. 2. PROVIDE TEST WEIGHTS TO CALIBRATE THE EXISTING PORTABLE SCALES. 3. RECONSIDER PLACING LOAD CELLS IN THE WORK STANDS.
PLB CLEANING & CLOSEOUT • PAYLOAD BAY CLEANING AND CLOSEOUT--TENTPOLE 5• • PAYLOAD BAY MUST BE INSPECTED AND CLEANED PRIOR TO INSTALLING CARGO • PAYLOAD BAY IS CLOSED OUT DURING CLEANING • CLEANLINESS REQUIREMENTS OF SOME PAYLOADS ARE VERY TIGHT • MANY MANHOURS ARE SPENT ON CLEANING	SHUTTLE GROUND OPS EFFICIENCY STUDY, OPERATIONS ANALYSIS, 12/15/86 MSFC/MSIA COST REDUCTION AND CREDIBILITY WORKSHOP 9/18/86 NSTEC SPACE SHUTTLE SYSTEM ASSESSMENT BRIEFING OCT, 1984	NO TIME WAS ALLOTTED FOR CLEANING BECAUSE THERE WAS NO REQUIREMENT 27.5 HOURS WAS USED ON BOTH 61-B & 51-L IN THE DPF TO COMPLETE THIS OPERATION	PRIOR TO INSTALLING A PAYLOAD IN THE PAYLOAD BAY, THE BAY IS INSPECTED AND CLEANED TO ONE OF THREE STANDARDS. THEY ARE; 1. VC1 VISUAL 50 FT/CANDLES @ 5-10 FT DISTANCE 2. VC1A VISUAL 50 FT/CANDLES @ 2-4 FT DISTANCE 3. VC2 VISUAL 100-200 FT/CAND. @ 6-10 IN DISTANCE CLEANING AS REQUIRED TO OBTAIN THE REQUIRED LEVEL	PROVIDE ADEQUATE FACILITIES IF THE DPF TO DELIVER CLEAN ROOM CONDITIONS IN THE PAYLOAD BAY REDEFINE FUTURE CARGO TO REDUCE THEIR REQUIREMENTS	AS LONG AS CONTAMINATION CONTROL IS A REQUIREMENT THIS TIMELINE WILL REMAIN THE TIME CAN BE REDUCED IF BETTER CONTROLS ARE PROVIDED IN THE DPF	1. PROVIDE NEW FACILITIES IN THE DPF TO CONTROL THE CONTAMINATION IN THE PAYLOAD BAY AND ACCESS TO THE BAY FOR INSTALLING PAYLOADS IN THE HORIZONTAL. 2. FOR FUTURE VEHICLES REQUIRE THE CARGO DESIGNERS TO EITHER PROVIDE THEIR OWN CONTROL OR REDUCE THE LEVEL THAT THE VEHICLE MUST MAINTAIN

TECHNICAL ANALYSIS SUMMARY (TECHNOLOGY APPLICATIONS)   04/30/87

RELATED ISSUES	ISSUE SOURCE	SCHEDULE DATA	TODAY'S METHODS	TECHNOLOGY REQUIREMENTS	COST TRADES	RECOMMENDATIONS
ANOMALY RESOLUTION ANOMALY RESOLUTION -- TENTPOLE AN 24 OMI S ARE CURRENTLY REQUIRED TO TROUBLESHOOT PROBS & RETEST SYSTEMS DURING EACH TURNAROUND PROCESSING OF THE ORBITER IN THE OPF. SYSTEM DOWNTIME COULD BE DECREASED BY INCORPORATION OF BOTH ANOMALY DETECTION & FAULT DETECTION. HIGH LEVERAGE TECHNOLOGY AREAS FOR FUTURE: EXPERT SYSTEMS/ARTIFICIAL INTELLIGENCE FOR - FAULT DETECTION & ISOLATION; VEHICLE C/O & LAUNCH; AUTOMATED SOFTWARE GENERATION; AND FAULT TOLERANT AVIONICS. FOR 51-L, 45 OF 300 REQUIRED PARTS WERE CANNIBALIZED. SPARES REQUIRED.	SHUTTLE GROUND OPS EFFICIENCY STUDY, OPERATIONS ANALYSIS, 12/15/86 STS MAINTENANCE TECH STUDY, RI, 5/30/86 MSFC/MSIA COST RE-DUCTION & CREDI-BILITY WORKSHOP, 9/18/86 PRES.COMM.RPT.,1-16, VOL II, 5/27/86	DURING NOV-DEC 85 IN THE OPF, 51-L ANOM-ALY RESOLUTION IN-VOLVED 48-SHIFTS AND 966 TECHNICIAN M/H S PLUS APPROX 180 QA, ENGR, & SUPPORT M/H. APPROX. 24 OMI S WERE REQUIRED TO ACCOMPLISH THE TROUBLESHOOTING AND SYSTEM RECERTIFICA-TION.	BRUTE FORCE TROUBLESHOOTING; FORM ACCESS TO TEST POINTS; REMOVE, REPLACE, & RETEST NON-RELATED EQUIP BECAUSE OF LACK OF ACCESS; LIMITED CAPABILITY TO ANALYZE ANOMALIES THAT OCCUR IN FLIGHT FOR TURNAROUND PLNG; INADEQUATE LRU SPARES RESULTING IN EXTENSIVE CANNIBALIZATION WHICH AT A MINIMUM, DOUBLES THE RELATED MANHOURS REQUIRED; FOR 51-L, 45 OUT OF APPROX 300 REQUIRED PARTS WERE CANNIBALIZED.	TECHNIQUES OF EXPERT SYS, ARTIFICIAL INTELLIGENCE, SMART KIT, SMART BITE, REDUNDANCY, FLY-BY-WIRE, EMBEDDING, TRANSPARENCY, --WITH APPLICATION DEVELOPMENT REQUIRED IN AREAS OF: FAULT DETECTION FAULT ISOLATION FAULT RESOLUTION FAULT-TOLERANT COMPUTERS FAULT-TOLERANT SOFTWARE FAULT-TOL SYSTEM HARDWARE LRU REPLACEMENT WITHOUT SYSTEM SHUTDOWN SPARES SELECTION AND AVAILABILITY	BOTTOM LINE: BY DEVELOP-ING AND INCORPORATING ANOMALY RESOLUTION TECH-NIQUE IN DESIGN,LCC COST CAN BE CUT BY 5% OF STAE \$BILLION COST, WITH SOME POTENTIAL ON STS THROUGH BLOCK MODIFICATIONS. INDIRECT BENEFITS, WHILE NOT AS APPARENT AS DIRECT SAVINGS CAN PROVIDE EVEN GREATER BENEFITS, WITH STS ONE ADDITIONAL FLT/YR FROM IMPROVED TURNAROUND TIME COULD RESULT IN AN 8 1/2% GAIN IN USE OF A MULTI-\$BILLION NATIONAL RESOURCE. PROBABLY NOT COST	NASA SHOULD BECOME ACTIVE IN THE AF/INDUSTRY TEAMS WORKING ON EXPERT SYSTEMS AND AI FOR TESTABILITY. WITH STS ACTIVITY PLANNED ANOTHER 15 YRS, IMPROVED ANOMALY RESOLUTION SHOULD BE INCORPORATED IN THE EARLY 1990'S. SYSTEMS TO BE CONSIDERED SHOULD INCLUDE EPDC, PRSD, ECLSS, OPS, COMM, DMC, MPS, APU, AND HYD. COMBINE WITH MAND. SAFETY MODS. MAXIMIZE INCORPORATION OF ANOMALY TECHNIQUES IN THE PRELIMINARY DESIGN PHASE OF FUTURE PROGRAMS TO ACHIEVE FULL POTENTIAL OF 5% REDUCTION IN LIFE CYCLE COSTS. RECOGNIZE THE EXTREME COSTS AND TIME PENALTIES INVOKED BY SPARE SHORTAGES
					PROBABLY NOT COST-EFFECTIVE FOR CURRENT ORBITERS UNLESS COMBINED WITH MANDATORY SAFETY MODS.	
MCCS FUNCTIONAL CHECKS MCCS FUNCTIONAL CHECKS--TENTPOLE BE 1. ACCESSIBILITY OF THE UNITS FOR INSPECTION OR REMOVAL/REPLACEMENT. 2. REMOVAL OF SOME ASSEMBLIES REQUIRE DISASSEMBLY OF OTHER ORBITER COMPONENTS. 3. NEED TO HAVE SPARES AVAILABLE. 4. NEED A POSITIVE INDICATOR THAT CAN BE BELIEVED. 5. REQUIREMENTS ARE NOT IN LINE WITH FREQUENT FLIGHT PHILOSOPHY. 6. SUCCESS RATE OF COMPONENTS ARE NOT PERIODICALLY FACTORED INTO TEST RATE.	WE-PRO MOD LIST POST 51-L PRELIM. MOD LISTING	1. NO TIME WAS ALLOTTED IN THE ORIGINAL 160-HOUR TURNAROUND FOR THIS TASK. 2. THE STS-11 SCHED. ALLOTTED 92-HOURS 3. THE 51-L FLOW REQUIRED 152-HOURS TO COMPLETE 4. QUICK CHANGE MODULES WITHOUT SAMPLING COULD BE DONE IN 8 HOURS.	INSPECT AFTER EVERY FLIGHT, CHANGE OUT DESICCANT AFTER EVERY OTHER FLIGHT. TEST CHECK VALVE AFTER EVERY OTHER FLIGHT ALONG WITH A LEAK CHECK AND FLOW TEST.	A LONG LIFE DESICCANT WITH RELIABLE INDICATORS THAT WOULD REQUIRE LESS FREQUENT CHANGE-OUT. A DESICCANT THAT CAN BE RECHARGED IN PLACE.	BY REDESIGNING FOR ACCESSIBILITY WE CAN GAIN MODERATE SAVINGS, MAINLY IN MANHOURS. PROBABLY NOT COST EFFECTIVE FOR SHUTTLE.	1. THE DESICCANT ASSEMBLIES SHOULD BE RELOCATED TO BE READILY ACCESSIBLE 2. THE DESICCANT ASSEMBLIES SHOULD BE REDESIGNED TO BE "QUICK CHANGE". 3. TESTED SPARES AT THE ASSEMBLY LEVEL SHOULD BE PROVIDED.

TENTPOLE ANALYSIS SUMMARY (TECHNOLOGY APPLICATIONS)

04/30/87

RELATED ISSUES	ISSUE SOURCE	SCHEDULE DATA	TODAY'S METHODS	TECHNOLOGY REQUIREMENTS	COST TRADES	RECOMMENDATIONS
WINDOW POLISHING						
• WINDOW POLISHING -- TENTPOLE C. 1. THIS IS A SLOW LABOR INTENSIVE OPERATION. 2. WINDOWS NEED TO BE CLEAR FOR LANDING. CONTAMINATION OCCURS DURING SRB SEPARATION AND CLEANING (POLISHING) DOESN'T OCCUR UNTIL AFTER LANDING. CONSEQUENTLY POLISHING ONLY PREVENTS BUILD-UP FROM MORE THAN ONE FLIGHT.	• WE - PRC MOC LIST POST 51-L PRELIM. MOD LISTING	1. NO TIME WAS ALLOCATED FOR THIS TASK IN THE 160 HR SCHEDULE 2. 60 HOURS IS ALLOCATED ON THE STS-11 INTEGRATED OPERATIONS ASSESSMENT. 3. 144-HOURS WERE REQUIRED TO ACCOMPLISH THIS TASK DURING 51-L PROCESSING.	BUILD A TENT AROUND WINDOWS. INSTL TILE PROTECTIVE COVERS. WINDOWS ARE BRUSHED AND VACUUMED. WINDOWS ARE POLISHED WITH AN ALPHALAP PAD AND CERAMIC OXIDE/DEIONIZED WATER. WINDOWS ARE CLEANED WITH JOY SOAP/DEIONIZED WATER. PHOTOGRAPHS ARE TAKEN OF A RESOLUTION CHART THROUGH THE WINDOWS FROM THE NEAREST SEAT. PHOTOGRAPHS ARE INSPECTED TO VERIFY CLEANING IS SATISFACTORILY.	DEVELOP A NEW MATERIAL FOR THE WINDSHIELD WITH A SURFACE THAT CONTAMINATION WILL NOT ADHERE TO. DEVELOP AN OVERLAY THAT IS JETTISONED USING SHAPE-MEMORY RETAINER/SPRING.	SMALL COST OF COATING. NO ON-LINE TIME SAVINGS, SIGNIFICANT DIRECT LABOR SAVINGS.	BEST BET - CARBON COATING (DIAMOND LIKE) FOR ORBITER WINDSHIELDS. RECOMMEND CONTACTING BRUCE BANKS, ELECTROPHYSICS OFFICE CHIEF, LEWIS RESEARCH CENTER FOR FURTHER FOLLOW-UP.
TPS INSPECTION						
• TPS INSPECTION -- TENTPOLE D • INSPECTION METHODS ARE UNRELIABLE, UNREPEATABLE, INVASIVE AND TIME CONSUMING.	ROCKWELL LSS E/T STUDY OPS ANALYS JSC RESIDENT OFFICE	DPF-11 SCHEDULE FOR INSPECTION, TEST, AND REPLACEMENT IS 336 HRS. MANHOURS RANGE FROM 200 TO 3000. SIGNIFICANT PORTION IS INSPECTION AND TEST.	MOISTURE DETECTION IS QUALITATIVE. BOND STRENGTH REQUIRES PULL TESTING. DEPENDENDS HEAVILY ON VISUAL INSPECTION.	A RELIABLE TEST METHOD TO INSPECT THE TILE SYSTEM TO INCLUDE: CRACKS OR WATER IN THE TILE ADEQUATE BOND LINE AND CONDITION OF FILLER BAR INSPECTION METHOD SHOULD BE NON-INVASIVE, AUTOMATED, AND CAPABLE OF COMPUTER ANALYSIS.	SIGNIFICANT IMPLEMENTATION COST FOR R & D OF AUTOMATED SYSTEM MAJOR REDUCTION IN ON-LINE TIME AND OFF-LINE MANHOURS.	ACCELERATE E846 ACOUSTIC EXCITATION/LASER SENSING STUDY MAKE BONDED TILES AVAILABLE FOR LIMITED BACKSCATTER X-RAY TESTS.
FUEL CELL OPERATIONS (PRSD)						
• FUEL CELL OPERATIONS - TENTPOLE E• MAINTAINABILITY OF THE ORBITER FUEL CELL SYSTEM IS DIFFICULT AND REQUIRES EXCESSIVE TIME AND MANHOURS.	ROCKWELL LSS KSC HISTORICAL SCHED S6DE/T STUDY	51-L EXAMPLE: TANK SET 4 R&R - 120 HRS DPF OPS & 1/5 - 36 HRS 17 HRS PAD CLEAR & 17 HRS LOCAL CLEAR TIME.)	3794 PAGES OF OMI INSTRUCTIONS	DEVELOP NEW, HIGH POWER-DENSITY FUEL CELLS OR BATTERIES THAT REQUIRE SIGNIFICANTLY LESS ON-LINE MAINTENANCE THAN THE CURRENT FUEL CELL SYSTEM. REPLACE THE CURRENT FUEL CELLS.	REQUIRES DEVELOPMENT OF NEW LOW MAINTENANCE FUEL CELLS. SIGNIFICANT IMPROVEMENT IN ON-LINE AND OFF-LINE MANHOURS.	FOR EXISTING MISSION LENGTH FUEL CELLS ARE BEST OPTION. HIGH DENSITY STATE-OF-THE-ART FUEL CELLS COULD BE ADDED AS A BLOCK MOD TO IMPROVE THOSE NOW IN USE. FUTURE VEHICLES SHOULD INVESTIGATE AREAS OF: REGENERATIVE FUEL CELL SYSTEMS NI/H2 BATTERIES NA/S BATTERIES LI/SOCL2 BATTERIES THE NA/S BATTERY APPEARS TO BE THE BEST FOR MEETING LONG TERM FUTURE REQUIREMENTS, BUT WILL REQUIRE FURTHER INVESTIGATION.

TENTPOLE ANALYSIS SUMMARY (TECHNOLOGY APPLICATIONS) 04/30/87

RELATED ISSUES	ISSUE SOURCE	SCHEDULE DATA	TODAY'S METHODS	TECHNOLOGY REQUIREMENTS	COST TRADES	RECOMMENDATIONS
ORDNANCE--TENTPOLE F* 1. ORDNANCE DEVICES DO NOT LEND THEMSELVES TO QUICK TURNAROUND OPERATIONS.	NATIONAL SPACE TRANSPORTATION STRATEGY	1. THE 160-HOUR SCHEDULE HAS 8 HOURS FOR ORDNANCE INSTL. AT THE OPF	OMI V5812 INSTALLS SOME ORDNANCE IN ORBITER AT OPF. OMI B5304 INSTALLS ORDNANCE IN SRB AT VAB.	REPLACE ORDNANCE WITH NON-EXPLOSIVE DEVICES.	MODERATE REDESIGN AND MATERIAL COSTS COMPARED WITH SIGNIFICANT LABOR SAVINGS AND REDUCED TURNAROUND TIME.	A SIGNIFICANT REDUCTION CAN BE MADE IN SHUTTLE AND FUTURE VEHICLE TURNAROUND TIME WITH ELIMINATION OF ORDNANCE DEVICES.
2. WORKING WITH ORDNANCE REQUIRES PRECLUDING OTHER WORK BEING PERFORMED.		2. CURRENTLY 112 HRS OF PROCESSING TIME IS SPENT IN ORDNANCE OPERATIONS: OPF 8 HRS ET CELL 24 HRS VAB 44 HRS PAD 36 HRS (120 HR OF PAD CLR)	OMI T5142 INSTALLS ORDNANCE IN ET AT VAB.		VERY SIGNIFICANT ON-LINE REDUCTION;	NITINOL TECHNOLOGY HAS POTENTIAL TO ACCOMPLISH AT LEAST PART OF THIS FOR NON-IGNITION ORDNANCE.
3. PERSONNEL WHO HANDLE ORDNANCE MUST HAVE SPECIAL TRAINING AND CERTIFICATION.			OMI S5099 INSTALLS REMAINING ORDNANCE AT PAD.		WOULD SPEED UP ENTIRE SHUTTLE PROCESSING FLOW;	RECOMMEND DEVELOPMENT OF STATEMENT-OF-WORK FOR MSMC TO PROVIDE NITINOL DESIGN PARAMETERS APPROPRIATE TO DESIGN OF SUCH DEVICES.
4. ORDNANCE DEVICES REQUIRE SPECIAL HANDLING THROUGHOUT THE LOGISTICS SYSTEM.		44 HRS IS SERIAL PROCESSING TIME.			SIGNIFICANT SAVINGS.	USING MSMC NITINOL PARAMETERS AND BASIC SHUTTLE DESIGN REQUIREMENTS, PREPARE RFP FOR SUBSTITUTE ORDNANCE DEVICES - BUT NOT LIMITED TO NITINOL TECHNOLOGY.
PAPERWORK & REQUIREMENTS (OLCE) MANAGEMENT DISCIPLINE	PRES. COMM. REPORT 51-L FINDINGS AND PAPERWORK COMMITTEE REPORTS		NO INTEGRATED DATA SYSTEM	INTEGRATED DATA SYSTEM INCLUDING ALL PHASES OF THE PROJECT: DEF, DESIGN, MANUFACTURING, OPERATIONS	SHUTTLE PROCESSING FLOW	FUTURE: MANDATE USE OF UNIFIED LIFE CYCLE ENGINEERING(OLCE) AND DESIGN/BUILD TEAM MANAGEMENT CONCEPTS
OMSD COMPLIANCE					SIGNIFICANT SAVINGS IN OPERATIONAL LIFE CYCLE COSTS	SHUTTLE: IMPLEMENT IMIS CONCEPTS (INTEGRATED MAINTENANCE INFORMATION SYSTEM)
QA CLOSEOUT						
STANDARDS						
TRAINING CERTIFICATION						
CHANGE CONTROL						
SUPPORTABILITY/MAINTAINABILITY						
ACCESSIBILITY						

-34-

1.4.1 SSME PROCESSING (Tentpole 1)

1.4.1.1 Summary

At the completion of the sixth flight of the shuttle the program was declared to be operational. This would be all systems of the orbiter including the Space Shuttle Main Engines (SSME). Based on the continuing technical issues and the resulting modifications on the SSME's, the engines are still not fully operational. To perform all of the required inspections, repairs, and modifications with the engines installed in the orbiter causes many operational problems.

Due to the limited space in the aft section of the orbiter, the amount of work that can be accomplished at one time is very restricted so any work on the engines precludes any other work to be worked in parallel. Also work on the engines requires the support of almost all of the orbiter systems which means that work on these systems cannot be done at the same time. With the limited access to the engines operations require more time to complete.

To alleviate this situation, the present engine shop should be up graded to provide space, equipment, and facilities to support total engine maintenance and modification capability. Rocketdyne has submitted a plan to accomplish this which would approximately 1.2 million dollars.

Much time could be saved if ready spare engines were provided so that all maintenance and mod work could be completed off line. Engines would be ready for installation as soon as a mission is completed. Then only serial flow time would be required in the OPF for engine R&R and interface retest.

1.4.1.2 Related Issues

1. <u>Operational status of the SSME's</u>. SSME's were designed to be used for 10 flights before they would require any maintenance. So far no engine has been used for more than one flight without some work being performed. Modifications are also being incorporated to correct technical problems. The engines will not be fully operational until the maintenance is reduced and modifications completed.

2. <u>Accessibility of the SSME when installed in the orbiter</u>. The aft section of the orbiter is a plumber's nightmare. So much equipment is installed in a small volume that access is a problem for working on any equipment. This also means that only limited systems can be worked in parallel. Damage to electrical connectors is a result of the close quarters and people entering and leaving the area.

---

3. <u>Serial schedule time during OPF processing</u>. Any engine operation performed while installed on the vehicle requires support of many of the Orbiter systems. This means most engine work requires serial schedule time to complete. Systems that are needed to support engine operations include: EPD&C, GN&C, PV&D, HYD, OPS and INS. (Electrical Power Distribution and Control, Guidance Navigation and Control, Purge Vent and Drain, Hydraulics, Operations, Instrumentation).

4. <u>Cost of manhours required to inspect, maintain, and modify SSME's</u>. During processing of 51-L in the OPF, 47 shifts <u>of</u> work were used to service on the SSME's. This required 3792 technician manhours plus support of other systems, engineers, QC and other support groups.

Following are some examples taken from the Issues database:

```
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
ID: < 506.00>           Issue(s): LOGISTICS/SPARES   :
Issue(s) cont.:                   :                  :
Issue Source: <ASAP        >    JAN. '85 ANNUAL REPORT, P.37
Description:
CONCERN EXPRESSED FOR LACK OF SPARES
"NASA SHOULD CONTINUE TO GIVE HIGH PRIORITY TO ACQUISITION OF SPARE PARTS ANS
TO UPGRADE THE RELIABILITY (PLANNED LIFE) OF HARDWARE, ESPECIALLY ITEMS
ASSOCIATED WITH SPACE SHUTTLE MAIN ENGINE."


::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

ID: <3106.00>           Issue(s): LOGISTICS/SPARES   :
Issue(s) cont.:                   :                  :
Issue Source: <SSME GSE REVIEW >    7/66 TEAM A4 PRES TO STS GSE REV BD
Description:
HARDWARE REVIEW SUMMARY
: NO NEW CRITICAL SINGLE POINT FAILURES WERE FOUND
: STRUCTURAL ITEMS RELY ON PROOF LOAD VERIFICATION FOR HAZARD ELIMINATION
     - OMI'S NEED UPDATE
: PNEUMATIC SYSTEM GSE DEPENDS ON INTERFACE FILTER AND RELIEF VALVE/GAUGE
  CALIBRATION TO CONTROL CONTAMINATION/OVERPRESSURIZATION
       - OMI'S NEED UPDATE
       - NEW FILTER REQUIRED FOR C70--908 FLOWMETER USE
: FLIGHT HARDWARE DAMAGE IS LIKELY DUE TO INADEQUATE ACCESS DURING
  LRU OPERATIONS
     - A70--663 ENGINE SERVICE PLATFORM
     - A70-0885 OPF SWING PLATFORMS
: SSME NOZZLE THERMAL PROTECTION INSULATION (TPS) IS DAMAGED BY H70-0568
  HORIZONTAL INSTALLER
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
```

1.4.1 SSME PROCESSING (Tentpole 1)
(Continued)

1.4.1.3 Schedule History

Design goal for SSME's allowed 24.0 hours for propulsion system scheduled maintenance (reference the 160 hour turnaround level II schedule). During the 51-L precessing a total of 893.0 schedule hours were expended. This included 581.0 hours with the engines installed on the vehicle and 312.0 hours accomplished in the engine shop (See Figure 1 for OPF work performed.) The shortest processing flow to date was the 61-B flow and 394.5 hours were expended on engine work, all of which was done with the engines installed on the orbiter.
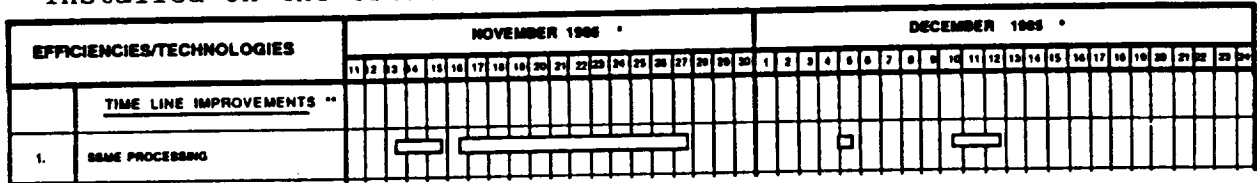
EFFICIENCIES/TECHNOLOGIES		NOVEMBER 1986 *	DECEMBER 1986 *
	TIME LINE IMPROVEMENTS **		
1.	SSME PROCESSING		

* All timebars indicate 3 shift/day operations
** Does not require new technology - but goes beyond the bandaid fix

SCHEDULE
Figure 1

1.4.1.4 Current STS Methods

All engine inspections, most repairs and modifications are accomplished with the engines installed on the orbiter. To gain access to the engines the base heat shields must be removed. Thompson rails are installed to remove and replace the high pressure turbopumps and support must be provided by several orbiter systems to position, power-up and test the engines. This is very costly in both time and manpower and prevents other activities being accomplished on the supporting systems while engine operations are being performed. Engines are removed for major repairs and modifications. Some of this work is performed in the current engine shop but configuration of the shop prevents many tasks. Problems include: 1. Engine stands not designed for total access to the engine 2. Shop is not a clean area 3. Lighting is not adequate 4. Space is limited 5. No office space is available 6. Access to area is not easily controlled.

The following is a list of procedures currently being used:

<u>V1001</u> -- SSME ELECTRICAL INTERFACE VERIFICATION

> <u>OBJECTIVE</u>: Provide standard instructions to test all Engine Interface Unit (EIU) and SSME controller copper paths after engine installation, after electrical LRU replacement and after engine hot firing.

1.4.1 SSME PROCESSING (Tentpole 1)
(Continued)

V1011 -- SSME DRYING AND FUNCTIONAL

OBJECTIVE: .01 - Perform post flight drying of High Pressure Fuel Turbo Pump (HPFTP) and Main Combustion Chamber (MCC) using heated GN_2.

.02 - Perform internal/external inspection of major SSME components post flight.

.03 - Verify operational integrity of internal working parts of all turbopumps required after each flight.

.04 - Verify operational integrity of hex fluid systems.

.05 - Verify operational integrity of SSME HGM, LOX and LH_2 fluid systems. Interface leak checks post installation.

.06 - Perform pneumatic checkout and leak checks and routine module checkouts of the SSME's.

.07 - Verify operational integrity of all SSME/orbiter fluid and electrical interfaces following 10 engine starts.

V0043 -- SSME HEAT SHIELD REMOVAL

OBJECTIVE: Provide instructions for installation and/or removal of SSME-mounted and orbiter-mounted heat shield segments.

V5E02 -- SSME LRU (Line Replacable Unit) COMPONENT REMOVAL/INSTALLATION HIGH PRESSURE OXIDIZER TURBOPUMP

OBJECTIVE: To provide procedures to remove SSME high pressure oxidizer turbopump (LRU) in the OPF (hor.) and VAB, PAD (vert.). SSME engine shop.

NOTE: (Under the new method this would be performed in the engine shop.)

V5E06 -- SSME LRU COMPONENT REMOVAL/INSTALLATION HIGH PRESSURE FUEL TURBOPUMP

OBJECTIVE: To provide procedures to remove or to install space shuttle high pressure fuel turbo pump (LRU).

NOTE: (Under the new method this would be performed in the engine shop.)

1.4.1 SSME PROCESSING (Tentpole 1)
(Continued)

1.4.1.5 Timeline Improvements

Rocketdyne has made a survey of the present engine shop and the adjacent space in cell 6 in the VAB and has made a proposal to modify and enlarge the present shop so that all but complete engine overhauls can be done off the vehicle at KSC (see attached sketches). They have submitted 16 Engineering Support Requests (ESR's) to accomplish the modifications. Lockheed has estimated the job to cost $1,213,092.

Estimated saving in the process time to change a High Pressure Turbopump is approximately two days of overall time and four days of serial time in the vehicle processing. This is based on the following:

1. The as-run data shows the average time required to change a high pressure turbopump, while the engine is installed in the vehicle, is six days

2. To remove and replace an SSME requires two days maximum

3. Pump removal and replacement in the shop with adequate accessibility could be accomplished in 7-8 shifts

1.4.1.6 Operational Evaluation

The processing of the SSME's is rapidly becoming one of the long tentpoles in vehicle flow. In the current environment this will only get worse. Operation time on the vehicle is affected by SSME processing and will be increasing due to additional requirements. Flow time in the OPF will grow drastically. To avoid this, and to improve later flows, improved capability of the engine shop appears to be a must.

Savings will be 4 serial days in the orbiter processing flow for a pump change and a cost savings of 2 days of shop time due to improved in accessibility.

_____

1.4.1.7   Conclusions and Recommendations

CONCLUSIONS

Timeline improvements and cost savings can be immediately
realized in this area with modification to the engine shop.
Money spent to accomplish the mods will be repaid from savings in
the serial processing time reduction of each vehicle, and the
overall simplification in maintaining the SSME's.

RECOMMENDATIONS

1. Approve the 16 ESR's that have been submitted by Rocketdyne
   and accomplish the work in time to support processing of the
   second flow of each vehicle through the OPF after program
   restart.   Status: Cell 5 improvements have been approved at
   $400K with a BOD of October 1987. $400K for FY-88 and $400K
   for FY-89 are in the approval cycle.

2. Provide enough spare SSME's to support engine changeouts as
   required for flight problems and modifications.

1.4.2 AFD/PLB RECONFIGURATION (Tentpole 2)

Aft Flight Deck & Payload Bay Reconfiguration

1.4.2.1 Summary

To satisfy the Cargo Community and to attract more space business for the Space Shuttle Program, as much flexibility as possible has been designed into the payload bay/cargo interfaces. This flexibility has caused the time required to reconfigure the payload bay from one mission to the next flight, to become one of the longest tentpoles in the Orbiter Processing Facility (OPF) flow. A total of 37 shifts were required during the OPF processing of 51-L to reconfigure and test the Aft Flight Deck (AFD) and Payload Bay (PLB), plus 8 shifts to prepare for installation of the cargo.

The original concept was to locate all cargo in a limited number of positions in the payload. The center of gravity of the vehicle would be adjusted without weights being added or subtracted in the aft section. Due to growth of the vehicle weight and its effect on the available weight for cargo, this method was discarded and provisions were made to locate cargo to allow for center of gravity (CG) adjustment. This also required that provisions be made so electrical interfaces could be located to support different locations of cargo.

The only feasible approach for the present orbiters would be to provide a strongback that could be used to remove or install all of the payload bay bridges and cargo fittings simultaneously. With two strongbacks and an extra set of bridges available, the configuration of the next mission could be established and ready prior to the landing of the previous mission. This could reduce time for this operation by 50 to 60%. Any other change would require a complete redesign of the payload bay and very costly, time consuming modifications.

A much more standard approach to the installation of cargo is needed if the time is going to be reduced in reconfiguring the payload from one mission to the next.

1.4.2.2 Related Issues

1. Time required on the vehicle to reconfigure the payload bay

2. Cost in manhours to support the reconfiguration operation

3. Design criteria that dictate the amount of work required to reconfigure the payload

4. Final design of the payload bay and aft flight deck that requires reconfiguration and retest between every flight

Below are excerpts from the Preliminary Issue Data Base of papers that have been prepared giving examples of findings from other groups to support the recommendations for standardization and simplification of cargo-to-vehicle interfaces.

::

ID: (500.00)   Issue(s): COMMONALITY   : INTERFACE
Issue(s) cont.:   :   :
Issue Source: (ASAP   )   JAN. '85 ANNUAL REPORT, P.38
Description:
REPORT RECOMMENDS THAT WHEREVER POSSIBLE THERE SHOULD BE AN INCREASING
EFFORT TO PREPARE AND CARRY PAYLOADS IN A STANDARDIZED FASHION.

::

ID: (714.00)   Issue(s): COST/MANHOURS   :
Issue(s) cont.:   :   :
Issue Source: (NSTS   )   DRAFT DATED 5/86, TABLE G-1
Description:
"   LOGISTIC SYSTEM   : OPERATIONAL CONCEPTS :   SYSTEM
         COST DRIVER   :   :   REQUIREMENTS

PAYLOAD ACCOMMODATIONS * MINIMIZE PAYLOAD   * P/L TO BE AUTONOMOUS
 - MISSION UNIQUE MODS   UNIQUE FEATURES   FROM LAUNCH VEHICLE
 - IN-LINE FUNCTION   * P/L TESTING OFF-LINE
   VERIFICATION   PRIOR TO LAUNCH VEHICLE
 - ON-BOARD SERVICES   INTEGRATION
 "

::

ID: (1725.00)   Issue(s): ISOLATION   : INTERFACE
Issue(s) cont.:SECURITY   : STANDARDS   :
Issue Source: (AFSC/NSIA   )   (P.074)COST RED & CRED WORKSHOP 9/18/86
Description:
"TO REDUCE PAYLOAD TO VEHICLE INTERFACES TO THE ABSOLUTE MINIMUM, PAYLOADS WILL
PROBABLY BE ENCAPSULATED IN SOME KIND OF MODULE AT AN OFFLINE FACILITY. THE
MODULE WILL THEN BE INSTALLED ON THE LAUNCH VEHICLE. DEPENDING ON VEHICLE CON-
FIGURATION, THE MODULE SHELL MAY FUNCTION AS THE PAYLOAD FAIRING AS ON CURRENT
EXPENDABLE VEHICLES. ON VEHICLES WITH INTEGRAL PAYLOAD BAYS, THE MODULE MIGHT
PERFORM A THERMAL SHIELDING FUNCTION AND SERVE AS CLEANLINESS PROTECTION, LIKE
THE CURRENT PAM HEAT SHIELDS, AS WELL AS ENSURE SECURITY. PROVISIONS FOR MOUNT-
ING THE MODULE TO THE VEHICLE MUST BE STANDARDIZED ASSUMING ONLY POWER AND AIR
CONDITIONING ARE PROVIDED AS BASIC STANDARD SERVICES. THIS IS TO AVOID THE
CURRENT PROBLEMS OF RECONFIGURING THE PAYLOAD/VEHICLE INTERFACES. PAYLOAD
CONTROL AND DATA LINES MUST BE INDEPENDENT OF LAUNCH VEHICLE INTERFACES OTHER
THAN A SIMPLE ANTENNA CONNECTION, IF REQUIRED. SECURITY WILL BE ENHANCED BY
SUCH A SYSTEM BECAUSE ALL ENCAPSULATED PAYLOADS HAVE SIMILAR APPEARANCE AND
HANDLING.

::

1.4.2 AFD/PLB RECONFIGURATION (Tentpole 2)
(Continued)

::

ID: ⟨1729.00⟩   Issue(s): INTERFACE   : COST/MANHOURS
Issue(s) cont.: STANDARDS   : MODULARIZATION   :
Issue Source: ⟨AFSC/NSIA   ⟩   (P.075)COST & CRED WORKSHOP 9/18/86
Description:
POTENTIAL AREAS OF PAYLOAD PROCESSING COST REDUCTIONS:
ACTION: PROVIDE ELECTRICAL & FLUID INTERFACE PLATES.
COMMENT: MINIMIZE THE NUMBER OF INTERFACE CONNECTORS TO BE HANDLED: : LESS
        CHANCE OF DAMAGE   : REDUCTION IN PROCESSING COSTS.

ACTION: STANDARDIZE SPACECRAFT HARDWARE.   :INCORPORATE STANDARD INTER-
        FACE FORMATTING INTO UPPER STAGE OR LAUNCH VEHICLE.   : MODULARIZE FOR
        GROWTH AND REDUCING COST.   : REDUCES INTEGRATION COSTS.

::

ID: ⟨1731.00⟩   Issue(s): DESIGN CRITERIA   : MODULARIZATION
Issue(s) cont.: INTERFACE   : STANDARDS   : COST/MANHOURS
Issue Source: ⟨AFSC/NSIA   ⟩   (P.077)COST & CRED WORKSHOP 9/18/86
Description:
        ---PAYLOAD COMMUNITY RECOMMENDATIONS---
: DEVELOPMENT OF DESIGN STANDARDS   : DESIGN FOR MAXIMUM AUTONOMY
: PAYLOAD ENCAPSULATION   : SIMPLER INTERFACES
: PROVISION OF ON ORBIT SERVICING   : GREATER PERFORMANCE MARGINS
  AND REPAIR
: USE OF FEWER "UNIQUE" COMPONENTS   : DESIGN PERFORMANCE MARGINS
: APPLICATION OF NEW AND INNOVATIVE   ALL LAUNCH VEHICLES CONTAINED IN AN
  DESIGN AND MANUFACTURING CONCEPTS   ARCHITECTURE.
  AND TECHNOLOGIES.
::
ID: ⟨1739.00⟩   Issue(s): PLANNING   : INTEGRATION
Issue(s) cont.: INTERFACE   : STANDARDS   : DESIGN CRITERIA
Issue Source: ⟨AFSC/NSIA   ⟩   (P.121)COST RED & CRED WORKSHOP 9/18/86
Description:
        ------STS PAYLOAD INTEGRATION/INTERFACE------

: ESTABLISH COMMON ORBITER/PAYLOAD INTERFACES
    + STANDARDIZE ELECTRICAL AND ATTACH POINT FITTINGS/DEVICES
    + POWER AND CONTROL WIRING ON STARBOARD AND PORT SIDES OF THE CARGO BAY
    + ATTEMPT TO MINIMIZE OR ELIMINATE ACTIVE HEATING REJECTION REQUIREMENTS
      WHILE IN THE PAYLOAD BAY
    + DESIGN PAYLOADS TO FUNCTION IN NORMAL ORBITER ENVIRONMENT (AVOIDS
      SPECIAL ATTITUDE AND THERMAL CONSTRAINTS)
: AUTONOMOUS STS PAYLOADS
    + STANDARDIZE TT&C PACKAGES ON ALL SPACECRAFT WITH ACTIVE DOWNLINK
    + ORBITER/PAYLOAD COMMUNICATION EQUIPMENT SHOULD BE SEGREGATED
    + SEPARATE COMPUTER FOR PAYLOAD INTERFACE
    + SELF-CONTAINED POWER AND COOLING CAPABILITY FOR PAYLOADS
: CARGO INTEGRATION
    + INCREASED USE OF TELECONS(SECURE & NON-SECURE) FOR LA MEETINGS
    + ONE LAUNCH SUPPORT INTEGRATION CONTRACTOR
    + EARLY JSC/PAYLOAD CONTACT

::

```
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
```

ID: ⟨1788.00⟩   Issue(s): INTERFACE   : STANDARDS
Issue(s) cont.: MISSION   : REQUIREMENTS   :
Issue Source: ⟨AFSC/NSIA   ⟩   (P.308)COST RED & CREW WORKSHOP 9/18/86
Description:
:::OPERATIONS & SUPPORT FOR NEXT GENERATION STS:::   (SAWAYA/FEASTER/ET AL)
    ----KENNEDY SPACE CENTER GUIDANCE---- (PAYLOAD ACCOMMODATION)

: ACCOMMODATIONS FOR PAYLOADS/CARGOS SHALL BE DESIGNED FOR EASE OF INSTALLA-
  TION, REMOVAL, AND INTERFACE VERIFICATION.
: SIMPLIFY, MINIMIZE, AND STANDARDIZE INTERFACE REQUIREMENTS BETWEEN PAYLOADS
  /CARGOS AND LAUNCH VEHICLES.
: SIMPLIFY MISSION-TO-MISSION CARGO BAY RECONFIGURATION REQUIREMENTS.
```
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
```
ID: ⟨1790.00⟩   Issue(s): DESIGN CRITERIA   : MISSION
Issue(s) cont.: STANDARDS   : INTERFACE   : TRAINING/CERTIF
Issue Source: ⟨AFSC/NSIA   ⟩   (P.309)COST RED & CREW WORKSHOP 9/18/86
Description:
:::OPERATIONS & SUPPORT FOR NEXT GENERATION STS:::   (SAWAYA/FEASTER/ET AL)
          -----JOHNSON SPACE CENTER GUIDANCE----
: SPACECRAFT DESIGNER SHALL BE PROVIDED STANDARD HARDWARE INTERFACE DEFINI-
  TION AND STD OPERATIONS PROCEDURES EARLY IN THE SPACECRAFT DESIGN CYCLE.
: OPERATIONS ORBITS SHALL BE STANDARD--INCLINATION AND ATTITUDE.
: FLIGHT PHASES SHALL BE STANDARD: ASCENT/PROXIMITY OPERATIONS/DEPLOYMENT/
  SPACECRAFT HANDLING-RMS/SPACECRAFT SEPARATION/THERMAL PROFILES/RENDEZVOUS/
  ENTRY.
: SPACECRAFT DEPLOYMENT SYSTEMS AND PROCEDURES SHALL BE STANDARD.
: THE PAYLOAD MISSION REQUIREMENTS DOCUMENTATION PROCESS SHALL BE STANDARD.
: PAYLOAD HARDWARE & OPS INTERFACE DESIGN REQUIREMENTS SHALL BE STANDARD-POWER,
  COOLING, COMMAND, DATA, INTEGRATION HARDWARE, RMS, DOCKING MECHANISMS, CREW
  INTERFACES.
: SPACECRAFT SERVICING FUNCTIONS, INTERFACES, & PROCEDURES SHALL BE STANDARD.
: FLIGHT CONTROL CENTER FLIGHT RECONFIGURATION:
    + DATA REQUIREMENTS SHALL BE MINIMUM AND STANDARD. + GENERATION & VERIFI-
      CATION PROCESS SHALL BE STANDARD.
: FLIGHT AND GROUND CREW TRAINING AND SIMULATION:
    + BASED UPON STD FLIGHT PROFILES/PHASES. + SIMULATION DATA SHALL BE MINI-
      MUM & STANDARD. + BASED UPON STD SPACECRAFT INTERFACES & OPS PROCEDURES.
: NECESSARY CARGO MIX FLEXIBILITY SHALL BE INDUCED BY STD P/L INTERFACES, OPS
    PROCEDURES, AND STANDARD ACCOMMODATION ALLOCATION.
```
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
```
ID: ⟨4111.00⟩   Issue(s): DESIGN CRITERIA   : INTERFACE
Issue(s) cont.: STANDARDS   :   :
Issue Source: ⟨KSC GO-MPO   ⟩   NOX WILEY -- OCT '85
Description:
----------------GROUND TESTING AND CHECKOUT PHILOSOPHIES--------------------
: DESIGN FOR NO DESERVICING DURING TURNAROUND.
: ACCOMMODATIONS FOR PAYLOADS/CARGOS SHALL BE DESIGNED FOR EASE OF
  REMOVAL, AND INTERFACE VERIFICATION.
: SIMPLIFY, MINIMIZE, AND STANDARDIZE INTERFACE REQUIREMENTS BETWEEN PAYLOADS/
  CARGOS AND LAUNCH VEHICLES.
: SIMPLIFY MISSION TO MISSION CARGO BAY RECONFIGURATION REQUIREMENTS.
      + PROVIDE VARIOUS ATTACHMENT LOCATIONS. + PROVIDE MULTIPLE INTERFACE
      + FLY SCAR WT IN PANELS/CABLES/FLUID   PANELS/CONNECTION LOCATIONS.
        CONNECTIONS & ATTACH FITTINGS TO REDUCE TURNAROUND RECONFIGURATION REQ.
```
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
```

1.4.2.3 Schedule History

For a mission that would require cargo to be installed in the orbiter while at the PAD, the Level II 160 hour turnaround design goal allowed a total of 32 hours to remove the down cargo and remove and install the mission unique payload accommodation equipment during OPF operations. Nine hours were alloted at the PAD to install and perform a launch readiness verification test. Actual schedule hours used to support the 51-L flow was 454.4 hours in the OPF and 273.5 hours at the PAD. Payload installation into the PCR was predicted to take 13.0 hours and the actual time used for 51-L was 174.0 hours. See Figure 1.

* All timebars indicate 3 shift/day operations
** Does not require new technology - but goes beyond the bandaid fix

SCHEDULE
Figure 1

1.4.2.4 Current STS Methods

Nondeployable payloads are retained by passive retention devices, whereas, deployable payloads are secured by motor driven, active retention devices.

Payloads are secured in the orbiter payload bay by means of the payload retention system or are equipped with their own unique retention systems.

The orbiter payload retention system provides three-axis support for up to five payloads per flight. After the initial orbiter development flights, the payload bay was modified to accommodate attach fittings for five payloads.

The payload retention mechanisms secure the payloads during all mission phases and provide for installation and removal of the payloads when the orbiter is either horizontal or vertical.

Attachment points in the payload bay are in 9.9-centimeter (3.933-inch) increments along the left- and right-side longerons and along the bottom centerline of the bay. Of the potential 172 attach points on the longerons, 45 are unavailable because of the proximity of spacecraft hardware. The remaining 127 may be used for carrier/payload attachment; of these, 111 may be used for deployable payloads. Along the centerline keel, 104 attach points are available, any of which may be used for payloads.

There are 13 longeron bridges per side and 12 keel bridges available per flight. Only the bridges required for a particular flight are flown. The bridges are not interchangeable because of main frame spacing, varying load capability, and subframe attachments.

The longeron bridge fittings are attached to the payload bay frame at the longeron level and at the side of the bay. Keel bridge fittings are attached to the payload bay frame at the bottom of the payload bay.

The payload bay trunnions are the interfacing portion of the payload with the orbiter retention system. The trunnions that interface with the longeron are 8.2 centimeters (3.25 inches) in diameter and 17.78 or 22.22 centimeters (7 or 8.75 inches) long, depending upon where they are positioned along the payload bay. The keel trunnions are 7.62 centimeters (3 inches) in diameter and vary in length from 10.16 to 29.21 centimeters (4 to 11.5 inches), depending upon where they fit in the payload bay.

The orbiter/payload attachments are the trunnion/bearing/journal type. The longeron and keel attach fitting have a split, self-aligning bearing for nonrelease-type payloads in which the hinged half is bolted closed. For on-orbit deployment and retrieval payloads, the hinged half fitting releases or secures the payload latches that are driven by dual redundant electrical motors.

Payload guides and scuff plates are used to assist in deploying and berthing payloads in the payload bay. The payload is constrained in the X direction by guides and in the Y direction by scuff plates. The guides are mounted to the inboard side of the payload latches and interface with the payload trunnions and scuff plates. The scuff plates are attached to the payload trunnions and interface with the payload guides.

The guides are V shaped with the forward part of the V being 5.08 centimeters (2 inches) taller than the aft part. This difference enables the operator monitoring the berthing or deployment operations through the aft bulkhead TV cameras to better determine when the payload trunnion has entered the guide. The top of the forward portion of the guide is 60.96 centimeters (24 inches) above the centerline of the payload trunnion when it is all the way down in the guide. The top of the guide has a 22.86-centimeter (9-inch) opening. These guides are mounted to the 20.32-centimeter (8-inch) guides that are a part of the longeron payload retention latches.

The payload scuff plates are mounted to the payload trunnions or the payload structure. There are normally three or four longeron latches and a keel latch for on-orbit deployment and retrieval of payloads. These latches are controlled by dual redundant electric motors with either or both motors releasing or latching the mechanism. The operating time of the latch is four seconds with both motors operating or eight seconds with one motor operating.

The latch/release switches on the aft flight deck display and control panel station control the latches. Each longeron latch has two microswitches sensing the ready-to-latch condition. Only one is required·to control the ready-to-latch talkback indicator on the aft flight deck display and control panel station. Each longeron latch also has two microswitches to indicate latch and two to indicate release. Only one of each is required to control the latch or release talkback indicator on the aft flight deck display and control panel station.

The keel latch also has two microswitches that sense when the keel latch is closed withe the trunnion in it. Only one of the switches is required to operate the talkback indicator on the aft flight deck display and control panel station. The keel latch also has two microswitches that verify if the latch is closed or open, with only one required to control the talkback indicator on the aft flight station display and control panel station.

It is noted that the keel latch centers the payload in the payload bay; therefore the keel latch must be closed before the longeron latch is closed. The keel latch can float plus or minus 6.9 centimeters (plus or minus 2.75 inches) in the X direction.

This flexibility requires that the electrical interfaces also have the option of location in the vicinity of the mechanical attach fittings. This is done by providing a Standard Mission Cable Harness (SMCH) that plugs into one of two interface panels on either side of the orbiter, then routed to appropriate bay where a Standard Interface Panel (SIP) is installed. This SIP provides pass-through connectors and the cargo interface cable is connected to the other side. In some cases the cargo requires a special panel which must be installed. The Inertial Upper Stage (IUS) is a cargo that requires a special panel. This operation is time consuming and requires a great deal of manpower because all the panels must be removed and reinstalled; the SMCH tie-wraps must be cut loose, repositioned and retied; and retested.

Depending on the power requirements of the cargo, the fourth Power Reactant Storage and Distribution (PRSD) tank set is installed or removed from the payload bay. If the cargo requires a lot of power, then more reactant propellants are needed for the mission and tank set 4 is installed. To save weight on missions not requiring as much power to the cargo, the tank set is removed. This is both time consuming and labor intensive.

The requirements for fluid services to a cargo can also change from one cargo to the next. Again providing this service to the cargo community greatly effects the processing time and cost of preparing the vehicle for launch.

_____

1.4.2.5   Timeline Improvements

A major redesign of the payload bay would be required to change
the present orbiters to a system that would accept only standard
cargos. The only minor improvements that could be made to reduce
the processing time would be to:

1.   Provide spare payload accommodation equipment so that all
       required parts could be adjusted and kitted prior to the
       landing of the previous mission.

2.   Design and build ground support equipment that would allow
       all bridges and fittings to be installed at the same time.

3.   Control the frequency of reconfiguration by assigning
       similar cargos to successive flights of the same orbiter.

To enhance the ground operations of future programs,
standardization of the cargo must be one of the design criteria.
Requirements imposed on cargo should include the following:

1)   All cargo interfaces, both electrical and mechanical, should
       be standardized,

2)   Power supplied from the vehicle and instrumentation through
       the vehicle should be kept to a minimum,

3)   Containerized cargo would provide the following advantages:
                 A.   contamination control
                 B.   better security
                 C.   reduce ground transportation problems
                 D.   fixed and standard interfaces.

1.4.2.6   Operational Evaluation

If all the present problems with the orbiter are solved (or even
reduced), the payload bay reconfiguration and cargo installation
would become the long tentpole. A very costly redesign and
modification of the payload bay would be required to completely
solve this problem.   Providing the strongback and the spare
bridges and fittings should reduce the time required for payload
bay reconfiguration by 50 to 60%. Improvements should be made in
the initial design of the next generation of Space Transportation
Vehicles so that it will accept standard cargo with a minimum of
interfaces and services required.   This could reduce the
processing time and cost of preparing a vehicle for launch.

1.4.2.7   Conclusions and Recommendations

Based on the extent of redesign and modification required to change the present orbiters .to accept standard cargo, and the cost to change cargos now designed and built, it is not feasible to change any flight hardware. Future cargos could be restricted in their requirements to improve ground operations.

STS

The area of highest payback potential would be to provide ground support equipment that could reconfigure all payload fittings at the same time. This would still be labor intensive, but could be a big saving to the processing time for each flow.

FUTURE VEHICLES

Make the design criteria for standardized cargo interfaces a primary requirement for the next generation of vehicles. Extra cost during the design and build phases of the vehicle would have favorable paybacks for the duration of the operational phase of the program.

1.4.3 CABIN AIR RECIRCULATION SYSTEM MAINTENANCE (Tentpole 3)

1.4.3.1 Summary

Accessibility of the filters in the crew module cabin air recirculation system is very poor. Little thought was given in the design phase to the operation and maintainability of the system. After every flight the debris screens and filters are removed, pictures taken and samples collected from the avionics bays, cabin fan/avionics bays and Internal Measurement Unit (IMU) screen. In each case, equipment must be removed to access the screens and filters. Since the fans must be off during this operation, power must be removed from the vehicle and no troubleshooting can be accomplished on any other Orbiter system. After all the hardware is reinstalled, all electronic boxes that were removed must be retested.

Present operation is to power the vehicle to support safing and deservicing activities then power down as soon as possible to clean the screens and filters. If processing of the vehicle requires more than two months to finish, then this operation must be repeated. Approximately 80% of the lint collected to date has been blue lint; the same shade as the blue astronauts suits.

A redesign of the system could provide accessibility to the screens and filters and reduce the time required for this operation. Also if better control of contamination in the crew cabin was maintained the requirement for this operation could be reduced.

1.4.3.2 Related Issues

1. Very poor accessibility to debris screens and filters. It would appear that no thought was given to accessibility in the initial design of the crew cabin.

2. Maintainability was not considered during the initial design.

3. On line schedule time serial to other operations. Other systems must be shut down because power must be removed any time cooling is off in the cabin. This makes this operation serial to almost all orbiter electrical testing.

4. Contamination control procedures in crew module. Contamination control was not a factor in the original design of the crew module which has resulted in quicker build up of lint and dust on the filters.

5. Retest of removed and replaced parts. Retest of the electrical boxes that have to be removed to gain access to the screens and filters adds time to the overall schedule.

1.4.3 CABIN AIR RECIRCULATION SYSTEM (Tentpole 3)
(Continued)

1.4.3.3 Schedule History

A total of 24 hours were allotted in the 160- hour turnaround for all scheduled maintenance on the orbiter. During the 51-L flow, V6018, Cabin Air Recirculation Inspection and Maintenance, required 120 hours to complete. See Figure 1. Of this time 24 hrs. were performed with power off the vehicle and the remainder of the time with power on. The preferred method to perform this operation is to conduct all of the operations with the power removed. If time is not available for this the procedure may be accomplished by working around other activities in the crew module. This method is very hard to track and presents the shop many problems in maintaining records and supporting with manpower at the proper time.

EFFICIENCIES/TECHNOLOGIES		NOVEMBER 1985 *
		11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
	TIME LINE IMPROVEMENTS **	
1	CABIN AIR RECIRC. MAINTENANCE	

* All timebars indicate 3 shift/day operations
** Does not require new technology - but goes beyond the bandaid fix
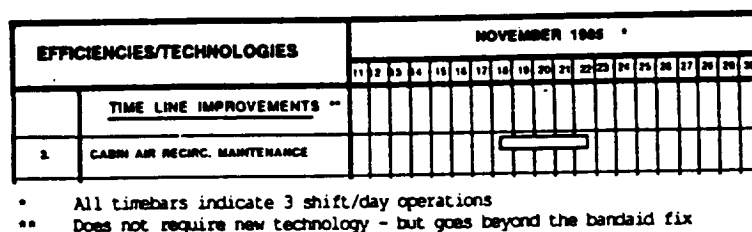
51-L OPF PROCESSING
Figure 1

1.4.3.4 Today's Methods

<u>V6018</u>   -- CABIN AIR RECIRCULATION INSPECTION AND MAINTENANCE

<u>OBJECTIVE</u>: To perform routine maintenance on the cabin fan, IMU and avionics bay 1, 2, 3 debris screens. In addition, the condensing heat exchanger will be inspected for corrosion and biological growth. Water samples will also be obtained from the condensing heat exchanger and analyzed for biological growth. Air cooled avionics will be inspected for cleanliness and vacuum cleaned as required.

<u>OPERATIONS</u>: To gain access to the debris screens and filters, close out panels must be removed. In some cases electronic boxes must also be removed. After the access is available, photos are taken of the screens and filters. If any lint or debris is present it is collected, labeled and sent to Johnson Space Center (JSC). The area is vacuumed, close out photos are taken and the panels are reinstalled.

1.4.3.4 Today's Methods (Continued)

This operation is repeated for the following equipment:

1. Avionics Bay 1,2,&3 inspection and cleaning

2. Cabin Fan/Avionics Bay 1,2,&3 debris screen inspection and cleaning

3. IMU screen inspection and cleaning

4. Condensing Heat Exchanger inspection

5. Flight Deck Air Cooled Avionics inspection and cleaning

1.4.3.5 Timeline Improvements

Two improvements can be made that would reduce the amount of time that is required to support this operation. The first would be to redesign the air recirculation system so that the screens and filters are accessible without removing panels and equipment boxes. If spare screens and filters were made available, the operation on the vehicle could be limited to a simple change out of the screens and filters. The photo's (if still required) and cleaning could be accomplished off line in the shop.

The second improvement would be to change the fabric of the astronaut's suits to a lint-free material or require that they change into cleanroom garments before entering the crew cabin.

1.4.3.6 Operational Evaluation

With improved accessibility to the screens and filters and the availability of spare hardware, the time required to complete this operation should be reduced to approximately 4 hours from 36 hours.

Requirements could also be reduced so the system would not have to be inspected after every flight. This would be acceptable if lint could be diminished so the build-up on the screens and filters would not restrict the air flow cooling the electronic equipment. This operation could be performed on every fifth flight or less.

1.4.3.7 Conclusions and Recommendations

CONCLUSIONS

There are two factors that affect the requirement and length of operation. First is the amount of lint and dust that collects in the crew module to clog the screens and filters. The majority of this contamination (approximately 80%) is being generated by the fabric used to make the astronaut's jump suits. Secondly, design of the system adds time to the operation by installing the debris screens and filters behind other equipment that makes accessibility very poor.

RECOMMENDATIONS

Redesign the air recirculation system to provide better access to debris screens and filters. The modification would have to be installed during a block mod period on each orbiter.

Change the material of the astronaut's suits so they are lint free.

1.4.4 WEIGHT AND CENTER OF GRAVITY DETERMINATION (Tentpole 4)

1.4.4.1 Summary

A weight log is maintained for every orbiter to account for all changes to the vehicle during processing in the Orbiter Processing Facility (OPF). Just prior to rollout to the Vehicle Assembly Building (VAB), it is weighed to verify accuracy of the log; requiring 4 to 8 hours of serial time. The actual weighings will be discontinued when the data compares favorably with the log book totals. To date these have not compared, so weighings have continued.

Weighing is presently done in the OPF using portable scales. With the limited clearance between the OPF work stands and the orbiter, many observers are required any time the orbiter is moved. This causes the weighing operation to be costly and adds serial time to the processing flow.

A better method must be developed in maintaining the weight log so this operation can be eliminated. If the weight log is tied to the new paper control system, the computer could maintain the log more accurately. Until this is accomplished, load cells could be designed into the OPF jack stands so a separate operation would not be required.

1.4.4.2 Related Issues

1. Serial time to accomplish task. Four to eight hours are required to complete this task and it is serial to rollout of the Orbiter from the OPF.

2. Manpower required to support the operation. Sixteen technicians are required as observers for the jacking and leveling operation.

3. Ground support equipment design (not including load cells in OPF jack stands). If load cells were incorporated in the OPF jack stands, the weight could be obtained any time the orbiter was in the proper attitude.

4. Inadequate method of maintaining a weight log. Current methods to maintain the weight log do not have adequate controls to track all equipment and hardware removed and installed on the vehicle.

1.4.4 WEIGHT & CENTER OF GRAVITY DETERMINATION (Tentpole 4) (Continued)

1.4.4.3 Related Schedule History

The Level II design goal for the close out and preps to transfer the orbiter allowed 10 hours to accomplish all work. 51-L required a total of 359.5 schedule hours of which 8.0 hours of serial time were used for the jacking and weighing operation. See Figure 1.

EFFICIENCIES/TECHNOLOGIES		DECEMBER 1985 *
		1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
	TIME LINE IMPROVEMENTS **	
4.	WEIGHT & CG	

* All timebars indicate 3 shift/day operations
** Does not require new technology - but goes beyond the bandaid fix

51-L OPF PROCESSING
Figure 1

1.4.4.4 Current STS Method

V5101 -- Orbiter weight and center of gravity determination using platform scales and OPF platform lifting system

OBJECTIVE: This Operations and Maintenance Instruction (OMI) will configure and perform a three point orbiter weighing utilizing model A70-0544 electronic portable platform aircraft weighing system. The orbiter will have been previously supported on the fwd and aft body jacks with orbiter facility fluid and electric lines disconnected.

OPERATIONS: As soon as the orbiter is closed out and ready to be rolled over to the VAB, it is transferred from the OPF jacks to the aft jack set. The portable scales are then placed on the OPF jacks and the vehicle raised to the weighing position. Since the orbiter is still in the confines of the OPF work stands, 16 observers must be used every time the vehicle is raised or lowered.

A weight log is maintained, but there are so many modifications and equipment changes to the vehicles that it is impossible with the current paper system to track the weight accurately.

At the present time there is no way at KSC to calibrate the portable scales. The normal way to test them has been to ship them back to the west coast. This has normally resulted in some kind of damage to the scales in transit and has been a real problem. A request has been submitted to provide a 20,000 pound weight set used to calibrate the scales but has not been made available yet.

1.4.4   WEIGHT & CENTER OF GRAVITY DETERMINATION (Tentpole 4)
        (Continued)

_____

1.4.4.5   Timeline Improvements

This operation could be completely eliminated once a method for
maintaining the weight log is proven. Since there is an effort
under way to track and close out requirements by bar codes and
computers, the weight data could be added to the system and have
the computer maintain the log.

Until the computer log system can be verified there are two
things that could be done to reduce the cost and time to support
this operation. The first would be to provide the test weight so
that the scales could be maintained locally. Secondly if there
is a chance the computer aided log will not be available soon,
load cells could be designed into the OPF jacks. This would
reduce the time required during this serial operation.

1.4.4.6   Operational Evaluation

Elimination of the weighing operation completely is the preferred
answer to this tentpole. It has been the experience of both the
missile and aircraft industries that as the program matures that
weight logs are adequate for any data required for mission
planning. This method would by far have the highest payback over
the remainder of the program.

Both of the other proposals would only be recommended as stop gap
measures until the computer log is total operational. Providing
the test weight would be less costly than installing load cells
in the jack stands, but would still save the overall program time
and money.

1.4.4.7   Conclusions and Recommendations

Insure that provisions are made to include the weight data in the
new computer-controlled paper close out system now being
implemented for Operational Maintenance Requirements ' and
Specifications Document (ORMSD) requirements satisfaction. To
fill in the gap until the computer log system is verified, the
test weight should be provided.

1.4.5 PAYLOAD BAY CLEANING AND CLOSEOUT (Tentpole 5)

1.4.5.1 Summary

Design criteria for the Space Shuttle was to make the operations as much like an airline as possible. This called for no special cleanliness requirements. All facilities were to be "Good Shop Practice" only. The first thing that happened when the first orbiter arrived at KSC was to build a crude tent around the crew ingress hatch to prevent dirt from entering the crew module.

Over the life of the Shuttle Program the requirements for contamination control have become more demanding. The cargo community has imposed some very tight requirements on the payload bay. Design of the Orbiter Processing Facility (OPF) did not provide for any contamination control. Some movable curtains have been installed on the work platforms and control is maintained on people allowed into the area.

With the current requirements and facilities, several shifts (3-1/2 during 51-L processing) are required to clean and inspect the payload bay prior to cargo installation in the vehicle.

If the operational timeline is to be trimmed, one of three things must be done. The first is to modify the OPF to the standards of a clean room. Another approach would be to require cargo to be designed to accept the current conditions; or the cargo could be containerized, providing its own controlled environment.

1.4.5.2 Related Issues

1. Prior to installing cargo the payload bay must inspected and cleaned. Cleaning is performed on every mission and is requiring an average of 3-1/2 shifts per flight.

2. Payload bay is closed out during cleaning. Since people and activities generate contamination, all activities must be complete and all personnel except the inspectors must be out of the payload bay.

3. Requirements of some payloads are very demanding on contamination control. After a blackbox failed on the second Tracking and Data Relay Satellite (TDRS) while at the Pad a decision was made to to return the Spacecraft to the Vertical Processing Facility (VPF) so it could be cleaned while the box was being replaced. One DOD spacecraft would like to have a cover installed on it while in the Payload Changeout Room (PCR) and Payload Bay (with doors open) to protect it from contamination.

4. Many manhours are spent on cleaning. 144 technician hours are required to support the cleaning operation.

1.4.5 PAYLOAD BAY CLEANING (Tentpole 5)
(Continued)

Below are some examples extracted from the Issues database:

```
:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
ID: (1730.00)          Issue(s): MAINTAINABILITY   : ACCESSABILITY
Issue(s) cont.: MODULARIZATION    : REQUIREMENTS   :
Issue Source: (ASPC/NSIA    )   (P.075)COST RED & CREW WORKSHOP 9/18/86
Description:
POTENTIAL AREAS OF PAYLOAD PROCESSING COST REDUCTIONS:
ACTION: DESIGN FOR MAINTAINABILITY.
COMMENT: : PLACE CRITICAL OR LOW MEAN-TIME-BETWEEN-FAILURES COMPONENTS IN
          ACCESSIBLE AREAS - DO NOT REQUIRE "MAJOR SURGERY" TO REMOVE AND
          REPLACE A COMPONENT.    :BUILD IN MODULAR FASHION.

ACTION: ESTABLISH CLEANLINESS REQUIREMENTS.
COMMENT: ENCAPSULATE OR USE BAGS AND LOCAL PURGES WHENEVER POSSIBLE TO
REDUCE DEMANDS ON FACILITIES.

:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
ID: (1847.00)          Issue(s): DESIGN       .    :
Issue(s) cont.:                  :              :
Issue Source: (NE-PRO MOD LIST )   (POST 51-L PRELIM. MOD LISTING)
Description:
DESIGN ENGINEERING -- JIM PHILLIPS

STUDY/ESR/MOD

"PCR CEILING - PAD A:  NEED TO REPLACE THE PERFORATED PANELS WITH SOLID
ONES AND RTV IN PLACE, TO KEEP DEBRIS FROM ABOVE THE CEILING FALLING ONTO
THE PAYLOADS.  (30/6)"



:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
ID: (2140.00)          Issue(s): DESIGN        :
Issue(s) cont.:                  :              :
Issue Source: (NE-PRO MOD LIST )   (POST 51-L PRELIM. MOD LISTING)
Description:
PCR  --  ROWLAN NORRIS

STUDY/ESR/MOD

"IMPROVE CONTAMINATION PREVENTION OF PAYLOAD CHANGEOUT ROOM, E.Q., SIDE 1 DOORS
H2O PROOFING (RAIN ENTRY).   (1/7)


ID: (2445.00)          Issue(s): MAINTAINABILITY   :
Issue(s) cont.:                  :              :
Issue Source: (DE RTN FLT MODS )   16-JUN-86
Description:
CATEGORY 3 (DESIRABLE)
"PCR PGHM WHITE PAINT PADS A & B : THE EXISTING EPOXY PAINT CHIPS AND
CONTAMINATES THE PCR AND PAYLOADS.  (29/13)"

:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
```

1.4.5.3 Related Schedule History

Since there was no requirement for contamination control in the original design criteria, no.time was allotted in the 160 hours turnaround for this activity. For the 51-L OPF processing 27.5 hours were spent in cleaning and inspecting the payload bay. See Figure 1. During this time other operations in the payload bay were restricted. The same amount of time was used on the 61-B flow for cleaning and the cargo was two PAM's, which are the simplest cargo.

EFFICIENCIES/TECHNOLOGIES		DECEMBER 1985 •																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	TIME LINE IMPROVEMENTS **																▭								
L	PAYLOAD BAY CLEANING & CLOSEOUT									▭															

* All timebars indicate 3 shift/day operations •
** Does not require new technology - but goes beyond the bandaid fix

51-L OPF PROCESSING
Figure 1

1.4.5.4 Current STS Methods and Timeline Improvements

CURRENT STS METHODS

<u>V1176</u> -- PAYLOAD BAY CLOSEOUT CLEANING (STANDARD, SENSITIVE/ HIGHLY SENSITIVE) - OPF

OBJECTIVE:
A. To clean accessible Payload Bay (PLB) surfaces to one of three cleanliness level options as required to support turnaround and mission requirements.

B. To qualitatively assess the types and levels of various contaminants with the intent of improving contamination controls.

OPERATIONS: Design of the OPF was based on good clean shop practice. No provisions were made for a class 100,000 clean facility. The only environmental control is a standard air conditioning system. After more requirements were imposed by the cargo community, a curtain was added around the upper platform and control is maintained on the personnel allowed into the area. Before cargo is installed in the Orbiter, or the payload bay is closed out prior to transfer to the VAB, an inspection and cleaning is performed. The entire midbody is inspected for one of the following specifications:

Visual Clean 1 - (VC1) (standard)- Absence of all particulate and non-particulate visible to the normal unaided eye at a minimum light level of 50 ft. candles at a distance of 5-10 ft.

1.4.5 PAYLOAD BAY CLEANING (Tentpole 5)
(Continued)

<u>Visual Clean 1A (VC1A) (sensitive)</u>- Absence of all particulate and non-particulate visual to the normal unaided eye at a minimum light level of 50 ft. candles at a distance of 2-4 ft.

<u>Visual Clean 2 (VC2) (highly sensitive)</u>- Absence of all particulate and non-particulate vissable to the normal unaided eye at a minimum light level of 100 to 200 ft. candles at a distance of 6-18 in.

After the cargo bay doors are closed, the contamination is controlled by the orbiter purge air, which is maintained as class 5000, and the payload changeout room, which is maintained as class 100,000.

TIMELINE IMPROVEMENTS

If the proper facilities are provided, the time to perform the inspection and cleaning could be reduced by 90 to 95 per cent. A change in the cargo requirements to accept the original criteria of good shop practice could eliminate this timeline completely.

1.4.5.5 Operational Evaluation

Contamination control has always had a big effect on the operational timelines in processing spacecraft and launch vehicles. The initial requirement to eliminate this was an attempt to reduce the processing time between flights. When the requirements of the cargo community were accepted and no provisions were made to the facilities to maintain control of contamination, it added an extra amount of time to the flow.

Only a modification to the facility or a change of requirements can result in a reduction of time to maintain the proper cleanliness level of the payload bay.

1.4.5.6 Conclusions and Recommendations

STS

To support the present shuttle configuration and the cargos that have been designed and manufactured, the only practical solution would be to design a modification to the OPF. This design would have to provide the required contamination control plus access to the payload bay for installation of horizontal payloads in the OPF.

FUTURE VEHICLES

Future requirements for new cargo should include a provision that the cargo must be containerized to maintain the level of contamination control required by the cargo.

1.4.6 ANOMALY RESOLUTION (Tentpole A)

1.4.6.1 Summary

In the context of this study, Anomaly Resolution is considered to be the entire range of actions beginning with fault detection and including fault isolation, spares available for replacement, retest and reverification.

In today's STS ground processing environment, there is an unreasonable amount of time involved in troubleshooting anomalies, repairs, cannibalization, and system recertification. The reasons for this are based on Program decisions made during the early Orbiter design phases: (1) The state-of-the-art used fifteen years ago; (2) design compromises from the 160-hr turnaround design criteria because of funding, cost, weight, schedule, etc. (3) ignorance of operational requirements; and (4) disregard of the impact of operations manhours and on-line time on life cycle costs.

Traditionally, anomaly resolution for complex launch vehicle checkout has been a complicated, labor-intensive, time-consuming, costly task requiring extensive effort from large numbers of highly-trained system support technicians.

With on-line time costing in the neighborhood of $30K/hr during ground operations, it is imperative that the available technology be exploited to produce cohesive tools and results. This has not been done and the result is reflected in ground operations where the technician is furnished a myriad of tools and documentation, which are confusing and often contradictory. The end result of this is lengthy repair times and a significant waste of manpower and dollars.

Since the initial Orbiter design, the development curve of built-in-test(BIT) and built-in-test-equipment(BITE) has been almost vertical. It is necessary that these concepts and available hardware be incorporated in future vehicle design requirements -- otherwise, just the ground operations portion of the life cycle costs will drive us out of the Space business. The advisability of incorporating extensive mods of this type for the current shuttle is questionable from the standpoint of cost effectiveness and require specific and detailed cost trades. Weapon system development in DOD has provided the funding for this fast technology advance and NASA must take advantage of its availability. Our technology search readily revealed over 100 very pertinent papers and reports. Typical of these is the "Proceedings of the Joint Services Workshop: Artificial Intelligence in Maintenance" which includes 513 pages of relevant papers. Study recommendations for this topic of Anomaly Resolution draws heavily on these rich sources of documentation and describes the basic technology available.

1.4.6 ANOMALY RESOLUTION (Tentpole A)
(Continued)

During the analysis of available documentation, it became readily apparent that the technology required for a quantum jump in Anomaly Resolution (fault detection; fault isolation; fault resolution; fault-tolerant computers; fault-tolerant software; data-fault tolerance; fault-tolerant system hardware; replacement without shutdown; and spares selection) is here today with applications development proceeding at a remarkable pace. However, caution must be observed in assuming that the application of "Artificial Intelligence" is a panacea for the immediate future. Much of the applicable AI technology is still in development and not yet available for incorporation into systems; this is especially true of specific applications work.

This rapid advancement is being driven by the requirement to reduce life cycle costs -- resulting in R & D maintainability funding by the Air Force, Navy, Army, and Commercial companies for equipment and aircraft such as the F-16 and the Boeing 767 and 7J7. This technology is readily available so that NASA and its contractors do not have to reinvent the wheel, but can readily build on the in-progress development funded by DOD and the commercial airplane companies.

A complete discussion of anomaly resolution includes the topics of spares, cannibalization, and adequate line replaceable unit (LRU) repair facilities.

1.4.6.2 Related Issues

The STS problems and inefficiences in the process of fault detection, fault isolation, and fault resolution (all of which are combined here under the title of ANOMALY RESOLUTION) have been repeatedly documented by our Issue source documentation in:

* 51-L Findings

* Presidential Commission Report on 51-L

* Rockwell Maintenance Technology Study

* Air Force Operational & Test Evaluation Center Reports

* AFSC/NSIA Space Transportation Panel (Cost Reduction & Cost Credibility Workshop)

The specific ANOMALY RESOLUTION issues related to STS are documented in Volume 4 of this report under the categories of:

* Fault Detection   * Automation

* Design   * Techology

* Design Criteria,   * Cannibalization

* Expert System

The following related issue descriptions from the study database are typical:

1. "Approximately 24 OMI's (Operations & Maintenance Instructions) are currently required to troubleshoot problems and retest systems during each turnaround processing of the Orbiter in the OPF."

2. "System downtime could be decreased by incorporation of both anomaly detection and fault isolation."

3. "Provide increased built-in-testing for automatic fault detection/isolation."

4. "Provide the capability for ground systems to perform diagnostic monitoring and checkout of on-board systems."

5. "High leverage technology areas for Operations & Logistics include expert systems/artificial intelligence in the areas of fault detection & isolation, vehicle checkout & launch; automated software generation; and fault tolerant avionics.

6. "High leverage technology areas applicable to future architectures for Launch Operations: Expert systems & artificial intelligence for use in subsystem fault detection & isolation, vehicle checkout & launch. Avionics system improvements such as on-board fault detection, isolation, and diagnosis.

7. "The logistics support for Challenger in the 51-L ground processing was inadequate, since it created a need to remove parts from other orbiters to continue operations. For 51-L, 45 out of approximately 300 required parts were cannibalized. These parts ranged from bolts to an OMS TVC actuator and a fuel cell. The significance to operations of cannibalization is that it creates: (1) significantly increased efforts to accomplish the same work due to multiple installation and retest requirements, (2) schedule disruption due to added work and normally later part availability, and (3) orbiter damage potential due to increased physical activity in the vehicles. These efforts make cannibalization operationally unacceptable.

8. "Spare parts are in critically short supply. The Shuttle program made a conscious decision to postpone spare parts procurements in favor of budget items of perceived higher priority. Lack of spare parts would likely have limited flight operations in 1986."

Additional detail of related ANOMALY RESOLUTION issues can be obtained from VOLUME 4 of this report: ID numbers 1194, 1703, 1722, 1743, 1358, 1748, 1752, 1753, 1755, 1773, 1774, 112, 119, 158, 200, 412, 602, 608, 620, 626, 1000, 1707, 2734, and 4102.

1.4.6 ANOMALY RESOLUTION (Tentpole A)
(Continued)

1.4.6.3 Schedule History

The troubleshooting and system recertification as-run schedule for 51-L is shown here as Figure 1 because it is typical, most recent, and best documented. It shows that 51-L processing during November and December of 1985, anomaly resolution involved some 48 shifts and 964 technician manhours plus engineering, QA, and support manhours. There were approximately 24 OMI's required to accomplish the troubleshooting and system recertification.

EFFICIENCIES/TECHNOLOGIES		NOVEMBER 1985 · *	DECEMBER 1985 · *
	TECHNOLOGY		
A	TROUBLE SHOOTING & SYSTEM RECERT (ANOMALY RESOLUTION)		

* All timebars indicate 3 shift/day operations

51-L OPF PROCESSING
Figure 1

1.4.6.4 Current STS Methods

The inefficiency of todays methods of anomaly resolution in the Orbiter turnaround processing is, of course, a direct result of the Orbiter design not meeting the 160-hr design criteria. Because of cost, weight, and schedule compromises and the low priority of operational requirements and life cycle cost, during the design phase of STS, even the self-test and fault tolerant technology available in the early seventies was not utilized in the design. Consequently, the 50-hrs serial time allocated in the 160-hr schedule has grown to typically 384-hrs. Whereas the original design concept relied heavily on self-test, the actual design makes it necessary to brute force the troubleshooting with poor access to test points and a requirement to remove and replace equipment with the result that extensive retests are required.

A typical example of extensive retests, as a result of inaccessibility, is in the design of the air recirculation filters and debris screens. After each flight, these screens and filters must be removed and cleaned. To gain access to these, several electronic modules must be removed, then reinstalled and retested. This is not only a time consuming operation, but also requires power be removed from the orbiter with the result that access to the crew module is restricted during this time period.

1.4.6 ANOMALY RESOLUTION (Tentpole A)
(Continued)

There is very limited capability to analyze anomalies that occur in flight so that fault isolation procedures can be scheduled and completed within the time frame of the next turnaround.

Of course, no anomaly resolution can take place efficiently without adequate LRU spares, replacement parts, and local KSC maintenance and repair shops. Lack of these has led to extensive cannibalization, multiple remove and replace activity, and the resulting multiple retests required. During the STS-33 flow, for example, there were extensive cannibalization actions to and from Challenger (099). Examples are listed below:

 (1) Engine mounted heat shields and attaching hardware (to 102)
 (2) Fuel Cell #1 (from 103)
 (3) Plunger on flipper door (to 102)
 (4) R/H wing duct (from 104)
 (5) Engine mounted heat shields & attaching hardware (from 104)
 (6) Thermal barrier (from 103)
 (7) NLG tires (from 103)
 (8) WSB liquid sensor (from 103)
 (9) ET/Orb purge system line (from 104)
(10) PDI (from 103)
(11) WCS (from 104)
(12) ME #2 SSMEC (to 102)
(13) 12 MPS temp transducers (from 102)
(14) Spare MDM (from 102)
(15) Champ experiment camera (from 102)
(16) Gas sample bottle pyro plugs (from 102)
(17) EVA hatch cover (from 104)

1.4.6.5 Technology Application Requirements

It was an unfortunate compromise that the original STS design had to forego the available self-check and fault-tolerant capability available in the early 1970's. Since that time, the progress curve in these technical areas has been almost vertical because of DOD requirements and funding.

Even today, the full cost of Operations is not recognized by the NASA Design organizations; particularly, the fact that <u>Design typically represents only 3 to 10 percent of the Life Cycle Costs</u> and that it is in the Design Phase that Operational considerations can provide order-of-magnitude payoffs.

The competitive international environment and the need for a dependable, airline type schedule to meet immediate and forthcoming NASA and DOD launch requirements make it mandatory to provide fully automated anomaly resolution during the Design Phase of future vehicles and to provide where cost effective, through block changes, advanced capability for STS in the 1990's. The Technology to accomplish this exists today with the techniques of EXPERT SYSTEMS, ARTIFICIAL INTELLIGENCE, SMART BIT, BITE, REDUNDANCY, FLY-BY-WIRE, EMBEDDING, TRANSPARENCY, -- only application development is required in the areas of: * FAULT DETECTION * FAULT ISOLATION * FAULT RESOLUTION * FAULT-TOLERANT COMPUTERS * FAULT-TOLERANT SOFTWARE * FAULT-TOLERANT SYSTEM HARDWARE * LRU REPLACEMENT WITHOUT SYSTEM SHUTDOWN (WHERE LRU REDUNDANCY EXISTS) * SPARES SELECTION & AVAILABILITY

_____

FAULT   DETECTION: A process which discovers or is   designed   to
discover   the   existence   of   faults;   the   act   of   discovering
existence   of   a   fault.   One or more tests performed to   determine
if malfunctions or faults are present in a unit.

FAULT   ISOLATION: Where   a fault is known to exist,   a   process
which   identifies or is designed to identify the location of that
fault   within   a   small   number   of   replaceable   units.   Tests
performed to isolate faults within the unit under test.

FAULT   RESOLUTION: Where the defective replaceable unit has been
identified,   repaired   or   replaced,   and   system   satisfactorily
retested.

FAULT-TOLERANT   COMPUTERS,   SOFTWARE,   AND SYSTEM HARDWARE: Where
the   computer,   software,   or system hardware does not fail because
of an individual fault.

FAULT-TOLERANT   DATA: Transient   data errors must   be   absorbed
without causing false alarms or inappropriate action.

REPLACEMENT   WITHOUT SHUTDOWN: Where redundancy exists, have the
capability   to   replace   an LRU and retest without   shutting   the
system down.

SPARES SELECTION AND AVAILABILITY: Spares must have high funding
priority   and be selected through a thorough technical   selection
process.

1.4.6.6   Technology Evaluation

After   determining the anomaly resolution technology   application
requirements,   a   technology search was performed using the   XTKB
(Expanded Technology Knowledge Base) developed for this Study and
the   NASA RECON database.   Approximately 200 technical papers and
document   abstracts   were   screened   from   various   "anding"   of
available secondary search keys in RECON including:

AEROSPACE   TECHNOLOGY TRANSFER,   AIRCRAFT MAINTENANCE,   ARTIFICIAL
INTELLIGENCE,   AUTOMATIC   TEST   EQUIPMENT,   B-1   AIRCRAFT,   BLOCK
DIAGRAMS,   BOEING   AIRCRAFT,   CHECKOUT,   CYBERNETICS,   DATA
ACQUISITION,   DIAGNOSIS,   ELECTRICAL FAULTS,   ELECTRONIC   EQUIPMENT
TESTS,   EMBEDDED COMPUTER SYSTEMS,   EXPERT SYSTEMS,   F-15 AIRCRAFT,
F-16   AIRCRAFT,   FAILURE ANALYSIS,   FAILURE MODES,   FAILURE,   FAULT
TOLERANCE,   GLASS FIBERS,   GROUND SUPPORT EQUIPMENT,   GROUND TESTS,
IN-FLIGHT   MONITORING,   INTERFACES,   ISOLATION,   LEARNING,
MAINTENANCE,   MALFUNCTIONS,   MICROPROCESSORS,   ON-BOARD   DATA
PROCESSING,   ON-LINE   SYSTEMS,   PATTERN RECOGNITION,   R & D,   SPACE
MAINTENANCE,   SPACE   MISSIONS,   SPACE   SHUTTLE BOOSTERS,   SPACE
SHUTTLE   ORBITERS,   STANDARDIZATION,   STATISTICAL TESTS,   TECHNOLOGY
ASSESSMENT,   and TRADEOFFS.

Where   the   abstracts   appeared promising,   actual   documents   or
papers   were obtained and studied from an application standpoint.
The results of this effort were 42 papers with direct application
to   this   technology   requirement.   These   are   listed   in   the
bibliography at the end of this topic.

Improvement of FAULT DETECTION, FAULT ISOLATION, and FAULT RESOLUTION techniques is based on the rapidly developing technology of COMPUTERS, SOFTWARE, EXPERT SYSTEMS, and ARTIFICIAL INTELLIGENCE applied to TESTABILITY. EXPERT SYSTEMS, with a number of commercial successes demonstrated and many military developments are currently underway. Maintenance expert systems are currently difficult to implement, but there appear to be approaches that avoid the knowledge engineering bottleneck. Metarules and machine learning have the potential to substantially reduce cost, development time, and best of all -- Life Cycle Costs. Expert systems with ability to understand circuit function and malfunction are expected within the next three years. To have a common understanding of terms it is necessary to differentiate between EXPERT SYSTEMS and ARTIFICIAL INTELLIGENCE.

EXPERT SYSTEMS (ES)-- Store the knowledge of an expert. The system is able to retrieve and process the stored knowledge to perform such functions as diagnosis, monitoring, prediction, and planning. Currently, all expert systems are "rule based", that is, the knowledge is stored in the form of if-then or situation-action rules. These rules (also called production or meta rules) form a network of inferences that are used to perform the expert functions, Section 1.4.6.9.

ARTIFICIAL INTELLIGENCE (AI) -- Automated reasoning, which is the process of drawing conclusions from facts.

Our survey included the following six possible testability improvement areas with a potential for near-term application with, or as part of, an AI approach:

1. Self-improving diagnostics

2. More effective fault detection and isolation

3. Discrimination between false alarms and intermittent faults

4. Reduction of skills required for maintenance

5. Integrated diagnostics

6. Design for testability

1.4.6 ANOMALY RESOLUTION (Tentpole A)
(Continued)

Potential AI solutions for these six testability areas can be adapted to eight basic applications:

1. **Computer-aided Preliminary Design for Testability** (CAPDT) provides a testability assistant directly available during preliminary design phases.

2. **Smart Built-In Test** (Smart BIT) used in boxes or cards can identify intermittent faults and reduce false alarms.

3. **Smart System Integrated Test** (Smart SIT) is a system level Smart BIT which performs testing while the system is operating.

4. **Maintenance Expert - Box** (ME Box) provides offline test management with self-improvement of functional tests.

5. **Maintenance Expert - System** (ME SYS) describes the kind of capability that can be expected in the immediate future.

6. **Maintenance Expert - Smart** (ME Smart) incorporates the benefits/risks of including learning capability in the maintenance expert system and its ability to access to Smart BIT information.

7. **Automatic Test Program Generation** (ATPG) would be able to understand circuit functional operation; however, this application has the lowest payoff.

8. **Smart Bench** is a maintenance expert system developed for use with bench test equipment controlled by an engineering work station.

Figure 2 is a matrix of Anomaly/Testability Problems vs. potential AI Solutions.

TESTABILITY PROBLEMS / ARTIFICIAL INTELLIGENCE SOLUTIONS

PROBLEMS \ A.I.	CAPDT TEST	SMART BIT	SMART SIT	ME BOX	ME SYS	ME SMART	ATPG	SMART BENCH
INTERMITTATE FAILURE COVERAGE	X	X	X	X	-	-	-	-
SELF-DIAGNOSTIC DIAGNOSTICS	-	-	X	X	-	X	-	X
MORE DETECTED FAULT DET & ISOLATION	X	X	X	-	-	X	-	X
ELIMINATING INTERMITTENT/FALSE	-	X	X	-	-	X	-	-
REDUCING FALSE ALARMS	X	X	X	-	-	X	-	-
DETECTING INTERM. FAILURE	X	X	X	-	-	X	-	X
REDUCING SKILL LEVEL FOR M	X	X	X	-	-	X	-	X
TESTABILITY FOR	X	-	-	-	-	-	-	-
AUTO TEST PROCESS INTEG	X	-	-	-	-	-	-	-
TEST COMPLEXITY AND COST	X	X	X	X	X	X	X	X
DATA COMPRESSION AND MANAGEMENT	-	X	X	-	-	X	-	-
INTERFACING & GROUND COMPAT	X	-	-	-	-	-	-	-
MAN MACHINE INTERFACE	X	-	X	X	X	X	-	X

○ = YES ○ = AIDS TO PREVIOUS PROBLEMS

Testability Problems/Artificial Intelligence Solutions
Figure 2

COMMERCIAL DEVELOPMENT EXAMPLE: To remain competitive in the international market, BOEING is pursuing a reliable, low-maintenance design philosophy for its new 7J7 airplane. Use of avionics incorporating large-scale integrated circuits to provide multiple function capability is expected to reduce the number of LRU's in the 7J7 by 30-50% compared with 757/767 airplanes.

In addition to size, weight, and power requirement reductions, this approach is expected to yield MTBF 3 to 20 times better than today's equipment and reduce the cost of spares by 20 to 50%. An on-board maintenance system will interface 6 or 7 DATAC high-speed data buses to the central maintenance computer. Each data bus will communicate with several avionics subsystems, each containing one or more LRU's and associated BITE. Critical subsystems will interface to 3 data buses to assure redundancy in case of system failures, while less critical sub-systems will be linked with only 1 or 2 buses. The central maintenance computer for the on-board system would display subsystem status and fault information on a printer or control display unit located in the aircraft, or send it to a ground maintenance center by means of an Arinc Communications Addressing & Reporting System (ACARS) VHF.

An example of todays state-of-the-art commercial airplane checkout is the Boeing 757/767. An "on airplane" data system is provided that supports validation of the system-level operation of the Flight Management System (FMS) with built – in – test – equipment (BITE). The BITE test support equipment is shown in Figure 3. Figure 4 shows the relative locations of personnel and equipment during test and validation. The Study Team observed this system being used for a 767 airplane overall test conducted just prior to rollout. A semi-automatic Flightline Tester Van (SAFT van) was connected to the 767 data bus and flightdeck touchscreen control. The flightdeck technician, utilizing the touchscreen and a radio intercom was able to test, take corrective action and retest on command. All data was stored on a floppy disk in the SAFT van which provides a data trail for QA and closeout. QA was not required during testing; the floppy disk data trail was used after-the-fact for this purpose. The test was accomplished by 6 technicians over 3 regular 8-hour shifts for a total of 144 manhours. While not directly comparable to Orbiter checkout, Figure 4 makes an interesting point when compared to the OPF checkout of the Orbiter.
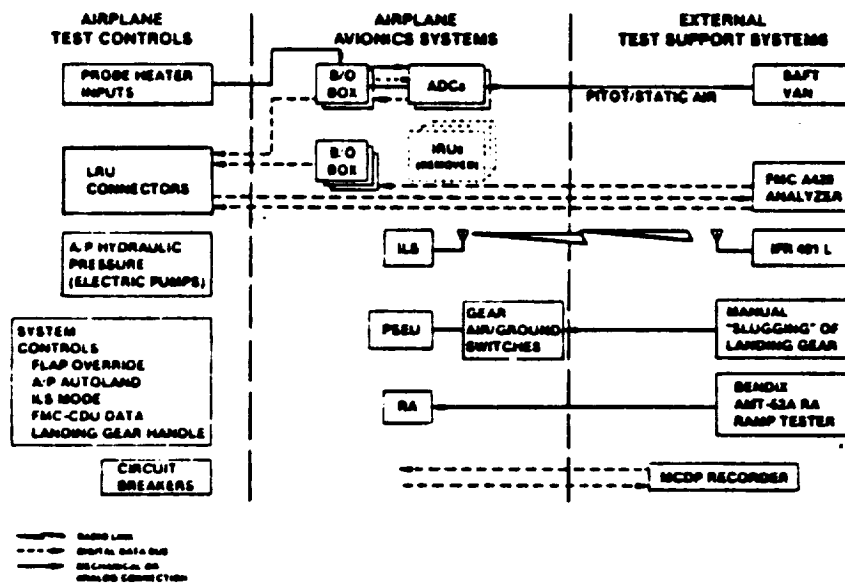
BITE TESTS
Figure 3
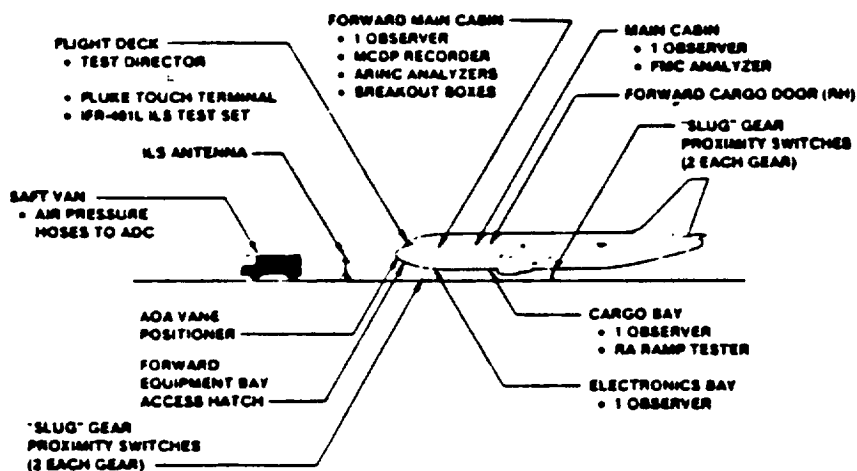
RELATIVE LOCATIONS OF PERSONNEL AND EQUIPMENT
Figure 4

Technology   Breakthroughs: Three   major   breakthroughs   have
occurred   that will have wide reaching effect on the productivity
of   maintenance expert system applications and on both   developer
and   user   interfaces.   These   are: (1)   the   comprehensive
development of diagnostic meta-rules (highly organized special
rules) for expert systems;   (2) the proliferation of engineering
work stations;   and (3) the recent announcement of "Universal Pin
Electronics"(UPE) developed by Giordano Associates under contract
with   the Army Electronics Command, Ft.   Monmouth, N.J.(This   UPE
integrates   analog and digital stimulus / measurement   capability
by   using   VLSI chips and extending that capability to every   ATE
pin eliminating the need for ATE switching.

Typical   useful expert systems have required more than 5 manyears
to   develop.   In   order   to create   maintenance   expert   systems
quickly,   they   must be built from generic components so   that   a
large   portion   of   the   software   can   be   reused   on   each
implementation.   Corporate developments, such as those at GE and
DEC   have   created   expert systems using these   techniques   which
intelligently   manage test sequences and can be adapted to a   new
system.

The   engineering   work   station   provides   a   common   host   for
development   of   all   the recommended AI applications.   Used   in
conjunction with the rule structure of expert systems, it permits
a   synergistic development of the requirements common to many   of
the   applications   (diagnostic   rules,   network   understanding,
graphical display, etc.).

Engineering   work   stations have gained widespread acceptance   in
the   aerospace   industry.   There are multiple sources   for   both
hardware   and   software that make work stations big enough,   fast
enough,   and   cheap enough to be really useful.   They   provide
direct,   personal   access   to AI applications by   the   electronic
designers.   As a result, the majority of end users will be   able
to make use of applications in engineering work stations.

These   basic   applications, using developing technology, and   the
ready   availability   of   engineering work   stations   provide   the
capability   to   drive   LIFE CYCLE COSTS   down   significantly   --
**Provided NASA and AIR FORCE   Program Management insist   on
contractual   requirements   to   put $$$ and   effort   into   forcing
OPERATIONAL   DESIGN   CRITERIA (Figure 5)   in   the   area   of   ANOMALY
RESOLUTION.**
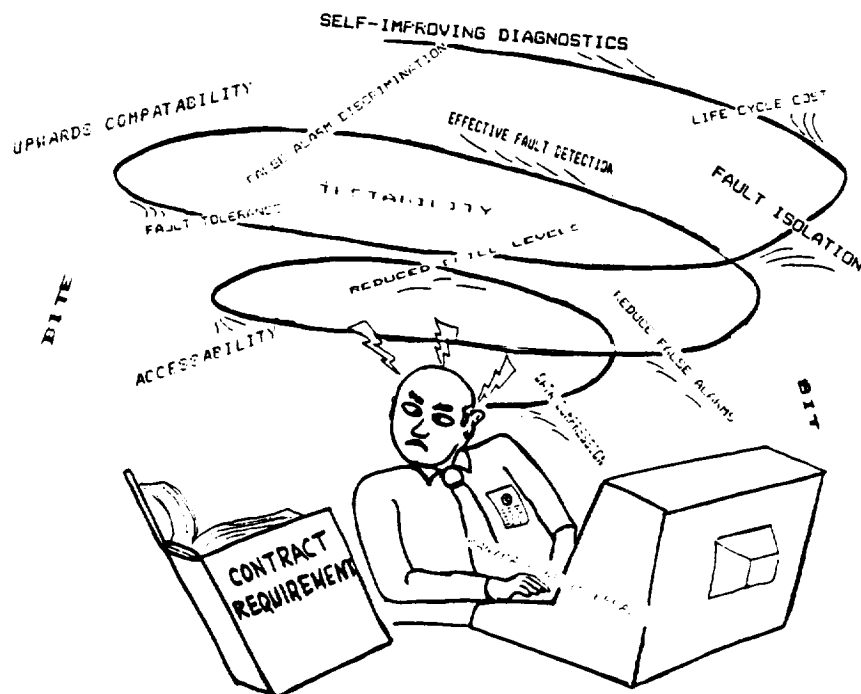
OPERATIONAL DESIGN CRITERIA
Figure 5

1.4.6.7   Cost Trades

There are two basic justifications for expending funds to improve the automation of ANOMALY RESOLUTION.   These are:

1.   Reduction of LIFE CYCLE COSTS (LCC)

2.   SCHEDULE   IMPROVEMENT -- The tangible improvement   of reducing   vehicle   turnaround time by eliminating   or reducing   anomaly resolution tentpoles, thus allowing more flights per vehicle in a given time period.

There   are   numerous   Air Force funded studies in   the   areas   of expert   systems   /   maintenance technology /   testability   /   and artificial   intelligence.   While these studies were performed for AF fighter activities, the maintenance function involved for fast turnaround and low LCC apply equally well to STS type activities. There are two Air Force sponsored reports which are comprehensive in their cost-trade analyses.   One of these reports was sponsored by   the Wright-Patterson Avionics Laboratory and the other by the Rome   Air Development Center (RADC).   These two reports form   the basis for this Study's cost-trade analysis:

"Integrated   Testing and Maintenance Technologies", Final   Technical Report for Period 25 Sept 81 -   15 Sept   83, prepared by Boeing Aerospace for Avionics Laboratory,   Air   Force   Wright   Aeronautical Laboratories,   AFSC,   Wright-Patterson AFB.   RECON 84N22528.

"Artificial   Intelligence   Applications   to Testability",   Final Technical Report,   Oct   1984, prepared   by Boeing Aerospace Company for Rome   Air Development   Center, AFSC, Griffiss AFB, NY.   RECON 85N24839.

To   assess   the LCC impact of improvement on testability   factors for   anomaly   resolution,   seven criteria were used in   the   RADC study:

1.   Test time reduced

2.   Hard fault detection

3.   Hard fault isolation

4.   Intermittent discrimination & isolation

5.   False alarm reduction

6.   Experience Level Reduced

7.   Reduced removals

A discussion of each of these factors is appropriate as a basis for understanding how improvement lowers life cycle costs.

Test Time Reduced: Many test programs must run through the entire test sequence every time, while providing the technician with no capability to make gross tests of entire sections, loop on a particular test sequence, or slowly accumulate test information to diagnose intermittents. The use of maintenance expert systems is not necessary to make the testing more flexible and hierarchical, but their incorporation produces this effect. A reduction in test time benefits LCC by increased utilization of test equipment and the test technicians for ATE (Automatic Test Equipment) bench and system tests. Large benefits in this area could also result in fewer ATE systems being required at depot repair sites.

Hard Fault Detection: At every level of testing it is desirable to have the best fault detection coverage for hard faults possible. This is relatively easy for digital circuits, but is much more difficult for circuits or systems which have poor DFT (Design for Testability), use analog circuits or microprocessors. Improving testability during the design phase of the electronics provides the greatest benefit for the effort expended, because improved fault detection in the unit has greater LCC benefits than improved fault detection solely based on ATE. Only by improving testability is it possible to detect all hard faults.

Hard Fault Isolation: Because it is a more difficult task and a less mature capability, there is more opportunity for improvement in hard fault isolation than in their detection. Both can be improved through the use of DFT (Design for Testability) techniques and by a maintenance expert system that can learn the isolation strategies for real world faults. However, it takes a greater level of DFT to locate a fault inside a complex network that to detect a fault at its output.

Intermittent Discrimination and Isolation: Intermittent discrimination and isolation is an immature field which could provide benefits to many types of systems. The test system must allow a fuzzy description of the state of a circuit (i.e., a description covering a range of states: good, most likely good-may have suspected as intermittent, degrading-but-not-yet-bad, and bad). Products which accumulate information about an item's marginally bad performance during the time it is running provide much more help in detecting and isolating intermittents than a single slow test of performance on an ATE system. That approach also provides the basic capability needed to discriminate between intermittents and false alarms.

<u>False Alarms Reduced</u>: Causes of false alarms are most easily eliminated using CAD tools to help reduce false alarm causes through better designs.   CAD can provide the ability to simulate full system operation with BIT and software running and to simulate various hard and soft faults.   The simulation results interpreted by the designer allow him to find and then eliminate many of the causes of false alarms. Additionally, methods to acquire and record fault information during circuit and system debug (in full scale development), will find many real world/environmental causes of false alarms. This information is most easily acquired by some form of BIT that has non-volatile memory after it's fielded, hardware becomes virtually unalterable; however, the BIT test software can still be changed (under configuration control).   Smart BIT with reprogrammable features allows experimentation with proposed modifications and would also ease their incorporation.

<u>Experience Level Reduced</u>:   Much of commercial and military electronic testing has gone from bench to ATE so as to increase the reliability of testing and to reduce time.   The military ATE software, however, has greatly limited the technician in what he can do.   The technician is rarely able to modify the test sequence or test limits to diagnose a problem.   As circuits become more complicated, especially microprocessors, there tends to be little or no information available to the test technician on their operation.   ATE has also become very complex to operate and each one is different.   It requires 6-12 months of training for technicians to become familiar with operations of complex ATE, and learn how to compensate for its limitations to perform the testing and diagnosis required.

Skill level reduction is, based on the reality of military service experience, better expressed as "experience level reduction." Because of this, it has been the conclusion in segments of the military community that ATE should be changed so as to require less training for use in performing maintenance. As a corollary, ATE must be configured to work with the technician, rather than just having him serve as a "button pusher". Instead of having a computer-guided probe, where the technician is told where to place a probe so that the computer can make a test, there should be interactive diagnosis where both the human and the computer can suggest areas of the circuit to be tested. This is already being done with sophisticated software in some commercial card-testing ATE. At KSC, where the technician skill level is more experienced and stable, the interactive diagnosis capability is even more important.

<u>Reduce Removals</u>: Removing an item from a system causes a whole chain of costly actions to occur. Field maintenance data exists showing that 40% of the avionics equipment removed from an aircraft is fault-free. Using better DFT to provide less isolation ambiguity reduces removals directly. Improved fault isolation decreases the need for spares.

1.4.6 ANOMALY RESOLUTION (Tentpole A)
(Continued)

Reduce Removals (Continued): Shotgun substitution methods break
    spares -- typical Boeing experience is that with a printed
    circuit board with 5 or more layers, there is a 50-50 chance
    of a layer interconnection being destroyed if the board is
    removed twice.

The above definitions provide a basis for understanding how the
Operations and Logistics Support portion of LCC can be reduced.
By looking at the distribution of costs against the DOD Life
Cycle Phases, Figure 4, and identifying the element in such a way
as to support cost analysis, the typical distribution of DOD is
shown below:

	Total Weapon Sys	ATE Type Sys
* Design	3%	10%
* Fabrication	21%	30%
* Operations Personnel	7%	
* Support Spares	7%	
* Replacement Spares	10%	60%
* Maintenance Personnel	35%	
* Replacement Material	5%	
* Other	12%	
	100%	100%

Note: It should be noted that designers are often not aware that
detailed design phase is typically only 3-10% of the total life
cycle cost.

Cost Analysis: Specific cost analysis cannot be provided
    without defining the system and its operation and support
    concept. It is the intent of this section to provide
    insight into the scope of cost savings to be gained by
    implementation of automated anomaly resolution.

Figure 6: illustrates the distribution and time relationship of
    the contributions to the life cycle cost of a typical
    system.

Figure 7 & 8: further detail the operation and maintenance
    cost.

Figure 9:   illustrates the LCC savings that could be realized by
    developing   integrated   testing   and   maintenance
    state-of-the-art.   Shown   are   cost   deltas   to   current
    implementation of onboard test and maintenance methods.

Figure 10:   shows that testability incorporation during
    preliminary design has the largest potential impact (70%)
    on life cycle costs.
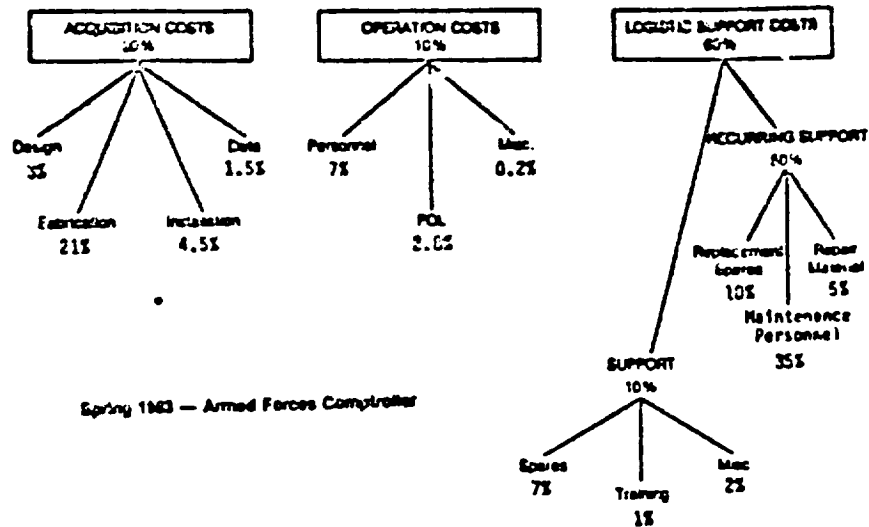
DISTRIBUTION OF LIFE CYCLE COST
Figure 6
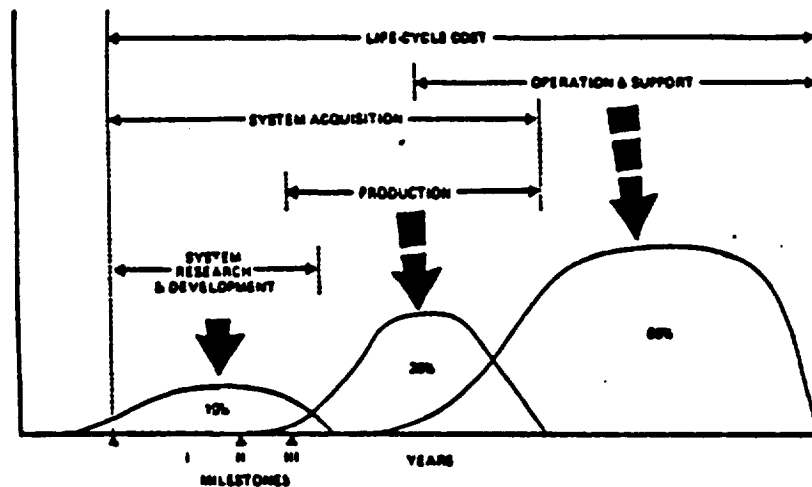
TYPICAL SYSTEM LIFE-CYCLE COST
Figure 7

Source: Program Management for Functional Managers,
The Defense Systems Management College, Fort Belvoir

ORIGINAL PAGE IS
OF POOR QUALITY
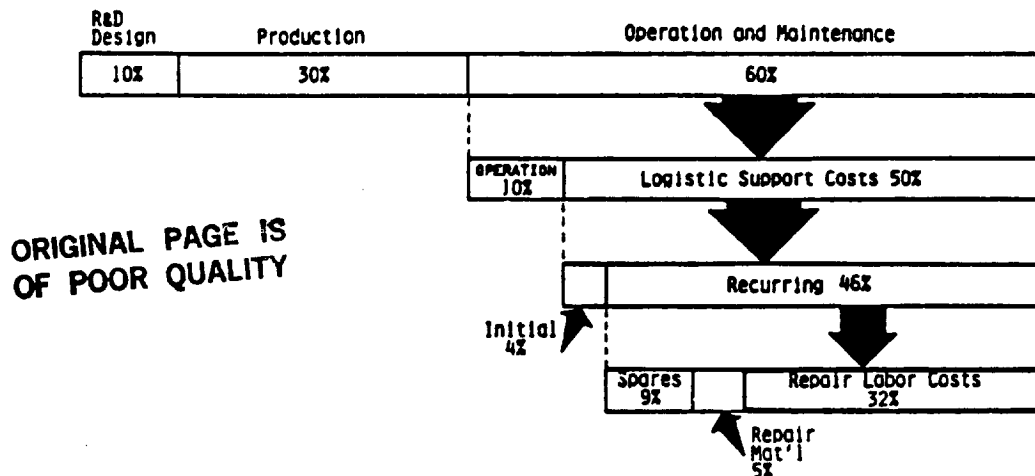
TYPICAL SYSTEM LIFE-CYCLE COST BREAKDOWN
Figure 8

From Program Management for Functional Managers
The Defense Systems Management College, Ft. Belvoir, Virginia

1.4.6 ANOMALY RESOLUTION (Tentpole A)
        (Continued)

LIFE CYCLE PHASE	% OF SYSTEM LIFE-CYCLE COST	X	ROUGH ESTIMATE OF ITM COST IMPACT	=	IMPACT OF ITM ON LIFE-CYCLE COST
● R&D Design	10%		Up 10%		Up 1.0%
● Production	30%		Up 5%		Up 1.5%
● Operation & Maintenance	(60%)				
Repair Labor Costs	32%		Down 13.1%		Down 4.2%
Spares & Repair Material	14%		Down 15%		Down 2.1%
Operation	10%		Down 15%		Down 1.5%
·Initial Logistics Support	4%		—		—
	100%				Down 5.3%

POTENTIAL ITM COST IMPACT
Figure 9

% of LCC Cost Impact on Operations and Support Costs
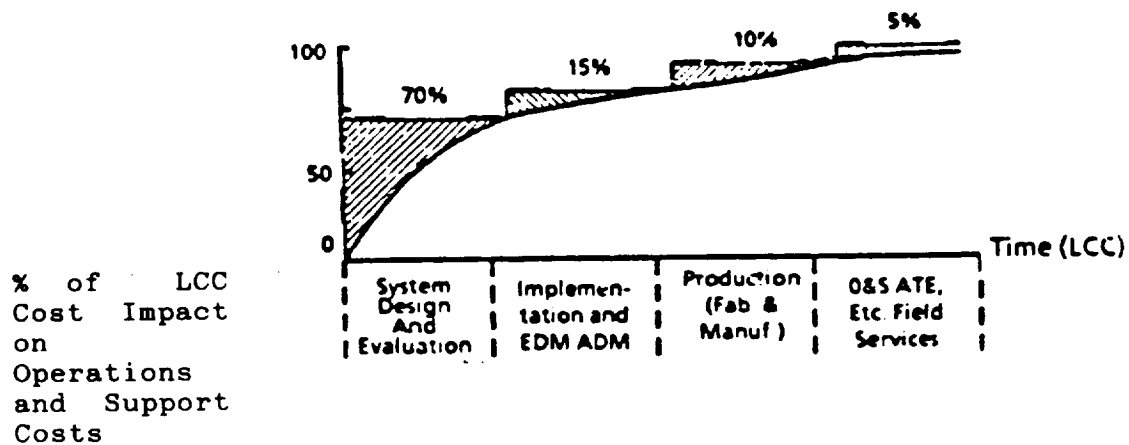
TESTABILITY INCORPORATION DURING
PRELIMINARY DESIGN, HAS LARGEST IMPACT
Figure 10

1.4.6 ANOMALY RESOLUTION (Tentpole A)
(Continued)

The bottom line is that by developing and incorporating anomaly resolution techniques in the early design phases, Life Cycle Costs can be reduced by at least 5% -- a significant amount when you are dealing with $billions on STS or STAS.

Indirect Benefits: while not as apparent as the direct savings, can provide even greater benefits. Reduced processing time leads to more flights/year. Based on a 3-orbiter fleet and 12 total flights/year, an improvement in processing time sufficient to provide one additional flight of payloads would be an 8 1/2 percent gain in use of a multi-billion dollar national resource.

Anomaly Resolution technology would make a significant contribution to this end. This improvement could dwarf the direct manhour savings. DOD analyses for aircraft life cycle costs do not include this type of factor.

COST ANALYSIS EXAMPLE
OF ANOMALY RESOLUTION TECHNOLOGY APPLIED TO 51-L

Since neither the SPC Contractor or NASA were able to provide significant manpower/manhour vs. OMI data, we have extrapolated any data available to create the following 51-L cost analysis for Anomaly Resolution with a confidence factor of 1.5. The following table provides a cost estimate from the best data available.

OMI	HOURS	TECH(M/H)
V1003	23,16	234
V1005	3,4,3	40
V1008	8	32
V1022		432
V1028		16
V1034		?
V1048	5	40
V1053	8	40
V1060	6	60
V1062	8	40
V1065	8	56
V1080	4	32
V1084	8	64
V1086	44	220
V1098	4	40
V1103	16	64
V1123		16
V1161	19,9	112
V1173		15
V1177	3	12
V1178	8	56
V1200	8	40
V3500	?	?
TOTALS:	222+?	1211+?
SUPPORT M/H @ 33%		400+?
TOTAL M/H		1600+?

OMI's not required on 51-L had the potential of another 100 online hours and 500+ manhours plus 150 direct support (engr, QA, etc.) manhours.

Also not included in the above figures are the additional hours brought about by lack of spares and the resulting cannibalization with its resultant time and manhours for reinstallation and retest.

1.4.6.8 Conclusions and Recommendations

1. Because of the significant investment required to develop the hardware, software and techniques in the areas of EXPERT SYSTEMS and ARTIFICIAL INTELLIGENCE for testability, NASA should join the DOD/Industry team who have been funding and developing the early progress in this area. Specifically, for the STS and STAS design agencies to develop direct contact with key AFSC personnel at the Rome Air Development Center and the Wright-Patterson Avionics Laboratory.

2. With STS activity planned for another 15 years, serious consideration should be given to incorporating some degree of improved anomaly resolution via block changes in the early 1990's when the improvements now under intensive development begin to reach fruition. Cost effectiveness would be most likely when improvements are combined with mandatory safety mods. Proof of concept mods to the current Orbiters may also be a high priority for future vehicle development. Systems which should be considered include:

   * Electrical Power Distribution & Control (EPD&C)
   * Power Reactant Storage & Distribution (PRSD)
   * Environmental Control & Life Support System (ECLSS)
   * Data Processing System (DPS)
   * Communications (Comm)
   * Guidance, Navigation, & Control (GN&C)
   * Main Propulsion System (MPS)
   * Auxiliary Power Unit (APU)
   * Hydraulic System (Hyd)

3. In June 1984, an Artificial Intelligence Applications Committee with ten DOD and Industry members and chaired by Anthony Coppola, Chief of the Reliability & Maintainability Engineering Techniques section of the Rome Air Development Center developed four major recommendations in this area for DOD. Allowing for very minor changes in the past two years, these recommendations are still valid and have been implemented by DoD. The results of these actions are available for use by the NASA design agencies. Because of their comprehensiveness and currency, these recommendations are quoted below:

ARTIFICIAL INTELLIGENCE APPLICATIONS COMMITTEE
RECOMMENDATIONS TO THE DEPARTMENT OF DEFENSE

"Despite the fact that the members of the committee worked completely independently, there is only one area of significant disagreement in the position papers. This is the recommended language in which AI programs should be written. An area of general agreement was that expert consultant systems can, and should, be applied to maintenance now. There was even a general consensus of the development resources required for an expert system: two years time, $200,000 in computer costs, and five to ten man-years per year. However, discussions after review of the position papers would cause these to be considered minimum projections, with perhaps double the computer resources and five years of time required. The following recommendations are the chairman's consolidation of the position papers, discussions with the RADC contributors, and his derivations from the information given above.

RECOMMENDATION NO. 1

The DoD should take advantage of the relative maturity of technology for creating expert systems. Specific applications of maintenance expert systems should be started immediately, and multi-application maintenance experts developed and standardized.

The Dod should immediately develop expert systems for existing maintenance applications where maintenance is particularly troublesome. As an example, the AFIT-RADC-WRALC program would attempt to create a system to work with the F-15 analog printed circuit board test station. It would first be programmed with the knowledge required to troubleshoot only one board, the most troublesome of those - the ATE handles. This would show the value of the approach and permit debugging of the system. More knowledge would be added incrementally until the system handled every board assigned to the original ATE. At this point, it would hopefully be cost effective to scrap the original system. If not, the expert system would still earn its keep by its superior handling of problem boards. Each service could pick a promising candidate (a system which is not handled well by the ATE, and for which expert maintenance personnel are both available and willing to cooperate in creating the expert maintenance system). As it builds and refines the maintenance expert system, the service would improve the Operational readiness of the candidate system while it gains experience and confidence with the AI technology. No risk would be involved, since the existing ATE would still be in place. Resources would be two to five years calendar time, 10-20 manyears of effort and $200,000 to $500,000 in computer costs for each system. Each system would pay for itself in short order, by reducing maintenance time as much as 50%. However, the real value of these first efforts would be in the knowledge gained.

To permit immediate application, the first AI maintenance systems should be built in the language and architecture most convenient to the builder and user, with a blanket exemption from any current policies on languages. The only exception would be that any test sequence generated by the system for outside use would be in ATLAS. No cost involved. Will cause a proliferation of languages for first systems, but will permit earllier implementation, by years, and provide information needed for ultimate standardization. (Chairman's recommendation based on conflicting inputs in position papers.)

To improve cost-effectiveness in the longer term, the DoD should develop versatile maintenance experts for specific domains, such as digital electronics, which are used in many different systems They would contain the necessary theory and diagnostic strategies for their specific domains. They must be user friendly (interact in a subset of English, explain their actions, and adapt to the skill of the user), and, presuming progress in computer aided instruction (CAI) techniques, each system could ultimately serve as an integrated ATE, maintenance trainer and training aid. One basic system (for one domain) could be built in two years with 10 manyears effort. System specific data bases would be incorporated during the development of the systems to be tested. Refinements would be added as developed. Benefit would be the elimination of the need for reinventing the engine for every application, easily worth millions in development and training savings. Technical risk is moderate.

Further improvements in cost-effectiveness would be made possible by developing a system building tool to automate the creation of the system specific data required by the expert system discussed in the preceding paragraph. The tool would extract the needed knowledge whether from a human expert, or, ideally, from a description of the system to be tested. This will minimize one of the major costs of the expert system. Cost would be about $200,000 a year in computer costs and ten manyears per year. A prototype could be available in two years, but it might take a five year program to complete a supportable product. Benefit would be significant savings in time and elimination of errors for every new system to which it is applied. No more than five applications, if that much would repay the costs with a dividend in earlier test system availability and easier modification as the design of the system under test changes. Technical risk is presently considered high.

Note: The expert systems would eliminate the long test programs now used in conventional ATE systems. To do so the DoD could prohibit all new ATE systems to use inflexible sequential test procedures. Instead, require the use of segmented test programs which are called out in the order needed for most rapid fault isolation using the strategies now available in LOGMOD, STAMP, and FIND. Cost will be a significant increase in effort required to program the ATE and some additional memory. Will probably permit the elimination of one maintenance shift, paying for itself in one year or two. (Chairman's recommendation)

1.4.6   ANOMALY RESOLUTION (Tentpole A)
        (Continued)

RECOMMENDATION NO. 2

Develop "smart" BIT for digital electronic system to minimize false alarms, identify intermittent failures, improve coverage of BIT. An RADC proposed FY-84 effort hopes to provide design concepts which could be used by individual designers to construct smart BIT in their particular applications. A complete series of studies leading to the design of an on-board knowledge based monitoring system or the design and test of experimental BIT systems could run two to four years and one to six million dollars. Benefits are incalculable since they include the work of reduced mission aborts due to false alarms. More tangible benefits could be a 90% reduction in false alarms, and the decrease of the portion of units sent to repair which test good, from the present 30% to perhaps 10%. A successful application should pay for itself in two years of operation on one system, and provide a measurable improvement in the ready rate of the system using it.

RECOMMENDATION NO. 3

Fund applied Research and Development of AI for maintenance, both to improve the capabilities of maintenance expert systems and to apply AI to other maintenance applications. Some specific topics are:

1.   Automating the creation and presentation of Technical Manuals.

2.   Applying AI to Maintenance Information Systems and databases.

3.   Developing crisis alerting systems.

4.   For expert maintenance systems, developing requirements for languages and computer systems, techniques for improving user friendliness, and more sophisticated approaches (e.g., means of forming rules from the circuit itself rather than from an expert familiar with the circuit.)

5.   Developing AI systems for Automatic Test Program Generation (ATPG). The current AI programs used to develop test patterns for digital combinatorial logic should be extended to sequential logic and analog circuits. Systems should work from the circuit description and provide test vectors in ATLAS.

6.   Applying AI techniques to VLSI, VHSIC design for fault tolerance and testability. This should be incorporated into the VHSIC phase three study plans.

7.   Developing knowledge based computer aided instruction (CAI) systems for maintenance training. Note: this could ultimately be incorporated into the ATE itself.

8.   Developing self-improving diagnostics and test program sets.

Other topics will be identified by the FY-83 studies begun by RADC, NAEC, AFHRL. Recommend 6.2 programs be started by all three services, funded at one million dollars per service per year, to begin work. Promising developments should be followed by 6.3 projects with appropriate higher funding.

RECOMMENDATION NO. 4

Foster an integrated DoD-industry approach.

Coordinate the various efforts of DoD agencies through a tri-service group on AI applications to maintenance. Recommended group would be a committee under the JLC Automatic Testing Panel. It could also be under JDL working group for AI, but seems more appropriate for the Automatic Testing Panel because of its interface with other committees. Participants would include all service agencies involved to share responsibilities and avoid duplication of efforts. It would also provide a contract point for DoD and industry. (Chairman's recommendation)

Encourage private avenues of development of AI applications to maintenance: continue to support industrial IR&D in the area, express DoD interest at appropriate meetings, provide copies of this report to Industry. The NSIA Testability Committee, which parallels the JLC panel, should be encouraged to create a subgroup on AI applications to serve as an industry focal point. The close working relationship of the NSIA committee and the JLC panel would be a natural avenue for creating a dialog on AI applications. (Chairman's recommendation)"

1.4.6.9 Bibliography

(Each of the references listed below has its own bibliography)

(1)   RECON 84N22528; ASWAL-TR-83-1183
      Denney, Robert O.; Partridge, Mike J.;
      Williams, Roger; 319 pages
      Boeing Aerospace Company, Seattle; December 1983
      INTEGRATED TESTING AND MAINTENANCE TECHNOLOGIES
      Final Technical Report for period Sept 81 - Sept 83
      (for AFSC, Avionics Lab, Wright-Patterson AFB, OH.)

(2)   RECON 85N24839; RADC-TR-84-203
      Lahore, Henry; 178 pages
      Boeing Aerospace Company, Seattle; October 1984
      ARTIFICIAL INTELLIGENCE APPLICATIONS TO TESTABILITY
      Final Technical Report for period Apr 83 - May 84
      (for AFSC Rome Air Development Center (RADC), Griffiss
      AFB, NY)

(3)   RECON 85N11592; AFHRL-TR-84-25
      Multiple Authors; 35 papers; 513 pages; June 1984
      ARTIFICIAL INTELLIGENCE IN MAINTENANCE: PROCEEDINGS OF
      THE JOINT SERVICES WORKSHOP
      AFSC, Air Force Human Resources Laboratory, Brooks AFB,
      Texas

(4)   RECON 85N27936; NASA-CR-175881
      Automation and Robotics Panel; 127 pages; 25 Feb 85
      Administered by Calif. Space Inst., Univ. of Calif.
      (for NASA)
      AUTOMATION & ROBOTICS FOR THE NATIONAL SPACE PROGRAM

(5)   RECON 84X10528; NASA-CR-172385
      Multiple authors, 123 pages
      Mandex, Inc: SRI Intl.; Battelle Memorial Inst.; Sept 84
      STUDY OF FAULT-TOLERANT SOFTWARE TECHNOLOGY

(6)   NASA Tech Memo 88236
      Shaver, Charles; Williamson, Michael; 34 pages
      DEVELOPMENT OF AN INTERFACE FOR AN ULTRARELIABLE FAULT-
      TOLERANT CONTROL SYSTEM AND AN ELECTRONIC SERVO-CONTROL
      UNIT
      NASA Ames Research Center, Moffett Field, Calif.

(7)   RECON 85N16731; AGARD-CP-361
      Multiple authors; 29 papers; 250 pages; May 1984
      DESIGN FOR TACTICAL AVIONICS MAINTAINABILITY: AGARD
      CONFERENCE PROCEEDINGS No. 361
      NATO Advisory Group for Aerospace R & D (AGARD)

(8)   RECON 83N34652; MATRA ref. DM55/JPS/JP/317-83
      Multiple authors; 254 pages; 1983
      STANDARD GENERIC APPROACH FOR SPACECRAFT INTELLIGENCE AND
      AUTOMATION (Final Technical Report)
      Prepared by MATRA ESPACE for ESA

1.4.6.9   Bibliography (Continued)

(9)   RECON 85N27576; AD-A151 918; AFIT/GE/ENG/84D-53
      Ramsey, James E., 1st Lt.; 250 page thesis
      Air Force Institute of Technology, Wright-Patterson AFB
      DIAGNOSIS: USING AUTOMATIC TEST EQUIPMENT AND AN
      ARTIFICIAL INTELLIGENCE EXPERT SYSTEM

(10) RECON 86A40591
      FERNEYHOUGH, DALLAM G. JR.; 5-page paper; 1986
      IBM Federal Systems Division, Gaithersburg, MD.
      ANOMALY DETECTION AND RESOLUTION SYSTEM

(11) RECON 84A26768
      Lee, H. F.; Carson, D.P.; 7-page IEEE paper; 1983
      Boeing, Seattle
      TESTING BITE ON BOEING 757/767 IN A SIMULATED OPERATIONAL
      ENVIRONMENT

(12) RECON 85N16752
      Neumann, Geo. W., Giordana Associates;
      Battaglia, Michael, Naval Electronic Systems Command
      6-page paper
      A WEAPON SYSTEM DESIGN APPROACH TO DIAGNOSTICS

(13) RECON 84A26795
      Kovalan, Mark; Rockwell-Collins, Cedar Rapids, Iowa
      6-page paper
      PROCESSOR MONITORING AND SELF-TEST IN THE BOEING 767/757
      FLIGHT CONTROL COMPUTER

(14) RECON 82A14841
      Allen, Don R.; Ferch, Blaine C.; Wright-Patterson AFB
      10-page report
      PROGRESS IN DESIGNING FOR TESTABILITY

(15) RECON 84A26771
      Hitt, Ellis F.; Battelle, Columbus, Ohio; Eldredge, Don,
      DOT/FAA Technical Center, Atlantic City Airport, NJ.
      8-page IEEE paper; 1983
      FAULT, DETECTION, ISOLATION, AND RECOVERY TECHNIQUES FOR
      FAULT TOLERANT DIGITAL AVIONICS

(16) AVIATION WEEK & SPACE TECHNOLOGY, 17 Nov 1986
      BOEING FOCUSING ON RELIABILITY, LOW MAINTENANCE FOR 7J7
      ELECTRONICS   (3-pages)

(17) RECON 86N19060; AFHRL-TR-85-7
      Richardson, J.J. & Keller, R.A., Denver Research Inst.,
      Univ. of Denver; Maxion, R.A., & Polson, P.G., Inst. of
      Cognitive Science, Univ. of Colorado; DeJong, K.A.,
      Center for Applied Research in AI, Naval Research Lab.
      ARTIFICIAL INTELLIGENCE IN MAINTENANCE: SYNTHESIS OF
      TECHNICAL ISSUES
      (Prepared for Training Systems Division, Air Force Human
      Resources Lab, Lowry AFB).

1.4.7 WCCS FUNCTIONAL CHECKS (Tentpole B)

1.4.7.1 Summary

The Window Cavity Conditioning System (WCCS) is designed to allow the cavity between inner and outer windows to "breathe" to prevent condensation during flight. The current system is made up of eight assemblies, each with a desiccant assembly and two check valves with interconnecting tubing. The eight are:

1. command module inner
2. command module outer
3. right hand forward inner
4. right hand forward outer
5. left hand forward inner
6. left hand forward outer
7. left hand aft outer
8. right hand aft outer

The active elements in the desiccant are buff colored with random blue beads that change to buff when the moisture limit is reached. Early in the program the designer lost confidence in the indicator beads and the units were changed after each flight. The current procedure inspects them every flight and changes them every other flight. The units are not readily accessible even for inspection because the initial design did not properly address maintainability. The leak check and flow test setup has a number of flex hoses that are susceptible to damage during testing.

Although the initial 160-hour schedule did not allow any time for this activity it took 152 hours for 51-L.

Future programs must have more consideration of maintainability in early stages of design. Maintainability and accessibility must be "designed in", not merely "tacked on" at the end of the program.

It is recommended that the desiccant/check valve assembly be redesigned slightly to allow for "quick changeout" operation and spares be stocked so serial time impact be minimized. Desiccant materials should be researched to be sure that we are still using the most effective product.

1.4.7.2 Related Issues

1. Accessibility of the units for inspection or removal/ replacement.

2. Removal of some assemblies require disassembly of other orbiter components.

3. Need to have spares available.

4. Need a positive reliable indicator.

5. Requirements are not in line with frequent flight philosophy.

6.   Success rate of components is not periodically factored into test rate.

7.   Test set-up and tear-down cycles are wearing out flex hoses.

The following are examples from the Issues database:

```
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

ID: (2825.00)            Issue(s): DESIGN            :
Issue(s) cont.:                       :              :
Issue Source: (NE-PEC MOD LIST)      (POST 51-L PRELIM. MOD LISTING)
Description:
PV&D

STUDY

"PROVIDE AN EXTRA SET OF WCCS DESICCANTS SO THAT THE DESICCANTS CAN BE
REFURBISHED OFF-LINE TO REDUCE V1076 CRITICAL PATH TIME."
(55/11)  #C

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

ID: (2497.00)           Issue(s): REQUIREMENTS       :
Issue(s) cont.:                       :              :
Issue Source: (NE-PEC MOD LIST)      (POST 51-L PRELIM. MOD LISTING)
Description:
CATEGORY 3 (DESIRABLE)

"PROVIDE LAMINAR FLOW BENCH IN OPF AREA FOR WCCS REFURBISHMENT.  (1/12)"

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

ID: (2496.00)           Issue(s): DESIGN             :
Issue(s) cont.:                       :              :
Issue Source: (NE-PEC MOD LIST)      (POST 51-L PRELIM. MOD LISTING)
Description:
CATEGORY 2 (DESIRABLE)

"MODIFY WCCS GSE TO HARDLINE THE SYSTEM AS MUCH AS POSSIBLE.  THE EXISTING
LONG (EXPENSIVE) FLEX HOSE ARE DAMAGED NEARLY EVERY FLOW  (1/9.1)

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
```

1.4.7.3   Schedule History

1.   No time was allotted in the original 160-hour turnaround for this task.

2.   The STS-XX schedule allotted 92-hours.

3.   The 51-L flow required 152-hours to complete.   See Figure 1.

4.   Quick-change modules without sampling could be done in 3
      hours.

EFFICIENCIES/TECHNOLOGIES		NOVEMBER 1985 *																			DECEMBER 1985 *															
		11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	TECHNOLOGY																																				
B	WCCS FUNCTIONAL CHECKS																																				

*   All timebars indicate 3 shift/day operations

51-L OPF PROCESSING
Figure 1

1.4.7.4   Current STS Methods

CMI V1076 -- ORBITER WCCS FUNCTIONAL TEST

      OBJECTIVE: To provide procedures   to verify   function
      of the orbiter window cavity conditioning system.

      OPERATIONS: The current procedure inspects them every flight
      and changes them out every other flight.   OMRSD requires
      retest of all portions of the system that have been opened.
      The units are not readily accessible, even for inspection.
      Forward reaction control system (FRCS) access panels 21-27
      and 21-28 must be removed to access the forward inner and
      forward outer desiccant assemblies.   The right hand payload
      support avionics (PSA) beam must be removed to access the aft
      outer cavity desiccants.   The desiccant assembly is then
      removed from the orbiter.   On alternate flights the desiccant
      cartridge is removed from the assembly and sent to an
      off-line clean room facility for refurbishment.   The check
      valves are tested while the desiccants are being refurbished.
      The cartridge is then replaced in the assembly and the
      assembly reinstalled.   A leak check and flow test is
      performed and dew point samples are taken.

1.4.7.5 New Technology Requirements

A long life desiccant with reliable indicators that would require less frequent change-out.

A desiccant that can be recharged in place.

Research through RECON and other databases have not uncovered anything promising in either area.

1.4.7.6 Technology Application Requirements

A rechargeable nitrogen blanket system in place of the desiccants.   This could probably be accomplished with no weight penalty.

A simple, and perhaps the most practical, solution would be to redesign the assembly to be quickly and easily changed out with spare units.   The desiccant could be replaced off-line, the assembly tested, and put in stores. A simple design with flat faces and a rubber-type sealing surface and easy to install fasteners could substantially reduce the change-out time.   This method could even be performed every launch and still save flow time if units were tested prior to returning them to stores.

1.4.7.7 Technical Evaluation

The initial design did not properly address maintainability. Four shifts could be saved if the units could be accessed without removal of other orbiter parts.   Relocating the desiccant assemblies to an accessible location (such as to the payload bay) could help here.   If the initial design had been a quick-change module and spares had been provisioned to allow for off-line refurb the current test length could be reduced to a minimum. The Shuttle Processing Contractor (SPC) system engineer feels that changeout of desiccant every four or five flights would be more reasonable than the current every other flight procedure. See Figure 2 below for an example of one of the present assemblies.
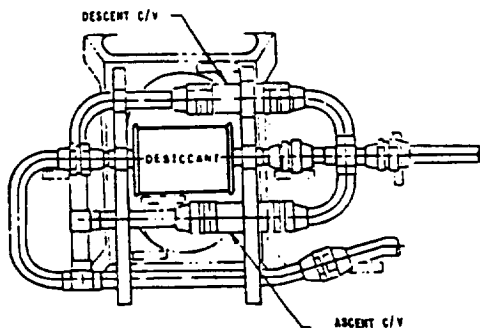
LR/RH OUTER AFT DESSICANTS
Figure 2

The desiccant assembly could be replaced with a small GN_2 container and regulator to maintain a pressure slightly above external orbiter pressure. The container could be recharged in place. Since the unit is recharged in place and doesn't have to be removed accessability should not be an issue.

1.4.7.8 Shuttle Cost Trades

IMPLEMENTATION DESCRIPTION: Redesign of desiccant/check valve assembly to be accessible and to allow for quick changeout for unit from spares.

IMPLEMENTATION COST ESTIMATE:

Item	Manhours	Materials	Comment
Design & Qual. Tests			
Manufacturing			cost for 3 vehicles
Modification & Installation	_____	_____	cost for 3 vehicles
TOTALS			

GROUND OPS COST SAVINGS PER FLIGHT AFTER IMPLEMENTATION:

		Current			New			Delta	
Item	OCF	DMH	MAT	OTHE	DMH	MAT	OTHE	DMH	MAT	OTHE
quick change unit	96	450	10		164	10		464		

IMPLEMENTATION DESCRIPTION: Revise requirement to allow 5 flights between changeout of desiccant cartridges.

IMPLEMENTATION COST ESTIMATE: This would be an OMRSD paper change only.

GROUND OPS COST SAVINGS PER FLIGHT AFTER IMPLEMENTATION:

		Current			New			Delta	
Item	OCF	DMH	MAT	OTHE	DMH	MAT	OTHE	DMH	MAT	OTHE
every 5th flight	96	450	100		192	20		288		

IMPLEMENTATION DESCRIPTION: Redesign of WCCS to have a small GN2 bottle to supply a blanket purge in the cavities.

IMPLEMENTATION COST ESTIMATE:

Item	Manhours	Materials	Comment
Design & Qual. Tests			
Manufacturing			cost for 3 vehicles
Modification & Installation	_____	_____	cost for 3 vehicles

1.4.8 WINDOW POLISHING (Tentpole C)

1.4.8.1 Summary

During SRB (Solid Rocket Booster) separation a haze of contamination forms on the Orbiter front windows. Since the most critical use of the windows is during landing this has become a plaguing problem. The requirement to clean (polish) the windows was not anticipated in the initial 160-hour turnaround schedules. The 144 hours required to prepare for 51-L launch is an unreasonable amount of time for an operational vehicle so this t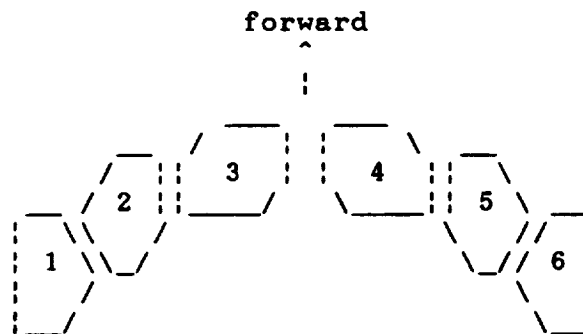ask is a candidate for improvement (Operations and Maintenance Instruction [OMI] V7253). The placement of the protective tent required during the cleaning operation precludes or impedes parallel work for some jobs performed at the nose of the vehicle.

A second reason this problem should be addressed is because cleaning (polishing) the windows cannot be accomplished prior to landing when it is most needed. Cleaning back on the ground merely precludes accumulation from more than one launch.

The solution therefore needs to allow the windows to be clear at the time of Orbiter landing. Redirecting the SRB separation motor exhaust would solve the problem but that would cause more problems than it solved, i.e., re-design and retest. The more logical solution then would be a non-stick surface for the windows or a jettisonable overlay. The chemical vapor deposition (CVD) of a diamond film on the outer pane appears to be a potential solution.

Future programs can avoid a similar occurrence by profiting from the lesson we have learned on the STS by careful design requirements. The data and experience gathered during the Shuttle flights provides a new baseline for future programs.

1.4.8.2 Related Issues

1. This is a slow, labor intensive operation. It is a "hand" operation that cannot be performed as precisely by any mechanized method.

2. Window contamination occurs during SRB separation and the need for clear windows is during landing. The cleaning (polishing) is accomplished after the actual need.

1.4.8 WINDOW POLISHING (Tentpole C)
       (Continued)

The following is a quote from document 84X10356, Space Shuttle Orbiter Thermal Protection System Flight Experiences:

ORBITER WINDOW CONTAMINATION

"The Shuttle Orbiter windows must meet normal aircraft requirements for pressure redundance and provide optical clarity and freedom from distortion to allow for operation typical of standard aircraft and other operations. In addition, the windows must have multimission capability to survive entry heating, insure single-flight safety after a micrometeoroid strike, and endure pressure stresses for at least 100 7-day missions. To satisfy these requirements, the window configuration consists of a three-pane construction: an outer fused-silica thermal, an inner alumino-silicate pressure pane, and a center fused-silica pane to serve as a redundant pressure pane.

Contamination of the outer surface of the windshields' thermal pane has occurred after each STS flight. This deposit or haze is most pronounced on the two center windshields, and efforts to remove this deposit with standard window cleaning agents (i.e., isopropyl alcohol, deionized water) have been unsuccessful. The source of this deposit has not been specifically identified, but the prime candidate appears to be the gasses from the plume generated by the solid rocket booster separation motors. Since this buildup of haze reduces pilot visibility, each window has been evaluated for acceptability prior to each flight. A hand polishing procedure, using cerium oxide, has been developed and used after each flight starting with STS-5. However, this polishing does not remove all the deposit and still requires an evaluation of each window's acceptability for the next flight."

1.4.8.3 Related Schedule History

1.   No time was allocated for this task in the original 160-hour schedule.

2.   60-hours are allocated on the STS-XX integrated operations assessment.

3.   144-hours were required to accomplish this task during 51-L processing. See Figure 1.

EFFICIENCIES/TECHNOLOGIES		NOVEMBER 1985 *																			
		11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	TECHNOLOGY																				
C	WINDOW POLISHING																				

*   All timebars indicate 3 shift/day operations

51-L OPF PROCESSING
Figure 1

The placement of the protective tent required during the cleaning
operation precludes or impedes parallel work for some jobs
performed at the nose of the vehicle. Although this activity has
not yet been a "show stopper" as the flows become shorter it
could easily become a real problem.

1.4.8.4   Current STS Methods

OMI V7253 -- WINDOW POLISHING FOR CONTAMINATION REMOVAL

OBJECTIVE: This OMI is to polish the orbiter window surfaces
for contamination removal. It will polish windows 2 thru 5
(L/H and R/H forward and mid). See Figure 2.   It will
photograph an Air Force resolution chart through windows 1
thru 6.   See figure 2 below.

forward

```
                        forward
                          ^
                          :
                  _  / ___  :  ___ \  _
                /  !!/   3  :  : 4  !!  \
           _  / 2 !!____/    \____!! 5 \  _
           : \\  /                      \ //  :
           : 1 \\_/                    \_// 6 :
           :  /                           \   :
           :__/                            \__:
```

Window Layout
Figure 2

OPERATIONS: A tent is built around the windows with a   catch
bag at the lower portion.   Tile protective covers   are
installed over window perimeter tiles on the forward and   mid
windows on each side.   The windows are then brushed   and
vacuumed to remove dust and lint particles. A polishing   pad
is fabricated by assembling alphalap felt polishing   material
over a rubber pad. The windows are then polished with   a
ceramic oxide/deionized water mixture. The polishing compound
is cleaned off the windows with deionized water/Joy soap. The
window surface is inspected with a fiberoptic light source to
see if the process needs repeating. After all windows have
been cleaned a resolution chart is placed on the outside of
the window and a photograph is taken from the nearest seat in
the orbiter cockpit. The photographs are inspected to verify
that the windows are now cleaned satisfactorily.

1.4.8.5 New Technology Requirements

Develop a new material for the windshield with surface that contamination will not adhere to. (Present outer window pane is low expansion fused silica glass chosen for its high optical qualities, 5/8 inch thick.)

1.4.8.6 Technology Application Requirements

1) Provide an overlay that could either be jettisoned after ascent or be removed after flight.

2) Apply a treatment to the windshield that the contamination will not adhere to.

3) Redesign the Solid Rocket Booster (SRB) separation motor exhaust to prevent it from impinging on the windows.

1.4.8.7 Technical Evaluation

Polishing the windows does not solve the real problem here, it merely keeps from compounding it. The windows are contaminated at the time of separation and the real need for clear windows is at landing, so the polishing comes after the need. Therefore the best solution would be a material that the contaminants could not adhere to.

Technical databases were researched for new materials that might be hard enough to resist the contaminants. Two candidates were found. First, polycrystalline magnesium aluminate spinel ($MgAl_2O_4$) possesses an unusual combination of optical, dielectric, physical and mechanical properties that make it an attractive candidate for windows. It is exceptionally strong and hard for an optical material, has good thermal shock resistance and moderate thermal expansion coefficient. (Refer to paper "POLYCRYSTALLINE $MgAl_2O_4$ SPINEL FOR HIGH PERFORMANCE WINDOWS" by D. W. Roy and J. L. Hastert.)

The second and most promising material is the diamond film. The following are excerpt taken from High Technology Magazine/April 1987:

> "Initially U. S. scientists were skeptical about reports from Russia in the 1970s that investigators at Moscow's Institute of Physical Chemistry had made true diamond films via chemical vapor deposition – a process by which a carbon vapor is deposited on a substrate. The claims "seemed almost like alchemy," says Russell Messier, associate professor of engineering science and mechanics art Penn State. The scoffing waned during the early 1980s, however, when Japan's National Research in Inorganic Materials (Ibaraki) repeated the Russian work."

"The coatings are now made either by CVD techniques
or by bombarding a substrate with high-velocity carbon
ions, which then form a film. In the latter method,
carbon ions may be generated from a hot carbon cathode
or produced by "sputtering"-that is, knocked off a solid
carbon block by a high-energy beam. Various ion-beam
and sputtering methods are under study at the NASA Lewis
Research Center in Cleveland.

Both types of techniques have generally yielded
diamond-like rather than true diamond films. The
diamond-like films are perfectly adequate for many
applications, according to Bruce Banks, chief of the
Electrophysics Office at NASA/Lewis. For example, this
could be used to make abrasion- and corrosion-resistant
computer disks, and infrared-transparent windows in
aircraft that would stand up against pitting and
scarring from raindrops at high speeds.

Among the most important developments in the CVD are
methods (based largely on the addition of hydrogen to
the methane) that allow diamond to be deposited on a
wide range of surfaces, including metals, silicon, and
glass; early methods allowed deposition only on other
diamonds. Crystallume president says his company plans
to use the Penn State technology to make a variety of
novel products, including cutting tools, knives,
surgical scalpels, computer disks, and windows for
planes and spacecraft; also in the docket are heat
sinks and heat-resistant enclosures for high-temperature
electronic equipment."

1.4.8 WINDOW POLISHING (Tentpole C)
(Continued)

1.4.8.8 Shuttle Cost Trades

IMPLEMENTATION DESCRIPTION: Design outer pane with CVD diamond on outer surface.

IMPLEMENTATION COST ESTIMATE:

Item	Manhours	Materials	Comment
Design & Qual. Tests			
Manufacturing			cost for 3 vehicles
Modification & Installation	_____	_____	_____
TOTALS			▪

GROUND OPS COST SAVINGS PER FLIGHT AFTER IMPLEMENTATION:

	Current				New			Delta		
Item	OLH	DMH	MAT	OTHR	DMH	MAT	OTHR	DMH	MAT	OTHR
V7253 Window Po$1K Polishing for Contamination Removal	100	300	$1K	___	0	0	0	300		

GROUND OPERATIONS SAVINGS FOR FUTURE VEHICLES:

The cost savings for future vehicles is approximately equal to cost avoidance of the current STS costs.

$$ COST ANALYSIS: This data is presented in Section 1.5.3, COST TRADE SUMMARY.

1.4.8.7   Conclusions & Recommendations

STS

A jettisonable overlay is a possible solution for this problem. Using shape-memory (Nitinol or similar material) for retainers and springs, a system could be designed to be energized by the temperature extremes of outer space. This would be automatic, with no crew involvement, and would not require penetrations through the vehicle surface for wires or linkages. Once back on the ground the shape-memory could be reset and new overlays easily installed. Jettisoning, without damaging the Orbiter is, in itself, a problem.

The best solution, however, would be the one where no flight maintenance is required. The diamond hard surface currently being developed appears to be the better solution. This study therefore recommends that the diamond surface be further investigated.

FUTURE VEHICLES

The "lesson learned" from this problem should be to analyze designs that have retro rocket plumes pointed toward surfaces that might be contaminated. Advances in Computer Aided Design and data collected by STS should allow for more accurate prediction of flow patterns on future programs.

Diamond-type coatings on windows of manned vehicles should be considered as a low cost standard procedure.

1.4.8 WINDOW POLISHING (Tentpole C)
        (Continued)

_____

1.4.8.8 Bibliography (Window Polishing)

(Each of the references listed below has its own bibliography)

1. RECON 84X10356; NASA Conference Publication 2315;
        D. M. Curry, D. J. Tillian
        Space Shuttle Orbiter Thermal Protection System Flight
        Experiences
        Advances in TPS and Structures for Space Transportation
        Systems Conference
        December, 1983:

2. RECON 84A13505; AD-P003 202
        Donald W. Roy, James L. Hastert,Coors Porcelain Company
        600 Ninth Street, Golden, Colorado 80401
        POLYCRYSTALLINE MgAl$_2$O$_4$ SPINEL FOR HIGH PERFORMANCE
        WINDOWS

3. RECON 84N25089;
        Clete J. Siebert, Fred A. Morris, 9 pages
        PASSIVE SUN SEEKER/TRACKER AND A THERMALLY ACTIVATED
        POWER MODULE
        Martin Marietta Denver Aerospace, Denver, Colorado

4. HIGH TECHNOLOGY Magazine
        Gordon Graff
        April 1987 issue
        "Diamonds find new settings", pages 45-47

1.4.9 THERMAL PROTECTION SYSTEM (TPS) INSPECTION (Tentpole D)

INTRODUCTION

The development of a reusable thermal protection system was a major technical accomplishment of the early Shuttle development. Although the current TPS is far from optimal, it has proved to be durable as well as forgiving. However, future vehicles will require or benefit from more advanced and capable TPS. This requirement is fully recognized by NASA and Industry and extensive effort is already being expended in this direction (see TPS Reference 8). Consequently, this study has concentrated on the maintenance and non-destructive testing (NDT) and flight readiness verification of TPS tiles used on the Orbiter. In the case of the current Orbiter, the NDT of over 30,000 tiles during each turnaround is not even possible. This study examines R & D effort in the area of NDT of the tiles and reduced life cycle costs.

1.4.9.1 Related Issues

From the <u>AFOTEC Launch Rate Capability Study</u>:

"Repairs to the TPS, especially tile, have caused launch delays. Data collected during Orbiter processing shows that time to repair or remove and replace damaged tile, and the time needed to rewaterproof after flight, are major constraints to reducing turnaround time.

The characteristics of the TPS (low-density, porous silica glass) make it susceptible to absorbing water when exposed to certain environmental conditions. Thunderstorms can cause significant amounts of water to be absorbed by the tile while the Orbiter is at the Pad. The absorbed water is added weight that is carried into orbit. This reduces the performance margin and requires Orbiter positioning to evaporate the absorbed water. Water still trapped in the tile starts to evaporate and boil off during descent as the temperature rises. With the rise in temperature and if sufficient amounts of water are present, pressure will increase in the tile and cause damage.

Problems caused by water absorption were identified early in the program and the need to rewaterproof the TPS after each flight was known and planned for. Scotchgard was applied by spraying in order to waterproof the tiles. This method proved ineffective as heavy precipitation washes off the Scotchgard. The rewaterproofing ' method was changed on STS-7/OV-099. The application ' method used involved injecting a small quantity of silane and acetic acid solution, known as DC6079, into the tile. There were no known problems associated with technique until after the STS-17 mission.

1.4.9 THERMAL PROTECTION SYSTEM (TPS) (Tentpole D)
(Continued)

Post-flight inspections of OV-99 after the STS-17 mission (sixth flight of OV-099) revealed that a thermal protection tile was missing from the lower surface of the fuselage. Inspection of the tile cavity revealed that RTV577, used as screed material and RTV560, used as an adhesion material, had softened. A decision was made to remove other tile bonded over screed in the area of the missing tile and inspect for the same condition. The RTV was found not to meet the required hardness specification, leading to the removal of approximately 4100 tiles bonded over screed. Extensive investigation and laboratory testing has concluded that the waterproofing material, DC-6079, combined with water and thermal cycles causes softening of the screed. The rewaterproofing procedure was again changed to require Scotchgard spraying over areas that has screed and to use injections with DC-6079 in other areas for near-term solution.----"

"Flight experience has demonstrated that inadequate TPS waterproofing can have mission impacts, as well as impact to ground processing flows. Until a more effective agent than Scotchgard can be certified for use on the Orbiter, the potential for launch delays due to water-soaked tiles as well as changes to planned on-orbit attitudes to facilitate TPS drying will exist."

From the National Space Transportation and Support Study (1995-2010), May 1986. " The TPS maintenance is a Logistic System Cost Driver. Future Operational Concepts should minimize TPS inspections & closeouts and minimize repair. System Requirements should be -- no between flight servicing and weatherproofing."

From our Operational Analysis in this study -- The turnaround time on-line required for TPS inspection, repair, and validation has decreased drastically since the first several flights; nevertheless, the on-line time and the manhours involved are still very significant.

1.4.9 THERMAL PROTECTION SYSTEM (TPS) (Tentpole D)
(Continued)

1.4.9.2 Schedule History

The initial design criteria (160-hr turnaround) allowed 40-hours flow time for TPS refurbishment. After the first 20 flights, the TPS tile replacements are shown in Figure 1. The OPF-XX schedule show on-line TPS refurbishment time as 336 hours. Typically, total manhours would be in the range of 2000 to 3000. A significant portion of this time is associated with test and verification of tile flight readiness.

		STS 29	STS 30	STS 31	STS 32	STS 33	STS	STS	STS	STS	STS	AVG.
R E A S O N R E P L A C E D	FLT. DAMAGE/LOSS	2	128	17	26	43						43
	ENVIR./TRANSIT DMG	0	0	0	302	0						60
	ENG'G CHANGE/MOD	305	83	7	394	778						313
	GRND DAMAGE/ERROR	14	21	0	17	9						12
	ACCESS&ENG TEST/EVAL	5	5	25	9	17						12
	REPLACEMNT TILE/BOND	31	21	10	28	11						20
	MISCELLANEOUS	6	1	1	14	0						4
	TOTAL	363	259	60	790	858						466
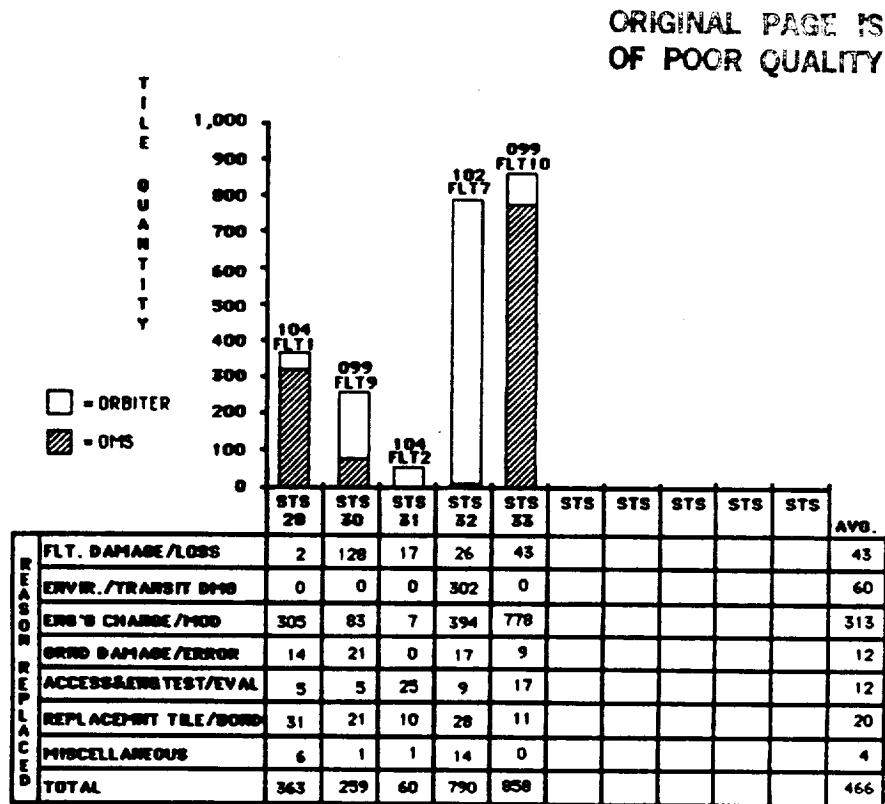
TILE REPLACEMENT HISTORY
Figure 1

1.4.9 THERMAL PROTECTION SYSTEM (TPS) (Tentpole D)
(Continued)

1.4.9.3 Todays Methods

For inspection and flight readiness verification there are two remaining major inspection problems associated with the TPS tiles, moisture intrusion and bonding. Flight damage is readily detected by macro and micro visual inspection.

Evolution into a macro-micro visual inspection was brought about by insufficient time available to perform both the original overall inspection and the needed repairs. With the macro-micro inspection, the overall vehicle TPS is given a gross inspection while selected areas receives detailed inspection. If a number of discrepancies show up in the detailed inspection, the option exists to expand into other areas. Also, the macro may lead directly to micro if the conditions warrant it.

<u>Moisture intrusion</u> on the Orbiter's lower surface is grossly detected with the use of infrared scanners but it is not a qualitative inspection.

A major problem with the tile system is verification of the <u>bond strength</u> in a non-destructive manner. Currently there are no NDT methods available; this has dictated the use of proof or pull testing as a means of bond verification.

The objective of OMI V6028, "Post Flight Orbiter Reusable Surface Insulation Inspection", is to perform post-landing and pre-ferry survey/inspection of the TPS and determine if components exhibit obvious latent/mission-induced damage that would require reservicing, repair, redesign, or replacement. The tasks involved are:

(1) Post landing Orbiter debris inspection and mapping verification.

(2) Engineering macro inspection of RSI (pre-ferry flight)

(3) RSI inspection (macro and micro)

(4) Engineering inspection / additional micro inspections

(5) Micro inspection of leading edge subsystem and nose cap (internal)

(6) Micro inspection of RCC panels no. 10 and 17 (internal)

(7) Micro inspection of RCC panel no. 9 (internal OV-102)

(8) Micro inspection of RCC panel no. 16 (internal OV-099) The procedures and authorization for infrared tests for moisture and pull tests for bonding are not OMI's.

1.4.9 THERMAL PROTECTION SYSTEM (TPS) (Tentpole D)
(Continued)

1.4.9.4 Technology Application Requirements

The requirement for improved thermal protection systems is well understood and in work; consequently, this requirement is not addressed by this report.

This study does address the requirement which exists for developing fast, dependable, qualitative, repeatable, non-destructive tests for moisture and bonding. This is critical for reducing turnaround time for the existing STS tile and blanket thermal protection systems. Depending on the future type TPS used, these new techniques will be useful in whole or part for future vehicles.

1.4.9 THERMAL PROTECTION SYSTEM (TPS) (Tentpole D)
(Continued)

1.4.9.5 Technical Evaluation

After determining the technology requirement for TPS tile non-destructive testing, a technology search was made using the XTKB (Expanded Technology Knowledge Base) developed for this Study and the NASA RECON database. Technical papers and document abstracts were screened from various "anding" of available secondary keys in RECON including:

THERMAL PROTECTION, ABSORPTIVITY, ACOUSTIC FATIGUE, ACCEPTABILITY, ADHESION TESTS, ANOMALIES, ASSEMBLING, BONDING, CONTAMINATION, CREEP TESTS, DAMAGE ASSESSMENT, MOISTURE, MOISTURE RESISTANCE, NONDESTRUCTIVE TESTS, PERFORMANCE TESTS, PREDICTIONS, PREFLIGHT OPERATIONS, PRELAUNCH PROBLEMS, QUALITY CONTROL, RADAR EQUIPMENT, SPECTROSCOPIC ANALYSIS, TENSILE TESTS, TEST EQUIPMENT, CHALLENGER, DYNAMIC TESTS, FAILURE MODES FATIGUE TESTS, GROUND SUPPORT EQUIPMENT, GROUND SUPPORT SYSTEMS, GROUND TESTS, ILLUMINATING, INSPECTION, LOAD TESTS, MATERIALS TESTS, MAINTENANCE, LASER APPLICATIONS, TENSILE TESTS, VIBRATION TESTS, WAVELENGTHS, WINDOWS, X R, X RAY DIFFRACTION, X RAY SPECTROSCOPY.

Where the abstracts appeared promising, actual documents or papers were obtained and analyzed from an application standpoint. The result of this effort was papers with direct application to this technology requirement. These are listed in the bibliography at the end of this topic.

PROBLEM DESCRIPTION: The tile material is made of microscopic silica fibers that are slurried with a binder, pressed and sintered into rigid, lightweight (9#/ft^3) ceramic blocks. Individual tiles are machined from the blocks. The tile dimensions are typically 6"x6" and varies in thickness from 1/2" to 4". After machining, the top and sides of the tiles are coated with a thick borosilicate glass coating impregnated with pigments to provide the coating with its high temperature emittance properties. The coating also affords limited protection against moisture pick-up and handling damage.

The attachment of the tile to the aluminum skin of the vehicle is accomplished by adhesive bonding the components of the bonded system are shown in Figure 2.
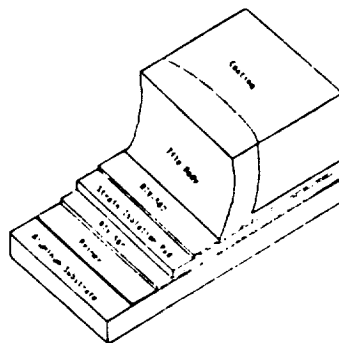
TILE ATTACHMENT SYSTEM
Figure 2

Because of the low strength of the tile material and the thermal
expansion mismatch between the tile and the aluminum, they could
not be bonded directly to each other. A nomex felt pad called a
strain isolation pad (SIP) was bonded between the tile and the
aluminum to minimize lateral strain transfer.

Needling of the nomex pad to control its thickness and stiffness
resulted in fibers oriented straight through the thickness of the
pad. On loading of a tile, the straight fibers created hard
points or stress concentrations in the bottom of the tile. This
condition is shown in Figure 3. The net result was a lower bond
strength than the design had taken into account.

ALUMINUM SUBSTRATE
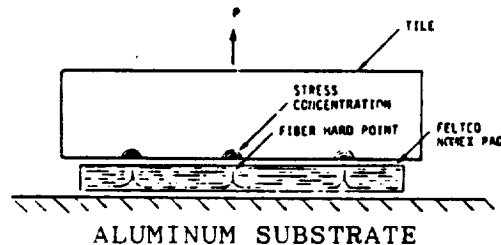
STRESS CONCENTRATIONS IN TILE
Figure 3

The tiles are extremely critical to reentry survival of the
vehicle. The loss of a single tile could have serious
consequences. Because of the extreme criticality of the tiles,
successful completion of a proof test, although very important
and confidence building, was not considered sufficient to ensure
the adequacy of the tile bond strength. An NDT technique is
required to ensure no significant damage occurs to to the tiles
during testing.

ACOUSTIC TESTING (ref 86A34627): Early in the STS program, a
crash test program was implemented by JSC and Rockwell/Downey, to
develop and implement an acoustic emission monitored proof test
system. This was implemented at KSC on a 24-hr, 7-day/week
schedule. Eighteen systems (Figures 4 & 5) were used to certify
approximately 30,000 tiles for the first Orbiter flight. Each
test required about one hour to complete and a total of about
20,000 tests were performed overall. Although many problems were
encountered in this application of acoustic emission,
particularly extraneous noise sources causing high reject rates,
the problems were generally solved or worked around. Application
of acoustic emission in this instance was extremely beneficial in
that it added confidence to an unusually critical system that was
yet to be proven. Acoustic emission helped screen out tiles that
had inadequate strength. Acoustic emission monitoring is no
longer used in tile testing; however, to obtain a confidence
level prior to the first flight, it was the only method
available.
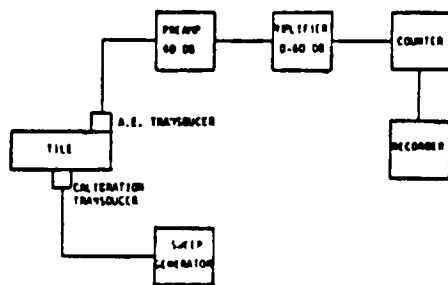
ACOUSTIC EMISSION SYSTEM
Figure 4
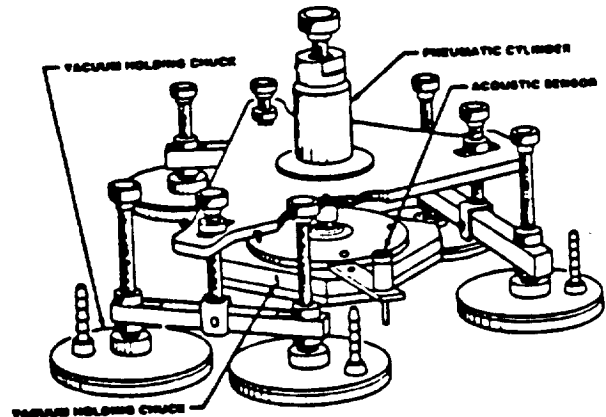
PROOF TEST DEVICE
Figure 5

The objective of the tests was to establish a pass/fail criteria based on acoustic activity or signatures prior to failure. Full size tiles with the intermediate SIP layer were bonded to aluminum substrates. Loading conditions evaluated for acoustic emission signatures included high and low strain rates, sustained loading, and fatigue cycling. Acoustic activity could be detected long before actual failures occurred. The progressive nature or time dependency of the bondline failures were ideally suited for acoustic emission monitoring. The difficulty was establishing gain settings that were not overly sensitive and yet still provided enough conservatism to ensure that early damage signatures could be identified. A fatigue test sequence was utilized that enabled the difficulty to be overcome. The sequence consisted of the following: (1) incremental proof load with 60-second holds at each level, (2) terminate hold when significant acoustic activity occurred, (3) decrease load to 80% of maximum proof load attained and (4) fatigue cycle from zero to 80% until failure occurred or 400 cycles were reached. A typical fatigue test profile is shown in Figure 6.
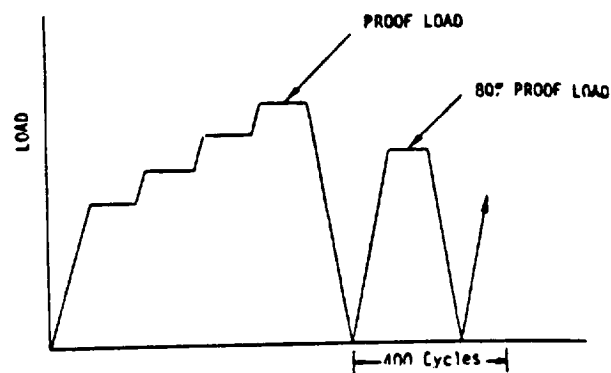
TYPICAL FATIGUE TEST SEQUENCE
Figure 6

The acoustic emission acceptance criteria were based on the fatigue test results. Tiles which passed the 400 cycles without failure were considered successes or good tiles and those that failed were considered failures or bad tiles. The acoustic counts that occurred during the proof test prior to the start of each fatigue were evaluated for criteria that would screen all of the bad tiles and maximize the acceptance of good tiles. The logic is illustrated in Figure 7. Criteria were established such that each failure was rejected by two or more of the acceptance criteria. The criteria that were established are shown in Figure 8.

	ACCEPT	REJECT
GOOD TILE	MAXIMUM ATTAINABLE	LOWEST ATTAINABLE
BAD TILE	MUST BE ZERO	MUST BE ALL

ACCEPTANCE LOGIC
Figure 7
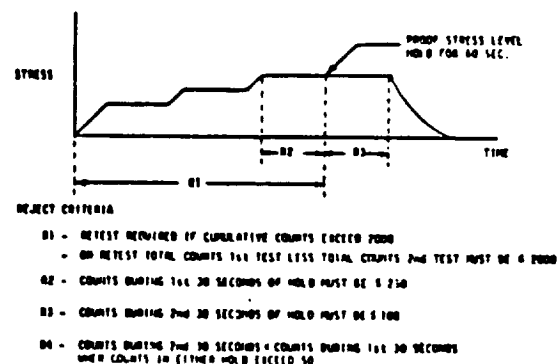
ACOUSTIC EMISSION REJECT CRITERIA
Figure 8

In addition to passing the proof test, each tile had to pass the four acoustic emission criteria. Failure to meet any one of the criteria was cause for rejection.

ACOUSTIC EXCITATION-/-LASER SENSING: The search for a cost-effective NDT for bond integrity led NASA/KSC, in 1984, to begin discussions with the Idaho National Engineering Laboratory (INEL) and its contractor, EG&G. The outgrowth of these discussions led to a contract to develop an experimental technique using acoustic excitation and laser measurement of the tile response.

In early tests, the tiles were excited using a variety of methods including white noise and impulses from an acoustic speaker, as well as mechanical methods. In all cases, the tiles showed characteristic spectra with several distinct vibration modes present. The two strongest modes of vibration were believed to be fundamental frequencies of two plate modes in the anisotropic composite material from which the tile is formed. The relative amplitudes of these oscillations have been shown to be directly dependent on the bond between the SIP and the tile and the SIP

and the aluminum plate used in these tests. When bond deterioration was induced, a large drop in amplitude of the second spectral peak was consistently observed as well as several less dramatic but possibly significant spectral shifts. It was a consistent observation that the spectra generated by the tile were very sensitive to variations in the bond condition.

A second phenomenon was investigated in which the tile-SIP oscillation was examined at lower frequencies where the system would behave as a simple mass-spring with the tile being the mass and the SIP as the spring. The spring constant would then depend on the total area of good bond. Tests were limited in this area, however, by the difficulty in obtaining a simple excitation method with sufficient low frequency content to give an acceptable signal/noise ratio. This approach has promise as an independent or complementary measurement.

PHASE I RESULTS from the EG&G STUDY (summarized)

1. Non-contacting acousto-optic sensing is feasible. Good agreement between laser-acoustic sensor system and standard accelerometer between 200 and 5000 Hertz. No apparent problems in sensing directly off a tile surface even after normal mission degradation.

2. Resonance vibrations of the tiles studied are affected by disbonds. Both the point and image data showed the effects of bond slicing in the single tile tests.

3. Similar tiles have significantly different spectra, but all of the tiles studied show common spectral features.

4. Phase I Study results provide beginning point for complete understanding of the phenomena.

EG&G STUDY PHASE II PLANNING

1. Refine and qualify the sensor design.

2. Model and analyze the dynamic tile behavior.

3. Prototype system design.

4. Fabrication, checkout, integration into Orbiter processing. (See Figure 9).

1.4.9 THERMAL PROTECTION SYSTEM (TPS) (Tentpole D)
(Continued)

ORIGINAL PAGE IS
OF POOR QUALITY
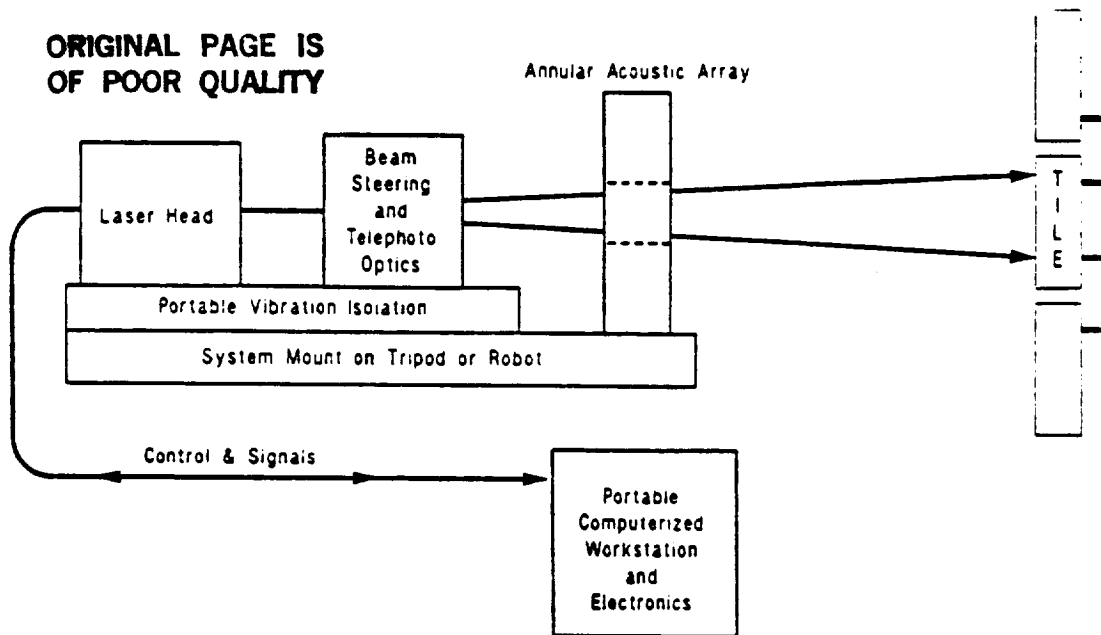
ACOUSTO-OPTIC SENSING SYSTEM CONCEPT (EG&G)
Figure 9

BACKSCATTER X-RAY TECHNOLOGY

During PHASE 2 of this STS Ground Operations Efficiencies / Technologies Study, it is planned to further investigate the potential of backscatter x-ray techniques using actual Orbiter tiles and IUS engine inspection facilities.

1.4.9.6 Conclusions and Recommendations

Extensive effort is going on the development of improved thermal protection systems. This Study was limited to investigating the problems and potential solutions for ground operations efficiencies in non-destructive testing of Orbiter tiles.

An automated non-contact NDE is required to reduce turnaround time and provide the degree of reliability necessary.

Based on the Phase 1 reported progress of the EG&G, KSC sponsored, investigation into an Acoustic Excitation/Laser Sensing System, it is recommended that this effort be accelerated to provide an on-line system to support Shuttle processing as soon as possible.

It is also recommended that bonded samples of Orbiter tiles be provided to Boeing for a preliminary check into the feasibility of using backscatter X-ray techniques currently being used on the IUS solid rocket motors.

1.4.9   THERMAL PROTECTION SYSTEM (TPS) (Tentpole D)
(Continued)

1.4.9.7   Bibliography - TPS

(Each of the references listed below has its own bibliography)

(1)   EGG-SD-7571
Barna, B.A.; Allemeier, R.T.; Rodriguez, J.G.;
26 pages, Informal Report, February 1987
NDE OF THE ORBITER THERMAL TILE PROTECTION SYSTEM
EG&G, Idaho (DOE Idaho National Engineering Laboratory)
Prepared for NASA KSC, Contract No. DE-AC07-76IDO1570

(2)   RECON 86A18037
Shideler, J.I.,et al; 7 pages; May 1985
NASA Langley Research Center, Hampton, Va.
VERIFICATION TEST OF DURABLE THERMAL PROTECTION SYSTEM
CONCEPTS

(3)   RECON 85N16979
Dotts, R.L.; Curry, D.M.; Tillian, D.J.
19 page paper, June 1983
NASA Johnson Space Center, Houston, Texas
ORBITER THERMAL PROTECTION SYSTEM

(4)   RECON 84A49504
Cooper, P.A., et al;
NASA Langley Research Center
7 page paper, October 1984
EFFECT OF SIMULATED MISSION LOADS ON ORBITER THERMAL
PROTECTION SYSTEM UNDENSIFIED TILES

(5)   RECON 84A36557
Sawyer, J.W.
NASA Langley Research Center
8 page paper, June 1984
MECHANICAL PROPERTIES OF THE SHUTTLE ORBITER THERMAL
PROTECTION SYSTEM STRAIN ISOLATION PAD

(6)   RECON 84A17175
Mack, F.E. and Hogenson, P.A.
Rockwell International Corporation
15 page paper, April 1983
ULTRASONIC INSPECTION TECHNIQUES APPLIED TO STRENGTH
EVALUATION OF SHUTTLE ORBITER THERMAL PROTECTION TILES

(7)   RECON 83N30702
Cooper, P.A.
NASA Langley Research Center
9 page paper, undated
SPACE SHUTTLE THERMAL PROTECTION SYSTEMS

(8)   RECON 84X10356
KELLEY, H.N. et al
NASA Langley Research Center
516 page Symposium Document, December 1983
ADVANCES IN TPS AND STRUCTURES FOR SPACE TRANSPORTATION
SYSTEMS

1.4.10 POWER REACTANT STORAGE & DISTRIBUTION (PRSD) (Tentpole E)

1.4.10.1 Summary

With the existing mission requirements for STS, the fuel cell still appears the best option for the Orbiter energy storage system. If the mission duration should change drastically in either direction, however, batteries or solar systems could become viable options subject to detailed trade studies.

While the Orbiter fuel cells are several times more efficient than those for Apollo, they are not state-of-the-art. The requirement exists for development of reliable, easily maintainable, high density fuel cells to be incorporated in a Shuttle Block Modification.

For future vehicles, there are a number of promising energy storage devices in various stages of development in the areas of: regenerative fuel cell systems, Ni/H$_2$ batteries, Na/S batteries, and Li/SOCL$_2$ batteries. Any specific recommendations would, of course, involve detailed trade studies of performance, energy density, maintainability, life cycle costs, development risk, etc. The NaS batteries appear to be the best known bet for further development in the area of materials research.

1.4.10.2 Related Issues

```
ID:             ( 080.00
Issue:          (REQUIREMENTS
Issue Source:  (51-L FINDINGS        PAGE 065
Operation:     (PROPELLANT       )
Location:       PAD
Orb.No/Mission: (099/51-L
Hardware/Software:(POWER         )   PRSD
Reference Data:  PRACA              IPR33V-0007, PR STS-0817-0-0149
Description:
IPR 33V-0007-- PRSD LO2 DEWAR VACUUM LOSS. DURING MONITORING OF THE DEWAR
VACUUM, IT WAS NOTED THAT THE VACUUM HAD GONE FROM BELOW 25 MICRONS, THE OMRSD
REQUIREMENT, TO ABOVE 100 MICRONS. THE SYSTEM WAS USED IN THAT CONFIGURATION
FOR STS-33 PRSD LOADING. NO WAIVER WAS REQUESTED.
```

```
IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
ID:             ( 004.00
Issue:          (COST/MANHOURS   )
Issue Source:  (51-L FINDINGS   )   PAGE 075
Operation:     (TEST            )
Location:      (PAD             )   PAD B
Orb.No/Mission: (099/51-L
Hardware/Software:(GSE               MANPOWER SYPHONED FROM STS-33 O/C....
Reference Data:  N/A
Description:
"THE PRSD GSE CHECKOUT WAS COMPLETED JUST PRIOR TO SCRUB."
```

1.4.10 POWER REACTANT STORAGE & DISTRIBUTION (PRSD) (Tentpole E) (Continued)

```
ID:              304.00
Issue:           REQUIREMENTS
Issue Source:    LUCAS LTR TO HQ     5/13/82 "OPERATIONS EFFECTIVENESS"
Operation:       GENERIC
Location:        KSC
Orb.N/Mission:   GENERIC
Hardware/Software: SRB
Reference Data:  N/A                 PROGRAM REQ REDUCTION REVIEW--LL TEAM
Description:
RRR No.    TITLE                               (CONTINUED FROM 303.00)
LL-24  ELIMINATE LPONS STANDBY FOR HYPER AND PRSD SERVICING
LL-25  REDUCE MANNING OF LCC FIREX CONSOLE TO ONLY PERIODS WHEN PAD IS CLEARED
       PRESENCE REQUIRED ANY TIME THERE ARE RESIDUALS ON THE ORBITER
LL-26  REDUCE PNEUMATICS SAMPLING REQUIREMENTS
LL-27  PERFORM MODIFICATION TO OVERPRESSURE PIPING TO ELIMINATE J-PIPES
LL-28  MACHINING AND WELDING SPECIFICATIONS- IT IS RECOMMENDED THAT A REVIEW
       OF THE MANUFACTURING/FABRICATING TOLERANCES BE CONDUCTED BY THE DESIGN
       ORGANIZATIONS WITH EMPHASIS ON REDUCING AND STANDARDIZING REQUIREMENTS
LL-29  ELIMINATE NEED FOR PAD SEARCHLIGHTS
:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

ID:              1960.00
Issue:           DESIGN
Issue Source:    NE-PR MOD LIST      (POST 51-L PRELIM. MOD LISTING)
Operation:       GENERIC
Location:        KSC
Orb.N/Mission:   GENERIC
Hardware/Software: GSE             PRSD LEAK & FIRE DETECTION SYSTEM
Reference Data:  ESR             ESR K11010     (6/9)
Description:
LSOC  --   C. FLOYD

STUDY ESR/MOD

LOCAL POWER CONTROL SHOULD BE PROVIDED FOR THE PRSD LEAK AND FIRE DETECTION
SYSTEM, TO PERMIT POWER APPLICATIONS LOCALLY AS WELL AS FROM THE CONSOLE. THIS
WOULD PERMIT THE SYSTEM TO REMAIN POWERED DURING A LOSS OF GSE LINK OR
TEMPORARY SHUTDOWN OF THE HIM. ESR K11010. (6/9)


:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
ID:              2045.00
Issue:           DESIGN
Issue Source:    NE-PR MOD LIST      (POST 51-L PRELIM. MOD LISTING)
Operation:       GENERIC
Location:        KSC
Orb.N/Mission:   GENERIC
Hardware/Software: GSE             PC/PRSD
Reference Data:  ESR             ESR K11560, K11561, K10534.  (39/14)
Description:
LSOC  --   C. FLOYD

STUDY ESR MOD

SIMPLIFY OPR PC PRSD GO + NO SYSTEMS (ESR'S APPROVED BUT NOT YET IMPLEMENTED.
REF.: ESR K11560, K11561, K10534.   (39/14)
```

ID: <2808.00>   Issue(s): DESIGN   :
Issue(s) cont.:   :   :
Issue Source: <NE-FEC MOD LIST >   (POST 51-L PRELIM. MOD LISTING)
Operation: <FLIGHT   >
Location: <ORBITR>
Orb.No/Mission: <GENERIC   >
Hardware/Software:<ORBITER   >   FUEL CELLS
Reference Data: N/A   (58/5)
Description:
PRSD/FC

STUDY

"FUEL CELL IMPROVEMENT MODIFICATION. DELETE END CELL HEATERS AND MODIFIES
START-UP HEATER."
(58/5) (#2)

ORIGINAL PAGE IS
OF POOR QUALITY

::

ID: <2809.00>   Issue(s): DESIGN   :
Issue(s) cont.:   :   :
Issue Source: <NE-FEC MOD LIST >   (POST 51-L PRELIM. MOD LISTING)
Operation: <FLIGHT   >
Location: <ORBITR>
Orb.No/Mission: <GENERIC   >
Hardware/Software:<ORBITER   >   INSTRUMENTATION FOR CELL VOLTAGES
Reference Data: N/A   (58/4)
Description:
PRSD/FC

STUDY

"PROVIDE SUFFICIENT INSTRUMENTATION CHANNELS SO THAT FUEL CELL SINGLE CELL
VOLTAGES ARE AVAILABLE."
(58/4 #1)

::

ID: <2810.00>   Issue(s): DESIGN   :
Issue(s) cont.:   :   :
Issue Source: <NE-FEC MOD LIST >   (POST 51-L PRELIM. MOD LISTING)
Operation: <FLIGHT   >
Location: <ORBITR>
Orb.No/Mission: <GENERIC   >
Hardware/Software:<ORBITER   >   PRESSURE TRANSDUCERS FOR REACTANT REGS
Reference Data: N/A   (65/9)
Description:
PRSD/FC

STUDY

"INSTALL PRESSURE TRANSDUCERS AT OUTLET OF REACTANT REGULATORS."
(65/9 #1)

___

ID: (2511.00)   Issue(s): DESIGN   :
Issue(s) cont.:   :   :
Issue Source: (NE-PRO MOD LIST)   (POST 51-L PRELIM. MOD LISTING
Operation: (FLIGHT   )
Location: (ORBITER)
Orb.No.Mission: (GENERIC   )
Hardware/Software:(ORBITER   )   COOLANT ACCUMULATOR INSTRUMENTATION
Reference Data: N/A   (65/10)
Description:
PRSD/FC

STUDY

"PROVIDE COOLANT ACCUMULATOR WITH QUANTITY READOUT INSTRUMENTATION."
(65/10. (#L)

:::

ID: (2512.00)   Issue(s): DESIGN   :
Issue(s) cont.:   :   :
Issue Source: (NE-PRO MOD LIST)   (POST 51-L PRELIM. MOD LISTING)
Operation: (FLIGHT   )
Location: (ORBITER)
Orb.No/Mission: (GENERIC   )
Hardware/Software:(ORBITER   )   PURGE VALVE POSITION INDICATORS
Reference Data: N/A   (65/11)
Description:
PRSD/FC

STUDY

"PROVIDE INDIVIDUAL POSITION INDICATORS AND COMMENTS TO H2 AND O2 PURGE VALVES"
(65/11) (#C)

:::

ID: (2513.00)   Issue(s): DESIGN   :
Issue(s) cont.:   :   :
Issue Source: (NE-PRO MOD LIST)   (POST 51-L PRELIM. MOD LISTING)
Operation: (FLIGHT   )
Location: (ORBITER)
Orb.No.Mission: (GENERIC   )
Hardware/Software:(ORBITER   )   FUEL CELL PH SENSOR
Reference Data: N/A   (58/2)
Description:
PRSD/FC

STUDY

"PROVIDE A "SELF CHECK" CIRCUIT IN FUEL CELL PH SENSOR."
(58/2)

ID: <3900.00>
Issue: <MISSION   >
Issue Source: <FLORIDA TODAY   >   NEWSPAPER ARTICLE DATED APRIL 12, 1986
Operation: <FLIGHT   >
Location: <KSC   >
Orb.No/Mission: <102/STS-2   >
Hardware/Software:<N/A   >
Reference Data: N/A
Description:
STS-2: COLUMBIA
CREW: JOSEPH ENGLE AND RICHARD TRULY
LAUNCH: NOVEMBER 12, 1981 AT 10:10 AM
LANDING: NOVEMBER 14 AT EDWARDS AIR FORCE BASE, CALIF. AFTER 36 ORBITS
OF NOTE: FLIGHT CUT SHORT AFTER FAILURE OF A FUEL CELL

ORIGINAL PAGE IS
OF POOR QUALITY

‡‡

ID: < 200.00>
Issue: <LOGISTICS/SPARES>
Issue Source: <51-L FINDINGS   >   PAGE 036
Operation: <REPLACEMENT LRU >
Location: KSC
Orb.No/Mission: <099/51-L   >
Hardware/Software:<N/A   >
Reference Data: N/A
Description:
"THERE ARE INSUFFICIENT SPARE PARTS TO MAINTAIN THE ORBITER FLEET IN AN
OPERATIONAL CONFIGURATION. THEREFORE, THE PRACTICE OF PARTS CANNIBALIZATION
HAS BEEN RESORTED TO IN ORDER TO MEET MANIFEST SCHEDULE DEMANDS. MANY LRU'S
(LINE REPLACEABLE UNIT) WERE REMOVED AND REPLACED DURING THE STS-33 FLOW.
LISTED BELOW ARE THOSE MAJOR VEHICLE COMPONENTS/LRU'S WHICH WERE CANNIBALIZED
FROM ANOTHER VEHICLE AND THOSE THAT WERE DONATED BY OV-099: 1. ENGINE MOUNTED
HEAT SHIELDS AND ATTACHING HARDWARE,TO 103). 2. FUEL CELL #1(FROM 103).
3. PLUNGER ON FLIPPER DOOR(TO 103). 4. R/H WING DUCT(FROM 104). 5. ENGINE
MOUNTED HEAT SHIELDS AND ATTACHING HARDWARE(FROM 104). 6. THERMAL BARRIER(FRM
103). 7. NLG TIRES FROM 103).   (CONTINUED ON ID 200.01)
‡‡
ID: <4909.00>
Issue: < TIME ON-LINE   >
Issue Source: <STAS   >   BOEING IPR-2 GROUND OPS. SPLNT. 3-12-86
Operation: <N/A   >
Location: <ALL   >   SPACE TRANSPORTATION ARCHITECTURE STUDY
Orb.No/Mission: <
Hardware/Software:<N/A
Reference Data: N/A
Description:
"LESSONS LEARNED: PRESENT ORBITER EXHIBITS EXCESSIVE FAILURE RATES.

EXAMPLES: * BRAKING SYSTEM REQUIRES CONTINUAL REPLACEMENT
           * APU FAILURE RATES TOO HIGH
           * FUEL CELLS HAVE POOR LIFE EXPECTANCY

1.4.10.3 Schedule History

The ground operations turnaround time for the PRSD is not consistent with the requirements for an operational capability.

Figure 1 shows the shifts of work for processing the PRSD system for 51-L at the OPF. The total time for 51-L includes the PAD time shown below:

Tank Set 4 R & R	120 hours	
OPF Ops & T/S	139 hours	
Pad Ops (Purge/Load)	36 hours	(7 hrs were Pad clear and 17 hrs local clear for this operation)

EFFICIENCIES/TECHNOLOGIES		NOVEMBER 1985 *	DECEMBER 1985 *
		11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
	TECHNOLOGY		
E	FUEL CELLS OPERATION		

*   All timebars indicate 3 shift/day operations

51-L OPF PROCESSING
Figure 1

1.4.10.4 Current STS Methods

The descriptions below of the current STS OMI's for the Power Reactant and Storage System (PRSD) provide a graphic view of the complications, time on-line, and manhours expended because of the current design. These descriptions represent 3794 pages of OMI's and exclude a very significant page count for non-OMI procedures.

DESCRIPTIONS:

V1091 -- ORBITER PRSD CRYO DRAIN (LPS) (407 pages)

OBJECTIVE: OMI is to provide instructions to detank and inert Orbiter PRSD LO_2 and LH_2 tanks at the OPF using the Launch Processing System (LPS). This is a hazardous OMI due to LO_2 from Orbiter through GSE to vents.

PREPARATION: Includes Pneumatic Systems Setup; Cryogenic Systems Setup; and Engineering Walkdown.

GSE/VERIFY POWER UP: LPS activated; OPF GH_2 and LH_2 Systems Power Up; HWS Power Up by instrumentation; OPF GO_2 amd LO_2 Systems Power Up; Verify Orbiter Power and Cooling per Standard Power Up.

OPERATIONS: GH$_2$/LH$_2$ and   GO$_2$/LO$_2$ Systems   Purges/
Pressurization;   Moisture Sample using S72-1106-1;   Sample
Pressure   for Purity;   Pressurize and Leak Check Orbiter/GSE
Interface;   Power Down Fuel Cell Power Plants and Start Cool
Down;   Drain Orbiter PRSD LH$_2$ System until Tanks/GSE   Drain
Warmup   is Accomplished;   Purge Orbiter T-0 Line and   Lockup
Static Purge in Orbiter PRSD LH$_2$ System;   Drain Orbiter PRSD
LO$_2$ System   until Tanks/GSE Drain Warmup   is   Accomplished;
Purge Orbiter T-0 line and Fuel Cells Lockup Static Purge in
Orbiter PRSD LO$_2$ System.

V1022 --   FUEL CELL AND PRSD SYSTEM TEST - ORBITER
          VEHICLE - LPS (810 pages)

OBJECTIVE: Provide   procedures   for verification   of   fuel
cell/PRSD instrumentation and controls, including functional
operation   of   system relief valves and control circuits   on
the Orbiter.

PREPARATION: Perform -- Pre-Power Switch List and Pre-Power
GSE Placards and Setups.

POWER-UP: Perform   --   Power Up LPS;   Power   Up   PRSD   Gas
Systems (O$_2$H$_2$).

PERFORM: H$_2$O   RV Checks - ISOL VLVS to ECLSS   Water   Tanks
Closed.   Display VDR   O$_2$ STS GSE and VDR29   H$_2$ Sys   GSE.;
Perform   Purity and Moisture Samples as follows: Purge   and
Sample   O$_2$ Sys GSE, Gas and Liquid Systems with GHe;   Purge
and   Sample H$_2$ System GSE, Gas and Liquid Systems with   GHe;
Depress   GSE   to   Pad Pressure. Mate   Umbilical   Lines   at
Mid-Body,   T-0,   Horizontal   Drains,   and   Overboard   Relief
Ports.   Display VDR51 - Orbiter Mechanical System. (Cont'd)

Verify   Orbiter   Power   and Cooling per Standard   Power   Up;
Vehicle   Valve   Cycle   (EM) and Flow   Checks   Utilizing   Pad
Pressure   from   GSE;   FC/Cool   and   Loop   Instrumentation
Verification;   FC   Heater   Operational Checks: FC   Heater
Operational   Checks;   H$_2$O   Line Strip   Heaters,   H$_2$O   Valve
Heaters;   H$_2$O Relief Port Heaters;   O$_2$/H$_2$ Vent Port Heaters.

DISPLAY: VDR29,   H$_2$ System GSE and VDR51,   FC   Operations.

PERFORM: Modify Cryo Tank Control Logic PGMS VCR05 and   06
to   Allow   Checkout;   Pressurize   Vehicle   Manifolds   via
Horizontal   Drain   Line   and Perform Manifold Decay   Test;
Instrumentation   Checks and Pod External Leak Checks;   Tank
CV Reverse Leakage Checks;   Manifold RV Crack/Reseat Checks;
Horizontal   Drain   Pod I/F Leak Checks at Flight   Pressures;
T-0   Valve   Leak   Check   and   T-0 Pod Poppet Leak   Check;
Pressurize   T-0   Line Run and Leak Check Pod I/F   at   Flight
Pressure;   Open   Gas Supply Valve and Vent Vehicle   to   Pad
Pressure.

DISPLAY: VDR50 ORBITER H_2 Electrical Control and Monitor and VDR51, FC Operations.

PERFORM: On Cryo tanks -- Vac-ion Pump Checks and Monitor vacuum Levels; Tank Quantity Checks; Modify Limits of Tank Heater Monitor Control Logic; Tank Heater Checks via Cockpit Control; Tank LO/Hi Pressure Checks Using GSE Ramp Rate with Tank Heaters Off; Tank Heater Auto On/Off Checks using GSE Ramp Rate with Tank Heaters in Auto.

DISPLAY: VDR29, H_2 System GSE and VDR50, Orbiter Electrical Control and Monitor H_2.

PERFORM: Modify Tank Heater Control Logic Limits and Tank Temperature Monitor Limits; Slowly Pressurize Cryo Tanks and Perform Instrumentation Checks. Lo Pressure CW Checks, Heater Turn On Check (Lo Pressure-Auto Mode) Cutoff Checks, and Heater Manual On/Off Checks above Auto Cutoff Pressure; Leak Check Mid-Body Pos I/F and FC Interface; FC Instrumentation Checks at Flight Pressures; Cryo Tank RV Crack/Reseat Checks and Post Reseat Internal Leak Check; Vent Cryo Tank to Soak Pressure.

DISPLAY: VDR22, O_2 SYSTEM GSE and VDR51, FC Operations.

PERFORM: Modify VCR03 and 04 to Allow Checkout; Include leak checks for uninsulated connections on O_2 System.

DISPLAY: VDR49 Orbiter Electrical Control and Monitor -- O_2, FC Operations.

PERFORM: Vac-Ion Pump Checks and Monitor Vacuum Levels; Tank Quantity Checks; Modify Limits of Tank Heater Monitor Control Logic; Tank Heater Checks via Cockpit Control; Tank LO/HI Pressure Checks Using GSE Ramp Rate with Tank Heaters Off; Tank Heater Auto ON/OFF Checks using GSE Ramp Rate with Tank Heaters in Auto; Tank Current Sensor Trip/Reset Test, Tank Heaters Off; Tank Heater Current Sensor Tests - Tank Heaters On (In Auto-Mode, Tank Pressure LO.

DISPLAY: VDR22, O_2 System GSE and VDR49, Orbiter Electrical Control and Monitor - O_2.

PERFORM: Modify Tank Heater Control Logic Limits and Tank Temperature Monitor Limits; Slowly Pressurize Cryo Tanks and Perform Instrumentation Checks. Lo Pressure CW Checks, Heater Turn On Check (Lo Pressure-Auto Mode) Cutoff Checks, and Heater Manual ON/OFF Checks Above Auto Cutoff Pressure; Leak Check Mid-Body Pod I/F and FC Interface; FC Instrumentation Checks at Flight Pressures; Cryo Tank RV Crack/Reseat Checks and Post Reseat Internal Leak Check; Vent Cryo Tank to Soak Pressure; Leak Check Uninsulated LO_2 Connections.

_____

DISPLAY: VDR29, H₂ GSE, FC Operations

PERFORM: Moisture and Purity Checks from H₂ Tanks; Vent H₂ System to Pad Pressure.

V1077 -- ORBITER FUEL CELL COOLANT SERVICING AND SAMPLING (LPS)
              (120 pages)

OBJECTIVE: Provide procedures to measure compressibility and sample the fuel cell coolant loops.

DESCRIPTION: The supporting equipment will be set up at the Orbiter servicing Access Panel (Door 44); A Compressibility Test will be conducted, Accumulator ullage established, and the quantity of dissolved gas in the coolant measured;   to meet periodic OMRS requirements to sample on board F/C 40 per SE-S-0073.   Sample will be taken, dissolved gas measured,   ullage established and compressibility test performed; Compressibility GSE will be disconnected from the orbiter and servicing disconnects visually leak checked prior to flight caps installation.

V1093 -- FUEL CELL SINGLE CELL VOLTAGE TEST (LPS)(575 pages)

OBJECTIVE: Provide procedure to conduct a single cell voltage test (both the TAFEL test and GN₂ Diagnostic Test) of the Orbiter fuel cells. The TAFEL Test will only be performed if a fuel cell is suspect and not as part of the normal Diagnostic Test.

TEST PREPARATION: Placard reactant GSE;   placard Single Cell

GSE; configure FC for Single Cell Test; prepower Switch List.   POWER UP: LPS powered up; Power up Reactant GSE; Verify Orbiter Power and Cooling per Standard Power Up. OPERATIONS: Reactant Gas Purge Orbiter;   Connect Single Cell Cables;   Load Test and Voltage Scan (VAH01) -- Under LPS control, 4 calibrated loads are applied for a maximum of 15 seconds each. While each load is applied, and LPS scan of the 96 individual cells is made. A minimum of 2 minutes rest is allowed between load tests.   Then with reactants in the fuel cells, the baseline GN₂ Diagnostic Test is run. The O₂ side of the fuel cells are next purged with GN₂ and the Diagnostic Test is run again;   disconnect load cables;   inert fuel cell. When V1091 follows the performance of V1093, the inerting will be done in V1091; inert GSE. POWER DOWN: Power down Orbiter (if required); Power down reactant GSE unless V1091 is to be run immediately after completion of V1093. In this case the GSE PNLS may be left powered up; secure Single Cell GSE; secure LPS.

1.4.10 POWER REACTANT STORAGE & DISTRIBUTION (PRSD) (Tentpole E)
(Continued)

V5R01 -- FUEL CELL POWER PLANT INSTALLATION/REMOVAL (620 pages)

OBJECTIVE: Provide the sequence of operations for Fuel Cell 1, 2, and 3 transfer from shipping container to vehicle and reverse procedure from vehicle to shipping container.

DESCRIPTION: This procedure contains hazardous steps since a critical flight item, fuel cell, will be lifted into and out of vehicle.

OPERATIONS: Connect vacuum pump, FC-40 canister, reg pnl and entrained gas detection unit on lvl 4E; connect test setups for fuel cell bench servicing; transfer fuel cell from shipping container to bench; remove cover from shipping container. Using overhead crane lift fuel cell from container to work bench; pressurize fuel cell O_2 and H_2 ports with 100psi (min) GHe supply; connect FC-40 coolant fluid canister and a vacuum pump in parallel to fuel cell coolant disconnects. -----------; disconnect fuel cell vehicle electrical and fluid interfaces, ------------; remove fuel cell from vehicle and transfer to bench ------------; transfer replacement fuel cell from bench to vehicle -----------; connect fuel cell vehicle electrical and fluid interfaces; transfer fuel cell from bench to shipping container; GSE teardown.

V5R02 -- PRSD BASELINE TANK INSTALLATION/REMOVAL(462 pages)

OBJECTIVE: Task 1 - To configure and validate OPF O_2/H_2 GSE panels for tank removal/installation. Task 2 - To remove or install PRSD H_2 tank 1 as required. Task 3 - To remove or install PRSD O_2 tank 1 as required. Task 4 - To remove or install PRSD H_2 tank 2 as required. Task 5 - To remove or install PRSD O_2 tank 3 as required.. The above brief descriptions of the related PRSD procedures are indicative of the complications induced in turnaround operations by the current design.

V5R03 -- PRSD MISSION KIT TANK SET REMOVAL/INSTALLATION (LPS) (800 pages)

OBJECTIVE: To remove or install PRSD H_2/O_2 Tank Sets 3,4, & 5 as required to meet mission objectives.

1.4.10.5   Technology Application Requirements

The requirement exists to drastically improve the Energy Storage System (ESS) for the current Orbiter and future vehicles . Improvement is required in energy density, reliability, and maintainability.

1.4.10.6   Technology Evaluation

The breadth and size of this Study necessarily limits depth of the technology evaluation. The goal here is to utilize previous in-depth surveys in related areas. In the case of energy storage systems, work being done for Space Station and led by the NASA Lewis Research Center (LeRC) is most appropriate. LeRC is supported by contractor teams of Rocketdyne (Ford Aerospace, Harris, Garrett, and Sunstrand) and TRW (General Dynamics and General Electric). The following information is extracted in large part from the Bibliography, Section 1.4.10.8.

In the case of the current Orbiter, we are interested in technology which would lend itself to block modifications in the time frame of the early 1990's. In the case of future vehicles we are interested in the technology extending to 2010.

In addition to the obvious requirement of meeting performance requirements, life cycle costs (LCC) must be considered with equal importance. The major LCC factors that will provide low LCC are:

* Minimal Launch Cost

  * Low mass
  * Low volume

* Minimal Operations Cost

  * Automation
  * Minimal impact on other systems
    + Power generation subsystem drag
    + Thermal control subsystem drag

* Minimal maintenance/replacement cost

  * High reliability and long wear-out life
  * Low replacement cost
    + Low mean-time-to-repair
    + Modularity
    + Low mass and volume (launch cost)
    + Low production cost

ENERGY STORAGE SYSTEMS FOR SPACE STATION

The energy storage options initially considered for Space Station included battery systems, regenerative fuel cell systems, and flywheels:

* Battery Systems

    + Nickel-cadmium

    + Nickel-hydrogen (CPV)

    + Nickel-hydrogen (IPV)

    + Nickel-hydrogen (Bipolar)

    + Sodium-Sulfur

* Regenerative Fuel Cell Systems

    + Alkaline/alkaline hydrogen-oxygen

    + Alkaline-FC/SPE-EM hydrogen-oxygen

    + SPE/SPE Hydrogen-oxygen

    + Hydrogen-halogen

When the characteristics necessary to meet Space Station IOC were considered (maturity, development cost, production cost, solar array cost, thermal control cost, launch cost), the initial survivers were:

* Alkaline/alkaline regenerative fuel cell (RFCS)

* Nickle-cadium battery

* Nickle-hydrogen IPV battery

Of these options, Ni-Cad is relatively heavy and costly; Ni-H$_2$ appears lower in overall IOC and operational cost, and is favored for maintainability and safety. The RFCS has a mass advantage, but an overall small disadvantage in Space Station IOC cost and development risk. Bottom line is that the RFCS and the Ni-H$_2$ battery are apparently the finalists based on an IOC date.

Short descriptions of energy storage systems considered for Space Station follows.

OVERVIEW OF ESS DESIGNS CONSIDERED FOR SPACE STATIONS

Regenerative Fuel Cell.   The aklaline regenerative fuel cell
system (RFCS) consists of four identical assemblies.   Each
includes a fuel cell module (FCM), a water electrolysis module
(WEM), a FCM accessory section, and a WEM accessory section. The
accessory sections contain the valves, pumps, regulators, heat
exchangers, etc., required for RFCS operation. A set of hydrogen
and oxygen tanks serves two of the assemblies.   The electrode
areas of the FCM and WEM are sized to provide a relatively high
efficiency of 62%, which includes losses associated with
accessory section operation. Typical operating voltages of the
FCM and WEM stacks are 155 V.

IPV Ni-H$_2$ battery. The individual pressure vessel (IPV) Ni-H$_2$
battery option consists of four batteries of 275 Ah capacity in
series, distributed over five identical assemblies.   These
assemblies hold their 21 cells supported on structural beams that
carry heat pipes for efficient heat removal.   Twenty assemblies
are held in two "oven-rack" type arrangements, one per utility
center.   Typical discharge voltage is 133 V averaged over the
35-minute, 40% DoD discharge.

Bipolar Ni-H$_2$ battery.   The bipolar Ni-H$_2$ battery uses the design
concept developed by Ford Aerospace and Yardney under NASA-LeRc
sponsorship.   It consists of four batteries, each with three
assemblies in parallel.   The assemblies each consist of a
pressure vessel containing two cell stacks of 52 cells in series,
with a capacity of 90 Ah.   The cells have the long, rectangular
configuration: about 12 cm wide by 160 cm long. The 16 panels
are mounted in "oven-rack" type arrangements in the Station
utility center.

ESS OPTIONS COMPARISON FOR SPACE STATION

Ni-Cd Battery.   The Ni-Cd System consists of 16 batteries of 125
Ah capacity and with 104 series cells.   Each battery is divided
into four 26-cell battery packs, mounted on a honeycomb panel
with embedded heat pipes.   The 16 panels are mounted in
"oven-rack" type arrangements in the Station utility centers.

Na-S Battery.   The sodium-sulfur (Na-S) battery, operating at 300
to 400°C, uses cell sizes close to those being produced
currently.   The 75-kW system would consist of four batteries each
with four 87-kg modules of 70 cells of 65 Ah capacity, delivering
about 126 V on discharge.   Each module has a variable conductance
radiator system on its external surface.   The modules are placed
on the outside of the utility module.

Energy Wheels.   The energy wheel data shown represents a blend of
various approaches.   This was necessary because of the extremely
wide range of characteristics reported for point designs for
Space Station flywheels.

1.4.10 POWER REACTANT STORAGE & DISTRIBUTION (PRSD) (Tentpole E)
(Continued)

A comparison of ESS alternatives are presented in Figure 2. The alkaline H_2-O_2 RFCS is used as the baseline in this comparison.

CHARACTERISTIC	H_2-O_2 RFCS	Ni-H_2 IPV	Ni-H_2 BIPOLAR	Ni-Cd	Na-S	ENERGY WHEELS
ROUND-TRIP EFFICIENCY (%)	62	80	82	80	85	85
DEPTH-OF-DISCHARGE (%)	(40)	40	40	20	40	40
MASS (KG)						
ENERGY STORAGE	2300	4550	3600	9600	1400	6000
THERMAL CONTROL	2100	1100	1100	1100	100	800
SOLAR ARRAY CREDIT	-	(270)	(270)	(270)	(360)	(360)
* TOTAL *	4400	5380	4430	10430	1140	6440
VOLUME (m^3)	19	14	3	11	2	9
ECLIPSE HEAT REJECTION (kW)	55	19	18	19	18	10
TEMPERATURE (°C)	80	10	10	10	350	30

**SS ESS OPTIONS CHARACTERISTICS COMPARISON
Figure 2**

PERFORMANCE

The RFCS has a much lower mass than the other feasible systems, the Ni-Cd, IPV Ni-H_2, and bipolar Ni-H_2 batteries. However, its thermal control equipment is considerably heavier than that of the others, because of the RFCS's relatively low roundtrip efficiency and its resulting high heat rejection rate, albeit at a higher temperature. In the case of the room temperature systems, it is also feasible to use a common thermal control loop for the ESS and PMAD, which is difficult to do with the RFCS. The roundtrip efficiency difference also results in solar array mass "credit" for the non-RFCS systems. When all the impacts have been included, the RFCS has still the lowest mass, but the other systems become more competitive.

By far, the most attractive is the Na-S battery system; however, this technology has not reached the maturity required for serious consideration for the IOC Space Station. It provides low mass, high efficiency, and minimal thermal support requirements due to the high rejection temperature. With sufficient development, its benefits may be applicable to the growth Station.

MATURITY

The development maturity for the alkaline/alkaline RFCS is split. The fuel cell part has been used on the current Orbiter with success; the electrolyzer has so far been demonstrated only as a laboratory breadboard.

In the case of the IPV Ni-H_2 battery a 220-AH cell has been demonstrated by Ford Aerospace and Yardney. Production costs are lowest for the Ni-H_2 system due to low complexity, moderate modularity, and replication. The RFCS is intermediate due to greater complexity and lower modularity. Solar array costs and thermal control system costs are somewhat higher for the RFCS because of the greater heat rejection requirement. The RFCS is about 20% lower than the Ni-H_2 in total mass. Overall, for the early 1990's time frame, costs appear lowest for the Ni-H_2 batteries with the RFCS not far behind. NiCad batteries are not in the running because of cost and weight.

COSTS

Operations costs appear lowest for the Ni-H_2 batteries because of lower complexity while the RFCS has higher drag related fuel costs because of the larger solar arrays and more extravehicular repair activity.

ENERGY STORAGE SYSTEMS FOR CURRENT ORBITER

The development time scale involved for Orbiter block modification consideration roughly coincides with Space Shuttle IOC. Consequently, any major improvement in the fuel cells for the Orbiter could be related to Space Station development.

A significant change in Orbiter mission length could alter the ESS requirements to reconsider the trades for fuel cells, Ni-H_2 batteries, and solar cells.

The state-of-the-art for fuel cells is, even today, well advanced over the design used for the Orbiter. Further advancement could be enhanced with more competition, however. Detailed trade studies are recommended which would consider implementation of an improved system with 80% (80 flights) of an Orbiter's life expectancy left.

ENERGY STORAGE SYSTEMS FOR FUTURE VEHICLES

Looking ahead to future vehicles past the mid 1990's allows much more latitude in our consideration of alternate energy storage systems.

Specific mission requirements will undoubtedly require up-to-date trade studies with the latest projected state-of-the-art. Today it looks like a run-off between RFCS and Ni-H_2 batteries. Looking far ahead, however, there is the developing lithium cell (Li/SO_2, Li/Thionyl, Li/Sulfuryl Chloride) technology and the very promising NaS battery.

SODIUM-SULFUR (NaS) BATTERIES

Future space missions will require much higher power levels than the 5kw needed today. Directed energy weapons, ultrahigh resolution radar, and direct broadcast will boost the maximum requirements several orders of magnitude. Scale-up of present energy storage systems to these high power levels is not practical because of tremendous weight penalties.

The NaS battery is different in that both the anode and cathode are liquids instead of solids (Figure 3). As such, they do not experience the fatigue and degradation problems associated with the continuous cycling of solid electrodes. Conceivably, the sodium and sulphur could continue to cycle forever in an ideal cell. The life limiting factor in this case is not the electrode, but the solid ceramic electrolyte and the cathode container. Shaped in the form of a tube, the electrolyte serves as both an ion conductor and a separator in the cell.
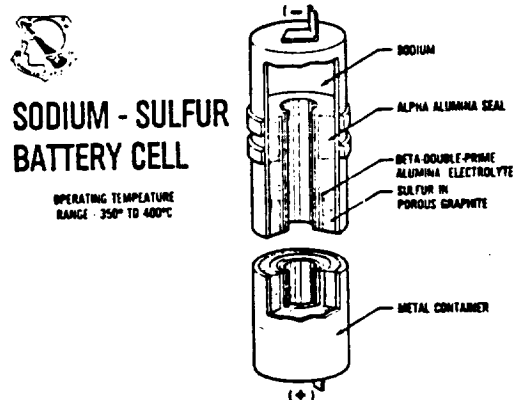
SODIUM - SULFUR BATTERY CELL

OPERATING TEMPERATURE RANGE - 350° TO 400°C

SODIUM

ALPHA ALUMINA SEAL

BETA-DOUBLE-PRIME ALUMINA ELECTROLYTE

SULFUR IN POROUS GRAPHITE

METAL CONTAINER

SODIUM-SULFUR BATTERY CELL
(Operating temperature range - 350° to 400° C)
Figure 3

Commercialization goals for terrestrial sodium-sulfur technology set energy storage costs of the battery at between $50 and $100 per kilowatt-hour. Compare this with the current average of $50K per kw-hr for a spacecraft battery. Goals of 30,000 cycles and ten years life should be achievable through advancements in research by the year 2000.

Efficiency is the amount of energy withdrawn from the battery during discharge divided by the amount of charging energy put into the battery during one typical electrical cycle. NaS batteries are 85-90% efficient while Ni-Cad and Ni-H$_2$ have efficiencies of 75%. This is an additional savings (up to 10%) in weight for NaS because of reduced solar array requirements.

This also results in reduced drag, smaller radar signature, and reduced altitude maintenance propellant requirements -- while each is small, their total is significant.

NaS TECHNOLOGY DEFICIENCIES

The cells commonly fail by breakage of the tube resulting from flaws in the ceramic. Corrosion of the cathode container is the other factor presently limiting cell lifetime.

Sufficient lifetime and reliability of the NaS cell for GEO and MAO are questionable. The life goal of ten years is yet to be attained and will not be known for several years. Cell reliability is also unacceptable due to something less than 10% of cell failures still occur within the first 200 cycles.

The NaS battery, at this time, appears to be the best possibility for meeting future requirements. Its current shortcomings are well known and only require further development.

In short, there is immediate need of accelerated materials research for the solid ceramic electrolyte and cathode container.

1.4.10.7   Conclusions and Recommendations

The launch processing time required for the PRSD system is not consistent with the requirements for an operational system.

A new technology requirement exists for fuel cells with minimal maintenance -- or replacement of fuel cells with new technology batteries. The latter alternative, batteries, does not appear to be a reachable goal with known technology. However, any R & D goals for fuel cells should place maintainability on equal status with the performance specifications. Even a cursory look at the 3794 pages of OMI's for the current Orbiter PRSD makes it readily apparent that this is not an operational type system.

It is understood that there is an RFP being released by SDIO for development of a fuel cell with 30 times the power density of the current Orbiter cells. Details of this RFP were not available at the release date of this report.

1.4.10 POWER REACTANT STORAGE & DISTRIBUTION (PRSD) (Tentpole E)
(Continued)

1.4.10.8 Bibliography

(1)   RECON 85N16947
      Simon, William E.; Johnson Space Center, Texas
      18 page paper, presented at "Space Shuttle Technical
Conference" at JSC, June 1983.
SPACE SHUTTLE ELECTRICAL POWER GENERATION AND REACTANT
SUPPLY SYSTEM

(2)   NASA Conference Publication 2434, "The 1985 Goddard Space
Flight Center Battery Workshop", November 1985.
      Dueber, R.E.; Aero Propulsion Lab, Wright-Patterson AFB
      12 page paper
SODIUM-SULFUR BATTERIES FOR SPACECRAFT ENERGY STORAGE

(3)   NASA Conference Publication 2434, "The 1985 Goddard Space
Flight Center Battery Workshop", November 1985.
      van Ommering, G.; Ford Aerospace, Palo Alto, CA.
      10 page paper
ENERGY STORAGE SYSTEMS COMPARISON FOR THE SPACE STATION

(4)   NASA Conference Publication 2434, "The 1985 Goddard Space
Flight Center Battery Workshop", November 1985.
      Smith, R.A.; Honeywell Power Sources Center, Horsham, PA.
      23 page paper
GALILEO Li/SO_2 BATTERY MODULES

(5)   NASA Conference Publication 2434, "The 1985 Goddard Space
Flight Center Battery Workshop", November 1985.
      Halpert, G., et al; JPL
      14 page paper
TEST RESULTS OF JPL $LiSOCl_2$ Cells

(6)   NASA Conference Publication 2434, "The 1985 Goddard Space
Flight Center Battery Workshop", November 1985.
      Hagedorn, N., et al; Lewis Research Center (LeRC), OH.
      6 page paper
NASA LEWIS EVALUATION OF REGENERATIVE FUEL CELL (RFC)
SYSTEMS

(7)   NASA Conference Publication 2434, "The 1985 Goddard Space
Flight Center Battery Workshop", November 1985.
      Namkoong, D.; Lewis Research Center (LeRC), OH.
      10 page paper
AN OVERVIEW OF SOLAR DYNAMIC SYSTEMS FOR SPACE
APPLICATIONS

(8)   NASA Conference Publication 2434, "The 1985 Goddard Space
Flight Center Battery Workshop", November 1985.
      Miller, Lee; Eagle-Picher Industries, Inc.
      10 page paper
AN ADVANCED NiCd BATTERY CELL DESIGN

(9)   NASA Conference Publication 2434, "The 1985 Goddard Space
      Flight Center Battery Workshop", November 1985.
         Gonzalez-Sanabria, Olga D., et al; LeRC, OH.
         10 page paper
         RECENT ADVANCES IN NiH$_2$ TECHNOLOGY AT NASA LeRC

(10) NASA Conference Publication 2434, "The 1985 Goddard Space
      Flight Center Battery Workshop", November 1985.
         McDermott, J.K.; Martin Marietta Denver Aerospace
         11 page paper
         NICKEL-HYDROGEN LOW-EARTH ORBIT TEST PROGRAM

(11) NASA Conference Publication 2434, "The 1985 Goddard Space
      Flight Center Battery Workshop", November 1985.
         Miller, Lee; Eagle-Picher Industries, Inc.
         7 page paper
         4.5" DIAMETER IPV NiH$_2$ CELL DEVELOPMENT PROGRAM

(12) NASA Conference Publication 2434, "The 1985 Goddard Space
      Flight Center Battery Workshop", November 1985.
         Green, R.S.; RCA Astro-Electronics Div., Princeton, NJ
         4 page paper
         IMPACT OF SHUTTLE ENVIRONMENT ON PRELAUNCH HANDLING OF
         NICKLE-HYDROGEN BATTERIES

1.4.11 ORDNANCE OPERATIONS (Tentpole F)

1.4.11.1 Summary

Ordnance devices must be handled with care and have rigid safety restrictions to prevent accidental detonation. All ordnance operations are performed slowly and carefully. "Slowly" often means a task time that is not ideal for an operational type transportation system. In addition to being slow the hazardous nature of ordnance causes other work to be rescheduled or stopped. Forty-four hours of ordnance operations performed in the OPF and at the VAB are serial hours where time is at a premium. Personnel must have special training and equipment and this limits who may perform the work.

The shuttle uses ordnance to perform several different types of operations:

1. Ignition devices

2. Release devices

3. Separation devices

4. Range Safety devices

The release and separation devices appear to be candidates for timeline improvement by substituting non-hazardous and reusable devices. The use of the shape memory metal Nitinol (Nickel-Titanium-Naval Ordnance Laboratory) for release or separation devices is a definite possibility. One of the early uses of Nitinol was a torsion tube use to trigger the rapid and reliable release of satellite instrument booms, replacing an explosive bolt. Contact with the originators of Nitinol about using shape memory devices to replace ordnance was very encouraging.

The ignition devices and the Range Safety devices were excluded from detailed examination because of study time limitations and no readily apparent technology.

It is recommended, for both Shuttle and Future Programs, that concentrated effort be made to eliminate ordnance devices to make ground operations more efficient. Specifically, it is recommended that Nitinol technology be explored as a starting point in replacing ordnance type release and separation devices. Further technology such as lasers should be investigated for ignition devices and a complete assessment be made of Range Safety requirements and ordnance devices.

1.4.11.2 Related Issues

1. Ordnance devices do not lend themselves to quick turnaround operations.

2. Working with ordnance requires clearing the adjacent or pad area thus precluding other work being performed.

3. Personnel who handle ordnance must have special training and certification.

4. Ordnance devices require special logistic handling.

The following are examples from the Preliminary Issues Database:

```
:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
ID: ( 706.00`         Issue(s): TIME/ON-LINE       : SAFETY
Issues(s) cont.: PLANNING          :            :
Issue Source: (NSTS       )      DRAFT DATED 5/86, ANNEX G PAGE 6
Description:
"HAZARDOUS OPERATIONS AND CONDITIONS IN THE VEHICLE PREPARATION AREA GREATLY
AFFECT OPERATIONS TIMES AND INCREASE COSTS. DURING SUCH TIMES, TECHNICIANS ARE
PREVENTED FROM DOING USEFUL WORK ON THE VEHICLES, AND ONLY ONE TASK CAN PROCEED
AT ANY ONE TIME. TO MINIMIZE THESE DELAYS, ORDNANCE OPERATIONS MUST BE
ABSOLUTELY MINIMIZED AND PREFERABLY ELIMINATED FROM THE PROCESSING FLOW.
SIMILARLY, THE USE OF TOXIC MATERIALS SHOULD BE ELIMINATED OR STRICTLY
CONTROLLED. NECESSARY TOXIC MATERIALS SYSTEMS SHOULD BE MODULARIZED OR
CONTAINERIZED SO THAT EQUIPMENT CAN BE CHANGED OUT WITHOUT REQUIRING EVACUATION
OF THE SURROUNDING AREA."


:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
ID: ( 710.00`         Issue(s): COST/MANHOURS      : SAFETY
Issues(s) cont.:          :            :
Issue Source: (NSTS       )      DRAFT DATED 5/86, TABLE 6-1
Description:
"    LOGISTIC SYSTEM      OPERATIONAL CONCEPTS   :      SYSTEM
       COST DRIVER     :                    :      REQUIREMENTS


PYRO DEVICES            * USE NON ELECTRICAL    * MINIMIZE PYRO DEVICES
 -HAZARDOUS OPERATIONS   PYROTECHNIC INITIATORS  * USE LASER INITIATED
 -REFURBISHMENTS        * CONDUCT ORDNANCE        PYRO DEVICES
  INSTALLATION OFF-LINE * USE MECHANICAL/
                          ELECTRO/PNEUMATIC
                          DEVICES
.

:::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
```

1.4.11   ORDNANCE OPERATIONS (Tentpole F)
(Continued)

1.4.11.3   Related KSC Schedule History

1. The 160-hour schedule had 8 hours for ordnance installation at the Orbiter Processing Facility (OPF).

2. Currently 112 hours of processing time is spent in ordnance operations in the following areas:

```
OPF............................................................8 hours
External Tank (E/T) CHECKOUT CELL.....................24 hours
Vehicle Assembly Building (VAB).......................44 hours
PAD.................................................................36 hours
       (20 hours requires complete pad clear)
                                    Total            112 hours
                    (Total on-line serial time       44 hours)
```

This schedule is primarily taken from the as-run of 51-L, then modified to simulate a typical STS flow.

The eight hours of scheduled ordnance work in the OPF is considered serial time since clearing is required and restrictions are placed on other activities.

The 68 hours in the VAB (including the E/T checkout cell is parallel work since it is primarily done while the orbiter is in the OPF. It does restrict some other work in the VAB.

The 36 hours at the pad is the most detrimental to the schedule. At least 20 hours requires clearing the whole pad and it would be hard to calculate how many man-hours of other work are lost.

1.4.11 ORDNANCE OPERATIONS (Tentpole F)
(Continued)

1.4.11.4 Current STS Methods

The descriptions below of the current STS OMI's for the installation of ordnance provide a graphic view of the complications, time on-line, and manhours expended because of the current design:

OMI V5012, Ordnance Installation and Checkout (LPS), is worked in the OPF. The following ordnance items are installed requiring a 10-foot radius to be cleared during hazardous operations. The nose landing gear strut thruster cartridge, the forward separation bolt pressure cartridge, the Remote Manipulator System (RMS) Manipulator Positioning Mechanism (MPM) pyro, the KU-BAND pyro, the fire extinguisher pyro and the fire suppression pyro. Power-off stray voltage checks, shield-to-ground resistance checks and electrical connection of ordnance are performed requiring a 10-foot clear around the affected areas.

OMI B5304, SRB Systems Mate and Closeout, is performed at the VAB. The Linear Shaped Charge (LSC) is installed in the boosters requiring clearing of levels D, B, & E and roped area on ground floor. Installation of the Confined Detonating Fuse (CDF) assemblies requires clearing of platform E-main. Installation of Solid Rocket Booster (SRB) Ignitor Safe and Arm (S&A) device requires clearing extensible platform E-main. A 10-foot radius around the SRB must be cleared for installation of NASA Standard Initiators (NSI's). The E-main, E-roof and AP-100 platforms are cleared for cable installation. The SRB holddown post-ordnance installation requires a 10-foot clear from the SRB aft skirt area. Closeout firing-line continuity checks require the above mentioned areas to be cleared.

OMI T5142, SRSS Ordnance Installation, is also performed in the VAB. The external tank Shuttle Range Safety System (SRSS) LSC is installed in the LO$_2$ and LH$_2$ cable trays. The appropriate levels of the E/T checkout cell are cleared during LSC installation.

OMI S5009, Final Ordnance Installation/Connection, and Aft Closeout (LPS), is final ordnance installation, connection and aft closeout at the pad. This procedure is performed in two parts. The first part requires clearing to pad perimeter for SRB ordnance operations, Cargo ordnance operations, Tail Service Mast (TSM) ordnance operations, Orbiter forward Launch Control Amplifier (LCA) and aft Left Hand/Right Hand (LH/RH) separation ordnance operations. The blast danger area is cleared for Pyro Initiator Controller (PIC) resistance testing on the Orbiter, external tank and solid rocket boosters. Part 2 requires clearing to the pad perimeter for stray voltage testing and ordnance electrical connection.

_____

1.4.11.5 New Technology Requirements

Replacement for current Shuttle : ordnance release or separation
devices with non-explosive devices. Candidates for replacement
are:
- Orbiter main & nose gear strut release
- Orbiter/ET separation bolts
- SRB holddown bolts
- SRB/ET aft separation system
- SRB/ET fwd separation system
- SRB frustum separation
- SRB parachute cutter
- SRB main parachute release
- TSM drop weight release bolts
- E/T H_2 vent arm release

Shape-memory metal (Nitinol) has been used to trigger release of
satellite instrument booms replacing an explosive bolt. The
shape-memory can be returned to the original configuration so
those applications on recoverable portions of the vehicle would
not require replacement.

For Future Vehicles:

Eliminate all ordnance devices which require special handling and
restrictive safety measures. This will require innovative
technology for ignition and Range Safety devices. It also means
early coordination with and qualification of devices by the
Range Safety Organizations.

1.4.11.6   Technology Evaluation

The initial 160-hour schedule reflects 8 hours in the OPF to install ordnance. The safety considerations required for handling ordnance preclude ever approaching this amount of time. To reduce the time involved we must consider performing the same functions by other means. First the required operating time must be evaluated for each application to determine actual need. Present Operational Maintenance Requirements and Specifications Document (OMRSD) requirements have 10 or 20 millisecond requirements on many applications. Each application can then be evaluated to see if a non-explosive device can be substituted.

Candidate Devices:

The Orbiter main & nose gear strut release pyros are a back-up system and are initiated if the main hydraulic unlocking mechanism fails to operate. These devices are initiated by pressure cartridges. They are installed at the OPF and the OPF is the last point they can be accessed. See Figure 1 for location of main landing gear pyrotechnic release thruster. Nose gear is similar.

Emergency Uplock
Pyrotechnic Release Thruster

Up

Forward
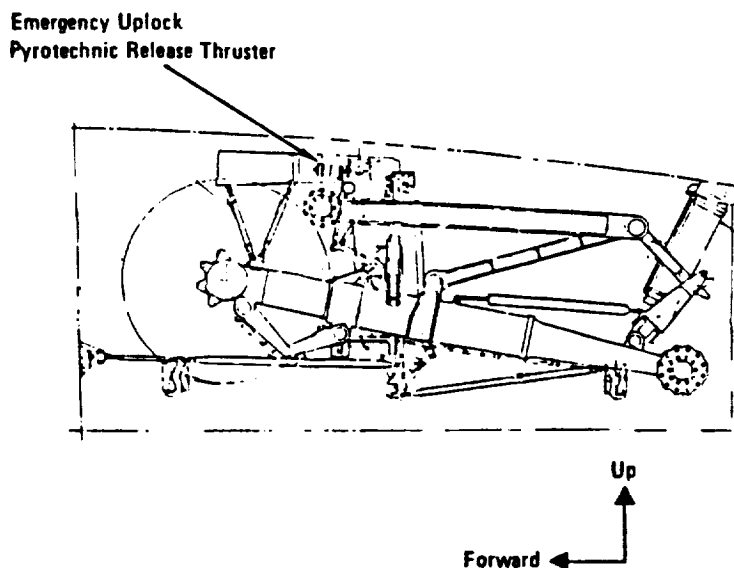
ORBITER MAIN AND NOSE RELEASE PYRO
Figure 1

The <u>SRB holddown bolts</u> have a load limit of 1,135,000 pounds and a minimum ultimate load of 1,512,000 pounds. They are preloaded to 725,000 to 834,000 pounds. They must operate between 20°F and 150°F. These devices are initiated by detonators. They are installed at the VAB and the PAD is the last point they can be accessed. The frangible nut is shown in Figure 2 and the installation in Figure 3.
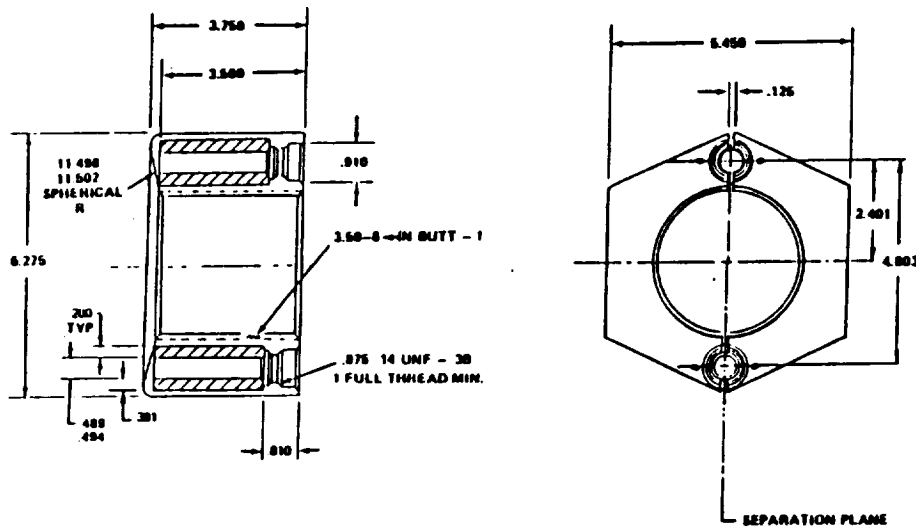
FRANGIBLE NUT
Figure 2
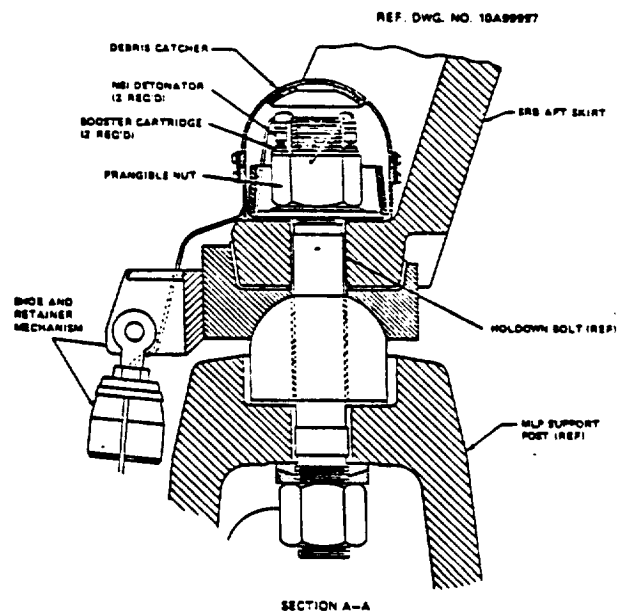
SRB/MLP HOLDDOWN RELEASE PYROTECHNICS
Figure 3

1.4.11 ORDNANCE OPERATIONS (Tentpole F)
        (Continued)

The Orbiter/ET forward separation bolts operate similar to the
SRB holddown bolts described above. These devices are initiated
by pressure cartridges. They are installed at the OPF and the
OPF is the last point they can be accessed. See Figure 4.

ORIGINAL PAGE IS
OF POOR QUALITY
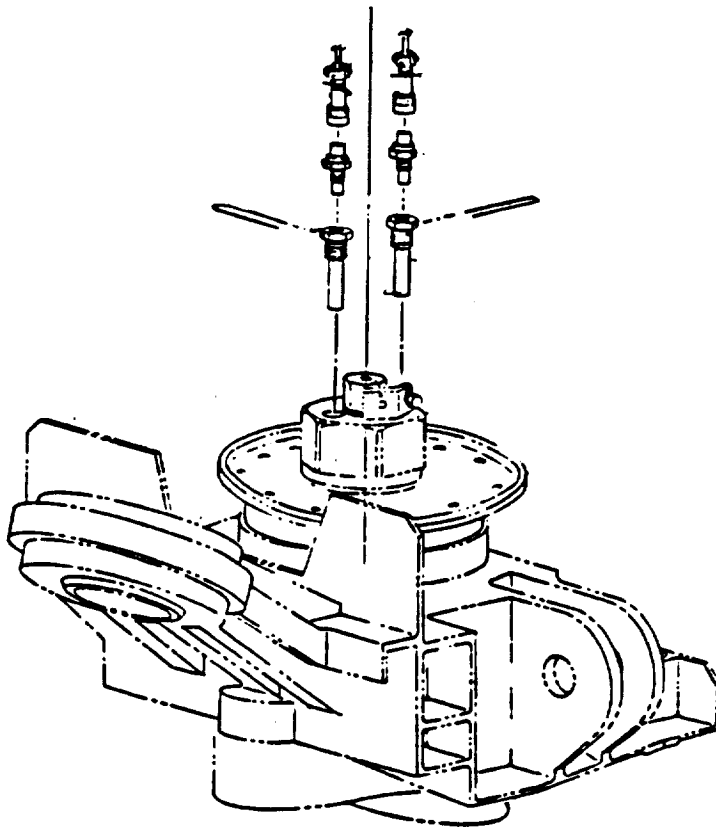
ORBITER/ET SEPARATION BOLTS
Figure 4

1.4.11 ORDNANCE OPERATIONS (Tentpole F)
(Continued)

The <u>SRB/ET aft separation bolts</u> have a flight load limit of 393,000 pounds axial tension and must operate within 10 milliseconds of initiation signal. They must operate between 20°F and 120°F. These bolts have an installation torque of 1000 foot-pounds. These devices are initiated by NSI pressure cartridges. They are installed at the VAB and the PAD is the last point they can be accessed. See Figure 5.

The <u>SRB/ET forward separation system bolts</u> have a flight load limit of 189,000 pounds axial tension limit load with a 55,344 inch-pound end moment. They must separate within 10 milliseconds of initiation signal and operate within -10°F to 120°F. These devices are initiated by NSI pressure cartridges. They are installed at the VAB and the PAD is the last point they can be accessed. See Figure 5.
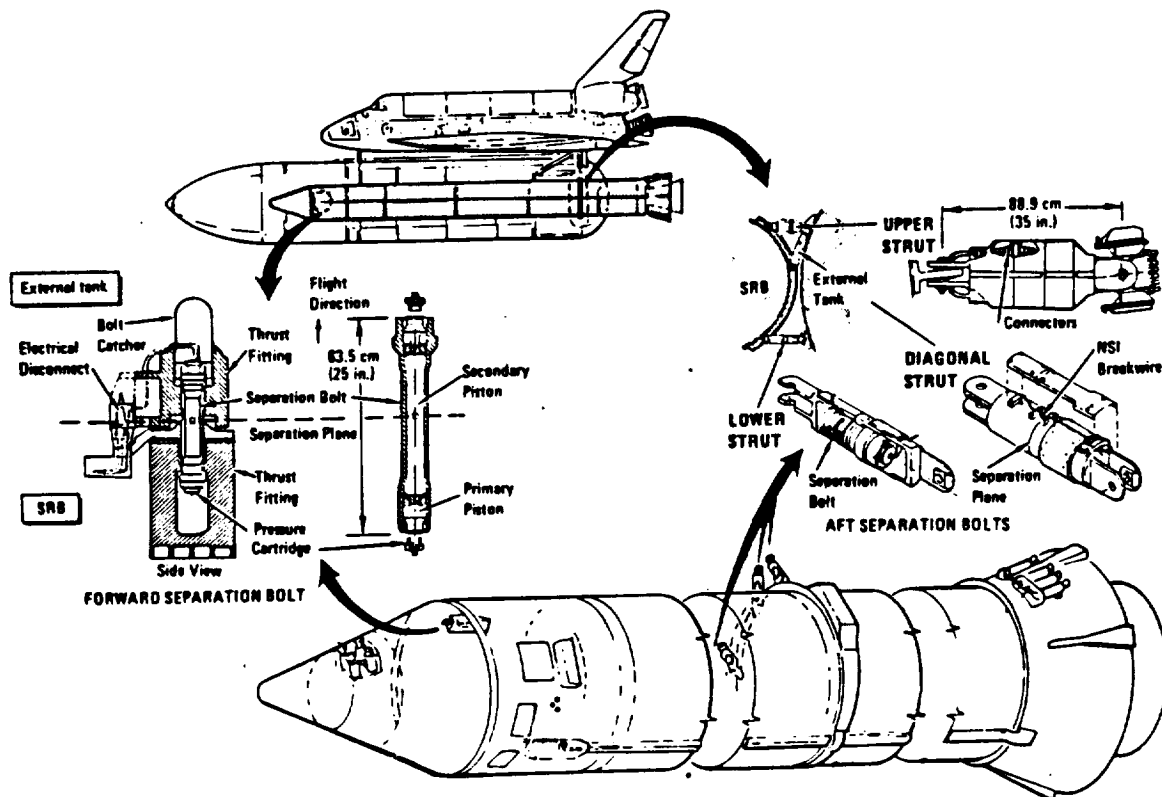
SRB SEPARATION SYSTEM ELEMENTS
Figure 5

ORIGINAL PAGE IS
OF POOR QUALITY

The SRB frustum separation currently uses a linear shaped charge
that runs around the periphery of the frustrum. It must operate
between 25°F and 105°F. The ring thickness at the separation
line is 0.25 inches thick. This device is initiated by a
detonator.   It is installed at the VAB and the PAD is the last
point it can be accessed. See Figure 6.

The SRB parachute line cutter must be capable of cutting 3 plies
of 1 ¹/₆ inch MIL-W-4088, type XX III 12,000 lb. webbing.   The
operating temperature range must be 20°F to 200°F. This would
appear to be the easiest device to replace with a Nitinol device.
See Figure 7.
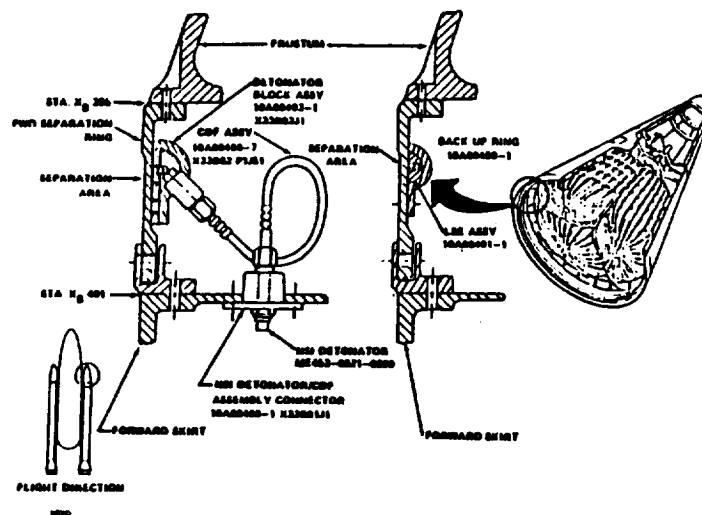
SRB FRUSTUM SEPARATION/CHARGE
Figure 6
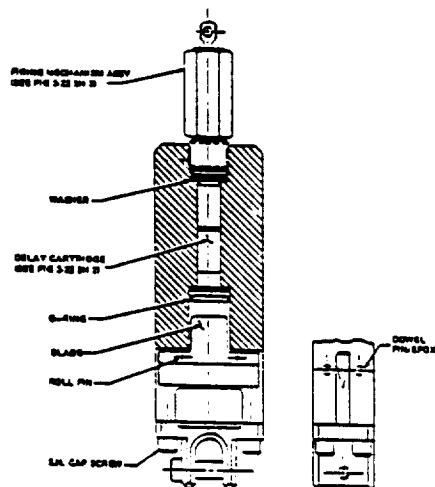
PARACHUTE LINE CUTTER
Figure 7

The SRB main parachute release bolt is a 1.25-12 UNJ-3A bolt under a tension load of 135,000 pounds. The bolt is torqued to 775 +/-25 foot-pounds and must operate at 20°F to 200°F. The current release spec is for 20 milliseconds after initiation signal. This device is initiated by a detonator. They are installed at the VAB and the PAD is the last point they can be accessed. See Figure 8.
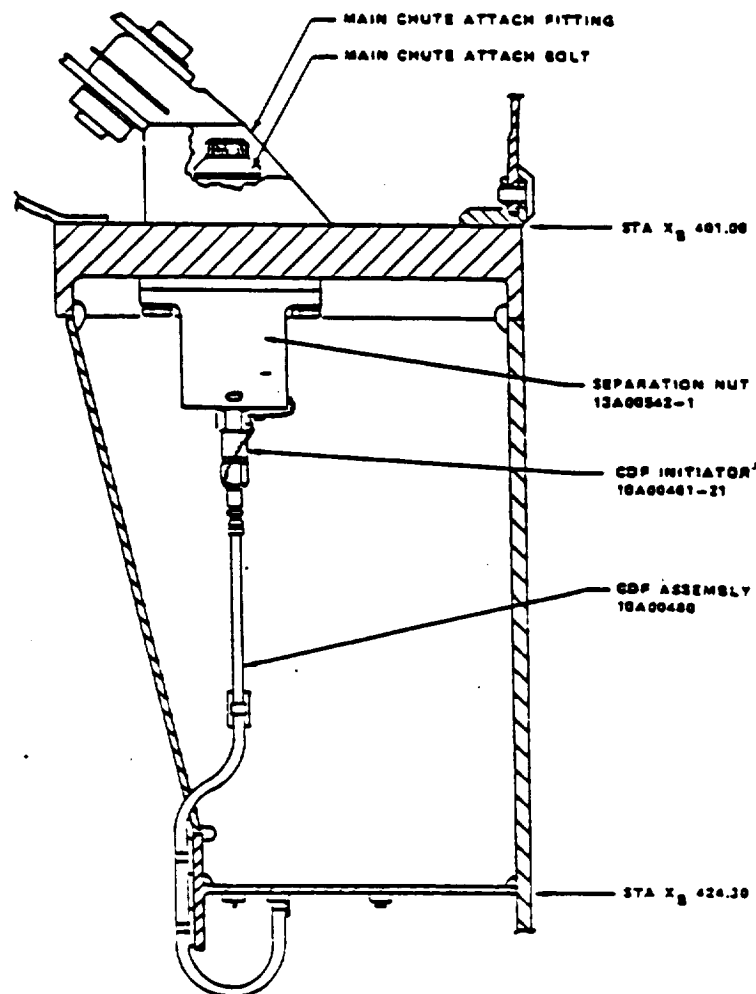
MAIN PARACHUTE RELEASE SYSTEM
Figure 8

-143-

TSM drop weight release bolts and the E/T H2 vent arm release are
of a design similar to the SRB/ET and Orbiter/ET forward
separation bolts. All are initiated by NSI pressure cartridges
that make the bolt fracture at a predetermined location. They
are installed at the PAD; and the PAD is the last point they can
be accessed.

Two prime candidates for Nitinol application would seem to be the
SRB parachute cutter and main release. The timing is not as
sensitive and the type of application lends itself to an
electro-mechanical device (solenoid type) or perhaps
shape-memory. Either of these cases could be reusable and not
sensitive to low level stray voltage actuation.

Candidate Technology - Nitinol

A number of articles and papers indicate potential uses of shape
memory are still emerging. The following excerpt from June 1984
Materials Engineering is a sample:

> When shape-memory alloys are deformed at one temperature,
> they remember the previous shape and completely recover it
> when heated to a higher temperature. The shape recovery
> produces a displacement or a force, or a combination of the
> two, as a function of temperature. Shape-memory alloys
> (SMAs) are used in applications such as pipe and tube
> couplings and electronic tight seals and connectors.

> In additions, improved alloy processing and a better
> understanding of the shape-memory effect (SME) mechanism has
> provided alloys that have a precise mechanical response to
> small and repetitive temperature changes. This
> characteristic is put to use in mechanical and
> electromechanically controlled systems.

> Although the shape-memory phenomenon occurs in many alloy
> systems, including austenitic stainless steels, most of
> these alloys cannot be used because of some inherent
> limitation, such as low ductility, which causes fracture
> during shape recovery.

> Two alloy systems well suited for commercial application due
> to the combination of SME and favorable mechanical
> properties are NiTi alloys and CuZnAl alloys.

> Alloys having the shape-memory characteristic need to
> satisfy certain conditions to obtain shape memory and a
> number of variables must be controlled to fabricate a useful
> engineering device.

Foremost, an alloy must undergo an austenite to martensite transformation. Such transformations are crystallographically reversible and typically occur in ordered alloys. The crystal structure can shift into the configuration known as martensite when subjected to a certain temperature or stress and then shift out of it. Those alloys having a thermoelastic martensite transformation also have the shape-memory effect.

For example, a wire of shape-memory alloy can be bent into some configuration at room temperature and then heated until the austenite crystal structure is attained. When the wire is quenched, the atoms rearrange themselves into the crystal form of martensite. If the wire is bent into another configuration and then heated to a temperature above that at which martensite reverts to the austenite or parent phase, an orderly shift of atoms restores the wire to the original configuration. The memory is accomplished at the martensite formation temperature or at a higher temperature - where the alloy reverts to austenite. Transformation temperature is determined by composition for each memory alloy but can also be shifted by applied stress. For many alloys, composition must be controlled within very close tolerances to obtain the required sensitive temperature.

If a shape-memory metal is mechanically deformed at a specific temperature, it will return to its original form when the temperature is raised. The process is known as one-way shape-memory effect - "one-way" because the shape change occurs only in heating. Cooling the material subsequently will not reverse the shape change.

Further research of the shape-memory effect mechanism has provided shape-memory alloys that can be "trained" to remember two configurations. This phenomenon is know as two-way memory effect because the shape changes both on heating and cooling. The metal is trained by appropriate stress and/or thermal cycling below the critical temperature, which limits the number of variants of martensite formed. Stressing the alloy while cooling from the elevated temperature to the critical temperature favors the initial formation of particular variants of martensite. Repeating the sequence of austenitizing, quenching, deforming, and reaustenitizing eventually trains the structure. When this condition is achieved, a specimen will bend spontaneously during the austenite/martensite transformation and unbend to the original shape during the reverse transformation. In both cases, the shape changes with the absence of an external stress.

By restricting the shape-memory transformation, a usable force associated with the shape change is available for doing work or gripping another object. The mechanical stresses produced are limited only by the material. The deformation of a part is limited to an internal strain of between 2 and 9% to achieve 100% shape recovery.

Shape memory alloys also have excellent fatigue properties.
For example, the cyclic strain required to cause fracture
after a number of cycles is higher by a factor of ten than
that required for conventional alloys. Generally, after the
first three to five reversals of temperature, the material
stabilizes to repeated values. However, if a part, such as
an actuator, is overstressed or exposed to temperatures out
of the working range of the alloy for long periods, the
metal can fail by thermal or mechanical fatigue or the
memory can fade.

Although the nickel-titanium (NiTi) intermetallic compound
was not the first system that demonstrated the shape-memory
effect, as a result of the austenite/martensite
transformation, it was the first used for commercial
shape-memory applications. Called Nitinol, for
Nickel-Titanium Naval Ordnance Laboratory, the alloy
provides high yield strength and ductility, high
strength-to-weight ratio, and good corrosion resistance.
With alterations in the nickel-titanium ratio and additions
of small amounts of other elements of small amounts of other
elements, the martensite transformation temperatures range
of -459 to 212°F.

One of the first applications was the use of a Nitinol
torsion tube to trigger the rapid and reliable release of
satellite instrument booms, replacing an explosive bolt.
Since the phase change from martensite to austenite is
diffusionless, the shape-memory effect occurs very rapidly
over a narrow temperature range.

Other typical satellite uses include sun seeker/tracker, torsion
drives and trigger mechanisms.

Activity in the application of Nitinol Devices is accelerating
from 1967 to 1980 there were 90 patents. By 1987 there were 160
patents.

The following chart of physical and mechanical properties of
55-Nitinol was taken from the October 1969 issue of **Materials
Engineering**:

Density, lb/in.^{3}	0.234
Melting Point,°F	2390
Magnetic Permeability	<1.002
Ult Tensile Strength,100 psi	125
Elongation, %	60
Modulus of elasticity, 10^6 psi	10.2
Shear Modulus, 10^6 psi	3.6
Poisson's Ratio	0.33
Fat. Strength (10^7 cyc),1000 psi	70

Although the shape-memory effect was discovered in 1962 most of the effort to develop practical applications has been fairly recent. Design News, 12-1-86, names several active participants and their products:

Beta Phase Inc.,Menlo Park,CA, is making shape-memory eyeglass frames.

Innovation Technology International Inc.,Beltsville,MD, headed by Fredrick Wang (one of the original researchers) is developing an engine to run on low cost heat sources.

Raychem Corp.,Menlo Park, CA.,has developed several items including the "Cryotact" ZIF socket and a flexure arm in a hard disc drive that prevents head crashes.

Memory Metals, Inc.,Stamford ,CT.,is working on electrical and optical connectors and a line of safety related devices including an anti-scald shower valve.

Nitinol Investigation:

During the Seattle technical survey trip, robotic applications were demonstrated which further indicated further development of Nitinol or similar alloys have potential for this technology application.

A special technical survey trip was made to the Naval Surface Weapons Center (ex Naval Ordnance Lab) to provide a cursory look at the potential application of Nitinol to substitute ordnance type devices. Discussion of the ten selected devices with David Goldstein of NSWC, a Nitinol Specialist, revealed that the technology should support innovative design of substitute devices. Nitinol is capable of providing 300K PSI as a one-shot operation or 200K+ PSI on a repetitive basis. Reaction time is not a parameter that has been thoroughly researched. Although Nitinol has the approximate resistivity of nichrome wire, there is a need for basic energy versus mass curves. Also, a requirement for innovative design to minimize triggering mass and the required power/energy for triggering.

1.4.11.7 Cost Trades

SHUTTLE COST TRADES

Implementation Description: Eliminate ordnance devices by making
                              substitute devices using Nitinol.

Implementation Cost Estimate:

Item	Manhours	Materials	Comment
Design & Qual. Tests	_____	_____	_____
Manufacturing	_____	_____	cost for 3
Modification &			vehicles
Installation	_____	_____	___ _
TOTALS		■	

Ground Ops Cost Savings Per Flight After Implementation: (N/A = not available

	Current				New			Delta		
Item	OLH	DMH	MAT	OTHR	DMH	MAT	OTHR	DMH	MAT	OTHR
V5012 OPF	44	312	__ __		234	__ __		78	__ __	
B5304 VAB	17	N/A	__ __		N/A	__ __		N/A	__ __	
T5140 ET o/o cell	64	N/A	__ __		N/A	__ __		N/A	__ __	
S5009 PAD	100	N/A	__ __		N/A	__ __		N/A	__ __	
Safety & Logistics		N/A	__ __		N/A	__ __		N/A	__ __	

Ground Operations Savings for Future Vehicles:

The cost savings for future vehicles is approximately equal to cost
avoidance of the current STS costs.

$$ COST ANALYSIS: This data is presented in Section 1.6.3, COST
                    TRADE SUMMARY.

1.4.11.8 Conclusions & Recommendations

Due to the criticality of the operations that ordnance devices perform, a high confidence level will be required for any replacement device. Careful analysis should be performed on the OMRSD requirements for each application. A careful study should be performed for other possible substitute devices. Nitinol appears to be a very likely candidate for these devices. Since a number of companies are trying to enter the shape-memory market the timing for research or study contracts should be ideal. This study therefore recommends that further research into the use of shape-memory devices(for ordnance substitutes) be done as soon as possible.

The ignition devices and the Range Safety devices were excluded from detailed examination because of study time limitations and no readily apparent technology.

It is recommended, for both Shuttle and Future programs, that concentrated effort be made to eliminate ordnance devices to make ground operations more efficient. Specifically, it is recommended that Nitinol technology be explored as a starting point in replacing ordnance type release and separation devices. Further, that other technology, such as lasers, be investigated for ignition devices and a complete assessment be made of range safety requirements and ordnance devices.

In the case of Nitinol technology, it is specifically recommended that NASA KSC fund a small investigation by the Naval Surface Weapon Center to provide the missing basic data on reaction time and energy/power/mass relationships as a basis for a later RFP for substitute ordnance devices.

ORIGINAL PAGE IS
OF POOR QUALITY

1.4.11.9 Bibliography - Ordnance Operations

(Each of the references listed below has its own bibliography)

(1) RECON 72N30468; NASA-SP 5110
     C. M. Jackson, H. J. Wagner, R. J. Wasilewski; 86 pages ; 1972
     55-NITINOL--THE ALLOY WITH A MEMORY: ITS PHYSICAL METALLURGY,
     PROPERTIES, AND APPLICATIONS
     Battelle Memorial Institute, 505 King Avenue, Columbus, OH
     43201

(2) RECON 85N26966; AD-A152 089; NSWC TR 84-326
     David M. Goldstein; 28 pages; 15 October 1984
     PRODUCTION OF SHAPED PARTS OF NITINOL ALLOYS BY SOLID-STATE
     SINTERING
     Naval Surface Weapons Center, Dahlgren, VA 22448 - Silver
     Spring, MD 20910

(3) RECON 82N19033; AD-A108278; NSWC TR 81-129
     David M. Goldstein, John Tydings; 53 pages; 1 July 1981
     NITINOL INTERCONNECT DEVICE FOR OPTICAL FIBER WAVEGUIDES
     Naval Surface Weapons Center, Dahlgren, VA 22448 - Silver
     Spring, MD 20910

(4) RECON 84N25089;
     Clete J. Siebert, Fred A. Morris, 9 pages
     PASSIVE SUN SEEKER/TRACKER AND A THERMALLY ACTIVATED POWER
     MODULE
     Martin Marietta Denver Aerospace, Denver, CO

(5) RECON 86N27356;
     R. G Hostenkamp, 5 pages, October 1985
     FEATURES OF THE SOLAR ARRAY DRIVEN MECHANISM FOR THE SPACE
     TELESCOPE
     Dornier System GmbH, Friedrichshafen, FR Germany

(6) Materials Engineering, October 1969
     H. J. Wagner, C. M. Jackson
     WHAT YOU CAN DO WITH THAT 'MEMORY' ALLOY
     Battelle Memorial Institute, 505 King Avenue, Columbus, OH
     43201

(7) Design News, 12-1-86
     MEMORY METAL MAKES ITS MARK

(8) Materials Engineering, June 1984
     Edward J. Kubel, Jr.
     SHAPE MEMORY METALS

(9) NSWC - TR80-59
     David Goldstein, Research & Technology Dept. NSWC, 53 pages,
     Feb. 1980
     A SOURCE MANUAL FOR INFORMATION OF NITINOL AND NiTi, 1st
     REVISION
     Naval Surface Weapons Center, Silver Spring, MD, 20910

1.4.12 PAPERWORK & REQUIREMENTS (ULCE) (Tentpole G)

1.4.12.1 Introduction

Design for performance has been the priority goal for new systems for decades. Consequently, many analytical procedures and data bases have been developed to accomplish these design activities. In contrast, design for support has had much lower priority; consequently, few analytical procedures and databases have been developed which allow the support factors to be included in the design process.

However, the opportunity exists today to significantly, and dramatically, improve the capability to design for supportability. The opportunity exists now because of the convergence of four historical trends.

The first trend is the steadily increasing demand by the Department of Defense to drastically improve the maintenance and support of systems while reducing manpower and costs.

The second trend is the accumulation of evidence from recent research performed by the Human Resources Laboratory at Wright-Patterson Air Force Base which indicates that maintenance and logistics support characteristics must begin with early concept studies. This research indicates, also, that one of best ways to improve design for support is to put the maintenance and logistics data and factors directly into the daily working procedures used by the design engineering personnel. (Reference 1)

The third trend is the "explosive" emergence of computer aided design (CAD) as the daily working procedure within American industry for design of products. One of the main reasons for this rapid growth is that CAD greatly reduces the time and engineering labor hours required to produce a new design. The opportunity, therefore, is to link these trends and develop the technical capability to put maintenance factors, logistics factors and operational requirements directly into the CAD process being used by the aerospace industry. This technical capability does not exist today except in limited scope and then only in isolated cases. The current status of design for support is primarily that of analyses being performed "off-line" from the main performance engineering design activities, and then being performed "after the fact" without input to major design decisions. Development of the technical capability to put maintenance and logistics factors directly into the main CAD process can change this picture. Design for supportability can become an on-line design activity.

The fourth trend is one that will tie together the first three and maximize their combined effect on development of the next generation systems. As costs have risen, the competitive position of aerospace industry in the world market has been further weakened by the inequity of foreign governments subsidizing manufacturing and operating costs. To meet this challenge the Boeing Commercial Airplane Company has developed the Design/Build Team (DBT) concept as a dramatic approach to cost reduction and product improvement.

1.4.12 PAPERWORK & REQUIREMENTS (ULCE) (Tentpole G)
(Continued)

1.4.12.2   Issues

This Study used the STS 51-L(the last Challenger flight) launch operations data and the post 51-L reports as a point of departure. This data was then used to analyze the launch operations characteristics and place documented problems into one or more of several categories called "ISSUES".

A total of 40 different categories were identified, 18 of which will be discussed here. The following list contains those Issues that have a potential for avoidance in the future by incorporation of techniques within ULCE.

ACCESSIBILITY	MAINTAINABILITY
CHANGE CONTROL	MANAGEMENT
CONSTRAINTS	PAPERWORK
DESIGN	PROCEDURE
DESIGN CRITERIA	QA
DISCIPLINE	RELIABILITY
DRAWING SYSTEM	REQUIREMENTS
INTEGRATION	STANDARDS
LOGISTICS/SPARES	TRAINING/CERTIFICATION

1.4.12.3   ULCE Related Issues

Each of the issues described above is listed in the following section with a brief description of the general nature of the problem. Source of these quotes is the Issues Database from this Shuttle Ground Operations Efficiencies/Technologies Study. The number of occurrences of the issue in the database will give the reader a relative feeling of its severity as evidenced by the degree of documentation by numerous committees and organizations.

Accessibility:
(104
 occurrences)

"...Contract specifications need to stress LRU maintainability/accessibility...Fund maintainability and accessibility up front to significantly reduce unnecessary support costs in the operational area...include a logistics representative on the design team to continually address the problems of standardization, ease of maintenance, and accessibility..."

Change Control:
(30)

"...The qualification of the test article was not in all cases representative of the flight configuration...Work accomplished on Flight 10 was formally approved for Flight 11...This OMI was deviated to change the configuration of the holddown post-blast shields for launch, formal engineering was not available for the operations, verbal agreements were reached and four of the blast shields were modified, post launch inspection revealed that the items incorporated for the mod were blown away at launch..."

Constraints:
(18)

"...Events associated with the STS 51-L mishap identified SRM flight safety issues not addressed in the FRR process...Manpower limitations due to high workload created scheduling difficulties and contributed to operational problems...MSFC is not part of the formal IFA (Inflight Anomaly) tracking system...Team members identified several problems with the constraint system which hampered effective traceability of open work items...Limited visibility of the constraints status make it difficult to identify and schedule work to support the test flow..."

Design:
(750)

"...Designers of black boxes should position PCBS so they will be vertical when the black box is installed in the system. Locate electrical feed through connectors on the side or back, not on the bottom...Design specs would require simplicity of design/accessibility to facilitate maintenance, maintainability verification should be conducted to identify & correct maintenance deficiencies before design is "frozen"..."

Design Criteria:
(298)

"...Perform fit checks of mission equipment hardware on a high fidelity mock-up at the design agency to preclude field problems...Provide a defined maintainability design criteria at the inception of the program and a design review board to monitor adherence to these criteria..."

Discipline
(125)

"...Five weeks after the 51-L accident, the criticality of the solid rocket motor field joint was still not properly documented in the problem reporting system at Marshall...Work authorization documentation audit, the review has found that the ability of the work control documentation system to guarantee proper real time execution of tasks and their subsequent traceability is inhibited by factors that must be identified and corrected by KSC management..."

Drawing System:
(30)

"...Incremental delivery of Orbiter/payload mod kits is a problem. A system must be devised to I.D. problems/delays before becoming constraints to the field...Reference designators should be of a constant format across all program elements: Orbiter, External Tank (ET), Solid Rocket Booster (SRBS), develop a uniform system...Enforce a standardized drawing and part number system on all contractor and government furnished equipment..."

Integration:
(11)

"... Provide a full fidelity model for sub-system maintainability testing, to be used early in the design phase to verify design requirement compliance..."

Logistics:
(81)

"...Use standard industry hardware rather than unique hardware, unique limits the availability of spares and drives up the cost..."

Maintainability:
(226)

"...Maintenance requirements should be: Identified prior to design; Imposed at the sub contractor level, design requirements must address maintenance..."

1.4.12 PAPERWORK & REQUIREMENTS (ULCE) (Tentpole G)
(Continued)

Management:
(82)

".....Methods should be developed which assure more direct design contractor involvement in the processing and testing effort at the launch sites...Signature requirements on 'Real Time' work paper (deviations,TPS' IPR'S etc.) are lengthy and required personnel are geographically scattered ..."

Paperwork:
(104)

"...The OMRSD system is very difficult to paper track with respect to auditing requirements. The OMP and PSP which are often incorrect in the deviations and revisions are incorporated between the publication of one document and another. The OMP is not a closed loop system and is sufficiently complex such that cognizant systems engineer is the only person who knows the full status of OMRSD requirements..."(ref. to,'Paperwork Problems' for details)

Procedure:
(94)

"...Of the 51 work documents generated by the MCR's, 96% were found to have errors of an administrative or format type as defined by the SPI (Standard Practice Instructions)...Task deviation log does not indicate effectivity of temporary deviations. Therefore, there is no foolproof way to determine if a temporary deviation is effective on a given run..."

QA:
(107)

"...OMRSD V41BG0.010 which checks the redundancy of individual regulators was not verified under flow conditions...The leak check steps for test port #4 were inadvertently omitted from OMI V1009.04. This is a violation of OMRSD V41AZ0.070..."

Reliability:
(51)

"...Design is a compromise between performance, reliability, maintainability, weight, space restrictions, safety, etc. Management must re-prioritize these factors so maintainability receives it's deserved attention..."

Requirements:
(167)

"...The processing support plan is a KSC document that lists all work that may be performed on a specific STS flow and lists OMRSD requirements and OMI's that will be released. The PSP is published about 50 days prior to OPF roll-in and is continually updated by system engineers. There is NO feedback into the OMP..."

Standards:
(33)

"...Problem reporting requirements are not concise and fail to get critical information to the proper levels of management..."

Training/Certif:
(31)

"...Training must be adequate to ensure that all workers are able to comply with the regulations which govern the paperwork system, ...The OMRSD requirement of 1 psid in the manifold was violated in that 6 psid were present causing the valve to slam..."

This multiplicity of problems is astonishing! It is imperative that a system be developed to control these interrelated problems. ULCE can provide the core solution !!

1.4.12.4 Today's Methods

The problems identified in the previous Issues section all have a common denominator, lack of SUPPORTABILITY. Each of the issues discussed in the previous section are the result of vehicle supportability being de-emphasized early in the design phase. This problem can be seen in almost all vehicle sub-systems as well as ground support systems.

The emphasis on performance has resulted in many tools being developed to support the evaluation of a given design for performance. The evaluation of supportability is primarily performed off-line, after-the-fact and if it is performed at all, too late for initial design influence.

It is clearly defined that the life cycle cost (LCC) of a system can be divided into four primary phases.

1. The **Mission Definition** phase involves conceptualizing the system; defining the problem to be resolved and considering initial architectures.

2. The **Design** phase in which the system is designed and the prototype is constructed and tested.

3. The **Production** phase entails manufacturing the product.

4. The **Operations** phase involves repair, operations, spares, training, product improvements, maintenance testing etc.

The distribution of the LCC for a DOD or commercial system is given in Figure 1;

LCC Phase	LCC %
1. Definition	<1 %
2. Design	<10 %
3. Production	30 %
4. Operations	60 %

DOD LCC Distribution (reference 3)
Figure 1

The current STS LCC has a distribution as shown in Figure 2;

LCC Phase	LCC %
1. Definition	<1 %
2. Design	6 %
3. Production	8 %
4. Operations	86 %

SHUTTLE LCC DISTRIBUTION (reference 4)
Figure 2

1.4.12 PAPERWORK & REQUIREMENTS (ULCE) (Tentpole G)
(Continued)

In the past, <u>up front costs</u> and <u>performance</u> have been given priority at the expense of <u>reliability and maintainability</u>. The design of future systems will have to consider **Operational** requirements including reliability and maintainability; at the same level as performance, if our designs are to provide life cycle costs competitive in the market place.

The prime reason for this trend has been **political economics**. If inadequate funds are allocated for the initial design and manufacturing, then proof of concept (initial flight) take all the allocated funds leaving none for maintainability, and reasonable life cycle costs factors.

1.4.12.5 New Technical Requirements

The previous sections have identified the urgent need for a radical shift in design techniques. The methods used to design systems in the past, although adequate in their time, are no longer suitable for systems of the future where low cost operations are paramount.

There are several CAD (Computer Aided Design) technologies currently available or in development that can alleviate many of the operational problems associated with today's Shuttle.

To define the nature of the work required to provide CAD capability, it is necessary first to understand the <u>relevant characteristics</u> of such a system: (Reference 1)

1. <u>Quickness of reaction</u> time is probably the characteristic of CAD that will most affect the future design for supportability. Entire vehicle system design must be established within days or weeks. Support analyses for proposed designs cannot exist off-line. Support analyses will need to respond rapidly or they will be disregarded.

2. Computer-based <u>automated analysis models</u> are an essential part of the CAD process. Presently these models are used to assess performance characteristics or weight and balance. These automated analysis models are one of the reasons for quick reaction time of the CAD process. Automated maintenance and logistics analyses models will also be required.

3. The ability to view objects in three dimensions is now resident within many CAD systems. Color representation of objects is now possible. These characteristics will afford opportunities to use CAD to perform <u>mockup maintainabilty evaluations</u> of equipment during early design.

4. The design and drawing data generated by CAD are being bridged to the databases that operate numerically controlled machines within the manufacturing facility. The data flows from CAD to CAM and eventually to field and service engineering. Unfortunately, the databases that are used in maintenance and logistics analysis models are not linked with the CAD/CAM engineering databases. Design tasks for future systems will have to provide for <u>supportability analysis data interchange with CAD/CAM</u>.

5. Design systems of the future will be required to provide an integrated data path, providing a <u>birth-to-death documentation tracking capability</u>. Data generated during the design and manufacturing phase will have to be compatible with the data structures and processing systems used in the field and vice versa.

6. To achieve the maximum benefit from new computer aided design techniques will require **new management techniques** that can instill within the project four basic steps (William E. Conway, Conway Quality Inc.):

      A. **Desire** to change

      B. **Belief** that change can be accomplished

      C. **Wherewithal** to change

      D. **Doing**

1.4.12.6 Technology Evaluation

The Air Force Human Resources Laboratory, Wright-Patterson AFB (AFHRL) is involved in the development of future aerospace systems design techniques to reduce LCC (Life Cycle Costs) and increase supportability, this project is known as ULCE (Unified Life Cycle Engineering).

There are three primary components in ULCE;

1. **IDSS** (Integrated Design Support System)

2. **RAMCAD** (Reliability and Maintainability through Computer Aided Design)

      CREW CHIEF and **TARS** (Turnaround and Reconfiguration Simulation).

3. **IMIS** (Integrated Maintenance Information System)

IDSS

The integration of dissimilar CAE/CAD/CAM and operational data sources on local and geographically distributed networks is the major problem faced in the development of ULCE. The development of the IDSS by the Air Force will provide a means to accomplish this integration. The goal of IDSS is to develop a computer software methodology for the acquisition, storage, retrieval and coordination of technical information between design engineering efforts and operational activities to support such developments as Operations and Maintenance Instructions (OMI), training programs, and operations problems analyses. The IDSS will provide for the reduction and duplication of data while also providing for rapid distribution and increase in quality of the data. (Figure 3.)

ORIGINAL PAGE IS OF POOR QUALITY
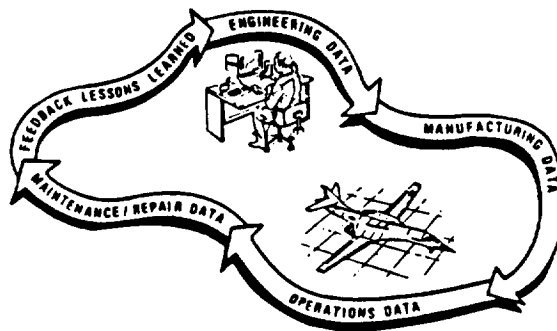
**IDSS
Figure 3**

The architecture of the IDSS is comprised of two main areas the Executive Control System (ECS) and the Data Acquisition System. (see Figure 4.)
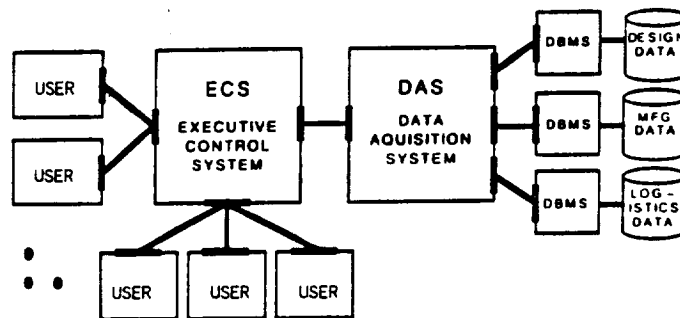
**ECS
Figure 4**

The ECS will provide for:

1. User interface
2. Application software (e.g Data query,Data Edit, etc)
3. Data coordination and distribution
4. Configuration control
5. Project management
6. Data security (i.e Data access control)

The DAS portion will provide for;

1. Heterogeneous H/W and S/W systems
2. Distributed database management
3. Network communications protocol
4. Data integrity

IMIS

The modern operational environment is being increasingly inundated with additional information systems. Each new "operational aid" is an operations hindrance because it forces technicians to learn yet another "system". To utilize the valuable information these new systems offer, while eliminating the specialization required for each, AFHRL is developing IMIS.

IMIS will utilize a very small portable computer/display to interface with on-board systems and ground computer systems to provide a single, integrated source of information needed to perform required tasks on-line and in the shop. IMIS will consist of a workstation for use in-shop, a portable computer for flight line use, and a vehicle interface panel. (Figure 5.)

ORIGINAL PAGE IS OF POOR QUALITY
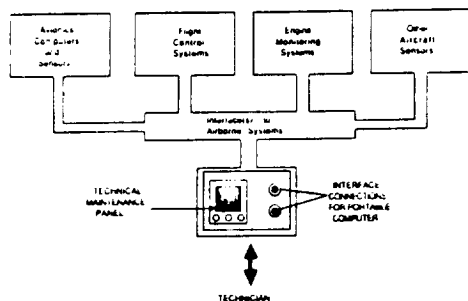
IMIS SYSTEM
Figure 5
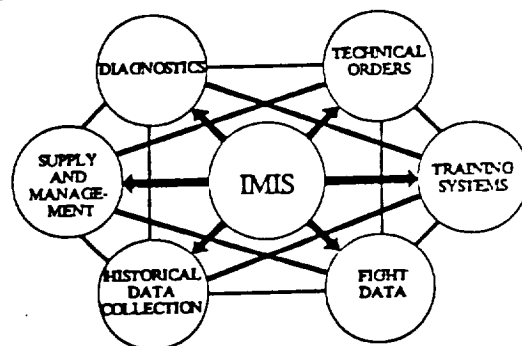
IMIS
Figure 6

The system will provide the technician with direct access to several information systems and databases compatible with IDSS. IMIS will process, integrate, and display maintenance information to the technician. The system will display graphic and/or technical instructions, provide intelligent diagnostic advice, analyze in-flight performance and failure data, and access and interrogate on-board built-in-test capabilities. It will assure that all of the Operational and Maintenance requirements are satisfied by directly interrogating the requirements database. (see Figure 6.)

It will also provide the technician with easy, efficient methods to receive work orders, report maintenance actions, order parts from supply, and computer-aided training lessons complete with a simulation capability.

RAMCAD

RAMCAD is a joint Air Force in-house and contractor study to develop an analysis model and database structure for assessing the location of line replaceable units (LRUs) within a vehicle with regard to failure rate of the components and accessibility for maintenance actions. The goal is to develop an automated assessment model which will yield a quantitative index of the "goodness" of a given arrangement of LRUs within a housing.

CREW CHIEF and TARS

Crew Chief is a computer-based model of the technician which can be used to assist in the evaluation of equipment designs. The early design was based on the COMBINATION model which was an earlier product of Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base. The Crew Chief model can be used to provide mockup-type evaluations of equipment on 3-D interactive graphic displays.

Crew Chief can be utilized to evaluate such maintenance operations as component testing, component removal and replacement, vehicle servicing and turnaround activities, engine removals, fuel and ordnance loading. The operations may be performed with the model wearing various types of clothing, such as warm weather, cold weather, and chemical defense gear(SCAPE). Exploded view enlargements of hand and arm activities to include manipulation of tools are included. It is also possible to evaluate human strength capabilities for various lifting and pulling tasks. (see Figure 7.)
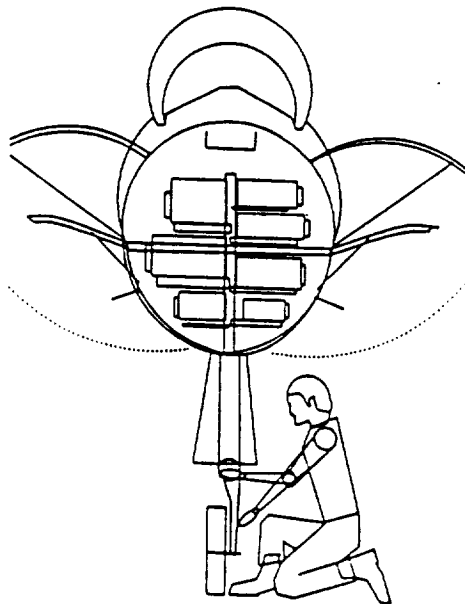
ORIGINAL PAGE IS
OF POOR QUALITY

CREW CHIEF
Figure 7

TARS is a tool similar to Crew Chief except the emphasis is on the interaction of the entire operations team with the vehicle. Provisions are also made for placing the vehicle within a processing facility. This system will provide for the same level of detail as Crew Chief including 3-D interactive graphics while also allowing the designer to evaluate the operations team accessibility to the vehicle, such as the process of engine removal, placement of work stands , positioning and access for robotics, payload bay reconfiguration, and assorted OMI development.

1.4.12.7 Management Technology

Without management acceptance, implementation and followup, no successful system can be installed. The discussion of new management technology is a topic deserving of a paper of its own. The topic is so important to the success of any project that it must be mentioned here in an attempt to convey its meaning.

The first two management steps **Desire** and **Belief**, of the four basic requirements to instill a change, represent about 80% of the effort required to accomplish a change. The aforementioned computer aided techniques are the **Wherewithal** to accomplish the change and will only be of use if the first two steps are completed. For example the Boeing Commercial Airplane Company is placing new management techniques "on-line" that will provide the means to accomplish the first two steps. Boeing believes this is necessary to survive in tomorrow's marketplace.

Productivity improvement planning requires the same kind of systematic approach as financial planning. <u>Every manager from the highest level</u> (i.e. Presidential and Congressional) down must establish a plan to instill the **Desire and Belief** that change is required and possible. This must be a continuous process requiring frequent follow-up reinforcement.

The manager's greatest responsibility is to work on the system itself; this requires making changes in the ways in which work is performed at all levels of the project. These types of changes are usually highly effective at producing both increased quality and reduced costs. Experts in productivity improvement estimate that 80% or more of the opportunities for change are the result of management's improvement of the system to allow change. The workers accomplish the remaining 20%.

If a problem is shared among several groups, it is important for these groups to share the accountability for it and to work together to solve it. Design Build Teams (DBT) are an effective way to do this. The DBT has members from **all of the affected** functional areas; design engineering, manufacturing, materials, operations, etc. <u>All team members participate directly</u> in the design process, each assuring that the initial design meets all of the operational and performance requirements.

A quote from W. Edwards Demming (of Japanese industry fame) may be best to close this brief discussion of new management techniques;

> "Eliminate targets, slogans, pictures, posters for the
> work force, urging them to increase productivity,
> ...<u>What is needed is not exhortations but a road map
> to improvement, management's obligation.</u>"

Pressure to work harder or better does not achieve productivity improvement. Most workers already believe they are doing the best they can in the current environment. Evaluating them by the quality of their work places the entire responsibility for improvement on them alone.

1.4.12.8 COST TRADE

Improvements in the paperwork processing systems using the IMIS concepts described above can produce a reduction in Life Cycle Cost for the present configuration of the Shuttle of about 5%.

The following figures 8 & 9 present Net Present Value curves showing 5%, 7.5%, & 10% discounts assuming a realistic flight rate of 10 per year. Figure 8 is based on $246M per flight which is actual 1985 expenditures during which 8 STS's were launched. Figure 9 shows the same information based on a per-flight cost of $100M, which is an estimate based on achieving a flight rate of 24 per year or a 300% increase in the flight rate over the rate of 1985.

The best that can be hoped for without major Shuttle block modifications is to improve the launch processing sytems to minimize the paperwork and establish this system for future vehicles. If the Shuttle flies an additional 45-55 flights then a payback may be achieved for the current Shuttle configuration. If the current Shuttle does not manage another 55 flights then the system will be on-line and available for the next generation STS configurations.
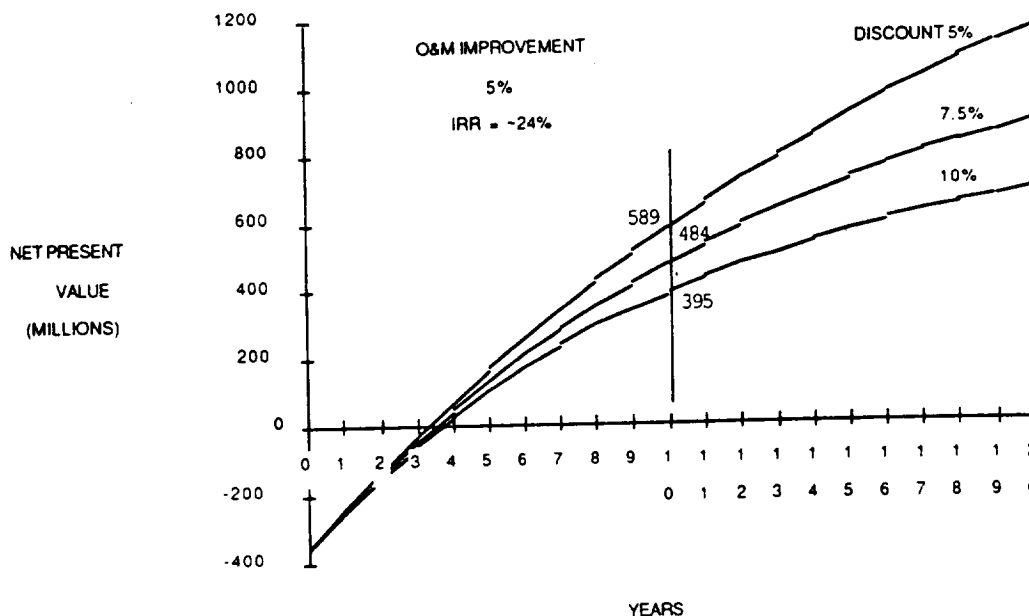
IMIS IMPLEMENTATION

(10 FLIGHTS PER YEAR - $246 MILLION PER FLIGHT)

Figure 8

-163-

1.4.12 PAPERWORK & REQUIREMENTS (ULCE) (Tentpole G)
(Continued)
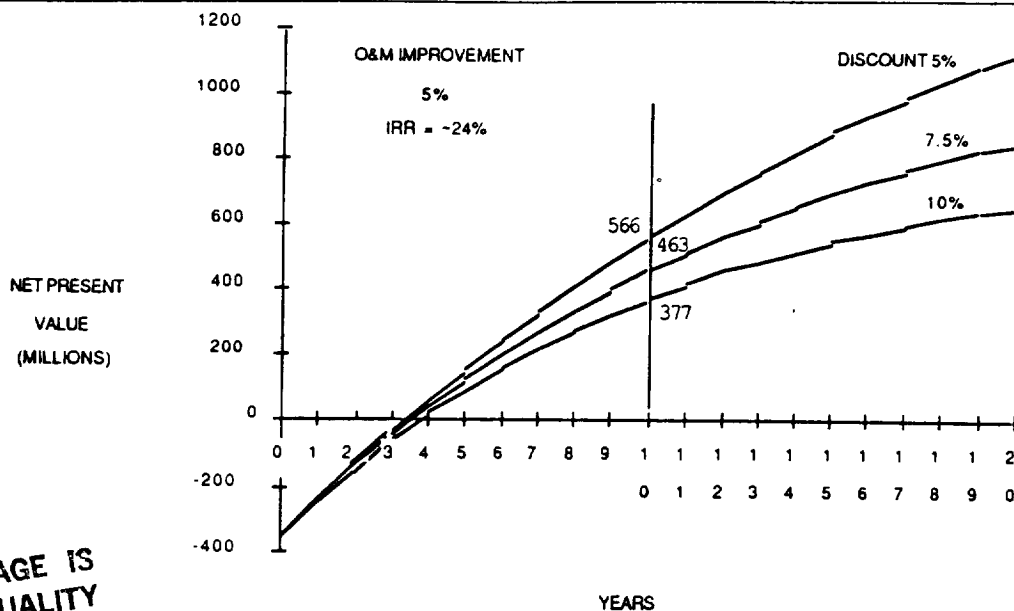
IMIS IMPLEMENTATION
(24 FLIGHTS PER YEAR - $100 MILLION FULL COST PER FLIGHT)
Figure 9

1.4.12.9 Conclusion

Design for Performance has been the priority goal for new systems
for decades. The result when supportability takes a back seat to
performance is exemplified in the overwhelming Life Cycle Cost
and schedule delays evident in the operation of the current
Shuttle.

The Shuttle Ground Operations Efficiencies/Technologies Study,
using data made available primarily as a result of the 51-L
incident has been able to document a host of problems that are
relatable to the lack of supportability considerations in design
of the Shuttle.

The current CAD design tools utilized are all related to
performance with little or no consideration being given to
reliability and maintainability requirements. The USAF has a
major effort underway to improve supportability for new systems,
by developing design tools to provide on-line analysis of
supportability for a proposed design. These tools will include
maintenance and reliability factors within CAD.

It is realized that improved design for support is not the only
means to an end. Improved training of maintenance personnel,
better job performance through new management techniques, and
better automated maintenance aids and concepts will also
contribute. However, improved design for support will make a
significant contribution, and including reliability and
maintainability factors in CAD will make a significant
contribution to improving the design.

1.4.12.10 Paperwork Problem References

PAPERWORK PROBLEMS -- SUMMARY

The Presidential Commission Report on the Space Shuttle Challenger Accident noted that of the approximately 5000 documents evaluated, a large percent were found to be incorrectly executed. The discrepancies were generally minor in nature, such as incorrect signatures, missing signatures, lack of Quality Control, incomplete rationale for closure, etc. An in-depth review of all KSC Shuttle Processing paperwork was also conducted by several paperwork review teams. These teams were co-chaired by both NASA and SPC, and team members included representatives from the organizations responsible for Space Shuttle Processing. **The information below is taken from these reports.**

PAPERWORK PROBLEMS -- CURRENT KSC METHODS

Operation Maintenance Instruction (OMI)

LSOC/NASA quality reviewed 121 OMI's, 47% (57 OMI's) had paper errors, of a relatively minor nature. 13% of the OMI's had some data recording points missing or incorrectly documented (such as calibration dates, voltage, temperature, and pressure readings not recorded).

Work Authorization Documents (WAD)

A total of 479 Orbiter WAD's in the IPR, PR, or TPS category were reviewed, of the 479 70% had the following anomalies:

    36% - Inadequate/inaccurate level of detail
    24% - WAD not properly stamped by Shop/QC/QE
    29% - Correct signatures not obtained
    20% - Inadequate summary for closure/deferral
     9% - Task not performed correctly the first time
     3% - Retest not adequate/satisfactory
     2% - Inadequate rational to defer WAD

Modification Change Requests (MCR)

A total of 22 MCR's were applicable to the 51-L processing flow. An independent safety review of all MCR's discovered the following errors:

    20% - Critical skills or wrong numbers for skills
    20% - No certification annotated
    80% - Procedure/format problems
    20% - Missing Safety stamp
    40% - Quality disposition on a Safety area

These MCR's generated 51 Work Authorization Documents which were reviewed, 96% were found to have the following errors of an administrative or format error as defined by the SPI (Standard Practice Instructions).

            85% - WAD format incorrect
            69% - Improperly stamped by Shop/QC
            35% - Incorrect Signatures
            35% - Required data not recorded
            31% - Inaccurate level of detail
            22% - Proper Engineering not identified
            10% - Engineering from Design Center not timely
            10% - Work accomplished did not match Engineering
             6% - Retest required not identified
             4% - Inaccurate summary for closure deferral

Operation Maintenance Plan (OMP)

KSC maintains an OMP database to track the OMRSD requirements and the OMI's and Task Numbers where the requirements will be met. 327 OMI's listed for 51-L the following observations were made:

            10% - Of the OMI's not applicable to STS-33
            13% - Of the OMI's were contingency procedures

Also, noted that the OMP is not a closed-loop, therefore as revisions to OMI's are published, page and task numbers are frequently incorrect. The OMP does not reflect the current OMRS implementation. And, the OMP does not contain a "clock" such that when LRU changeouts occur the interval requirement can be updated to indicate the true effective date.

Processing Support Plan (PSP)

The Processing Support Plan is a KSC document that lists all work that may be performed on a specific STS flow and lists the OMRSD requirements and OMI's that will be released. The PSP is published about 50 days prior to OPF roll-in and is continually updated by system engineers. There is no feedback into the OMP.

General Findings

An unacceptable error rate in the work paper was approximately 50% and had these contributing factors:

- Signature requirements on "real time" work paper (deviations, TPS's IPR/PR's, etc.) are lengthy and required personnel are geographically scattered (usually miles, not feet). Rapid response to problems or changing work schedules is precluded; encouraging "short cuts".

- The signature "loop" is manpower intensive, requiring many "processors" as well as full time availability of system engineers.

- The amount of time required to complete any category of documentation from open to close is unacceptably high when compared to the actual time to do the work.

- Many tasks cannot be "bought off" at the location due to Safety or physical restrictions: later transferring stamps provides another failure point.

- Due to its complexity, writers, performers, and "buyers" of tasks have difficulty in understanding the paper system.

- There are many different levels and categories of paper and many inconsistencies in the preparation and disposition of this paper.

- The "tiering" from integrated OMI, to standalone OMI, to RTOMI, to job card (plus all deviations) creates a very complicated control and status trail for Quality Assurance personnel, as well as Operations Management.

- Many tasks, due to the system or poor discipline in the origination process, end up with multiple items of work paper, compounding the buy-off process.

- No single organization has the responsibility for final review for closure.

Conclusions: During the document review, many areas of unclear or inconcise documentation were noted. Instructions in WAD's are frequently not clear or precise. The OMRSD system is very difficult to paper track with respect to auditing requirements. The OMP and PSP, which are the KSC supporting documents to the OMRSD system, are usually incorrect in that the deviations and revisions are invariably incorporated between the publication of one document and the other. Finally, the OMP is not a closed loop system and is sufficiently complex that the cognizant systems engineer is the only person who knows the full status of OMRSD requirements.

Basically, the system is not simplified for the originator, performer, or verifier; and therefore, is not a tool, but an impediment to good work and good records - the only reasons for it's existence.

1.4.12 PAPERWORK & REQUIREMENTS (ULCE) (Tentpole G)
(Continued)

Recommendations: The solution to this or any problem with a
system as complex as the Space Shuttle Processing paperwork
system requires a team effort.   Most importantly, in this
instance, a commitment to compliance with processing procedures
and requirements by high level management and the proper training
and discipline of personnel responsible for using the paperwork
system is required.

To assist management , engineering, and the technicians, in the
Space Shuttle processing operation, maximum emphasis on current
efforts to develop automated systems to facilitate the planning,
tracking and management of processing operations.   Many changes
being contemplated during this review period will increase the
time required to manually process the paperwork.   The
incorporation of integrated automated systems is imperative in
order to ensure proper completion of orbiter turnaround
requirements as the launch rate increases.

Paperwork Problem Improvements In-work: All the work performed
on Shuttle flight hardware, Shuttle facilities, and Shuttle
ground support equipment must be documented for traceability.
This results in a large amount of documentation which must be
processed each flow.   The time spent preparing documentation for
each flight can be greatly reduced by the use of computers.

In addition to planned work and scheduled maintenance, the
process team must be prepared to react efficiently to real time
problems which result in unscheduled maintenance.   Problems are
documented into three categories. An Interim Problem Report
(IPR) is used to describe a problem when troubleshooting is
required to determine the cause of the problem.   A Problem Report
(PR) is used to describe a problem and remedial instructions when
the cause of the problem has been determined.   A Discrepancy
Report (DR) is used to solve minor problems which can easily be
returned to normal configuration.   In a nominal flow, there are
approximately 4000 IPS's, PR's, and DR's written for STS vehicle
processing.

1.4.12.11 Bibliography

1.   NASA RECON 84A16548
      Askern, William B.; Air Force Human Resources Lab,
      Wright-Patterson AFB.; NAECON May 1983
      MAINTENANCE AND LOGISTICS FACTORS IN COMPUTER-AIDED DESIGN

2.   NASA RECON 86A35709
      Lowenstein, Al; Winter, Greg
      IEEE Design and Test, April 1986
      VHDL'S IMPACT ON TEST

3.   Congressional Budget Office Data -- FY-1985
      OPERATIONS COST PER FLIGHT

4.   REPORT OF THE PAPERWORK AND PREPAREDNESS REVIEW TEAMS
      Teams A through I, January 7, 1987, KSC.

5.   51-L DATA AND DESIGN ANALYSIS TASK FORCE FINDINGS (KSC)
      March 1986.

6.   REPORT OF THE PRESIDENTIAL COMMISSION ON THE SPACE SHUTTLE
      CHALLENGER ACCIDENT
      Volumes I and II, May 1986.

7.   HEARINGS BEFORE THE SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND
      SPACE OF THE COMMITTEE ON COMMERCE, SCIENCE, AND
      TRANSPORTATION - 99th CONGRESS - FIRST SESSION ON NASA
      AUTHORIZATION FOR FY-1986. February, March, April 1985.

1.5   SPACE STATION TECHNOLOGY APPLICATIONS

Significant technology developments are being funded by the Space Station Program which will be directly applicable to Ground Operations for both Shuttle block changes and future programs. The same is true for SDIO activities.

A minimal look at Space Station development activity was accomplished in the study. This resulted in Figure 1, which illustrates typical Space Station technologies under investigation and their eventual application to space vehicle ground operations.

SPACE STATION DEVELOPMENT $$$	VEHICLE & GROUND OPERATIONS (SHUTTLE/STAS)			
	Elect Pwr	GN&C	Data Mgmt	Assembly & Checkout
EXPERT SYSTEM				
Fault Diagnosis	X	X	X	
Trend Analysis	X	X	X	
Power Management	X	X		
Fault Tolerance	X	X		
Attitude Control		X		
ROBOTICS				
Teleoperation				X
Proximity Touch & Force Sensing				X
Range & Image Understanding				X
End Effectors				X
POWER				
Batteries	X			
Fuel Cells	X	/		
OTHER				
Video Probe				X
Electron Beam Welding				X

SPACE STATION TECHNOLOGIES
APPLICABLE TO SHUTTLE AND STAS
Figure 1

1.6 GROUND OPERATIONS EVALUATION SUMMARY

The background and rationale for the future program and Shuttle recommendations presented in this section were described in detail in Section 1.4, "Tentpole and Related Issues Analyses".

1.6.1 Future Program Applications

FUTURE VEHICLES

The significant conclusions and recommendations related to the trade studies for future vehicles follows:

1. Major changes in design and management methodology are required.

2. New technology involves management and computer-aided tools.

3. ULCE/CALS (Unified Life Cycle Engineering/Computer Aided Logistics System). This will provide the means to avoid maintenance problems such as accessibility, commonality, change control, interfaces, isolation, procedures, standards, training, QA, integration, spares, etc.

4. DBT/DTC (Design-Build Team/Design to Cost)

5. Without consistent long-term management commitment, 1 through 4 will not work.

6. **Future vehicles, beginning with the Design Concept Phase, must put life cycle costs ahead of performance. We are hauling cargo via freighter -- not participating in a yacht race.**

7. All engine maintenance should be accomplished off-line with adequate facilities and spares.

8. Cargo should be self-sufficient with minimal power / control / data interfaces. It should be containerized and processed entirely off-line. Weight penalties to provide containerization should be absorbed by system robustness.

9. Design for testability, fault tolerance, transparency to changes, self-improving diagnostics, false alarm discrimination, data compression, optimum man/machine interfaces must all be firm design requirements.

10. Large, complex, launch control centers must be eliminated by incorporation of BIT, BITE, and concepts such as self-check "automatic test equipment on a chip technology" in the vehicle itself. For manned vehicles, the crew/machine interface should be capable of performing the countdown.

11. Artificial Intelligence and Expert Systems are now in an infantile stage and are not a panacea for the next round of new vehicles. It will be the second round and into the late 1990's before there will be reasonable risk designs available.

12. Ordnance devices must be eliminated to accomplish efficient processing. It appears practical to eliminate ordnance type release devices at an early date through the use of technology such as Nitinol. SRB ignition and range safety devices are a tougher proposition. Some innovative concepts will be required in these areas. Perhaps something as far out as lasers for ignition and weapon systems (infrared seeker missiles) for range safety.

There are a large number of desirable (required) features for future vehicles which were not investigated because of Study limitations. These include:

1. Eliminate vehicle hydraulic systems with electromechanical devices to simplify ground operations.

2. Eliminate hydrazine systems to simplify ground operations.

3. Minimize facility/GSE/vehicle interfaces to simplify ground operations. Eliminate hardwire electrical interfaces and swing arms.

4. Eliminate requirement for ECS GSE to simplify ground operations.

5. Maximize automation of structural inspections to eliminate requirement for off-line periodic inspections.

6. Provide easily maintainable Thermal Protection System.

7. Standardize propellants, fluids, and grades.

8. Incorporate automated servicing in vehicle design.

9. Vehicle/GSE design such that assembly and checkout, intrasite transportation, and landing/recovery are not constrained by weather.

10. Etc., etc. (See Volume 4, Preliminary Issues Database for additional operational needs under topics such as accessibility, commonality, integration, interface, isolation, logistics/spares, maintainability, redundancy, safety, security, and surface transportation).

1.6.2   SHUTTLE RECOMMENDATIONS

1.6.2.1   IMIS (Integrated Maintenance Information System)

Shuttle derived ground operational efficiencies require major
block level modifications, and as shown in the cost trade section
are not recommended. The single item with the largest payback is
a redesign of the SPDMS to conform to IMIS specifications.

The operational environment is being increasingly inundated with
additional information systems. Each new "operational aid" is an
operations hindrance because it forces technicians to learn yet
another "system". To utilize the valuable information that these
new systems offer, while eliminating the specialization required
for each, the Air Force Human Resources Laboratory (AFHRL) is
developing IMIS. IMIS will utilize a very small portable
computer/display to interface with on-board systems and ground
computer systems to provide a single, integrated source of the
information needed to perform required tasks on-the-line and
in-shop.

The system will provide the technician with direct access to
several information systems and databases. IMIS will process,
integrate, and display maintenance information to the technician.
The system will display graphic and/or technical instructions,
provide intelligent diagnostic advice, analyze in-flight
performance and failure data, and access and interrogate on-board
built-in-test capabilities. It will assure that all of the
operational and maintenance requirements are satisfied by
directly interrogating the requirements database.

It will also provide the technician with easy, efficient methods
to receive work orders, report maintenance actions, order parts
from supply, and computer-aided training lessons complete with a
simulation capability.

1.6.2.2   Orbiter Block Change Candidates

DE, the NASA Engineering Development organization at KSC, and
NE-PEO, the NASA Shuttle Engineering Project Office at KSC have
over 500 specific candidates for vehicle and GSE modifications.
These return-to-flight-status mod candidates have been developed
at the system engineer level. These candidates are recorded in
the Preliminary Issues Database, Volume 4 of this report, with
ID's of 1800 to 2900.

Time limitations of the study prohibited an in-depth look at
these DE/NE-PEO candidates. However, based on our Operations
Analysis and approached from the standpoint of OMI processing, we
identified 32 operations which appear to have likely system
candidates for design changes that could significantly reduce
both processing time and manhours. There is some overlap where
these operations overlap the DE/NE-PEO candidates. (Figure 1
lists the OMI's, related systems, the technician manhours, the
TIS reference number (from Vol.3 of this Report), and an
indication if there are related DE/NE-PEO candidates).

TIS	OMI	TECH HOURS	M/H	SYSTEM	DE/NE-PEO MODIFICATONS
3	V1158	56	336	FRCS and OMS pod	Y
5	V1091	48	192	PRSD LO2 and LH2	Y
10	V9001VL1-V14	?	?	power up and power down	N
15	V5043VL1-VL3	96	1632	SSME heat shield removal/inst.	N
17	V1011.01-.07	252	2064	SSME eng leak and functional	Y
19	V5006.01-.03	12	96	PLB doors	N
21	V1009.01-.05	264	2112	MPS leak and functional	N
22	V6018	92	368	cabin air debris screens	N
23	V5E02	36	360	SSME hp turbopump	N
24	V5E06	36	324	SSME hp turbopump	N
34	V9002.01-.10	68	212	ground power	N
35	V1131	24	120	hydraulic system GN2	N
38	V1134	8	48	water drain	N
39	V1078	48	288	APU lube oil	Y
41	V1153	8	56	APU water servicing	Y
47	V1018.02-.04	8	48	APU/water spray boiler	Y
48	V1055	24	168	potable water	Y
54	V1196	24	168	APU fuel tank servicing	Y
56	V1165	72	288	nose landing gear	Y
57	V1003	12	72	electrical power	N
68	V1041	12	72	ECLSS	N
69	V5050	24	96	crew equipment	N
74	V1037	24	240	ammonia boiler	N
79	V1007	24	96	PVD structural leakage test	N
81	V1034	?	?	flight control	N
82	V5101	12	192	weight and balance (GSE only)	N
83	N52XX	48	240	cargo/equipment removal	N
85	N/A	168	336	cargo/equipment reconfiguration	N
86	N/A	192	1344	payload bay reconfiguration	N
87	N/A	120	840	PLB radiator	N
88	N/A	72	288	Orbiter/PLB interface	N
204	S0024	100	?	hydrazine	N

VEHICLE BLOCK CHANGE CANDIDATES
(TECHNOLOGY IMPROVEMENTS)
Figure 1

1.6.3 COST TRADE SUMMARY

Generally, cost trade information is to be found in the appropriate Tentpole and Related Issues Analysis section. This summary section provides an overview and examples. It should be noted that the data required for a rigorous cost trade (manhour data by OMI) was either not available or only partially available since cost data has not been accumulated at this level by the Shuttle Processing Contractor.

Figure 1 provides a brief qualitative summary of each tentpole discussed in detail in Section 1.4, Tentpole and Related Issues Analysis.

The two major cost trades provided in the study are for ANOMALY RESOLUTION and ULCE (Unified Life Cycle Engineering). The prime source of data for these cost trades comes from the Air Force, DoD, and the NASA Congressional Budget Hearings. Improvement factors come from the Air Force and DoD while actual costs and projected costs come from the Nasa Congressional Hearings and the Congressional Budget Office.

It should be noted, in examining cost data in this study, that there is a significant difference in cost data from this Study and those in STAS or the NASA budget hearings:

STAS and NASA use a projected figure of 24 total flights per year and an overall life of 100 flights per vehicle. Based on FY-85 actuals for all operations, this gives an approximate operations cost figure of $100 million per flight.

In this study, we have used a more conservative projected figure of 10 total flights per year based on our operations analysis and as an extrapolation of the fact that the best accomplished to date, FY-85, was 8 flights. 100 flights per vehicle was used as an overall life. Based on FY-85 actuals for all operations this gives an approximate operations full cost figure of $246 million per flight.

The following is a quote from Eric Hanushek, Deputy Director, Congressional Budget Office, in hearings before the Senate Subcommittee on Science, Technology, and Space for FY-86:

> "The estimated full costs are particularly sensitive to the number of flights, because fixed costs, either operational or capital, must be spread over a smaller base if flights are less than 24 per year estimated by NASA. In table 3 of my full testimony, there is an indication of the sensitivity of the estimates. For example, if there are only 12 flights instead of 24 in 1989, the average full cost increases to $258 million."

1.6.3 COST TRADE SUMMARY
(Continued)

Full Operations Cost Derivation: (From Congressional Budget Office data)

$2189.4M for 8 flights, FY-85 or $273M/flight (total ops cost)

Example: Launch Operations = $347.5M for 8 flights

$$= \$347.5/\$2189.4 = 15.9\% \text{ of Total Ops}$$

$$= \$347.5M/8 = \$43.4M/flight$$

Note: The $273M/flight was used to verify validity of the $246M derived from other sources and the $246M was used as a more conservative figure determining cost benefits in the cost analysis below.

Life Cycle Cost Derivation:

Operations = $246M/flt $\times$ 100 flts/vehicle = 24.6B/vehicle = 86%

R & D = 1.65B/vehicle = 6%

Manufact. = 2.4B/vehicle = 8%

_____ _____

Total LCC $ 28.6B/vehicle   100%

1.6.3.1 Anomaly Resolution and ULCE Cost Trades

The following series of figures, based on AF and DoD references quoted earlier in Section 1.4.6, provide the rationale and Life Cycle Cost savings for the following:

Figure 2, Anomaly Resolution (Future Vehicles)

Figure 3, IMIS (Shuttle)

Figure 4, IMIS Implementation Curves (Shuttle)
        (10 flights/yr, $100M/flt.)

Figure 5, IMIS Implementation Curves (Shuttle)
        (24 flights/yr, $100M/flt.)

Figure 6, ULCE (Shuttle)

Figure 7, ULCE (Future Vehicles)

ORIGINAL PAGE IS
OF POOR QUALITY

LIFE CYCLE PHASE	% OF SYSTEM LIFE-CYCLE COST	**X**	ROUGH ESTIMATE OF ITM COST IMPACT	**=**	IMPACT OF ITM ON LIFE-CYCLE COST
● R&D Design	10%		Up 10%		Up 1.0%
● Production	30%		Up 5%		Up 1.5%
● Operation & Maintenance	(60%)				
Repair Labor Costs	32%		Down 13.1%		Down 4.2%
Spares & Repair Material	14%		Down 15%		Down 2.1%
Operation	10%		Down 15%		Down 1.5%
·Initial Logistics Support	4%		——		——
	100%				Down 5.3%

(FOR 100 FLIGHT SHUTTLE THIS WOULD HAVE BEEN (.053 X 28.6B) = $1.5B)

ANOMALY RESOLUTION (FUTURE VEHICLES)
(POTENTIAL COST IMPACT)
Figure 2

LIFE CYCLE PHASE	% OF SYSTEM LCC	ULCE COST IMPACT	IMPACT OF ULCE ON LCC
R & D DESIGN	6%	0%	N/A
PRODUCTION	8%	0%	N/A
O & M	86%	DOWN 3.4%	DOWN 3%

NET: DOWN 3%

SHUTTLE LIFE CYCLE COST SAVINGS
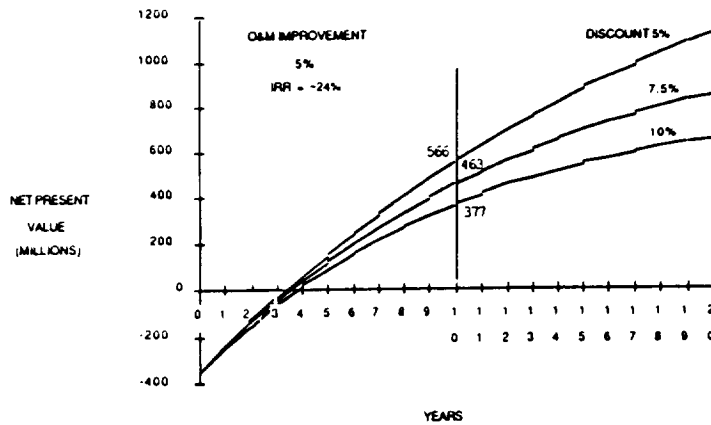UTILIZING ONLY IMIS CONCEPTS

IMIS (SHUTTLE)
Figure 3
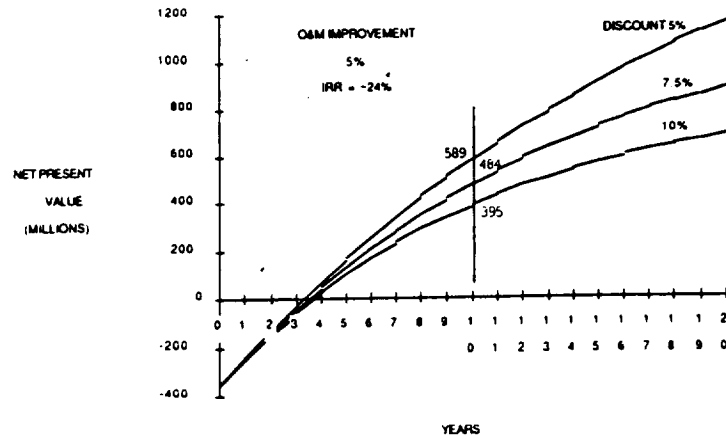
IMIS IMPLEMENTATION CURVES (SHUTTLE)
(10 flts/yr, $246M/flt)
Figure 4

IMIS IMPLEMENTATION CURVES (SHUTTLE)
(24 flts/yr, $100M/flt)
Figure 5

-179-

LIFE CYCLE PHASE	% OF SYSTEM LCC		ULCE COST IMPACT	IMPACT OF ULCE ON LCC
	current	goal		
R & D DESIGN	6%	10%	up 66%	up 6.6%
PRODUCTION	8%	30%	up 375%	up 112.5%
O & M	86%	60%	down 30.2%	down 18.1%

net: up 101%

ULCE (SHUTTLE)
Figure 6

LIFE CYCLE PHASE	% OF SYSTEM LCC	ULCE COST IMPACT	IMPACT OF ULCE ON LCC
R & D DESIGN	10%	UP 20%	UP 2%
PRODUCTION	30%	UP 10%	UP 3%
O & M	60%	DOWN 19%	DOWN 11.4%

NET: DOWN 6.4%

ULCE (FUTURE VEHICLES)
Figure 7

1.6.3 COST TRADE SUMMARY
(Continued)

1.6.3.2 Trade Studies Conclusions and Recommendations

SHUTTLE

The significant conclusions and recommendations for the current Shuttle vehicle are listed below:

*   The current Shuttle will always be an R&D vehicle because it was not designed for efficient operations.

*   Major block modifications of the Orbiter to make it an operationally efficient vehicle are not cost effective. Besides, the out-of-service time would lose 3 to 6 flights. Cost effectiveness will also be a function of remaining Orbiter life. The launch processing manhour data necessary for credible detailed cost trades is not readily available.

    There are two additional considerations, however, for block modifications. (1) If Orbiters are taken out-of-service for mandatory safety mods, then there are efficiency and technology candidates which may be cost effective if packaged with the safety mods, and (2) Shuttle vehicle modifications may be best used as proof-of-concept for future vehicles even though, in themselves, they may not be cost effective.

*   Without major block modifications to the Shuttle or the Shuttle Processing Data Management System (SPDMS) only minimal ground operations efficiencies can be achieved. The potential for increasing launch operations efficiency without major block mods or major overhaul of the SPDMS is minimal (in the order of 10%) -- and this potential will be overwhelmed by additional safety requirements for some time to come.

*   The Study analysis indicates that very significant improvement in current operations can be gained via redesign of SPDMS to conform to IMIS specifications. Potential savings -- $2.6B plus increase of up to 30% in launch rate (based on FY-85 rate of 8/year).

FUTURE VEHICLES

The significant conclusions and recommendations related to the trade studies for future vehicles follows:

*   Major changes in design and management methodology are required.

*   New technology involves management and computer-aided tools.

*   ULCE/CALS (Unified Life Cycle Engineering/Computer Aided Logistics System)

*   DBT/DTC (Design-Build Team/Design to Cost)

*   Without consistent long-term management commitment, this will not work.

*   **Future vehicles, beginning with the Design Concept Phase, must put life cycle costs ahead of performance. We are hauling cargo via freighter -- not participating in a yacht race.**

1.7 FOLLOW-ON STUDY RECOMMENDATIONS

The following follow-on study recommendations are provided with the objective of establishing launch operations requirements for probable future vehicle configurations:

* Based on Phase 1 Study results, and using STAS architectures as an input, specific configurations will be recommended to the NASA KSC Study Manager for his approval prior to their analysis.

* Prepare a be conceptual ground operations plan for the vehicles to identified from two selected architectures; e.g., (1) an expendable unmanned cargo vehicle and (2) a manned cargo vehicle.

* Design concepts/requirements for ULCE/CALS will be expanded; coordination between DoD and NASA/KSC will be established, with participation on associated technical advisory groups encouraged and developed.

* Develop operational support requirements and design concepts including a checklist handbook for designers and program managers.

* Launch site facility concepts for the vehicles under study will be developed. These concepts will describe the most efficient processing with respect to time and manhours and will be optimized in conjunction with the operations concepts.

* Highlight new and developing technologies that apply to subjects of the Study.

* Place the Expanded Technology Knowledge Base on line for use by NASA and Air Force personnel.

1.8 APPENDIX -- BIBLIOGRAPHY ABSTRACTS FROM NASA RECON

References which were obtained through NASA RECON have abstracts which make up this appendix. They are listed in numerical order. Some RECON numbers listed are top numbers for Conference documents and contain numerous papers.

72N30468*# ISSUE 21 PAGE 2836 CATEGORY 17 RPT#: NASA-SP-5110
       LC-74-177266 72/00/00 91 PAGES UNCLASSIFIED DOCUMENT

UTTL: **The Alloy With a Memory, 55-Nitinol: Its Physical Metallurgy, Properties and Applications**

UNOC: Metallurgy, characteristic properties, and industrial applications of nickel titanium alloy with shape memory
       TLSP: Technology Utilization

AUTH: A/JACKSON, C.M. ; B/WAGNER, H.J. ; C/WASILEWSKI, R.J.

CORP: Battelle Memorial Inst., Columbus, Ohio. AVAIL.NTIS

SAP: ; SOD $1.00

CIO: UNITED STATESWashington NASA Sponsored by NASA

MAJS: /*CHEMICAL PROPERTIES /*MECHANICAL PROPERTIES /*METALLURGY
       /*NITINOL /*PHYSICAL PROPERTIES

MINS: / INDUSTRIES/ METAL WORKING/ NASA PROGRAMS/ STRUCTURAL
       STABILITY/ TECHNOLOGY UTILIZATION/ THERMAL STABILITY

ABA: Author

ABS: A series of nickel titanium alloys (55-Nitinol), which are unique in that they possess a shape memory, are described. Components made of these materials that are altered in their shapes by deformation under proper conditions return to predetermined shapes when they are heated to the proper temperature range. The shape memory, together with the force exerted and the ability of the material to do mechanical work as it returns to its predetermined shape, suggest a wide variety of industrial applications for the alloy. Also included are discussions of the physical metallurgy and the mechanical, physical, and chemical properties of 55-Nitinol; procedures for melting and processing the material into useful shapes; and a summary of applications.

****

82A14841# ISSUE 4 PAGE 531 CATEGORY 33 81/00/00 10 PAGES
UNCLASSIFIED DOCUMENT

UTTL: **Progress in Designing for Testability --- of Avionics and Test Equipment**

AUTH: A/ALLEN, D. R.; B/FERCH, B. C. PAA: B/(USAF, Wright-Patterson AFB,OH)

CIO: UNITED STATES

In: NAECON 1981; Proceedings of the National Aerospace and Electronics Conference, Dayton, OH, May 19-21, 1981. Volume 3. (A82-14676 04-01) New York, Institute of Electrical and Electronics Engineers, Inc., 1981, p. 1362-1371.

MAJS:/*AVIONICS/*DESIGN ANALYSIS/*ELECTRONIC EQUIPMENT TESTS/*FAILURE ANALYSIS /*RELIABILITY ENGINEERING/*TEST EQUIPMENT/*USER REQUIREMENTS

MINS: / AIRBORNE/SPACEBORNE COMPUTERS/ AUTOMATIC TEST EQUIPMENT/ CIRCUIT RELIABILITY/ NONDESTRUCTIVE TESTS/ ONBOARD DATA PROCESSING/ TECHNOLOGY ASSESSMENT ABA: (Author)

ABS: This paper presents an overview of recent developments in testability concepts, testability measures, and testability enforcement in the design of avionics and test equipment. Each of the joint services has efforts recently concluded or underway to better define requirements for testability in the areas of built-in test, the inherent testability of units under test, and the interfaces with test equipment. This paper brings out the significant contributions from the various activities, and provides a critique of proposed solutions.

****

C-3

82N19033# ISSUE 9 PAGE 1297 CATEGORY 74 RPT#: AD-A108278
NSWC/TR-81-129 NAVSEA-S562-78 81/07/01 71 PAGES
UNCLASSIFIED DOCUMENT

UTTL: Nitinol interconnect device for optical fiber
waveguides   TLSP: Final Report

AUTH: A/GOLDSTEIN, D.; B/TYDINGS, J.

CORP: Naval Surface Weapons Center, Silver Spring, Md.
AVAIL.NTIS

SAP: HC A04/MF A01

CIO: UNITED STATES

MAJS: /*CONNECTORS/*FIBER OPTICS/*NITINOL ALLOYS/*OPTICAL
WAVEGUIDES

MINS: / BUNDLES/ FABRICATION/ OPTICAL COMMUNICATION/ PIPES
(TUBES)/ POWDER METALLURGY

ABA: Author (GRA)

ABS: Two different interconnect devices for optical fibers have
been developed. Each uses the shape memory effect alloy
'NITINOL'. The simpler of the two is of tubular design
and accommodates fibers as small as 200 micron diameter.
The more complex multi-component design accommodates 125
micron diameter fibers. The complex design is simpler to
use, easier to manufacture and lower in cost. It permits
less than 1 db loss and is re-matable. A description of
NITINOL manufacture is given.

****

83N30702*# ISSUE 19 PAGE 3100 CATEGORY 27 82/05/00 10 PAGES
UNCLASSIFIED DOCUMENT

UTTL: <u>**Structural Characteristics of the Shuttle Orbiter Ceramic
Thermal Protection System**</u>

AUTH: A/COOPER, P. A.

CORP: National Aeronautics and Space Administration. Langley
Research Center, Hampton, Va. AVAIL.NTIS

SAP: HC A09/MF A01 In Shock and Vibration Inform. Center The
Shock and Vibration Bull., No. 52. Part 2 p 101-110 (SEE
N83-30692 19-31)

CIO: UNITED STATES

MAJS: /*REENTRY SHIELDING/*REUSABLE HEAT SHIELDING/*SPACE
SHUTTLE ORBITERS/* SPACE SHUTTLES/*THERMAL
PROTECTION/*TILES

MINS: / CERAMICS/ CERTIFICATION/ FLIGHT TESTS/ TENSILE STRENGTH

ABA: R.J.F.

ABS: The thermal protection system (TPS) of the Space Shuttle
Orbiter is described as well as the results of dynamic
reponse studies conducted in support of the efforts to
certify the TPS for flight. The ceramic Thermal
Protection System consists of ceramic tiles bonded to felt
pads which are in turn bonded to the Orbiter substructure
to protect the aluminum substructure from the heat of
reentry.

****

83N34652# ISSUE 22 PAGE 3696 CATEGORY 63 RPT#:
DM55/JPS/JP/317-83-VOL-2 ESA-CR(P)-1759-VOL-2 CNT#:
ESTEC-4869/81/NL-PP 83/00/00 2 VOLS 276 PAGES UNCLASSIFIED
DOCUMENT DCAF E003091

UTTL: **Standard Generic Approach for Spacecraft Intelligence and Automation.** Phase 1, volume 2: Technical report TLSP: Final Report

AUTH: A/BERGER, G.; B/CORNET, J.; C/CELLIER, M.; D/RIOU, L.; E/SOTTA, J.; F/THIBAUT, M.

CORP: MATRA Espace, Paris-Velizy (France). AVAIL.NTIS

SAP: HC A12/MF A01

CIO: FRANCE Paris ESA

MAJS: /*ARTIFICIAL INTELLIGENCE/*AUTONOMY/*ONBOARD DATA PROCESSING/*SATELLITE CONTROL/*SPACECRAFT DESIGN

MINS: / DATA MANAGEMENT/ DECISION MAKING/ GROUND SUPPORT EQUIPMENT/ HIGH LEVEL LANGUAGES/ MICROPROCESSORS/ PATTERN RECOGNITION/ STRESS ANALYSIS

ABA: Author (ESA)

ABS: Applications of onboard autonomy and data processing, and the corresponding spacecraft and ground control organization were identified by analyzing the Viking 75 deep space mission and the ERS-1 (ESA satellite) Earth observation mission. Telecommunication satellites, STS, data relay satellites and large space stations were also studied. An approach to spacecraft intelligence and autonomy based on a hierarchical decentralized system structure, in order to limit failure propagation, simplify interfaces, and improve performance predictability, is proposed. Onboard management is subdivided into routine, crisis, and end product management. Orbit determination and control is autonomous.

****

84A16548# ISSUE 5 PAGE 643 CATEGORY 60 83/00/00 5 PAGES
UNCLASSIFIED DOCUMENT

AUTH: A/ASKREN, W. B. PAA: A/(USAF, Human Resources Laboratory, Wright-Patterson AFB, OH)

CIO: UNITED STATES

IN: NAECON 1983; Proceedings of the National Aerospace and Electronics Conference, Dayton, OH, May 17-19, 1983. Volume 1 (A84-16526 05-01). New York, Institute of Electrical and Electronics Engineers, 1983, p. 221-225.

MAJS: /*COMPUTER AIDED DESIGN /*DESIGN ANALYSIS /*LOGISTICS /*MAINTENANCE /*PRODUCT DEVELOPMENT/*SYSTEMS ENGINEERING

MINS: / AEROSPACE INDUSTRY/ BIODYNAMICS/ COMPUTER AIDED MANUFACTURING/ DATA BASES/ MATHEMATICAL MODELS/ RESEARCH AND DEVELOPMENT

ABA: Author

ABS: The concept of including maintenance and logistics factors in computer aided design (CAD) of new systems and equipment is presented. Air Force Human Resources Laboratory's plans for research and development in this area are described. The concept includes the role that CAD could play in improving design for supportability, the characteristics of CAD that are relevant to including maintenance and logistics factors, and the products that are needed to integrate maintenance and logistics factors into CAD. The research and development includes four efforts: the development of a maintenance analysis model for CAD; a biomechanical model of the maintenance technician; demonstrations of maintenance and logistics factors in CAD in the aerospace industry; and integrating a logistics data base with CAD/CAM engineering data bases.

****

84A17175 ISSUE 5 PAGE 605 CATEGORY 38 83/00/00 16 PAGES
UNCLASSIFIED DOCUMENT

UTTL: **Ultrasonic Inspection Techniques Applied to Strength Evaluation of Shuttle Orbiter Thermal Protection Tiles**

AUTH: A/MACK, F. E.; B/HOGENSON, P. A. PAA: B/(Rockwell International Corp. Space Transportation and Systems Group, Downey, CA)

CIO: UNITED STATES

IN: Materials and processes - Continuing innovations; Proceedings of the Twenty-eighth National SAMPE Symposium and Exhibition, Anaheim, CA, April 12-14, 1983 (A84-17101 05-23). Azusa, CA, Society for the Advancement of Material and Process Engineering, 1983, p. 1069-1084.

MAJS: /*ACOUSTIC VELOCITY/*CERAMICS/*SPACE SHUTTLE ORBITERS/*TENSILE STRENGTH/ THERMAL PROTECTION/*ULTRASONIC TESTS

MINS: / CERAMIC COATINGS/ FIBER ORIENTATION/ NONDESTRUCTIVE SHIELDING/ TILES

ABA: Author

ABS: The development of an ultrasonic technique for determining the strength of the thermal protection tiles used on the Space Shuttle Orbiter is described. The basic test approach was to experimentally relate through transmission pulse velocity readings for 1-inch by 1-inch coupons to ultimate strengths of the same coupons and in turn extrapolate this information to the full size tiles. Factors affecting the pulse velocity such as material thickness variability, sonic coupling, and influences of the higher velocity components of the coating and densified layer were studied. These effects on pulse velocity were integrated in a software correction factor which was applied to the tile data so the strength properties of the basic tile material could be compared with the coupon reference system and the appropriate accept/reject criteria used. Use of the ultrasonic technique to evaluate strength variability within the large blocks of material from which the tiles are machined is also described........

****

84A26768 ISSUE 11 PAGE 1506 CATEGORY 6 83/00/00 7 PAGES
UNCLASSIFIED DOCUMENT

UTTL: **Testing BITE on Boeing 757/767 In a Simulated Operational Environment**

AUTH: A/LEE, H. F.; B/CARSON, D. P. PAA: B/(Boeing Co., Seattle, WA)

CIO: UNITED STATES

IN: Digital Avionics Systems Conference, 5th, Seattle, WA, October 31-November 3, 1983, Proceedings (A84-26701 11-06). New York, Institute of Electrical and Electronics Engineers, 1983, p. 15.4.1-15.4.7........

MAJS: /*AIRCRAFT CONTROL/*AUTOMATIC TEST EQUIPMENT/*DATA SIMULATION/*FLIGHT CONTROL/*GROUND TESTS/*SYSTEMS MANAGEMENT

MINS: / BOEING 757 AIRCRAFT/ BOEING 767 A RCRAFT/ DATA ACQUISITION/ DESIGN ANALYSIS/ ELECTRONIC AIRCRAFT/ FAULT TOLERANCE/ FLIGHT SIMULATION/ FLIGHT TESTS

ABA: Author

ABS: To provide 'on-airplane' data that supports validation of the system-level equipment (BITE), a series of ground tests were conducted with simulated airplane flight and fault conditions. These tests provided qualitative support for establishing BITE credibility, and usage experience prior to airplane service introduction. BITE indications were correlated with the cockpit effects, simulated fault conditions, and simulation limitations to determine proper correlation and utility of indications. Results either indicated proper operation or improvements needed.

****

84A26771 ISSUE 11 PAGE 1506 CATEGORY 6 83/00/00 8 PAGES
UNCLASSIFIED DOCUMENT

UTTL: **Fault, Detection, Isolation, and Recovery Techniques for Fault Tolerant Digital Avionics**

AUTH: A/HITT, E. F.; B/ELDREDGE, D. PAA: A/(Battelle Columbus Laboratories, Columbus, OH); B/(FAA, Technical Center, Atlantic City, NJ)

CIO: UNITED STATES

IN: Digital Avionics Systems Conference, 5th, Seattle, WA, October 31-November 3, 1983, Proceedings (A84-26701 11-06). New York, Institute of Electrical and Electronics Engineers, 1983, p.16.1.1-16.1.8.........

MAJS: /*AIRBORNE/SPACEBORNE COMPUTERS/*AVIONICS/*COMPUTER SYSTEMS PERFORMANCE/ DIGITAL SYSTEMS/*ELECTRONIC EQUIPMENT TESTS/*FAULT TOLERANCE

MINS: / CIRCUIT RELIABILITY/ FAILURE ANALYSIS/ IN-FLIGHT MONITORING/ SYSTEM FAILURES/ RELIABILITY ENGINEERING

ABA: Author

ABS: Fault tolerant design technologies for digital avionics system are described in this paper. The techniques include both hardware and software methods used for detecting faults at three levels. These levels should be implemented to assure (1) the correct operation of each processing unit, (2) valid communication of data between digital subsystems, and (3) data validity, prior to use in subsequent computation and after conversion of digital data. Once a fault is detected, system recovery must take place to assure the continued performance of the function(s) affected by the fault. The methods used to control the system recovery techniques are dependent upon the systems ability to isolate the detected fault to the lowest the lowest possible level. The system recovery techniques are also dependent upon system architecture. Fault isolation and system recovery techniques require knowledge of the system status vector and its history in sophisticated systems.

****

84A26795 ISSUE 11 PAGE 1615 CATEGORY 60 83/00/00 7 PAGES
UNCLASSIFIED DOCUMENT

UTTL: <u>**Processor Monitoring and Self-test In the Boeing 767/757 Flight Control Computer**</u>

AUTH: A/KOVALAN, M. PAA: A/(Rockwell International Corp., Collins Air Transport Div., Cedar Rapids, IA)

CIO: UNITED STATES

IN: Digital Avionics Systems Conference, 5th, Seattle, WA, October 31-November 3, 1983, Proceedings (A84-26701 11-06). New York, Institute of Electrical and Electronics Engineers, 1983, p 21.1.1-21.1.7..........

MAJS: /*AIRBORNE/SPACEBORNE COMPUTERS/*CENTRAL PROCESSING UNITS/*COMPUTER SYSTEMS PROGRAMS/*FAILURE ANALYSIS/*FLIGHT CONTROL/*RELIABILITY ENGINEERING/*SELF TESTS

MINS: / BOEING 757 AIRCRAFT/ BOEING 767 AIRCRAFT/ ERROR DETECTION CODES/ MICROPROGRAMMING/ PROGRAM VERIFICATION (COMPUTERS)/ SELF TESTS/ SYSTEM FAILURES

ABA: Based primarily through frequent execution of a comprehensive self-test design is basef on functional verification of the processor's ability to properly execute all steps associated with integrated interrupt response. An analysis of the processor alogrithms and interrupt response. An analysis of the processor self-test and monitor was performed to assess the coverage of processor functions obtained through the chosen monitoring arrangement. The undetected failure rate for CAPS-6B was predicted to be about 10 to the -7th per hour, corresponding to less than 1 percent of the total processor failure rate.

****

84A36557*# ISSUE 17 PAGE 2438 CATEGORY 18 84/06/00 8 PAGES
UNCLASSIFIED DOCUMENT

UTTL: **Mechanical Properties of the Shuttle Orbiter Thermal Protection System Strain Isolator Pad**

AUTH: A/SAWYER, J. W. PAA: A/(NASA, Langley Research Center, Structures and Dynamics Div., Hampton, VA)

CORP: National Aeronautics and Space Administration. Langley Research Center, Hampton, Va.

CIO: UNITED STATES
(Structures, Structural Dynamics and Materials Conference, 23rd, New Orleans, LA, May 10-12, 1982, Collection of Technical Papers. Part 1, p. 23-31) Journal of Spacecraft and Rockets (ISSN 0022-4650), vol. 21, May-June 1984, p. 253-260.

MAJS: /*FATIGUE TESTS/*ISOLATORS/*MECHANICAL PROPERTIES/*SPACE SHUTTLE ORBITER /*SPACECRAFT SHIELDING/*THERMAL PROTECTION

MINS: / COMPRESSION LOADS/ CYCLIC LOADS/ HYSTERESIS/ LOAD TESTS/ SHEAR PROPERTIES/ STATIC LOADS/ STRESS CYCLES/ STRESS-STRAIN DIAGRAMS/ TENSILE STRENGTH/ TILES

ABS: Previously cited in issue 19, p. 2029, Accession no. A82-30079

****

84A49504*# ISSUE 24 PAGE 3499 CATEGORY 18 84/10/00 7 PAGES
UNCLASSIFIED DOCUMENT

UTTL: **Effect of Simulated Mission Loads On Orbiter Thermal
Protection System Undensified Tiles**

AUTH: A/COOPER, P. A.; B/MISERENTINO, R.; C/SAWYER, J. W.;
D/LEATHERWOOD, J D. PAA: D/(NASA, Langley Research
Center, Hampton, VA)

CORP: National Aeronautics and Space Administration. Langley
Research Center, Hampton, Va.

CIO: UNITED STATES
(Structures, Structural Dynamics and Materials
Conference, 23rd, New Orleans, LA, May 10-12, 1982,
Collection of Technical Papers. Part 1, p. 32-40)
Journal of Spacecraft and Rockets (ISSN 0022-4650), vol.
21, Sept.-Oct. 1984, p. 441-447. Previously cited in
issue 13, p. 2029, Accession no. A82-30080.

MAJS: /*DYNAMIC LOADS/*DYNAMIC STRUCTURAL ANALYSIS/*SPACE
SHUTTLE ORBITERS/* SPACECRAFT DESIGN/*THERMAL
PROTECTION/*TILES

MINS: / CERAMICS/ CLIMBING FLIGHT/ DYNAMIC RESPONSE/ LOAD TESTS/
RANDOM LOADS/ STATIC LOADS/ TENSILE TESTS/ THERMAL
SIMULATION

****

84N22528# ISSUE 13 PAGE 1925 CATEGORY 1 RPT#: AD-A138587
     AFWAL-TR-83-1183 CNT#:   F33615-81-C-1517 AF PROJ. 2003
     83/12/00 323 PAGES UNCLASSIFIED DOCUMENT

UTTL: **Integrated Testing and Maintenance Technologies** TLSP:
       Final Technical Report, 25 Sep. 1981 - 15 Sep. 1983

AUTH: A/DENNEY, R. O.; B/PARTRIDGE, M. J.; C/WILLIAMS, R.
       B.

CORP: Boeing Aerospace Co., Seattle, Wash. AVAIL.NTIS

SAP: HC A14/MF A01

CIO: UNITED STATESWright-Patterson AFB, Ohio AFWAL

MAJS: /*AVIONICS/*EXPERT   SYSTEMS/*FIGHTER
       AIRCRAFT/*MAINTENANCE/*ONBOARD   EQUIPMENT/*SYSTEMS
       INTEGRATION

MINS: / ARTIFICIAL INTELLIGENCE/ COST ANALYSIS/ DATA
       ACQUISITION/ LIFE CYCLE COSTS/ MILITARY AIRCRAFT/ SYSTEMS
       ANALYSIS/ SYSTEMS INTEGRATION/ WEAPON SYSTEMS

ABA: Author (GRA)

ABS: Maintenance of weapon systems is becoming an increasingly
       important consideration in weapon system development,
       because the cost of maintenance is a significant portion
       of the life cycle cost of the system. The objective of
       the Integrated Testing and Maintenance Technology effort
       is to define requirements for an onboard test system for
       the avionic suite planned for tactical fighters in the
       1990's. Problems with current onboard test systems were
       analyzed to determine where improvements could be made.
       In addition, the anticipated avionic architecture and
       mission of the 1990's were evaluated to determine the
       impact on maintenance capability. Requirements for the
       Integrated Testing and Maintenance System were developed
       and documented in a system specification. Identified
       improvements over current systems include better
       filtering of intermittent failure reports, better
       isolation of intermittent failures through the use of
       recorded data, more extensive use of system-level tests
       of mission operational data and a man-machine interface
       providing more information to the maintenance technician.
       In addition, artifically where the intelligence
       applications were evaluated to determine might be
       effectively applied to ITM. A design concept for fault
       classification expert system was developed.

****

84N25089*# ISSUE 15 PAGE 2348 CATEGORY 39 84/05/00 15 PAGES
UNCLASSIFIED DOCUMENT

UTTL: **Passive Sun Seeker/tracker and a Thermally Activated Power Module**

AUTH: A/SIEBERT, C. J.; B/MORRIS, F. A.

CORP: Martin Marietta Corp., Denver, Colo. AVAIL.NTIS

SAP: HC A14/MF A01 In NASA. Goddard Space Flight Center The 18th Aerospace Mech. Symp. p 171-185 (SEE N84-25078 15-39)

CIO: UNITED STATES

MAJS: /*HOMING DEVICES/*NITINOL ALLOYS/*POWER MODULES (STS)/*SOLAR RADIATION

MINS: / ALGORITHMS/ KINEMATICS/ PARABOLIC REFLECTORS/ PHASE TRANSFORMATIONS/ PLASTIC MEMORY/ THERMAL ENERGY

ABA: Author

ABS: Development and testing of two mechanisms using a shape memory alloy metal (NITINOL) as the power source described. The two mech developed are a passive Sun Seeker/Tracker and a generic type power module. These mechanisms use NITINOL wire initially strained in pure torsion which provides the greatest mechanical work capacity upon recovery, as compared to other deformation modes (i.e., tension, helical springs, and bending).

****

84X10356*# ISSUE 8 CATEGORY 16 RPT#: NASA-CP-2315 L-15790 NAS
1.55:2315 84/07/00 516 PAGES UNCLASSIFIED DOCUMENT
DOMESTIC

UTTL: **Advances in TPS and Structures for Space Transportation Systems**

AUTH: A/KELLY, H. N.; B/GARDNER, J. E. PAT: A/comp.; B/comp.

CORP: National Aeronautics and Space Administration. Langley Research Center, Hampton, Va.

SAP: Limited by ITAR

CIO: UNITED STATES Symp. held in Hampton, Va., 13-15 Dec. 1983

MAJS: /*CONFERENCES/*SPACE SHUTTLE ORBITERS/*SPACE TRANSPORTATION SYSTEM/* SPACECRAFT STRUCTURES/*THERMAL PROTECTION

MINS: / AEROTHERMODYNAMICS/ CARBON-CARBON COMPOSITES/ CERAMICS/ COMPOSITE STRUCTURES/ METALS/ STRUCTURAL ENGINEERING

ANN: Flight experiences with the Space Shuttle orbiter thermal protection system are described and evaluated, and research on new concepts in metallic, ceramic, and advanced carbon-carbon TPS and structures is presented. Advanced and alternate configurations and missions for next-generation space transportation systems and issues and technology needs are discussed.

****

85N11592#   ISSUE   2   PAGE   244   CATEGORY   63   RPT#:   AD-A145349
AFHRL-TR-84-25   CNT#:   F33615-82-C-0013 84/06/00 525 PAGES
UNCLASSIFIED DOCUMENT

UTTL: <u>Artificial   Intelligence   in   Maintenance: Proceedings   of
the   Joint   Services   Workshop</u>   TLSP: Interim   Report,   Sep.
-1982 Sep.   1983

CORP: Denver Research Inst., Colo.   AVAIL.NTIS

SAP: HC A22/MF A01

CIO: UNITED   STATES   Workshop held in Boulder, Colo., 4-6   Oct.
1983

MAJS: /*ARTIFICIAL   INTELLIGENCE/*AUTOMATIC   TEST
EQUIPMENT/*INFORMATION
DISSEMINATION/*MAINTENANCE/*MANAGEMENT METHODS/*TECHNOLOGY
TRANSFER

MINS: /   CONFERENCES/   DEFENSE   PROGRAM/   EDUCATION/   MILITARY
TECHNOLOGY/   PRODUCT   DEVELOPMENT/   RESEARCH/   RESEARCH   AND
DEVELOPMENT

ANN: This   report   presents   the   proceedings of a   workshop   on
artificial   intelligence   (AI)   in   maintenance   that   was
sponsored   by   7   Department   of   Defense   agencies.   The
workshop,   entitled Joint Services Workshop on   Artificial
Intelligence in Maintenance, was held October 4-6, 1983 in
Boulder,   Colorado.   The primary objective of the workshop
was   to provide an exchange of technical information among
personnel involved in on-going research and development in
artificial   intelligence applicable to automatic   testing,
maintenance   aiding,   and maintenance training.   A   second
objective   was to identify both theoretical and   practical
applications issues in the use of AI in maintenance.   This
report   is   organized into four sections: Overview;   The
Science;   Department   of Defense Programs   and   Projects;
and   Commercial and Industrial Development Projects.   The
material   in   the   report   includes   contributed   and,
significant   papers   previously   published,   and   edited
transcripts   of   presentations made at the workshop.   For
individual titles see N85-11593 through N85-11627.

****

85N16731# ISSUE 8 PAGE 1063 CATEGORY 1 RPT#: AGARD-CP-361
ISBN-92-835-0366-10 AD-A149199 84/10/00 281 PAGES In
ENGLISH and FRENCH UNCLASSIFIED DOCUMENT

UTTL: **Design for Tactical Avionics Maintainability**

CORP: Advisory Group for Aerospace Research and Development,
Neuilly-Sur-Seine (France). AVAIL.NTIS

SAP: HC A13/MF A01

CIO: FRANCELoughton, England Conf. held in Brussels, 7-10 May
1984

MAJS: /*AIRCRAFT EQUIPMENT/*AIRCRAFT MAINTENANCE/*AUTOMATIC TEST
EQUIPMENT/* AVIONICS/*MAINTAINABILITY

MINS: / AIRBORNE/SPACEBORNE COMPUTERS/ ARTIFICIAL INTELLIGENCE/
CHECKOUT/ COST REDUCTION/ ELECTRONIC MODULES/ PROGRAM
VERIFICATION (COMPUTERS)/ RELIABILITY ENGINEERING/ SERVICE
LIFE

ANN: Advanced methods and tools to support design for avionic
maintainability and testability are discussed. Both
hardware and software design for maintainability issues
and approaches are addressed. For individual titles see
N85-16732 through N85-16756.

****

85N16752# ISSUE 8 PAGE 1066 CATEGORY 1 84/10/00 6 PAGES
UNCLASSIFIED DOCUMENT

UTTL: **A Weapon System Design Approach to Diagnostics**

AUTH: A/NEUMANN, G. W.; B/BATTAGLIA, M. PAA: A/(Giordano
Associates, Inc., Arlington, Va.)

CORP: Naval Electronic Systems Command, Washington, D. C.
AVAIL.NTIS

SAP: HC A13/MF A01 In AGARD Design for Tactical Avionics
Maintainability 6 p (see N85-16731 08-01)

CIO: UNITED STATES

MAJS: /*AVIONICS/*GOVERNMENT/INDUSTRY
RELATIONS/*MAINTENANCE/*WEAPON SYSTEMS

MINS: / ARTIFICIAL INTELLIGENCE/ COMPUTER AIDED DESIGN/ COMPUTER
AIDED MANUFACTURING/ COSTS/ EDUCATION/ FAULT TOLERANCE/
SYSTEMS ENGINEERING

ABA: R.S.F.

ABS: Providing a diagnostics capability for today's weapon
systems requires a multifaceted combination of hardware,
software, and personnel. The approach to providing this
capability is fractionated among a number of different
communities (e.g., testing, training, human engineering,
publication writers). The result is reflected in the
field, where the technician has been furnished a myriad of
tools and documentation, which is confusing, complex and
often contradictory. The result is lengthy repair times
and a waste of manpower and dollars. The basic reason for
this diagnostic deficiency is the lack of an integrated
design approach providing this capability and the
inability to transition technological advancements to
weapon systems acquisitions. Recent Department of Defense
and U.S. industry efforts to solve this problem are
discussed.

****

85N16947**# ISSUE 8 PAGE 1099 CATEGORY 16 85/01/00 18 PAGES
UNCLASSIFIED DOCUMENT

UTTL: **Space Shuttle Electrical Power Generation and Reactant Supply System**

AUTH: A/SIMON, W. E.

CORP: National Aeronautics and Space Administration. Lyndon B. Johnson Space Center, Houston, Tex. AVAIL.NTIS

SAP: HC A01/MF A01 In its Space Shuttle Tech. Conf., Pt. 2 p 702-719 (SEE N85-16937 08-12)

CIO: UNITED STATES

MAJS: /*CRYOGENIC FLUID STORAGE/*FUEL CELLS/*SPACE SHUTTLE ORBITERS/*SPACECRAF POWER SUPPLIES/*SYSTEMS ENGINEERING

MINS: / APOLLO PROJECT/ CIRCUIT PROTECTION/ LIFE SUPPORT SYSTEMS/ OPERATIONAL PROBLEMS/ POTABLE WATER/ STRUCTURAL WEIGHT/ SYSTEM EFFECTIVENESS

ABA: A.R.H.

ABS: The design philosophy and development experience of fuel cell power generation and cryogenic reactant supply systems are reviewed, beginning with the state of technology at the conclusion of the Apollo Program. Technology advancements span a period of 10 years from initial definition phase to the most recent space transportation system (STS) flights. The development program encompassed prototype verification, and qualification hardware, as well as post-STS-1 design improvements. Focus is on the problems encountered, the scientific and engineering approaches employed to meet the technological challenges, and the results obtained. Major technology barriers are discussed, and the evolving technology devolopment paths are traced to their conceptual beginnings to the fully man-rated systems which are now an integral part of the shuttle vehicle.

****

85N16979*# ISSUE 8 PAGE 1104 CATEGORY 16 85/01/00 20 PAGES
UNCLASSIFIED DOCUMENT

UTTL: **Orbiter Thermal Protection System**

AUTH: A/DOTTS, R. L.; B/CURRY, D. M.; C/TILLIAN, D. J.

CORP: National Aeronautics and Space Administration. Lyndon B.
Johnson Space Center, Houston, Tex. AVAIL.NTIS

SAP: HC A23/MF A01 In its Space Shuttle Tech. Conf., Pt. 2 p
1062-1081 (SEE N85-16937 08-12)

CIO: UNITED STATES

MAJS: /*AEROTHERMODYNAMICS/*SPACE SHUTTLE ORBITERS/*THERMAL
PROTECTION

MINS: / ABLATIVE MATERIALS/ PERFORMANCE TESTS/ REUSABLE HEAT
SHIELDING/ SPACECRAFT DESIGN/ TEMPERATURE CONTROL/ THERMAL
INSULATION

ABA: E.A.K.

ABS: The major material and design challenges associated with
the orbiter thermal protection system (TPS), the various
TPS materials that are used, the different design
approaches associated with each of the materials, and the
performance during the flight test program are described.
The first five flights of the Orbiter Columbia and the
initial flight of the Orbiter Challenger provided the data
necessary to verify the TPS thermal performance,
structural integrity, and reusability. The flight
performance characteristics of each TPS material are
discussed, based on postflight inspections and postflight
interpretation of the flight instrumentation data.
Flights to date indicate that the thermal and structural
design requirements for the orbiter TPS are met and that
the overall performance is outstanding.

****

85N24839# ISSUE 14 PAGE 2407 CATEGORY 63 RPT#: AD-A150694
RADC-TR-84-203 CNT#: F30602-83-C-0048 84/10/00 187 PAGES
UNCLASSIFIED DOCUMENT

UTTL: <u>Artificial Intelligence Applications to Testability</u> TLSP:
Final Report, Apr. 1983 - May 1984

AUTH: A/LAHORE, H.

CORP: Boeing Aerospace Co., Seattle, Wash. CSS: (Engineering
Technology Organization.) AVAIL.NTIS

SAP: HC A09/MF A01

CIO: UNITED STATESGriffiss AFB, N.Y. RADC

MAJS: /*ARTIFICIAL INTELLIGENCE/*COST EFFECTIVENESS/*MILITARY
TECHNOLOGY

MINS: / COMPUTER AIDED DESIGN/ ELECTRONIC EQUIPMENT/ EXPERT
SYSTEMS/ MAINTENANCE/ RELIABILITY/ WORKSTATIONS

ABA: GRA

ABS: This study provides the foundation for a logical and
cost-effective for five years. The primary near term
applications are design support and maintenance
applications. Eight potential applications are developed
and evaluated: (1) computer aided preliminary design for
testability, (2) Smart Built-in Test, (3) Smart System
Integrated Test, (4) Box Level Maintenance Expert, (5)
System Level Maintenance Expert, (6) Smart Maintenance
Expert, (7) Automatic Test Program Generation, and (8)
Smart Bench Tester. All of these application
opportunities can be implemented with engineering
workstations which are becoming available directly to
designers.

****

85N26966# ISSUE 16 PAGE 2749 CATEGORY 26 RPT#: AD-A152089
NSWC/TR-84-326 CNT#: F66-512 84/10/15 32 PAGES
UNCLASSIFIED DOCUMENT

UTTL: **Production of Shaped Parts of NITINOL Alloys by Solid-state Sintering**

AUTH: A/GOLDSTEIN, D. M.

CORP: Naval Surface Weapons Center, Silver Spring, Md.
AVAIL.NTIS

SAP: HC A03/MF A01

CIO: UNITED STATES

MAJS: /*METAL WORKING/*NITINOL ALLOYS/*PLASTIC MEMORY/*SINTERING

MINS: / DEFORMATION/ EXTRUDING/ FITTINGS/ LOW TEMPERATURE/ PIPES
(TUBES)/ POWDER METEALLURGY/ SHAPES

ABA: GRA

ABS: Nitinol is an alloy of nickel and titanium which exhibits
a shape memory effect. The term shape memory effect (SME)
is used to describe the ability of certain alloys which,
if deformed at a low temperature, will recover their prior
shape when heated. A solid state sintering process has
been successfully adapted to consolidating Nitinol alloy
powders. Nitinol alloys are noted for their shape memory
properties. The sintering process is performed at
atmospheric pressure upon powders contained in an
evacuated glass container. Processing parameters are
reported. Tubes and tubular tees were were made as well
as solid round bars. Round bar stock was extruded and
swaged excellent shape memory properties were obtained.

****

85N27576# ISSUE 16 PAGE 2851 CATEGORY 63 RPT#: AD-A151918
AFIT/GE/ENG/84D-53 84/12/00 367 PAGES UNCLASSIFIED
DOCUMENT

UTTL: **Diagnosis: Using Automatic Test Equipment and an Artificial Intelligenc Expert System** TLSP: **M.S. Thesis**

AUTH: A/RAMSEY, J. E., JR.

CORP: Air Force Inst. of Tech., Wright-Patterson AFB, Ohio.
CSS: (School of Engineering.) AVAIL.NTIS

SAP: HC A16/MF A01

CIO: UNITED STATES

MAJS: /*ARTIFICIAL INTELLIGENCE/*DATA BASES/*EXPERT SYSTEMS/*F-15 AIRCRAFT/* SOFTWARE ENGINEERING

MINS: / AIRCRAFT MAINTENANCE/ CIRCUIT BOARDS/ CODING/ COMPUTER PROGRAMS/ ELECTRONIC MODULES/ PERFORMANCE TESTS/ PROBLEM SOLVING

ABA: GRA

ABS: This reviews three different expert systems (ATEOPS, ATEFEXPERS, and ATEFATLAS) created to direct automatic test equipment (ATE). Although related, each expert system uses a different knowledge base or inference engine and base their testing on the circuit schematic, test requirements document (TRD), or ATLAS code. Implementing generalized modules allows the expert systems to be used for any unit under test. Because of numerous errors in the ATLAS code and problems with the actual hardware connection, a fully operational system was not developed. These expert systems provide insight into the necessary knowledge bases and inference engines needed by an expert system to direct ATE. Using converted ATLAS to LISP code allows the expert system to direct any ATE using ATLAS. The CP-FRL allows the expert system to expand its control by creating the ATLAS code, checking the code for good software engineering techniques, directing the ATE, and changing the test sequence as needed.

****

85N27936*# ISSUE 17 PAGE 2909 CATEGORY 18 RPT#: NASA-CR-175881
NASA 1.26:175881 CSI/85-01 CNT#: NAGW-629 85/02/25 142
PAGE UNCLASSIFIED DOCUMENT

UTTL: **Automation and Robotics for the National Space Program**

CORP: California Univ., San Diego. CSS: (Automation and
Robotics Panel.) AVAIL.NTIS

SAP: HC A07/MF A01

CIO: UNITED STATES

MAJS: /*AUTOMATIC CONTROL/*ROBOTICS/*SPACE STATIONS/*TECHNOLOGY
UTILIZATION

MINS: / COMPUTER SYSTEMS DESIGN/ EXPERT SYSTEMS/ NASA PROGRAMS/
RESEARCH AND DEVELOPMENT

ABA: E.R.

ABS: The emphasis on automation and robotics in the
augmentation of the human centered systems as it concerns
the Space Station is discussed. How automation and
robotics can amplify the capabilities of humans is
detailed. A detailed developmental program for the space
station is outlined.

****

86A18037*# ISSUE 6 PAGE 701 CATEGORY 18 85/12/00 7 PAGES
UNCLASSIFIED DOCUMENT

UTTL: <u>Verification Tests of Durable Thermal Protection System Concepts</u>

AUTH: A/SHIDELER, J. L.; B/WEBB, G. L.; C/PITTMAN, C. M.
PAA: C/(NASA, Langley Research Center, Hampton, VA)

CORP: National Aeronautics and Space Administration. Langley Research Center, Hampton, Va.

CIO: UNITED STATES (AIAA, Thermophysics Conference, 19th, Snowmass, CO, June 25-28, 1984, AIAA Paper 84-1767) Journal of Spacecraft and Rockets (ISSN 0022-4650), vol. 22, Nov.-Dec. 1985, p. 598-604. Previously cited in issue 17, p. 2439, Accession no. A84-37493.

MAJS: /*HEAT RESISTANT ALLOYS/*HONEYCOMB STRUCTURES/*REUSABLE HEAT SHIELDING/* SPACE TRANSPORTATION/*THERMAL PROTECTION

MINS: / ACOUSTIC MEASUREMENT/ AEROTHERMODYNAMICS/ ATMOSPHERIC ELECTRICITY/ CARBON-CARBON COMPOSITES/ ENVIRONMENTAL TESTS/ INCONEL (TRADEMARK)/ TITANIUM/ VACUUM TESTS/ VIBRATION TESTS

****

86A35709   ISSUE 16 PAGE 2401 CATEGORY 61 CNT#:   F33615-83-C-1003
86/04/00 11 PAGES UNCLASSIFIED DOCUMENT

UTTL: **VHDL - Feature Description and Analysis**

AUTH: A/AYLOR,   J.   H.;   B/WAXMAN, R.;   C/SCARRATT,   C.   PAA:
A/(Virginia,   University, Charlottesville);   C/(IBM Corp.,
Federal Systems Div., Manassas, VA)

CIO: UNITED STATES IEEE Design and Test of Computers   (ISSN
0740-7475), vol. 3, April 1986, p. 17-27.

MAJS: /*COMPUTER   AIDED   DESIGN/*HARDWARE/*PROGRAMMING
LANGUAGES/*VHSIC (CIRCUITS)

MINS: /ARCHITECTURE   (COMPUTERS)/ CRM (COMPUTERS)/ IN COMPU-
TERIZED   SIMULATION/ DESIGN   ANALYSIS/   DOCUMENTATION/
HEIRARCHIES/ INTERFACES/ USER REQUIREMENTS

ABA: M.S.K

ABS: Features of the modern hardware description language for
VHSIC devices (VHDL) are described and compared with the
features of eight other current languages and to the
requirements of a VHDL language. The criteria for
flexibility of design-acceptable VHDL are applications,
semantics   independent   of   any   particular   language
implementation, user-friendliness, and parts with a
programming language orientation. Each requirement is
expanded in detail, and comparisons are made with the
interactive design language (IDL), the computer design
language (CDL), the TI hardware description language
(TI-HDL), a hardware programming language (HPL), the ZEUS
hardware description language, the consensus language
CONLAN, the test generation and simulation language
(TEGAS) and the instruction set processor specifications
(ISPS). The discussion shows that only VHDL permits
user-controlled conversion and alternative interface.
Both inertial and transport explicit interface, and no
syntactic and semantic extensions to the language. *

****

86A40591# ISSUE 19 PAGE 2859 CATEGORY 66 RPT#: AIAA PAPER 86-1183 86/00/00 5 PAGES UNCLASSIFIED DOCUMENT

UTTL: **Anomaly Detection and Resolution System**

AUTH: A/FERNEYHOUGH, D. G., JR. PAA: A/(IBM Corp., Federal Systems Div., Gaithersburg, MD)

CIO: UNITED STATES

IN: Space Systems Technology Conference, San Diego, CA, June 9-12, 1986, Technical Papers (A86-40576 19-12). New York, American Institute of Aeronautics and Astronautics, 1986, p. 106-110.

MAJS: /*EXPERT SYSTEMS/*SPACECRAFT DESIGN

MINS: / COST REDUCTION/ LIFE CYCLE COSTS/ MILITARY TECHNOLOGY/ TELEMETRY

ABA: Author

ABS: The traditional approaches to anomaly detection and resolution for modern weapons systems, spacecraft, and complex ground installations are inadequate to meet the requirements incumbent upon future systems. Expert system technology appears to offer a solution, but new types of expert systems will be required. IBM has developed and implemented a concept for such a system. This paper describes that concept, its potential applications, and some of the implications that this general approach has for the design of future spacecraft.

****

86N19060# ISSUE 9 PAGE 1490 CATEGORY 63 RPT#: AD-A160863
AFHRL-TR-85-7 CN T#: F33615-82-C-0013 85/10/00 85 PAGES
UNCLASSIFIED DOCUMENT

UTTL: <u>Artificial Intelligence in Maintenance: Synthesis of
Technical Issues</u>

TLSP: Interim Report, Jan. 1984 - Jan. 1985

AUTH: A/RICHARDSON, J. J.; B/KELLER, R. A.; C/MAXION, R.;
D/POLSON, P. G.; E/DEJONG, K. A.

CORP: Denver Research Inst., Colo. CSS: (Social Systems
Research and Evaluation Div.) AVAIL.NTIS

SAP: HC A05/MF A01

CIO: UNITED STATES

MAJS: /*ARTIFICIAL INTELLIGENCE/* AUTOMATIC CONTROL/*
DETECTION/* EXPERT SYSTEMS/* HUMAN BEINGS/*
MAINTENANCE/*MAN MACHINE SYSTEMS/* MANAGEMENT
ORGANIZATIONS/* PROBLEM SOLVING/* SYSTEMS PERFORMANCE

MINS: / ARMED FORCES (UNITED STATES)/ CYCLES/ FAILURE/ IMPACT/
MILITARY TECHNOLOGY/ NATURAL LANGUAGE (COMPUTERS)/
POLICIES

ABA: GRA

A: The principle subdisciplines of AI (e.g., expert systems,
problem solving, planning and natural language
understanding) are presented as well as the larger systems
engineering issues. In a chapter devoted to automate
sysytems for managing systems for managing hardware
failures, the components of the failure cycle (detection,
diagnosis, and repair) are described in tandem with
machine approaches and applicable AI methodology. In this
report, effective improvement in military maintenance is
viewed to be dependent not only on automated systems but
also on the development of human resources and the
organizational context of maintenance. Evidence and
information are provided to support the recomendation that
it is possible to build more effective less costly
automated diagnostic systems only if these systems exploit
human problem-solving capabilities. Four hypothetical
examples of advanced systems and a comparison of human vs.
machine strengths and weaknesses as problem solvers are
outlined. Five research and development recommendations
for the use of AI in maintenance conclude that: (1) there
is a good match between the need for improved maintenance
and the emerging science of AI, (2) AI research should be
guided by a policy of integrated diagnostics, (3) field

evaluations of AI applications should focus on organizational impact as well as technical issues, (4) programs should be targeted at both fielded systems and systems under development, and (5) basic research should investigate cooperative human-machine device diagnosis problem solving and the coordination of the specification- and symptom-based approaches.

****

86N27356# ISSUE 18 PAGE 2861 CATEGORY 18 85/12/00 5 PAGES
UNCLASSIFIED DOCUMENT DCAF E003091

UTTL: **Features of the Solar Array Drive Mechanism For the Space Telescope**

AUTH: A/HOSTEMKAMP, R. G.

CORP: Dornier-Werke G.m.b.H., Friedrichshafen (West Germany).
AVAIL.NTIS

SAP: HC A15/MF A01; ESA, Paris FF 150 or $18 Member States, AU, CN, NO (+20% others) In ESA Second European and Space Mechanisms and Tribology Symposium p 13-17 (SEE N86-27353 18-18)

CIO: GERMANY,FEDERAL REPUBLIC OF

MAJS: /*HUBBLE SPACE TELESCOPE/*MECHANICAL DRIVES/*SOLAR ARRAYS

MINS: / DATA TRANSMISSION/ ELECTRIC POWER TRANSMISSION/ NITINOL ALLOYS/ SYSTEMS ENGINEERING/ TORQUE

ANN: Spacecraft mechanisms; motors and actuators; tribology; space stations; and mechanism analysis and testing were discussed.

ABA: ESA

ABS: The Solar Array Drive Mechanism for the Space Telescope is described. Power and signal transfer is achieved by a flexible wire harness for which the chosen solution, consisting of 168 standard wires, is described. The torque performance data of the harness over its temperature range is presented. The load system which protects the bearings from the launch loads is based by a trigger made from Nitinol, a memory alloy. The benefits of memory alloy and the caveats for the design are discussed.

NASA

(logo)

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle	5. Report Date
Shuttle Ground Operations Efficiencies/Technologies Study (SGOE/T)	May 5, 1987
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
A. L. Scholz/ M. T. Hart/ D. J. Lowry	
	10. Work Unit No.

9. Performing Organization Name and Address	11. Contract or Grant No.
Boeing Aerospace Operations PO Box 220 Cocoa Beach, FL 32931	NAS10-11344
	13. Type of Report and Period Covered FINAL

12. Sponsoring Agency Name and Address	
National Aeronautics and Space Administration Washington, DC 20546-0001: (Kennedy Space Center)	June 1986 to May 1987
	14. Sponsoring Agency Code

15. Supplementary Notes * 16. (Continued)
These additional benefits include items such as: a smaller chance for "human error" through automation, reduced number of people required for operations, smaller number of documentation changes, and an increase in test-to-test consistency. Document these findings and capabilities for use as guidelines for use on STAS and other future programs for both manned and unmanned vehicles.

16. Abstract Using the current STS as a working model: identify existing, or new technologies, changes to flight hardware, or changes to processing methodologies that would reduce the processing time and program manpower costs of space vehicle processing. Document methods of improving efficiency of ground operations and identify tehcnology elements that could reduce cost. Study emphasis is on:
1) Identification of specific technology items.
2) Management approaches required to develop, operate, support and control operationally efficient ground processing activities.
Prime study results are:
1) Identification of existing, or new technology that would make vehicle processing less costly. 2) Recommendations for the use of selected technology items in the current STS program. 3) Recommendations for the research and/or development of specific technology items for use on future programs to make their processing (and operation more efficient. 4) Identification of new management techniques necessary to achieve and control these more efficient operations.
Increased use of automation to provide current and more comprehensive managements reports, operational analysis support, evaluation of systems, conduct of operations and other ways to cut costs and provide additional benefits.   *see 15

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Ground Operations: Life Cycle Cost; Operational Issues; CALS; Paperless Processing; ULCE; Shuttle;	Unclassified - Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
		1255	

NASA FORM 1626 OCT 86