CR-128921

Final Report

NASA-MSC CONTRACT NO.
NAS 9-12452
DRL NO. T-728, LINE
ITEM NO. 4
DRD NO. MA-183T

ENVIRONMENTAL CONTROL SYSTEM TRANSDUCER DEVELOPMENT STUDY

72-8537-1

February 10, 1973

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Prepared for

NASA Manned Spacecraft Center
Houston, Texas 77058

GARRETT

AIRESEARCH MANUFACTURING COMPANY
Los Angeles, California

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M.J. Brudnicki
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Prepared for

NASA Manned Spacecraft Center
Houston, Texas 77058

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ABSTRACT

A failure evaluation of the transducers used in the environmental control systems of the Apollo command service module, lunar module, and portable life support system is presented in matrix form for several generic categories of transducers to enable identification of chronic failure modes. Transducer vendors were contacted and asked to supply detailed information. The evaluation data generated for each category of transducer were compiled and published in failure design evaluation reports which are contained in the Appendix of this report. The evaluation reports also present a review of the failure and design data for the transducers and suggest both design criteria to improve reliability of the transducers and, where necessary, design concepts for required redesign of the transducers. Remedial designs were implemented on a family of pressure transducers and on the oxygen flow transducer. The design concepts were subjected to analysis, breadboard fabrication, and verification testing. The results of this work are included in this report.

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SECTION 1

INTRODUCTION AND SUMMARY

STUDY OBJECTIVES

The objective of this study was the evaluation of spacecraft environmental control system (ECS) transducer failures, and the origination and development of techniques for the correction of chronic transducer failure mechanisms. During the study the existing space-flight-qualified Apollo transducers were compared to those required by future spacecraft, and in certain cases superseding hardware or formulated design concept fixes for existing hardware were recommended. The study also formulated criteria for design, manufacturing, test, and system application for ECS transducers.

The design criteria were directed toward providing the rules by which transducer deficiencies may be avoided before they reach manufacturing or are incorporated in a project.

BACKGROUND

Many of the transducers used in existing spacecraft ECS applications have exhibited only marginal reliability during both flight and test. This is demonstrated in failure data compiled on conventional transducers, which show that in many cases the transducers and signal conditioners are more prone to failure than most other components in the system.

Generally, a transducer is used in one of two ways in an ECS: (1) as a monitor for system health, or (2) as a sensing element for system control. Thus, transducer failures can result in a false indication of system failure or can produce an erroneous control signal, which changes the normal operation of the system. These factors coupled with the increasing use of automated checkout systems have led to requirements for transducers that exhibit significantly greater reliability than is exhibited by the systems in which they are installed.

PROGRAM SCOPE

The tasks required of this program, as stated in the contract statement of work, include the following:

- Transducer Evaluation--Evaluate the operational characteristics of transducers and precision switches that are used for ECS application in the Apollo spacecraft to determine the area(s) that are sensitive or subject to malfunction. The evaluation shall include, but not be limited to, a comprehensive review of the Apollo ECS instrumentation failure reports. A complete file of ECS transducer failure reports will be supplied GFE.

- Design Concept--Using the results from the transducer evaluation, conceptual designs shall be developed for rugged, reliable ECS transducers and precision switches.

- Verification Testing--Demonstrate by bench test the conceptual designs formulated to generate the required data for proof of concept.

- Design Criteria--Formulate design criteria for rugged, reliable ECS transducers, precision switches and the associated signal conditioning equipment for ECS space flight application. The criteria shall include, but not be limited to, the types of transducers evaluated in the transducer evaluation task.

- Final Report--Submit a comprehensive final report at the completion of the contract. The report shall contain, but not be limited to:

  (a) A discussion of the technical parameters affecting the design of rugged, reliable ECS transducers and precision switches.

  (b) Results of the verification testing.

  (c) Design criteria for rugged, reliable ECS transducers and precision switches.

  (d) Recommendations.

This program was initiated after the receipt of approximately 800 Apollo trouble reports. These trouble reports were evaluated, and the data summarized on failure evaluation forms. The data were then sorted into generic categories of transducers and summarized in a matrix format that provided insight into the chronic failure modes and mechanisms for each type of transducer.

To review the status of each of the transducers adequately, it was necessary to obtain design details of the units. A program of vendor contact was undertaken to solicit vendor cooperation in obtaining design details.

The evaluation data generated for each generic category of transducer were compiled and published in failure and design evaluation reports. The evaluation reports also presented a review of the failure data and design data for the transducers and suggested both design criteria to improve reliability of the transducers and, where necessary, design concepts for required redesign of the transducers.

For two of the transducers for which redesign was indicated as necessary to meet future reliability goals, the potential design concepts were evaluated and the most promising were subjected to analysis, breadboard fabrication and verification testing.

SUMMARY OF PROGRAM ACTIVITIES

The task activities accomplished during the course of this program are summarized in Figure 1-1. These tasks included performing the following:

(a) Evaluating approximately 800 GFE trouble reports

(b) Performing data search for transducer performance and design data

(c) Analyzing design and failure data and preparing evaluation reports

(d) Identifying transducer problem areas

(e) Developing a new design concept for gas flow sensors to solve basic problems found during the failure investigations

(f) Developing an electronic circuit design modification for Bourdon-tube, variable reluctance pressure sensors that would allow power reversal to the unit without damage, thus eliminating a large class of failures that have occurred in the past

(g) Performing verification testing of the new gas flow sensor design concept

(h) Preparation of monthly progress reports and a final report

ACCOMPLISHMENTS AND CONCLUSIONS

During the study, approximately 800 trouble reports relating to failures of Apollo ECS transducers were reviewed, tabulated, and statistically analyzed. Design data were gathered for each of the transducers that were studied and design and failure analysis reports for several generic types of transducers were prepared. From a review of the design and failure data, transducer design criteria were generated that were aimed at correcting the design, manufacturing, or test problems that have occurred.

For two types of transducers, the Bourdon tube pressure sensors and the oxygen flowmeter, design concepts were developed to eliminate the most prevalent causes of failure.

Approximately 17 percent of the reported failures of Bourdon tube pressure sensors with variable reluctance transduction elements was due to the test technician errors in which the 28-vdc supply was connected to the transducer output terminals. Thus, a recommended design improvement was to build output circuit protection for this type of test error. A program was initiated to investigate the required circuitry changes to guard against this type of error and its results are presented in detail in Section 3 of this report.

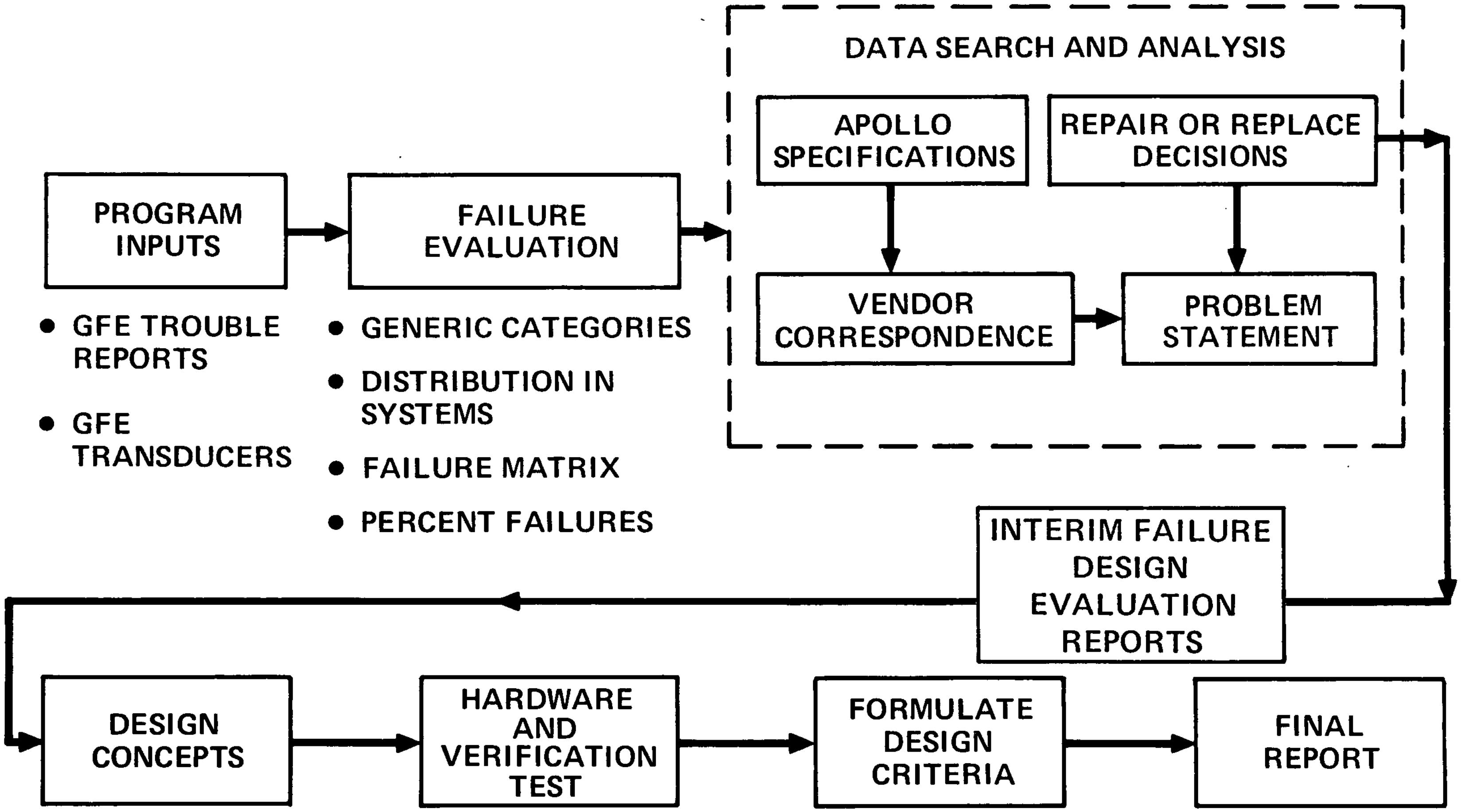


Figure 1-1. Task Activities

The oxygen flowmeter used on Apollo had resistive coils mounted in the gas stream to heat the gas and measure the temperatures of the heated and unheated coils thus determining the flow rate. Discussion with the sensor manufacturer revealed that a newer design exists which appears to be a better choice for future environmental control systems.

In the newer design, the resistive coils are wrapped around a bypass tube rather than installed in the gas stream, which results in several immediately apparent advantages over the old design. Since the sensing elements are external to the plumbing, it is easier to support the elements more rigidly with the advantages of occupying less of the flow path with sensors and having potentially less complex installation. A disadvantage of the new approach, however, is that the theoretically obtainable response to flow changes is slower, because the sensor is external to the flow line.

A program was initiated to develop a prototype sensor of the newer type, which would conform to the environmental and performance requirements for future spacecraft ECS applications of this type of transducer. This program successfully produced a sensor that appears to satisfy the desired requirements. The details of this program are presented in Section 5 of this report.

REPORT ORGANIZATION

This report is organized into a general section of study methodology (Section 2) followed by specific sections for each major category of ECS transducers: pressure (Section 3), temperature (Section 4), flow (Section 5), speed sensor (Section 6), pressure switches (Section 7) and position switches (Section 8). Each section is organized in accordance with the contract work statement by title, work breakdown structure (WBS) number and statement of work (SOW) paragraph number.

The major WBS tasks are summarized below:

1. Transducer evaluation (WBS 1.0, SOW 3.2.1).

2. Design concept (WBS 2.0, SOW 3.2.2).

3. Verification testing (WBS 3.0, SOW 3.2.3).

4. Design criteria (WBS 4.0, SOW 3.2.4).

Interim reports were prepared and submitted to NASA-MSC during the program. These reports were assigned a dash number of the final report number and were published as separate volumes. All of these interim reports are included in the appendix. The final report is identified as a dash one (-1) of the same basic report No. 72-8537 to differentiate it from the interim reports. The interim reports contained in the appendix are listed on the following page by document number, title, and transducer generic type.

Document Number	Document Title	Transducer Generic Type
72-8537-2, Rev. 1	Report on Failure and Design Evaluation of Apollo ECS Pressure Transducers, Variable-Reluctance Twisted Bourdon Tube Type	Pressure
72-8537-3, Rev. 2	Report on Failure and Design Evaluation of Apollo ECS Pressure Transducers, Variable-Reluctance Diaphragm with Electronics Type	Pressure
72-8537-12, Rev. 1	Report on Failure and Design Evaluation of Apollo ECS Temperature Sensors, Thermistor Type	Temperature
72-8537-13, Rev. 1	Report on Failure and Design Evaluation of Apollo ECS Temperature Sensor, Thermistor Bead and Coil Type	Temperature
72-8537-14, Rev. 1	Report on Failure and Design Evaluation of Apollo ECS Cabin Temperature Sensor, Thermistor with Electronics Type	Temperature
72-8537-15, Rev. 1	Report on Failure and Design Evaluation of Apollo ECS Temperature Sensors, Coil with Electronics Type	Temperature
72-8537-22, Rev. 1	Report on Failure and Design Evaluation of Apollo ECS Oxygen Flow Transducer Temperature Sensor with Electronics Type	Flow
72-8537-51, Rev. 1	Report on Failure and Design Evaluation of Apollo ECS Valve Position Indicator Switches	Position Switch

SECTION 2

STUDY METHODOLOGY

This section presents the general study methodology employed to accomplish the study objectives. The general methods are discussed followed by more detailed discussion of each study task.

GENERAL METHODS AND APPROACH

The study program approach that was used during this study is presented in the methodology flow diagram of Figure 2-1. This methodology was implemented by the tasks outlined below.

The study was initiated by a review of the NASA-supplied failure reports for Apollo instrumentation. The first phase of the program was transducer evaluation based upon the failure reports. Specific tasks during this phase included the following:

- Evaluation of the NASA-supplied failure reports
- Sorting the failure data into basic categories
- Statistical evaluation of the failure data to determine chronic failure modes

The second phase of the program, the design concept phase, included the following specific tasks:

- Review of future spacecraft ECS transducer requirements
- Soliciting of transducer design data from the various transducer manufacturers
- Evaluation of transducers to determine where a significant redesign appears necessary
- Preparation of a failure and design evaluation report for generic types of transducers
- Review of the current state of the art for two types of transducers requiring redesign
- Exploration of possible design fixes for these two transducers with the transducer manufacturers
- Evaluation to determine the most favorable design fix concepts

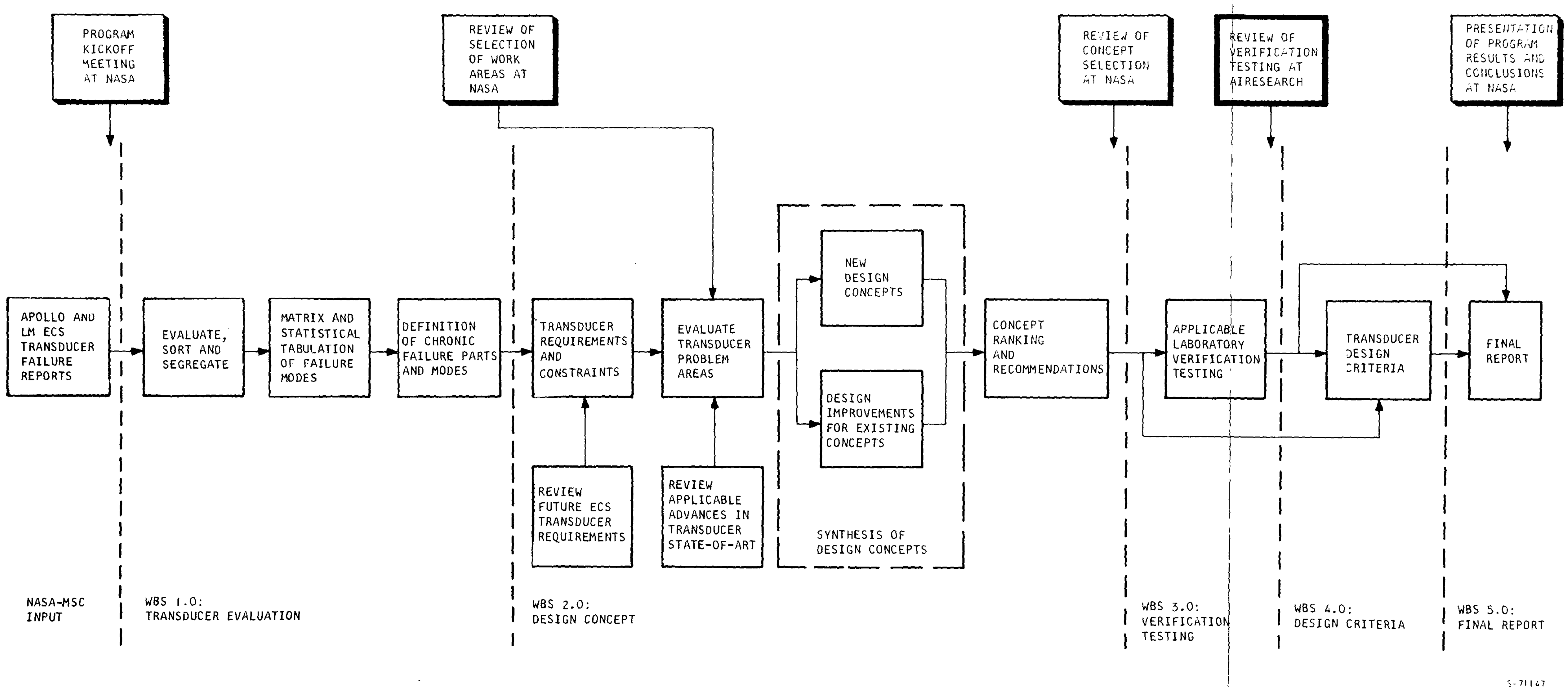


Figure 2-1. Methodology Flow Diagram

During the third program phase, verification testing was conducted to validate certain design concepts. The necessary verification testing and development was performed by the transducer vendor under subcontract to AiResearch. The specific tasks required during this phase included the following.

- Preparation of verification test plan and test procedures for testing a new design concept for a gas flow transducer
- Fabrication of required laboratory test equipment
- Testing of the concept to establish performance characteristics
- Evaluation and documentation of the test results

In the fourth program phase, the transducer design criteria that were established from the evaluation phase and from verification testing were developed.

The final study phase involved preparation of this final report to document the study. This report includes the final design criteria generated during the fourth phase and the results of the verification testing performed during the third phase.

TRANSDUCER EVALUATION (WBS 1.0, SOW 3.2.1)

Various methods of evaluating and sorting the GFE trouble reports were considered during the study. The objective was to ensure an evaluation method that would allow maximum visibility of the failure reports, include all of the data that might prove significant, and yet be efficiently prepared and used.

A decision was made to tabulate the trouble reports for each of the transducer part numbers on an evaluation form. These failure report summaries were then evaluated for commonality of malfunction on the following bases:

(a) Problem areas common to transducers of a given type or operating principle

(b) Problem areas associated with a given transducer part number

Insight into these problem areas came from preparation of failure matrixes for these classes that drew attention to a recurring failure mode, failure mechanisms, or failure causes.

The format that was selected for the failure evaluation task is presented in Figure 2-2. This form was completed for each transducer basic part number.

TRANSDUCER APPLICATION ____________________

BASIC PART NUMBER ____________________

TRANSDUCER MANUF. ____________________

TROUBLE REPORT SOURCE ____________________

TRANSDUCER TYPE ____________________

OPERATING PRINCIPLE ____________________

MEASUREMENT RANGE ____________________

MEASUREMENT MEDIA ____________________

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS

Figure 2-2. Failure Evaluation Form

The selected format is relatively self-explanatory, although, for clarification, the definitions of certain terms are presented below:

- Failure Type--This refers to the general type of failure, usually either mechanical, electrical or human.

- Failure Mode--This refers to the failure symptom which the transducer exhibits. Examples would be drift, no output, high output, or set-point shift.

- Failure Mechanism--This refers to what has failed, and in what manner that resulted in the given failure mode. Examples would be bellows leakage, broken leadwire, failed transistor, or cracked sensing bead.

- Failure Cause--This refers to the action that resulted in the occurrence of the failure mechanism. Examples would be overpressure applied to the unit, poor weld quality, inadequate circuit design or test procedure not followed.

- Problem Area--This refers to the general area responsible for the failure cause. This would generally be either design, manufacturing, testing, installation, handling, human, or random.

- Corrective Action--This refers to the corrective action taken that is referred to on the trouble report.

Figure 2-3 presents a sample of the matrix configuration used in presentation of failure categories and their analytical qualities. This figure is a superimposed composition of three different matrixes, three summation columns, and four percentage columns.

Rows in all three of the matrixes list the problem areas. Columns are related to the failure information. Matrix A in Figure 2-3 is concerned with the failure mode, matrix B is concerned with the failure type, and matrix C is concerned with the failure mechanism. Because the row designations of the matrixes are identical, the matrixes have been placed side by side so one listing of row nomenclature, D, will apply to all three matrixes.

Nomenclature of rows have been categorized to distinguish the problem responsibility sources. The major problem sources are engineering, manufacturing, test equipment, cleaning, handling, final installation, random failures, and error on the part of failure reporter where the failure can not be duplicated. Various activities within the engineering, manufacturing, and final installation areas are designated as subheadings of the respective rows.

FAILURE

D PROBLEM AREA		A MODE															B TYPE		
	PERCENT	NO OUTPUT	SHIFT	LOW OUTPUT	HIGH OUTPUT	FIXED OUTPUT	LOW RESISTANCE	LEAKAGE	ERRATIC	RIPPLE	DRIFT	PEELING				NONE	HUMAN	ELECTRICAL	MECHANICAL
ENGINEERING: DESIGN	4.8		4														4		
ENGINEERING / TESTING: PROCEDURE, ATP	-																		
ENGINEERING / TESTING / QUAL: ERROR	8.3				6		1										7		
ENGINEERING / TESTING / QUAL: PROCEDURE	-																		
MANUFACTURING: PLANNING	1.2		1														1		
MANUFACTURING: FABRICATION	3.6											3					3		
MANUFACTURING: ASSEMBLY	20.2		8		6	1	1				1						16		1
MANUFACTURING: QUALITY CONTROL	-																		
MANUFACTURING: INSPECTION	1.2							1									1		
MANUFACTURING: ATP TEST ERROR	34.5	3	10	1	14					1							29		
TEST EQUIPMENT FAILURE	3.6		1			1										1	3		
LOX CLEANING	2.4		2														2		
HANDLING	7.1		4		1		1										6		
FINAL INSTALLATION: RECEIVING INSPECTION (TEST AND EQUIPMENT)	-																		
FINAL INSTALLATION: INSTALLATION	1.2		1															1	
RANDOM FAILURE	8.3		1	2	1	1			1		1						1	6	
UNCONFIRMED FAILURE	2.4															2	2		
NOT ANALYZED FAILURE REPORT	1.2		1														1		
TOTALS	100	3	33	3	28	3	3	1	1	1	2	3				3	76	7	1
PERCENT		3.6	39.2	3.6	33.2	3.6	3.6	1.2	1.2	1.2	2.4	3.6				3.6	90.5	8.3	1.2

D PROBLEM AREA	C MECHANISM: SENSING MECHANISM — ELEC.		SENSING MECHANISM — MECHANICAL					SIGNAL CONDITIONING AND TRANSMISSION MECHANISM														
FAILURE CAUSE	OPEN	SHORT	FROZEN	OVERPRESSURIZED	LEAKAGE	DAMAGED		UNKNOWN	MISCONNECTED	SHORT	POOR ASSEMBLY	DEGRADED	PROCESS	MATERIAL	CONTAMINATION	DAMAGED	TEST EQUIPMENT	NOT ANALYZED				
ENGINEERING: DESIGN														2			2					
ENGINEERING / TESTING: PROCEDURE, ATP																						
ENGINEERING / TESTING / QUAL: ERROR									6						1							
ENGINEERING / TESTING / QUAL: PROCEDURE																						
MANUFACTURING: PLANNING								1														
MANUFACTURING: FABRICATION													3									
MANUFACTURING: ASSEMBLY			1	11						2	3											
MANUFACTURING: QUALITY CONTROL																						
MANUFACTURING: INSPECTION					1																	
MANUFACTURING: ATP TEST ERROR				20		1			8													
TEST EQUIPMENT FAILURE														1			2					
LOX CLEANING						2																
HANDLING						2						1			1	2						
FINAL INSTALLATION: RECEIVING INSPECTION (TEST AND EQUIPMENT)																						
FINAL INSTALLATION: INSTALLATION				1																		
RANDOM FAILURE								1		3		2				1						
UNCONFIRMED FAILURE								2														
NOT ANALYZED FAILURE REPORT																		1				
TOTALS			1	32	1	5		4	14	5	3	3	3	3	2	3	4	1				
PERCENT			1.2	38.0	1.2	5.9		4.8	16.6	5.9	3.6	3.6	3.6	3.6	2.4	3.6	4.8	1.2				

Figure 2-3. Sample Failure Matrix Configuration

Under the general column heading, FAILURE, there are three subheadings, MECHANISM, TYPE, and MODE, each representing a distinct matrix.

Matrix A, MODE, presents the failure indicators. Basically, besides the visual inspection that locates the physically damaged parts, the out-of-specification-limits performance of the components is the failure indication. Therefore, the column headings of this matrix are directly related to the performance parameters and their measurement criteria.

Matrix B, TYPE, shown in Figure 2-4, provides distinction between induced and unpreventable types of failures. Unpreventable failures are either mechanical or electrical failures, and are generally of random type. On the other hand, induced failures are those that result from errors in design, manufacturing, testing, handling, cleaning and final installation. Categorically, all of the induced failures are the result of human error and, therefore, are both preventable and correctable.

Matrix C, MECHANISM, presents the failed part or mechanism. Because this matrix is designed for transducers only, matrix columns have been grouped under two categories: those related to the sensing mechanism, and those related to the signal conditioning and transmission mechanism. The subheadings within these two groups, which indicate the failure cause, are listed in the lower end of the columns for convenience.

The row designated TOTALS presents the totals of each column in all three matrixes. The row designated PERCENT presents the percent of the number in each column with respect to the total failures listed in each matrix. The column designated PERCENT presents the percent of the problem area incidents with respect to the total number of failures.

Any failure report that is to be registered in this matrix first will have its failure responsibility area established. Then the failure mechanism as determined by the failure analyst will be registered in the corresponding column and in the row representing the responsibility area. Next, the type of failure will be established and registered in the corresponding failure type column, and in the same row of responsibility area. Last, the failure indication mode as listed in the failure report will be registered in the corresponding failure mode column. Thus, after registering all the failure reports of a part number in a composite matrix, summations are made for each column and percentage values calculated for each summation.

Such a composite failure matrix of any specific design enables the observer to evaluate the reliability of that design at a glance. By studying the failure types and various percentages, the observer can pinpoint the problem areas that can be eliminated and failures that can be prevented

The failure matrix was prepared for each generic category of ECS transducers shown in Figure 2-5.

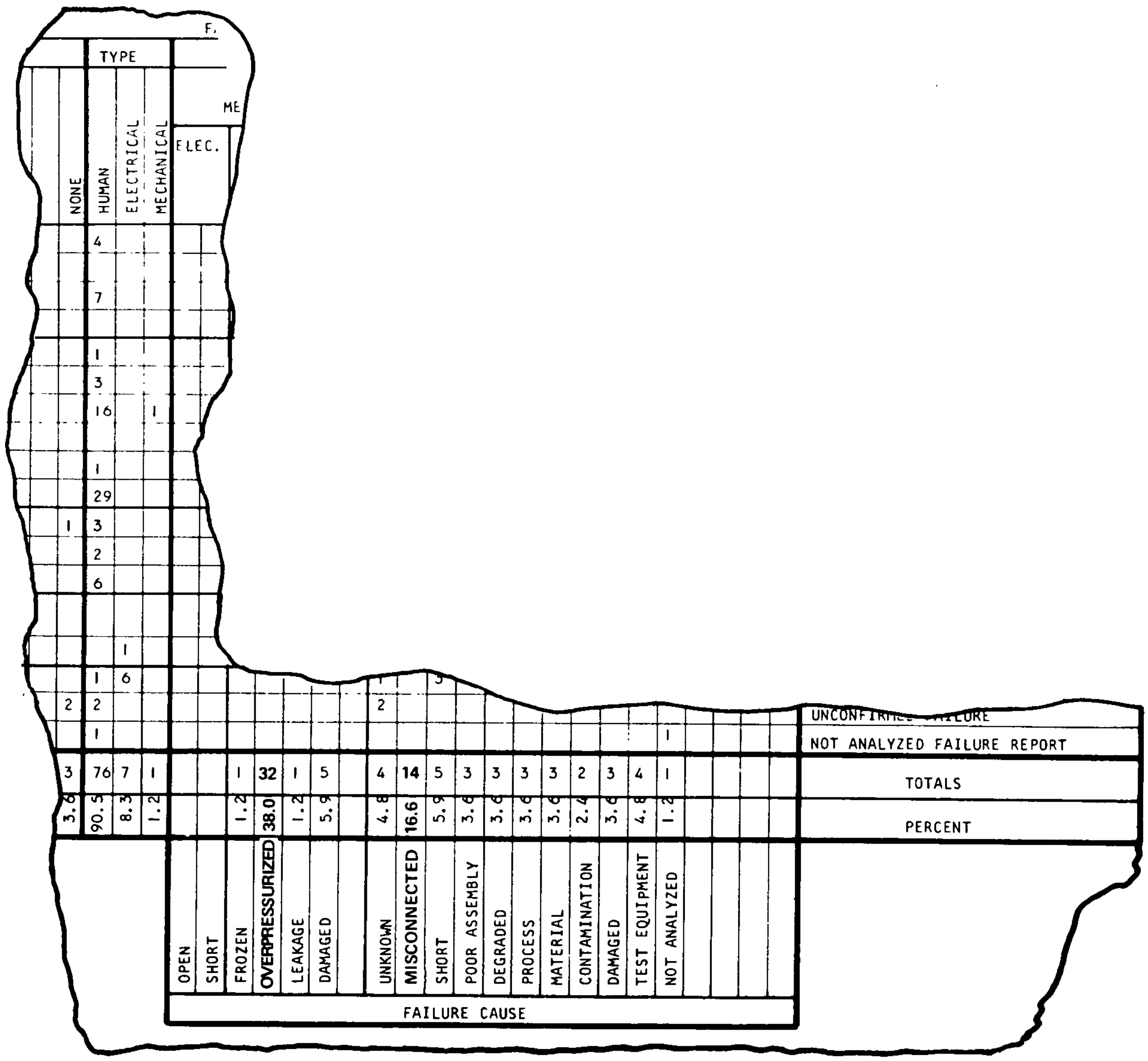


Figure 2-4. Failure Type Matrix

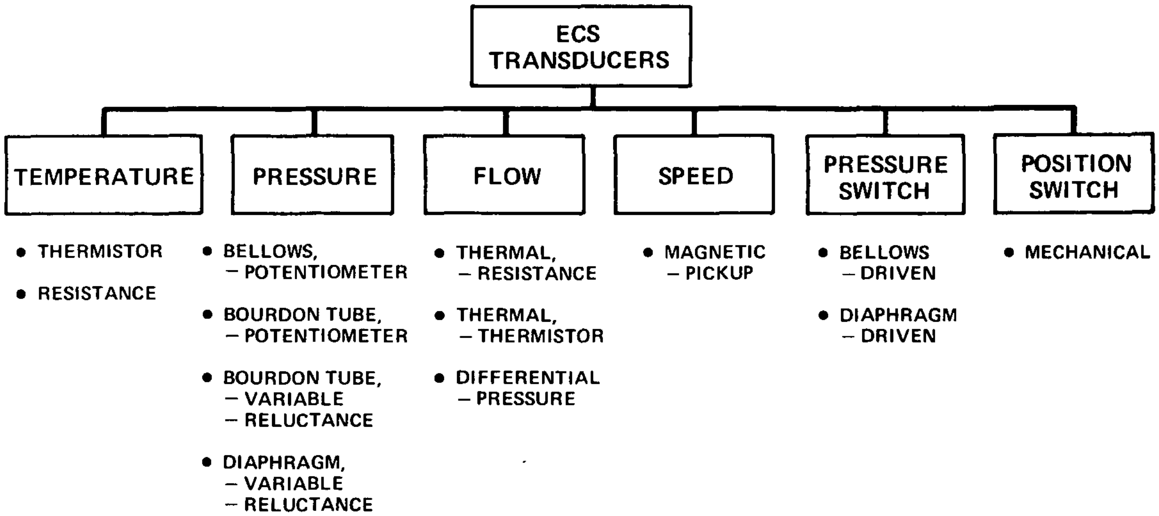


Figure 2-5. Generic Categories of ECS Transducers

To obtain maximum value from the information obtained during the evaluation phase, it became apparent that detailed information on the various transducer designs was required. A literature search was initiated to gather as much information as possible. NASA was requested to supply as much data, in the form of component specifications, outline drawings, principle of operation and performance and design data, as possible. In addition, AiResearch attempted to gather the data by correspondance with each of the vendors that produced Apollo ECS transducers. A copy of one of these letters, addressed to the Whittaker Corporation, is presented as Figure 2-6.

DESIGN CONCEPT (WBS 2.0, SOW 3.2.2)

A review of the failure and design data generated during the program led to the definition of problem areas associated with the various transducers. Certain of these problem areas could be cured by a relatively obvious design change which directly resulted in a recommended design criteria. Other changes were more complex, with a variety of alternate solutions available.

In Reply Refer To:
RMG2074

19 May 1972

BCC: M. Brudnicki
H. Kay
Chrono
File

Whittaker Corporation
Pace-Wiancko Division
9601 Canoga Avenue
Chatsworth, California

Attention: Sales Manager

Subject: Request for Quotation No. 1372-2

Gentlemen:

In the interest of economy, space shuttle contractors are being urged to select instrumentation including transducers, switches, etc., from existing qualified sources. As a result, NASA, MSC contracted Garrett-AiResearch to study and analyze instrumentation failures recorded on the Environmental Control System (ECS) for the Apollo program. This includes the Apollo Command Service Module (CSM), the Lunar Excursion Module (LEM) and the Portable Life Support System (PLSS).

The purpose of the study is to categorize transducer failures with the objective of defining the chronic failure causes so that solutions for eliminating or reducing them can be determined. It is recognized that improvements were incorporated during the course of the Apollo program as noted by transducer part number changes and/or changes to the dash number of the basic part. It is also conceivable that design improvements and fabrication techniques were developed and not incorporated because of the design configuration freeze that occurred on the Apollo program. Further, it is possible that completely new transducers have been designed and developed which supersede the units used on the Apollo program. The above information is much needed to greatly enhance the selection of the appropriate transducer for the ECS on the Space Shuttle.

Your cooperation is solicited in obtaining the following information in order to avoid an inadvertent misrepresentation of your hardware. It is understood that the information you supply will not contain any proprietary data such as detail drawings, etc.

1. Total number of P/N 600255-2 transducers supplied AiResearch in accordance with AiResearch SCD 836130 and the total of P/N 600255-2 transducers supplied to other contractors for the Apollo program.

2. Any design improvement changes or improved fabrication techniques incorporated during the course of the Apollo program.

3. Any changes to P/N 600255-2 you recommend for future use.

Figure 2-6. Vendor Correspondence

4. Any newly developed and qualified transducer you recommend to supersede P/N 600255-2.

5. Outline drawing, brochure information, operational descriptions and any other information to provide the potential user with sufficient details to enable the selection of the appropriate transducer for the application considered.

6. Cost and delivery information on 1 to 5 pieces of transducer P/N 600255-2.

7. Any special precautions relative to handling, testing and using this particular transducer.

AiResearch intends to reduce the NASA furnished failure reports on this part number transducer to a matrix showing the cause of failure and the mechanism within the transducer affected by the cause. The failure causes and or mechanisms representing the largest percentage of the failures will be followed up by a data search including actual testing if necessary so that precautionary criteria can be specified for this transducer. For example, if a pressure spike during system testing is the greatest cause for permanent distortion of the twisted bourdon tube then the design criteria will caution the system engineer to be sure pressure spikes of a given magnitude are dampened to prevent damage to the transducer.

Please include similar information for the following additional transducers supplied by your company for the Apollo ECS.

AiResearch Source Control Drawing	Whittaker-Pace-Wiancko Part Number
837044-4-1	600245-1
837044-5-1	630027-5
836132-2-1	600265-1
836132-3-1	600265-3
837016-1-1	54628-1
837016-2	600225
837016-3	600225

Figure 2-6 (Continued)

Technical problems may be resolved by Supplier's direct contact with AiResearch's cognizant engineer, Mike Brudnicki, phone: (213) 323-9500, extension 1773, or the undersigned.

Please address all replies and requests for further information to AiResearch Manufacturing Company, a Division of The Garrett Corporation, 2525 West 190th Street, Torrance, California 90509, attention R. M. Grotz.

Very truly yours,

AIRESEARCH MANUFACTURING COMPANY

RMGrotz

R. M. Grotz
Administrator
Major Subcontracts

RMG:daw

CC: Mr. Frank Collier
Contract Technical Monitor
NASA Contract NAS 9-12452
NASA, MSC
Houston, Texas 77058

Figure 2-6 (Continued)

The order of tasks that were followed in developing the design concepts was:

(a) Determine applicable design requirements and constraints

(b) Synthesize types of concept fixes possible

(c) Evaluate and select a fix based on weighing of benefit versus cost, practicality, and similar considerations.

These tasks are discussed below.

To determine the design requirements and constraints for the next generation of spacecraft ECS transducers, a review of the transducer requirements for future spacecraft programs was performed. This review permitted a decision to be made as to the basic suitability of the transducers being studied for future use. The review was based on an analysis of the transducer requirements for the ECS systems proposed by the different space shuttle vendors, the requirements that have been generated in the past for various other spacecraft, such as MOL, Skylab, etc., and the transducer requirements for fault detection and failure isolation as developed under other contracts.

The required ECS instrumentation was classified according to the following basic types of transducers:

Pressure transducers

Temperature transducers

Flow transducers

For each of these categories, the required transducers were tabulated on the basis of the following:

Measurement media

Measurement range

Signal type

Accuracy requirements

Response time

The completed tabulations for future ECS transducer requirements are presented in the appropriate sections of this report.

With the transducer design and failure data generated during the transducer evaluation phase of the study, the transducer requirements generated for future

ECS systems, such as the space shuttle, and the design data obtained from vendor correspondence, a repair or replace decision could be made and a transducer problem statement subsequently generated. A diagram that enumerates the various factors that were considered is presented in Figure 2-7.

During the review of future ECS transducer requirements, it was seen that longer mission times and rapid vehicle turnaround are two factors that will influence transducer selection. Thus, even in the case of temperature sensors that have a good history, it must be expected that they will fail at some time and it must be realized that the Apollo requirements for purging and backfilling liquid loops to replace liquid temperature sensors represent a very undesirable requirement from the point of view of attaining rapid turnaround. Consequently, part of the review of transducer advances is the investigation of sensing techniques that do not require internally installed sensing elements. Specifically, the use of temperature sensors that can be attached to the outside of the fluid lines and removed and replaced easily was investigated. The most promising sensors of this type are resistive temperature sensors made of platinum (as were most of the Apollo resistive temperature sensors) or nickel. Surface temperature sensors of this type have been used in aircraft applications for liquid measurements such as engine oil temperature.

For the two types of transducers that were selected for incorporation of a design fix (twisted Bourdon tube type pressure transducers, and oxygen flow transducers) the state of the art of the transducer designs was reviewed to arrive at a number of possible fixes,which were evaluated to arrive at a recommended design fix.

VERIFICATION TESTING (WBS 3.0, SOW 3.2.3)

The transducer design concepts selected for verification testing were fabricated in a breadboard configuration and tested as required to verify that the performance and design requirements were met. The role of verification testing in the repair or replace decision is presented in Figure 2-7.

DESIGN CRITERIA (WBS 4.0, SOW 3.2.4)

Based on the design and failure analysis data generated for all transducers and the verification testing performed on two types of transducers, design criteria were developed. The design criteria are instructions and recommendations aimed at the correction and prevention of transducer failures. They include the following categories:

Transducer component design

Materials and processes

Manufacturing techniques

Testing

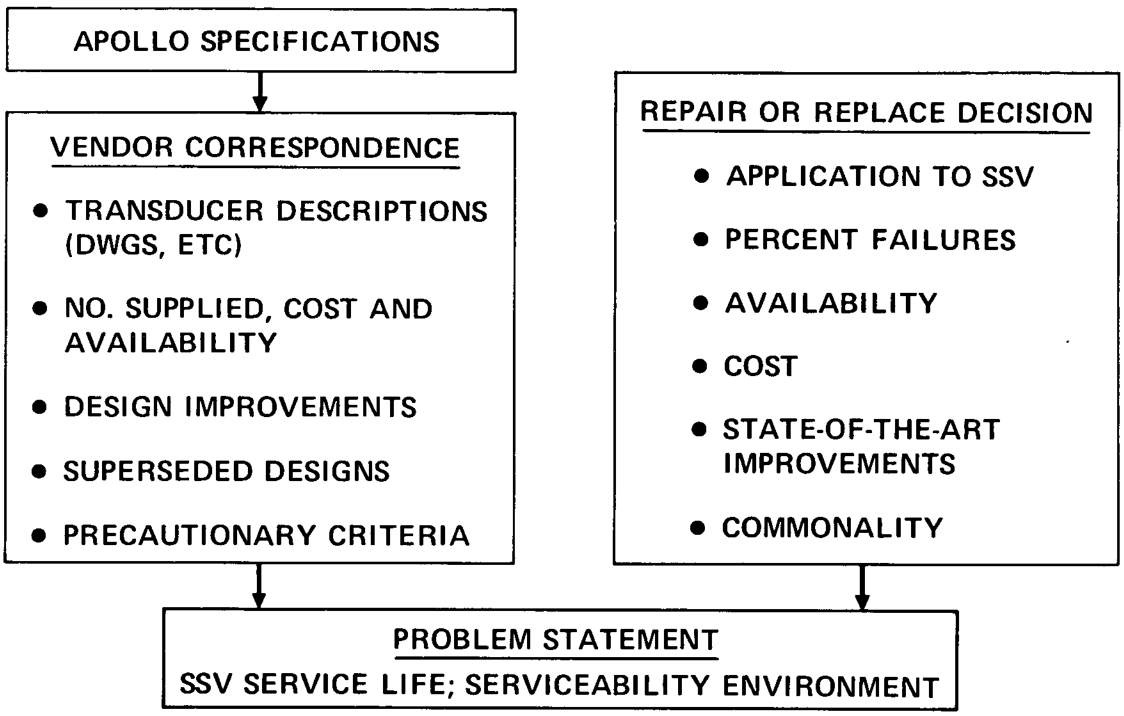


Figure 2-7. Data Search and Analysis

SECTION 3

PRESSURE TRANSDUCERS

TRANSDUCER EVALUATION (WBS 1.0, SOW 3.2.1)

Table 3-1 summarizes all of the pressure transducers that were used on the Apollo ECS programs. A failure evaluation was made for those units shown in Table 3-1 for which failure reports were available. Each of the transducer suppliers was contacted and requested to supply technical data relative to operating principle, cross-sectional and outline drawings, performance characteristics, number of parts delivered, and current cost information for 1 to 5 articles.

The percent of pressure transducers rejected was determined from the number of parts delivered versus the number of recorded failure reports for each particular part number. The average rejection rate of several part numbered units was approximately 27% for a total of 320 pressure transducers. The rejection rate for specific part numbered units varied considerably. These data, including failure matrixes that show the cause of the failures, are contained in AiResearch Reports 72-8537-2 and 72-8537-3 in the Appendix.

DESIGN CONCEPT (WBS 2.0, SOW 3.2.2)

Twenty of the 24 part numbers shown in Table 3-1 are supplied by Celesco Industries. These transducers represent the Pace-Wiancko pressure transducer product line that Celesco recently purchased from The Whittaker Corporation. A failure evaluation was made on the Celesco transducers that were used in the ECS of the Apollo command service module. This evaluation shows (see Figure 2-6 of AiResearch Report 72-8537-2) that most of the transducer failures were caused by overpressurizing the transducer in the form of a pressure spike (38%) causing the sensing mechanism to take a permanent set and misapplication of input 28 vdc electrical power to the 0-5 vdc output pins (16.6%). This latter condition caused an open failure of the electrical circuitry in the transducer. Recommendations in the form of design concepts were made and described in Report 72-8537-2 for modifying the units so that they would be less prone to failure when subjected to the above conditions. These recommendations were discussed with the NASA Technical Monitor and it was agreed, due to the funding limitations, to concentrate on the development of design concepts to make the units withstand an electrical power reversal. As a result, making the units capable of withstanding a reasonable overpressure spike was deferred for possible follow-on work.

Several meetings were held between AiResearch and Celesco personnel and correspondence in the form of letters and telephone calls made between the months of May and December 1972. During the early part of the program, AiResearch submitted Report 72-8537-2 to Celesco and reviewed it with Celesco engineers. The report describes the failures and recommendations for the Celesco transducers used in the Apollo command service module. During the discussions it was determined that provisions for withstanding an inadvertent

TABLE 3-1

PRESSURE TRANSDUCERS USED IN THE APOLLO CSM, LM, AND PLSS ENVIRONMENTAL CONTROL SYSTEMS

Pressure Range Operating	Proof	Burst	Media	Transducer Title - Application	Item No.	Specification A/R, H.S., GAEC & NR (Dash No.)	Vendor Name	Vendor Part No.	Output Signal	Accuracy	Remarks	Unit Max. Wt.
0-25 in. H_2O	7.5 psig*	12.5 psig*	Oxygen	Suit Compressor ΔP	7.12 CSM	A/R 837054-3	Consol. Controls	R41PD34-15	0-5 vdc	±0.625 in. H_2O	*Applied simultaneously to both ports. Proof and burst of 1.35 and 2.25 psid when applied to high pressure port only.	15 oz
.05-.25 psia	22.5 psia	37.5 psia	Steam	Steam duct pressure	8.17 CSM	A/R 837036-2	Celesco	601555	0-5 vdc	±0.005 psi		22 oz
0-2 psid	-15 psid +50 psid	-30 psid +100 psid	Oxygen & water	Suit loop to water system ΔP	126 LEM	SV HS 4098 (SV728378)	Celesco	630021-5	0-5 vdc	+.04 psi	Input polarity 32 vdc may be reversed.	9 oz
0-5 psia			Water	Feedwater press. Xducer & switch	239 PLSS	SV HS 3867 (SV718788)	Bourns	2004419301	0-5 vdc	±.25 psi	Switch actuates at 1.2 to 1.7 psia.	6 oz
2.5-5.0 psid			Oxygen	Press garment (PGA) ΔP Xducer	203 PLSS	SV HS 3380 4311 (SV714171)	Bourns	2004414601	0-5 vdc	±0.15 psi		2.5 oz
0-17 psia	22.5	43	Oxygen	Cabin pressure	10.5 CSM	A/R 836132-3	Celesco	600265-3	0-5 vdc	±.425 psia		9 oz
0-17 psia	25.5	43	Oxygen	Suit & cabin pressure	7.6 CSM	A/R 837044-7	Celesco	630027-7	0-5 vdc	±0.34 psia		9 oz
0-25 psi	-15 psig +90 psig	150 psig	Water Glycol	Accumulator quantity	8.16 CSM	A/R 837026-4	Celesco	600235-1	0-5 vdc	±0.625 psi		10 oz
0-50 psid	±100 psid	±200 psid	Oxygen & glycol-water	Glycol-water pump ΔP	202 LEM	SV HS 4098 (SV728380)	Celesco		0-5 vdc	±0.75 psi	Input polarity 32 vdc may be reversed.	9 oz
0-60 psi	115 psia	190 psia	Water glycol	W-G pump press rise	8.1 CSM	A/R 836130-2	Celesco	600255-2	0-5 vdc	±1.5 psi		9 oz
0-150 psig	225	375	Oxygen	Oxygen-supply pressure	9.8 CSM	A/R 837016-2	Celesco	600225	0-5 vdc	±3.0 psig		9 oz
0-1500 psia			Oxygen	Pri. O_2 press Xducer	232.1 PLSS	SV HS 3226 (SV714168) SV HS 4901 (SV723032	Gulton Servonic	2191-0201 2191-0301	0-5 vdc	±41.3 psi		6.4 oz
0-4000 psi	6000	5.0 times operating range	1) helium, 2) oxygen, 3) distilled-deionized water, 4) nitrogen tetroxide (N_2O_4), 5) hydrazine-uns-dimethyl-hydrazine (50% N_2H_4-50% UDMH), 6) distilled deionized water with 13 ppm iodine (I_2).	Xducer, pressure absolute		LSC360-601-101-3	Celesco	630037-1 (A)	0-5 vdc	±32 psi	These units are capable of withstanding an input 32 vdc power polarity reversal and an application of input power to the signal output leads.	6 oz
0-3500 psi	5250					103-3		-3		±28 psi		
0-350 psi	700					105-3		-5		±2.8 psi		
0-300 psi	600					107-3		-7		±2.4 psi		
0-2000 psi	3000					109-3		-9		±16 psi		
0-1000 psi	1500			Press ascent O_2 tanks 1 & 2	GF3582P GF3583P	201-3		-21		±8 psi		
0-60 psi	120			Pri. pump discharge press	GF2741P	203-3		-23		±.48 psi		
0-25 psi	50			Press safety valve No. 1 & 2 servo	GF3591P GF3592P	205-3		-25		±0.2 psi		
0-10 psi	20.5			Cabin pressure Xducer	GF3571P	207-3		-27		±0.1 psi		
0-3000 psi	4500			Press descent O_2 tank	GF3584P	209-3		-29		±24 psi		
0-10 psi				Xducer, pressure absolute		207-51		-41(A)		±0.08 psi		
0-25 psi				Xducer, pressure absolute		213-3	Celesco	630037-43 (B)	0-5 vdc	±0.2 psi		6 oz

reversal of input 28 vdc power on the 0-5 vdc output pins had been incorporated in Celesco transducers that were supplied to Grumman Aircraft and Engineering Co. (GAEC) for use in the lunar module. These transducers are tabulated in Table 3-1 and are identified by Celesco part numbers 630037-1 through -43. A study was made to determine if the electronics package contained in Celesco pressure transducer PN 630037 could be incorporated in the pressure transducers made for the Apollo command service module. The objective of the proposed transfer of electronics would: (1) provide the capability of withstanding an input 32-vdc power polarity reversal and misapplication of input power to the signal output leads for all the Celesco-supplied Apollo pressure transducers; (2) retain the status of being highly qualified Apollo equipment; (3) provide transducers covering many pressure ranges; and (4) retain the external shape of the Apollo CSM transducers so that next assembly interfaces would not be affected.

An AiResearch statement of work for a design analysis including verification testing was negotiated with Celesco for the purpose of determining the best approach for modifying six different part numbered Celesco transducers that were used in the Apollo command service module. The study tasks for eliminating failures caused by inadvertent reversal of 28-vdc power on the 0-5 vdc output pins included the following options:

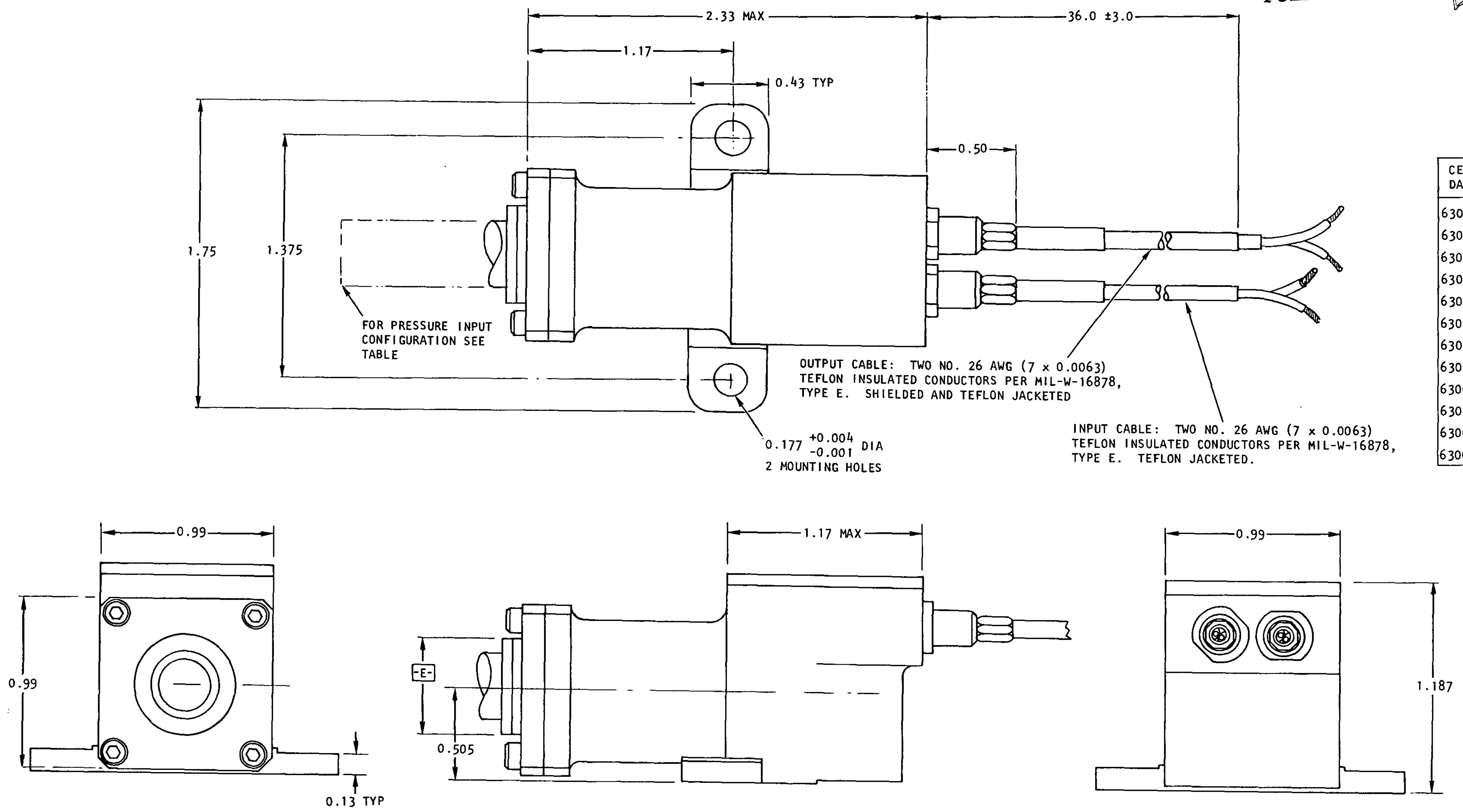
1. Modify the electronics by adding diodes.

2. Supersede the CSM style transducers with an LM style transducer that currently contains provisions to withstand inadvertent power reversals. The outline dimensions of these units are much different from the CSM style transducers. The shape and size of the Celesco transducers made for the CSM are described in AiResearch Report 72-8537-2. The configuration of the Celesco transducers designed for the LM are shown in Figure 3-1 which also contains appropriate reference to the GAEC part numbers.

3. Transfer the electronics from the LM transducer to each of the CSM units. The electronic package for the LM unit is much smaller and will fit within the CSM units with room to spare.

4. Redesign a new electronics package that utilizes the latest state-of-the-art electronics including power reversal protection that will fit within all of the Celesco transducers.

A detailed design analysis including laboratory verification tests was made by Celesco to assure protection of proprietary design details. The analysis was reviewed in detail with AiResearch personnel and the results are summarized in Celesco letter LP-L586, reproduced as Figure 3-2.



CELESCO DASH NO.	FIGURE	GAEC PART NUMBER	RANGE PSIA	PRESS. INPUT TUBE: 250 ± 0.003/0.000 O.D.
630037-1	A	LSC-360-601-101-3	0-4000	0.027
630037-3	A	LSC-360-601-103-3	0-3500	0.027
630037-5	A	LSC-360-601-105-3	0-350	0.016
630037-7	A	LSC-360-601-107-3	0-300	0.016
630037-9	A	LSC-360-601-109-3	0-2000	0.027
630037-21	C	LSC-360-601-201-3	0-1000	0.016
630037-23	C	LSC-360-601-203-3	0-60	0.016
630037-25	C	LSC-360-601-205-3	0-25	0.016
630037-27	B	LSC-360-601-207-3	0-10	0.016
630037-29	C	LSC-360-601-209-3	0-3000	0.027
630037-41	D	LSC-360-601-207-5-1	0-10	NONE
630037-43	C	LSC-360-601-213-3	0-25	0.016

WALL THICKNESS

CABLE COLOR CODE

YELLOW	+	INPUT	20-32 VDC
BLACK	-	INPUT	
RED	+	OUTPUT	0-5 VDC
GREEN	-	OUTPUT	
SHIELD		NO CONNECTION	

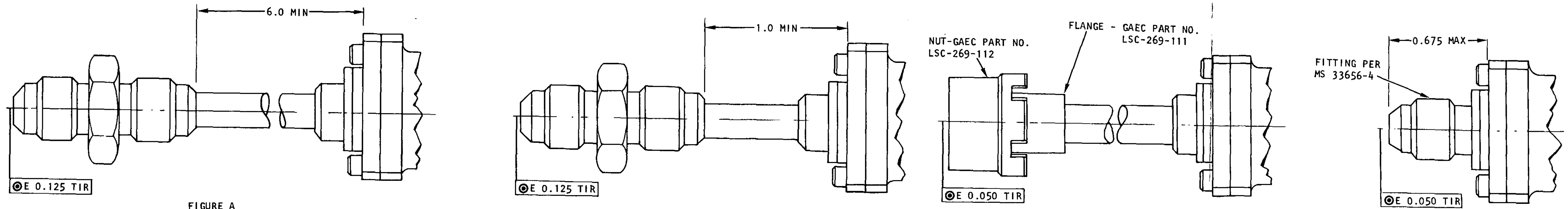


FIGURE A FIGURE B FIGURE C FIGURE D

S-77122

Figure 3-1. Lunar Module Pressure Transducers

celesco industries

environmental and
industrial products division
7800 Deering Avenue
Canoga Park, Calif. 91304
(213) 884-6860

In reply refer to:
LP-L586

December 13, 1972

Airesearch Manufacturing Company
2525 West 190th Street
Torrance, California 90509

Attention: R. M. Grotz
Administrator
Major Subcontracts

Reference: (a) Airesearch Manufacturing Company Report 82-8537-2 dated July 1972

(b) Airesearch RFQ 1372

(c) Celesco Q-7054

Gentlemen:

The subject report points out that 17% of the failures of the pressure transducers supplied to Airesearch on the Apollo Program was attributed to application of 28 VDc to the 5 VDc output terminal of the transducer electronics. We have investigated the possibility of modifying the electronics and adding circuit protection of 28v. We have also considered modifying the transducer by substituting an amplifier design which does provide for mis-circuit protection. The transducer which contains this amplifier was supplied to Grumman and qualified for the Apollo Program.

The feasibility of providing protection to the E-package used in Airesearch pressure transducer against misapplication of 28 VDc to the output terminals of the E-package was evaluated and due to major design work involved, it is recommended by Celesco that this solution shall not be considered.

The second possible solution was interfacing the present sensor to the present Grumman E-package. This solution was considered since the Grumman E-package design does provide the circuit protection. The differences between

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Figure 3-2. Summary of Results of Design Analysis the present Airesearch E-package and Grumman E-package was studied by Celesco. A summary of these differences and their effects follow:

Differences Between Two E-packages:

Two E-packages are completely different from each other in their design approach. Following are the main differences which are of main concern.

1. The Airesearch pressure transducer uses a sensor whose coil inductance is approximately 3.2 mh. The transducer used in conjuction with Grumman E-pak has coil inductance of approximately 22 mh. Hence, there is approximately 1:7 ratio in sensor inductances.

2. The oscillator frequency in the Airesearch E-pak is 22 KHz $\pm$1 KHz. The oscillator frequency in the Grumman E-pak is 17.5 KHz $\pm$1.75 KHz.

3. The amplitude between the secondary windings of the transformer used for sensor excitation in the Airesearch E-pak is approximately 75v p-p. The amplitude between secondary windings of the transformer used for sensor excitation in the Grumman E-pak is 33v $\pm$1v p-p.

Effects of the above Differences on Performances:

1. Since the oscillator frequency and the coils inductance determine the impedance of the sensor. As noted above, the Airesearch sensor used low inductance coil and Grumman E-pak has low oscillator frequency. Both of these factors tend to give low impedance to the sensor because $X_L = 2\pi fL$; where X_L is the impedance of the sensor at frequency f and with coil inductance L. If this sensor was used in conjuction with Grumman E-pak, the secondary winding of the transformer will be loaded down and the amplitude of excitation to the sensor will drop. Also, due to heavy inductive loading on the transformer secondary, the oscillator circuit will possibly produce a ringing effect and excessive noise in the circuit.

2. The frequency difference between the oscillators of E-pak has no significant effect in the performance of the transducer except that it does lower the sensor impedance as discussed above.

3. The low amplitude between the transformer secondary windings in the Grumman E-pak reduces the sensor excitation. This will reduce the sensor

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Figure 3-2 (Continued)

excitation. This will reduce the sensor output proportionally. Hence, to get 5 VDc output at the final output at full-scale pressure, the gain of the amplifier in the Grumman E-pak will have to be increased.

Comments and Recommendations:

The following recommendations are offered as a solution to the problem:

1. Redesign the sensor coils in the present sensor so that the coil inductance is $\leq$30 mh. This will enable Celesco interface this new sensor with Grumman E-package with minimum or no changes in the E-package. Redesign of the sensor will be such that it will not change the mechanical configuration of the sensor. The change in the coil inductance will be accomplished by changing the wire size and the number of turns.

2. Redesign the complete new E-package which will interface with the present Airesearch sensor directly. The present Airesearch E-package uses transformers and discrete components in its design. The new E-package will be designed with the state-of-the-art components using integrated circuits. Hence, the new E-package will be updated using the present day technological advancements in the semiconductor industry.

After we have had an opportunity to discuss the solution to the problem, we will be happy to supply you with cost estimates. If we can be of further assistance, please do not hesitate to contact me.

Sincerely,

CELESCO INDUSTRIES INC.

Larry Penssiero

Larry Penssiero
Manager, Marketing
Environmental & Industrial Products Division

fet/

A Division of The Susquehanna Corporation

Figure 3-2 (Continued)

VERIFICATION TESTING (WBS 3.0, SOW 3.2.3)

Laboratory tests were performed by Celesco Industries to verify the design details of the analysis. The results of these tests are reflected in the summary data contained in the Celesco letter of Figure 3-2.

DESIGN CRITERIA (WBS 4.0, SOW 3.2.4)

Design criteria appropriate to the Celesco pressure transducers are described on page 2-13 in AiResearch Report 72-8537-2. The design criteria specific to the design analysis made by Celesco Industries consist of recommendations for a complete redeisgn of the electronics package using state-of-the-art components and integrated circuits. Redesign is recommended because many of the component electronic parts used in the Celesco transducer for the Apollo Program are obsolete (1965 circuit design), startup costs are required, part prices are high and high-rel parts are not available except by special test.

As a result of this analysis, Celesco has defined all circuit changes that will be required for future application of the Celesco-supplied pressure transducers contained in Table 3-1. In the event the Celesco transducers find application on future aerospace programs, it is recommended that the changes defined in the Celesco analysis be incorporated and qualification-tested in accordance with the requirements of the particular program.

A review of the pressure transducer requirements for the Shuttle ECS was made by the AiResearch Manufacturing Company. These requirements are tabulated in Table 3-2.

UNRESOLVED PROBLEMS

The data contained in this section of the report, including the referenced appendixes, were gathered to identify internal portions of the transducers that were responsible for chronic failures determined from an analysis of the GFE failure reports. It is suggested that failure reports be obtained from NASA files on the transducers procured to LSC 360-601 (refer to Table 3-1) and that additional data be gathered from the transducer suppliers. The data needed specifically include cross-sectional drawings, operational descriptions, performance and design data. These data are also needed for the Bourns and Gulton (Servonic) transducers. These data had been requested; however, the information received is not sufficiently complete to permit a thorough analysis to be made.

More information also is needed concerning the total number or parts delivered for each of the specific part numbers. Only partial data was made available by the suppliers because records were not kept for longer than five years and, in all cases, the major portion of the hardware was procured and delivered over a seven-year period. The total number of parts delivered is needed so that a rejection rate can be determined for each of the failure modes identified from a review of the NASA-furnished failure reports.

TABLE 3-2

PRESSURE TRANSDUCER REQUIREMENTS FOR SHUTTLE ECS

Transducer Identification		Qty Per System	Operating Range	Proof	Burst	Fluid Media	Normal Temperature, °F	Flight Environment		Accuracy Required	Response Required
Item Number	Part Description							Temperature, °F	Pressure		
1.100	N2 Source Tank Pressure	1	0-3500 psig	5250 psig	8750 psig	N2	-20 to 165	0 to 160	Vacuum	±3% F.S.	50 MS
1.101	N2 Source Tank Pressure	1	0-3500 psig	5250 psig	8750 psig	N2	-20 to 165	0 to 160	Vacuum	±3% F.S.	50 MS
1.102	N2 Source Tank Pressure	1	0-3500 psig	5250 psig	8750 psig	N2	-20 to 165	0 to 160	Vacuum	±3% F.S.	50 MS
1.103	N2 Source Tank Pressure	1	0-3500 psig	5250 psig	8750 psig	N2	-20 to 165	0 to 160	Vacuum	±3% F.S.	50 MS
1.104	N2 Source Tank Pressure	1	0-3500 psig	5250 psig	8750 psig	N2	-20 to 165	0 to 160	Vacuum	±3% F.S.	50 MS
1.105	N2 Source Tank Pressure	1	0-3500 psig	5250 psig	8750 psig	N2	-20 to 165	0 to 160	Vacuum	±3% F.S.	50 MS
1.106	N2 Source Tank Pressure	1	0-3500 psig	5250 psig	8750 psig	N2	-20 to 165	0 to 160	Vacuum	±3% F.S.	50 MS
1.107	N2 Source Tank Pressure	1	0-3500 psig	5250 psig	8750 psig	N2	-20 to 165	0 to 160	Vacuum	±3% F.S.	50 MS
1.108	02 Source Tank Pressure	1	0-3500 psig	5250 psig	8750 psig	02	-20 to 165	0 to 160	Vacuum	±3% F.S.	50 MS
1.109	02 Source Tank Pressure	1	0-3500 psig	5250 psig	8750 psig	02	-20 to 165	0 to 160	Vacuum	±3% F.S.	50 MS
1.110	N2 Manifold Pressure	1	0-200 psig	300 psig	500 psig	N2	-20 to 165	-40 to 120	14.7 psi, 2 psi min	±3% F.S.	50 MS
1.111	N2 Manifold Pressure	1	0-200 psig	300 psig	500 psig	N2	-20 to 165	-40 to 120	14.7 psi, 2 psi min	±3% F.S.	50 MS
1.112	02 Manifold Pressure	1	0-1000 psig	1500 psig	2500 psig	02	-20 to 165	-40 to 120	14.7 psi, 2 psi min	±3% F.S.	50 MS
1.113	02 Manifold Pressure	1	0-1000 psig	1500 psig	2500 psig	02	-20 to 165	-40 to 120	14.7 psi, 2 psi min	±3% F.S.	50 MS
1.114	N2 Water Tank Pressure	1	0-50 psig	37.5 psig	62.5 psig	N2	-20 to 165	60 to 120	14.7 psi, 2 psi min	±3% F.S.	50 MS
1.115	N2 Water Tank Pressure	1	0-50 psig	37.5 psig	62.5 psig	N2	-20 to 165	60 to 120	14.7 psi, 2 psi min	±3% F.S.	50 MS
1.126	Avionic Bay Delta P	1	-2 to 2 psid	22.5 psig	37.5 psig	02/N2	0 to 120	60 to 120	14.7 psi, 2 psi min	+0.1 psid	50 MS
1.127	Avionic Bay Delta P	1	-2 to 2 psid	22.5 psig	37.5 psig	02/N2	0 to 120	60 to 120	14.7 psi, 2 psi min	+0.1 psid	50 MS
1.128	Avionic Bay Delta P	1	-2 to 2 psid	22.5 psig	37.5 psig	02/N2	0 to 120	60 to 120	14.7 psi, 2 psi min	+0.1 psid	50 MS
1.190	Cabin Total Pressure	2	0 to 30 psia	22.5 psig	37.5 psig	02/N2	0 to 120	60 to 120	14.7 psi, 2 psi min	±3% F.S.	50 MS
2.100	Fan Delta P	2	0-10 In. H20	22.5 psig	37.5 psig	02/N2	70 to 100	60 to 120	14.7 psi, 2 psi min	±3% F.S.	50 MS
2.101	Debris Trap Delta P	1	0-2 In. H20	22.5 psig	37.5 psig	02/N2	70 to 100	60 to 120	14.7 psi, 2 psi min	±3% F.S.	50 MS
3.104	Secondary Pump Inlet Pressure	1	0-50 psig	45 psig	75 psig	Water	130 max	60 to 120	14.7 psi, 2 psi min	±3% F.S.	50 MS
3.105	Primary Pump Inlet Pressure	1	0-50 psig	45 psig	75 psig	Water	130 max	60 to 120	14.7 psi, 2 psi min	±3% F.S.	50 MS
3.150	Primary Water Pump Delta P	1	0 to 60 psid	110 psig	190 psig	Water	30 to 100	60 to 120	14.7 psi, 2 psi min	±3% F.S.	50 MS
3.151	Secondary Pump Delta P	1	0 to 60 psid	110 psig	190 psig	Water	30 to 100	60 to 120	14.7 psi, 2 psi min	±3% F.S.	50 MS
3.152	Avionics Bay-1 Fan Delta P	2	0-10 In. H20	22.5 psig	37.5 psig	02/N2	130 max	60 to 130	14.7 psi, 2 psi min	±3% F.S.	50 MS
3.153	Avionics Bay-2 Fan Delta P	2	0-10 In. H20	22.5 psig	37.5 psig	02/N2	130 max	60 to 130	14.7 psi, 2 psi min	±3% F.S.	50 MS
3.154	Avionics Bay-3 Fan Delta P	2	0-10 In. H20	22.5 psig	37.5 psig	02/N2	130 max	60 to 130	14.7 psi, 2 psi min	±3% F.S.	50 MS
4.100	Water Pressure (Primary Instr)	1	0-50 psig	32.5 psig	62.5 psig	Water	130 max	60 to 120	14.7 psi, 2 psi min	±3% F.S.	50 MS
7.100	Primary Pump Package Inlet Pressure	1	0-300 psig	375 psig	625 psig	F-21	30 to 100	0 to 160	Vacuum	±3% F.S.	50 MS
7.101	Secondary Pump Package Inlet Pressure	1	0-300 psig	375 psig	625 psig	F-21	30 to 100	0 to 160	Vacuum	±3% F.S.	50 MS
7.150	Primary Pump Package Delta P	1	0 to 80 psid	375 psig	625 psig	F-21	30 to 100	0 to 160	Vacuum	±3% F.S.	50 MS
7.151	Secondary Pump Package Delta P	1	0 to 80 psid	375 psig	625 psig	F-21	30 to 100	0 to 160	Vacuum	±3% F.S.	50 MS
7.152	Ammonia Tank Pressure (Pri)	1	0-1000 psig	1500 psig	2500 psig	NH3	0 to 160	0 to 160	Vacuum	±3% F.S.	50 MS
7.153	Ammonia Tank Pressure (Sec)	1	0-1000 psig	1500 psig	2500 psig	NH3	0 to 160	0 to 160	Vacuum	±3% F.S.	50 MS
7.154	Ammonia Manifold Pressure	1	0-200 psig	300 psig	500 psig	NH3	0 to 160	0 to 160	Vacuum	±3% F.S.	50 MS

SECTION 4

TEMPERATURE TRANSDUCERS

TRANSDUCER EVALUATION (WBS 1.0, SOW 3.2.1)

Table 4-1 lists all of the temperature sensors that were used in the ECS of the Apollo command service module. Failure and design evaluation reports have been prepared for each of the sensors. These reports are contained in the Appendix with the appropriate page number and report number referenced on Table 4-1.

All of the sensors listed in Table 4-1 employ thermistors as the temperature sensing element except for the sensors that are described in Report 72-8537-15. The thermistors were supplied to AiResearch by Fenwal Electronics, Inc., Framingham, Massachusetts, in accordance with AiResearch specification control drawings.

Thermistors are thermal resistors, or resistors with a high negative temperature coefficient of resistance. This is opposite to the effect of temperature changes on metals. Thermistors are semiconductors of ceramic material made by sintering mixtures of metallic oxides such as manganese, nickel, cobalt, copper and uranium. The thermistor is one of the simplest and most versatile components available. Its unique characteristics permit straightforward solutions to many sensing, measurement and control problems which would otherwise require elaborate equipment and complex circuitry.

Thermistors are near-ideal components mechanically. Small in size (some bead types are smaller in diameter than the period at the end of this sentence), their space requirements are negligible for most applications. They are extremely rugged, stable, and they demonstrate the reliability and extended life common to many semiconductor products.

Beads are made by forming small elipsoids of thermistor material on two parallel, fine wires about 0.010 in. apart. The material is sintered at high temperature and the leads become embedded tightly in the beads making good electrical contact inside the thermistors. Beads are usually coated with glass for protection. They are used where small size, fast response, high precision, stability and temperatures to 600°F are required. Resistance values of 100 ohms to over 10 megohms can be obtained in beads ranging from 0.006 in. to 0.100 in. diameter.

RESISTANCE - TEMPERATURE CHARACTERISTICS

The resistance of a thermistor is solely a function of its absolute temperature whether the source of heat is external or internal, or both. Thus, a thermistor responds to changes in environmental temperature and also to changes in internal temperature caused by passage of current through its resistance material (self-heating).

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE 4-1

APOLLO CSM TEMPERATURE TRANSDUCERS

Unit Operating Temperature Range in Apollo CSM, °F	Identification: Title/Application	Media	Item Number	Specification AiResearch	Unit Outline: Page	Unit Outline: AiResearch Report Number	Manufacturer: Name	Manufacturer: Part Number	Design Data: Sensing Element	Pressure: Proof, psig	Pressure: Burst, psig	Weight, lb	Performance Data: Time Constant, sec	Transducer Units: Supplied	Transducer Units: Rejected	Rejection Rate, %	Remarks
25 to 75	Glycol Temperature Sensor	Glycol	2.23 CSM	820920	2-4	72-8537-13	AiResearch	820920-2	Thermistor and Electronics	90	150	0.38	6	71	29	40.8	Bridge excitation voltage 2.7 ±0.5 vrms, 300 Hz, squ. type wave, 140 ma max.
25 to 75	Glycol Temperature Sensor	Glycol	2.23 CSM	820920	2-4	72-8537-13	AiResearch	820920-3	Thermistor and Electronics	90	150	0.38	6				Bridge excitation voltage 2.7 ±0.5 vrms, 300 Hz, squ. type wave, 140 ma max.
25 to 75	Glycol Temperature Sensor	Glycol	2.23 CSM	836172	2-3	72-8537-13	AiResearch	836172-1	Thermistor, Coil and Electronics	90	150	0.38	6	22	0	0	Bridge excitation voltage 2.7 ±0.5 vrms, 300 Hz, squ. type wave, 140 ma max.
20 to 70	Glycol Temperature Sensor	Glycol	2.45 CSM	836684-1	4-24	72-8537-12	Fenwal	K1200 A	Thermistor	150	200	0.07		25	0	0	
20 to 70	Glycol Temperature Sensor	Glycol	2.45 CSM	820980	4-26	72-8537-12	AiResearch	820980-2	Thermistor	90	150	0.1	120	32	2	6.25	
40 to 100	Glycol Temperature Sensor	Glycol	2.47 CSM	836684-2	4-24	72-8537-12	Fenwal	K1201 A	Thermistor	150	200	0.07		96	1	1.04	
40 to 100	Glycol Temperature Sensor	Glycol	2.47 CSM	820980	4-26	72-8537-12	AiResearch	820980-4	Thermistor	90	150	0.1	120	92	19	20.65	
40 to 100	Glycol Temperature Sensor	Glycol	2.50 CSM	836684-2	4-24	72-8537-12	Fenwal	K1201A	Thermistor	150	200	0.07					Performance information of this unit is included in Item No. 2.47, PN 836684-2
40 to 100	Glycol Temperature Sensor	Glycol	2.50 CSM	820980	4-26	72-8537-12	AiResearch	820980-4	Thermistor	90	150	0.1	120				Performance information of this unit is included in Item No. 2.47, PN 820980-4
0 to 212	Wick Temperature Sensor	Water	2.49 CSM	836250	3-11	72-8537-12	AiResearch	836250-1	Thermistor	35psia		0.1	0.5	89	4	4.5	
70 to 100	Cabin Temperature Anticipator	Cabin Gas	3.6 CSM	820110	5-3	72-8537-12	AiResearch	820110-3	Thermistor			0.1	8	47	4	8.51	
70 to 80	Cabin Temperature Sensor	Cabin Gas	3.8 CSM	820964	5-2	72-8537-12	AiResearch	820964-1	Thermistor			0.05	8	35	0	0	
20 to 95	Suit Supply Inlet Temperature Sensor	Oxygen	7.17 CSM	836950	4-4	72-8537-15	AiResearch	836950-1	Coil and Electronics	6	10	0.2	6	34	6	17.6	Bridge excitation voltage 2.7 ±0.5 vrms, 300 Hz, squ. type wave. 140 ma max.
20 to 95	Steam Duct Temperature Sensor	Steam	8.22 CSM	836950	4-4	72-8537-15	AiResearch	836950-2	Coil and Electronics			0.2	6	31	2	6.45	Bridge excitation voltage 2.7 ±0.5 vrms, 300 Hz, squ. type wave, 140 ma max.
-50 to 100	Radiator Outlet Temperature Sensor	Glycol	8.23 CSM	836058	3-3	72-8537-15	AiResearch	836058-1	Coil and Electronics	90	150	0.3	6	45	14	31.1	Bridge excitation voltage 2.7 ±0.02 vrms, 300 Hz, squ. type wave, 140 ma max.
-50 to 100	Radiator Outlet Temperature Sensor	Glycol	8.23 CSM	836058	3-3	72-8537-15	AiResearch	836058-2	Coil and Electronics	90	150	0.3	6				Bridge excitation voltage 2.7 ±0.02 vrms, 300 Hz, squ. type wave, 140 ma max.
20 to 95	Cabin Temperature Transducer	Cabin Gas	9.11 CSM	836930	2-3	72-8537-14	AiResearch	836930-1	Thermistor and Electronics			0.2	10	37	6	16.21	Output signal proportional to sensed temperature, '0' vdc at 40°F and 5 vdc at 125°F

The unique aspect of a thermistor's resistance versus temperature characteristic is its very high coefficient of change of resistance with temperature. This is typically 3 to 5% per degree Centigrade as compared with about 0.4% for platinum. Consequently, it is an ideal temperature transducer, sensitive to small temperature changes and requiring less amplification.

A common transducer power supply was provided for the temperature sensors installed in the Apollo CSM. The performance characteristics for the power supply are shown below.

TEMPERATURE TRANSDUCER POWER SUPPLY (Apollo PN 836066)

Purpose

The temperature transducer power supply furnishes dc operating power and square-wave-type excitation voltage to the amplifier assemblies of the CSM temperature signal amplifiers.

Description

The power supply is hermetically sealed. Solid-state devices are used to increase reliability and reduce power requirements. The power supply is of redundant design, having two identical sections.

Each section comprises a voltage regulator stage, a saturable-reactor-type static-inverter stage, and a differential-amplifier-type feedback circuit to control the voltage regulator. The voltage of the 28-vdc power is applied to the input of the static inverter and also to the temperature transducer amplifiers. The static inverter operates at 300 Hz and design parameters are such that +18-vdc power at the input of the stage produces a 5.4-v peak-to-peak square-wave-type (2.7 vrms) signal at one secondary winding of the inverter transformer. This signal is supplied to the temperature signal amplifiers for use as excitation voltage.

A second winding on the transformer controls a transistor switch used to sample the 5.4-v square-wave-type (2.7 vrms) output for voltage controlling purposes. This sample voltage is applied to one input of a differential amplifier stage. A stabilized reference voltage is applied to the other input of the differential amplifier. This reference voltage is developed in a zener diode filter network from the 28-vdc input power. The outputs from the differential amplifier are amplified in a second differential amplifier stage and then applied to a differential control amplifier, where the control signal for the voltage regulator stage is developed. This control signal corrects the input voltage to the static inverter to maintain an exact 5.4-v peak-to-peak square-wave (2.7 vrms) output.

The regulated +18-vdc power furnished by the power supply is used in the signal amplifier stages. The 5.4-v peak-to-peak (2.7 vrms) 300 Hz, square wave excitation voltage produced by the power supply is used in the chopper-demodulator stage of the temperature signal amplifier assemblies.

Output voltages	2.7 ±0.02 vrms, 300 (+30, -100) Hz, sq waves at 700 ma max normal load current
	18.0 ±1.0 vdc supply voltage at 165 ma max
	-0.5 ±0.2 vdc bias voltage at 30 ma max normal load current
Electrical power requirements	
Input voltage, vdc	28
Input power, watts	10.7 (max) at 28 +2, -3 vdc
Weight, lb	1.5
Envelope	See Figure 4-1

A common temperature sensor amplifier was used in the ECS of the Apollo CSM. The performance characteristics of the amplifier are tabulated below:

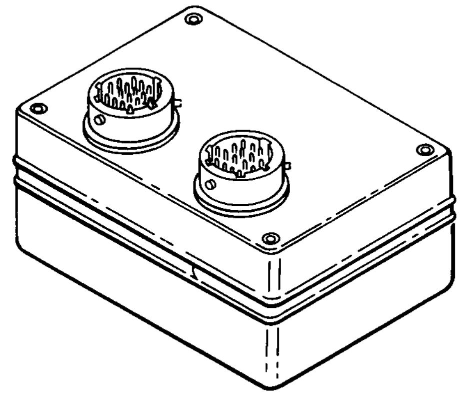
TEMPERATURE SIGNAL AMPLIFIER (Apollo PN 836056)

Purpose

The power required to operate each of the instrumentation temperature sensors is provided by the amplifier. The sensor output signal is then fed back into the amplifier where it is amplified and then transmitted to telemetry.

Performance and Design Data

Input signal	0 to 29.5 mv rms, 300 Hz, square-type wave from instrumentation temp sensor
Output signal	0 at 0 input, 5 vdc output across 30,000 ohms external load with 29.5 mv rms, 300 Hz, square-type wave input. Output is proportional to input
Output signal error	Output signal error shall not exceed ±0.5% (±0.025v) of full scale from 0% to 100% of input
Output ripple, mv rms	10 (max)
Input impedance, ohms	270 ±2.7



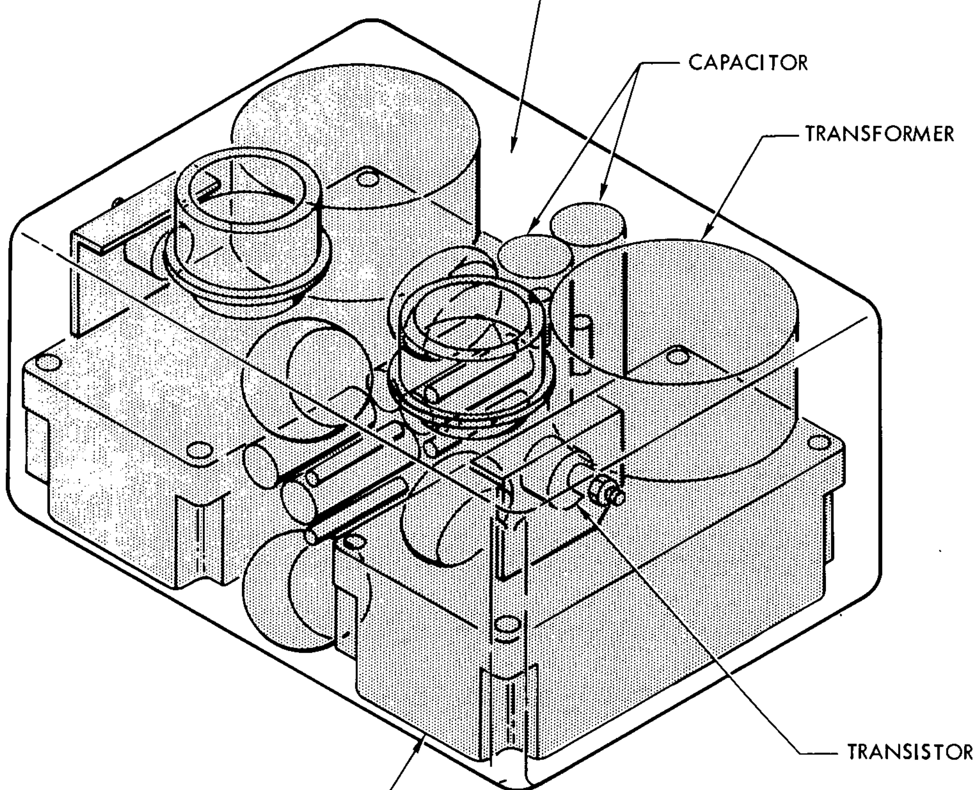


Figure 4-1. Temperature Transducer Power Supply

Output impedance, ohms	400 (max)
Load resistance, ohms	10,000 min; 30,000 nominal
Electrical power requirements	
Signal excitation	2.7 ±0.02 vrms, 300 (+30, -45) Hz, square-type wave at 140 ma
Supply, vdc	18.0 ±1.0 at 33 ma
Bias, vdc	-0.5 ±0.2 at 6 ma
Weight, lb	0.3
Envelope	See Figure 4-2

DESIGN CONCEPT (WBS 2.0, SOW 3.2.2)

The failure and design evaluation reports contained in AiResearch Reports 72-8537-12, -13, -14 and -15, describe the history of failures that were experienced during the course of the Apollo program and also describe changes that were made to reduce or eliminate the rejections. The resultant failure rate is sufficiently low to be considered acceptable for these units. Design criteria in the form of a training program relative to assembly and test are recommended to further reduce the rejection rate.

VERIFICATION TESTING (WBS 3.0, SOW 3.2.3)

The temperature sensors tabulated in Table 4-1 were not selected for corrective design/development during the course of this program; consequently, no verification testing was specified.

DESIGN CRITERIA (WBS 4.0, SOW 3.2.4)

Design criteria appropriate to each of the part numbered temperature sensors listed in Table 4-1 are contained in the AiResearch reports that were prepared during the failure and design evaluation of the temperature sensors. These reports are contained in the Appendix.

A review of the temperature sensor requirements for the Shuttle ECS has been made by the AiResearch Manufacturing Company. These requirements are contained in Table 4-2.

UNRESOLVED PROBLEM

This section describes the temperature measuring sensors and transducers that were used in the ECS of the Apollo CSM. The GFE failure reports provided the basis for the failure and design information reports that were published during the course of this program; however, reports were not published on the temperature transducers that were used in the environmental

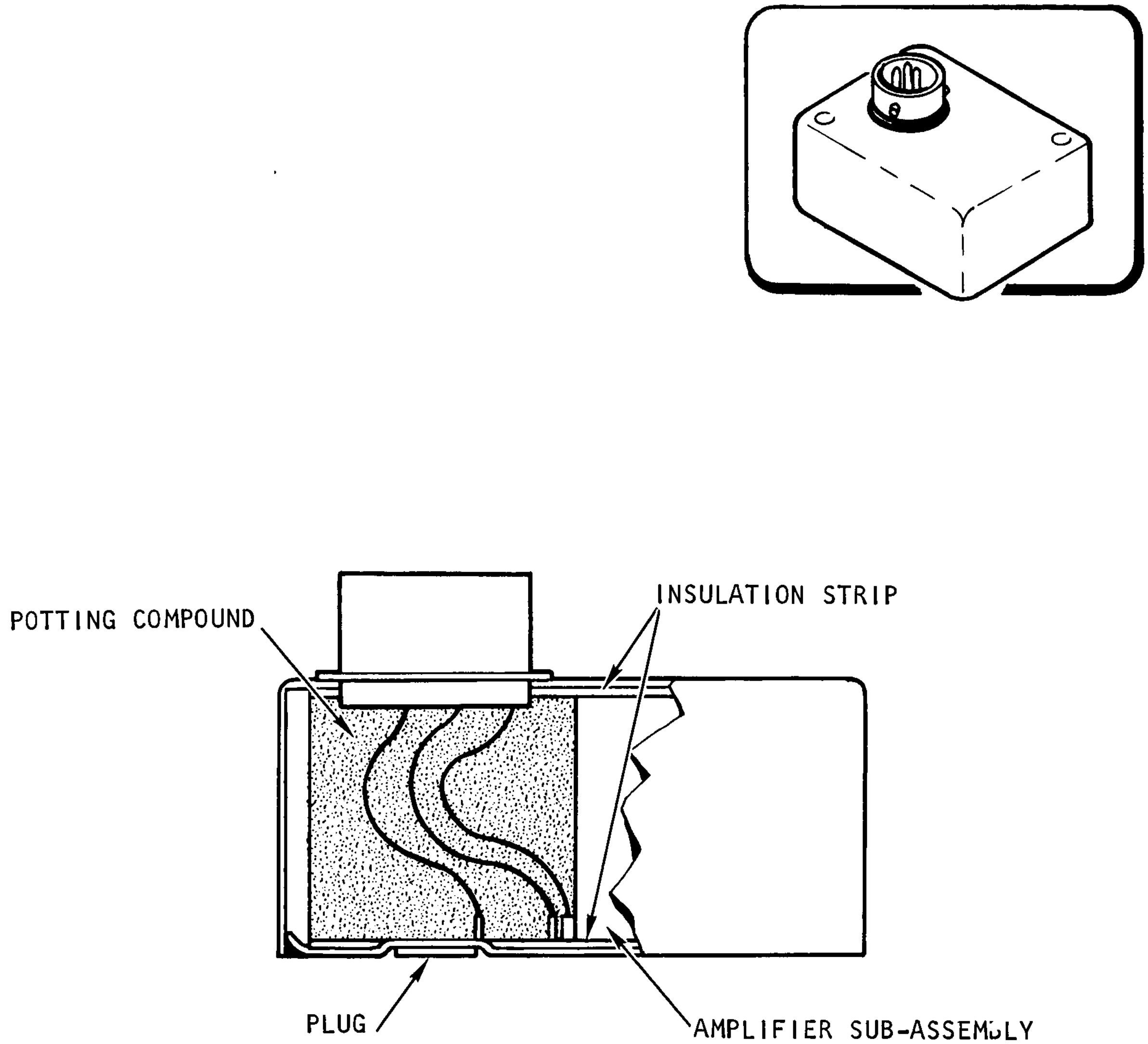


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Figure 4-2. Temperature Sensor Amplifier

TABLE 4-2

TEMPERATURE SENSORS REQUIREMENTS FOR SHUTTLE ECS

Transducer Identification		Qty Per System	Operating Temperature Range, °F	Proof, psig	Burst, psig	Fluid Media	Normal Temperature, °F	Flight Environment	
SSV Item	Part Description							Temperature, °F	Pressure
1.200	02 Manifold Temperature	1	-75 to 175	1500	2500	02	-75 to 175	60 to 120	14.7 psi, 2 psi min
1.201	02 Manifold Temperature	1	-75 to 175	1500	2500	02	-75 to 175	60 to 120	14.7 psi, 2 psi min
3.255	Interchanger Outlet (Primary)	1	0 to 200	22.5	37.5	02/N2	45 to 65	0 to 160	Vacuum
3.256	Evaporator Outlet (Primary)	1	0 to 100	22.5	37.5	02/N2	35 to 65	60 to 120	14.7 psi, 2 psi min
3.257	Interchanger Outlet (Secondary)	1	0 to 200	22.5	37.5	02/N2	45 to 65	0 to 160	Vacuum
3.258	Evaporator Outlet (Secondary)	1	0 to 100	22.5	37.5	02/N2	35 to 65	60 to 120	14.7 psi, 2 psi min
3.259	Evaporator Exit Temp (Secondary)	1	0 to 100	22.5	37.5	02/N2	35 to 65	60 to 120	14.7 psi, 2 psi min
3.260	Evaporator Exit Temp (Primary)	1	0 to 100	22.5	37.5	02/N2	35 to 65	60 to 120	14.7 psi, 2 psi min
3.290	Cabin Temp	1	0 to 120	22.5	37.5	02/N2	60 to 80	60 to 120	14.7 psi, 2 psi min
3.3	Cabin Temp	1	0 to 120	22.5	37.5	02/N2	60 to 80	60 to 120	14.7 psi, 2 psi min
4.200	Water Nozzle Temp Sensor	1	0 to 100	22.5	37.5	02/N2	0 to 100	60 to 120	14.7 psi, 2 psi min
7.10	Control Temp Sensor	2	0 to 250	22.5	37.5	02/N2	30 to 60	0 to 160	Vacuum
7.250	Radiator Inlet Temp (Primary)	1	0 to 250	22.5	37.5	02/N2	0 to 210	0 to 160	Vacuum
7.251	Interchanger Inlet Temp (Primary)	1	0 to 250	22.5	37.5	02/N2	30 to 200	0 to 160	Vacuum
7.252	Interchanger Inlet Temp (Secondary)	1	0 to 250	22.5	37.5	02/N2	0 to 200	0 to 160	Vacuum
7.253	Radiator Inlet Temp (Secondary)	1	0 to 250	22.5	37.5	02/N2	0 to 200	0 to 160	Vacuum
7.256	GSE HX Outlet Temperature (Secondary)	1	0 to 250	22.5	37.5	F-21	30 to 185	0 to 160	Vacuum
7.257	GSE HX Outlet Temperature (Primary)	1	0 to 250	22.5	37.5	F-21	0 to 160	0 to 160	Vacuum
7.258	Primary F-21 Boiler Outlet Temp	1	0 to 200	22.5	37.5	F-21	0 to 160	0 to 160	Vacuum
7.259	Secondary F-21 Boiler Outlet Temp	1	0 to 200	22.5	37.5	F-21	0 to 160	0 to 160	Vacuum

control system for the LM and PLSS. Technical information regarding these sensors was solicited from the manufacturers; however, the information received was not sufficiently complete to permit a thorough evaluation to be made. A follow-up effort to obtain more information from the manufacturers of the LM and PLSS temperature sensors is recommended. This information when supplemented by tests and analyses conducted on sensors that were supplied by NASA will enable failure and design evaluation reports to be prepared including the formulation of design criteria for reducing or eliminating chronic failure modes. A follow-on effort of this type has been proposed to NASA under separate cover.

SECTION 5

FLOW TRANSDUCERS

TRANSDUCER EVALUATION (WBS 1.0, SOW 3.2.1)

The flow transducer monitors the inflow of oxygen into the cabin to satisfy the crew metabolic needs and to make up the loss of cabin gas caused by overboard cabin leakage. The flow transducer also closes a switch which causes a warning light to become illuminated if a higher than normal inflow rate occurs due to excess cabin leakage.

AiResearch Report 72-8537-22, "Report on Failure and Design Evaluation of Apollo ECS Oxygen Flow Transducer," contained in the Appendix shows that approximately 46 percent of the flow transducers was rejected for problems giving cause for the recommendation to redesign the unit.

The oxygen flow transducer used in the Apollo CSM (Figure 5-1) measures the flow rate of the oxygen gas by heat transfer principles. The wire-wound heating element and resistance thermometers are contained in dual 90-degree tubular probes (see Figures 5-2 and 5-3) with the sensing ends located side by side in the main flow stream. This design is very difficult to fabricate and assemble because the heater and thermometer resistance coils, including the wire leads, must be routed through the small tubular probes. The ends of the probes are sealed by soft solder after the installation is completed. The difficulty of installing the heater and thermometer coils inside the small diameter probes frequently is manifested in development of heat transfer problems causing poor stability of the output signal. The problem is compounded by the difficulty of inspecting the miniature, hidden coils after assembly is completed.

Discussions with the manufacturer of the oxygen flow transducer (Tylan Corporation) indicated that this unit will not be available for application beyond the Apollo program. The growth in performance requirements imposed on this unit during the Apollo program resulted in extremely tight packaging. Tylan Corporation personnel stated that a portion of the subassembly is considered a blind assembly making in-step inspection impractical. They further stated that when sufficient subassembly has been accomplished to reach a test milestone, if an error was found, the subassembly was not reworkable, and therefore, had to be completely redone. This was the major cause for the high price of the unit. Personnel of the Tylan Corporation recommended that the oxygen flow transducer be redesigned to take advantage of the techniques used in a unit that has been sold commercially over the past four years. This unit employs a similar concept for flow measurement in a configuration that is relatively easy to assemble, inspect and test. A statement of work presented in Exhibit 5A was negotiated with the Tylan Corporation for the purpose of converting the commercial flow transducer to a flight-type design. AiResearch awarded the Tylan Corporation a subcontract in October 1972 to repackage the commercial transducer into an aerospace-type unit, correct the "g" sensitivity

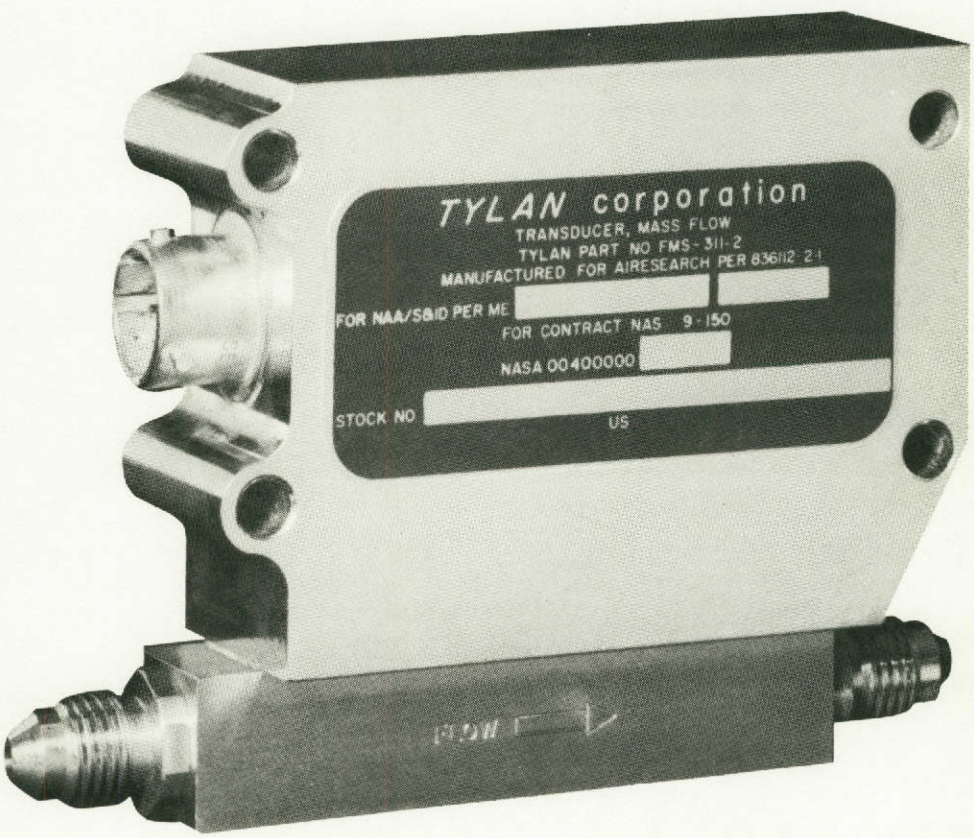

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Figure 5-1. Apollo CSM Oxygen Flow Transducer

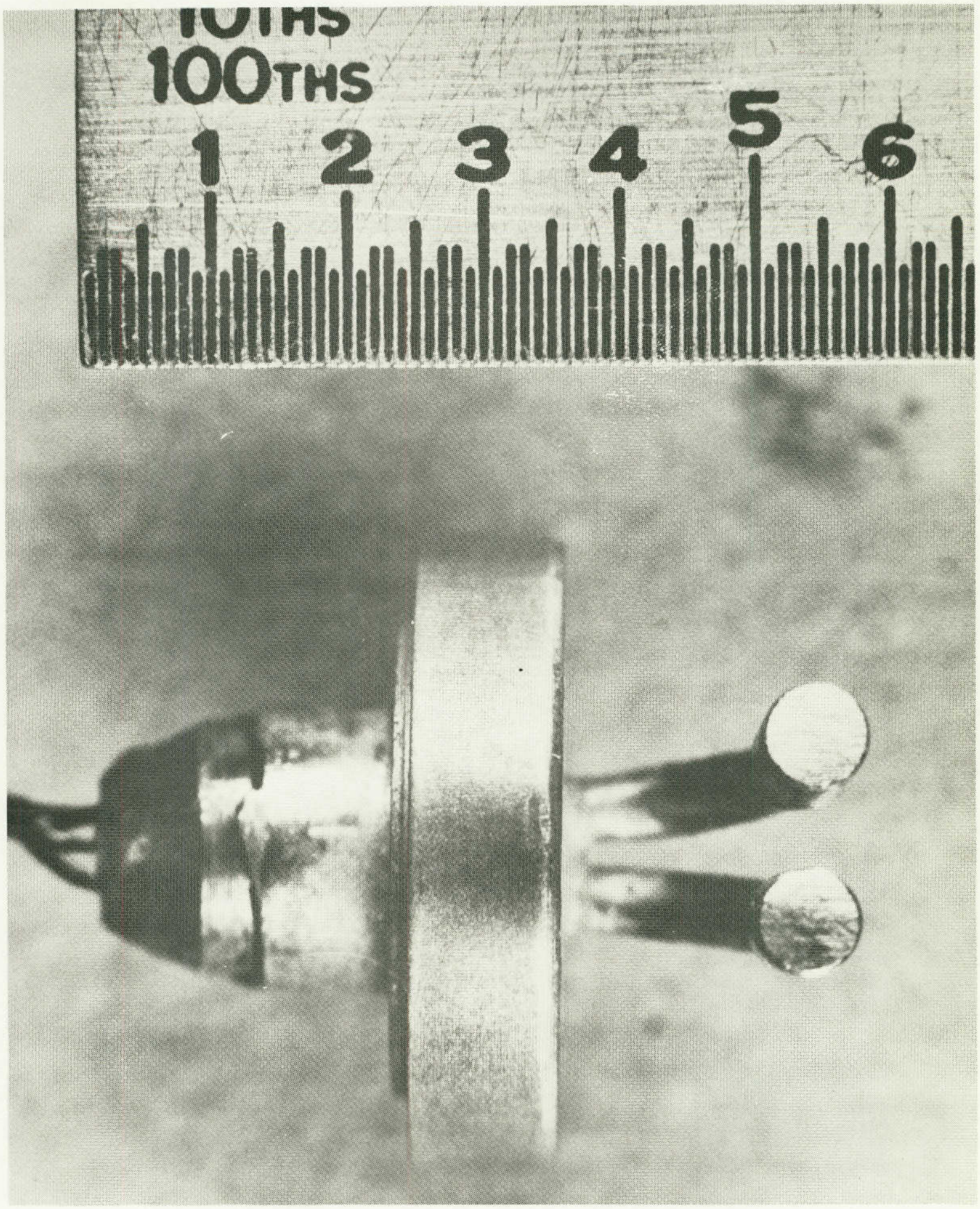

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Figure 5-2. Apollo CSM O_2 Flow Sensing Element

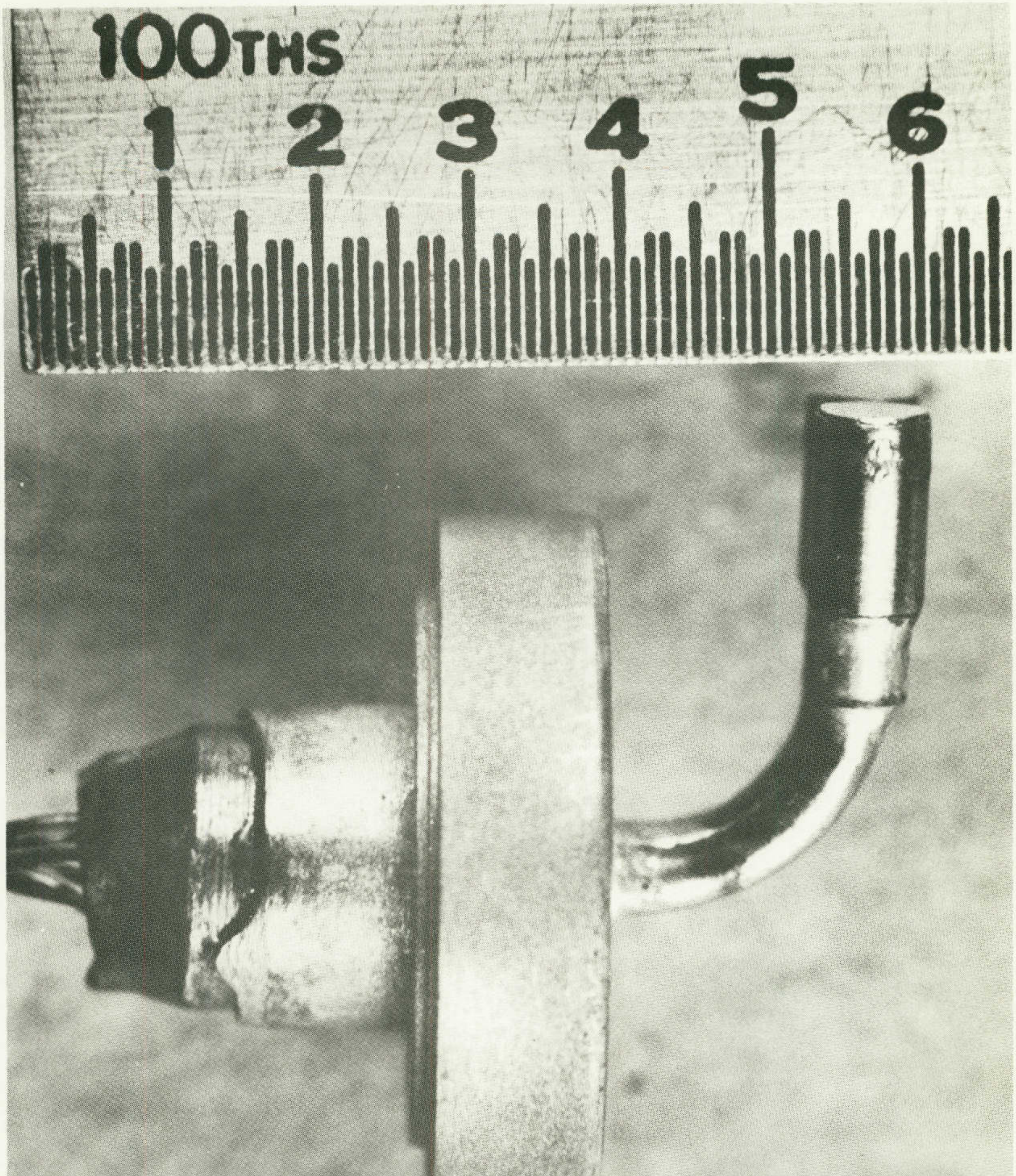

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Figure 5-3. Apollo CSM O_2 Flow Sensing Element of the sensing element and perform a vibration test of the sensor portion only, in accordance with SSV vibration requirements.

DESIGN CONCEPT (WBS 2.0, SOW 3.2.2)

The improved technique for measuring oxygen flow developed by Tylan for their commercial unit is shown in Figure 5-4. It measures the mass flow rate of the oxygen by heat transfer principles. A small portion of the oxygen gas flowing through the transducer is forced to flow through the sensor which consists of a small diameter capillary tube mounted across a laminar-flow bypass in the main flow line. The ΔP of the sensor and bypass is approximately 5 to 7 inches of water at full-scale flow rate.

The sensor is wound with a heater coil in the middle and a resistance thermometer is wound around the tube on both sides of the heater. A few milliwatts of heat applied by the heater raises the gas stream temperature slightly, changing the relative reading of the two thermometers. The design parameters are such that the temperature difference signal between the resistance thermometers is directly proportional to flow and is also linear. The reading is not affected by changes in gas pressure or temperature within specific ranges. This construction has several distinct advantages for space flight applications, all of which relate to the fact that the sensor elements are on the outside of the sensing tube.

1. There is no exposure of the elements to the gas in the tube, hence, no erosion or corrosion problems.

2. There are no electrical feed-throughs, so the flow passage has outstanding leak integrity.

3. Fabrication and inspection are facilitated, so quality control and reliability are enhanced.

The sensor is deliberately made small to achieve fast response and minimum power consumption; therefore, only a fraction of the total flow passes through the sensor. The greater portion of the flow passes through a bypass which is thermodynamically similar to the sensor and gives a constant bypass ratio under all extremes of operation. The use of the flow transducer in widely different flow range applications, involves bypass modification only; the sensor and signal conditioner are not changed.

Coordination meetings between AiResearch and the Tylan Corporation were held during the course of the subcontracted program to identify the problem statement for the new flow transducer with special emphasis placed on the Shuttle ECS requirements and review of progress and performance of the following tasks:

Task 1--Performance of a heat transfer analysis on the sensor to determine the tradeoffs in response, g-sensitivity and sensor gain as a function of the supporting insulation necessary for vibration survival.

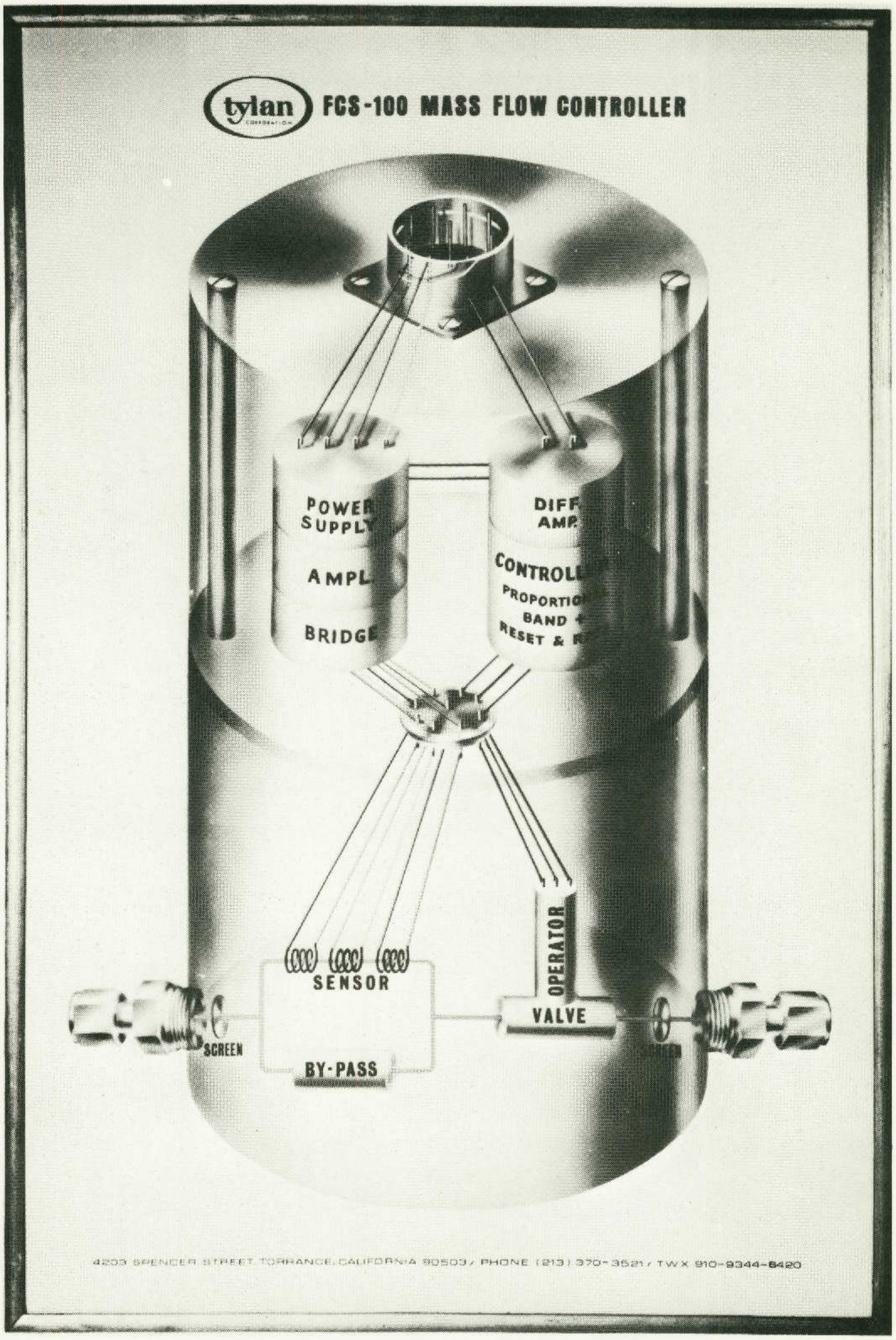

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Figure 5-4. Commercial Mass Flow Controller

Task 2--Fabrication of a prototype sensor section using existing hardware and the subsequent testing of g-sensitivity, temperature stability, response and vibration survival.

Task 3--Determination of the input-output parameters, built-in-test capability and the required circuitry for preventing damage due to misapplication of the input power.

Task 4--Design, breadboard and test of the electronic circuit required to operate with the modified sensor to meet the desired performance specifications.

Task 5--Identify and prescribe mechanical features of the flight transducer to ensure compliance with Shuttle performance and environmental requirements.

Task 6--Preliminary package design resulting in a proposed outline drawing.

The following paragraphs supply descriptive information that amplifies the above tasks.

Sensor Development (Task 1)

Figure 5-5 is a photograph of the sensor portion only for the new oxygen flow transducer. Two heavy sections are attached to each end of a 0.010-in. diameter capillary tube. The heavy sections install in two counterbored holes located on either side of a laminar flow bypass in the main oxygen flow line. The ΔP of the bypass is approximately 5 to 7 in. of water which forces a proportionate amount of flow through the capillary tube. The sensing element (capillary tube assembly) is wound with a heater coil in the middle and a resistance thermometer is wound around the tube on either side of the heater. The heater and thermometer wires are routed through plastic supports on each end of the U-tube.

The sensor measures flow by heat transfer principles. A few milliwatts of heat applied by the heater raises the gas stream temperature slightly, changing the relative readings of the two thermometers. In one "g", the heat rises vertically intersecting the sensor assembly in a given plane. As the sensor assembly is rotated, the heat continues to rise vertically, but intersects a different portion of the sensor causing a drastic change in the sensor output. A thermal analysis has been prepared by Tylan; this analysis shows that by maintaining a small air gap around the sensor and a specified amount of insulation located outside of the air gap, the "g" sensitivity can be virtually eliminated.

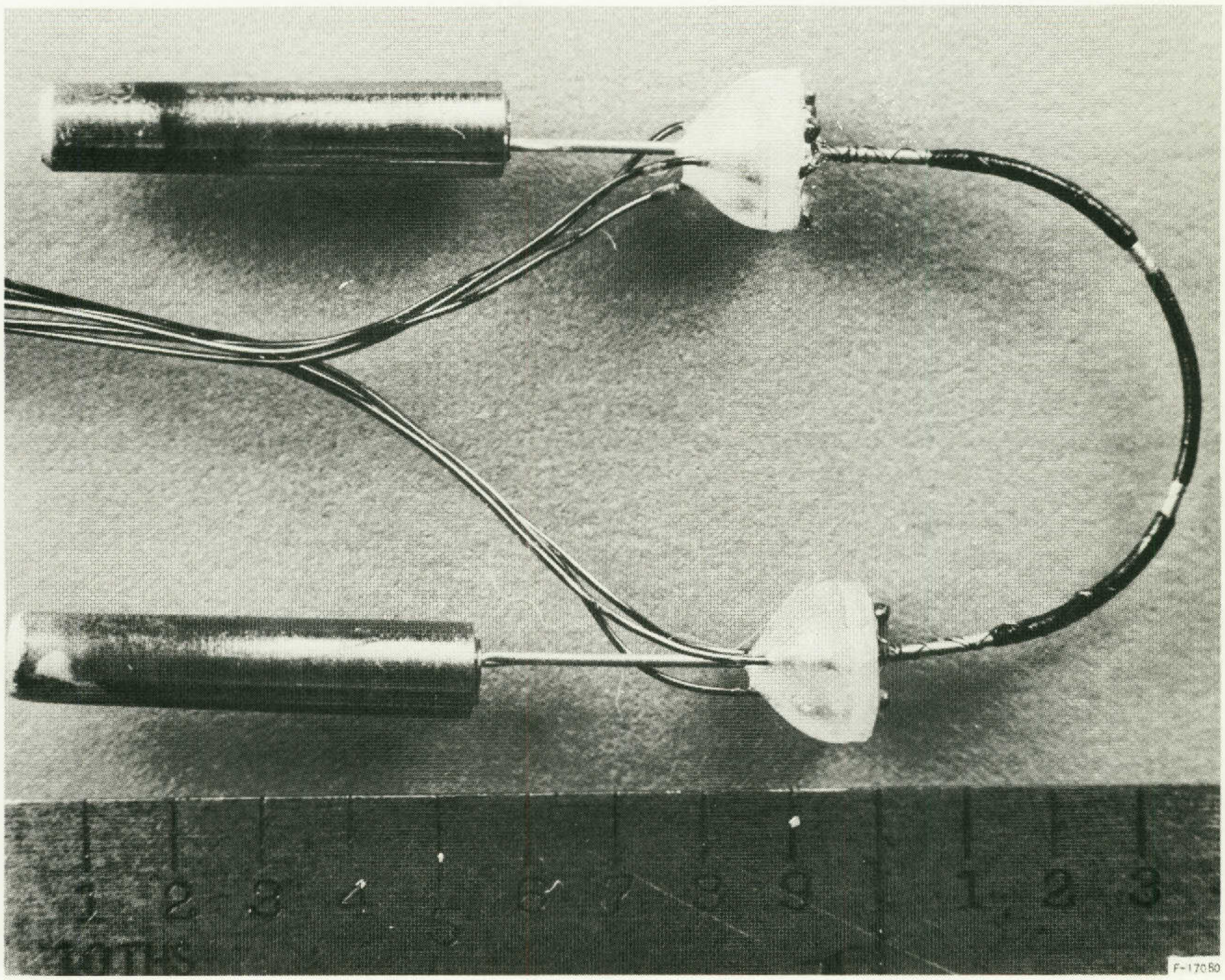


Figure 5-5. Oxygen Flow Sensor

Guidelines developed during heat transfer analysis showed that the primary consideration is the steady-state solution which shows that the insulation should be optimized primarily to have minimum heat transfer (small thermal conductivity of insulation material). This will result in a minimum reduction of sensor gain.

The optimum insulator is a vacuum while second best would be a gas with just enough solid in it to stop convection (foams, mats, honeycombs). Argon is better than air, but would diffuse from a foam unless contained.

It is desirable to maintain the smallest practical air gap between the insulation and the sensor because this gives the least g-sensitivity with a reasonably small heat transfer coefficient.

In summary, the best material would be a low-density foam with good insulating properties clamped onto the sensor to give a minimum (but finite) air gap and rigid enough to support the sensing tube during vibration.

Results of Sensor Tests (Task 2)

Preliminary g-sensitivity, gain, and response tests were run on two styles of modified sensors and several types of insulating methods and materials to determine an optimum configuration. The test results (see data sheets 1 through 17, Exhibit 5B) were found to verify the conclusions made from the heat transfer analysis. Simplicity and ease of manufacture were taken into consideration in selecting the optimum configuration used for the final environmental testing.

NOTE: The term, "doghouse", in the data sheets refers to an insulation enclosure shaped like a doghouse. This enclosure was placed over the sensor to isolate the test article from room air currents, etc. The flight design will incorporate insulation and hermetic sealing as determined necessary by these breadboard tests.

The final configuration consisted of a type B sensor, taped between two 1/8-in. blocks of beaded polystyrene foam, which was enclosed in a metal can for mechanical support. All of the final tests were run on this configuration using the breadboard electronics. The tests and test results follow.

1. G-sensitivity (Data Sheet No. 1F, Exhibit 5B)

With the flow set to give an output signal of 5.00 vdc, the unit was rotated around both axes to determine the shift due to attitude. The maximum shift in output voltage occurred at 90 deg along the pitch axis and was found to be no greater than 0.01 vdc (±0.2 percent f.s.).

2. Response (Data Sheet No. 1F, Exhibit 5B)

Response curves were run by producing step changes in flow from 10 to 100 percent and 100 to 10 percent full scale flow while recording the output voltage versus time. The worst-case time response was found to be from 100 to 10 percent which had a first-order time constant (to 63 percent of the change) of 4.0 sec and a time constant of 25 sec to be within 2 percent of final value. An electronic lead circuit was added and the tests were repeated with the result that, although the first-order time constant was reduced to 0.25 sec, a 15 percent overshoot resulted which had a settling time to within 2 percent of final value of 25 sec. Since this response curve could only be advantageous in a feedback control system, it was decided that the additional complexity was not warranted in this application.

3. Linearity (Data Sheet No. 2F, Exhibit 5B)

With the full scale output set at 1.0 lb/hr (arbitrarily determined by the adjustment of the bypass), the electronic linearity adjustment was calibrated to give 2.50 vdc output at 0.5 lb/hr. A curve of output voltage versus flow rate was run and the linearity was seen to be within ±0.4 percent full scale over the flow range. Separate tests run on the electronics shown that the adjustment was capable of linearizing up to a ±5 percent nonlinearity. Nominal sensor nonlinearity is ±2 percent.

4. Supply Voltage Sensitivity (Data Sheet No. 2F, Exhibit 5B)

With the flow adjusted to give 5.00 vdc output, the supply voltages were varied from 14 to 16 vdc and the output voltage was seen to remain constant within ±0.6 percent full scale.

5. Vibration (Data Sheet No. 3F, Exhibit 5B and Exhibit 5C)

A calibration curve was run of output voltage versus flow and the sensor assembly was then subjected to random vibration (for a reduced time duration). The overall sensor resistance was monitored during vibration testing and was observed to remain constant. The calibration curve was rerun after vibration and the output versus flow was seen to repeat the pre-vibration data within ±0.2 percent full scale from 0 to 5.00 vdc.

6. Temperature Stability - Sensor Only (Data Sheet No. 4F, Exhibit 5B)

Output voltage versus flow rate was run at $0^{\circ}F$, $70^{\circ}F$ and $160^{\circ}F$ with the bypass plugged and the calibration was seen to be stable to within ±2 percent.

7. Temperature Stability with 1.0 lb/hr Bypass (Data Sheet No. 5F, Exhibit 5B)

Output voltage versus flow rate was run at $0^{\circ}F$, $70^{\circ}F$, $120^{\circ}F$ and $160^{\circ}F$ with a bypass and the calibration was noted to be stable to within ±6 percent worst case. (Since existing hardware was used, a marginal bypass design was necessary due to the undersized bore of the bypass port. In the proposed package design, allowance has been made for adequate sizing of the bypass port to allow for a proper bypass design which should exhibit better flow spitting characteristics over the required temperature range and thus improve the temperature stability of the complete unit.) During the temperature tests, the electronics were held at room ambient temperature while the flow sensor assembly and gas were stabilized in an environmental chamber to the noted temperatures.

The proposed installation of the oxygen flow transducer in the Shuttle ECS shows the transducer installed in a line that may flow either oxygen or nitrogen depending on the demands established by the 2-gas control. An analysis was made to determine what effect the alternate flow of oxygen or nitrogen would have on the output signal of the transducer. Tests were run to verify the analysis and the results of both the analysis and the tests showed that the indicated flow rate would be different by no more than 0.5 percent because of the similar characteristics of nitrogen and oxygen.

Electronic Circuit Design Considerations (Task 3)

Guidelines established prior to the development of the electronic circuit included requirements pertinent to the Shuttle vehicle. These guidelines were:

- Simple design
- Require no maintenance or refurbinshment for 100 or more launches
- Require little or no ground checkout; such checkout to be simple
- Be unaffected by long quiescent periods in space environment
- Be economically produced
- Be lightweight
- Consume minimum electrical power

During the circuit analysis several design features were made mandatory to accommodate the requirements established by the Shuttle guidelines. These design features are given in the paragraphs that follow.

Design a circuit such that the end products can withstand an inadvertent application of 32 vdc to the 0-5 vdc output pins and also a reversal of polarity on the input power pins.

The circuit shall incorporate a switch that is activated when the flow of oxygen or nitrogen exceeds "normal." The purpose of this switch is to illuminate a warning light on the pilot's panel in the event cabin or system leakage exceeds specified limits. The vehicle 28 vdc electrical power system shall be used for energizing the warning lamp.

Incorporate built-in-test equipment (BITE) to permit all the circuitry between the input and output to be checked while the transducer is installed in the vehicle.

Design the circuitry in the transducer to interface with a separate power supply that is common for any other transducers on Shuttle. The various reasons for a separate power supply are described in the following:

(a) The power supply complexity and failure rate is greater than that of the flow transducer. The manufacturing cost of the transducer, however, will be much higher than the power supply because of its mechanical parts and specialized calibration testing. Economics of operation and repair will therefore result from separating the power supply failures from the transducer.

(b) Redundant separate power supplies can supply multiple transducers, whereas integral power supplies would require the same redundancy per transducer to achieve similar reliability. Cost, complexity, size and weight would suffer.

(c) Since power levels are low, the combining of numerous small power supplies into fewer larger power supplies will result in savings of size, weight and complexity.

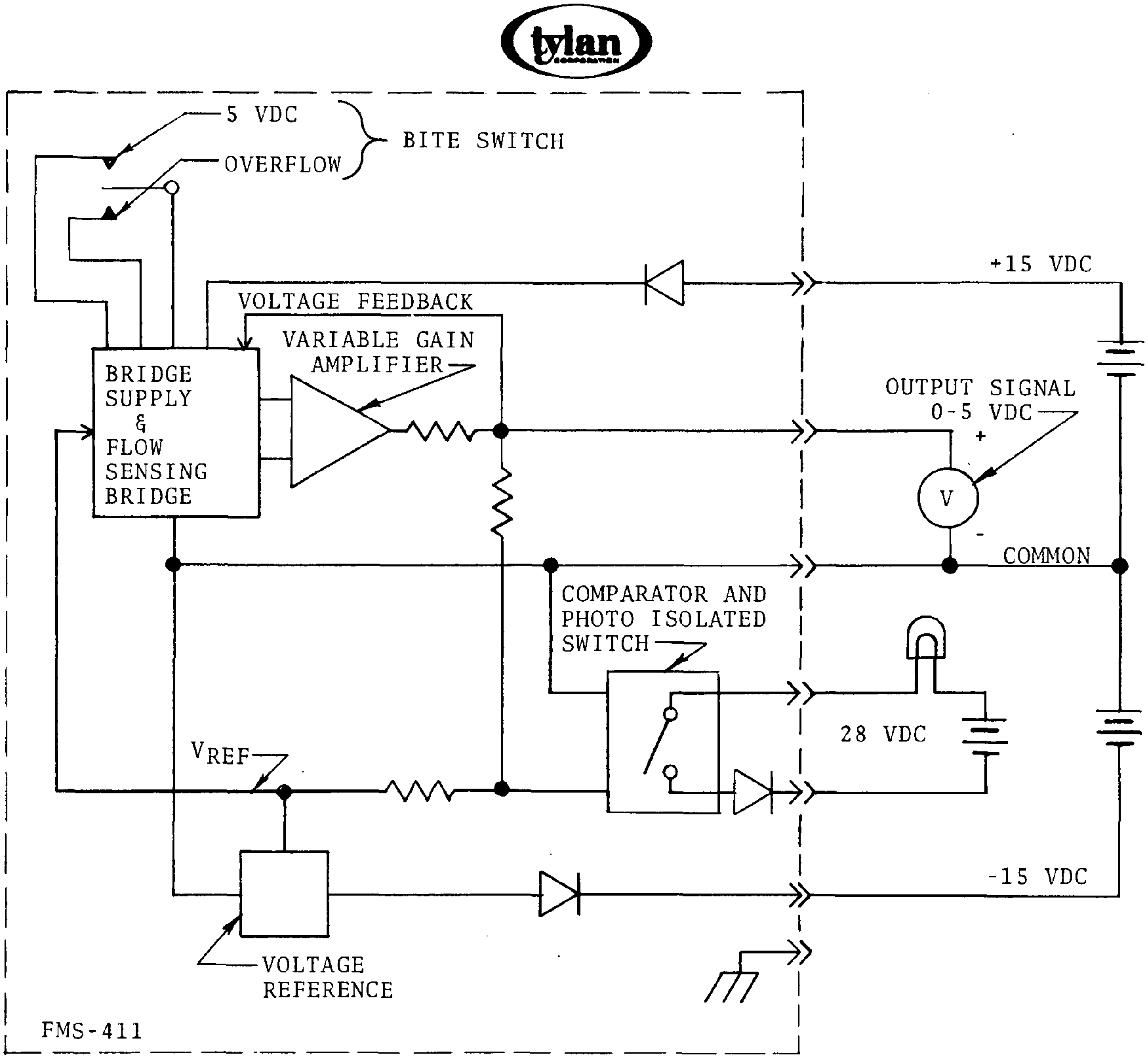
(d) The removal of the power supply converter from the transducer case eliminates the major source of EMI problems from the transducer. This is of considerable importance to reliability and to development costs.

Electronic Circuit Analysis and Test (Task 4)

The transducer electronic circuit diagram shown in Figure 5-6 includes amplification and associated signal conditioning, an isolated solid-state switch output for overflow indication and BITE for quantitative checking of zero, full scale, and overflow output signals. It does not include power supply isolation, but is designed to operate from an isolated ±15 vdc supply. Final power supply cleanup is included so that the specifications on the external power supply are eased. EMI protection is also included, although filtering problems are greatly reduced by the use of the separate power supply isolation and the fact that the entire transducer uses only low-frequency, low impedance signals and interface connections.

Built-in-test capability is accomplished by the use of one spring-loaded, 3-position switch which functions as follows:

(a) Normal position: output voltage = 0 ±0.15 vdc at no flow which is normal operation.



BLOCK DIAGRAM

Figure 5-6. Electronic Circuit Block Diagram

(b) Momentary left: output voltage = 5.0 ±0.15 vdc. The flow sensor bridge is unbalanced a precise amount, and the sensor, reference circuitry and amplifier are all checked simultaneously.

(c) Momentary right: output voltage +6.25 ±0.5 vdc and the overflow warning light illuminates. The flow sensor bridge is further unbalanced to actuate the overflow warning circuit to verify its operation.

The circuit can easily be protected from any combination of misapplication of input power by the use of diodes and current limiting resistors.

The electronic circuit was breadboarded as shown in Figure 5-7 for use in conjunction with the tests run on the sensing element. Several iterations were made to the circuit to achieve the desired design features. In addition, an electronic lead circuit was added which reduced the response time of the sensor to 0.5 sec. It was concluded from test results that the additional complexity of the lead circuit was not warranted because a satisfactory response time (6 sec) could be achieved without the electronic lead circuit.

The electronic breadboard was required during development and environmental testing of the sensing element; however, the circuit was not subjected to any of the test environments because of the nature of the breadboard packaging and because the circuit employs highly developed state-of-the-art components. Environmental testing of the circuit will be meaningful on a prototype unit that is designed and packaged in accordance with production type drawings.

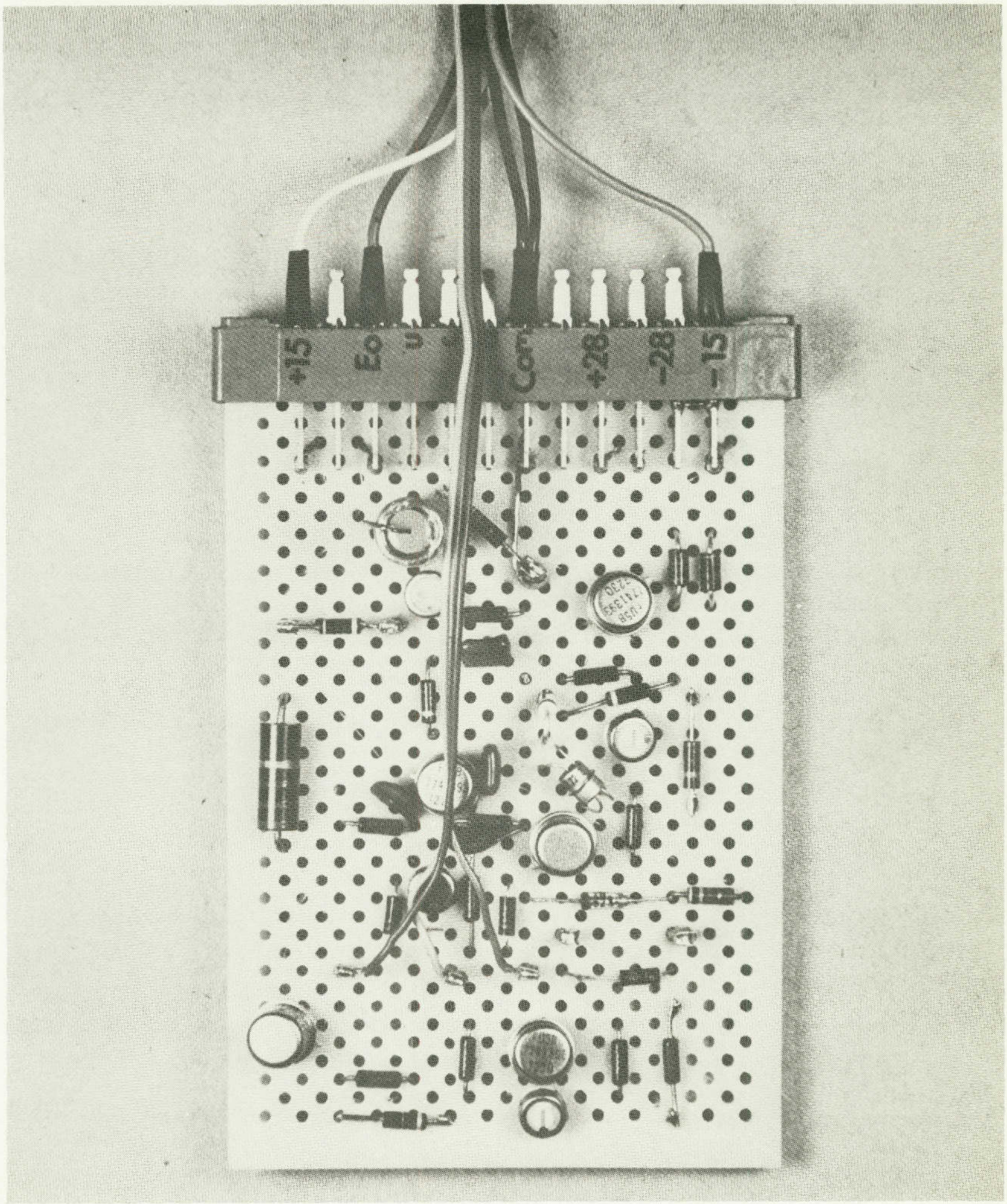
Transducer Mechanical Features (Task 5)

The Shuttle cabin holds 150 lb of oxygen and nitrogen when the cabin is pressurized to 14.7 psia. Oxygen gas is selected by the two-gas control at the start of cabin repressurization until a partial pressure of oxygen (PO_2) of 3.1 psia is achieved for a total of 35 lb of oxygen. Nitrogen gas is then selected by the two-gas control until 14.7 ±0.2 psia is achieved for a total of 115 lb of nitrogen.

The flow transducer is installed in the atmosphere repressurization line, therefore, it is required to flow 150 lb/hr of oxygen or nitrogen at a maximum allowable ΔP of 10 psi. The normal oxygen supply pressure is 100 psi and the pressure is 140 psi when nitrogen is flowing.

The oxygen/nitrogen flow transducer is designed to monitor flow rates in the range of 0 to 2 lb/hr. Only a fraction of the flow passes through the sensing element of the transducer, thus achieving fast response and minimum power consumption. The greater portion of this flow passes through a bypass which is thermodynamically similar to the sensor and gives a constant bypass ratio under all normal extremes of operation.

While the pressure drop of the flow transducer is low during normal operation, it may be excessive at a very high overflow; therefore, provision has been



F-17553

Figure 5-7. Breadboard Electronics Circuit for the O_2/N_2 Flow Transducer made for the addition of an external bypass relief valve. This valve would be closed at all flow rates in the normal sensing range, but would open when the pressure drop becomes excessive during high overflow conditions. Because of the rather large spread between normal maximum pressure drop and overflow pressure drop (1.0 to 10.0 psid), the pressure relief valve problem statement is considered to be rather simple.

The cartridge type relief valve is identical to a relief valve that has been used in the Gemini environmental control system. The housing for the relief valve is shown by dashed lines on outline drawing FMS 411. The inlet and outlet ports of the relief valve are sealed by static O-rings at the interface surface between the flow transducer and the relief valve.

As an alternate, a separate relief valve may be installed in the Shuttle ECS such that its flow is parallel to the flow transducer. This method, however, requires extra fittings to be used which results in more weight and volume and a greater possibility for leakage.

Stainless steel (type 316) is used for the flow passage, sensor, bypass, fittings and all other parts wetted by the working fluid. The signal conditioner case is aluminum, locally plated to receive the solder-mount connector. Interfaces between the case and cover and between the case and flow section are O-ring-sealed. The MS 33656 fittings are also O-ring-sealed in the flow housing. The mounting holes for the unit are a part of the cover; this part is inexpensive to replace if damaged by excessive handling.

Flow Transducer Package Outline (Task 6)

A layout drawing was prepared and reviewed jointly by AiResearch and Tylan personnel. The breadboard modules provided the basis for the general arrangement of the transducer. The component part sizes and interfacing techniques demonstrated on the breadboard were translated into a production design with emphasis on making the transducer easy to manufacture, assemble, inspect and test. The density of the electronic package was made similar to other recently developed electronic packages and is in conformance with the Shuttle guidelines. Several iterations were made to the layout drawing as a result of the design review culminating in the transducer outline drawing FMS 411. The overall size of the 2.0 lb/hr transducer, including a larger electrical connector and the addition of a BITE switch, is approximately the same size as the 1.0 lb/hr oxygen flow transducer used in the Apollo CSM.

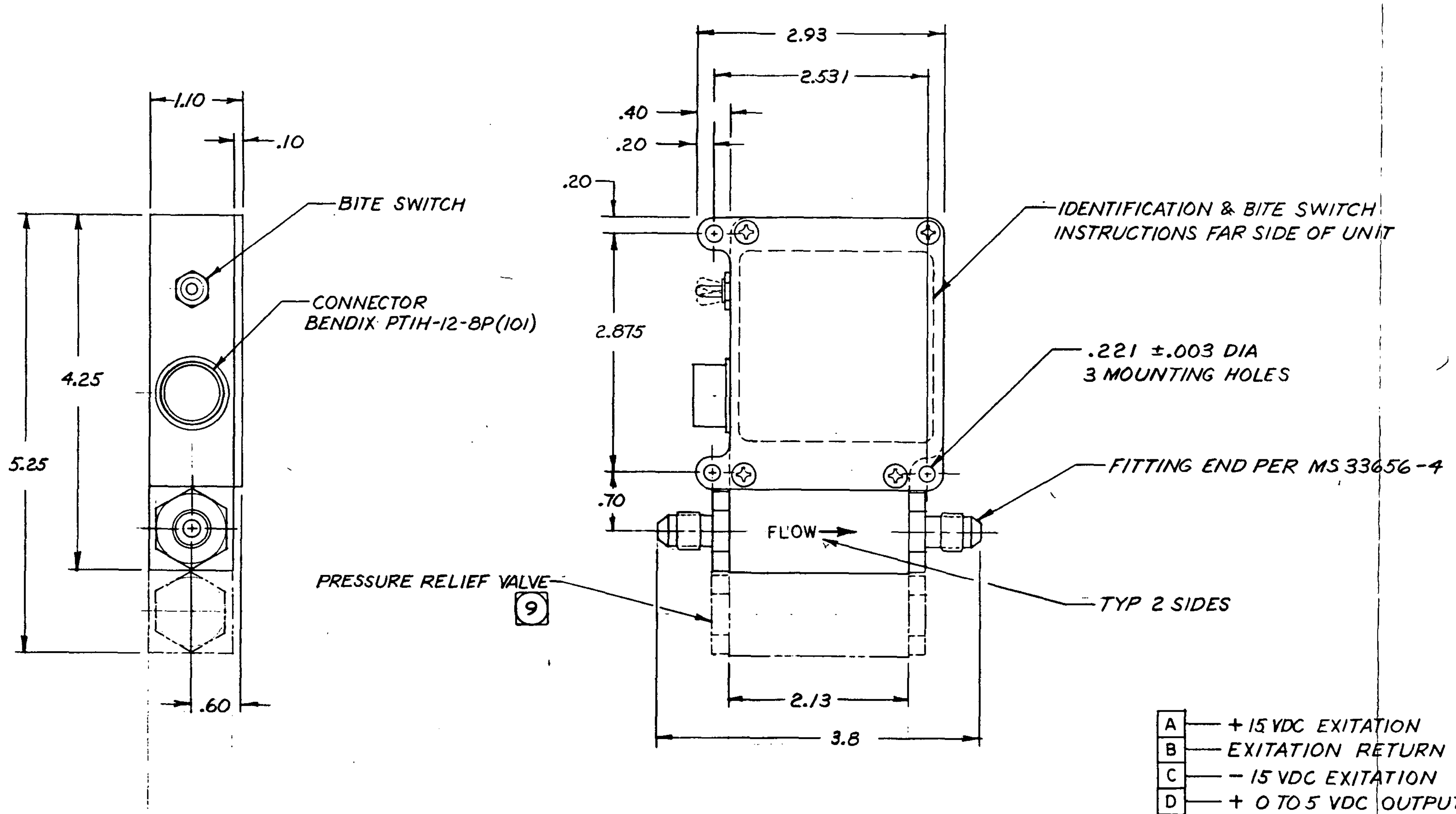
VERIFICATION TESTING (WBS 3.0, SOW 3.2.3)

The verification tests conducted on the oxygen/nitrogen flow transducer breadboard modules are described in this section under the heading Design Concept because of the iterations during analyses, design, breadboard fabrication and verification testing.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

CHG.	DESCRIPTION	DFTS.	APP.	DATE
A	TO NOTE 10 ADDED: (W/RELIEF VALVE)	[illegible]	[illegible]	1-1?-73



FMS-411 | A

- A — + 15 VDC EXITATION
- B — EXITATION RETURN
- C — − 15 VDC EXITATION
- D — + 0 TO 5 VDC OUTPUT
- E — − OUTPUT RETURN
- F — + } OVERFLOW WARNING SWITCH
- G — −
- H — CASE GROUND

SCHEMATIC

9 PRESSURE RELIEF VALVE IS NOT A PART OF FMS-411

8. OVERFLOW WARNING: SOLID STATE SWITCH CLOSURE AT 2.3 TO 2.8 LB/HR WITH INCREASING FLOW
7. ACCURACY: ±3% FULL SCALE FROM 40° TO 110°F, ±10% FULL SCALE AT -20°F & +165°F
6. OUTPUT SIGNAL: 0 TO 5 VDC OVER THE FLOW RANGE
5. MAXIMUM PRESSURE DROP: 1.0 PSI AT 2.0 LB/HR FLOW
   10.0 PSI AT 150 LB/HR FLOW (WITH RELIEF VALVE)
4. LINE PRESSURE: 80 TO 160 PSIG
3. TEMPERATURE RANGE: -20°F TO +165°F
2. FLOW RANGE: 0 TO 2.0 LB/HR
1. FLOW MEDIUM: GASEOUS OXYGEN OR NITROGEN

NOTES: UNLESS OTHERWISE SPECIFIED

ITEM NO.	QTY REQD	NOMENCLATURE OR DESCRIPTION	PART NO.	CODE IDENT	MATERIAL AND SPECIFICATION

LIST OF MATERIALS

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES ON DECIMALS: .X ± .1, .XX ± .03, .XXX ± .010
ON ANGLES ± 1/2°
BREAK SHARP EDGES .010 MAX.
SURFACE FINISH 63 RMS

NEXT ASSY FINAL
USED ON FINAL

SIGNATURES	DATES
DFT M.J. Hamilton	1-11-73
CHK [illegible]	1-15-73
APP [illegible]	1-15-73
APP	
DSGN ACTIVITY APP	
OTHER ACTIVITY APP	

TYLAN corporation TORRANCE, CALIF.

DWG TITLE: FLOWMETER

SIZE	CODE IDENT NO.	DWG NO.	REV
C	14260	FMS-411	A

SCALE: 1/1 WT: 16 OZ SHEET 1 OF 1

DESIGN CRITERIA (WBS 4.0, SOW 3.2.4)

The oxygen/nitrogen flow transducer is an outgrowth of the Apollo CSM oxygen flow transducer produced by Tylan Corporation (see Figure 5-1). The earlier unit was difficult to manufacture and troubled with stability problems locked in by an early design freeze, but otherwise showed a good reliability record on all of the Apollo lunar flights. About 70 units were made.

The proposed flowmeter is more closely related in sensor design to an industrial unit which has been in production for four years. This sensor is used on mass flowmeters, mass flow controllers and vaporizer controllers for many kinds of hard-to-handle gases. Tylan flow equipment using these sensors see daily workhorse production usage in the semiconductor industry throughout the free world. Approximately 2500 units are in use in the U.S., Japan and Europe, measuring and controlling the flow of hydrogen, oxygen, helium, silane, arsine, phosphine, anhydrous HCl gas and many other gases.

CONCLUSIONS

Based on the analyses and test results obtained during the development program, the feasibility of successfully producing a reliable oxygen/nitrogen flow transducer for space shuttle application has been established. The primary concerns of g-sensitivity, response, temperature stability and vibration survival appear to present no particular problems that cannot be solved by a sound electromechanical design.

The performance and design data of Table 5-1 summarize the characteristics of the oxygen/nitrogen flow transducer developed during this study program.

RECOMMENDATIONS FOR FUTURE WORK

The following is recommended for a continuing development of the oxygen/nitrogen flow transducer:

1. Design and fabrication of a prototype unit per the proposed outline drawing (FMS 411).

2. Circuit analysis (worst case stress and error).

3. Performance tests of the prototype including:

   (a) Calibration at $-20^{\circ}F$, $40^{\circ}F$, 75°, $110^{\circ}F$, $165^{\circ}F$

   (b) BITE functions

   (c) Power supply sensitivity

   (d) Attitude sensitivity

   (e) Dynamic response

   (f) Survival of incorrect connections

   (g) Vibration, operating

TABLE 5-I

PERFORMANCE AND DESIGN DATA

Input power	+15 vdc ±1 vdc, 25 ma max -15 vdc ±1 vdc, 25 ma max The circuit is protected so that the end product can withstand an inadvertent application of 32 vdc to any connector pins in any combination for a minimum period of one minute.
Flow range (oxygen or nitrogen)	0 to 2 lb/hr to be equivalent to 0-5 vdc The oxygen flow transducer installs in the SSV ECS in a line that may flow either oxygen or nitrogen depending on the level of the PO_2 in the cabin. The indicated flow when nitrogen is flowing will be different by no more than 1/2% because of the similar characteristics of nitrogen and oxygen. A spring-loaded, 3-position switch will check all of the circuitry between the plus and minus 15 vdc input and 0-5 vdc output. With the BITE switch activated and no oxygen flowing, the output of the transducer shall read 5 vdc, and with the switch in the normal position, the output shall read 0 vdc. Alternate actuation of the BITE switch tests the overflow warning.
Response time	6 seconds max (to 63% of final value following step change in flow rate)
Output signal	0 to 5 vdc linear over flow range
Output ripple	25 mv max
Output impedance	10 ohms max (5K min load)
Accuracy	±3% f.s., 40°F to 110°F ±10% f.s., -20°F to 165°F
Temperature range	-20°F to +165°F
High flow for switch point of panel warning light	2.3 to 2.8 lb/hr

TABLE 5-I (Continued)

Overflow switch rating	100 ma at 28 vdc A solid-state photo-isolator switch closes when the flow of oxygen or nitrogen exceeds "normal." The purpose of the switch is to illuminate a warning light on the pilot's panel in the event cabin or system leakage exceeds specified limits. The vehicle 28 vdc electrical power system shall be used for energizing the warning lamp. A second position on the BITE switch is incorporated for checking the photo-isolator circuit.
Maximum overflow requirement for cabin repressurization	*150 lb/hr *The SSV cabin holds 150 lb of oxygen and nitrogen when the cabin is pressurized to 14.7 psia. Oxygen gas is selected by the two gas control at the start of cabin repressurization until a partial pressure of oxygen (PO_2) of 3.1 psia is achieved for a total of 35 lb of oxygen. Nitrogen gas is then selected by the two-gas control unit 14.7 ±0.2 psia is achieved for a total of 115 lb of nitrogen.
Pressure range (supply)	80 to 160 psig
Pressure drop (max)	1.0 psid at 2.0 lb/hr 10.0 psid at 150 lb/hr*
Weight	16.0 oz (max) 24.0 oz (max* *With high-flow relief valve added
Electrical connector (6 pins plus 1 pin for case ground)	AiResearch Part No. 223-022-9016
EMI	Per MIL-STD-461 and 462
Environmental	Per AiResearch Document No. SC 633000
Envelope	See Drawing FMS 411

EXHIBIT 5A

OXYGEN FLOWMETER MODIFICATION STUDY
STATEMENT OF WORK

EXHIBIT 5A

OXYGEN FLOWMETER MODIFICATION STUDY
STATEMENT OF WORK

1. PUPROSE

1.1 OBJECTIVE

The objective of this statement of work (SOW) is to describe the effort required to modify an existing oxygen flowmeter design for space shuttle application.

1.2 END PRODUCT

The end product of this effort will be (a) test results, (b) a preliminary flowmeter package design, and (c) a final report.

1.3 BACKGROUND

The effort described in this SOW is in support of an environmental control system (ECS) transducer development study for NASA, Manned Spacecraft Center, under Contract No. NAS 9-12452. See AiResearch request for Quotation No. 1387-2, dated 15 June 1972 for further background information, Attachment 1. It seeks to determine the utility of an existing flowmeter, suitably modified for space shuttle application. See Tylan letter 2184 for further background on the flowmeter.

2. SCOPE

2.1 GENERAL

The contractor will provide the necessary resources to modify the oxygen flow transducer and perform the necessary tests and analyses per the technical requirements section of this SOW.

2.2 PROGRAM SCHEDULE

The contractor will comply with the schedule presented in Figure 1.

3. TECHNICAL REQUIREMENTS

3.1 GENERAL

The contractor will respond to the technical requirements described in this section.

3.2 SPECIFICATION DEVELOPMENT

3.2.1 Environmental

Typical spacecraft environmental system specifications are included as Attachments 2 and 3 to this SOW.

3.2.2 Configuration

Configuration specification including provisions for mounting and connections and size and weight will be determined jointly by AiResearch and the contractor.

Materials specification are per Attachments 2 and 3 for the sensor package and will be determined for the breadboard electronics package.

3.2.3 Interface

Interface considerations including power supply interconnections and computer and outputs connections to provide built-in-test capability will be determined by AiResearch and the contractor. Tylan will define and provide input-output parameters for normal and failure conditions for each of the functional blocks.

3.3 TRANSDUCER MODIFICATIONS AND TESTS

Modified sensors will be tested for g-sensitivity, temperature stability and response by the contractor. The breadboard signal conditioner will be used during these tests but need not be subjected to the transducer environment.

Modified sensors will be subjected to the launch vibration equipment level vibration specification per Figure 3 of Attachment 2 except that durations may be reduced.

3.4 PRELIMINARY PACKAGING DESIGN

The results of the preliminary packaging design will include drawings and descriptions of accessibility, sealing and space allocation. A layout drawing showing complete packaging will be provided up to but not including the power supply.

3.5 FINAL REPORT

A final report will be prepared by the contractor which includes the following items as a minimum.

3.5.1 Proposed Specifications

3.5.2 Outline Drawing

3.5.3 Results of Analyses

3.5.4 Results of Tests, Including Photographs

3.5.5 Conclusions

3.5.6 Recommendations for Future Work

4. COORDINATION MEETINGS

A minimum of three coordination meetings will be held between AiResearch and the contractor, as indicated on the program schedule. With the exception of the first meeting, each will include a detailed status report by the contractor regarding the current attainment of program objectives. Specific interested parties from AiResearch and NASA may witness tests, examine parts, review circuits, and otherwise technically monitor the proprietary portion of Tylan's effort which cannot be publicly revealed.

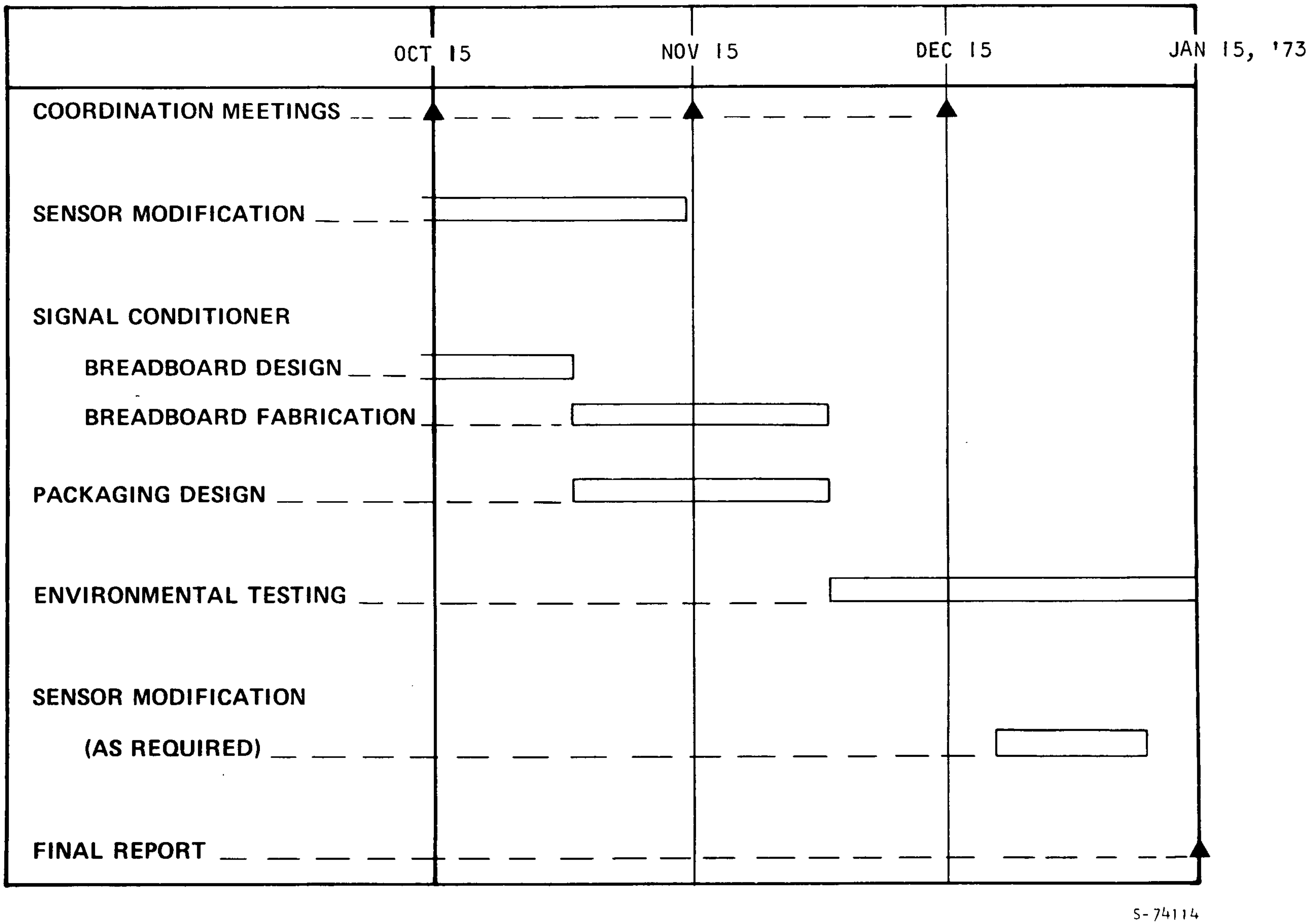


Figure 1. Program Schedule

EXHIBIT 5B

SENSOR TEST DATA SHEETS

TYLAN CORP.
DATA SHEET /
3046
Sensor Response and g-Sensitivity

Date 11-8-72
Part No. N/R
Report No. 1

Job No. 3046
Tested By Perry
Q.C. N/R

1. Sensor Configuration: TYPE B - BARE W/BEADED POLYSTYRENE COVER (DORVON-FR100) W/DOG HOUSE.

2. Current Thru Sensor, Eo= 5.00v (I_S): 12.8 ma

3. Risetime: 10 to 98% (.500 to 4.85v): 11 sec. To 63%(3.33v): 3 sec.

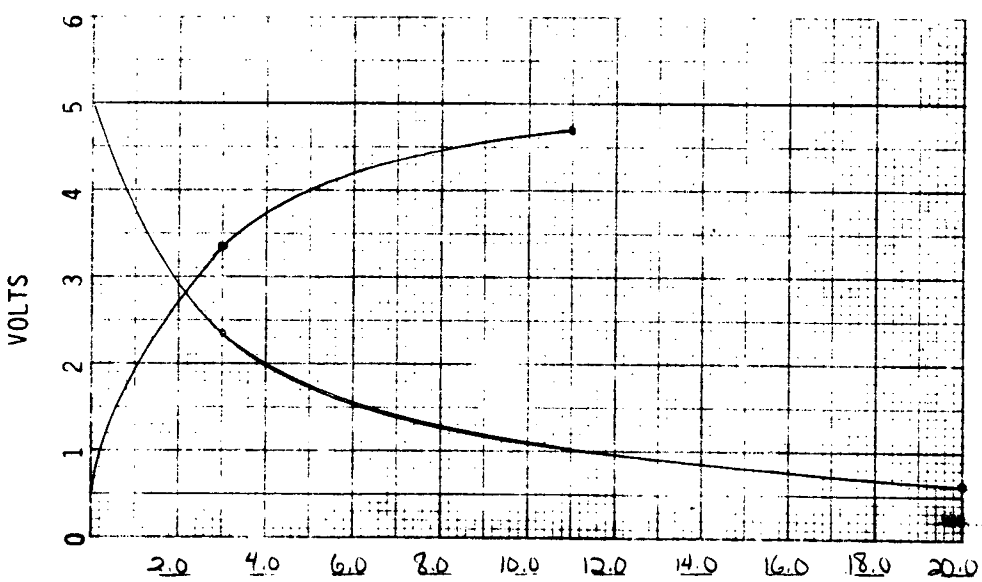
4. Falltime: 100 to 12% (5.00 to .600): 20 sec. to 63%(2.33v): 3 sec.

5. g- sensitivity, Eo= 4.99v (sensor Perpendicular to Horizon)

Pitch Axis:	Sensor 30° to Left of Perpendicular	4.86v	% -1.7
	Sensor 30° to Right of Perpendicular	5.09v	% +2.0
Roll Axis:	Sensor 30° to Left of Perpendicular	4.99v	% 0
(outlet side)	Sensor 30° to Right of Perpendicular	5.03	% +0.8

6. Resistance Values of:
R_{12} 750 Ω
R_1 20k
R_2 19.81K

7. Graph t_r and t_f



TYLAN CORP.
DATA SHEET 2
3046
Sensor Response and g-Sensitivity

Date 11-8-72
Part No. DP
Report No. 1

Job No. 3046
Tested By Pa...
Q.C. ...

1. Sensor Configuration: TYPE B - DIPPED IN POLYURETHANE FOAM. ...

2. Current Thru Sensor, Eo= 5.00v (I_S): 14.6 ma

3. Risetime: 10 to 98% (.500 to 4.85v): 15 sec. To 63%(3.33v): 3 sec.

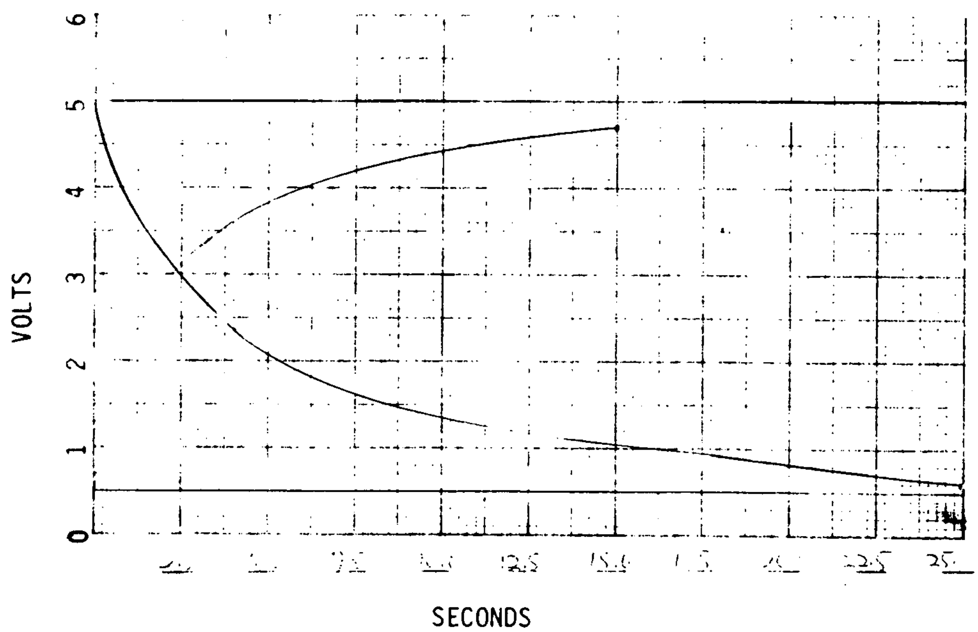
4. Falltime: 100 to 12% (5.00 to .600): 25 sec. to 63%(2.33v): 4 sec.

5. g- sensitivity, Eo= 4.99v (sensor Perpendicular to Horizon)

Pitch Axis:	Sensor 30° to Left of Perpendicular	4.59 v	% -8.0
	Sensor 30° to Right of Perpendicular	5.26 v	% +5.4
Roll Axis:	Sensor 30° to Left of Perpendicular	4.99 v	% 0
(outlet side)	Sensor 30° to Right of Perpendicular	5.06 v	% +1.4

6. Resistance Values of: R_{12} 630 Ω
R_1 20 K
R_2 19.73 K

7. Graph t_r and t_f



TYLAN CORP.
DATA SHEET 3
3046
Sensor Response and g-Sensitivity

Date 11-7-72 Job No. 3046
Part No. N/R Tested By Derry
Report No. 1 Q.C. N/R

1. Sensor Configuration: TYPE B BARE WITH BEADED POLYSTYRENE COVER W/DOG HOUSE

2. Current Thru Sensor, Eo= 5.00v (I_S): 12.9 ma.

3. Risetime: 10 to 98% (.500 to 4.85v): 10 sec. To 63%(3.33v): 3 sec.

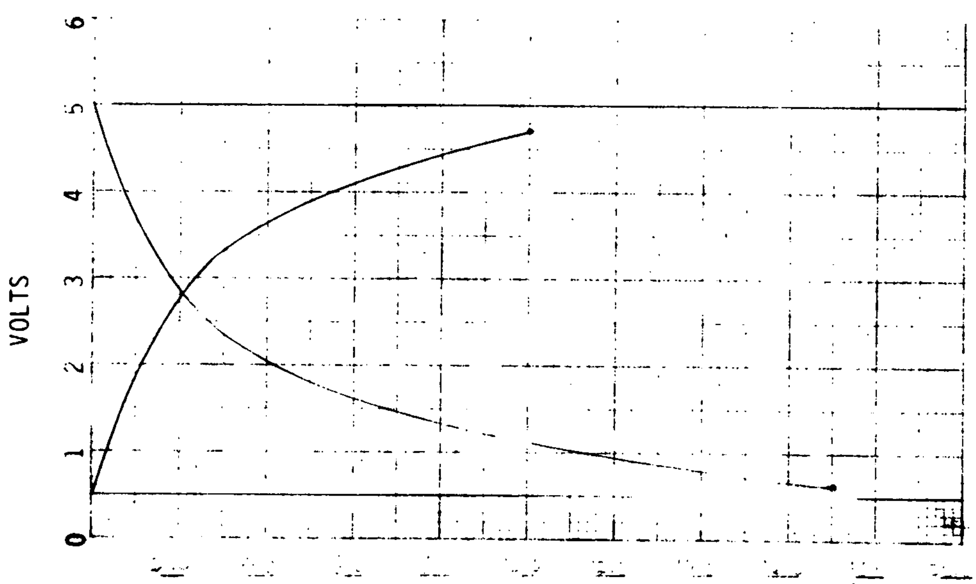
4. Falltime: 100 to 12% (5.00 to .600): 17 sec. to 63%(2.33v): 3 sec.

5. g- sensitivity, Eo= 4.99 (sensor Perpendicular to Horizon)

Pitch Axis: Sensor 30° to Left of Perpendicular 4.96 % -0.7
Sensor 30° to Right of Perpendicular 5.03 % +0.3
Roll Axis: Sensor 30° to Left of Perpendicular 4.99 % 0
(outlet side) Sensor 30° to Right of Perpendicular 4.99 % 0

6. Resistance Values of: R_{12}
R_1
R_2 195 K

7. Graph t_r and t_f



TYLAN CORP.
DATA SHEET 4
3046
Sensor Response and g-Sensitivity

Date 11-8-72
Part No. N/R
Report No. 1

Job No. 3046
Tested By Perry
Q.C. N/R

1. Sensor Configuration: TYPE B - H TAPE COVERING THE SENSOR. W/DOGHOUSE.

2. Current Thru Sensor, Eo= 5.00v (I_S): 14.9 ma.

3. Risetime: 10 to 98% (.500 to 4.85v): 13 sec. To 63%(3.33v): 3 sec.

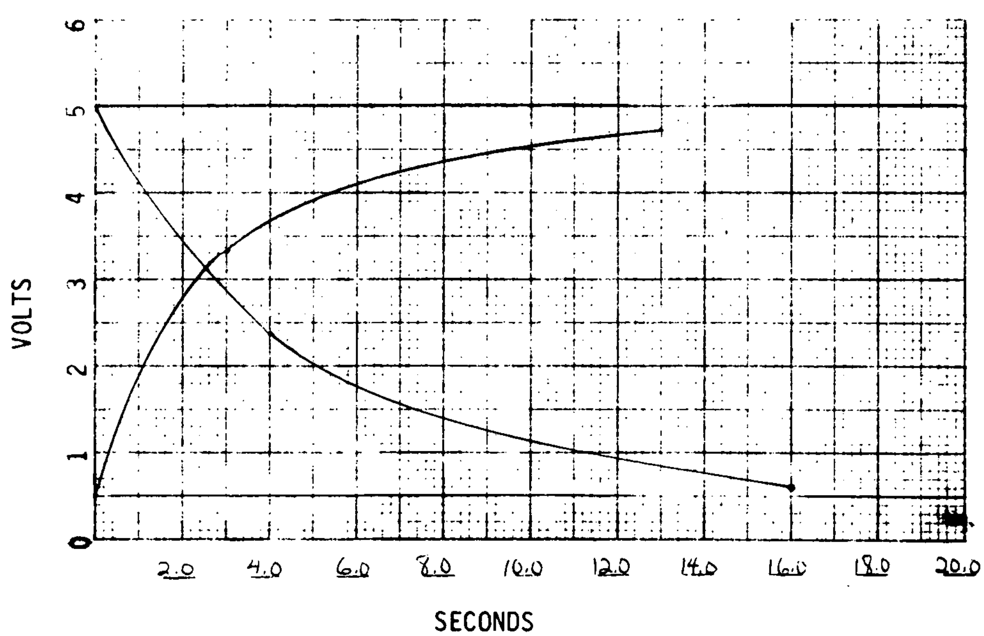
4. Falltime: 100 to 12% (5.00 to .600): 16 sec. to 63%(2.33v): 4 sec.

5. g- sensitivity, Eo= 4.99 (sensor Perpendicular to Horizon)

Pitch Axis:	Sensor 30° to Left of Perpendicular	4.60	%	-7.9
	Sensor 30° to Right of Perpendicular	5.40	%	+8.2
Roll Axis:	Sensor 30° to Left of Perpendicular	4.98	%	-0.3
(outlet side)	Sensor 30° to Right of Perpendicular	5.09	%	+2.0

6. Resistance Values of:
R_{12} 630
R_1 20K
R_2 19.81K

7. Graph t_r and t_f



TYLAN CORP.
DATA SHEET 5
3046
Sensor Response and g-Sensitivity

Date 11-8-72
Part No. N/R
Report No. 1

Job No. 3046
Tested By Perry
Q.C. N/R

1. Sensor Configuration: TYPE A, BARE WITH POLYURETHANE FOAM SLIGHTLY BELOW THE SENSOR. W/ DOGHOUSE

2. Current Thru Sensor, Eo= 5.00v (I_S): 14.4 ma.

3. Risetime: 10 to 98% (.500 to 4.85v): 15 sec. To 63%(3.33v): 3 sec.

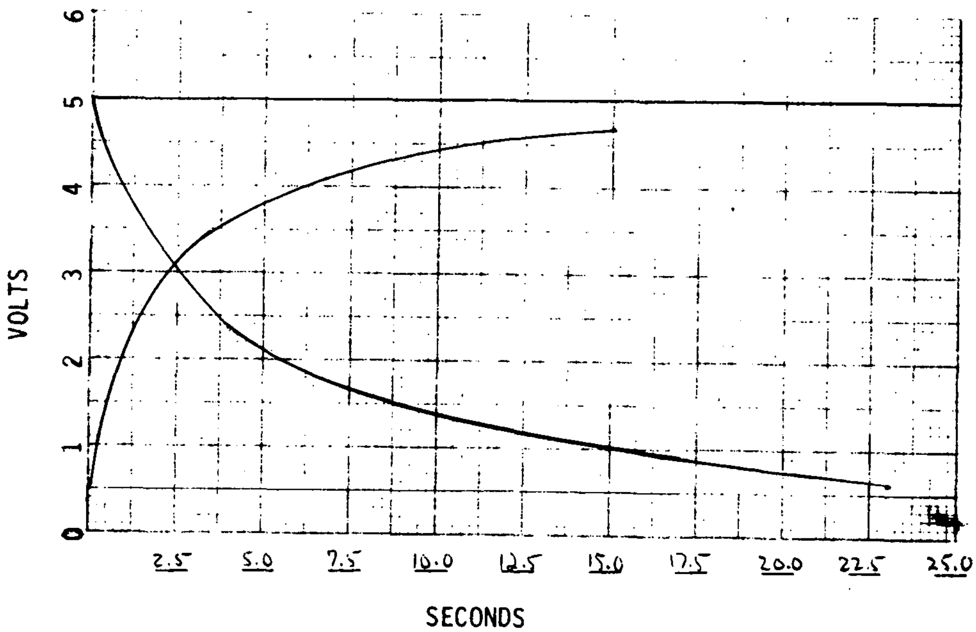
4. Falltime: 100 to 12% (5.00 to .600): 23 sec. to 63%(2.33v): 4 sec.

5. g- sensitivity, Eo= 5.13 v (sensor Perpendicular to Horizon)

Pitch Axis:	Sensor 30° to Left of Perpendicular	4.55v	% -11.4
	Sensor 30° to Right of Perpendicular	5.56v	% + 8.3
Roll Axis:	Sensor 30° to Left of Perpendicular	5.08v	% -1.0
(outlet side)	Sensor 30° to Right of Perpendicular	5.15v	% +0.3

6. Resistance Values of:
R_{12} 545 Ω
R_1 20K
R_2 20K

7. Graph t_r and t_f



TYLAN CORP.
DATA SHEET 6
3046
Sensor Response and g-Sensitivity

Date 11-8-72 | Job No. 3046
Part No. N/R | Tested By Perry
Report No. 1 | Q.C. N/R

1. Sensor Configuration: TYPE A - DIPPED IN POLYURETHANE FOAM. W/ DOG HOUSE

2. Current Thru Sensor, Eo= 5.00v (I_S): 15.6 ma.

3. Risetime: 10 to 98% (.500 to 4.85v): 40 sec. To 63%(3.33v): 8 sec.

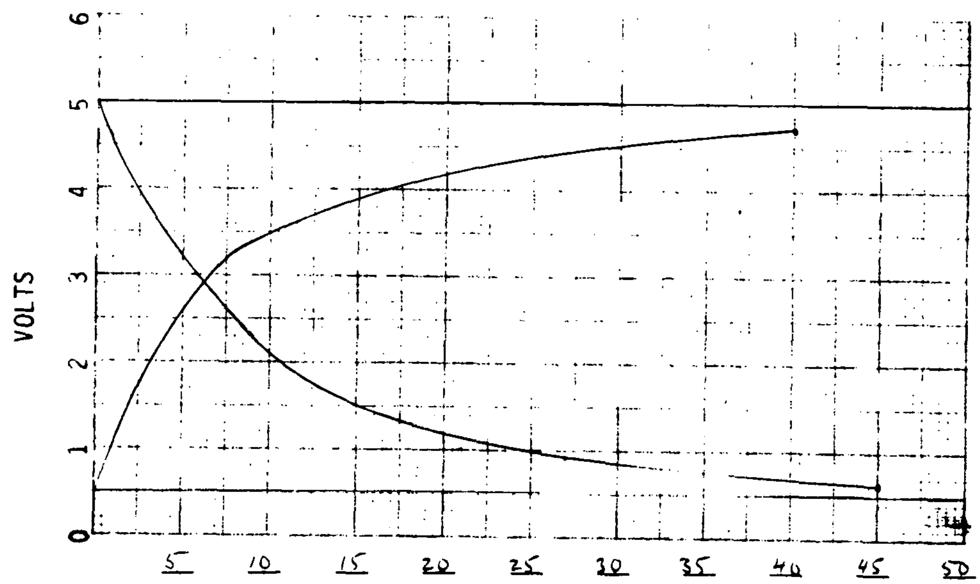
4. Falltime: 100 to 12% (5.00 to .600): 45 sec to 63%(2.33v): 9 sec.

5. g- sensitivity, Eo= 5.00v (sensor Perpendicular to Horizon)

Pitch Axis: Sensor 30° to Left of Perpendicular 4.65v % -7.0
Sensor 30° to Right of Perpendicular 5.26v % +5.2
Roll Axis: Sensor 30° to Left of Perpendicular 4.97v % -0.6
(outlet side) Sensor 30° to Right of Perpendicular 5.03v % +0.6

6. Resistance Values of: R_{12} 554Ω
R_1 19.87K
R_2 20K

7. Graph t_r and t_f



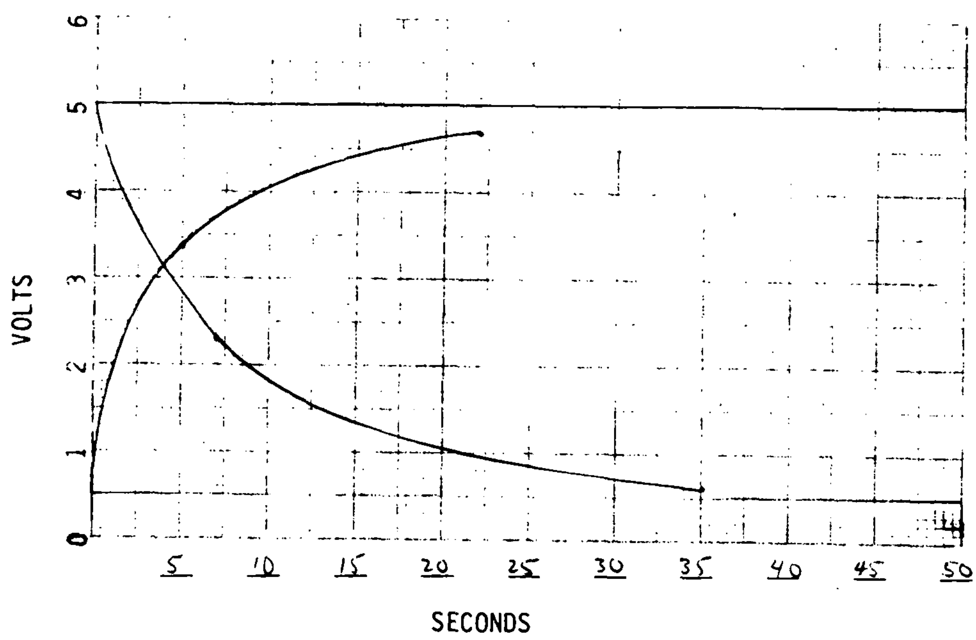
TYLAN CORP.
DATA SHEET 7
3046
Sensor Response and g-Sensitivity

Date 11-8-72	Job No. 3046
Part No. N/R	Tested By Perry
Report No. 1	Q.C. N/R

1. Sensor Configuration: TYPE A - HTAPE COVERING SENSOR WITH BEADED POLYSTYRENE COVER. W/DOGHOUSE
2. Current Thru Sensor, Eo= 5.00v (I_S): 13.4 ma.
3. Risetime: 10 to 98% (.500 to 4.85v): 22 sec To 63%(3.33v): 5 sec.
4. Falltime: 100 to 12% (5.00 to .600): 35 sec. to 63%(2.33v): 7 sec.
5. g- sensitivity, Eo= 5.14v (sensor Perpendicular to Horizon)

Pitch Axis:	Sensor 30° to Left of Perpendicular	4.85v	% -8.5
	Sensor 30° to Right of Perpendicular	5.30v	% +3.1
Roll Axis:	Sensor 30° to Left of Perpendicular	5.11v	% -1.0
(outlet side)	Sensor 30° to Right of Perpendicular	5.16v	% +0.3

6. Resistance Values of: R_{12} 545 Ω
   R_1 20K
   R_2 19.81K
7. Graph t_r and t_f



TYLAN CORP.
DATA SHEET 8
3046
Sensor Response and g-Sensitivity

Date 11-8-72
Part No. N/R
Report No. 1

Job No. 3046
Tested By PERRY
Q.C. N/R

1. Sensor Configuration: TYPE A BARE w/ BEADED POLYSTYRENE COVER w/ DOGHOUSE

2. Current Thru Sensor, Eo= 5.00v (I_s): 13.3 ma

3. Risetime: 10 to 98% (.500 to 4.85v): 17 sec To 63%(3.33v): 4 sec

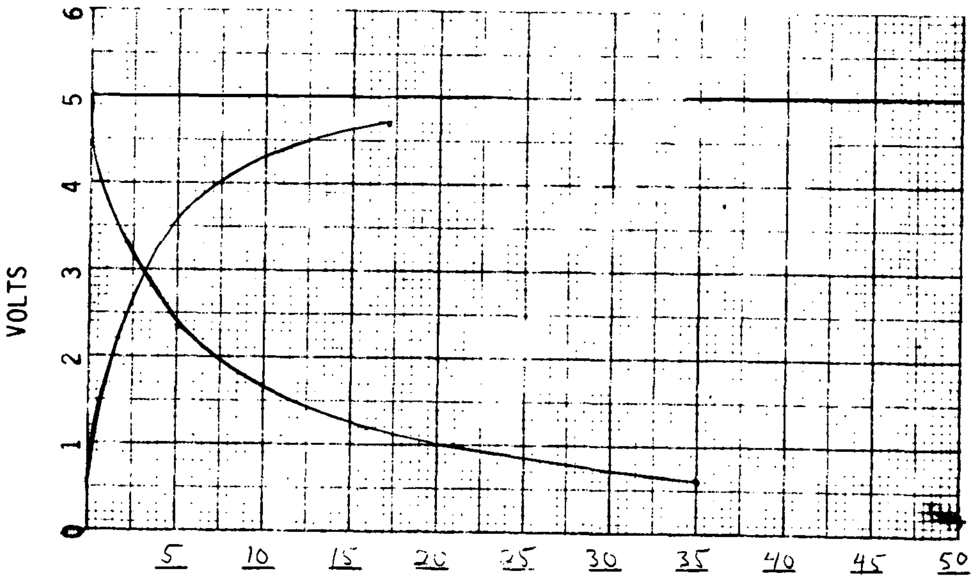
4. Falltime: 100 to 12% (5.00 to .600): 35 sec to 63%(2.33v): 5 sec

5. g-sensitivity, Eo= 5.07 (sensor Perpendicular to Horizon)

			%
Pitch Axis:	Sensor 30° to Left of Perpendicular	5.04v	− .6
	Sensor 30° to Right of Perpendicular	5.10v	+ .5
Roll Axis:	Sensor 30° to Left of Perpendicular	5.07	0
(outlet side)	Sensor 30° to Right of Perpendicular	5.07	0

6. Resistance Values of:
R_{12} 700Ω
R_1 19.8 K
R_2 20.0 K

7. Graph t_r and t_f



TYLAN CORP.
DATA SHEET 9
3046
Sensor Response and g-Sensitivity

Date 11-8-72
Part No. N/R
Report No. 1

Job No. 3046
Tested By Perry
Q.C. N/R

1. Sensor Configuration: TYPE A. POTTED WITH POLYURETHANE FOAM-NO Doghouse

2. Current Thru Sensor, Eo= 5.00v (I_s): 15.6 ma

3. Risetime: 10 to 98% (.500 to 4.85v): 135 sec To 63%(3.33v): 10 sec.

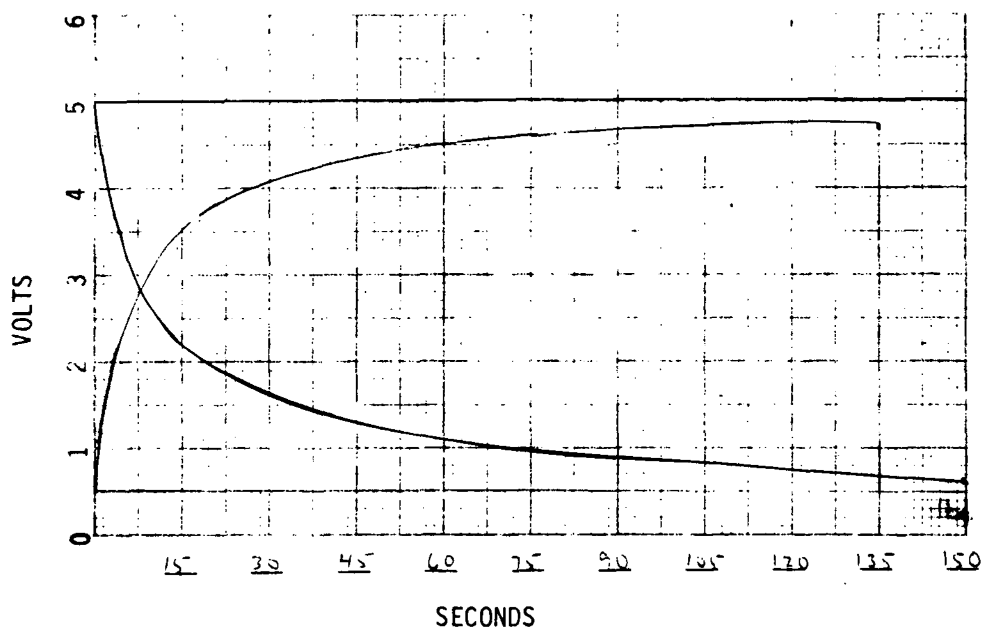
4. Falltime: 100 to 12% (5.00 to .600): 150 sec. to 63%(2.33v): 12 sec.

5. g- sensitivity, Eo= 4.99v (sensor Perpendicular to Horizon)

Pitch Axis: Sensor 30° to Left of Perpendicular 4.99v % 0
Sensor 30° to Right of Perpendicular 4.99v % 0
Roll Axis: Sensor 30° to Left of Perpendicular 4.99v % 0
(outlet side) Sensor 30° to Right of Perpendicular 4.99v % 0

6. Resistance Values of: R_{12} 554Ω
R_1 19.91K
R_2 200K

7. Graph t_r and t_f



TYLAN CORP.
DATA SHEET 10
3046
Sensor Response and g-Sensitivity

Date 11-8-72
Part No. N/R
Report No. 1

Job No. 3046
Tested By Perry
Q.C. N/R

1. Sensor Configuration: TYPE A - POLYURETHANE DIPPED WITH POLYSTYRENE COVER. W/DOGHOUSE

2. Current Thru Sensor, Eo= 5.00v (I_s): 15.3 ma

3. Risetime: 10 to 98% (.500 to 4.85v): 45 sec. To 63%(3.33v): 7 sec.

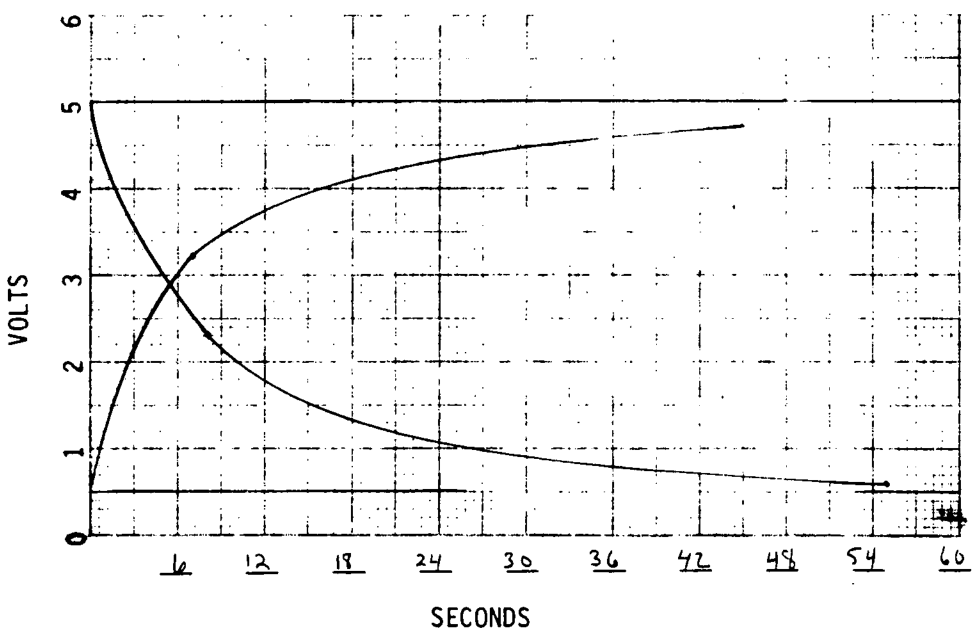
4. Falltime: 100 to 12% (5.00 to .600): 55 sec. to 63%(2.33v): 8 sec.

5. g- sensitivity, Eo= 5.00 v (sensor Perpendicular to Horizon)

Pitch Axis: Sensor 30° to Left of Perpendicular 4.61 v % -7.8
Sensor 30° to Right of Perpendicular 5.24 v % +4.8
Roll Axis: Sensor 30° to Left of Perpendicular 4.98 v % -0.4
(outlet side) Sensor 30° to Right of Perpendicular 5.02 v % +0.4

6. Resistance Values of: R_{12} 554 Ω
R_1 20K
R_2 20K

7. Graph t_r and t_f



TYLAN CORP.
DATA SHEET //
3046
Sensor Response and g-Sensitivity

Date 11-7-72
Part No. N/R
Report No. 1

Job No. 3046
Tested By PERRY
Q.C. N/R

1. Sensor Configuration: TYPE A-BAKE WITH Doghouse

2. Current Thru Sensor, Eo= 5.00v (I_S): 12.6 ma

3. Risetime: 10 to 98% (.500 to 4.85v): 7 sec. To 63%(3.33v): 3 sec.

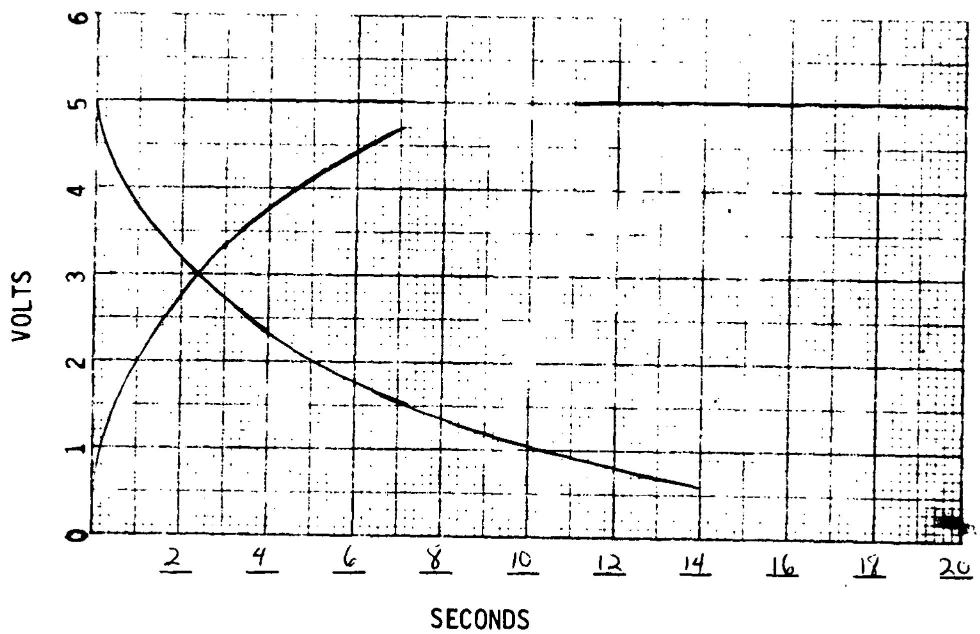
4. Falltime: 100 to 12% (5.00 to .600): 14 sec to 63%(2.33v): 4 sec.

5. g- sensitivity, Eo= 5.07v (sensor Perpendicular to Horizon)

Pitch Axis:	Sensor 30° to Left of Perpendicular	4.36v	% -14
	Sensor 30° to Right of Perpendicular	5.66	% +11.6
Roll Axis:	Sensor 30° to Left of Perpendicular	4.98	% -1.8
(outlet side)	Sensor 30° to Right of Perpendicular	5.13	% +1.5%

6. Resistance Values of: R_{12} 700 Ω
R_1 20K
R_2 20K

7. Graph t_r and t_f



TYLAN CORP.
DATA SHEET 12
3046
Sensor Response and g-Sensitivity

Date 11-8-72 Job No. 3046
Part No. N/R Tested By Perry
Report No. 1 Q.C. N/R

1. Sensor Configuration: TYPE A - WITH HTAPE COVERING THE SENSOR. W/DOGHOUSE.

2. Current Thru Sensor, Eo= 5.00v (I_S): 13.5ma

3. Risetime: 10 to 98% (.500 to 4.85v): 15 sec. To 63%(3.33v): 4 sec.

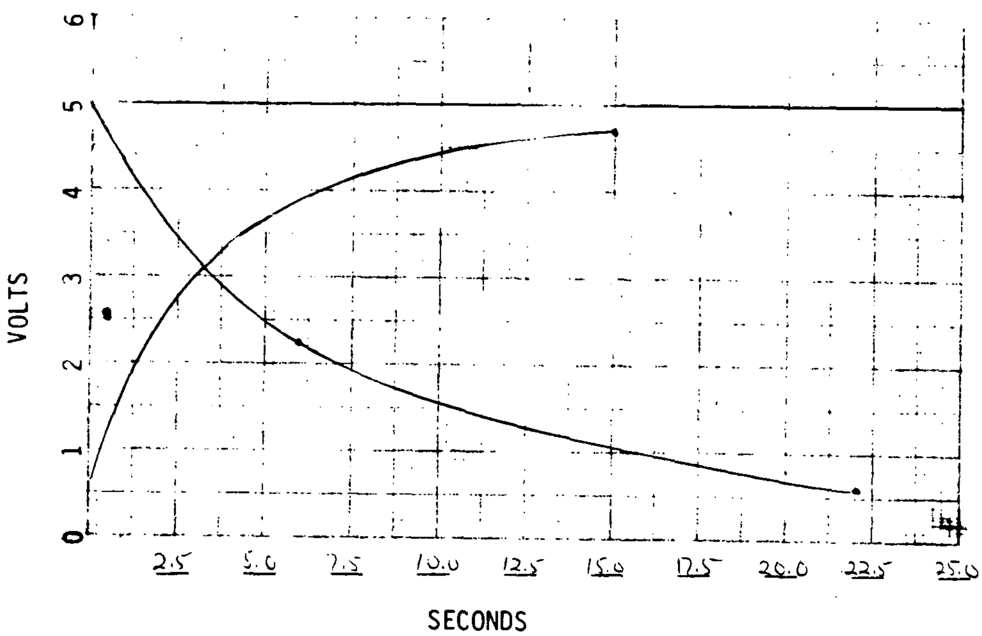
4. Falltime: 100 to 12% (5.00 to .600): 22 sec. to 63%(2.33v): 6 sec.

5. g- sensitivity, Eo= 5.07 (sensor Perpendicular to Horizon)

Pitch Axis: Sensor 30° to Left of Perpendicular 4.60 % -9.3
Sensor 30° to Right of Perpendicular 5.60 % +10.4
Roll Axis: Sensor 30° to Left of Perpendicular 5.04 % -0.6
(outlet side) Sensor 30° to Right of Perpendicular 5.23 % +3.1

6. Resistance Values of: R_{12} 545Ω
R_1 20K
R_2 19.87K

7. Graph t_r and t_f



TYLAN CORP.
DATA SHEET 13
3046
Sensor Response and g-Sensitivity

Date 11-8-72
Part No. N/R
Report No. 1

Job No. 3046
Tested By Perry
Q.C. N/R

1. Sensor Configuration: TYPE B - UTAPE WITH POLYSTYRENE COVER W/DOGHOUSE

2. Current Thru Sensor, Eo= 5.00v (I_s): 15.0 ma.

3. Risetime: 10 to 98% (.500 to 4.85v): 17 sec. To 63%(3.33v): 4 sec.

4. Falltime: 100 to 12% (5.00 to .600): 30 sec. to 63%(2.33v): 4 sec.

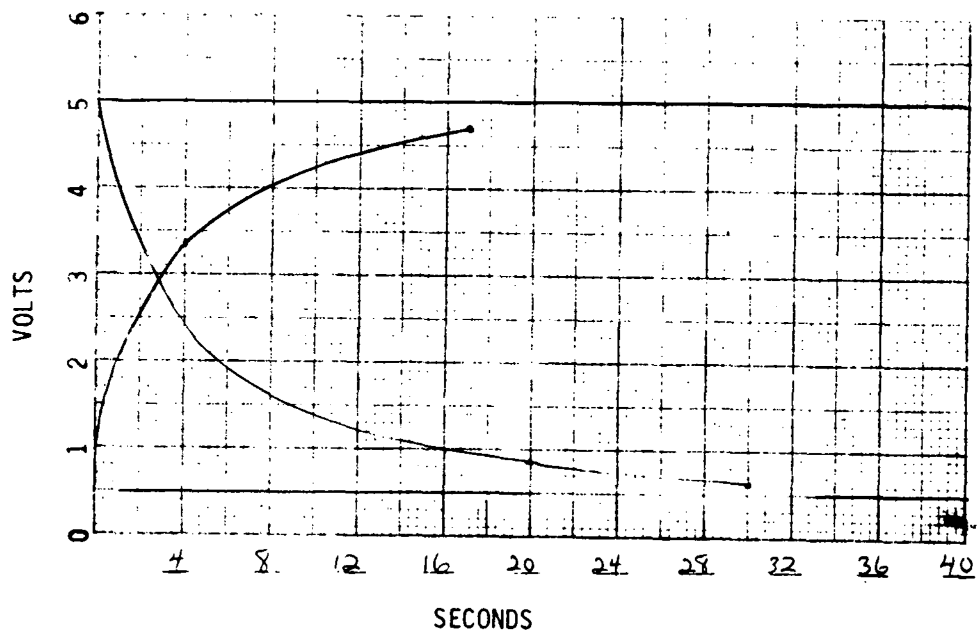
5. g- sensitivity, Eo= 5.02v (sensor Perpendicular to Horizon)

Pitch Axis:	Sensor 30° to Left of Perpendicular	5.00v	% -0.4
	Sensor 30° to Right of Perpendicular	5.00v	% -0.4
Roll Axis:	Sensor 30° to Left of Perpendicular	5.02v	% 0
(outlet side)	Sensor 30° to Right of Perpendicular	5.02v	% 0

6. Resistance Values of:

R_{12} 630Ω
R_1 20K
R_2 19.81K

7. Graph t_r and t_f



TYLAN CORP.
DATA SHEET 14
3046
Sensor Response and g-Sensitivity

Date 11-8-72 | Job No. 3046
Part No. N/R | Tested By Perry
Report No. 1 | Q.C. N/R

1. Sensor Configuration: TYPE B - BARE W/DOGHOUSE

2. Current Thru Sensor, Eo= 5.00v (I_S): 12.8 ma.

3. Risetime: 10 to 98% (.500 to 4.85v): 6 sec. To 63%(3.33v): 3 sec.

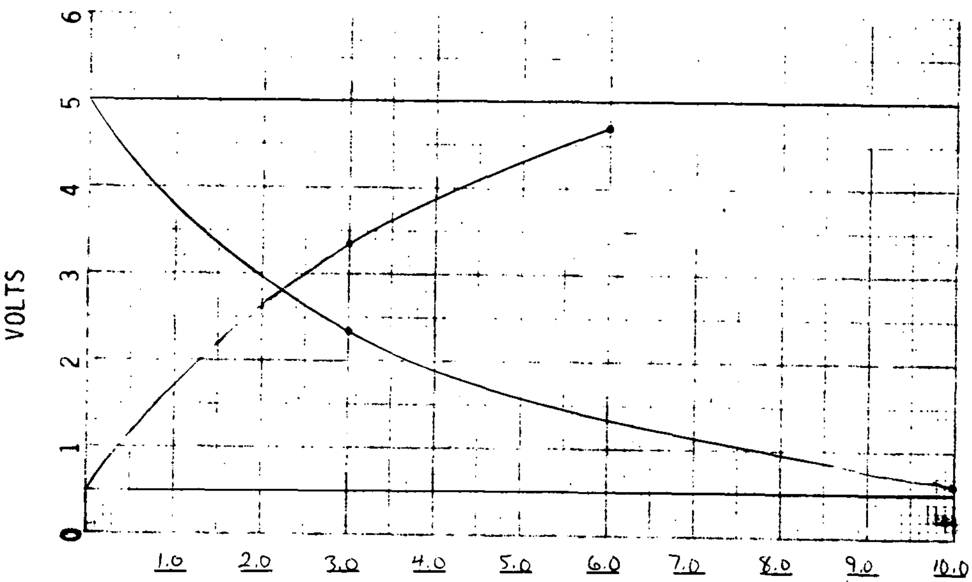
4. Falltime: 100 to 12% (5.00 to .600): 10 sec. to 63%(2.33v): 3 sec.

5. g- sensitivity, Eo= 4.99v (sensor Perpendicular to Horizon)

Pitch Axis: Sensor 30° to Left of Perpendicular 4.91 % -1.7
Sensor 30° to Right of Perpendicular 5.44 % +9.0
Roll Axis: Sensor 30° to Left of Perpendicular 4.91 % -1.7
(outlet side) Sensor 30° to Right of Perpendicular 5.01 % +0.4

6. Resistance Values of: R_{12} 687Ω
R_1 20K
R_2 19.81K

7. Graph t_r and t_f



TYLAN CORP.
DATA SHEET 15
3046
Sensor Response and g-Sensitivity

Date 11-8-72
Part No. N/R
Report No. 1

Job No. 3046
Tested By Perry
Q.C. N/R

1. Sensor Configuration: TYPE B - DIPPED IN POLYURETHANE FOAM WITH A POLYSTYRENE COVER. W/DOGHOUSE

2. Current Thru Sensor, Eo= 5.00v (I_S): 14.7 ma.

3. Risetime: 10 to 98% (.500 to 4.85v): 20 To 63%(3.33v): 4

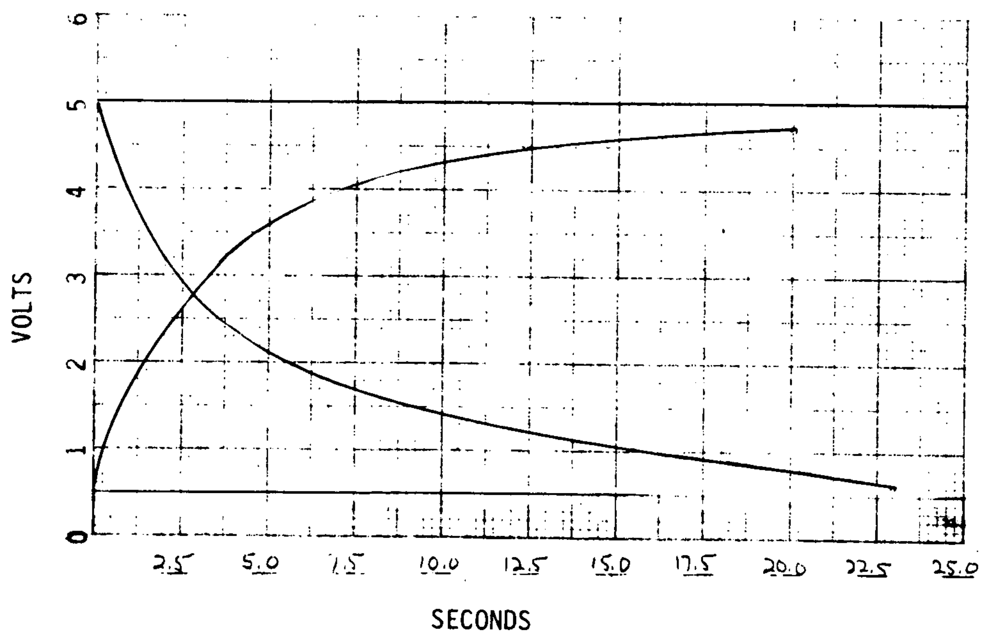
4. Falltime: 100 to 12% (5.00 to .600): 23 to 63%(2.33v): 4

5. g- sensitivity, Eo= 4.98v (sensor Perpendicular to Horizon)

Pitch Axis:	Sensor 30° to Left of Perpendicular	4.60	% -7.7
	Sensor 30° to Right of Perpendicular	5.19	% +4.2
Roll Axis:	Sensor 30° to Left of Perpendicular	4.99	% -0.2
(outlet side)	Sensor 30° to Right of Perpendicular	5.07	% +1.8

6. Resistance Values of:
R_{12} 630
R_1 20K
R_2 19.73K

7. Graph t_r and t_f



TYLAN CORP.
DATA SHEET 16
3046
Sensor Response and g-Sensitivity

Date 11-9-72
Part No. N/R
Report No.

Job No. 3046
Tested By Perry
Q.C. N/R

1. Sensor Configuration: TYPE B - Neat Felt Insulation WE 1200-A - Covered with Polystyrene. W/ Doghouse

2. Current Thru Sensor, Eo= 5.00v (I_s): 70 cv. 13.4 ma

3. Risetime: 10 to 98% (.500 to 4.85v): 24 sec. To 63%(3.33v): 4

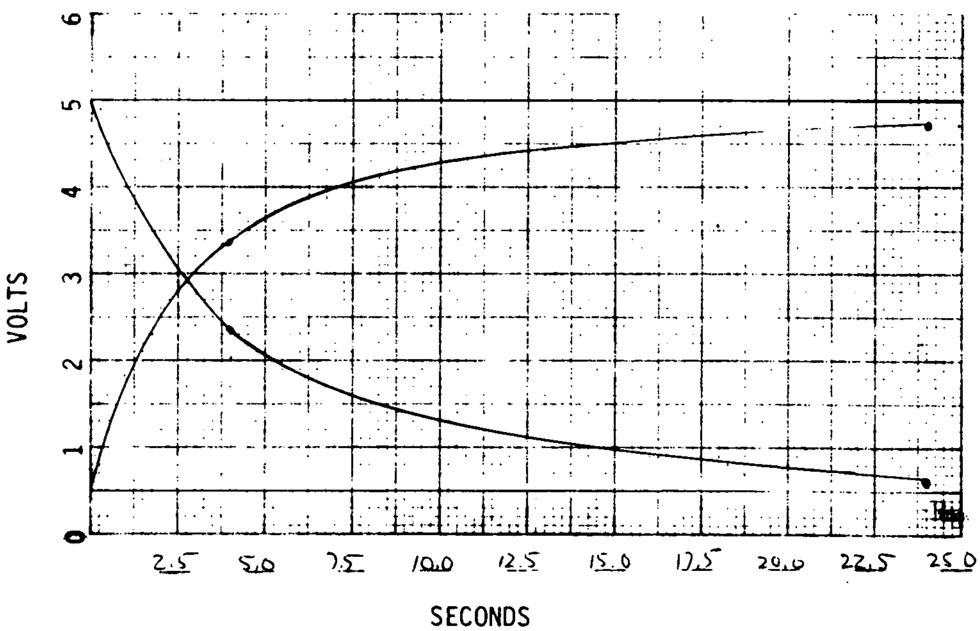
4. Falltime: 100 to 12% (5.00 to .600): 24 sec. to 63%(2.33v): 4

5. g- sensitivity, Eo= 5.00 (sensor Perpendicular to Horizon)

Pitch Axis: Sensor 30° to Left of Perpendicular 4.99 %
Sensor 30° to Right of Perpendicular 4.99 %
Roll Axis: Sensor 30° to Left of Perpendicular 4.99 %
(outlet side) Sensor 30° to Right of Perpendicular 4.99 %

6. Resistance Values of: R_{12}
R_1
R_2

7. Graph t_r and t_f



TYLAN CORP.
DATA SHEET 17
3046
Sensor Response and g-Sensitivity

Date 11-9-72
Part No. N/R
Report No. 1

Job No. 3046
Tested By PERRY
Q.C. N/R

1. Sensor Configuration: TYPE B - HEAT FELT INSULATION - HELD IN PLACE BY H-TAPE AROUND THE SIDES AND ACROSS THE TOP. W/ Doghouse.

2. Current Thru Sensor, Eo= 5.00v (I_S): 2.31 12.1 ma.

3. Risetime: 10 to 98% (.500 to 4.85v): 22 sec To 63%(3.33v): 3

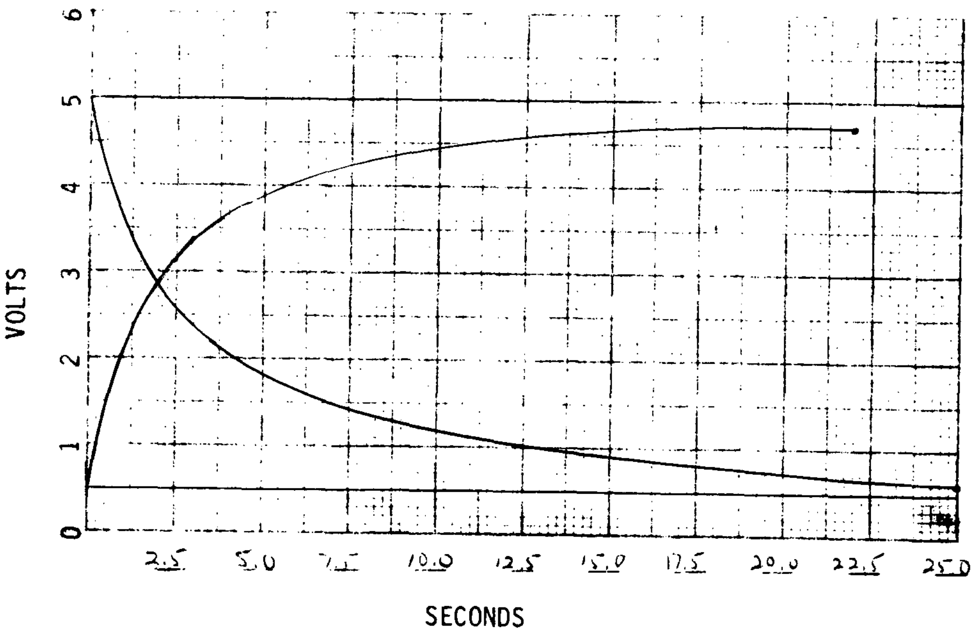
4. Falltime: 100 to 12% (5.00 to .600): 25 sec. to 63%(2.33v): 3

5. g- sensitivity, Eo= 4.98 (sensor Perpendicular to Horizon)

Pitch Axis:	Sensor 30° to Left of Perpendicular	4.93	% −1.0%
	Sensor 30° to Right of Perpendicular	4.99	% +0.2%
Roll Axis:	Sensor 30° to Left of Perpendicular	4.97	% −0.2%
(outlet side)	Sensor 30° to Right of Perpendicular	4.97	% +0.2%

6. Resistance Values of:
R_{12} 657Ω
R_1 20K
R_2 20K

7. Graph t_r and t_f



TYLAN CORP.
DATA SHEET NO. 1F
3046
Sensor Response and g-Sensitivity

Date Jan 4, 1973
Part No. EMS-911 Prototype
Report No. R-3046-1

Job No. 3046
Tested By R. F. Blair
Q.C. ____

1. Sensor Configuration: Final - Type B taped between 1/8" blocks of beaded Polystyrene foam, enclosed in metal can

2. Current Thru Sensor, Eo= 5.00v (I_S): 10.0 ma

3. Risetime: 10 to 98% (.500 to 4.85v): 20 sec To 63%(3.33v): 3.0 sec

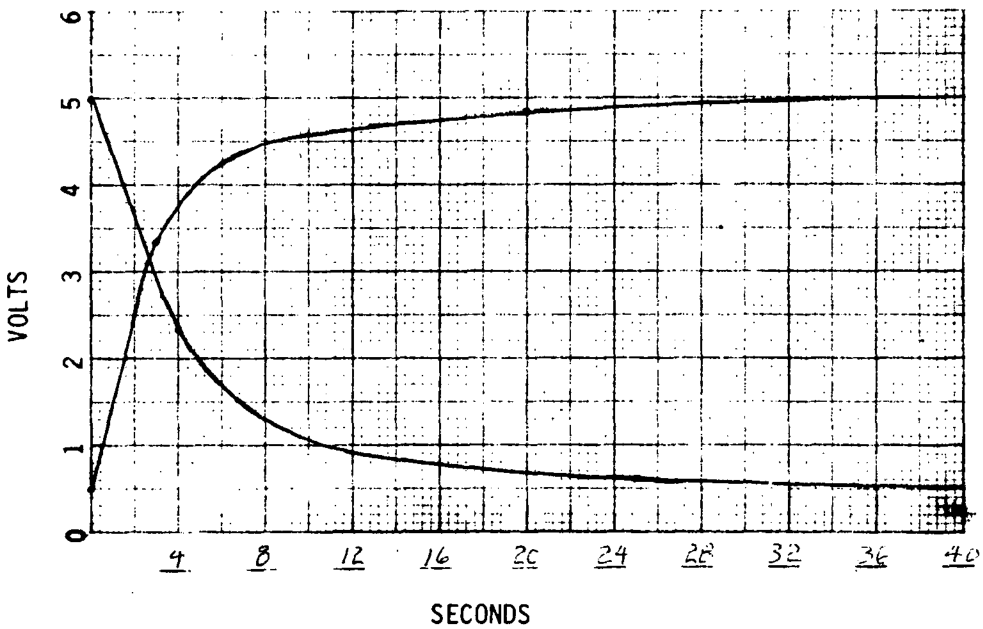
4. Falltime: 100 to 12% (5.00 to .600): 25 sec to 63%(2.33v): 4.0 sec

5. g- sensitivity, Eo= 5.00 (sensor Perpendicular to Horizon)

Pitch Axis:	Sensor 30° to Left of Perpendicular	5.01	%	+0.2
	Sensor 30° to Right of Perpendicular	4.99	%	-0.2
Roll Axis:	Sensor 30° to Left of Perpendicular	5.00	%	0
(outlet side)	Sensor ~~30°~~ 90° to Right of Perpendicular	5.00	%	0

6. Resistance Values of:
R_{12} 649 // 13K = 620 Ω
R_1 20.0K
R_2 19.8K

7. Graph t_r and t_f Bypass installed to give ω = 1.0 lb/hr @ E_0 = 5.0 VDC



Tylan CORPORATION

DATA SHEET
No. 2F

Specimen: Flow Sensor
Date: Dec 16, 1972
Part No.: FMS-411 Prototype
Serial No.:

Job No.: 3046
Report No.: R-3046-1
Specimen Temp.: 65°F
Amb. Temp.: 65°F

Test Title: Linearity & Supply Voltage Sensitivity

NO.	$\dot{\omega}$ lb/hr O_2	+15.0 / −15.0	+14.0 / −15.0	+16.0 / −15.0	+15.0 / −14.0	E_o − +15.0 / −16.0	VDC ← $+E_S$ / ← $-E_S$	VDC / VDC				
		1	2	3	4	5	6	7	8	9	10	11
1	0.00	0.00										
2	0.20	0.98										
3	0.40	1.99										
4	0.50	2.50										
5	0.60	3.00										
6	0.80	4.00										
7	1.00	5.00	5.00	5.00	4.97	5.02						
8	1.25	6.03										
9	1.50	6.94										
10												
11												
12												

GENERAL TEST NOTES:

Breadboard Electronics used with amplifier gain ≈ 50. Linearity adjusted at 0.50 lb/hr to give E_o = 2.50 VDC

Bypass made of 6 layers 20 micron S.S. screen, ID = 0.19", OD = 0.26"

Specimen Passed ✓
Specimen Failed
N.O.D. Written

Tested By: JF Blair Date: 12-16-72
Witness: Date:
Sheet No. of
Approved

GARRETT AIRESEARCH MANUFACTURING COMPANY Los Angeles, California

GARRETT AIRESEARCH MANUFACTURING COMPANY
Los Angeles, California

tylan CORPORATION

DATA SHEET
No. 3F

Specimen: Flow Sensor
Date: ~~Dec 29~~ Jan 2 & 3 1973
Part No.: FMS-411 Prototype
Serial No.:

Job No.: 3046
Report No.: R-3046-1
Specimen Temp.: 60-65°F
Amb. Temp.: 60-65°F

Test Title: Calibration Before & After Vibration

See AETL Report

NO.	$\dot{w}$ lb/hr O_2	1 Before Vibration	2 1/2/73	3 After Vibration	4 1/3/73	5 E_0 -	6 VDC	7	8	9	10	11
1	0.0	0.00		0.01								
2	0.25	1.23		1.23								
3	0.50	2.58		2.57								
4	0.75	3.89		3.89								
5	1.00	5.12		5.13								
6	1.25	6.13		6.16								
7												
8												
9												
10												
11												
12												

GENERAL TEST NOTES:

- Vibrated Prototype Sensor per Fig. 3 of Shuttle Environmental Requirements, 10 minutes duration each axis. The sensor resistance was monitored during vibration and was seen to be constant at 652 ohms ($R_u + R_D$).
- Electronics not adjusted between tests.
- Bypass was 14 layers 20 micron screen, 0.14 ID × 0.30 OD × 0.88 Long.

Specimen Passed ✓
Specimen Failed
N.O.D. Written

Tested By R.F. Blair Date: 1-3-73
Witness Date:
Sheet No. of
Approved

Tylan CORPORATION

DATA SHEET
NO. 4F

Specimen: Flow Sensor
Date: 12/17/72 , 12/30/72
Part No.: FMS-411 Prototype
Serial No.:

Job No.: 3046
Report No.: R-3046-1
Specimen Temp.: Noted
Amb. Temp.: 70°F

Test Title: Calibration vs Temperature – Sensor Only (Bypass Plugged)

		E_o – voc				Gas & Specimen Temp.						
	① $\dot{\omega}$ sccm O_2	70°F	0°F	160°F	70°F							
NO.		1	2	3	4	5	6	7	8	9	10	11
1	0	0.00		-0.01								
2	2.5	2.67		2.67		Sensor insulated with 1/8" thick Heat Felt #1200 A						
3	5.0	4.91		4.98		enclosed in metal can						
4												
5												
6	0	0.00	-0.01	-0.05	0.00							
7	3.5	2.72	2.74	2.72	2.72	Final Configuration – Polystyrene Block insulation						
8	7.0	5.03	5.05	5.13	5.01	enclosed in metal can						
9												
10												
11												
12												

GENERAL TEST NOTES: ① As measured by FMS-343, S/N 1038 in series with test unit

- 45 minute stabilization times at each temperature.
- Cooling rate = 5°F/minute , Heating rate ≈ 40°F/minute.
- Electronic Linearity not readjusted for this test.

Result: Calibration stable within ±2% f.s. from 0°F to 160°F

Specimen Passed ______
Specimen Failed ______
N.O.D. Written ______

Tested By D. F. Blair Date: 12/30/72
Witness ______ Date: ______
Sheet No. ______ of ______
Approved

GARRETT
AIRESEARCH MANUFACTURING COMPANY
Los Angeles, California

Tylan CORPORATION

GARRETT AIRESEARCH MANUFACTURING COMPANY Los Angeles, California

DATA SHEET
NO. 5F

Specimen Flow Sensor
Date 12/20/72 - 12/31/72
Part No. FMS-411 Prototype
Serial No.

Job No. 3046
Report No. R-3046-1
Specimen Temp. Noted
Amb. Temp. 70°F

Test Title: Calibration vs Temperature - with 1 lb/hr Bypass

NO.	$\dot{\omega}$ lb/hr O_2 ①	1 (70°F)	2 (0°F)	3 (120°F)	4 (160°F)	5 (70°F)	6 (0°F)	7	8	9	10	11
		E_o - VDC						Gas & Specimen Temp.				
1	0.0	0.00			0.00		0.01					12-20-72
2	0.50	2.49			2.57		2.61					
3	1.00	5.00			5.20		5.18					
4												
5	0.0	-0.01			0.00		0.00					12-21-72
6	0.50	2.53			2.59		2.59					
7	1.00	5.06			5.25		5.14					
8												
9	0.0	0.00	-0.02	-0.04	-0.01	0.00						12-31-72
10	0.50	2.50	2.48	2.58	2.55	2.47						
11	1.00	5.00	4.95	5.27	5.19	4.95						
12												

GENERAL TEST NOTES: ① Measured with Voloflow system

- Bypass made of 14 layers 20 micron SS screen, .14 ID × .30 OD × .88 long
- Stabilization times at each temperature = 45 minutes minimum
- Cooling rate ≈ 5°F/min, Heating rate ≈ 40°F/minute

Result: Calibration Stable within ± 5% f.s. from 0 to 160°F

Specimen Passed
Specimen Failed
N.O.D. Written

Tested By T. F. Blair Date: 12-31-72
Witness Date:
Sheet No. of
Approved

EXHIBIT 5C

VIBRATION TEST REPORT

APPROVED ENGINEERING TEST LABORATORIES

Report No. 5330-0777
P. O. No. 721447
Date: 8 January 1973

5 Page Report

TESTED FOR

Tylan Corporation
4203 Spencer Street
Torrance, California 90503

TEST ITEM

Sensor, Part Number FMS-411

TEST PERFORMED

Random Vibration

REFERENCES

Figure Number 3, Shuttle Requirements

TEST EQUIPMENT

AETL No.	Manufacturer	Instrument
D10L	M.B. Electronics	Vibration Exciter, M/N C-60
D11L	M.B. Electronics	Amplifier, M/N T452
D13L	M.B. Electronics	Control Console, M/N T388
D113L	Moseley	X-Y Recorder, M/N 2D-2A
D140L	Ballantine Labs	True RMS Voltmeter, M/N 320
D148L	Unholtz Dickie	Charge Amplifier, M/N D11MGV-8
D167L	Spectral Dynamics	Ensemble Averager, M/N SD301
D168L	Spectral Dynamics	Real Time Analyzer, M/N SD301A
D532V	Endevco Corp.	Accelerometer, M/N 2215E
E250L	M.B. Electronics	Elapsed Time Meter, M/N N220A

TEST PROCEDURES AND TEST RESULTS

The specimen was installed in a test fixture and was subjected to ten minutes of random vibration in each of the three major orthogonal axes over the frequency range of 20 to 2000 Hz at the following intensities:

Frequency (Hz)	Intensity
20 - 250	6 db/octave rise
250 - 500	0.25 g^2/Hz
500 - 2000	6 db/octave rolloff
Overall Acceleration:	14.8 grms

TEST PROCEDURES AND TEST RESULTS (Cont.)

Visual examination at the completion of testing in each axis revealed no damage or other adverse effects. The PSD plots are presented in this report.

AETL 26 03

STATE OF CALIFORNIA
COUNTY OF LOS ANGELES } ss

DEANE HELLER, Project Manager being duly sworn deposes and says: That the information contained in this report is the result of complete and carefully conducted tests and is to the best of his knowledge true and correct in all respects.

Deane Heller

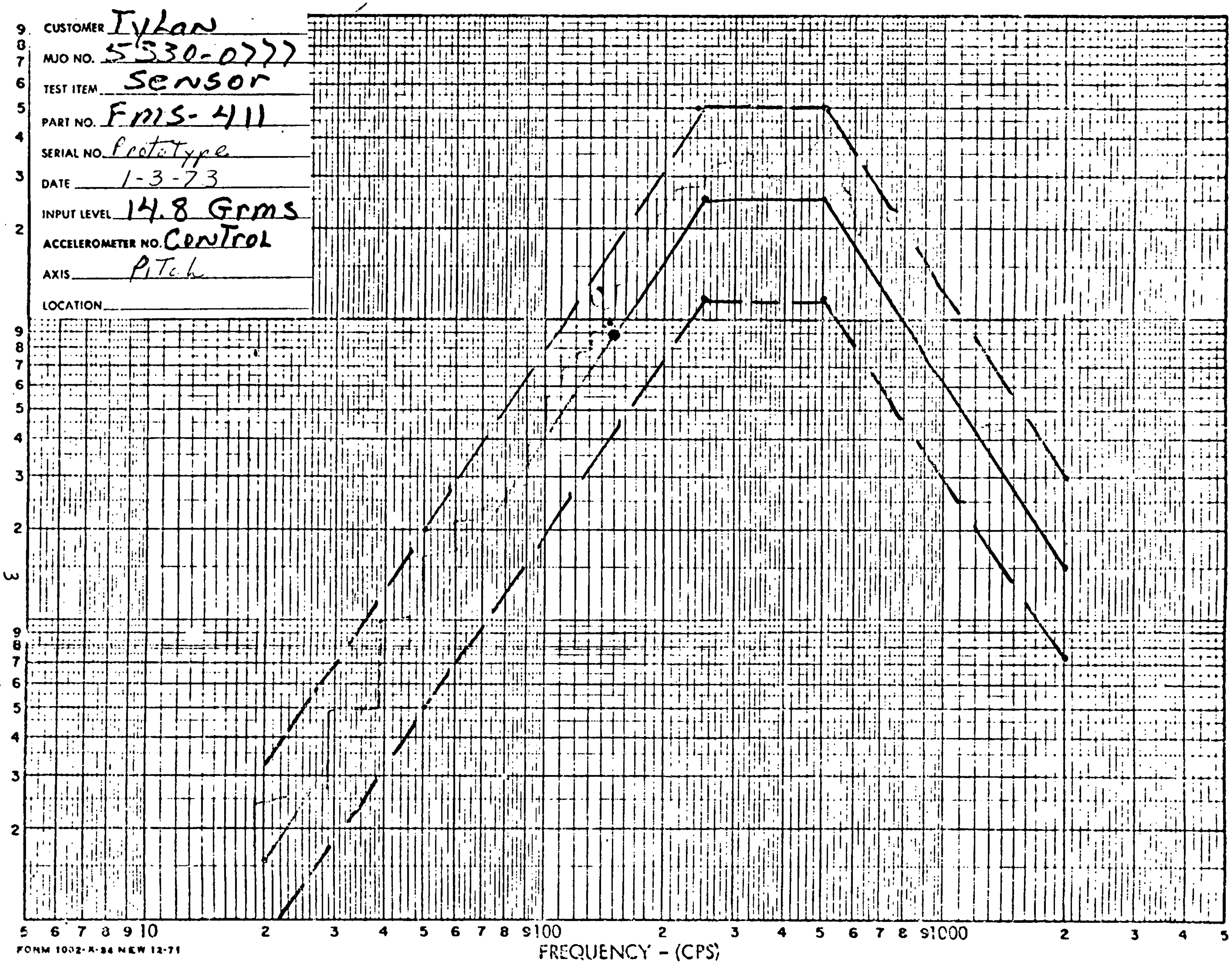
OFFICIAL SEAL
KARL G. SCHMIDT
NOTARY PUBLIC CALIFORNIA
LOS ANGELES COUNTY
My Commission expires Sept. 22, 1973

2

SUBSCRIBED and sworn to before me this 8 day of January 19 73

Karl G. Schmidt

Notary Public in and for the County of Los Angeles, State of California.



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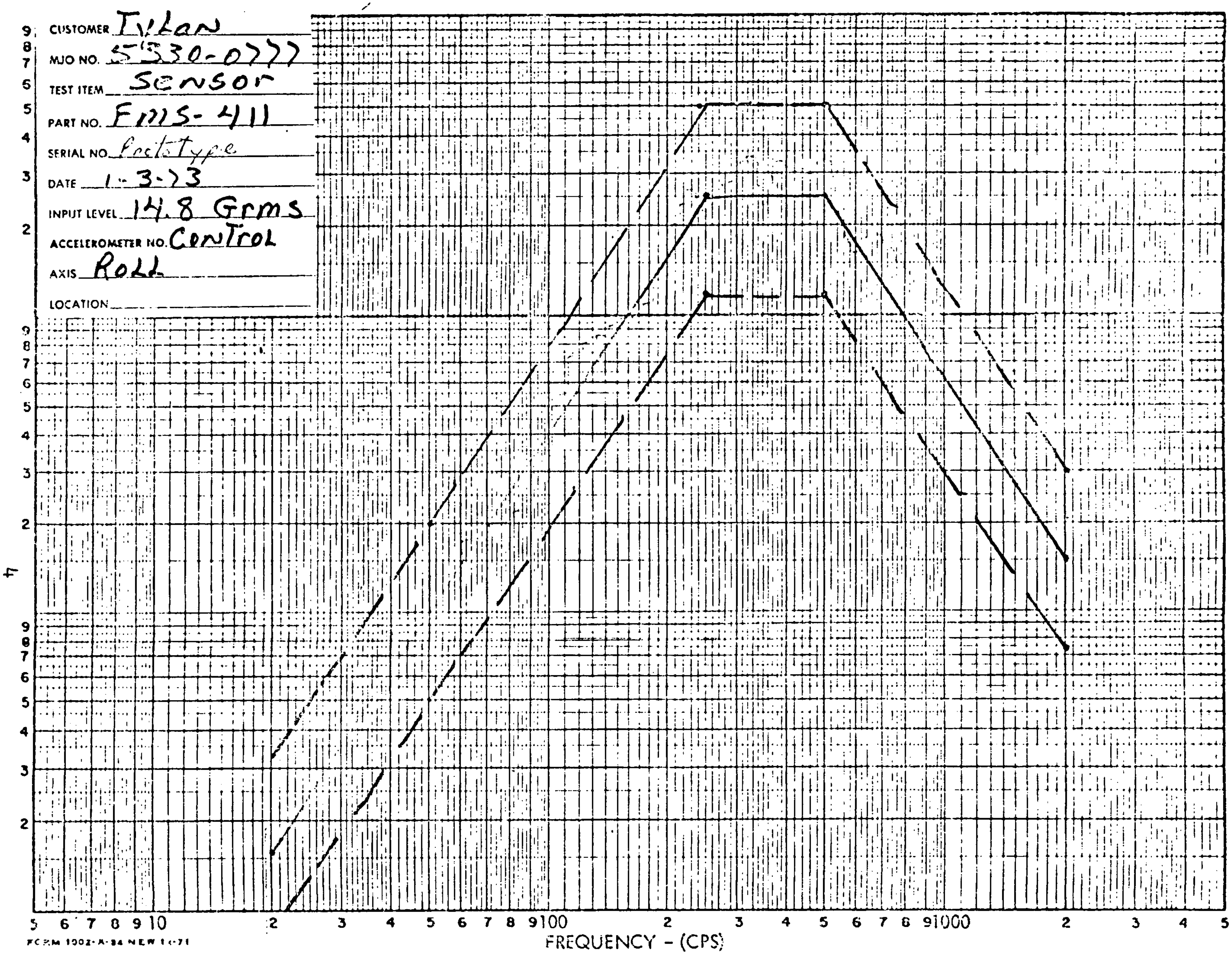

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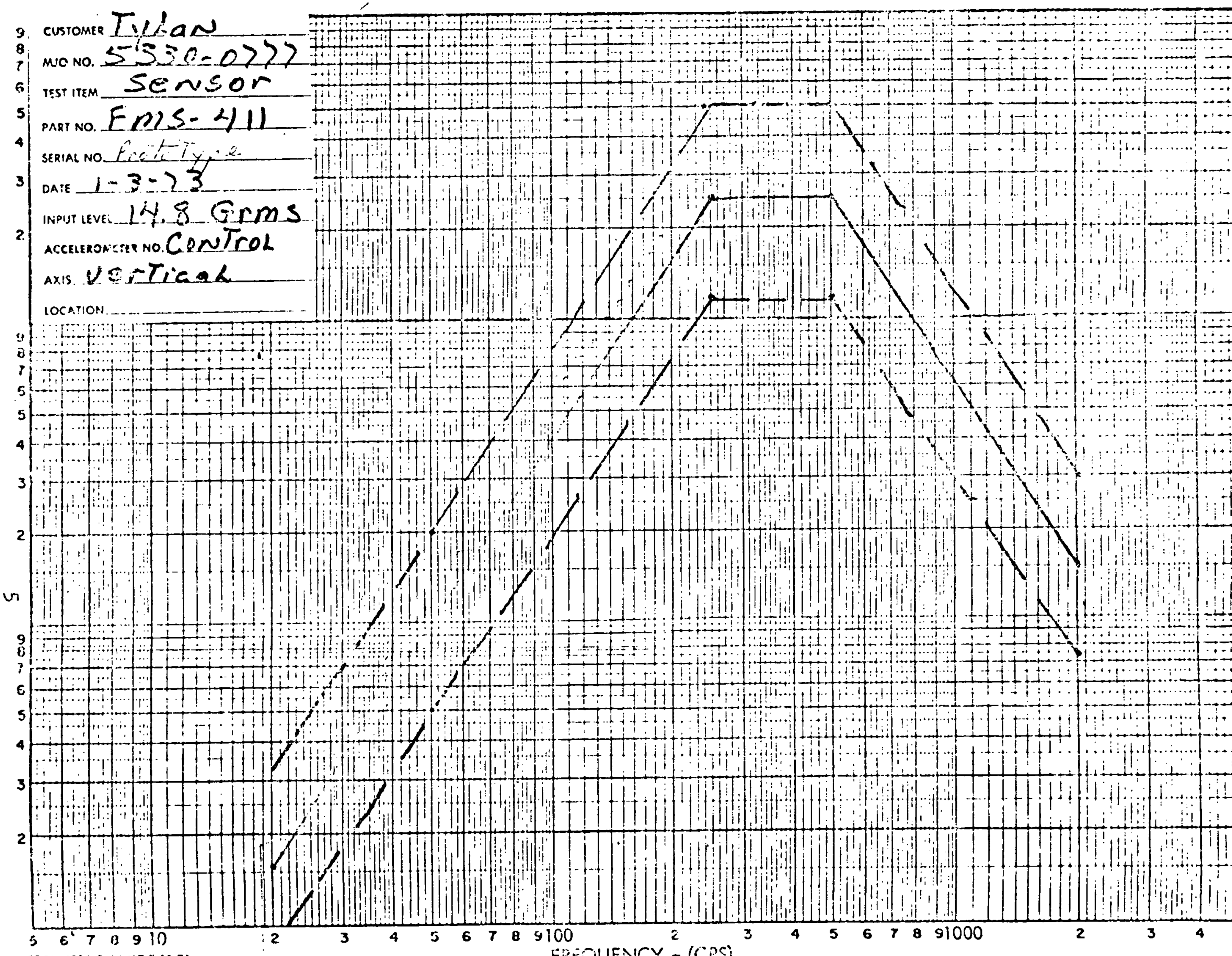

SECTION 6

SPEED SENSORS

Centrifugal water separators were used in the LM ECS to remove entrained water droplets from the suit loop gases. The performance of the separators was dependent on proper rotational speed. At high speeds, the water that is collected in the separator trough splashes, causing some to be carried downstream and into the suits. A variable reluctance speed sensor was made integral with the separator to monitor rotational speed.

The GFE trouble reports that were furnished to AiResearch at the start of the ECS transducer study contained only one failure report logged against the speed sensor. Discussions with NASA personnel indicated that the speed sensor was highly reliable; consequently, a failure and design evaluation of the sensor and signal conditioner was not made during the course of this study.

Performance and design data on the speed sensor are listed below.

Speed sensor type	The speed sensor is an angular velocity transducer used to develop a frequency signal proportional to the angular velocity of the water separator.
H. S. Part No.	SV 593257
Airpax Part No.	086-111-0008
Spec. weight	1.5 ounces
Construction	Environmentally sealed electronics
Output voltage	2.86 mv/ips surface speed with 0.010 in. min. gap
Output inductance	20 mh max.
Gap width	0.010 in. min.
Output resistance	200 ohms max.

SECTION 7

PRESSURE SWITCHES

The evaluation of the GFE failure reports has identified malfunctions in the pressure-actuated switches that were used in the Apollo environmental control systems for the LM and PLSS. The switches are briefly described in Table 7-1.

The failure information has been logged on failure evaluation forms and also has been compiled on separate matrixes as illustrated in Figures 2-2 and 2-3 in Section 2 of this report. AiResearch corresponded with the manufacturers of the switches; however, only minimal data has been received. Specific failure and design evaluation reports were not prepared on the pressure switches because of priorities that were established by the Contract Technical Monitor to develop corrective concepts on one or two transducers in lieu of a continuing data search.

Preliminary definition of the instrumentation on the Shuttle ECS indicates that pressure switches are not needed; however, application for pressure switches may exist on other subsystems on Shuttle; therefore, it is recommended that additional study be conducted on the pressure switches listed in Table 7-1 to define and correct the component parts that were responsible for the chronic failure modes.

TABLE 7-1

PRESSURE SWITCH DESCRIPTIONS

LM No. LSC-330-124 Fan Differential Pressure Switch

Specification No.	SVHS 2335
H.S. Part No.	SV 707755
Hydra-Electric Part No.	S 72169
Operation	When the pressure rise across the suit circuit fan drops below 6 in. of water, the switch provides a closed circuit to illuminate a cabin warning light. Switch actuates on increasing pressure by 9 in. of water
System pressure	3.5 psia to 20.5 psia
Proof pressure	3.5 psia to 20.5 psia
Differential	22.9 in. of water, max.
Applied to high and low ports simultaneously	6 psi
Operating temperature	0 to 160^{0}F
Electrical rating	1 amp at 28 vdc

LM No. LSC-330-218 Coolant Pump ΔP Switch

Specification No.	SVHS 2338/2757
H.S. Part Nos.	SV 715520/SV 718707
Hydra-Electric Part No.	8161
Operation	When the glycol pump pressure drops to 3.0 psid, the switch closes a circuit to activate a cabin warning light and initiates a sequence which switches from Pump No. 1 in the primary loop to Pump No. 2. The contacts open where pump pressure rise exceeds 7 psid.
Differential pressure	40 psid
Proof pressure	60 psig

TABLE 7-1 (Continued)

Burst pressure	90 psig
Operating temperature	0 to 160°F
Electrical rating	1 amp at 28 vdc

LM No. LSC-330-323 Cabin Pressure Switch

Specification No.	SVHS 3253/3477
H.S. Part Nos.	SV 716278/SV 731734/SV 731969
Century Electronics and Instruments, Inc. Part No.	92C115
Operation	When cabin pressure drops to 4.45-3.70 psia, the switch closes a circuit to open the cabin repressurization solenoid valve, activates a cabin warning light and starts the sequence that closes the suit circuit diverter to the cabin. Switch contacts open when cabin pressure rises to 4.4-5.0 psia
Electrical rating	
Current	1.5 amps max
Voltage	25 to 31.5 volts

PLSS No. 204 PGA Differential Pressure Switch

Specification No.	SVHS 4312
H.S. Part No.	SV 714170
Bourns Part No.	2004414701
Operation	Senses pressure differential between ambient and suit pressure, used to provide an input signal to an alarm system
Operating pressure	3.4 to 4.05 psid
Switch closure	3.4 to 3.10 psig
Switch opening	3.10 to 3.40 psid
Operating temperature	40 to 85°F

TABLE 7-1 (Continued)

PLSS No. 239 Feedwater Pressure Transducer and Switch

Specification No.	SVHS 3867
H.S. Part No.	SV 718788
Bourns Part No.	284419301
Operation	A pressure-sensing bellows actuating a potentiometer wiper element senses water pressure in the feedwater line and develops a signal for input to the telemetry system
Operating pressure	21 psia to 10^{-14} mm Hg
Excitation	Potentiometer excited by 5 vdc
Resistance	Total of potentiometer is 2000 ohms
Signal output	Linear 0 to 5 volt output into 100,000 ohm load for 0-5 psia input pressure
Switch actuation	1.2 to 1.7 psia
Current capacity	10 ma

SECTION 8

VALVE POSITION INDICATING SWITCHES

AiResearch Report 72-8537-51 in the Appendix describes an evaluation of the operational characteristics and reported failures of precision switches as part of the ECS transducer development program. The precision switches are position indicating and control switch assemblies used to indicate the position of ECS component controls and to control electrical power to other ECS components. The valve position indicating (VPI) switch assemblies develop a switch closure (or opening) as an input to the telemetry system.

A review of the VPI and control switch requirements show them to be unique to the Lunar Module ECS. Failure reports recorded against the next assembly valves were reviewed to isolate the failure reports that pertained to the precision VPI switches.

TRANSDUCER EVALUATION (WBS 1.0, SOW 3.2.1)

Section 3 of AiResearch Report 72-8537-51, "Report on Failure and Design Evaluation of Apollo ECS Valve Position Indicator Switches" describes the failure evaluation that was conducted on the VPI switches.

DESIGN CONCEPT (WBS 2.0, SOW 3.2.2)

Design recommendations governing the next assembly interfaces and suggested redesign of the VPI switches is contained in Section 4 of AiResearch Report 72-8537-51.

VERIFICATION TESTING (WBS 3.0, SOW 3.2.3)

Specific verification tests were not run on the VPI switches during the course of this study. The study of the Apollo VPI switches was limited to a data search in accordance with discussions and agreements reached with the NASA-MSC Contract Technical Monitor.

DESIGN CRITERIA (WBS 4.0, SOW 3.2.4)

Design criteria was formulated during the failure and design evaluation of the VPI switches. The design criteria is contained in Section 4 of AiResearch Report 72-8537-51.

APPENDIX

FAILURE AND DESIGN EVALUATION OF APOLLO ECS TRANSDUCERS

AiResearch conducted a study of transducers used in the Apollo environmental control systems for the CSM, LM, and PLSS. The failure analyses of approximately 800 trouble reports, supplemented by a review of the transducer specifications and system schematics, resulted in identification of generic types of transducers; these types are pressure, temperature, flow, speed, pressure switch, and position switch. Failure and design evaluation reports were prepared during the course of this study. The reports contained in this appendix are listed below by document number, title, and generic type.

Document Number	Document Title	Transducer Generic Type
72-8537-2, Rev. 1	Report on Failure and Design Evaluation of Apollo ECS Pressure Transducers, Variable-Reluctance Twisted Bourdon Tube Type	Pressure
72-8537-3, Rev. 2	Report on Failure and Design Evaluation of Apollo ECS Pressure Transducers, Variable-Reluctance Diaphragm with Electronics Type	Pressure
72-8537-12, Rev. 1	Report on Failure and Design Evaluation of Apollo ECS Temperature Sensors, Thermistor Type	Temperature
72-8537-13, Rev. 1	Report on Failure and Design Evaluation of Apollo ECS Temperature Sensor, Thermistor Bead and Coil Type	Temperature
72-8537-14, Rev. 1	Report on Failure and Design Evaluation of Apollo ECS Cabin Temperature Sensor, Thermistor with Electronics Type	Temperature
72-8537-15, Rev. 1	Report on Failure and Design Evaluation of Apollo ECS Temperature Sensors, Coil with Electronics Type	Temperature
72-8537-22, Rev. 1	Report on Failure and Design Evaluation of Apollo ECS Oxygen Flow Transducer Temperature Sensor with Electronics Type	Flow
72-8537-51, Rev. 1	Report on Failure and Design Evaluation of Apollo ECS Valve Position Indicator Switches	Position Switch

AIRESEARCH MANUFACTURING COMPANY

Los Angeles, California

REPORT ON FAILURE AND DESIGN EVALUATION OF
APOLLO ECS PRESSURE TRANSDUCERS
VARIABLE-RELUCTANCE TWISTED
BOURDON TUBE TYPE
CONTRACT NO. NAS 9-12452

72-8537-2, Rev. 1 February 10, 1973

Prepared by A. Saginian/H. Louie

APPROVED:
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Program Manager

APPROVED:
M. J. Brudnicki
Principal Investigator

NASA MANNED SPACECRAFT CENTER
HOUSTON, TEXAS 77058

ABSTRACT

This report presents the results of a failure and design evaluation study conducted on the Apollo ECS transducers, the generic group of variable-reluctance twisted Bourdon tube type pressure transducers. The study was conducted for NASA-MSC by the AiResearch Manufacturing Company, a division of The Garrett Corporation under Contract NAS9-12452.

The study purpose was to evaluate the integrity of design of this type transducer. Failure information is presented and summarized pertaining to six different transducer part numbers. A failure matrix is presented which describes the failure mode, type, mechanism, cause, and problem areas for 84 failures out of a lot total of 296 units.

The integrity of the design was confirmed. Recommendations are made to reduce the failure rate from the current level of 26 percent.

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SECTION I

INTRODUCTION

This report presents a summary of failure data of the generic group of variable-reluctance, twisted Bourdon tube type pressure transducers. This type is one of several pressure transducer types, which are described and categorized in AiResearch Report No. 72-8537-1. Six transducers were evaluated and are presented for discussion; however, the last one (AiResearch PN 837008-1) has been superseded by AiResearch PN 836130.

All of the transducer applications described in this report are with respect to Apollo environmental control subsystem (ECS) functions. They may be typically used in the command service module (CSM), lunar excursion module (LEM), or portable life support subsystem (PLSS) designs.

The transducers which are summarized are, by AiResearch part number:

PN 836130

PN 837026

PN 836132

PN 837044

PN 837016

PN 837008

Detailed failure data on each of these transducers are presented in Sections 3 through 8 of this report. Section 2 presents summary, descriptive information, and recommendations on all aspects common to the group, thus avoiding excessive repetition. Differences in the transducer design for this group are primarily due to differences in the pressure ranges of applications.

The results of the failure evaluation for each transducer were combined into a single failure matrix of 84 failures, presenting a useful statistical picture for this transducer type. A notable observation is that the great majority of the failures is due to human error and hence potentially preventable with no reflection on the design integrity.

SECTION 2

DESCRIPTION, FAILURE SUMMARY, AND RECOMMENDATIONS FOR VARIABLE-RELUCTANCE, TWISTED BOURDON TUBE PRESSURE TRANSDUCERS

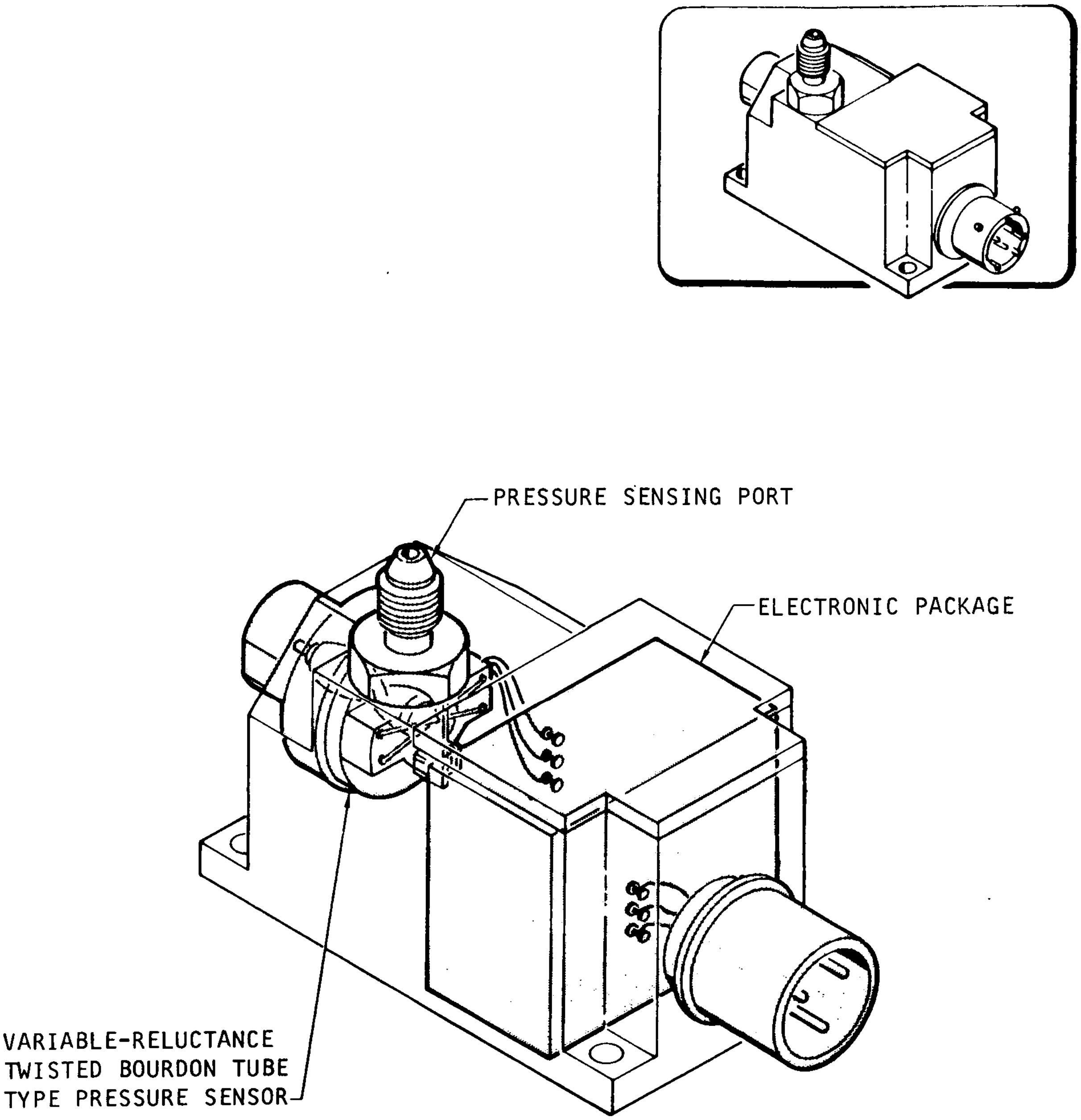
DESCRIPTION AND OPERATION

An isometric of a typical variable-reluctance twisted Bourdon tube pressure transducer is shown in Figure 2-1. The outline drawing is given in Figure 2-2. The transducer utilizes a Bourdon tube for the pressure-responsive element which is fabricated from tubing flattened into a non-circular cross section and twisted along its length. Axial rotation of the unrestrained end of the Bourdon tube is caused by a change in internal pressure. The tube deforms elastically until the stresses created in the tube balance forces arising from a pressure change. Increasing pressure tends to return the flattened cross section to its original circular shape. Opposing compressive and tensile stresses create a bending moment that tends to change the curvature of the tube.

Four types of Bourdon tubes commonly used are plain, spiral, helical, and twisted. Each is shown in Figure 2-3 with various cross sections used in their design. The twisted tube maintains a straight centerline along the length of the tube, but is twisted about the centerline at a uniform rate. The opening of the tube due to internal pressure causes the tube to unwind some finite angle about the tube centerline. The change in tube length is negligible. Different angles of twist alter the angular rotation for any given length of tube.

A variable reluctance-type transducer operates on the principle of electromagnetic induction, which produces an electric current (or voltage) by the movement of a conductor through a magnetic field. It consists of a sensing element Bourdon tube, a magnetic core, an armature to complete the magnetic circuit, and two or four inductance coils. A typical two-coil unit is shown in Figure 2-4. The armature is fastened to the twisted Bourdon tube and rotates in proportion to the pressure. The rotation changes the air gap, causing a change in the circuit inductance. The inductance coils are represented in the bridge circuit (Figure 2-4). Generally, the output is sufficiently high that amplification is unnecessary, but the output of the bridge may be doubled by adding an E-core opposite the one shown, creating a four-arm circuit. Any inductance change can be used to modulate the amplitude of a carrier voltage, or change the oscillator frequency. A schematic diagram of the instrumentation system for a variable reluctance transducer is shown in Figure 2-5.

The transducer electronics are powered by a 28-vdc supply. The output signal is in the range of zero to 5 vdc and is proportional to the magnitude of the sensed pressure. This signal is used for ground checkout, for crew visual information, and for telemetry data to be transmitted to a ground station.



A-11013

Figure 2-1. Typical Pressure Transducer

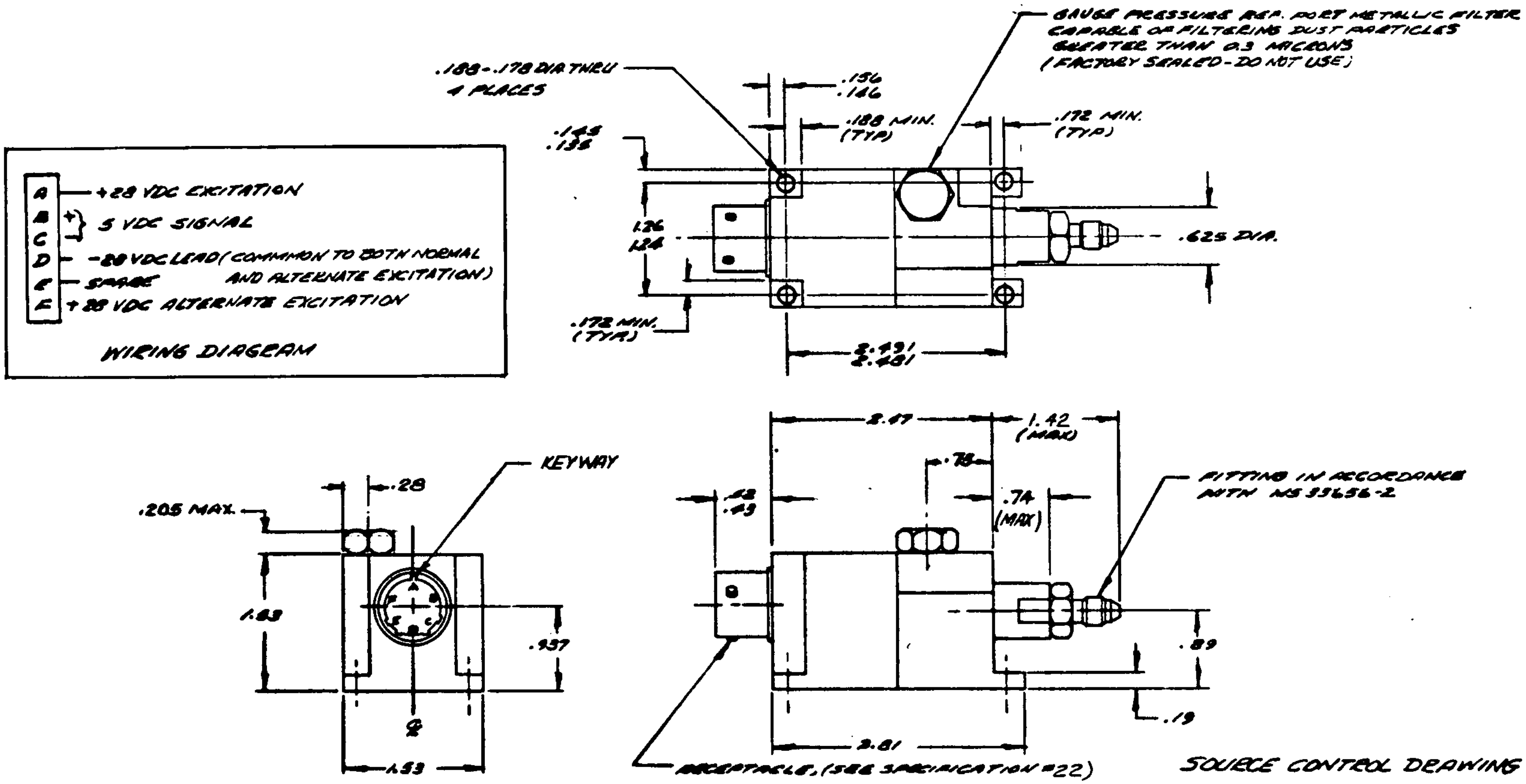


Figure 2-2. Typical Pressure Transducer Outline

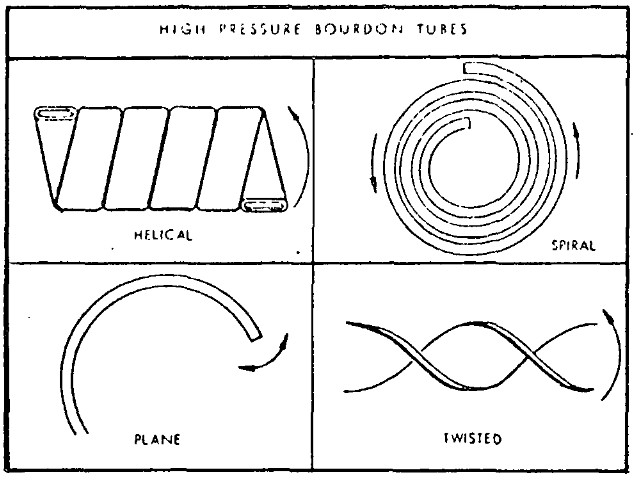


Figure 2-3. Bourdon Tube Designs

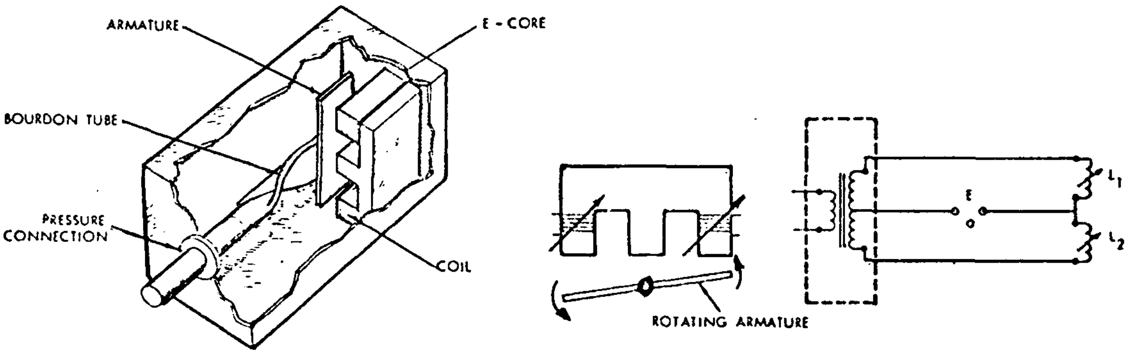


Figure 2-4. Variable Reluctance Transducer and Electrical Circuit

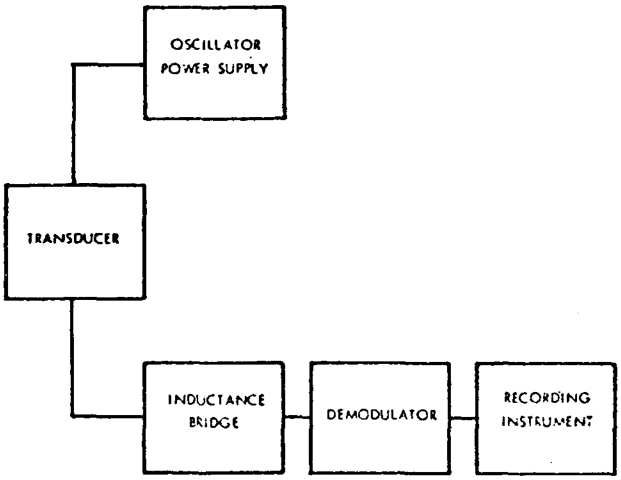


Figure 2-5. Schematic Diagram for a Reluctance Transducer System

FAILURE SUMMARY

A total of 91 failure reports, furnished by NASA-MSC, were reviewed. The results of 84 of these reports are summarized in the failure matrix shown in Figure 2-6. Seven failure reports, all written against PN 837008, were excluded from this total summary matrix because this part number has been superseded by PN 836130. The matrix in Figure 2-6 is a summation of the individual matrixes presented in turn for each transducer application in this report.

Seventy-six (90 percent) of the failures were judged to be due to human error. Thirty-two (38 percent) of these failures were caused by overpressurization and fourteen (17 percent) by misconnection of input potential to the output terminals.

It was observed, through tests, that the twisted Bourdon tube sensing element is sensitive to pressure spikes. However, laboratory tests of the transducer assembly have shown that no perceptible permanent distortion occurs when the pressure is increased slowly. Figures 2-7 and 2-8 show a typical resultant shift of the armature when the unit was subjected to physical shock or excessive pressure. Note the position of the armature which is attached to the unrestrained end of the Bourdon tube. In the case of Figure 2-8, this particular transducer had shifted positive approximately 300 millivolts over the entire range. Post failure tests conducted at Whittaker Corporation were summarized on AiResearch Trouble Reports Nos. 16668 and 19199, respectively, with the results quoted as follows:

> "The unit was subjected to extensive temp-cycle test (100 hr) to ascertain if the electronics package was stable. There were no further shifts in performance. The transducer was subsequently disassembled and the sensor section inspected. There was visible evidence of a slight distortion in the Bourdon tube. See attached photo [Figure 2-7]. Such distortion can result from physical shock as from mishandling or overpressurization. There was no external evidence of mishandling such as case damage. However, mishandling either at the vendor's facility prior to shipment or at AiResearch prior to test is considered the most likely cause, since the unit failed the initial calibration test point at AiResearch prior to application of any pressure.
>
> Upon verification of the reported discrepancy of subject glycol pump outlet pressure transducer, the unit was disassembled for analysis at Whittaker Corporation.
>
> A physical offset of the armature, relative to the coils, was immediately noticed (see attached photo [Figure 2-8]). This armature is a part of the pressure sensing "Bourdon Tube," and in this case, the said tube was permanently deformed resulting in a closed gap. This condition is normally seen when a pressure is applied to the tube but will recover the initial gap when relieved of the pressure. Further physical

Problem Area		Percent	Mode: No Output	Mode: Shift	Mode: Low Output	Mode: High Output	Mode: Fixed Output	Mode: Low Resistance	Mode: Leakage	Mode: Erratic	Mode: Ripple	Mode: Drift	Mode: Peeling	Mode: None	Type: Human	Type: Electrical	Type: Mechanical	Sensing Mechanism Elec.: Open	Sensing Mechanism Elec.: Short	Sensing Mechanism Mechanical: Frozen	Sensing Mechanism Mechanical: Overpressurized	Sensing Mechanism Mechanical: Leakage	Sensing Mechanism Mechanical: Damaged	Signal Conditioning and Transmission Mechanism: Unknown	Misconnected	Short	Poor Assembly	Degraded	Process	Material	Contamination	Damaged	Test Equipment	Not Analyzed
Engineering	Design	4.8		4											4															2			2	
Engineering	Testing: Procedure, ATP	-																																
Engineering	Testing, Qual: Error	8.3				6		1							7										6						1			
Engineering	Testing, Qual: Procedure	-																																
Manufacturing	Planning	1.2		1											1									1										
Manufacturing	Fabrication	3.6											3		3														3					
Manufacturing	Assembly	20.2		8		6	1	1				1			16		1			1	11					2	3							
Manufacturing	Quality Control	-																																
Manufacturing	Inspection	1.2							1						1							1												
Manufacturing	ATP Test Error	34.5	3	10	1	14					1				29						20		1		8									
Test Equipment Failure		3.6		1			1							1	3															1			2	
LOX Cleaning		2.4		2											2								2											
Handling		7.1		4		1		1							6								2					1			1	2		
Final Installation	Receiving Inspection (Test and Equipment)	-																																
Final Installation	Installation	1.2		1												1					1													
Random Failure		8.3		1	2	1	1			1		1			1	6								1		3		2				1		
Unconfirmed Failure		2.4												2	2									2										
Not Analyzed Failure Report		1.2		1											1																			1
Totals		100	3	33	3	28	3	3	1	1	1	2	3	3	76	7	1			1	32	1	5	4	14	5	3	3	3	3	2	3	4	1
Percent			3.6	39.2	3.6	33.2	3.6	3.6	1.2	1.2	1.2	2.4	3.6	3.6	90.5	8.3	1.2			1.2	38.0	1.2	5.9	4.8	16.6	5.9	3.6	3.6	3.6	3.6	2.4	3.6	4.8	1.2

FAILURE CAUSE

Figure 2-6. Variable-Reluctance Twisted Bourdon Tube Type Transducer Failure Matrix

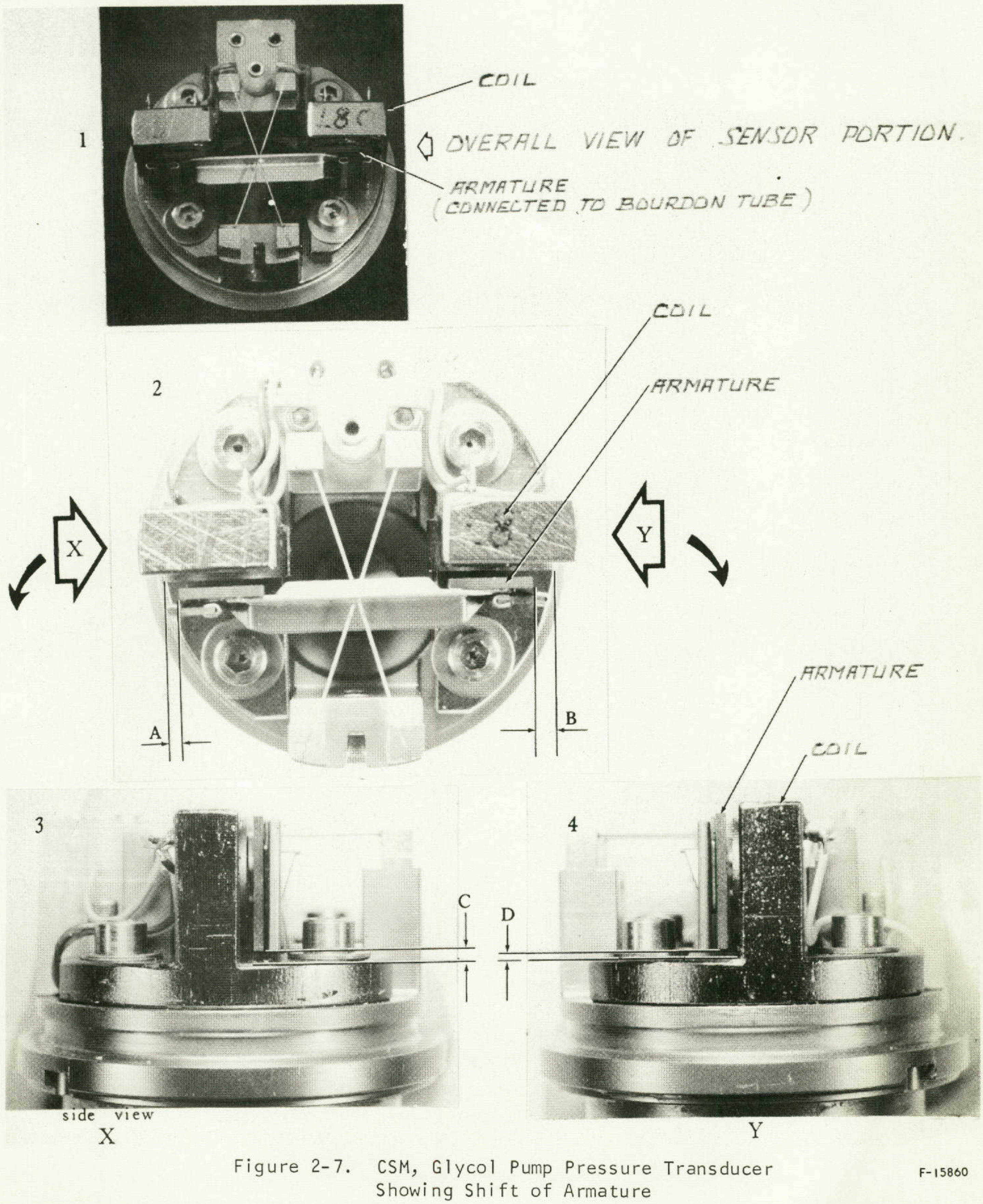
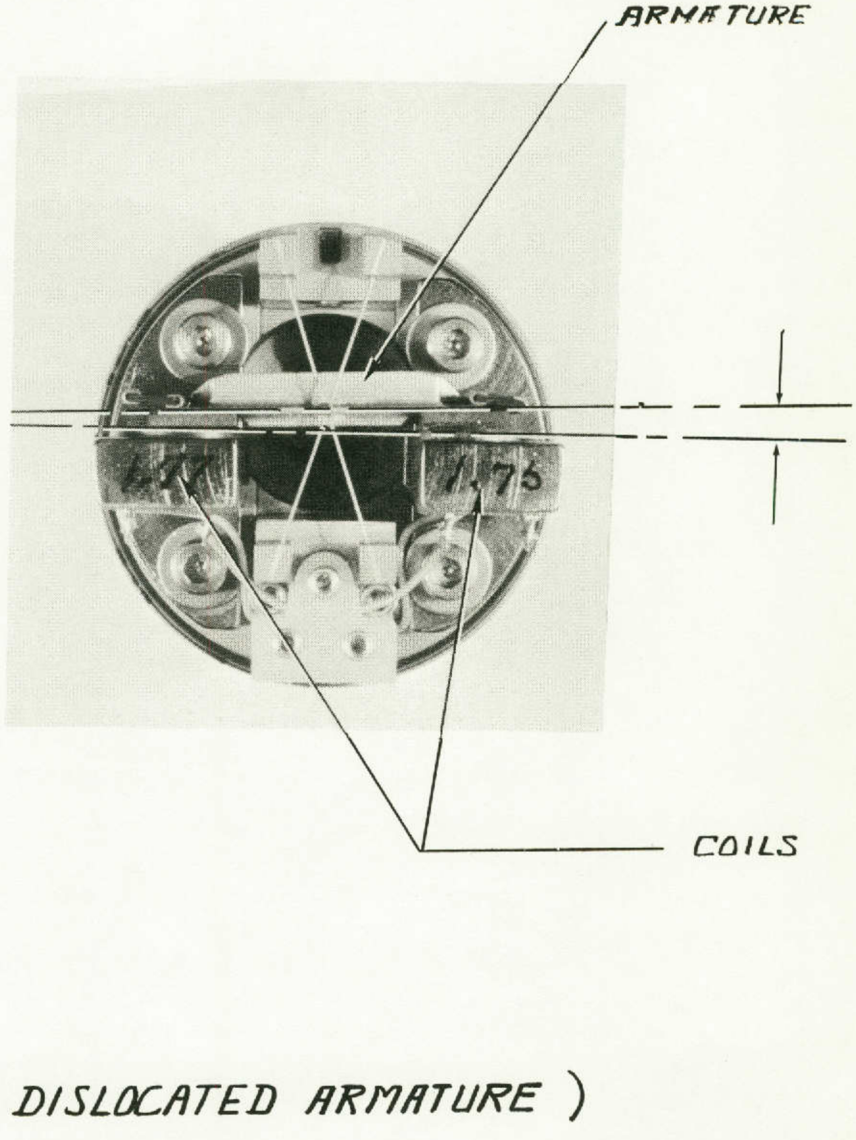


Figure 2-7. CSM, Glycol Pump Pressure Transducer Showing Shift of Armature

F-15860



(NOTE DISLOCATED ARMATURE)

F-15859

Figure 2-8. CSM, Glycol Pump Pressure Transducer
Showing Dislocated Armature

inspection of the Bourdon tube portion revealed that a bright spot existed on the transition area (inside the tube). This is a likely indication that it was struck by some hard object, distorting the original shape of the tube. The most probable place this could happen is during the final cleaning process where a person could attempt to clean the Bourdon tube by using a needle or other tool. It is noted that the unit was operating properly prior to final cleaning and failed the first test following cleanup. Investigation of the procedures uncovered that no detail steps are provided to the cleaning vendor by Whittaker for this configuration. It was concluded that this type of discrepancy can be prevented by proper communication between Whittaker and Cemarc (cleaning contractor)."

Although this pressure transducer was found to be sensitive to pressure surges or a pressure spike, the following test data show the unit to be quite capable of withstanding overpressure when applied slowly.

> "Four 836130 transducers were calibrated in the range of zero to 60 psig and then incrementally overpressurized from 60 psig to 250 psig. Calibration was performed after each pressure exposure to determine whether a shift had occurred. Zero shifts were apparent on two transducers, SN 9 and SN 33, after exposure to 100 psig. These transducers had a substantial shift; SN 33 had 2 psig and SN 9 had 3 psig after exposure to 230 psig. SN 8 exhibited essentially no shift until after exposure to 100 psig and had an ultimate shift of one (1) psig after the application of 250 psig. SN 25 exhibited no shift to all pressure applications up to 250 psig. Recalibration of the zero point verified that the shift was a linear displacement of the calibration curve."

A review of the failure matrix of Figure 2-6 indicates that there is no basic and chronic problem area for this transducer type. This conclusion is based on the following comments which are grouped according to problem area.

Non-Specific Problem Area

(a) There was no information given on the failure report which was not analyzed.

(b) Two failures were not confirmed and the responsibility of the reports belongs to their initiators.

(c) The seven random failures include only one human-induced failure and six failures of electronic components.

Since six of the random failures were registered against electronic components, it is evident that a more critical judgement should be exercised in the choice of electronic components.

Final Installation

Only one unit failed by overpressurization in the final installation. This can be considered a random human error.

Engineering

(a) There were four design problems, the sources of which have since been eliminated.

(b) There were seven qualification-test-induced failures, six of which are of recurring type.

A problem source exists in test equipment and procedure which must be eliminated.

Test Equipment and Handling

(a) There were three failures of test equipment which have no reflection on the integrity of the transducers.

(b) There were eight induced failures by mishandling.

A problem source exists in handling which must be eliminated.

Manufacturing

(a) One failure was due to poor planning.

(b) Three failures in fabrication were due to processing error.

(c) Sixteen failures in assembly were largely due to overpressurization during assembly tests.

(d) One failure in sensing mechanism was due to inspection.

(e) Twenty-nine failures in testing were due to test errors.

A problem source exists in testing equipment and procedure which must be eliminated.

Transducer Problem Area Evaluation

None of the problem areas mentioned above indicate a design problem. Therefore, the conclusion is that the transducer design is trouble-free and is recommended to be considered for future applications.

Failure Distribution

Figure 2-9 illustrates the distribution of failures according to problem area, and Figure 2-10 illustrates this distribution after design change which will eliminate the recurrence of engineering-error-related failures.

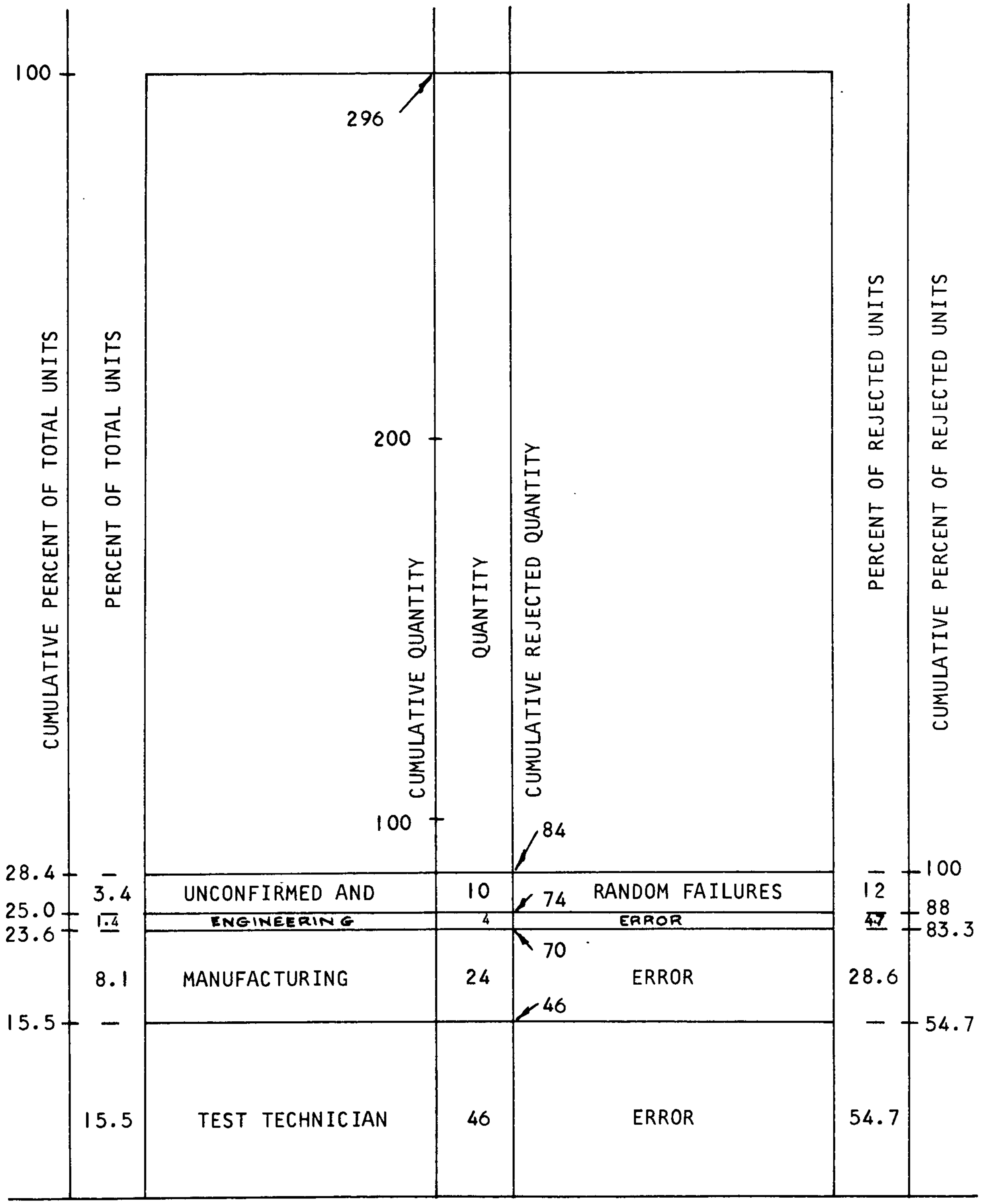


Figure 2-9. Distribution of Failures According to Problem Area

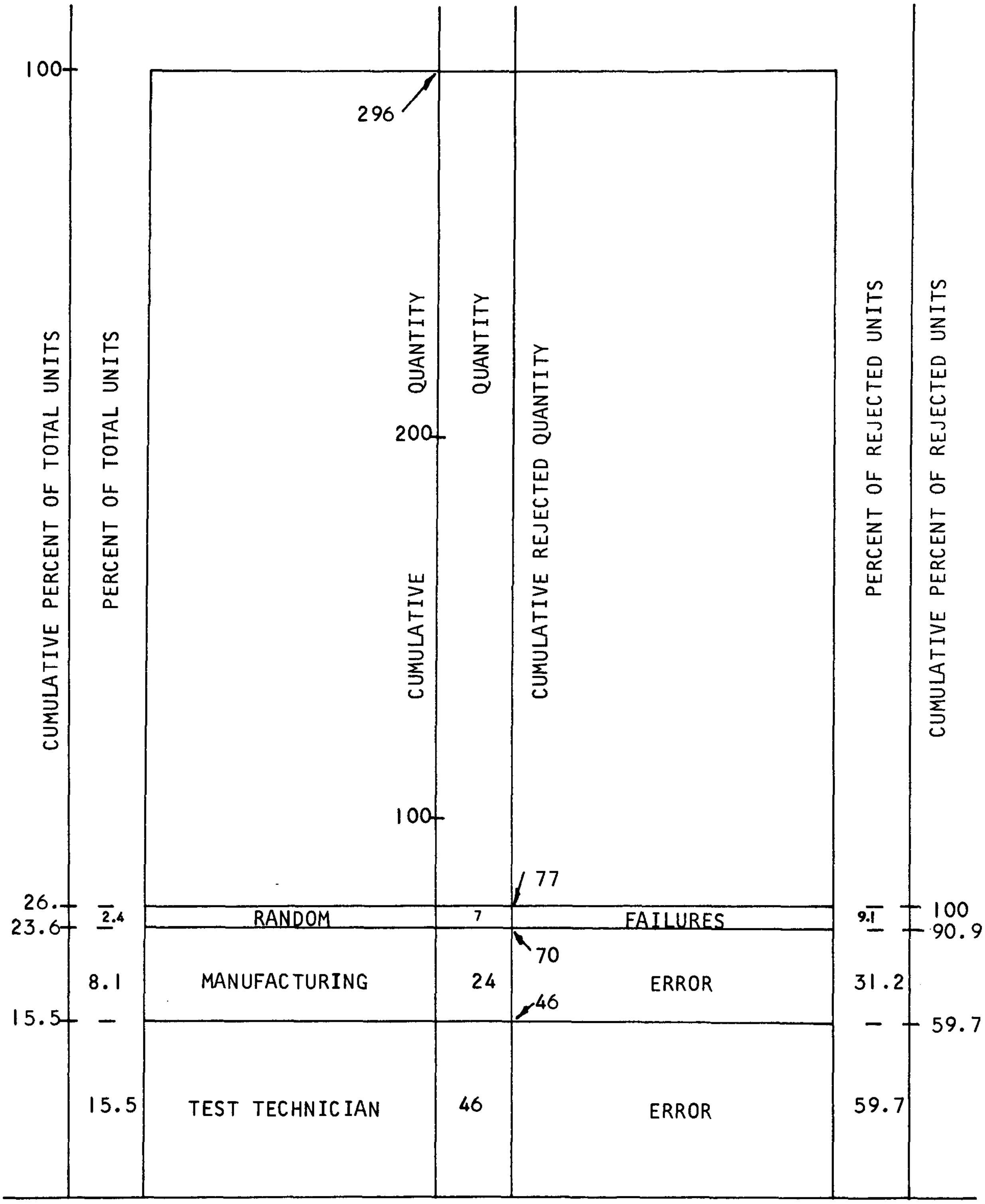


Figure 2-10. Distribution of Failures After Elimination of Engineering Errors

Twenty-six percent of the total population of 296 units were rejected. Of this, more than half were caused by test technician errors and all but seven were potentially avoidable. While the recurrence of random failures (representing a two-to-three-percent failure rate) can be prevented, definitive action to eliminate problem sources from manufacturing and test can be taken.

RECOMMENDATIONS

Most failure reports on variable-reluctance twisted Bourdon tube transducers were the result of overpressurization in the form of a pressure spike or a physical shock. Both of these had resulted in a permanent distortion of the pressure-sensing Bourdon tube. The second highest number of failures was the result of misconnection of the 28-vdc input power supply to the transducer output terminals by the test technician. As a result, the following recommendations are made with respect to design, test, and handling criteria:

Design Criteria

(a) Aging of the Bourdon tube pressure-sensing element on the order of six months with a simultaneous burn-in cycle on the overall transducer should be considered to verify stability of the pressure-sensing element and the electronics. A burn-in test consisting of a cyclic temperature from ambient to +135°F was made mandatory during the course of the Apollo Program and was effective on all transducers manufactured in accordance with 836130-2.

(b) Incorporate diodes in the electrical output circuitry such that the application of 28 vdc to the 0-5 vdc output pins does not cause any damage to the transducer.

(c) Incorporate a readily replaceable burst disc or blowout plug such that the application of pressure spikes or surges could not overpressurize and hence deform the sensing mechanism.

(d) It is desirable to select transducers with an allowable operating pressure limit 20 to 25 percent above normal working pressure to allow for transient conditions and to aid in trouble-shooting and determining the extent of inadvertent overpressurizations.

Test Criteria

(a) Pressure relief valves that are vented to ambient should be installed in ATP test setups, GSE filling and purging systems, and in the next assembly in which the transducer is installed to prevent pressure spikes.

(b) ATP test setup equipment should be color coded to clearly denote transducer electrical input power leads of 28 vdc and output signal leads of 0-5 vdc to avoid the possibility of damage to the transducer caused by interchanging the leads.

(c) ATP and QTP documents should be reviewed and amended as necessary to minimize the possiblity of inadvertent overpressurization of the sensing element and misconnection of input and output power leads.

Handling Criteria

(a) The transducer should be appropriately packaged to withstand shock loads when packaged of 30 g's intensity for 11 ±1 milliseconds applied along three mutually perpendicular axes.

(b) Planning documents should be reviewed and amended as necessary to minimize the possibility of induced failure in the forms of damage, contamination, and incorrect process.

SECTION 3

WATER GLYCOL PUMP PRESSURE TRANSDUCER
(AIRESEARCH PN 836130)

PURPOSE AND DESCRIPTION

The water-glycol pump pressure transducer measures the static pressure of the water-glycol coolant at the outlet of the pump assembly by sensing the pressure and generating a proportional electrical signal. This signal is used for ground check out, for the crew's visual information via an indicator, and for telemetry data to be transmitted to a ground station, and serves as an indication of water-glycol pump performance.

The transducer utilizes a Bourdon tube for the pressure-responsive element and a combination of a magnetic core, an armature (which completes the magnetic circuit), and inductance coils for translation of the physical motion into a proportional electrical signal.

PERFORMANCE AND DESIGN DATA

Table 3-1 lists performance and design data for this transducer.

FAILURE AND DESIGN REVIEW

Table 3-2 is a summary of the 21 failure reports which were reviewed for this transducer evaluation. The information indicated in Table 3-2 is summarized in the failure matrix of Figure 3-1. This and the other failure matrixes, subsequently presented in this report, were used as inputs to the summary matrix shown in Figure 2-6.

Nineteen of the total of 21 reported failures were caused by human errors. The other two were caused by (1) contamination during assembly, and (2) customer mistakes during final installations. Two of the failures included in the human error category were caused by engineering design error. The failure source of the engineering error has since been eliminated by design change.

Eight of the human-caused failures resulted from inadvertent overpressurization of the ECS coolant subsystem. Sensitivity of the Bourdon tube to pressure spikes and to inadvertent overpressurization is the mechanism of these eight failures. Laboratory tests have proved that such inadvertent pressure variations cause permanent distortion in the Bourdon tube.

Figure 3-2 shows the distribution of the failures according to the sources of problems. Figure 3-3 shows the distribution of the current failures after the redesign that removed the engineering error from the list of problem sources. The remaining current problem sources include (1) test technician errors (responsible for 52.6 percent of the failures) and (2) manufacturing and handling errors (responsible for 42.1 percent of the failures). These failures, which account for 94.7 percent of all failures, are potentially

TABLE 3-1

PERFORMANCE AND DESIGN DATA FOR PN 836130

Electrical power requirements	
Input voltage, vdc	24 to 32
Excitation current, ma	25 (max.)
Operating pressure range, psig	0 to 60
Operating temperature range, $^{\circ}F$	35 to 160
Accuracy, psig	±1.5 (±0.125 v)
Time constant of response	Minimum
Output signal	0 v at 0 psig to 5 vdc at 60 psig. Output signal shall not exceed 6.4 v in the event of overpressurization
Output ripple	Ripple component of output signal shall not exceed 10 mv rms
Load resistance, ohms	30,000
Output impedance, ohms	500 (max.)
Sensed fluid	Water-glycol solution per SS-1070-R
Proof pressure, psig	90 at $70^{\circ}F$
Burst pressure, psig	150 at $70^{\circ}F$
Sensing port	MS33656-2 (1/8-in. OD tube)
External leakage	1.3×10^{-4} cc/hr water-glycol max. with 60 psia internal pressure at $70^{\circ}F$

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE 3-2

GLYCOL PUMP PRESSURE TRANSDUCER FAILURE EVALUATION

TRANSDUCER APPLICATION Glycol Pump Pressure Transducer

BASIC PART NUMBER 836130

TRANSDUCER MANUF. Whittaker (Pace-Wiancko)

TROUBLE REPORT SOURCE AiResearch/North American Rockwell

TRANSDUCER TYPE Pressure Differential

OPERATING PRINCIPLE Variable Reluctance-Twisted Bourdon Tube

MEASUREMENT RANGE 0-60 psi

MEASUREMENT MEDIA Water-Glycol per AiResearch Report SS-1070-R

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
836130-1	50019	6-1-66	A/R 9917-9	Human	Shift	Bourdon tube	Cleaning processes	C-38 Cleaning	Improve cleaning procedure	
836130-1	50004	2-17-67	A/R 13061-9	Human	Shift	Electric output circuit	28 vdc applied to 5 vdc output leads	Testing ATP	Color code electric test box	Re-educate test technicians
836130-1	50015	3-23-67	A/R 11354-9	Human	Shift	Bourdon tube	Suspect over-pressurization spike of 1-1/2 times proof	Testing	Procedures reviewed and found acceptable	
836130-1	50025	7-26-67	A/R 15438	Human	Shift	Bourdon tube/ E-core	Unit shows damage of being dropped or hit	Handling	None	Source of damage was indeterminate
836130-1	50021	12-19-67	A/R 16530-9	Human	Shift	Bourdon tube/ E-core	Suspect mis-handling	Handling	None	Next assy pump was returned by NR for damaged tubes leading to the transducers
836130-2	50034	4-25-68	A/R 17680	Human	Shift	Bourdon tube distorted	Suspect over-pressurization	Testing	None	
836130-1	50016	7-12-68	A/R 16663	Human	Shift	Bourdon tube distorted	Suspect over-pressurization	Testing	--	
836130-1	50055	7-19-68	A/R 16668-9	Human	Shift	Bourdon tube distorted	Handling shocks	Handling	None	
836130-2	50055	7-26-68	A/R 16668	Human	Shift	Bourdon tube distorted	Suspect over-pressurization	Testing	--	

TABLE 3-2 (Continued)

TRANSDUCER APPLICATION Glycol Pump Pressure Transducer
BASIC PART NUMBER 836130
TRANSDUCER MANUF. Whittaker (Pace-Wiancko)
TROUBLE REPORT SOURCE AiResearch/North American Rockwell

TRANSDUCER TYPE Pressure Differential
OPERATING PRINCIPLE Variable Reluctance-Twisted Bourdon Tube
MEASUREMENT RANGE 0-60 psi
MEASUREMENT MEDIA Water-Glycol per AiResearch Report SS-1070-R

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
836130-2	50017	8-19-68	A/R 17794-9	Elec.	Shift	E-core package	Minor shift during burn-in cycle	Random	None	Burn-in is run to screen out this type failure
836130-2	50040	9-19-68	NR 119438-2	Human	Shift	Bourdon tube	Unit over-pressurized during system test	NR testing	None	System over-pressure could not be verified
836130-1	50057	10-3-68	A/R 19199-9	Human	Shift	Bourdon tube	Struck by mech. object during cleaning	C-38 Cleaning	Incorporate instructions in cleaning procedure	Cleaning vendor is Cemarc
836130-1	50016	10-13-68	A/R 19195	Mech.	Shift	Pressure sensing mechanism	Contamination	Manufacturing assembly	None	
836130-1	50020	11-7-68	NR 60878	Human	Shift	--	Unit over-pressurized during system test	Testing	--	
836130-1	50021	11-7-68	NR 60875	Human	Shift	--	Unit over-pressurized during system test	Testing	--	
836130-2	50063	12-5-68	A/R 19132	Human	High output ripple	Shorted transistor and two diodes	Input power applied to output pins	Testing	Use electric connector on test equipment was banana jacks	
836130-2	50037	5-2-69	A/R 19174	Human	Leakage	Welded joint	Cracked weld	Manufacturing inspection	Port replaced	
836130-2	50035	6-3-69	A/R 19181	Human	Shift	Variation in test equipment	Test equipment tolerance	Engineering	Recalibrate unit	

FOLDOUT FRAME 1

FOLDOUT FRAME 2

Table 3-2 (Continued)

TRANSDUCER APPLICATION Glycol Pump Pressure Transducer
BASIC PART NUMBER 836130
TRANSDUCER MANUF. Whittaker (Pace-Wiancko)
TROUBLE REPORT SOURCE AiResearch/North American Rockwell

TRANSDUCER TYPE Pressure Differential
OPERATING PRINCIPLE Variable Reluctance-Twisted Bourdon Tube
MEASUREMENT RANGE 0-60 psi
MEASUREMENT MEDIA Water-Glycol per AiResearch Report SS-1070-R

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
836130-2	50036	6-10-69	A/R 19182-9	Human	Shift	Variation in test equipment	Test equipment tolerance	Testing	Recalibrate unit	
836130	50030	11-14-69	NR PF108522	Human	Shift	Bourdon tube overstressed	Unit over-pressurized	(Testing) human	Relief valves added to coolant loops	
836130-2	0028	11-24-69	A/R 20328-0	Human	Shift	Bourdon tube overstressed	Unit over-pressurized	(Testing) human	Personnel cautioned	

PROBLEM AREA	PERCENT	MODE: NO OUTPUT	MODE: SHIFT	MODE: LOW OUTPUT	MODE: HIGH OUTPUT	MODE: FIXED OUTPUT	MODE: LOW RESISTANCE	MODE: LEAKAGE	MODE: ERRATIC	MODE: RIPPLE	MODE: DRIFT	MODE: PEELING	MODE: NONE	TYPE: HUMAN	TYPE: ELECTRICAL	TYPE: MECHANICAL	SENSING MECHANISM ELEC: OPEN	SENSING MECHANISM ELEC: SHORT	SENSING MECHANISM MECHANICAL: FROZEN	SENSING MECHANISM MECHANICAL: OVERPRESSURIZED	SENSING MECHANISM MECHANICAL: LEAKAGE	SENSING MECHANISM MECHANICAL: DAMAGED	SIGNAL CONDITIONING AND TRANSMISSION MECHANISM: UNKNOWN	MISCONNECTED	POOR ASSEMBLY	DEGRADED	PROCESS	MATERIAL	CONTAMINATION	DAMAGED	TEST EQUIPMENT	NOT ANALYZED
ENGINEERING: DESIGN	9.5		2											2																	2	
ENGINEERING: TESTING: PROCEDURE, ATP																																
ENGINEERING: TESTING: QUAL: ERROR																																
ENGINEERING: TESTING: QUAL: PROCEDURE																																
MANUFACTURING: PLANNING																																
MANUFACTURING: FABRICATION																																
MANUFACTURING: ASSEMBLY	4.8		1													1			1													
MANUFACTURING: QUALITY CONTROL																																
MANUFACTURING: INSPECTION	4.8							1						1							1											
MANUFACTURING: ATP TEST ERROR	47.5		9							1				10						7		1		2								
TEST EQUIPMENT FAILURE																																
LOX CLEANING	9.5		2											2								2										
HANDLING	14.3		3											3								2								1		
FINAL INSTALLATION: RECEIVING INSPECTION (TEST AND EQUIPMENT)																																
FINAL INSTALLATION: INSTALLATION	4.8		1												1					1												
RANDOM FAILURE	4.8		1											1																1		
UNCONFIRMED FAILURE																																
NOT ANALYZED FAILURE REPORT																																
TOTALS	100		19					1		1				19	1	1			1	8	1	5		2						2	2	
PERCENT			90.4					4.8		4.8				90.4	4.8	4.8			4.8	38.1	4.8	23.8		9.5						9.5	9.5	

FAILURE CAUSE

Figure 3-1. Glycol Pump Pressure Transducer Failure Matrix

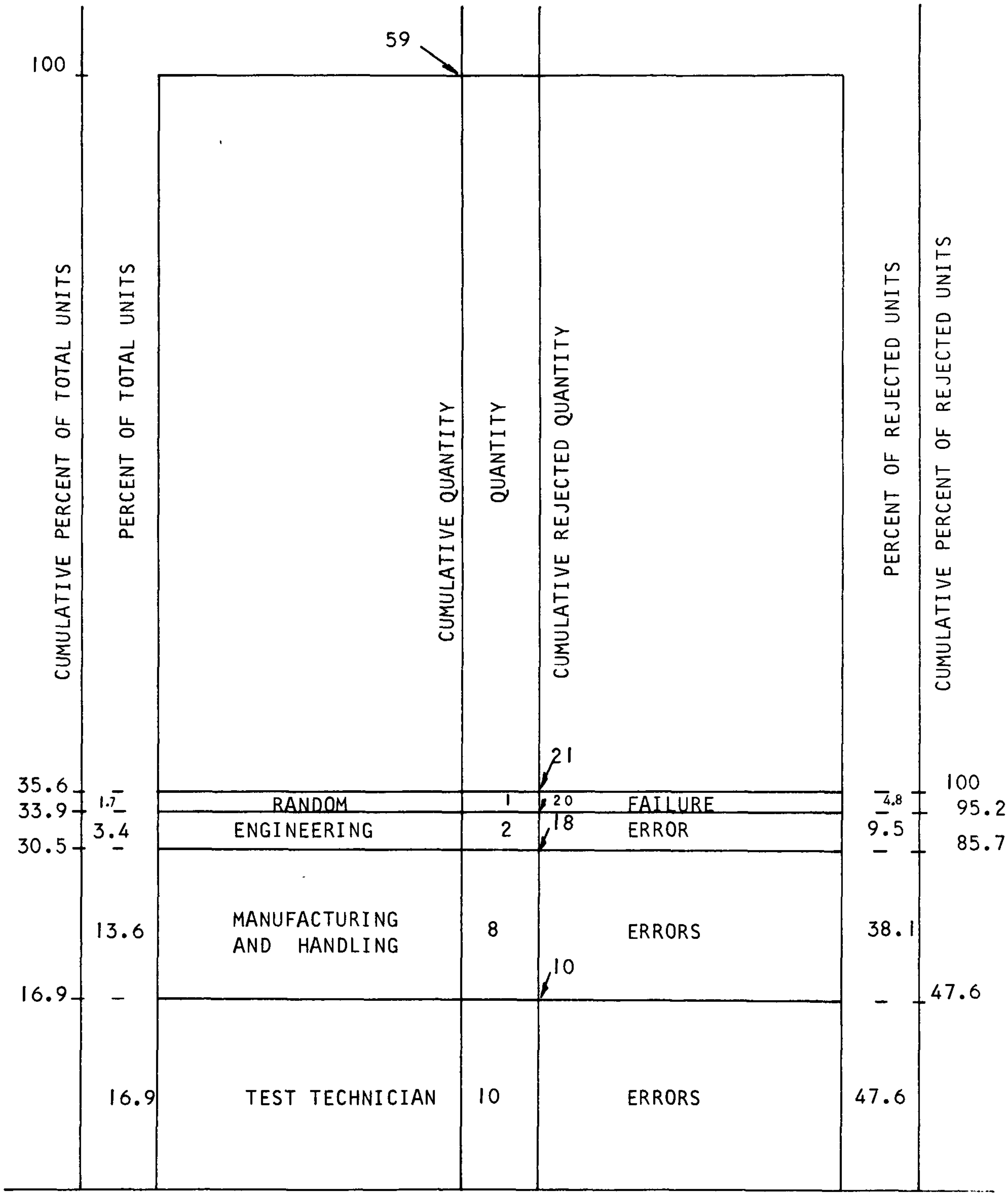


Figure 3-2. Distribution of Failures According to Problem Area

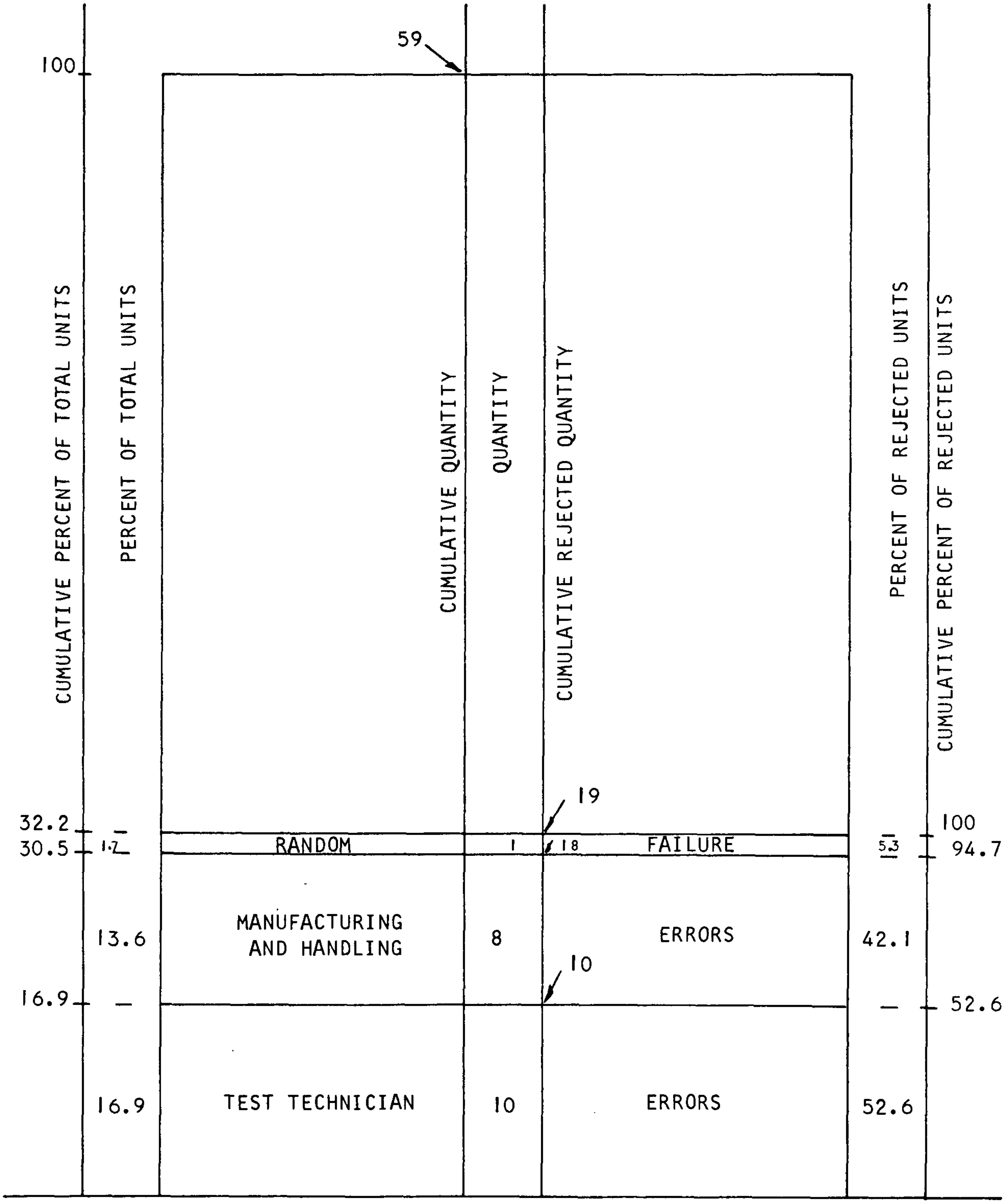


Figure 3-3. Failure Distribution after Engineering Redesign

avoidable. Recommendations for actions that will drastically reduce the quantity of failures resulting from these problem areas are summarized in Section 2 of this report.

SECTION 4

WATER GLYCOL QUANTITY TRANSDUCER (AIRESEARCH PN 837026)

PURPOSE AND DESCRIPTION

The water-glycol quantity transducer measures the volume of water-glycol stored in the accumulator. Depending on the volume of water-glycol stored in the accumulator, a differential pressure across the bellows of the accumulator is sensed by the transducer and a proportional electrical signal generated. This signal is used for telemetry purposes.

The transducer utilizes a Bourdon tube for the pressure-responsive element and a combination of a magnetic core, an armature (which completes the magnetic circuit), and inductance coils for the translation of physical motion into a proportional electrical signal.

PERFORMANCE AND DESIGN DATA

Table 4-1 lists performance and design data for this transducer.

FAILURE AND DESIGN REVIEW

Table 4-2 is a summary of the 32 failure reports which were reviewed for this transducer evaluation. The information indicated in Table 4-2 has been summarized in the failure matrix of Figure 4-1.

Twenty-nine of the total of 32 reported failures were random electrical failures.

Twelve of the human-caused failures resulted from inadvertent overpressurization of the transducer. Seven of the remaining failures resulted from misconnection of input leads to the output terminals. Among the remaining ten failure reports, two failures were unconfirmed, two were caused by test equipment failure, and six others were caused by errors at various stages of the production process. Figures 4-2 and 4-3 illustrate typical failures caused by errors in production processing.

Figure 4-4 shows the distribution of the failures according to the sources of problems. The two unconfirmed failure reports are not included in this histogram. The current problem sources include (1) test technician errors, responsible for 63.3 percent of the failures, and (2) manufacturing and other errors, responsible for 26.7 percent of the failures. These failures, which account for 90 percent of all failures, are potentially avoidable. Recommendations for actions that will drastically reduce the quantity of failures resulting from these problem areas are summarized in Section 2 of this report.

TABLE 4-1

PERFORMANCE AND DESIGN DATA FOR PN 837026

Electrical power requirements	
Input voltage, vdc	28 ±4
Excitation current, ma	35 (max.)
Accuracy, psig	±0.5 (±0.7 cu in.)
Quantity range, cu in.	0 to 35
Operating pressure range, psig	0 to 25
Operating temperature range, °F	
Liquid side	35 to 160
Gas side	0 to 150
Time constant	Within 30 ms
Output signal	0 volts at 0 psig to 5 vdc at 25 psig. Output signal shall not exceed 6.5 vdc.
Output ripple	Ripple component of output signal shall not exceed 10 mv rms
Output resistance, ohms	30,000
Output impedance, ohms	500 (max.)
Proof pressure, psig	37.5
Burst pressure, psig	62.5
External leakage	Zero with 25 psig internal pressure
Environmental conditions	Per AiResearch Report SS-1060-R; Type I equipment
Weight, lb	0.6
Electrical connector	Per MIL-C-26482C

FOLDOUT FRAME | FOLDOUT FRAME 2

TABLE 4-2

GLYCOL ACCUMULATOR QUANTITY TRANSDUCER FAILURE EVALUATION

TRANSDUCER APPLICATION Glycol Accumulator Quantity Transducer
BASIC PART NUMBER 837026-5-I
TRANSDUCER MANUF. AiResearch
TROUBLE REPORT SOURCE NR Space Div. and/or AiResearch Mfg. Co.

TRANSDUCER TYPE Pressure Differential
OPERATING PRINCIPLE Twisted Bourdon Tube and Variable Reluctance
MEASUREMENT RANGE 0-25 PSI Differential
MEASUREMENT MEDIA Water Glycol

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
837026-I	50059	6-8-69	AR18748	Elec	Output too low (Shift)	Transistor burnt out	Testing (Burn-in tests)	None Purpose of test	None	Purpose of burn-in test is to detect defective components.
837026-5-I	50059	2-17-69	AR19153	Elec	Output ripple	(Suspect) Transistor burnt out	Unknown	Random	Part was rejected for flight use	Failure cause could not be duplicated and failure can be detected during burn in
837026-5-I	50054	9-19-68	AI17262	Human	Output too high	Deformation	Part over-pressurized	Testing	None	E-core okay Bourdon tube over-stressed
837026-5-I	50038	8-6-68	AR10081	Human	Output too low	Output transistor and diode burnt out	Input power applied to output	Manufacturing	None	Wiring crossed during mfg. assembly resulting in misapplication of power during test.
837026-5-I	50013	7-18-68	AR16671	Human	Output too high	Bourdon tube damaged	Mishandling	Manufacturing	None	Physical evidence of mishandling evident.
837026-5-I	50027	4-26-68	AR17681	Human	None		NO FAIL	URE		Test equipment malfunction causing burn-in temp. for 5 min. Part is satisfactory.
837026-4-I	50030	2-22-68	AR16566	Human	Low insulation resistance	Internal wire short	Improper installation	Manufacturing	None - except Reliability Group will survey part	Low IR does not degrade test performance
837026-4-I	50023	6-12-67	AR8880	Human	Low insulation resistance	Contamination	Mishandling	Cleaning damage	None - Supplier QC adequate for contamination control.	This failure does not effect performance of transducer.
837026-4-I	50023	3-23-67	AR8899	Human	Low insulation resistance	Contamination	Mishandling	Testing	None	

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE 4-2 (Continued)

TRANSDUCER APPLICATION Glycol Accumulator Quantity Transducer

BASIC PART NUMBER 837026-5-1

TRANSDUCER MANUF. AiResearch

TROUBLE REPORT SOURCE NR Space Div. and/or AiResearch Mfg. Co.

TRANSDUCER TYPE Pressure Differential

OPERATING PRINCIPLE Twisted Bourdon Tube and Variable Reluctance

MEASUREMENT RANGE 0-25 PSI Differential

MEASUREMENT MEDIA Water Glycol

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
837026-4-1	50-003 and 50-005	2-17-67	AR13062	Human	Output too high (Shift)	Wires crossed	Input power applied to output	Manufacturing	All technicians reeducated on proper assembly of part	
837026-4-1	50011 and 50014	11-11-66	AR12036	Human	Output too high (Shift)	Wires crossed	Input power applied to output	Manufacturing	Surveillance program has been initiated between Vendor and AiResearch.	
837026-4-1	50004	10-21-66	AR11384	Human	Output too high (Shift)	Wires crossed	Input power applied to output	Manufacturing	Surveillance program has been initiated between Vendor and AiResearch.	
837026-4-1	50036	9-30-66	AR11324	Human	Output too high (Shift)	Wires crossed	Input power applied to output	Manufacturing	Surveillance program has been initiated between Vendor and AiResearch.	
837026-4-1	50007	8-9-66	REPORT	NOT	LEGIBLE.	NOT AIRESEARCH	REPORT.			
837026-4-1	50007	8-6-66	AR6632	Human	Shift	Variation in test equipment	Test equipment tolerance	Testing	Test set-up correct and part passed test.	
837036-1-1	9196	2-27-66	AR10748	Human	Shift	Stabilization	Part "set" changing calibration	Manufacturing or design	Mfg. process changed to add cycling test to cause part to "set" so that stabilization shift is prevented.	
837026-4-1	50039	7-12-66	AR10351	Human	Shift	Deformation	Overpressurized	Testing	Mfg. procedure revised so that part is not test out of sequence allowing it to be overpress.	Proof pressure should be performed prior to first assembly and calibration
837026-4-1	50030 and 50031	7-11-66	AR10217	Human	Output too high (Shift)	Deformation	Overpressurized	Testing	Mfg. procedure revised so that part is not test out of sequence allowing it to be overpress.	Proof pressure should be performed prior to first assembly and calibration

TABLE 4-2 (Continued)

TRANSDUCER APPLICATION Glycol Accumulator Quantity Transducer

BASIC PART NUMBER 837026-5-1

TRANSDUCER MANUF. AiResearch

TROUBLE REPORT SOURCE NR Space Div. and/or AiResearch Mfg. Co.

TRANSDUCER TYPE Pressure Differential

OPERATING PRINCIPLE Twisted Bourdon Tube and Variable Reluctance

MEASUREMENT RANGE 0-25 PSI Differential

MEASUREMENT MEDIA Water Glycol

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
837026-4-1	50032	7-11-66	AR10216	Human	Output too high (Shift)	Deformation	Overpressurized	Mfg Testing	Mfg. procedure revised so part is not tested out of seq. so that is out of calib. when proofed	Proof pressure should be performed prior to final assembly and calibration
837026-4-1	50040, 50035, and 50038	7-11-66	AR10213	Human	Output too high (Shift)	Deformation	Overpressurized	Mfg Testing	Mfg. procedure revised so part is not tested out of seq. so that is out of calib. when proofed	Proof pressure should be performed prior to final assembly and calibration
837026-4-1	50019, 50027, and 50023	7-11-66	AR9932	Human	Output too high (Shift)	Deformation	Overpressurized	Mfg Testing	Mfg. procedure revised so part is not tested out of seq. so that is out of calif. when proofed	Proof pressure should be performed prior to final assembly and calibration
837026-4-1	50031	7-2-66	AR9262	Human	Output too high (Shift)	Deformation	Overpressurized	Mfg. Testing	Mfg. procedure revised so part is not tested out of seq. so that is out of calib. when proofed	Proof pressure should be performed prior to final assembly and calibration
837026-4-1	50026	7-1-66	AR9261	Human	Output too high (Shift)	Deformation	Overpressurized	Mfg Testing	Mfg. procedure revised so part is not tested out of seq. so that is out of calib. when proofed	Proof pressure should be performed prior to final assembly and calibration
837026-4-1	50011 and 50018	6-6-66	AR9939	Human	Output too high (Shift)	Deformation	Overpressurized	Mfg Testing	Mfg. procedure revised so part is not tested out of seq. so that is out of calib. when proofed	Proof pressure should be performed prior to final assembly and calibration
837026-4-1	50010 and 50015	5-28-66	AR9983	Human	Output too high (Shift)	Deformation	Overpressurized	Mfg Testing	Mfg. procedure revised so part is not tested out of seq. so that is out of calib. when proofed	Proof pressure should be performed prior to final assembly and calibration
837026-4-1	50002	5-22-66	AR9905	UNCONFIRMED		Deformation	Overpressurized	Mfg Testing	Mfg. procedure revised so part is not tested out of seq. so that is out of calib. when proofed	Proof pressure should be performed prior to final assembly and calibration
837026-4-1	50008	5-11-66	AR9196	Human	Output too high (Shift)	Deformation	Overpressurized	Mfg Testing	Mfg. procedure revised so part is not tested out of seq. so that is out of calib. when proofed	Proof pressure should be performed prior to final assembly and calibration

TABLE 4-2 (Continued)

TRANSDUCER APPLICATION Glycol Accumulator Quantity Transducer
BASIC PART NUMBER 837026-5-1
TRANSDUCER MANUF. AiResearch
TROUBLE REPORT SOURCE NR Space Div. and/or AiResearch Mfg. Co.

TRANSDUCER TYPE Pressure Differential
OPERATING PRINCIPLE Twisted Bourdon Tube and Variable Reluctance
MEASUREMENT RANGE 0-25 PSI Differential
MEASUREMENT MEDIA Water Glycol

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
837026-4-1	50004	5-11-66	AR9176	Human	Output too high	Deformation	Overpressurized	Mfg. Testing	Mfg. procedure revised so that part is not tested out of seq. so that it is out of calib. when it is proofed.	
837026-3-1	0002	9-1-65	AR6132	Human	Output too high	Transistor shorted	Input power applied to output	Testing	None	
837026-3-1	69-201	5-20-65	AR6058	Human	Output too high	Transistor shorted	Input power applied to output	Testing	None	
837026-3-1	0002	3-29-65	AR4770	Human	Output too high (Shift)	Pressure sensing mechanism	Improperly adjusted	Manufacturing	None	During mfg locking cement was improperly applied allowing adj screw to loosen changing set point.
837026-2	69-201	2-4-65	AR4472	Elec	Fixed output	Output transistor	Unknown	Testing	None	

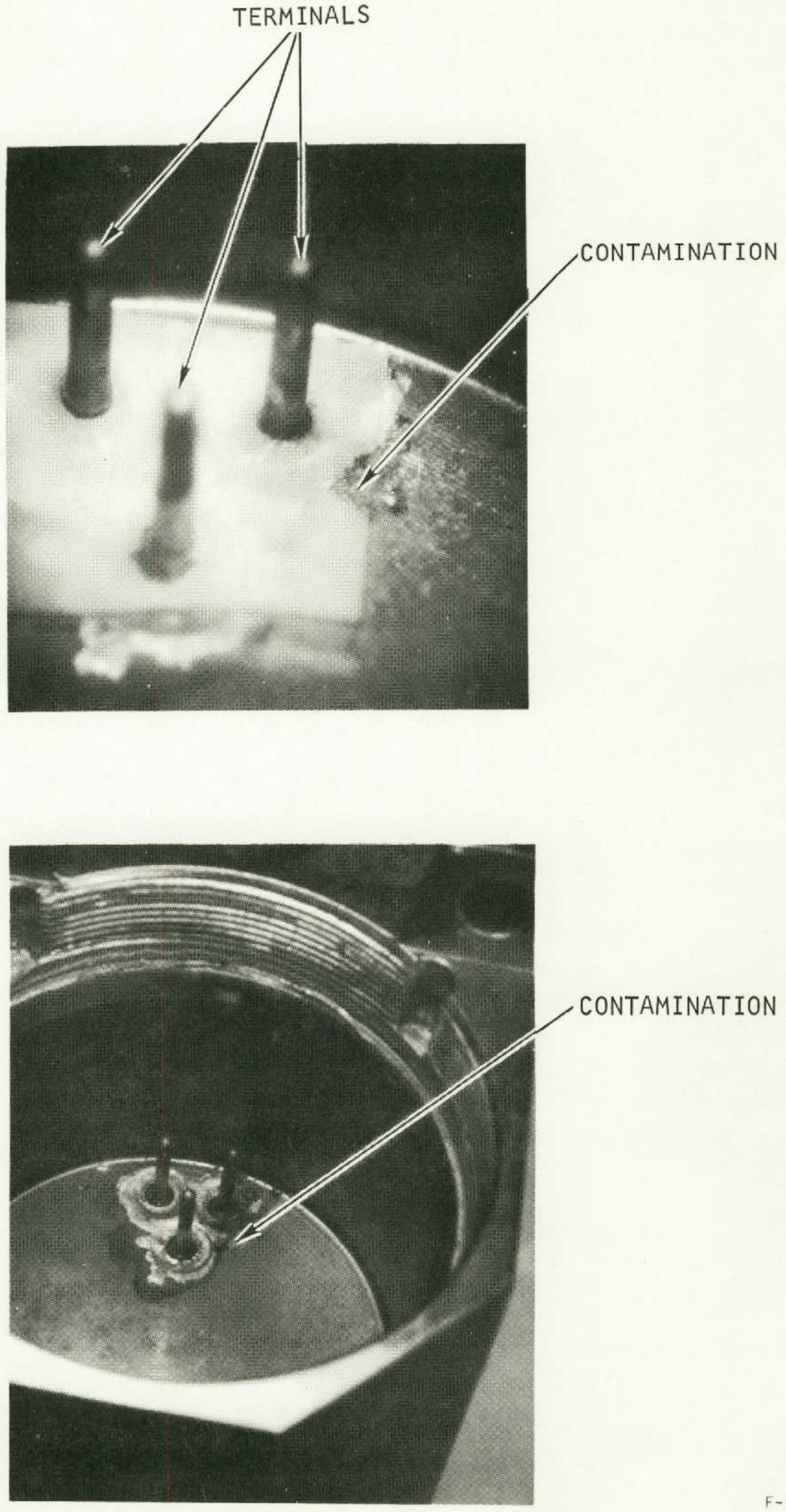
FAILURE — MODE / TYPE

PROBLEM AREA		PERCENT	MODE: NO OUTPUT	SHIFT	LOW OUTPUT	HIGH OUTPUT	FIXED OUTPUT	LOW RESISTANCE	LEAKAGE	ERRATIC	RIPPLE	DRIFT	PEELING	NONE	TYPE: HUMAN	ELECTRICAL	MECHANICAL
ENGINEERING	DESIGN																
ENGINEERING	PROCEDURE, ATP																
ENGINEERING	ERROR	21.9				6		1							7		
ENGINEERING	PROCEDURE																
MANUFACTURING	PLANNING	3.1		1											1		
MANUFACTURING	FABRICATION																
MANUFACTURING	ASSEMBLY	9.4				2		1							3		
MANUFACTURING	QUALITY CONTROL																
MANUFACTURING	INSPECTION																
MANUFACTURING	ATP TEST ERROR	37.6		1	1	10									12		
TEST EQUIPMENT FAILURE		6.2		1			1								2		
LOX CLEANING																	
HANDLING		6.2				1		1							2		
FINAL INSTALLATION	RECEIVING INSPECTION (TEST AND EQUIPMENT)																
FINAL INSTALLATION	INSTALLATION																
RANDOM FAILURE		9.4			2		1									3	
UNCONFIRMED FAILURE		6.2												2	2		
NOT ANALYZED FAILURE REPORT																	
TOTALS		100		3	3	19	2	3						2	29	3	
PERCENT				9.4	9.4	59.4	6.2	9.4						6.2	90.6	9.4	

FAILURE — MECHANISM / FAILURE CAUSE

PROBLEM AREA		SENSING MECHANISM — ELEC: OPEN	ELEC: SHORT	MECHANICAL: FROZEN	OVERPRESSURIZED	LEAKAGE	DAMAGED	SIGNAL CONDITIONING AND TRANSMISSION MECHANISM: UNKNOWN	MISCONNECTED	SHORT	POOR ASSEMBLY	DEGRADED	PROCESS	MATERIAL	CONTAMINATION	DAMAGED	TEST EQUIPMENT	NOT ANALYZED
ENGINEERING	DESIGN																	
ENGINEERING	PROCEDURE, ATP																	
ENGINEERING	ERROR								6						1			
ENGINEERING	PROCEDURE																	
MANUFACTURING	PLANNING							1										
MANUFACTURING	FABRICATION																	
MANUFACTURING	ASSEMBLY				1					1	1							
MANUFACTURING	QUALITY CONTROL																	
MANUFACTURING	INSPECTION																	
MANUFACTURING	ATP TEST ERROR				11				1									
TEST EQUIPMENT FAILURE																	2	
LOX CLEANING																		
HANDLING												1			1			
FINAL INSTALLATION	RECEIVING INSPECTION (TEST AND EQUIPMENT)																	
FINAL INSTALLATION	INSTALLATION																	
RANDOM FAILURE										1		2						
UNCONFIRMED FAILURE								2										
NOT ANALYZED FAILURE REPORT																		
TOTALS					12			3	7	2	1	3			2		2	
PERCENT					37.6			9.4	21.9	6.2	3.1	9.4			6.2		6.2	

Figure 4-1. AiResearch PN 837026, Apollo Block II ECS Component Water Glycol Quantity Transducer Failure Matrix



F-16411

Figure 4-2. Water-Glycol Quantity Transducer Failure Report Sample

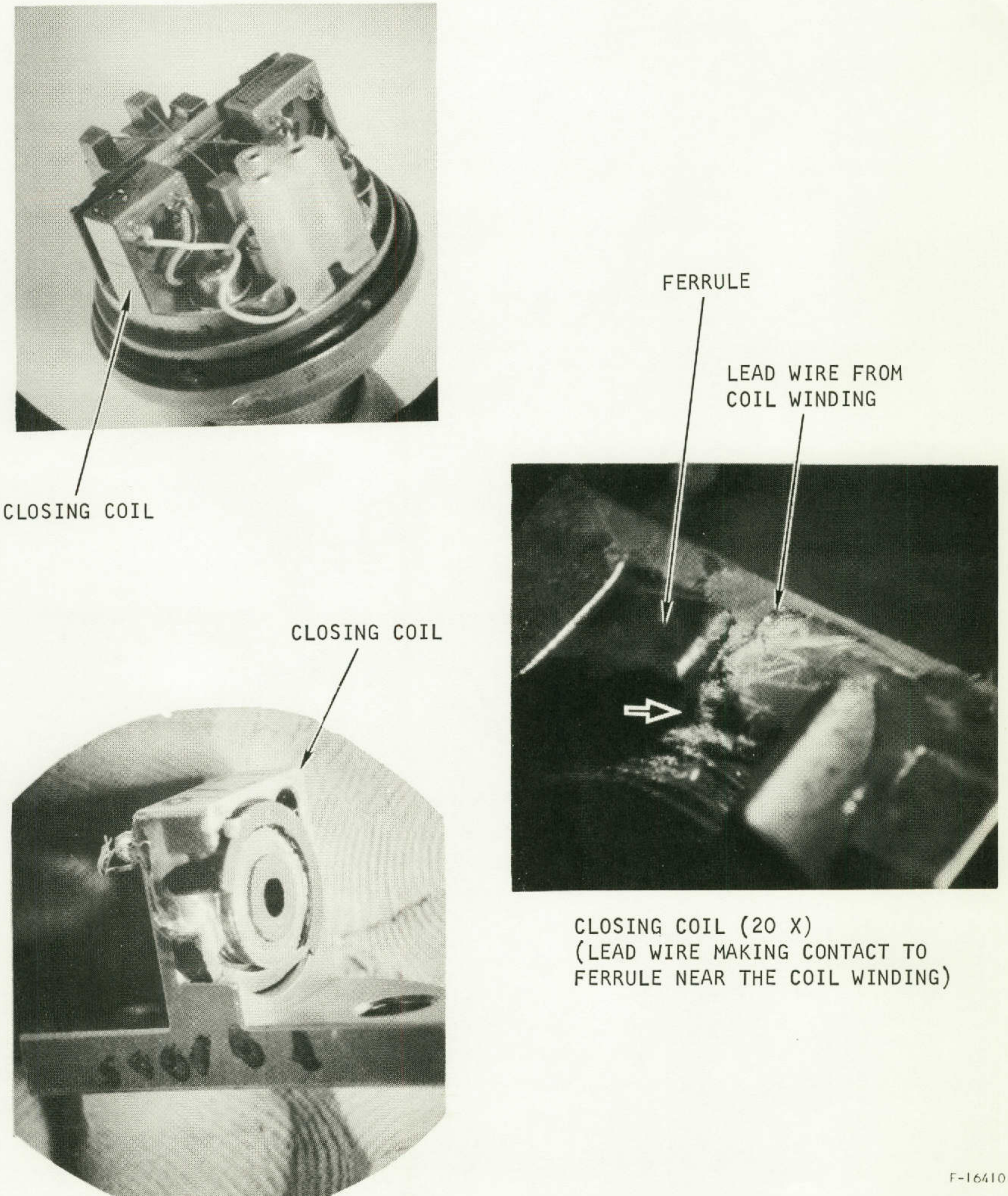


Figure 4-3. Water-Glycol Quantity Transducer Failure Report Sample

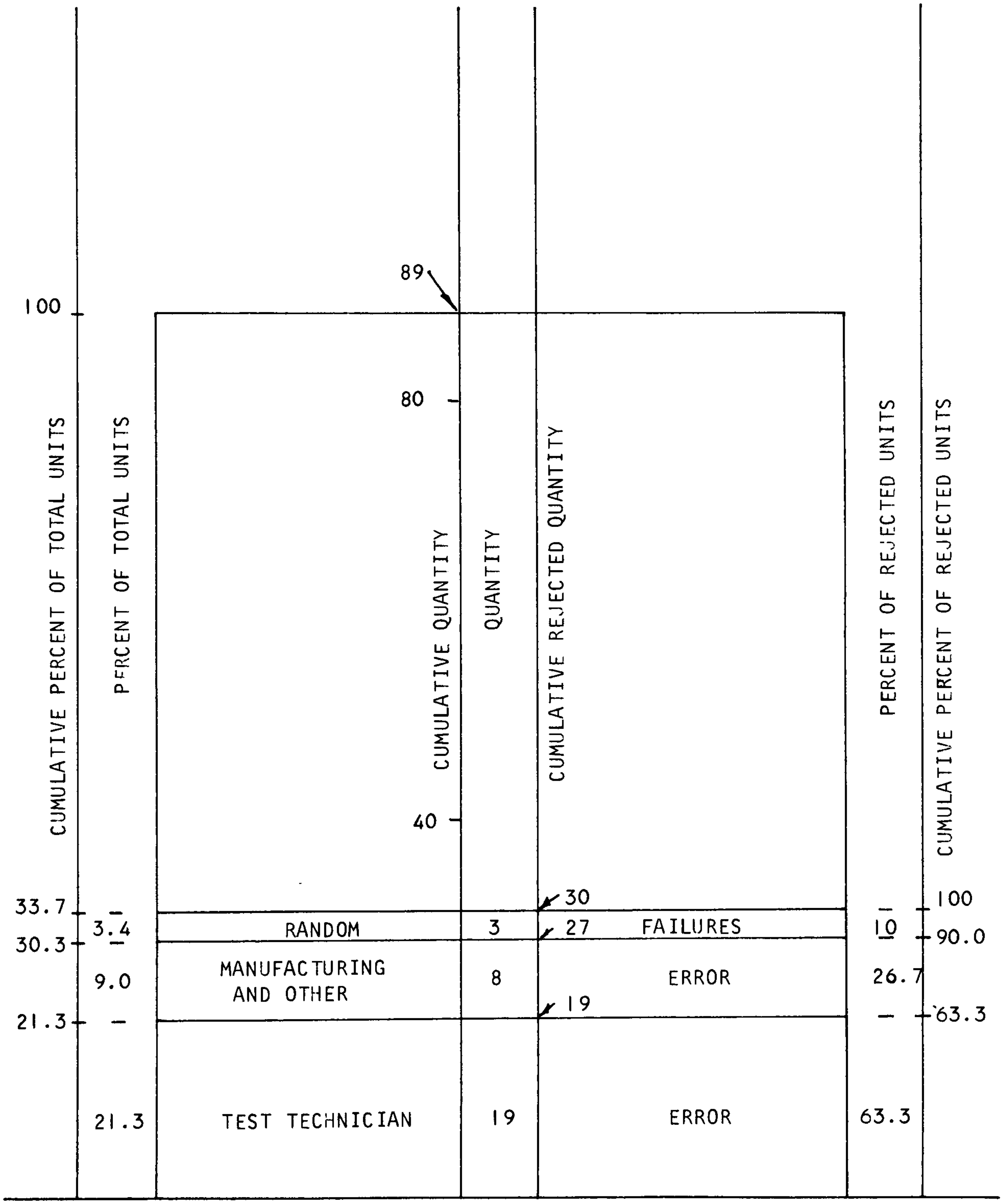


Figure 4-4. Distribution of Failures According to Problem Area

SECTION 5

CABIN PRESSURE TRANSDUCER (AIRESEARCH PN 836132)

PURPOSE AND DESCRIPTION

The cabin pressure transducer measures the static pressure of the cabin gases by sensing the pressure and generating a proportional electrical signal. This signal is used for ground checkout, for the crew's visual information via an indicator, and for telemetry data to be transmitted to a ground station, and serves as an indication of the performance of the cabin pressure regulator.

The transducer utilizes a Bourdon tube for the pressure-responsive element and a combination of a magnetic core, an armature (which completes the magnetic circuit), and inductance coils for the translation of physical motion into a proportional electrical signal.

PERFORMANCE AND DESIGN DATA

Table 5-1 presents performance and design data for this transducer.

FAILURE AND DESIGN REVIEW

Table 5-2 is a summary of the two failure reports which were reviewed for this transducer evaluation. Because of the very low quantity of the failures, a special matrix was not constructed. The information indicated in Table 5-2 has been directly transferred to a histogram in Figure 5-1. This figure shows that both of the failures were caused by human errors and hence are potentially avoidable. Recommendations for actions that will eliminate failures from these problem areas are summarized in Section 2 of this report.

TABLE 5-1

PERFORMANCE AND DESIGN DATA FOR PN 836132

Electrical power requirements	
Input voltage, vdc	28 per SS-1070
Excitation current, ma	25 (max.)
Operating pressure range, psia	0 to 17
Operating temperature range, ^{o}F	0 to 150
Accuracy, psia	±0.425 (±0.125 v)
Time constant of output signal	Minimum
Output signal	Proportional to sensed pressure. 0 v at 0 psia to 5 vdc at 17 psia. Output signal shall not exceed 6.5 v in the event of overpressurization.
Output ripple, mv rms	10 (max.)
Output load, ohms	30,000
Output impedance, ohms	500 (max.)
Pressure sensing port	Per MS 33656-4 (1/4in. OD tube)
Proof pressure, psia	25.5 at $70^{o}F$
Burst pressure, psia	43 at $70^{o}F$
External leakage	6×10^{-6} lb/hr O_2 max. when pressurized to 4 psig at $70^{o}F$
Weight, lb	0.5

TABLE 5-2

CABIN ABSOLUTE PRESSURE TRANSDUCER FAILURE EVALUATION

TRANSDUCER APPLICATION Apollo ECS, Cabin Abs. Press.
BASIC PART NUMBER 836132 (AiResearch)
TRANSDUCER MANUF. Whittaker (PN 600265)
TROUBLE REPORT SOURCE AiResearch/North American Rockwell

TRANSDUCER TYPE Pressure Transducer
OPERATING PRINCIPLE Twisted Bourdon Tube
MEASUREMENT RANGE 0-17 PSIA
MEASUREMENT MEDIA Breathing Oxygen

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
836132-2-1	50026	1-20-71	22400 (NR)	Human	Output high	Pressure sensing mechanism	Overpressurized	Manufacturing	None	E-pack wire slightly bowed.
ME449-0095-0021	500004	11-15-68	60921 (NR)	Unknown	Output high	Pressure sensing mechanism	Suspect overpressure	Unknown	None	Bourdon tube was not deformed.

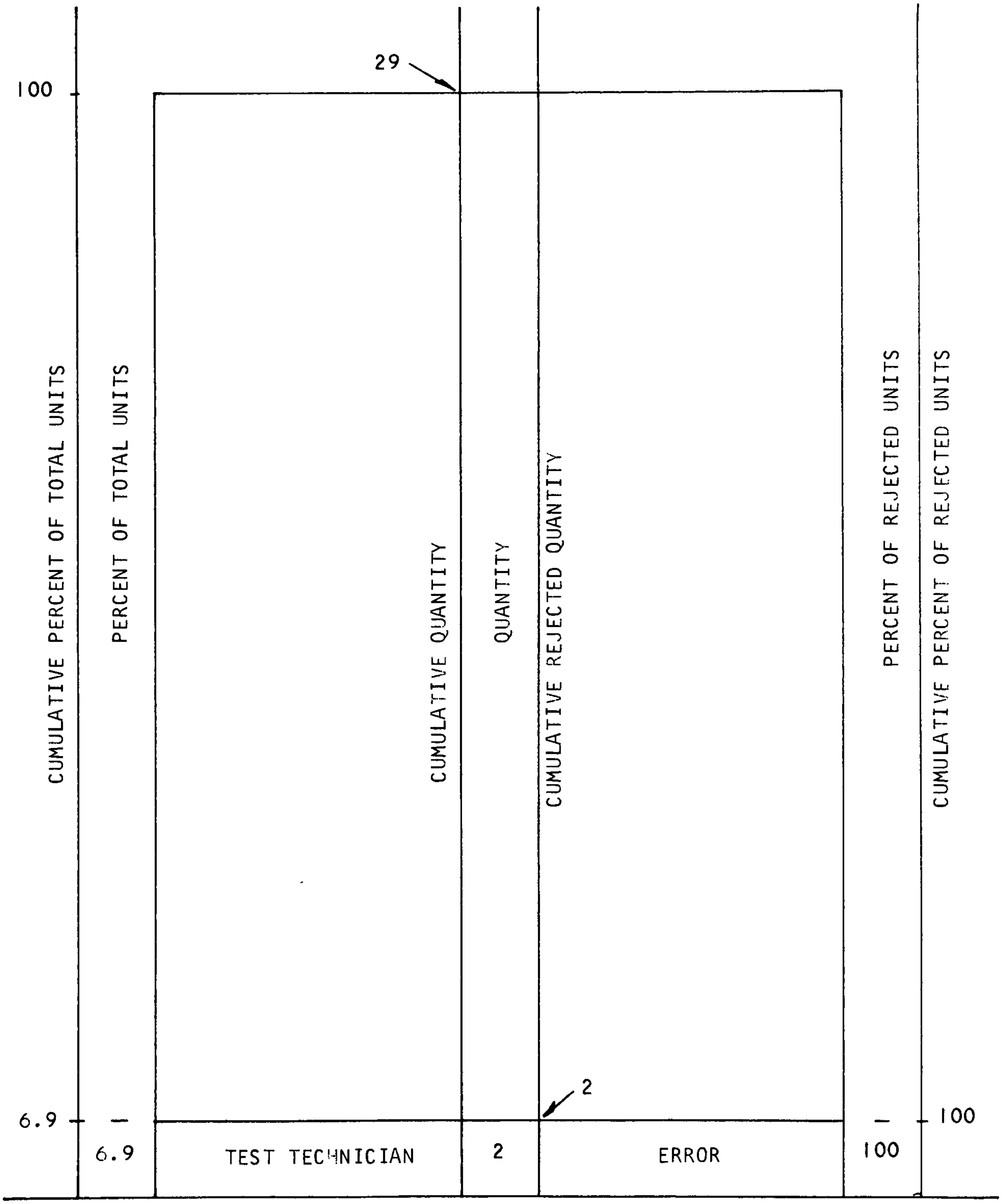


Figure 5-1. Distribution of Failures

SECTION 6

SUIT-SUPPLY AND CABIN PRESSURE TRANSDUCER (AIRESEARCH PN 837044)

PURPOSE AND DESCRIPTION

The pressure transducer is used as follows:

(a) To measure the static pressure of the gases flowing through the suit-supply inlet manifold just prior to entering the pressure suits.

(b) To measure the static pressure of the cabin gases. The gas pressure serves as an indication of the performance of the cabin pressure regulator.

The measurement is accomplished by sensing the pressure and generating a proportional electrical signal.

The transducer utilizes a Bourdon tube for the pressure-responsive element and a combination of a magnetic core, an armature (which completes the magnetic circuit), and inductance coils for translation of the physical motion into a proportional electrical signal.

PERFORMANCE AND DESIGN DATA

Table 6-1 presents the performance and design data for this transducer.

FAILURE AND DESIGN REVIEW

Table 6-2 is a summary of the 19 failure reports which were reviewed for this transducer evaluation. The information included in Table 6-2 has been summarized in the failure matrix of Figure 6-1. Seventeen of the total of 19 reported failures were caused by human errors. The other two were random electrical failures.

Eight of the human-caused failures resulted from inadvertent overpressurization of the transducer. Sensitivity of the Bourdon tubes to pressure spikes is the mechanism of these failures. One of the failures had not been analyzed. Two failures were caused by misconnection of the input power leads to the output terminals. One unit shorted out because of assembly errors. Three units were rejected because of fabrication process errors. One rejection was caused by the choice of wrong material in the test equipment. One unit was rejected because it was damaged in handling. There were two random electrical failures.

Figure 6-2 shows the distribution of the failures according to the sources of problems. These problem sources include (1) test technician errors (responsible for 52.6 percent of failures), and (2) manufacturing and handling errors (responsible for 31.5 percent of failures). These failures, which account for

TABLE 6-1

PERFORMANCE AND DESIGN DATA FOR PN 837044

Electrical power requirements	
Input voltage, vdc	28 ±4
Excitation current, ma	35 (max.)
Operating pressure range, psia	0 to 17
Accuracy, psia	±0.34
Time constant of output signal	Within 30 ms
Output signal	0 v at 0 psia, 5 vdc at 17 psia. Output signal shall not exceed 6.5 v in the event of overpressurization.
Output ripple , mv rms	10 (max.)
Output load, ohms	30,000
Output impedance, ohms	500 (max.)
Proof pressure, psia	25.5 at 70°F
Burst pressure, psia	43 at 70°F
Weight, lb	0.6

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE 6-2

SUIT INLET AND CABIN PRESSURE TRANSDUCER FAILURE EVALUATION

TRANSDUCER APPLICATION Suit Inlet and Cabin Pressure Transducer

BASIC PART NUMBER A/R No. 837044, Whittaker No. 600245 and 600247

TRANSDUCER MANUF. Whittaker-Wianko

TROUBLE REPORT SOURCE AiResearch

TRANSDUCER TYPE Pressure

OPERATING PRINCIPLE Variable Reluctance-Twisted Bourdon Tube

MEASUREMENT RANGE

MEASUREMENT MEDIA

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
837044-1	70248	11/6/64	4289	Human	Calibration Shift	Distortion of sense mechanism	Overpressure	Testing	None	
837044-1-1	69213	4/13/65	5895	Human	Explosion in test setup	-	-	Testing	-	Failure did not relate to unit. Unit was good.
837044-3-1	0018	4/22/65	5805	Human	Plating peeling off unit	-	Improper surface preparation prior to plating	Manufacturing	Properly prepare surface	
837044-4-1	50001	5/4/66	9168	Human	Calibration Shift	-	Unit thought to be overpressurized during cleaning	Manufacturing	Revise cleaning procedure	
837044-4-1	50002	5/12/66	8440	Human	Calibration Shift	-	Unit thought to be overpressurized during cleaning	Manufacturing	Revise cleaning procedure	
837044-4-1	50001	5/18/66	9901	Human	Calibration Shift	-	Unknown. Thought to be cleaning procedure.	Manufacturing	Add more calibration checks before, during and after cleaning	
837044-4-1	50008	5/28/66	9952	Human	No output	Failed transistor	Input voltage applied to output circuit	Testing	None	
837044-4-1	50012	6/7/66	9918	Human	Calibration Shift	Distortion of sense mechanism	Overpressure during cleaning	Manufacturing	Revise cleaning procedure	
837044-4-1	50016	7/2/66	9263	Human	Calibration Shift	Distortion of sense mechanism	Overpressure during cleaning	Manufacturing	Revise cleaning procedure	

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE 6-2 (Continued)

TRANSDUCER APPLICATION Suit Inlet Pressure Transducer

TRANSDUCER TYPE Pressure

BASIC PART NUMBER A/R No. 837044, Whittaker No. 600245

OPERATING PRINCIPLE

TRANSDUCER MANUF. Whittaker-Wianko

MEASUREMENT RANGE

TROUBLE REPORT SOURCE AiResearch

MEASUREMENT MEDIA

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
837044-3-1	0012	7/14/66	10047	Human	Drift	Defective capacitor	Excessive stress applied to lead during assembly	Manufacturing	Caution production personnel	
837044-4-1	50006	7/26/66	10745	Human	Calibration Shift	Distortion of sense mechanism	Overpressure during cleaning	Manufacturing	Revise cleaning procedure	
837044-3-1	0013	9/19/66	11139	Elec	Erratic output	Failed (shorted) capacitor	Unknown	-	None	Probably random failure
837044-4-1	50010	10/28/66	12006	Human	Calibration Shift	-	-	-	-	Unit failure not analyzed
837044-4-1	50018	3/16/67	12253	Elec	Drift	Failed zener diode	Unknown	-	None	Probably random failure
837044-5-1	50020	10/27/67	16501	Human	No output	Failed electrical components	Input voltage applied to output terminals	Testing	Color code electrical connectors	
837044-5	50007	12/8/67	16525	Human	Calibration Shift	Housing of unit distorted	Installing over a burr in test fixture	Testing	None	
837044-5-1	50031	1/9/68	19144	Human	Full output	Shorted terminals on circuit board	Human error during potting operation	Manufacturing	None	
837044-5-1	50006	11/14/69	N/A No. PAC 3-350	Human	Erratic Operation	Particles of nickle plate and lunar dust contaminating unit	Poor internal plating	Manufacturing	Add filtering to transducer line	

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE 6-2 (Continued)

TRANSDUCER APPLICATION Suit Inlet Pressure Transducer

BASIC PART NUMBER A/R No. 837044, Whittaker No. 600245

TRANSDUCER MANUF. Whittaker-Wianko

TROUBLE REPORT SOURCE AiResearch

TRANSDUCER TYPE Pressure

OPERATING PRINCIPLE

MEASUREMENT RANGE

MEASUREMENT MEDIA

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
837044-5-1	50002	4/11/70	NA No. PAC 3-365	Human	Output Shift	Particles of nickle plate contaminating unit	Inadequate cleaning of unit.	Manufacturing	Clean all units while disassembled. Assemble in clean room.	

FOLDOUT FRAME 1 FOLDOUT FRAME 2

FAILURE

PROBLEM AREA		PERCENT	MODE												TYPE		
			NO OUTPUT	SHIFT	LOW OUTPUT	HIGH OUTPUT	FIXED OUTPUT	LOW RESISTANCE	LEAKAGE	ERRATIC	RIPPLE	DRIFT	PEELING	NONE	HUMAN	ELECTRICAL	MECHANICAL
ENGINEERING	DESIGN																
ENGINEERING – TESTING	PROCEDURE, ATP																
ENGINEERING – QUAL	ERROR																
ENGINEERING – QUAL	PROCEDURE																
MANUFACTURING	PLANNING																
MANUFACTURING	FABRICATION	15.8											3		3		
MANUFACTURING	ASSEMBLY	47.3		7			1					1			9		
MANUFACTURING	QUALITY CONTROL																
MANUFACTURING	INSPECTION																
MANUFACTURING	ATP TEST ERROR	10.5	2												2		
	TEST EQUIPMENT FAILURE	5.3												1	1		
	LOX CLEANING																
	HANDLING	5.3		1											1		
FINAL INSTALLATION	RECEIVING INSPECTION (TEST AND EQUIPMENT)																
FINAL INSTALLATION	INSTALLATION																
	RANDOM FAILURE	10.5								1		1				2	
	UNCONFIRMED FAILURE																
	NOT ANALYZED FAILURE REPORT	5.3		1											1		
	TOTALS	100	2	9			1			1		2	3	1	17	2	
	PERCENT		10.5	47.3			5.3			5.3		10.5	15.8	5.3	89.5	10.5	

PROBLEM AREA	MECHANICAL – SENSING MECHANISM – ELEC.		SENSING MECHANISM – MECHANICAL				SIGNAL CONDITIONING AND TRANSMISSION MECHANISM										
	OPEN	SHORT	FROZEN	OVERPRESSURIZED	LEAKAGE	DAMAGED	UNKNOWN	MISCONNECTED	SHORT	POOR ASSEMBLY	DEGRADED	PROCESS	MATERIAL	CONTAMINATION	DAMAGED	TEST EQUIPMENT	NOT ANALYZED
DESIGN																	
PROCEDURE, ATP																	
ERROR																	
PROCEDURE																	
PLANNING																	
FABRICATION												3					
ASSEMBLY				8					1								
QUALITY CONTROL																	
INSPECTION																	
ATP TEST ERROR								2									
TEST EQUIPMENT FAILURE													1				
LOX CLEANING																	
HANDLING														1			
RECEIVING INSPECTION (TEST AND EQUIPMENT)																	
INSTALLATION																	
RANDOM FAILURE							1		1								
UNCONFIRMED FAILURE																	
NOT ANALYZED FAILURE REPORT							1										
TOTALS				8			2	2	2			3	1		1		
PERCENT				42.1			10.5	10.5	10.5			15.8	5.3		5.3		

FAILURE CAUSE

Figure 6-1. AiResearch PN 837044, Apollo Block II ECS Component Suit Inlet Pressure Transducer Failure Matrix

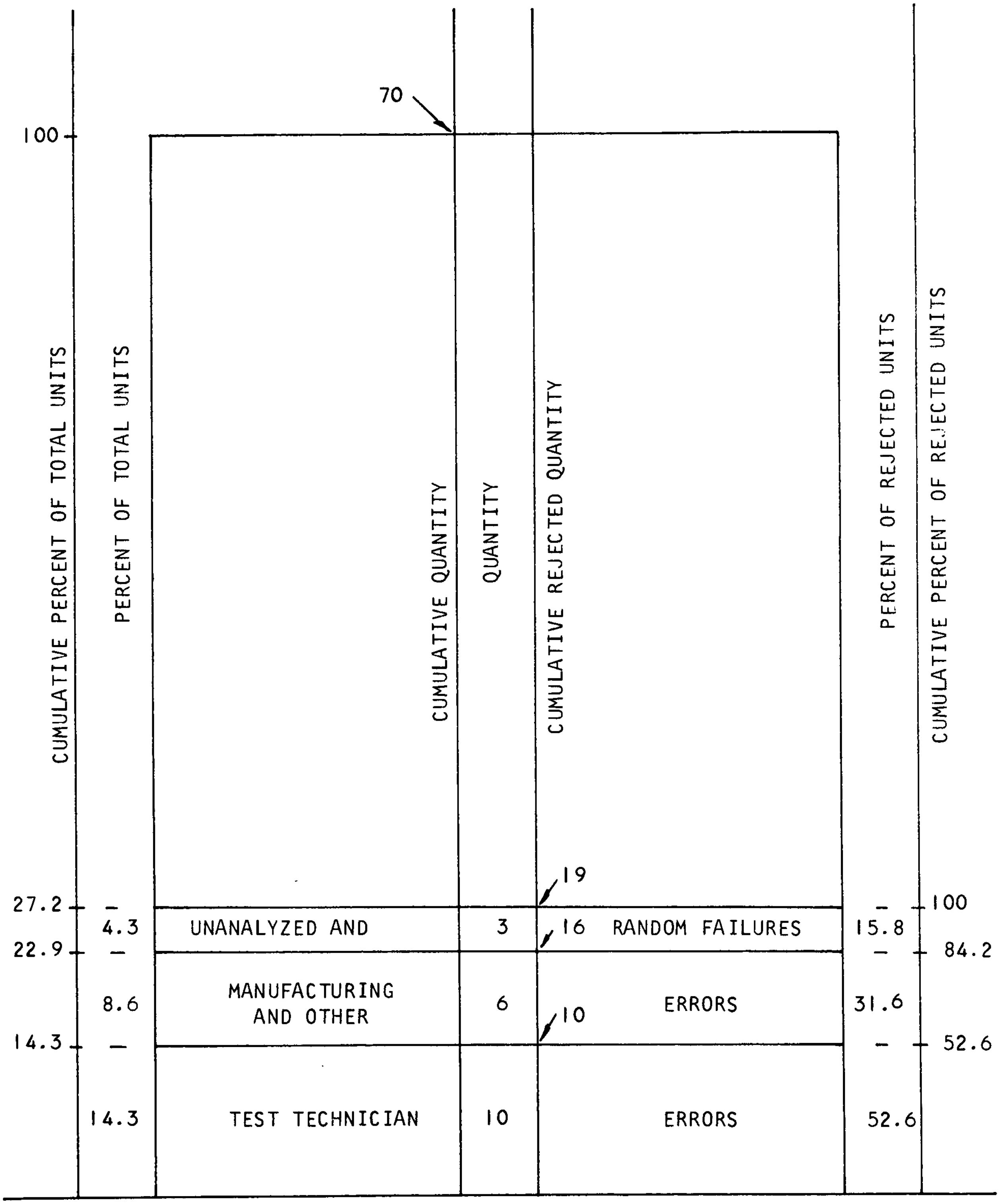


Figure 6-2. Distribution of Failures According to Problem Area

84.2 percent of all failures, are potentially avoidable. Recommendations for actions that will drastically reduce the quantity of failures resulting from these problem areas are summarized in Section 2 of this report.

SECTION 7

OXYGEN SUPPLY PRESSURE TRANSDUCER (AIRESEARCH PN 837016)

PURPOSE AND DESCRIPTION

The oxygen supply pressure transducer measures the static pressure in the oxygen supply line by sensing the pressure and generating a proportional electrical signal. This signal is used for ground checkout, for the crew's visual information (via an indicator) and for telemetry data to be transmitted to a ground station. This measurement is taken at a point just upstream of the demand pressure regulator and relief valve.

The transducer utilizes a Bourdon tube for the pressure-responsive element and a combination of a magnetic core, an armature (which completes the magnetic circuit), and inductance coils for translation of the physical motion into a proportional electrical signal.

PERFORMANCE AND DESIGN DATA

Table 7-1 lists performance and design data for this transducer.

FAILURE AND DESIGN REVIEW

Table 7-2 is a summary of the 10 failure reports which were reviewed for this transducer evaluation. The information indicated in Table 7-2 has been summarized in the failure matrix of Figure 7-1.

Nine of the total of 10 reported failures were caused by human errors. The remaining one was due to random electrical failure.

Two of the human-caused failures resulted from inadvertent overpressurization of the transducer. Three of the remaining failures resulted from misconnection of the input power leads to the output terminals. Two failures were caused by poor assembly practices, and two more failures were caused by the wrong choice of material by engineering. There was one random electrical failure.

Figure 7-2 shows the distribution of the failures according to the sources of problems. Figure 7-3 shows the distribution of the current failures after the redesign that removed the engineering error from the list of problem sources. The remaining current problem sources include (1) test technician error (responsible for 62.5 percent of failures), and (2) maufacturing and handling errors (responsible for 25 percent of failures). These failures, which account for 87.5 percent of all failures, are potentially avoidable. Recommendations for actions that will drastically reduce the quantity of failures resulting from these problem sources are summarized in Section 2 of this report.

TABLE 7-1

PERFORMANCE AND DESIGN DATA FOR PN 837016

Electrical power requirements	
Input voltage, vdc	28 ±4
Excitation current, ma	35 (max.)
Operating pressure range, psig	0 to 150
Accuracy, psig	±3.0
Time constant of response	Within 30 ms (to 63.2 percent of applied step pressure input)
Output signal	0 v at 0 psig to 5 vdc at 150 psig. Output signal shall not exceed 6.5 v in event of overpressurization.
Output supply, mv rms	10 (max.)
Output load, ohms	30,000
Output impedance, ohms	500 (max)
Proof pressure, psig	225 at 70°F
Burst pressure, psig	375 at 70°F
External leakage, lb/hr	6×10^{-6} with 150 psig internal pressure
Electrical connector	Per MIL-C-26482-C
Weight, lb	0.6

FOLDOUT FRAME 1

TABLE 7-2

FOLDOUT FRAME 2

OXYGEN PRESSURE TRANSDUCER FAILURE EVALUATION

TRANSDUCER APPLICATION Apollo ECS O_2 Pressure Transducer

BASIC PART NUMBER 837016 (AiResearch)

TRANSDUCER MANUF. Pace Wiancko (54628-1)

TROUBLE REPORT SOURCE AiResearch/North American Rockwell

TRANSDUCER TYPE Pressure Transducer Variable Reluctance

OPERATING PRINCIPLE Bourdon Tube

MEASUREMENT RANGE 0 to 150 psig

MEASUREMENT MEDIA Oxygen (gaseous)

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
837016-1	0007	2-29-68	16571	Human	Shift to no output	Electronic package	Input power applied to output	Testing	None - Block I part	Shorted diode
837016-2-1	50008	8-29-67	15159	Human	High output	Pressure sensing mechanism	Overpressurized	Testing	None - Test equipment correct earlier	
837016-2-1	50017	8-25-67	14620	Human	High output	Electronics package	Input power applied to output	Test	Test equipment reworked to prevent misapplication or power during test	
837016-2-1	50003	8-24-67	14618	Human	High output	Electronics package	Input power applied to output	Test	Test equipment reworked to prevent misapplication or power during test	
837016	50014	8-22-67	15477	Human	High output	Pressure sensing mechanism	Overpressurized	Test equipment	Leaky valve allowed to overpressurize and test revised	Deformed Bourdon tube
837016-2	50006	2-21-67	13065	Elect.	High output	Electronics package	Shorted transformer	Unknown	Accepted as a random failure	
837016-1	70243	1-28-67	12076	Human	Shift	Electronics package	Out tolerance caused by resistor	Design	Replace carbon resistor with film type	
837016-1	00001	9-16-66	NR 27061	Human	Shift	Electronics package	Out tolerance caused by resistor	Design	Replace carbon resistor with film type	
837016-1	0009	9-12-66	10986	Human	High output	Electronics package	Resistor wired improperly	Manufacturing	Assembly and test procedures incorporated to preclude problem	
837016-1	50001	8-23-66	10933	Human	High output	Electronics package	Resistor wired improperly	Manufacturing	Assembly and test procedures incorporated to preclude problem	

FAILURE — MODE / TYPE

PROBLEM AREA	PERCENT	NO OUTPUT	SHIFT	LOW OUTPUT	HIGH OUTPUT	FIXED OUTPUT	LOW RESISTANCE	LEAKAGE	ERRATIC	RIPPLE	DRIFT	PEELING				NONE	HUMAN	ELECTRICAL	MECHANICAL
DESIGN	20		2														2		
TESTING: PROCEDURE, ATP																			
TESTING: QUAL: ERROR																			
TESTING: QUAL: PROCEDURE																			
MANUFACTURING: PLANNING																			
MANUFACTURING: FABRICATION																			
MANUFACTURING: ASSEMBLY	20				2												2		
MANUFACTURING: QUALITY CONTROL																			
MANUFACTURING: INSPECTION																			
MANUFACTURING: ATP TEST ERROR	50	1			4												5		
TEST EQUIPMENT FAILURE																			
LOX CLEANING																			
HANDLING																			
FINAL INSTALLATION: RECEIVING INSPECTION (TEST AND EQUIPMENT)																			
FINAL INSTALLATION: INSTALLATION																			
RANDOM FAILURE	10				1													1	
UNCONFIRMED FAILURE																			
NOT ANALYZED FAILURE REPORT																			
TOTALS	100	1	2		7												9	1	
PERCENT		10	20		70												90	10	

FAILURE — MECHANISM / FAILURE CAUSE

PROBLEM AREA	SENSING MECHANISM, ELEC.: OPEN	SENSING MECHANISM, ELEC.: SHORT	SENSING MECHANISM, MECHANICAL: FROZEN	SENSING MECHANISM, MECHANICAL: OVERPRESSURIZED	SENSING MECHANISM, MECHANICAL: LEAKAGE	SENSING MECHANISM, MECHANICAL: DAMAGED		SIGNAL CONDITIONING AND TRANSMISSION MECHANISM: UNKNOWN	MISCONNECTED	SHORT	POOR ASSEMBLY	DEGRADED	PROCESS	MATERIAL	CONTAMINATION	DAMAGED	TEST EQUIPMENT	NOT ANALYZED
DESIGN														2				
TESTING: PROCEDURE, ATP																		
TESTING: QUAL: ERROR																		
TESTING: QUAL: PROCEDURE																		
MANUFACTURING: PLANNING																		
MANUFACTURING: FABRICATION																		
MANUFACTURING: ASSEMBLY											2							
MANUFACTURING: QUALITY CONTROL																		
MANUFACTURING: INSPECTION																		
MANUFACTURING: ATP TEST ERROR				2					3									
TEST EQUIPMENT FAILURE																		
LOX CLEANING																		
HANDLING																		
FINAL INSTALLATION: RECEIVING INSPECTION (TEST AND EQUIPMENT)																		
FINAL INSTALLATION: INSTALLATION																		
RANDOM FAILURE										1								
UNCONFIRMED FAILURE																		
NOT ANALYZED FAILURE REPORT																		
TOTALS				2					3	1	2			2				
PERCENT				20					30	10	20			20				

Figure 7-1. AiResearch PN 837016, Apollo Block II ECS Component Oxygen Supply Pressure Transducer Failure Matrix

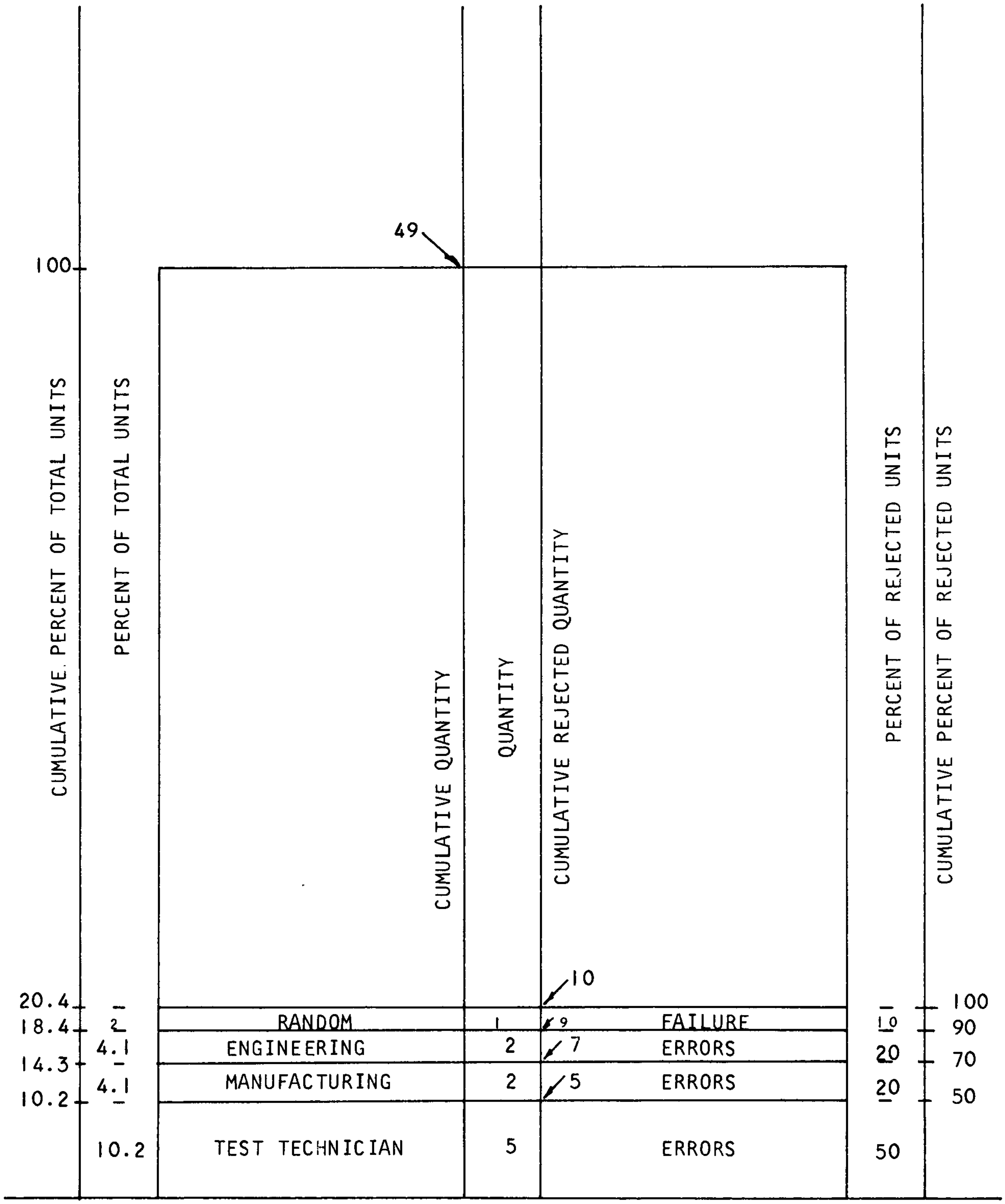


Figure 7-2. Distribution of Failures According to Problem Area

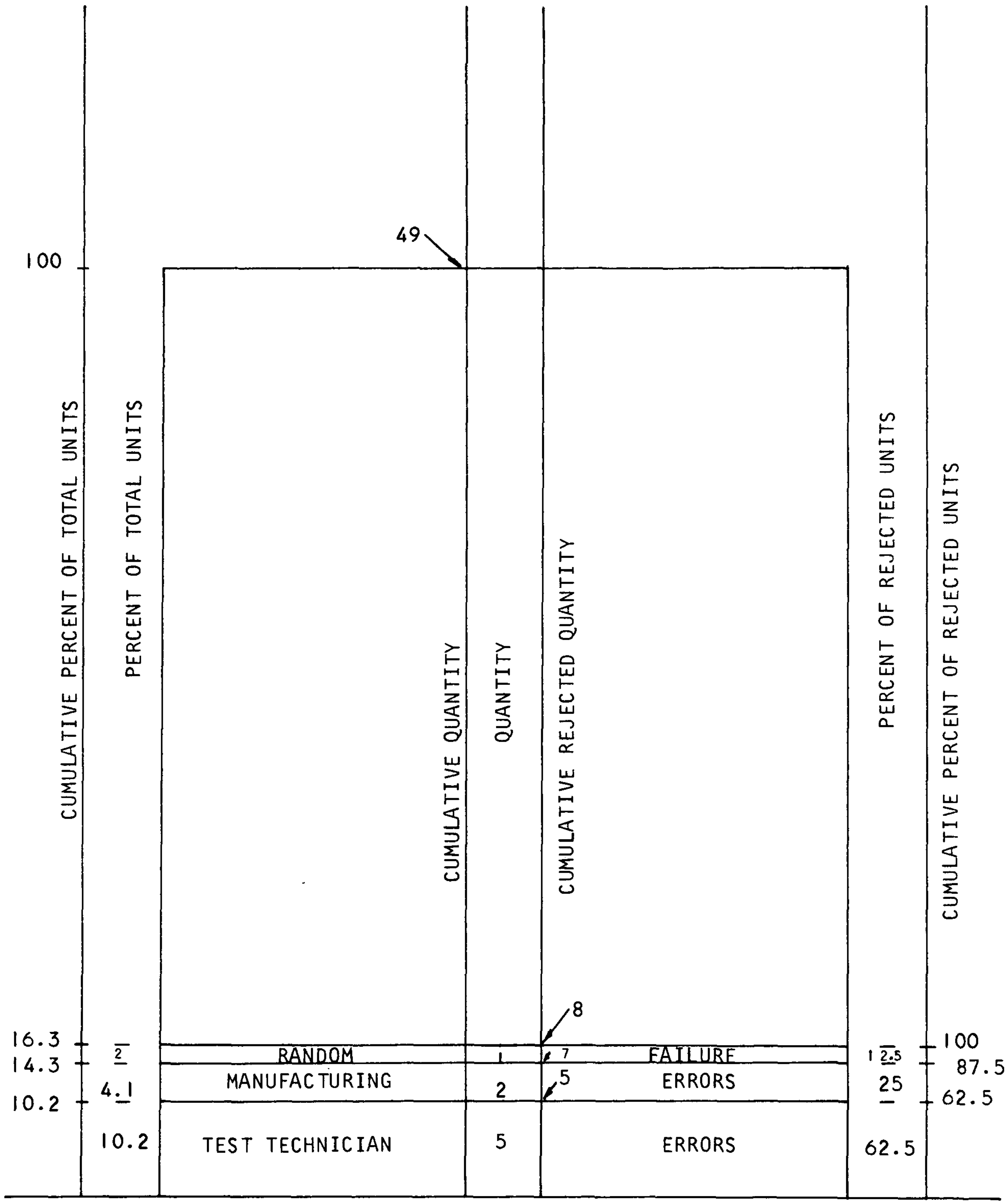


Figure 7-3. Distribution of Failures After Correction of Engineering Design

SECTION 8

WATER GLYCOL PUMP PRESSURE TRANSDUCER
(AIRESEARCH PN 837008)

PURPOSE AND DESCRIPTION

This pressure transducer is identical in application to water-glycol pump pressure transducer, PN 836130, described in Section 3 of this report. Since a large portion of the failures (approximately 72 percent) occurred in manufacturing assembly, the unit was replaced by PN 836130. AiResearch recommends that this item be closed, and that PN 836130 be used as the reference transducer.

PERFORMANCE AND DESIGN REVIEW

Table 8-1 is a summary of the 7 failure reports reviewed. All 7 of the failures were human-caused. Figure 8-1 presents the matrix of these failures. This summary of failures is presented for record purpose only.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE 8-1

WATER-GLYCOL ACCUMULATOR QUANTITY TRANSDUCER FAILURE EVALUATION

TRANSDUCER APPLICATION Water-Glycol Accumulator Quantity

BASIC PART NUMBER 837008 (AiResearch)

TRANSDUCER MANUF. Whittaker (Pace-Wiancko) (PN 54626-1)

TROUBLE REPORT SOURCE AiResearch or North American Rockwell

TRANSDUCER TYPE Press Transducer

OPERATING PRINCIPLE Twisted Bourdon Tube

MEASUREMENT RANGE 0 to 60 psia

MEASUREMENT MEDIA Water glycol

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
837008-2	50007	11-22-67	A/R 16900-0	Human	Shift	Minute leak in reference chamber	Leak path could not be determined	Manufacturing	Helium leak check all Apollo Blk II units (mass spec)	This failure was on an early Apollo Blk I unit
837008-2	50004	11-20-67	A/R 16805-0	Human	Shift	None found	Suspected NR test equipment was bad	NR test	Mark unit "not for flight use"	Failure could not be duplicated by A/R and Whittaker
837008-2	50006	11-13-66	A/R 12041-9	Elec.	Shift	Failed capacitor	Random	Manufacturing	None	
837008-2	50010	5-28-66	A/R 9951-9	Human	No output.	Open junction at transistor	Open circuit	Manufacturing technician error	None	First occurrence
837008-2	50005	7-5-66	A/R 9166-9	Human	Shift	Not determined	Used for wrong application	Manufacturing assembly	Revised blueprint to clarify xducer vs application	
837008-2	50007	5-3-66	A/R 9165-9	Human	Leakage	O-ring seal on banjo fitting defective	Excessive torque was applied to banjo fitting	Test	Proper torque was specified on vendor print. -none-	
837008-2	---	2-19-65	A/R 5034	Human	Diode voltage high	Added jumper wire	Added jumper wire was not done to print	Manufacturing	Personnel notified	

FAILURE

	PROBLEM AREA	PERCENT	MODE															TYPE			MECHANISM: SENSING MECHANISM – ELEC.		SENSING MECHANISM – MECHANICAL					SIGNAL CONDITIONING AND TRANSMISSION MECHANISM														
	FAILURE CAUSE →		NO OUTPUT	SHIFT	LOW OUTPUT	HIGH OUTPUT	FIXED OUTPUT	LOW RESISTANCE	LEAKAGE	ERRATIC	RIPPLE	DRIFT	PEELING				NONE	HUMAN	ELECTRICAL	MECHANICAL	OPEN	SHORT	FROZEN	OVERPRESSURIZED	LEAKAGE	DAMAGED		UNKNOWN	MISCONNECTED	SHORT	POOR ASSEMBLY	DEGRADED	PROCESS	MATERIAL	CONTAMINATION	DAMAGED	TEST EQUIPMENT	NOT ANALYZED	OPEN	LEAKAGE		
ENGINEERING	DESIGN																																									
ENGINEERING – TESTING	PROCEDURE, ATP																																									
ENGINEERING – TESTING – QUAL	ERROR																																									
ENGINEERING – TESTING – QUAL	PROCEDURE																																									
MANUFACTURING	PLANNING																																									
MANUFACTURING	FABRICATION																																									
MANUFACTURING	ASSEMBLY	71.4	1	2		1			1									5												1						1			2	1		
MANUFACTURING	QUALITY CONTROL																																									
MANUFACTURING	INSPECTION																																									
MANUFACTURING	ATP TEST ERROR																																									
	TEST EQUIPMENT FAILURE																																									
	LOX CLEANING																																									
	HANDLING																																									
FINAL INSTALLATION	RECEIVING INSPECTION (TEST AND EQUIPMENT)																																									
FINAL INSTALLATION	INSTALLATION																																									
	RANDOM FAILURE	14.3		1															1													1										
	UNCONFIRMED FAILURE	14.3		1														1										1														
	NOT ANALYZED REPORT																																									
	TOTALS	100	1	4		1			1									6	1									1		1		1				1			2	1		
	PERCENT		14.3	57.1		14.3			14.3									85.7	14.3									14.3		14.3		14.3				14.3			28.5	14.3		

Figure 8-1. AiResearch PN 837008, Apollo Block I ECS Component Glycol Pump Transducer Failure Matrix

AIRESEARCH MANUFACTURING COMPANY
Los Angeles, California

REPORT ON FAILURE AND DESIGN EVALUATION OF APOLLO ECS PRESSURE TRANSDUCERS, VARIABLE RELUCTANCE-DIAPHRAGM WITH ELECTRONICS TYPE

CONTRACT NO. NAS 9-12452

72-8537-3, Rev. 2 February 10, 1973

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ABSTRACT

This report presents the results for a failure and design evaluation study conducted on the Apollo ECS pressure transducers, the generic group of variable reluctance-diaphragm with electronics type pressure transducers. The study was conducted for NASA-MSC by the AiResearch Manufacturing Company, a division of the Garrett Corporation under Contract NASA-12452.

The study purpose was to evaluate the integrity of design of this type transducer. Failure information is presented and summarized pertaining to 3 transducer design groups comprising 5 different transducer part numbers.

These designs have had chronic calibration and stabilization problems. Design and supplier changes have not resolved this problem. Other types of pressure transducers should be studied for possible substitution in similar applications.

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4	BACK PRESSURE TRANSUDCER	4-1

SECTION 1

INTRODUCTION

This report presents a summary of failure data of the generic group of variable reluctance-diaphragm with electronics type pressure transducers, one of several pressure transducer types that are described and categorized in AiResearch Report No. 72-8537-1. Five variable reluctance-diaphragm with electronics pressure transducers were evaluated in three different configuration groups; (1) steam duct pressure transducer, (2) suit compressor differential pressure transducer, and (3) back pressure transducer.

All five part numbers were designed for Apollo ECS application. Requirement for back pressure transducer PN 836114, was eliminated from the system and the use of this transducer was discontinued. Two transducers were designed for suit compressor differential pressure sensing function where PN 836705 supersedes PN 837054; however, the superseded part number was never implemented in any system. Two transducers were designed for steam duct pressure sensing function where PN 837036 supersedes PN 836706.

The pressure transducer that are evaluated and summarized in this report are by AiResearch part number:

PN	Nomenclature
837036	Steam Duct Pressure Transducer
836706	Steam Duct Pressure Transducer
837054	Suit Compressor Differential Pressure Transducer
836114	Back Pressure Transducer

Detailed failure data on each of these pressure transducers are presented in Section 2 through 4 of this report. Each one of these three sections presents discriptive information, failure summary, and recommendations that apply to the transducer evaluated in that section. Differences in the transducer design configurations within these three groups are primarily due to differences in the intended transducer locations and media of application.

SECTION 2

SUIT COMPRESSOR DIFFERENTIAL PRESSURE TRANSDUCER

(AiResearch PN 837054 and PN 836705)

INTRODUCTION

The initial design of suit compressor differential pressure transducer PN 837054 has been implemented in Apollo ECS Block I and Block II. Because of numerous rejections as a result of unit instability this design was superseded by PN 836705 which has not been implemented in any system.

PURPOSE AND DESCRIPTION

The suit compressor differential pressure transducer in its Apollo application measures the gas pressure rise developed by the suit compressor. The pressure rise serves as an indication of suit compressor performance. The pressure sensing ports of the transducer are connected to the suit circuit ducting at a point upstream of the suit compressors and at a point downstream of the suit compressor check valves.

The transducer is powered by the 28 vdc supply of the spacecraft and operates over a differential pressure range of 0 to 25 in. H_2O. An electrical signal (0 to 5 vdc) proportional to the differential pressure across the suit compressor is provided by the transducer. This signal is used for ground checkout, for the crews visual information, via an indicator and for telemetry data to be transmitted to a ground station.

The transducer essentially converts a signal corresponding to the sensed differential pressure into a proportioned electrical signal.

PERFORMANCE AND DESIGN DATA

Table 2-1 presents the performance and design data for these differential pressure transducers. The data are identical for both of these designs. Figure 2-1 presents a typical isometric drawing of these transducers. Figure 2-2 presents the outline drawing of the current transducer design PN 836705. Engineering design error on PN 837054 was the problem source for 65 rejections in a total population of 51 units which represents a rejection rate of 127 percent. This high rejection rate motivated the effort for PN 836705 which was not implemented in the system and has two rejections in a total propulation of 11 units for a rejection rate of 18 percent.

FAILURE AND DESIGN REVIEW

Initial Design (PN 837054)

Table 2-2 is a summary of 65 failure reports written against PN 837054. Sixty three (63) units (97 percent) were rejected because of instability and two units (3 percent) because of attitude sensitivity.

Current Design (PN 836705)

Table 2-3 is a summary of two failure reports written against PN 836705. The reason for both of these rejections were ripple and shift caused by engineering error in design.

RECOMMENDATIONS

Both of these designs have been in trouble from the beginning; design revisions and changes have not eliminated the instability problem. It is recommended that other transducer designs be studied as possible substitution in this or similar applications.

TABLE 2-1

PERFORMANCE AND DESIGN DATA FOR PN 837054 AND PN 836705

Performance Requirements:

a. Operating differential pressure range: 0 to 25 in. water differential. (0.18 to 0.903 psi)

b. Accuracy ±0.5 in. water (also refer to h)

c. Time Constant of Output Signal: Within 30 ms

d. Output signal: 0 vdc at 0 in. water to 5 vdc at 25 in. water. Output signal shall not exceed 6.5v in the event of overpressurization

e. Output ripple: Ripple component of output signal shall not exceed 10 mv peak to peak

f. Output load: 30,000 ohms

g. Output impedance: 500 ohms max

h. Environmental error band: Output signal error resulting from the combined effects of nonlinearity, repeatability, and input voltage fluctuation during any rational combination of environmental conditions specified in AiResearch Report SS-1060-R, shall not exceed ±2.0 percent (±0.10 v) of full scale from 0 to 100 percent of differential pressure range.

Structural Requirements:

a. Proof pressure:

(1) Case: 7.5 psig at 70°F

(2) Differential: 37.5 in. H_2O at 70°F

b. Burst pressure:

(1) Case: 12.5 psig at 70°F

(2) Differential: 62.5 in. H_2O at 70°F

Leakage:

a. External: Oxygen leakage rate shall not exceed 6×10^{-6} lb/hr with 5 psia internal pressure and 10^{-4} torr external pressure.

b. Internal: Zero at 25 in. water differential

TABLE 2-1 Cont.

Electrical Power Requirements:

a. Input voltage: 28 ±4 vdc

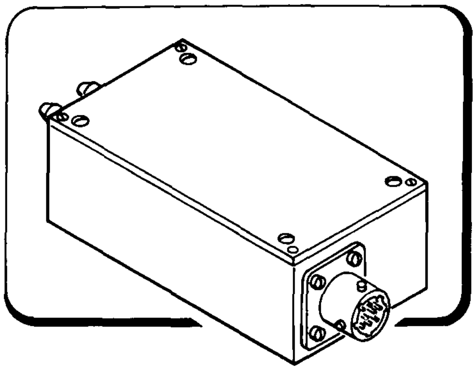
b. Input current: 35 ma max

Environmental Conditions: Per AiResearch Report SS-1060-R

Installation Envelope: Per AiResearch Drawing 837054

Weight: 0.6 lb

Electrical Connector: In accordance with MIL-C-26482-C



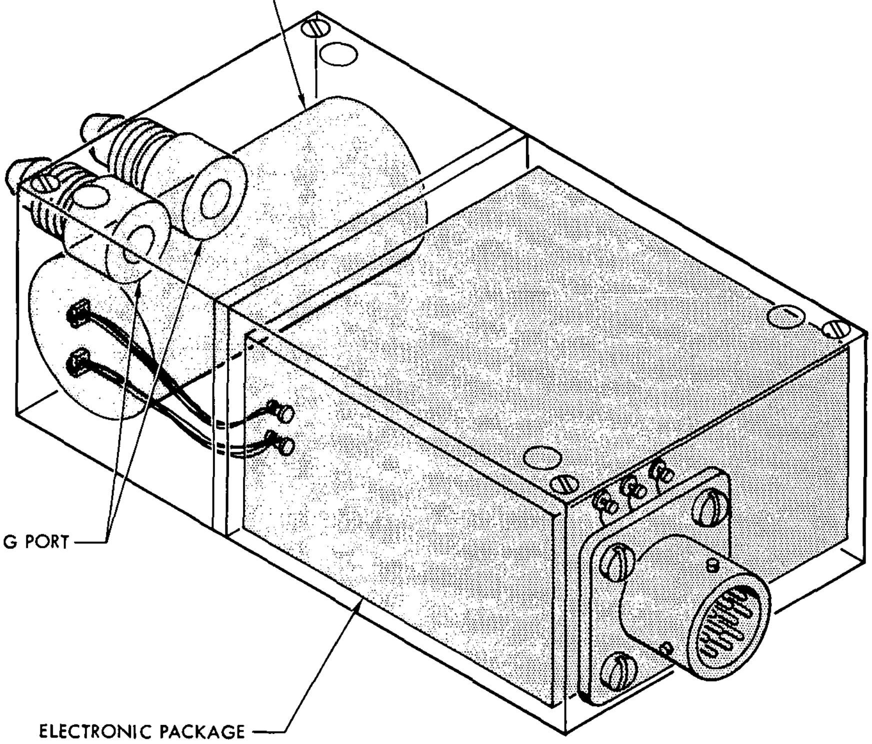


Figure 2-1. Isometric Drawing of a Typical
Suit Differential Pressure Transducer

S-32 135

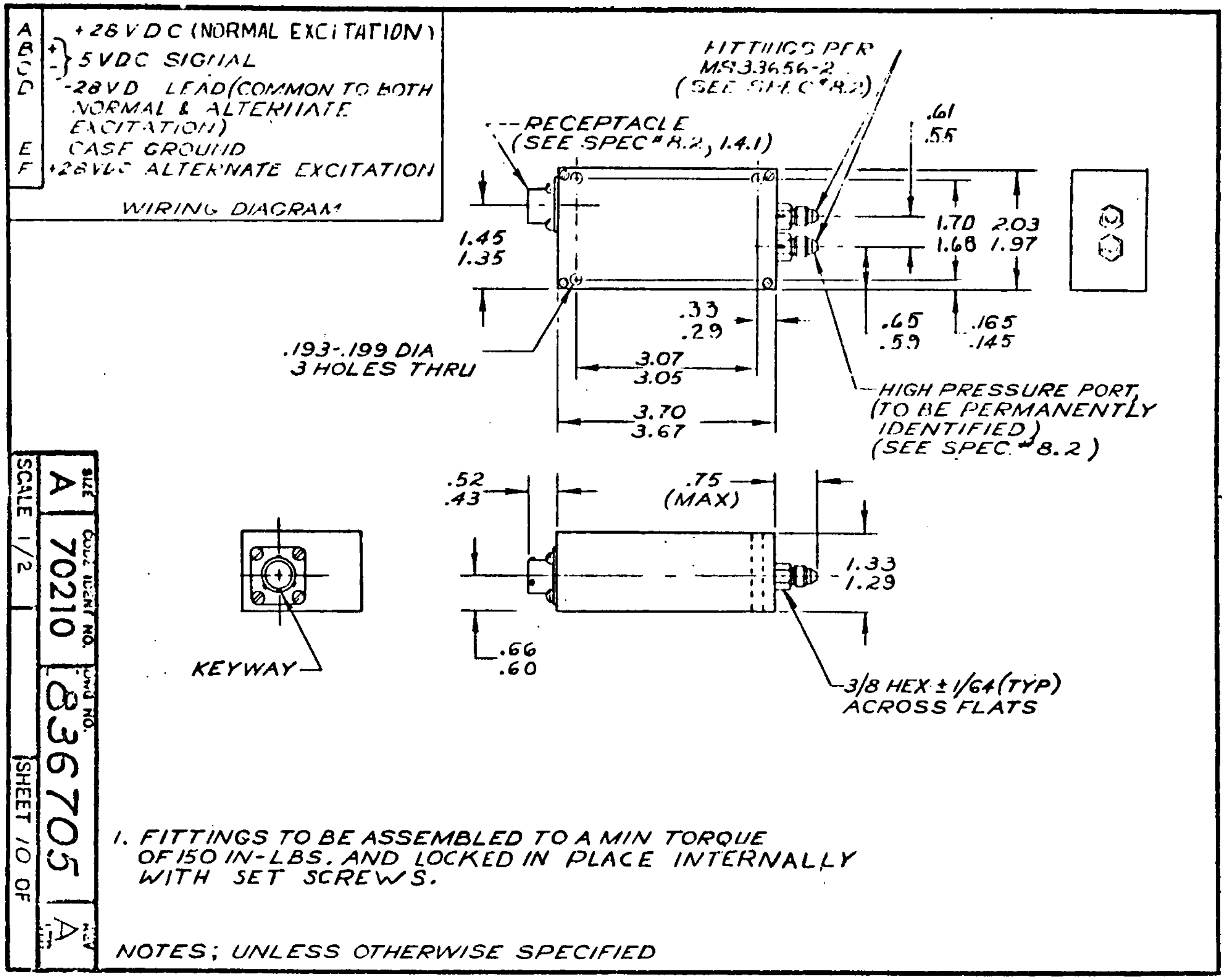


Figure 2-2. Outline Drawing of Current Suit Differential Pressure Transducer

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE 2-2

DIFFERENTIAL PRESSURE TRANSDUCER FAILURE EVALUATION

TRANSDUCER APPLICATION Suit Compressor ΔP Xducer

BASIC PART NUMBER A/R 837054

TRANSDUCER MANUF. Consolidated Controls Corporation

TROUBLE REPORT SOURCE North American and AiResearch

TRANSDUCER TYPE Pressure

OPERATING PRINCIPLE Variable Reluctance-Diagram with Electronics

MEASUREMENT RANGE 0 - 25 in. Water

MEASUREMENT MEDIA Gas

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
837054-3	00400-0008163	12.6-68	NR A137257	Human	Setpoint Shift	Electronic instability and unstable sensing diaphragm	Unit over pressurized	Design	Alert Test Personnel to follow the OCP's	This xducer is sensitive to over-pressurization
837054-3	9792	8-26-68	A/R 19107-0	Human	Setpoint shift	Instability	Inadequate design	Design	Improved cleaning and handling procedures	EDCP 1572 submitted and rejected by NR
837054-3	9976	7-24-68	NR AR16677	Human	Setpoint shift	Instability		Design		
837054-3-1	9976	7-14-68	A/R 16677-0	Human	Setpoint shift	Electronic instability		Design	Returned to vendor	
837054-3	9975	7-14-68	A/R 16665	Human	Setpoint shift	Electronic instability		Design		
837054-	9233	7-3-68	A/R 16645	Human	Shift	Attitude sensitive		Design	Return to vendor	
837054	8161	7-2-68	A/R 16647	Human	Shift	Electronic instability		Design	Return to vendor	
837054-3	8157	7-1-68	A/R 16646	Human	Shift	Electronic instability		Design	Return to vendor	
837054-3	8164	6-29-68	A/R 16644	Human	Shift	Electronic instabiltiy		Design	Return to vendor	

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE 2-2 (Continued)

DIFFERENTIAL PRESSURE TRANSDUCER FAILURE EVALUATION

TRANSDUCER APPLICATION Suit Compressor ΔP Xducer

BASIC PART NUMBER A/R 837054

TRANSDUCER MANUF. Consolidated Controls Corporation

TROUBLE REPORT SOURCE North American and AiResearch

TRANSDUCER TYPE Pressure

OPERATING PRINCIPLE Variable Reluctance - Diagram with Electronics

MEASUREMENT RANGE 0 - 25 in. Water

MEASUREMENT MEDIA Gas

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
837054-2	8158	6-3-68	A/R 16638	Human	Electronic instability			Design	Return to vendor	
837054-2	9221	5-28-68	A/R 16656-9	Human	Electronic instability			Design	Return to vendor	
837054-2	8162	5-22-68	A/R 16634-9	Human	Low insulation resistance			Design	Return to vendor	
837054-2	8910	5-8-68	A/R 16625-0	Human	Shift			Design	Return to vendor	
837054-1	9791	4-5-68	A/R 17667	Human	Shift			Design	Return to vendor	
837054-3	9192	4-15-68	A/R 17674	Human	Shift			Design	Return to vendor	
837054-3	9232	4-12-68	A/R 17672	Human	Shift			Design	Return to vendor	
837054-2	8157	12-28-67	A/R 16539-0	Human	Shift			Design	Return to vendor	
837054-2	8910	12-28-67	A/R 16539-0	Human	Shift			Design	Return to vendor	

TABLE 2-2 (Continued)

DIFFERENTIAL PRESSURE TRANSDUCER FAILURE EVALUATION

TRANSDUCER APPLICATION Suit Compressor ΔP Xducer

BASIC PART NUMBER A/R 837054

TRANSDUCER MANUF. Consolidated Controls Corpo ration

TROUBLE REPORT SOURCE North American and AiResearch

TRANSDUCER TYPE Pressure

OPERATING PRINCIPLE Variable Reluctance - Diagram with Electronics

MEASUREMENT RANGE 0 - 25 in. Water

MEASUREMENT MEDIA Gas

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
837054-2	8164	12-28-67	A/R 16533-0	Human	Shift			Design1	Return to vendor	
837054-2	8161	8-11-67	A/R 15470-0	Human	Low insulation resistance			Design	Return to vendor	
837054-1	8912	8-11-67	A/R 15469-0	Human	Shift	Attitude sensitive		Design	Return to vendor	
837054-2	9220	8-10-67	A/R 15472-0	Human	Shift			Design	Return to vendor	
837054		43 Repts		Human	Shift			Deign		43 trouble reports not tabulated common problem

GARRETT AIRESEARCH MANUFACTURING COMPANY
Los Angeles, California

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE 2-3

DIFFERENTIAL PRESSURE TRANSDUCER FAILURE EVALUATION

TRANSDUCER APPLICATION Suit ΔP Xducer

BASIC PART NUMBER 836705

TRANSDUCER MANUF. Pace Wiancko

TROUBLE REPORT SOURCE North American and AiResearch

TRANSDUCER TYPE Pressure

OPERATING PRINCIPLE Variable Reluctance - Diagram with Electronics

MEASUREMENT RANGE 0 - 25 in. Water

MEASUREMENT MEDIA Gas

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
836705-1	0006	10-3-69	A/R 20304-0	Elec	Excessive output ripple	--	--	Design	--	
836705-1	0005	10-3-69	A/R 20305-0	Elec	Shift					

SECTION 3

STEAM DUCT PRESSURE TRANSDUCER
(AiResearch PN 837036 and PN 836706)

INTRODUCTION

The initial design of steam duct pressure transducer PN 837036 was implemented on the Apollo Block I and Block II ECS.

Because of numerous failures this design was superseded by a new design, PN 836706, which was implemented on Apollo Block II ECS. Each of these designs is analyzed in this section.

PURPOSE AND DESCRIPTION

The pressure transducer, in the Apollo ECS application, measures the static pressure of the fluid in the glycol and suit evaporator steam discharge duct. The fluid pressure serves as an indication of the effectiveness of the evaporative cooling process in the ECS. The transducer is located in the steam discharge duct immediately downstream of the junction of the glycol evaporator and the suit evaporator outlets. This transducer converts a signal corresponding to the sensed pressure into a proportional electrical signal used for telemetry purposes or visual display.

The transducer is powered by the 28 vdc supply of the spacecraft and operates over a range of 0.05 to 0.25 psia. An electrical signal (0 to 5 vdc) proportional to the absolute pressure of the fluid is provided by the transducer.

PERFORMANCE AND DESIGN DATA

Table 3-1 presents the performance and design data for these transducers. The data are identical for both of these designs. Figure 3-1 presents a typical isolmetric drawing of these transducers. Figure 3-2 presents the outline drawing of the current transducer design PN 836706. Numerous rejections at qualification and acceptance test level motivated the effort for PN 836706. The new unit has had less rejections at test level; however, this new design has 17 rejections in a total population of 42 units which represents a rejection rate of 40 percent.

FAILURE AND DESIGN REVIEW

Initial Design (PN 837036)

Table 3-2 is a summary of two failure reports written against 77 units of PN 837036. One rejection was caused by calibration of test equipment, and the second rejection cause was not determined because the failure was not analyzed. However, this unit has been very troublesome and has accumulated unaccounted number of rejections at ATP and QTP levels. These numerous rejections were the basic reason for design and supplier change.

Current Design (PN 836706)

Table 3-3 is a summary of 17 failure reports written against 42 units of PN 836706 which represents a rejection rate of 40.5 percent. The two units (11.7 percent) were rejected because of design problems. Five units (29.4 percent) were rejected because contamination, damage, and overtorque suffered in assembly. Five units (29.4 percent) were rejected because of misconnection and installation problems during testing. One unit (5.9 percent) was rejected because of test equipment failure while the unit had not failed. Three units (17.7 percent) were rejected because of contamination and overpressurization suffered during LOX cleaning. One unit was rejected for oscillation but the failure was not confirmed. These information is presented in Figure 3-3 failure matrix. Only two of the failures which were the result of design error are unavoidable.

RECOMMENDATIONS

Both of these designs have been in trouble from the beginning; design revisions and changes have not eliminated the calibration instability problem. It is recommended that other transducer designs be studied as possible substitution in this or similar applications.

TABLE 3-1

PERFORMANCE AND DESIGN DATA FOR PN 837036 and PN 836706

Performance Requirements:

a. Operating pressure range: 0.05 to 0.25 psia.

b. Accurancy: ±0.004 osi (also refer to h)

c. Time constant of output signal: Within 30 ms (to 63.2 percent of applied step change in pressure)

d. Output signal: 0v at 0.05 psia to 5.0vdc at 0.25 psia. Output signal shall not exceed 6.5v in the event of overpressurization.

e. Output ripple: Ripple component of output signal shall not exceed 10 mv peak to peak

f. Output load: 30,000 ohms

g. Output impedance: 500 ohms max

h. Environmental error band: Output signal error resulting from the combined effects of non-linearity, repeatability, and input voltage fluctuation during any rational combination of environmental conditions specified in AiResearch Report SS-1060-R, shall not exceed ±2.0 percent (±0.10v) of full scale from 0 to 100 percent of pressure range for temperatures between 0° F and 150° F. For temperatures between 150° F and 200° F, the output signal shall not exceed ±3.0 percent of full scale.

Structural Requirements:

a. Proof pressure: 22.5 psia at 70° F

b. Burst pressure: 37.5 psia at 70° F

Leakage: Zero with 20.7 psia external pressure and 14.7 psia internal pressure

Electrical Power Requirements:

a. Input voltage: 28 ±4 vdc

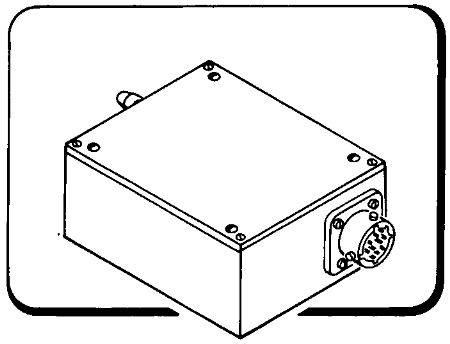
b. Excitation current: 35 ma max

Environmental Conditions: Per AiResearch Report SS-1060-R: Type I equipment

Installation Envelope: Per AiResearch Drawing 837036

Weight: 0.9 lb

Electrical Connector: in accordance with MIL-C-26482C



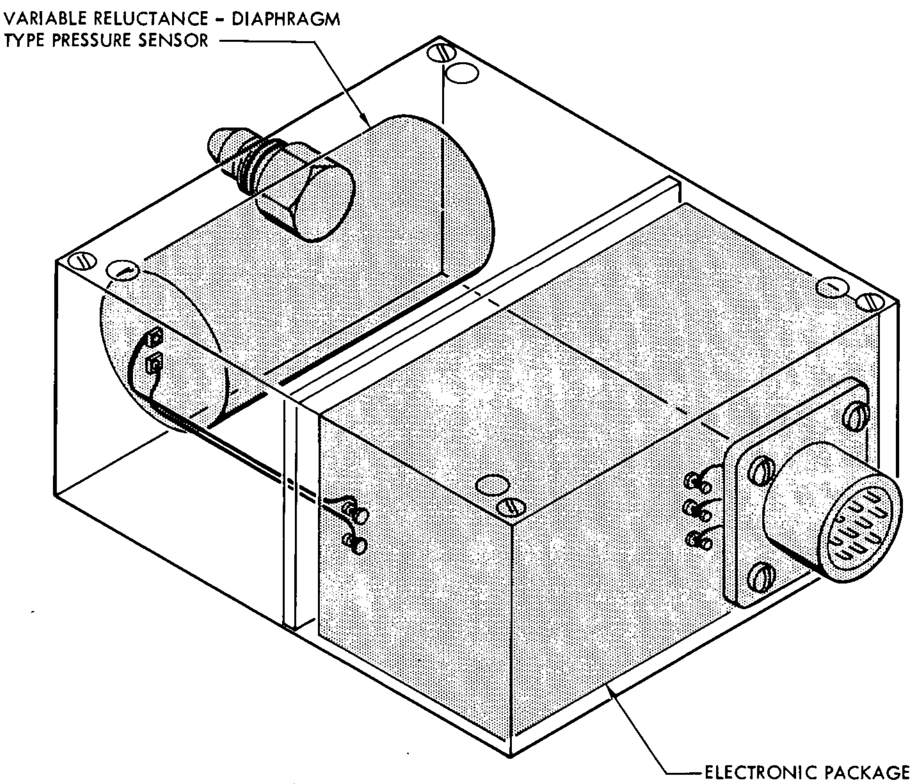


Figure 3-1. Isometric Drawing of a Typical
Steam Duct Pressure Transducer

S-32-125

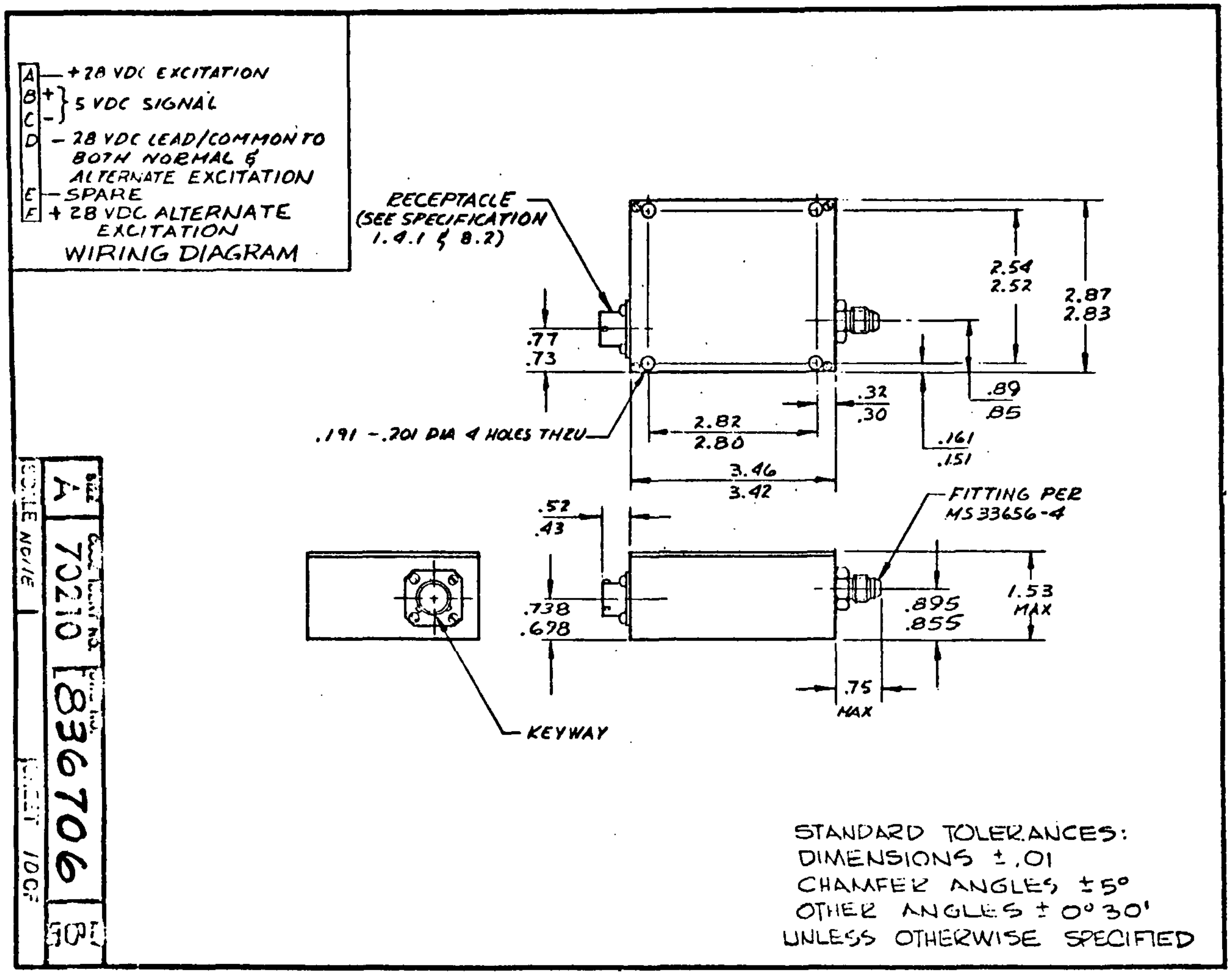


Figure 3-2. Outline Drawing of Current Steam Duct Pressure Transducer

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE 3-2

STEAM DUCT PRESSURE TRANSDUCER FAILURE EVALUATION

TRANSDUCER APPLICATION Evaporator Steam Duct Pressure Xducer

BASIC PART NUMBER 837036 (6300033-2-1, Pace Wianiko)

TRANSDUCER MANUF. AiResearch (Pace Wianiko to 836706-2-1)

TROUBLE REPORT SOURCE AiResearch Mfg Co/North American Aviation

TRANSDUCER TYPE Pressure Xducer

OPERATING PRINCIPLE Variable Reluctance - Diagram with Electronics

MEASUREMENT RANGE 0.05 to 0.25 psia

MEASUREMENT MEDIA Steam

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
837036-4-1	9214	11-30-67	A/R 16521	Human	Output to high	None	Variation in test equipment	Accept test	Test gage recalibrated and part passed test	
837036-1-1	9783	1-24-68	A/R 16540		Not analyzed since	837036-2 supersedes	837036-1-1			

TABLE 3-3

STEAM DUCT PRESSURE TRANSDUCER FAILURE EVALUATION

TRANSDUCER APPLICATION Item 8.17 Evaporator Steam Duct Pressure Xducer

BASIC PART NUMBER 836706-2

TRANSDUCER MANUF. AiResearch (630033-2-1 Pace Wiancko Div Wittaker)

TROUBLE REPORT SOURCE AiResearch Mfg Co/North American Rockwell

TRANSDUCER TYPE Pressure Xducer

OPERATING PRINCIPLE Variable Reluctance - Diagram with Electronics

MEASUREMENT RANGE 0-5 vdc proportional to press, 0 vdc = 0.05 psia = 5 vdc - 0.25 psig

MEASUREMENT MEDIA Water/Steam

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
836706-2	50034	5-18-70	AR 15703	Human	Shift (output high)	Pressure sensor	Contamination	Manufacturing	Addition cleaning operations and inspection added to prevent contamination	defect
836706-2-1	50035	3-19-70	AR 17773	Human	Shift output low	Distortion	Overtorqued	Manufacturing	Personnel cautioned about proper installation	Overtorquing or pressure fitting disturbed housing causing rated shift
836706-2	50038	4-29-69	AR 18776	Human	Intermittent	Soldered (jointed)	Shorted (under light pressure)	Manufacturing	None - considered isolated	Short caused by solder splash on pins causing intermittent condition
836706-2	50026	11-4-68	AR 113103	Human	Oscillation	Electronic output package	Transistor gain out of tolerance for circuit design	Design	Transistors are being selected for use during assembly that will preclude unstable operation	Transistor unstable in region of ATP test. Gain range is too large parts must be selected
836706-2	50017	10-1-68	AR 17785	Human	Low output (shift)	Electronic output package	Input power applied to output	Acceptance test	Placards added to test equipment to caution personnel against overpowering circuit	
836706-2	50010	9-27-68	AR 19113	Human	Output too high (shift)	Electronic output package	Input power applied to output	Acceptance test	Vendor has revised procedure to test input diode and Zener prior to assembly	
836706-2	50010	7-2-68	AR 16660	Human	Fixed output	Pressure sensing mechanism	Contamination	Manufacturing	Vendor required to improve cleaning and handling. All parts cleaned per Air C-39	Process
836706-2-1	50006	7-17-69	AR 14634	Human	No output	Electronic output package	Input power applied to output	Acceptance test	None	Excessive voltage applied to transmitter.
836706-2	50007	7-8-68	AR 16649	Human	Output low (shift)	Pressure sensing mechanism	Design	Manufacturing	Dimensional change made to O-ring grove to allow proper assembly	Shift due to output tolerance condition; causing load insufficient squash allowance

TABLE 3-3 (Continued)

STEAM DUCT PRESSURE TRANSDUCER FAILURE EVALUATION

TRANSDUCER APPLICATION Evaporator Steam Duct Pressure Xducer
BASIC PART NUMBER 836706-2 (630033-2-1 Pace Wiancko)
TRANSDUCER MANUF. Pace Wiancko for AiResearch
TROUBLE REPORT SOURCE AiResearch Mfg Co and North American Rockwell

TRANSDUCER TYPE Pressure Xducer
OPERATING PRINCIPLE Variable Reluctance - Diagram with Electronics
MEASUREMENT RANGE 0-5 vdc proportional to pressure, 0 vdc = 0.05 psia - 5 vdc = 0.25 psia
MEASUREMENT MEDIA Stema

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
836706-2	50002	4-3-68	AR 17662	Human	High output	Pressure sensing mechanism	Contamination	LOX cleaning	Cleaning procedures revised to prevent re-occurence of failure	
836706-2	50027	7-5-68	AR 17768	Human	Low output	Pressure	Contamination	Manufacturing	Wittaker has been made aware of problem and has improved QC	Brazing flux left in part causing diaphragm destruction
848400-9-1	58-110	6-30-68	AR 15150	Human	Low output	None	Improper test instruction	Acceptance test	Air has revised ATP to include larger tolerance because of system changes	System change cause parameter change which was not
836706-2	50004	6-2-68	AR 16637	Human	Oscillating voltage (intermittent)	Electronic package	Unknown	Unknown	Replaced package and part passed test	E-pack fault could not be determined
836706-2-1	50003	5-25-68	AR 17553	Human	Output too high EMI frequency	Electronics package	Poor installation	Acceptance test setup qualification	Test rerun with unit properly installed no fail	Part "C" clamped on to test fixture causing failure
836706-2-1	50001	4-22-68	AR 17679	Human	Low output	Electronic package	Poor installation	Manufacturing	Supplier has revised welding procedure (schedule) to proclude failure	
836706-2	50004	4-4-68	AR 17682	Human	Output too high	Pressure sensing mechanism	Overpressurized	LOX cleaning	Functional test added after cleaning and verify performance	
836706-2	50006	4-3-68	AR 17663	Human	Output too high	Pressure sensing mechanism	Overpressurization	LOX cleaning	Surveillance initiated on part by AiResearch Reliability group	

FOLDOUT FRAME 1 FOLDOUT FRAME 2

PROBLEM AREA		PERCENT	FAILURE MODE: HIGH OUTPUT	LOW OUTPUT	INTERMITTENT	OSCILLATION	FIXED OUTPUT	NO OUTPUT	FAILURE TYPE: HUMAN	ELECTRICAL	MECHANICAL	MECHANISM / SENSING MECHANISM / MECHANICAL — FAILURE CAUSE: DESIGN	CONTAMINATION	OVERPRESSURIZED	SIGNAL CONDITIONING AND TRANSMITTING MECHANISM — FAILURE CAUSE: INSTALLATION	OVERTORQUE	SHORTED	DESIGN	MISCONNECTED	UNKNOWN	NO FAILURE
ENGINEERING	DESIGN	11.7		1		1			2			1						1			
ENGINEERING — TESTING	PROCEDURE, ATP																				
ENGINEERING — TESTING — QTP	ERROR																				
ENGINEERING — TESTING — QTP	PROCEDURE																				
MANUFACTURING	PLANNING																				
MANUFACTURING	FABRICATION																				
MANUFACTURING	ASSEMBLY	29.4	1	2	1		1		5				3			1	1				
MANUFACTURING	QUALITY CONTROL																				
MANUFACTURING	INSPECTION																				
MANUFACTURING	ATP TEST ERROR	29.4	2	2				1	5						2				3		
TEST EQUIPMENT FAILURE		5.9		1					1												1
LOX CLEANING		17.7	3						3				1	2							
HANDLING																					
FINAL INSTALLATION	RECEIVING INSPECTION (TEST AND EQUIPMENT)																				
FINAL INSTALLATION	INSTALLATION																				
RANDOM FAILURE																					
UNCONFIRMED FAILURE		5.9				1			1											1	
NOT ANALYZED FAILURE REPORTS																					
TOTALS			6	6	1	2	1	1	17			1	4	2	2	1	1	1	3	1	
PERCENT			35.3	35.3	5.9	11.7	5.9	5.9	100						11.7	5.9	55.9	5.9	17.7	5.9	5.9

Figure 3-3. Steam Duct Pressure Transducer Failure Matrix

SECTION 4

BACK PRESSURE TRANSDUCER
(AiResearch PN 836114)

INTRODUCTION

The back pressure transducer was implemented in the initial stages of Apollo ECS as an obsolute pressure switch that sensed the pressure in the glycol evaporator steam discharge duct. The transducer functioned as a safety device to prevent the steam discharge pressure from falling below 5 mm Hg. The requirement of this transducer in the Apollo Block II ECS was eliminated, and the production of this transducer was discontinued. The available data on this transducer is presented in this section for the foundation and it is recommended that the analysis of this transducer not be continued.

DESCRIPTION

The back pressure sensor consists of a variable reluctance absolute pressure transducer and a solid state switch circuitry to switch the control signal from the glycol evaporator controller. The switch is open at pressures above 5.0 mm Hg and below 3.5 mm Hg, and is closed between 5.0 mm Hg and 3.5 mm Hg.

FAILURE AND DESIGN REVIEW

Figure 4-1 presents the isometric drawing of this pressure transducer. Table 4-2 is a summary of 19 failure reports written against 20 units out of a population of 39 units of PN 836114 representing a rejection rate of 51.3 percent. One unit (5 percent) was rejected because excessive voltage applied during testing shorted the electronic circuitry. Four units (20 percent) were rejected because units did not stabilize. The remaining rejected sixteen units (75 percent) were not analyzed because this item was deleted from the ECS.

PERFORMANCE AND DESIGN DATA

Table 4-1 presents the performance and design data for this pressure transducer.

TABLE 4-1

PERFORMANCE AND DESIGN DATA FOR BACK PRESSURE TRANSDUCER PN 836114

Operating pressure	0 - 15 psia
Proof pressure	21 psia
Burst pressure	30 psia
Leakage, external to internal	6×10^{-6} lb/hr with 6 psig differential
Operating voltage	28 +2, -3 v dc
Operating current	50 milliamp
Switch activation - decreasing pressure	5.0 ±0.2 mm Hg, close 3.5 ±0.2 mm Hg, open
Switch activation - increasing pressure	3.5 ±0.2 mm Hg, close 5.0 ±0.2 mm Hg, open
Switch voltage	5.0 volts dc
Switch current	5.0 milliamp
Switch voltage drop	0.2 millivolt
Pressure port	33656-4
Power requirement	50 ma max at 28 +2, -3 vdc
External leakage	6×10^{-6} lb/hr O_2 max with 6 psi ΔP
Electrical connector	AiResearch Comm Std 223-022-9009 or 223-021-9009
Envelope	3.50 x 2.90 x 1.60
Weight	0.6 lb

QUALIFICATION STATUS

This back-pressure sensor is a qualified Block II Apollo component.

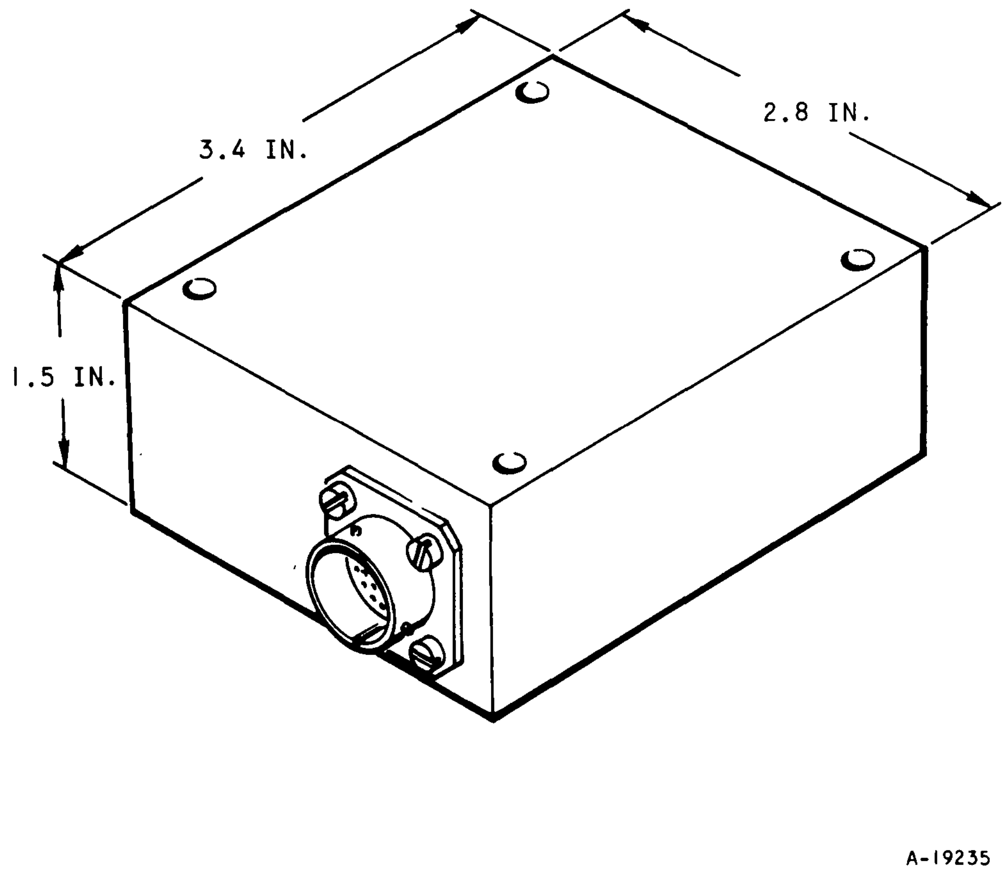


Figure 4-1. Isometric Drawing of Back Pressure Transducer

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE 4-2

BACK PRESSURE TRANSDUCER FAILURE EVALUATION

TRANSDUCER APPLICATION ESC Apollo Steam Duct Pressure Switch

TRANSDUCER TYPE Pressure Switch

BASIC PART NUMBER 836114

OPERATING PRINCIPLE

TRANSDUCER MANUF.

MEASUREMENT RANGE

TROUBLE REPORT SOURCE AiResearch

MEASUREMENT MEDIA

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
836114-1-1	9278	10-12-66	11342	Mech	Shift	Pressure sensing mechanism	Part not stabilized	Manufacturing	None - due to signal reocurring failure	Part deleted from ECU
836114-1-1	9286	10-11-66	11337	Mech	Closed	Unknown	Unknown	Unknown	Unknown	
836114-1-1	9271	9-24-66	11314	Unknown	High current consumation	Unknown	Unknown	Unknown	Unknown	
836114-1-1	9280	9-16-66	11035	Unknown	Low output	Unknown	Unknown	Unknown	Unknown	
836114-1-1	9279	9-1-66	10223	Unknown	Low output	Unknown	Unknown	Unknown	Unknown	
836114-1-1	9271	8-5-66	10249	Human	Shift	Shorted transistor	Excessive voltage applied to part	Testing	None - parts have previously been color code to prevent this	
836114-1-1	9274	8-1-66	10755	Unknown	Output high	Unknown	Unknown	Unknown	Unknown	
836114-1-1	9261	7-8-66	9607	Mech	Shift	Pressure sensing mechanism	Part not stabilized	Manufacturing	Vendor will pressure cycle part to achieve stable operation	
836114-1-1	9266	6-24-66	10395	Mech	Shift	Pressure sensing mechanism	Part not stabilized	Manufacturing	Vendor will pressure cycle part to achieve stable operation	
836114-1-1	9263	6-23-66	10394	Mech	Shift	Pressure sensing mechanism	Part not stabilized	Manufacturing	Vendor will pressure cycle part to achieve stable operation	

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE 4-2 (Continued)

TRANSDUCER APPLICATION ECS Apollo Steam Duct Pressure SW
BASIC PART NUMBER 836114
TRANSDUCER MANUF.
TROUBLE REPORT SOURCE AiResearch/North American Rockwell

TRANSDUCER TYPE Pressure Switch
OPERATING PRINCIPLE
MEASUREMENT RANGE
MEASUREMENT MEDIA

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
836114-1-1	9264	5-9-67	14196	Mech	Open	Unknown	Unknown	Unknown	Part deleted from ECU	Part deleted no failure analysis performed
836114-1-1	9279	5-12-67	14168	Mech	Open	Unknown	Unknown	Unknown	Part deleted from ECU	Part deleted no failure analysis performed
836114-1-1	9295	11-23-66	11943	Mech	Out of calibration	Unknown	Unknown	Unknown	Part deleted from ECU	Part deleted no failure analysis performed
836114-1-1	9294	11-21-66	11937	Mech	Open	Unknown	Unknown	Unknown	Part deleted from ECU	Part deleted no failure analysis performed
836114-1-1	9264	11-13-66	12042	Mech	Shift	Unknown	Unknown	Unknown	Part deleted from ECU	Part deleted no failure analysis performed
836114-1-1	9279	11-2-66	12017	Mech	Out of calibration	Unknown	Unknown	Unknown	Part deleted from ECU	Part deleted no failure analysis performed
836114-1-1	9272	10-25-66	11399	Mech	Output too high	Unknown	Unknown	Unknown	Part deleted from ECU	Part deleted no failure analysis performed
836114-1-1	9284	10-20-66	1183	Mech	Open	Unknown	Unknown	Unknown	Part deleted from ECU	Part deleted no failure analysis performed
836114-1-1	9288 and 9289	10-15-66	11370	Mech	Output high	Unknown	Unknown	Unknown	Part deleted from ECU	Part deleted no failure analysis performed

GARRETT

AIRESEARCH MANUFACTURING COMPANY

Los Angeles, California

REPORT ON FAILURE AND DESIGN EVALUATION OF
APOLLO ECS TEMPERATURE SENSORS,
THERMISTOR TYPE
CONTRACT NO. NAS 9-12452

72-8537-12, Rev. 1 February 10, 1973

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ABSTRACT

This report presents the results of a failure and design evaluation study conducted on the Apollo ECS temperature sensors, the generic group of bead-type thermistor temperature sensors. The study was conducted for NASA-MSC by the AiResearch Manufacturing Company, a division of The Garrett Corporation under Contract NAS9-12452.

The study purpose was to evaluate the integrity of design of this type sensor. Failure information is presented and summarized pertaining to three sensor design groups comprising eight different sensor part numbers. A failure matrix is presented which describes the failure mode, type, mechanism, cause, and problem areas for nine failures out of a lot total of 267 units.

The integrity of each of the three designs was confirmed. Recommendations are made to reduce the failure rate from the current level of 3.0 percent.

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SECTION 1

INTRODUCTION

This report presents a summary of failure data of the generic group of bead-type thermistor temperature sensors, one of several temperature sensor types that are described and categorized in AiResearch Report No. 72-8537-1. Eight bead-type thermistor temperature sensors were evaluated in three different configuration groups: (1) glycol evaporator wick temperature sensors, (2) water-glycol temperature sensors, and (3) cabin temperature sensors.

All temperature sensors evaluated in this report have been used in the Apollo environmental control system (ECS). In general, they may be used to perform any other temperature sensing function with similar requirements.

The temperature sensors that are evaluated and summarized in this report are, by AiResearch part number:

PN	Nomenclature
820972-2	Glycol Evaporator Wick Temperature Sensor
836250-1	Glycol Evaporator Wick Temperature Sensor
820918-1	Water-Glycol Temperature Sensor
820918-2	Water-Glycol Temperature Sensor
820980-1	Water-Glycol Temperature Sensor
820980-2	Water-Glycol Temperature Sensor
820880-3	Water-Glycol Temperature Sensor
820980-4	Water-Glycol Temperature Sensor
836684-1	Water-Glycol Temperature Sensor
836684-2	Water-Glycol Temperature Sensor
820110-3	Cabin Temperature Anticipator
820100-1	Cabin Temperature Sensor
820964-1	Cabin Temperature Sensor

Detailed failure data on each of these temperature sensors are presented in Sections 3 through 5 of this report. Section 2 presents descriptive information, a failure summary, and recommendations that apply to each of the three sensor groups. Differences in the sensor design configurations within these three groups are primarily due to differences in the intended sensor locations and media of application.

SECTION 2

DESCRIPTION, FAILURE SUMMARY, AND RECOMMENDATIONS FOR BEAD-TYPE THERMISTOR TEMPERATURE SENSORS

DESCRIPTION

Thermistors are "thermal resistors"--resistors that exhibit a high negative temperature coefficient of ohmic resistance. As the temperature of the thermistor increases, the thermistor resistance decreases, and as its temperature decreases, its resistance increases. (This is the opposite of the effect of temperature changes on metals.) Thermistors are semiconductors constructed of ceramic material made by sintering mixtures of metallic oxides such as those of manganese, nickel, cobalt, copper, iron, and uranium. Their electrical characteristics may be controlled by varying the type of oxide used and the physical size and configuration of the thermistor.

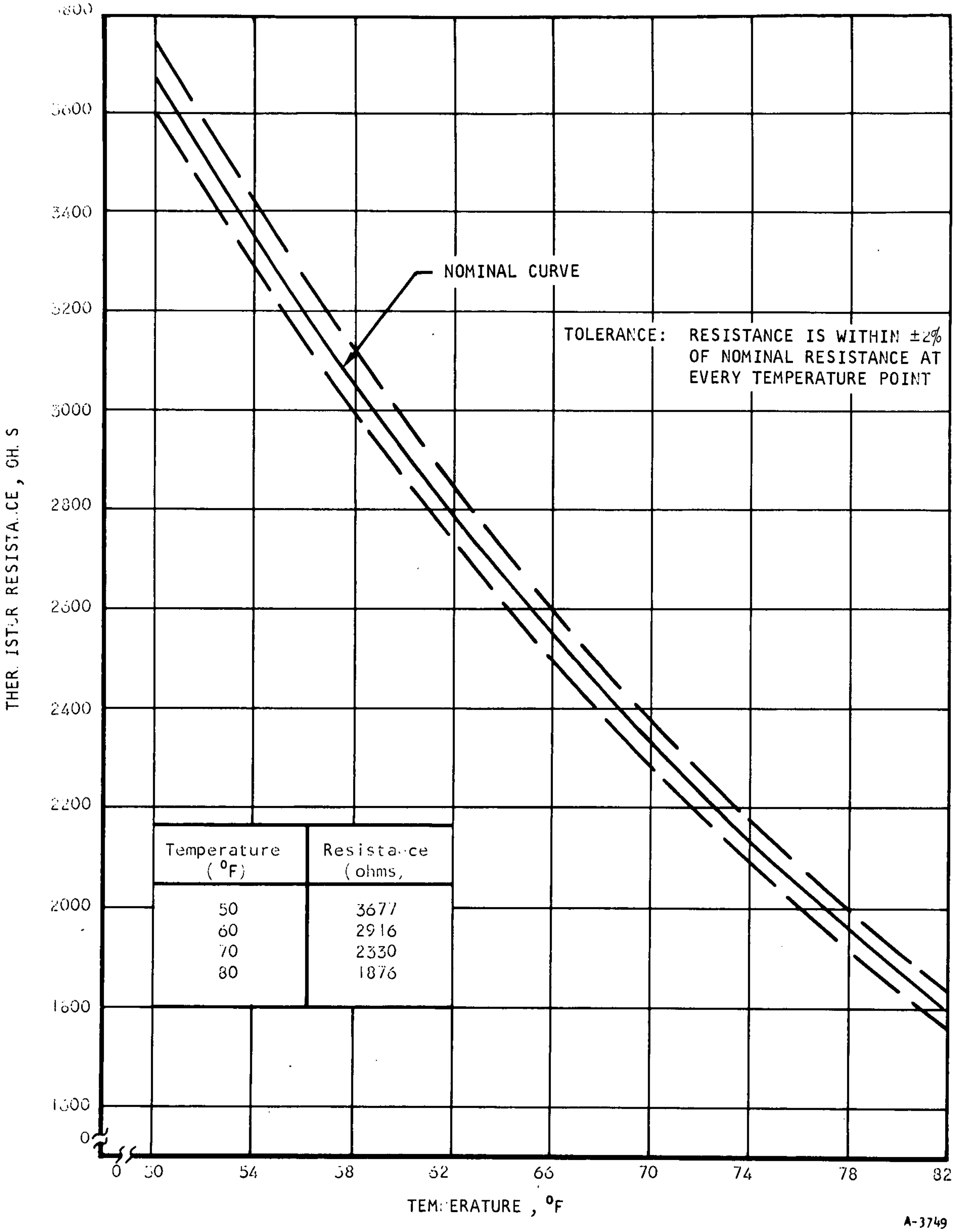
A typical thermistor resistance vs temperature characteristic curve is shown in Figure 2-1. A typical glass-sealed, dual-bead thermistor temperature sensor probe is illustrated in Figure 2-2. This sensor utilizes a dual-bead thermistor for the temperature-sensitive element.

The thermistor forms discussed herein include:

> Beads--A bead is made by forming a small ellipsoid of thermistor material on two fine, parallel wires about 0.010 in. apart. The material is sintered at high temperature and the leads become embedded tightly in the bead, making good electrical contact inside the thermistor material. Beads may be coated with glass for protection or mounted in evacuated or gas-filled bulbs. Resistance values of 300 ohms to over 100 megohms can be obtained in beads ranging in diameter from 0.006 in. to 0.100 in.

> Probes--A probe is made by sealing a bead-type thermistor into the tip of a solid glass rod of up to 0.100-in. diameter and 0.25 in. to 2 in. long.

This report evaluates sensors (consisting of one or more thermistor beads) that sense by direct contact the temperature of the media in which they are placed. The thermistor is connected through lead wires and a connector to a temperature control to form one leg of a temperature-sensing bridge circuit. Variation in temperature causes a change in the resistance of the thermistor and thus causes the bridge circuit to unbalance. The bridge circuit remains unbalanced as long as there is a temperature variation. The unbalanced bridge circuit produces a signal which is processed by separate equipment in accordance with the requirements of the thermistor application.



Temperature (°F)	Resistance (ohms)
50	3677
60	2916
70	2330
80	1876

Figure 2-1. Typical Thermistor Resistance-Temperature Curve

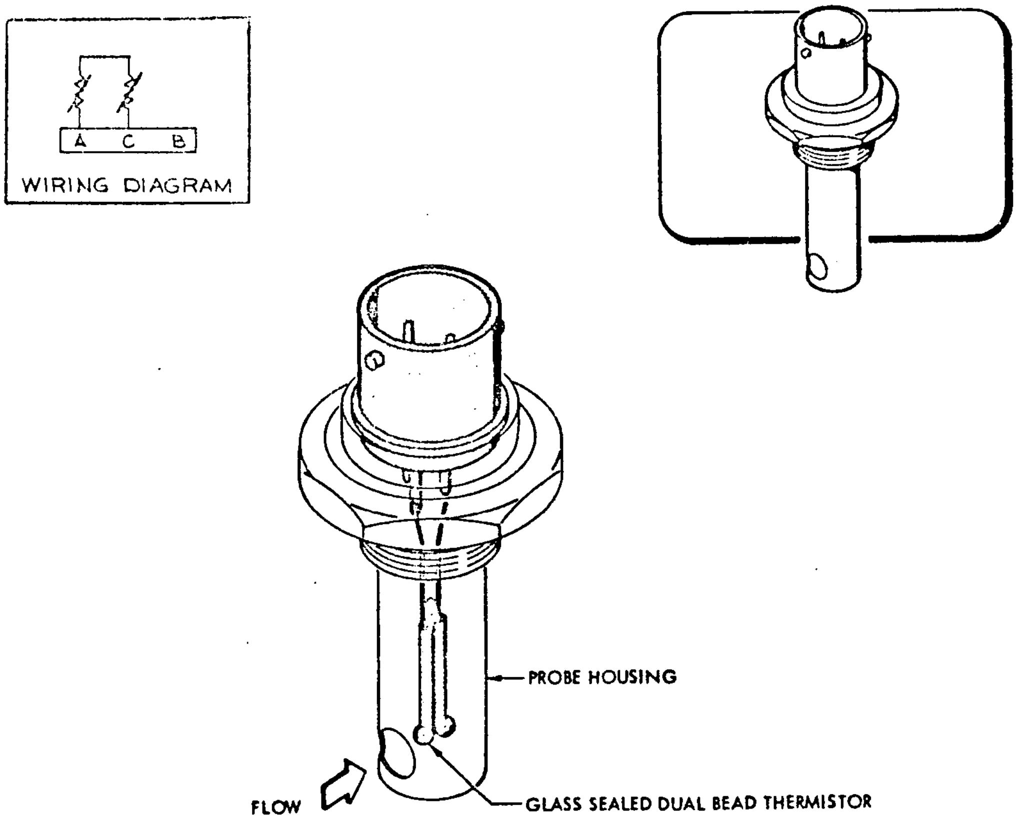


Figure 2-2. Glass-Sealed Dual-Bead Thermistor Temperature Sensor

FAILURE SUMMARY

Detailed failure analyses and summaries of each of the three temperature sensor groups evaluated in this report are presented in Sections 3 through 5 of this report. Each sensor group analysis presents the reliability data on the evaluation of each design configuration from the preliminary concept to the final design applied in the Apollo Block II ECS. Most of the trouble sources were removed from the problem area list during the process of design evaluation and modification; therefore, only the failure data on the current design configurations are analyzed in this section.

The current designs of the thermistor temperature sensors used in the Apollo Block II ECS include:

PN	Nomenclature
836250-1	Water-Glycol Wick Temperature Sensor
836684-1	Water-Glycol Temperature Sensor
836684-2	Water-Glycol Temperature Sensor
820964-1	Cabin Temperature Sensor
820110-3	Cabin Temperature Anticipator

All these temperature sensors, regardless of the quantity of the thermistors employed in each design, have the same principle of operation. Therefore, design data on individual units are combined to present the general value and reliability of the hardware in its temperature sensing application.

Nine failure reports, written against these part numbers and furnished by NASA-MSC, were reviewed. The results of these reports are summarized in the failure matrix shown in Figure 2-3. This matrix is a summation of the individual matrixes presented in turn for each of these five temperature sensors. Eight (89 percent) of the failures were determined to be due to human error and one (11 percent) due to random failure.

Figure 2-4 presents the relationship of these failures with respect to the total population of temperature sensors. A total of nine failures from a population of 267 units represents a rejection rate of 3.0 percent. Eight of the rejections, being due to human error, are potentially avoidable; therefore, the unavoidable rejection rate for one unanalyzed failure is 0.3 percent.

A review of the failure matrix of Figure 2-3 indicates that there is no basic and chronic problem area for this type of temperature sensor. This conclusion is based on the following observations on the failure matrix.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

Problem Area		Percent	Failure Mode: No Output	Failure Mode: Fixed Output	Failure Mode: Erratic	Failure Mode: Intermittent	Failure Mode: Low Resistance	Failure Type: Human	Failure Type: Electrical	Failure Type: Mechanical	Mechanism (Sensing Element: Elec.; Mechanical / Housing and Signal Transmission Mechanism) — Failure Cause: Unknown	Failure Cause: Poor Assembly	Failure Cause: Leakage	Failure Cause: No Failure
Design	Engineering													
Procedure, ATP (Testing)	Engineering													
Error (Testing, QTP)	Engineering													
Procedure (Testing, QTP)	Engineering													
Planning	Manufacturing													
Fabrication	Manufacturing													
Assembly	Manufacturing	56				1	4	5				1	4	
Q.C.	Manufacturing													
Inspection	Manufacturing													
ATP Test Error	Manufacturing													
Test Equipment Failure														
LOX Cleaning														
Handling														
Receiving Inspection (Test and Equipment)	Final Installation													
Installation	Final Installation													
Random Failure														
Unconfirmed Failure		33	1	1	1			3						3
Not Analyzed Failure Reports		11		1					1		1			
Total			1	2	1	1	4	8	1		1	1	4	3
Percent		100	11	22	11	11	45	89	11		11	11	45	33

Figure 2-3. AiResearch Current Thermistor Type Temperature Sensor Failure Matrix

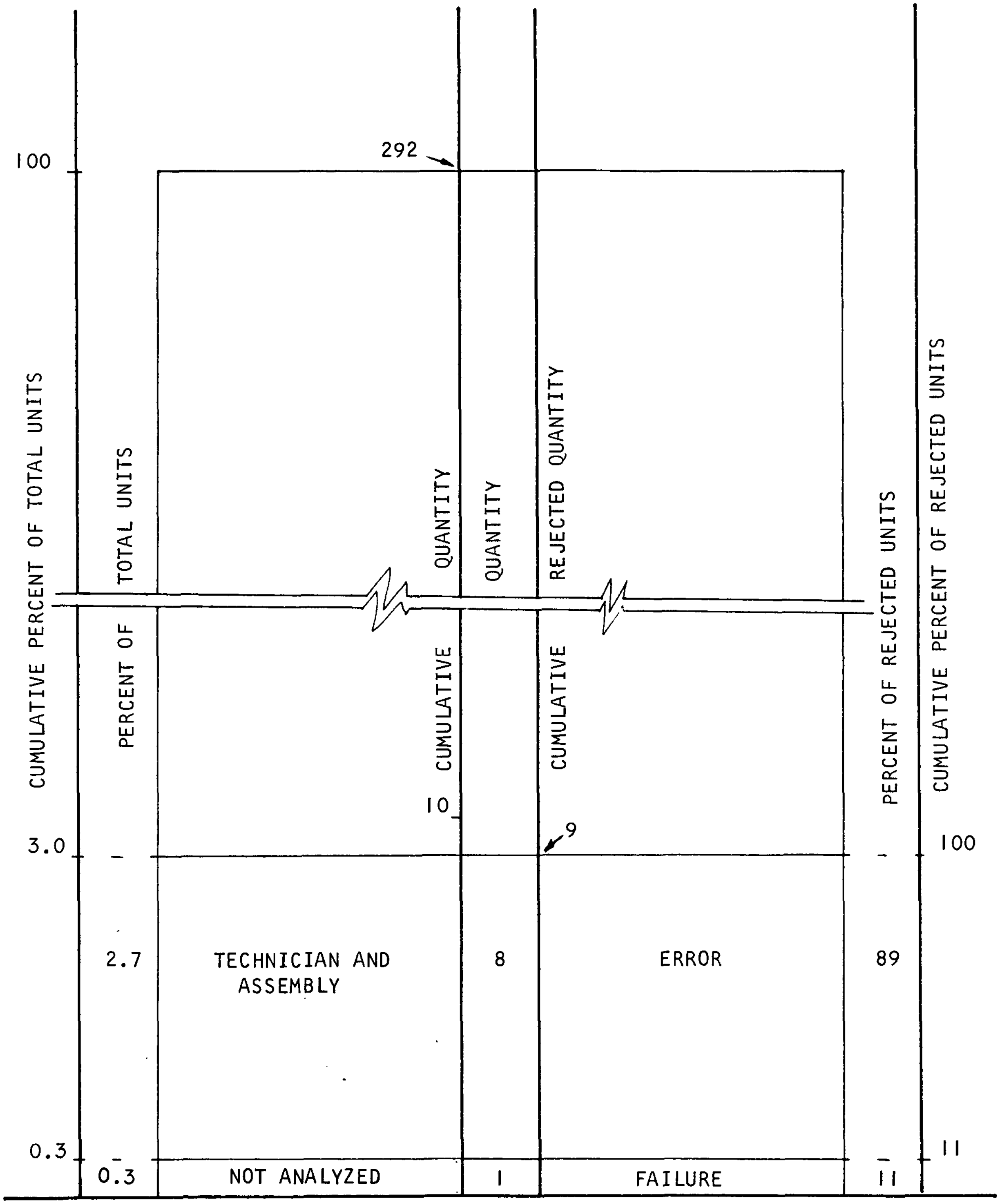


Figure 2-4. Distribution of Failures According to Problem Area for the Current Temperature Sensors

Non-Specific Problem Area

There was no information concerning the failure cause of the sensor in the failure report which was not analyzed.

Three failures were not confirmed and the responsibility of the reports belongs to their initiator.

Because three of the failures reported were not confirmed it is proper to retrain the laboratory technicians in the use of lab equipment and conduct of tests at scheduled intervals.

Manufacturing

Five failures were attributed to poor assembly practices.

A retraining program was conducted and the failure source was eliminated. It may be advisable to conduct retraining programs at scheduled intervals to keep personnel abreast of new techniques and skilled on the acquired knowledge.

RECOMMENDATIONS

Most of the failures reported on the current designs of the temperature sensors were the result of poor soldering and assembly practices. The remaining reports had three unconfirmed failures and one unit was scrapped before analysis. The design changes have already eliminated most of the previous problem sources. The following recommendations, based on the current design problems, are made to minimize the possibility of future rejections because of current problems.

Manufacturing Criteria

Provide detailed assembly and operations instructions to eliminate poor soldering.

Retrain assembly personnel at scheduled intervals.

Testing Criteria

Provide detailed test equipment checkout procedures.

Retrain test personnel at scheduled intervals.

Usage

Use the superseding designs which are trouble free.

SECTION 3

GLYCOL EVAPORATOR WICK TEMPERATURE SENSORS (AIRESEARCH PN 820972 AND PN 836250)

INTRODUCTION

The initial design of glycol evaporator wick temperature sensor PN 820970 was implemented on the Apollo Block I ECS. Because of numerous leakage problems this design was superseded by a new design, PN 836250, which was implemented on the Apollo Block II ECS. Each of these designs is analyzed in this section--the initial design is briefly reviewed and the superseding design is reviewed in detail.

PURPOSE AND DESCRIPTION

The wick temperature sensor senses the temperature of the wick in the water evaporator and thus detects whether the wick is wet or dry. The wick temperature sensor consists of a normal thermistor circuit and a redundant thermistor circuit. Each thermistor circuit consists of two thermistor probes connected in series. The thermistors are all connected by lead wires to a hermetic electrical connector.

PERFORMANCE AND DESIGN DATA

Table 3-1 presents the performance and design data for these temperature sensors. These data are identical for both of the designs. Engineering design error on PN 820972 was the problem source for 26 rejections in a total population of 65 units which represents a rejection rate of 40 percent. This high rejection rate motivated the design effort for PN 836250 which was approved as a new part for the Apollo Block II ECS. Four units of this new design were rejected because of poor potting adhesion. This assembly problem was detected immediately and an adhesive application training program was conducted which eliminated the problem source. The new design has a total population of 89 units, and 4 rejections represent a rejection rate of 4.5 percent. Figure 3-1 presents this information in a histogram. It is notable that there were no random failures, and all the rejections both in the intital and final designs were potentially avoidable.

FAILURE AND DESIGN REVIEW

Initial Design (PN 820972)

Table 3-2 is a summary of 12 failure reports written against 28 units of this sensor. Two of these failure reports were in error. The remaining 10 failure reports contained information on 26 rejected units which were reviewed for the evaluation of this sensor. The outline drawing of PN 820972 is presented in Figure 3-2 for reference. The information indicated

TABLE 3-1

PERFORMANCE AND DESIGN DATA FOR PN'S 836250 AND 820972

Thermistor resistance	7901 ±19 ohms at 47°F
	4002 ±13 ohms at 77°F
	2482 ±10 ohms at 100°F
Sensor time constant	0.50 sec in still oil
Operating pressure	0 to 15 psia
Proof pressure	25 psia
Low pressure	1×10^{-4} mm Hg abs
Operating temperature	0° to 212°F
Working media	Water and low-pressure steam
Electrical connector	AiResearch commercial standard 223-025-9013
Weight	0.1 lb

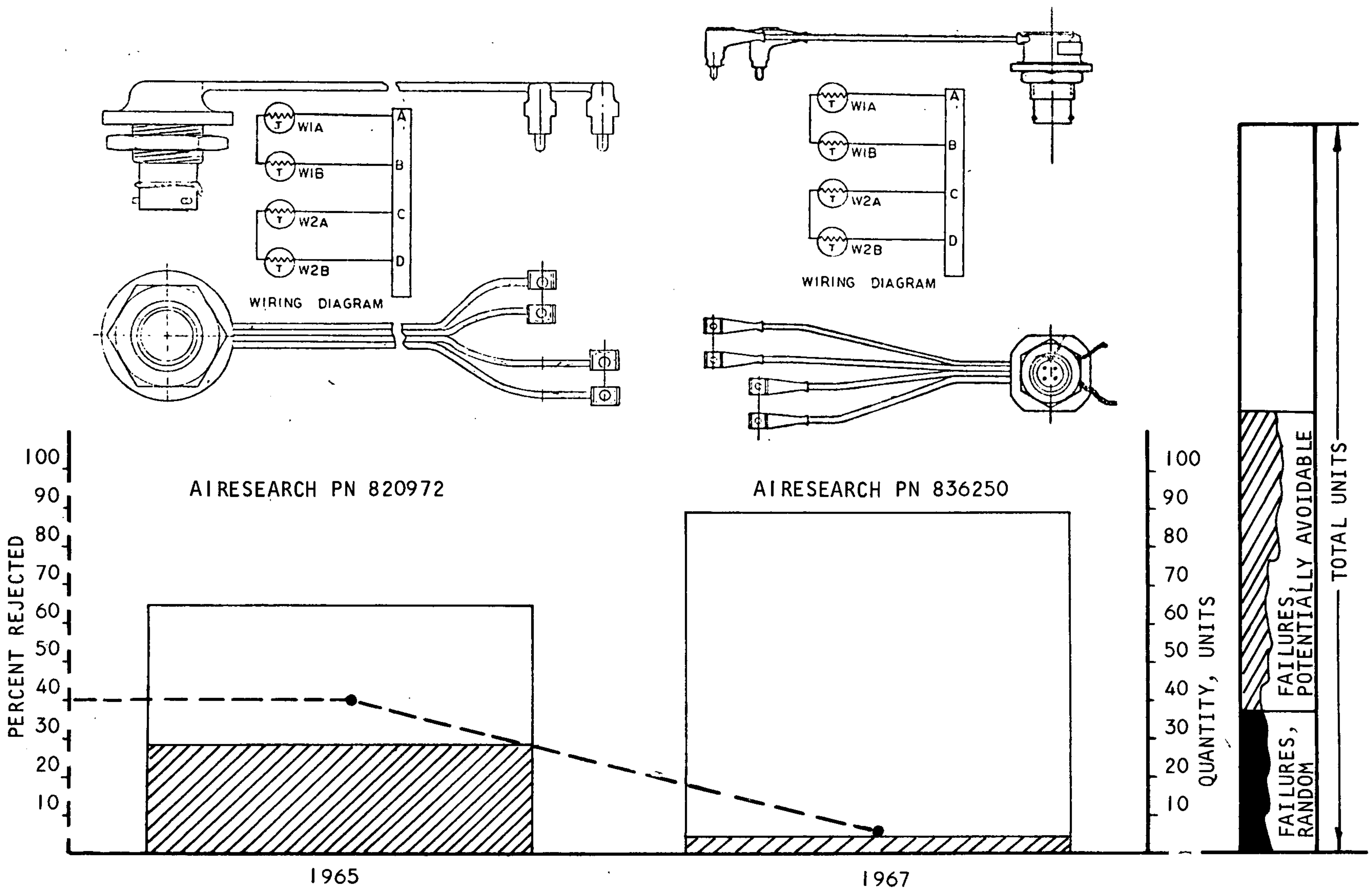


Figure 3-1. Glycol Evaporator Wick Temperature Sensor Population and Rejection Quantity Histogram in Chronological Order of Design

FOLDOUT FRAME 1

TABLE 3-2

FOLDOUT FRAME 2

GLYCOL EVAPORATOR WICK TEMPERATURE SENSOR FAILURE EVALUATION

TRANSDUCER APPLICATION Glycol Evaporator Wick Temperature Sensor
BASIC PART NUMBER 820972 (Page 1 of 2)
TRANSDUCER MANUF. Fenwal Electronics
TROUBLE REPORT SOURCE AiResearch

TRANSDUCER TYPE Temperature
OPERATING PRINCIPLE Thermistor
MEASUREMENT RANGE 47 - 100°F
MEASUREMENT MEDIA Glycol

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
820972-2-1	2,3,4,5 7,8,9,10 11,13,14 15	10-3-66	11331	Human	Low insulation resistance	Leakage at potting interface	Poor potting adhesion at suspected potted interfaces	Design	Redesign to metal clad potted unit	Redesigned unit designation 836250-1-1 will be used on Block II ECS
820972-2-1	31, 35	10-13-66	11362	Human	Low insulation resistance	--	--	--	--	Units scrapped
820972-1-1	37, 38	10-13-66	11363	Human	Low insulation resistance	--	Potting techniques	Design	Redesign to metal clad potted unit	Unit replaced with -2 configuration using improved potting
820972-2-1	9	11-11-66	12038	Human	Low insulation resistance	Leakage at potting interface	Poor potting adhesion at suspected potted interfaces	Design	Redesign to metal clad potted unit	Redesigned unit designation 836250-1-1 will be used on Block II ECS
820972-2-2	16	11-29-66	11946	Human	Low insulation resistance	Leakage at potting interface	Poor potting adhesion at suspected potted interfaces	Design	Redesign to metal clad potted unit	Redesigned unit designation 836250-1-1 will be used on Block II ECS
820972-2-1	25	12-14-66	11993	Human	Low insulation resistance	Leakage at potting interface	Poor potting adhesion at suspected potted interfaces	Design	Redesign to metal clad potted unit	Redesigned unit designation 836250-1-1 will be used on Block II ECS
820972-2	43, 44, 45	12-21-66	12550	Human	Low insulation resistance	Leakage at potting interface	Poor potting adhesion at suspected potted interfaces	Design	Redesign to metal clad potted unit	Redesigned unit designation 836250-1-1 will be used on Block II ECS
820972-2	44	1-11-67	7825	NOT A QUAL FAILURE. THIS WAS MISREPORTED						
820972-1-1	33	2-15-67	8868	Human	Low insulation resistance	Leakage at potting interface	Poor potting adhesion at suspected potted interfaces	Design	Redesign to metal clad potted unit	Redesigned unit designation 836250-1-1 will be used on Block II ECS

TABLE 3-2 (Continued)

TRANSDUCER APPLICATION Glycol Evaporator Wick Temperature Sensor

BASIC PART NUMBER 820972 (Page 2 of 2)

TRANSDUCER MANUF. Fenwal Electronics

TROUBLE REPORT SOURCE AiResearch

TRANSDUCER TYPE Temperature

OPERATING PRINCIPLE Thermistor

MEASUREMENT RANGE 47 - 100°F

MEASUREMENT MEDIA Glycol

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
820972-2-1	54, 56	2-15-67	13045	Human	Low insulation resistance	Leakage at potting interface	Poor potting adhesion at suspected potted interfaces	Design	Units scrapped. Redesigned to metal clad potted unit	Redesigned unit designation 836250-1-1 will be used on Block II ECS
820972-2	24	2-20-67	13063	Not reportable, not an acceptance test						
820972-2-1	12	3-23-67	8872	Human	Low insulation resistance	Leakage at potting interface	Poor potting adhesion at suspected potted interfaces	Design	Redesign to metal clad potted unit	Redesigned unit designation 836250-1-1 will be used on Block II ECS

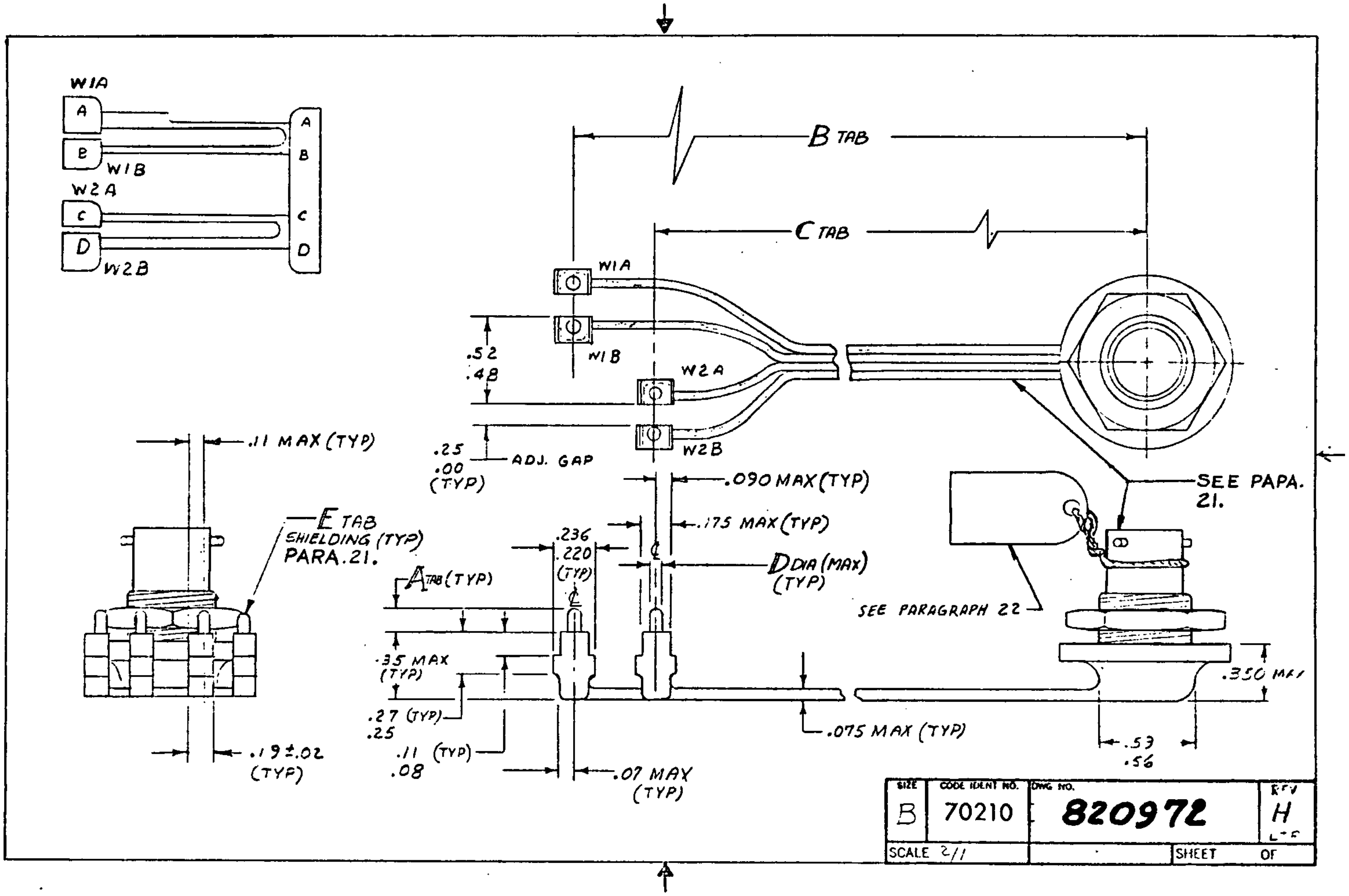


Figure 3-2. Outline of Wick Temperature Sensor

in Table 3-2 is summarized in the failure matrix of Figure 3-3. The histogram of Figure 3-4 presents the distribution of failures according to problem area.

The basic problem with this initial design was leakage caused by poor potting adhesion. The design change to a metal-clad potted unit eliminated this problem source.

Because this design has been superseded, it is recommended that the analysis of this design be discontinued. The notable information gained from this analysis is that thermistor probes should be well protected and, if necessary, metal-clad potted to prevent leakage failure.

Current Design (PN 836250)

Table 3-3 is a summary of four failure reports which were reviewed for the evaluation of this sensor which supersedes PN 820972. The outline drawing of PN 836250 is presented in Figure 3-5 for reference. The information indicated in Table 3-3 is summarized in the failure matrix of Figure 3-6. The histogram of Figure 3-7 presents the distribution of failures according to problem area.

The basic early problem with the current design was leakage caused by poor potting adhesion. The assembly adhesive application training program conducted at the time of these failures eliminated this problem source.

This is a design of proven integrity and, with assembly personnel who are well trained in up-to-date techniques of assembly and application procedures, the only failure source should be random failures.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

FAILURE	PERCENT	MODE: LOW RESISTANCE	TYPE: HUMAN	TYPE: ELECTRICAL	TYPE: MECHANICAL	MECHANISM: SENSING MECHANISM, ELEC.: OPEN	MECHANISM: SENSING MECHANISM, ELEC.: SHORT	MECHANISM: SENSING MECHANISM, MECHANICAL: LEAKAGE	MECHANISM: SIGNAL CONDITIONING AND TRANSMITTING MECHANISM
PROBLEM AREA									
ENGINEERING: DESIGN	100	26	26					26	
ENGINEERING: TESTING: PROCEDURE, ATP									
ENGINEERING: TESTING: QTP: ERROR									
ENGINEERING: TESTING: QTP: PROCEDURE									
MANUFACTURING: PLANNING									
MANUFACTURING: FABRICATION									
MANUFACTURING: ASSEMBLY									
MANUFACTURING: QUALITY CONTROL									
MANUFACTURING: INSPECTION									
MANUFACTURING: ATP TEST ERROR									
TEST EQUIPMENT FAILURE									
LOX CLEANING									
HANDLING									
FINAL INSTALLATION: RECEIVING INSPECTION (TEST AND EQUIPMENT)									
FINAL INSTALLATION: INSTALLATION									
RANDOM FAILURE									
UNCONFIRMED FAILURE									
NOT ANALYZED FAILURE REPORTS									
TOTALS	100		26					26	
PERCENT			100					100	

FAILURE CAUSE

Figure 3-3. AiResearch PN 820972, Apollo Block I ECS Item No. 2.49 Wick Temperature Sensor Failure Matrix

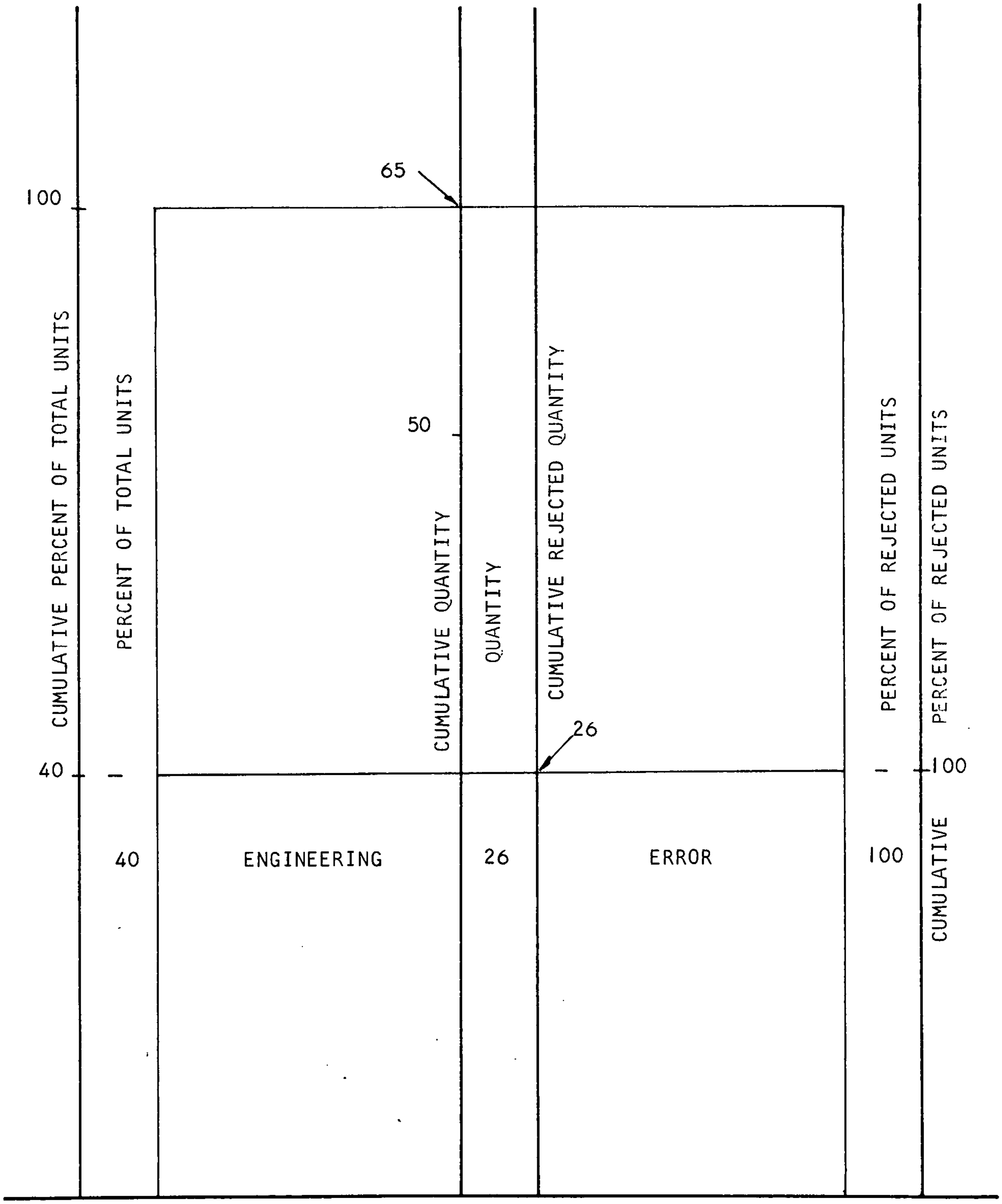


Figure 3-4. Distribution of Failures According to Problem Area

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE 3-3

GLYCOL EVAPORATOR WICK TEMPERATURE SENSOR FAILURE EVALUATION

TRANSDUCER APPLICATION Glycol Evaporator Wick Temperature Sensor
BASIC PART NUMBER 836250
TRANSDUCER MANUF. AiResearch
TROUBLE REPORT SOURCE AiResearch

TRANSDUCER TYPE Temperature
OPERATING PRINCIPLE Thermistor
MEASUREMENT RANGE 47 - 100°F
MEASUREMENT MEDIA Water Glycol

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
836250-1	87-139	9-29-67	15176	Human	Low insulation resistance	Leakage at potting interface	Poor potting adhesion at suspected potted interfaces	Design	Q.C. and production alerted	--
836250-1	118-199	4-3-69	19161	Human	Low insulation resistance	Leakage at potting interface	Poor potting adhesion at suspected potted interfaces	Design	Retraining of assembly personnel	--
836250-1	118-203	4-8-69	19163	Human	Low insulation resistance	Leakage at potting interface	Poor potting adhesion at suspected potted interfaces	Design	Retraining of assembly personnel	--
836250-1	188-204	4-8-69	19164	Human	Low insulation resistance	Leakage at potting interface	Poor potting adhesion at suspected potted interfaces	Design	Retraining of assembly personnel	--

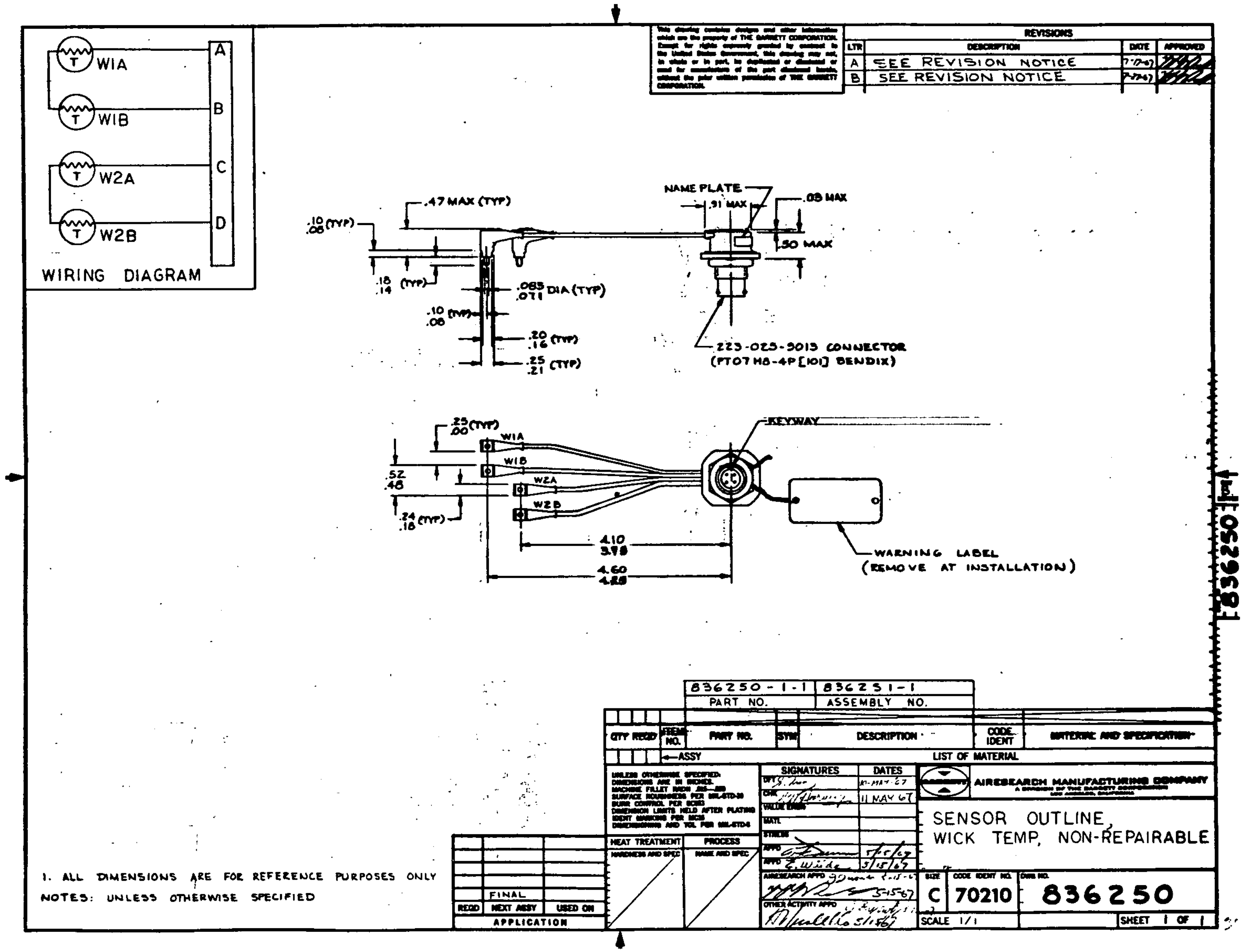


Figure 3-5. Outline of Wick Temperature Sensor

FOLDOUT FRAME 1

FOLDOUT FRAME 2

FAILURE										
PROBLEM AREA		PERCENT	MODE: LOW RESISTANCE	TYPE: HUMAN	TYPE: ELECTRICAL	TYPE: MECHANICAL	MECHANISM: SENSING MECHANISM: ELEC.: OPEN	MECHANISM: SENSING MECHANISM: ELEC.: SHORT	MECHANISM: SENSING MECHANISM: MECHANICAL: LEAKAGE	MECHANISM: SIGNAL CONDITIONING AND TRANSMITTING MECHANISM
ENGINEERING	DESIGN									
ENGINEERING – TESTING	PROCEDURE, ATP									
ENGINEERING – TESTING – QTP	ERROR									
ENGINEERING – TESTING – QTP	PROCEDURE									
MANUFACTURING	PLANNING									
MANUFACTURING	FABRICATION									
MANUFACTURING	ASSEMBLY	100	4	4					4	
MANUFACTURING	QUALITY CONTROL									
MANUFACTURING	INSPECTION									
MANUFACTURING	ATP TEST ERROR									
TEST EQUIPMENT FAILURE										
LOX CLEANING										
HANDLING										
FINAL INSTALLATION	RECEIVING INSPECTION (TEST AND EQUIPMENT)									
FINAL INSTALLATION	INSTALLATION									
RANDOM FAILURE										
UNCONFIRMED FAILURE										
NOT ANALYZED FAILURE REPORTS										
TOTALS		100	4	4					4	
PERCENT			100	100					100	

FAILURE CAUSE

Figure 3-6. AiResearch PN 836250, Apollo Block II ECS Item No. 2.49 Wick Temperature Sensor Failure Matrix

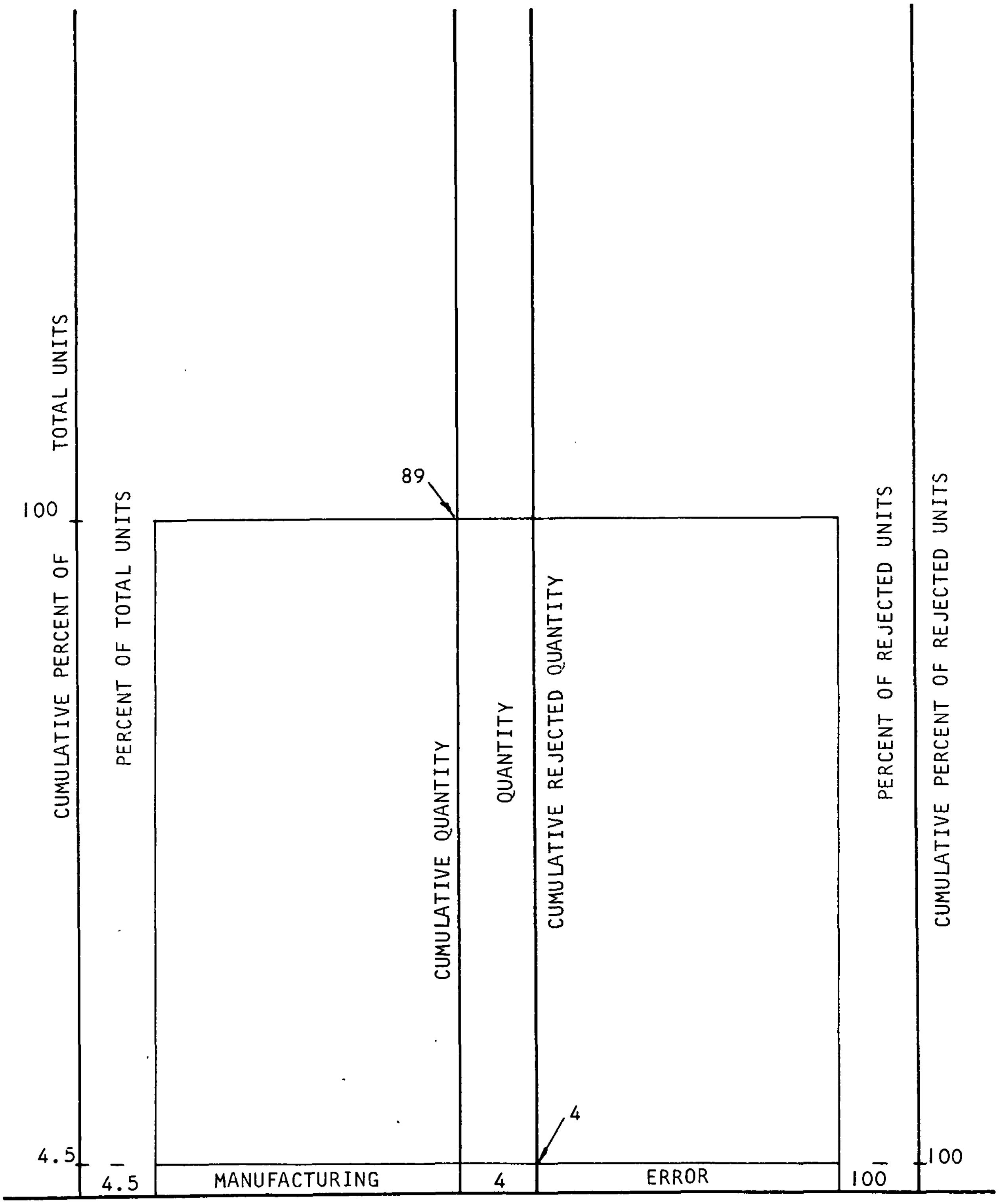


Figure 3-7. Distribution of Failures According to Problem Area

SECTION 4

WATER-GLYCOL TEMPERATURE SENSORS (AIRESEARCH PN'S 820918, 820980, 836684)

INTRODUCTION

Three different designs and a total of eight different variations of water-glycol temperature sensors were designed for three different applications. The basic principle of operation in all designs and their variations is the same; the only differences are in the resistivity of the probes and the series-parallel arrangements. The initial design, which is no longer in use, is reviewed in brief. More emphasis is placed on the reviews of the second and third designs, which are approved Apollo Block II components. Figure 4-1 presents the typical configuration of a water-glycol temperature sensor. Figure 4-2 presents the quantity and rejection histogram of each design of these sensors in their chronological order of design. This figure also includes the series-parallel arrangement of the thermistor beads of each design variation. Evaluation of each of these eight configurations is presented at the end of this section.

PURPOSE AND DESCRIPTION

The water-glycol temperature sensor is used to sense the temperature of water-glycol coolant and exhibits a change in resistance in accordance with change in temperature. These units consist of a metal housing containing two or more thermistor probes, one of which is in operation and the rest of which are in standby redundancy. The operating thermistor forms one leg of a resistance bridge in the control circuitry which compares the sensed temperature to a reference temperature, and initiates the control function accordingly.

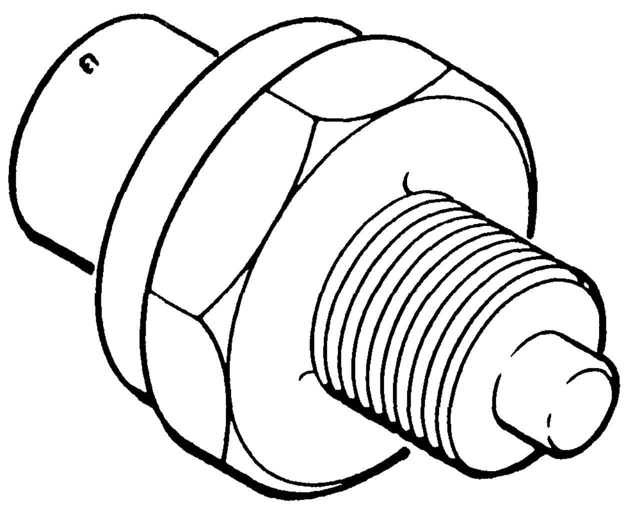
REJECTION SUMMARY

Figure 4-3 presents the failure matrix of all the failures in all eight different configurations of the water-glycol temperature sensor. The information indicated in this matrix is summarized in the histogram of Figure 4-4. This histogram indicates two random failures for 6.6 percent of the total rejections. The remaining 93.4 percent of the rejections are caused by handling, assembly, and engineering errors; all are potentially avoidable.

PERFORMANCE AND DESIGN DATA

Initial Designs

The performance and design data for initial designs PN's 820918-1, 820918-2, 820980-1, 820980-2, 820980-3, and 820980-4 are presented in Table 4-1 through 4-6.



A-11828

Figure 4-1. Typical Configuration of Water-Glycol Temperature Sensor

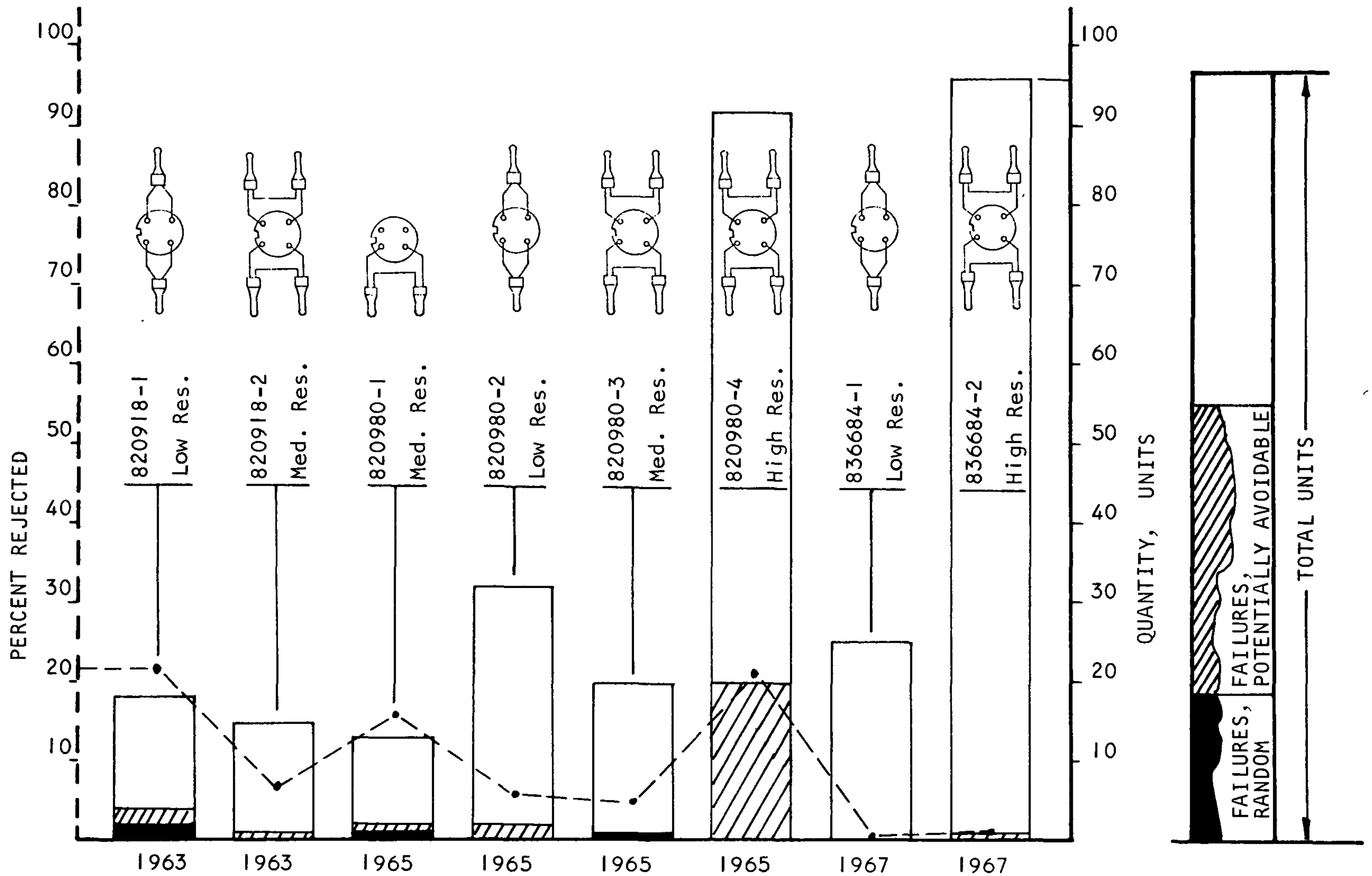


Figure 4-2. Water-Glycol Temperature Sensor Population and Rejection Quantity Histogram in Chronological Order of Design

FOLDOUT FRAME 1

FOLDOUT FRAME 2

Problem Area		Percent	Mode: High Output	Mode: Low Resistance	Mode: Drift	Mode: Disintegration	Mode: Intermittent	Mode: None	Type: Human	Type: Electrical	Type: Mechanical	Mechanism: Sensing Element, Elec	Mechanism: Sensing Element, Mechanical — Failure Cause: Cracked Bead	Mechanism: Housing and Signal Transmission Mechanism — Failure Cause: Unknown	Failure Cause: Poor Soldering	Failure Cause: Seal	Failure Cause: Potting	Failure Cause: No Failure
Engineering	Design																	
Engineering — Testing	Procedure, ATP																	
Engineering — Testing — Qual	Error																	
Engineering — Testing — Qual	Procedure	3.3		1					1									1
Manufacturing	Planning																	
Manufacturing	Fabrication																	
Manufacturing	Assembly	30.0		8			1		9						8		1	
Manufacturing	Q.C.																	
Manufacturing	Inspection																	
Manufacturing	ATP Test Error																	
Test Equipment Failure		30.3			9				9									9
LOX Cleaning																		
Handling		13.3		4					4				4					
Final Installation	Receiving Inspection																	
Final Installation	Installation																	
Random Failure		6.7				2					2					2		
Unconfirmed Failure		6.7		1				1	2					1				1
Not Analyzed Failure Reports		10.0	1		2				1	2				3				
Total			1	14	11	2	1	1	26	2	2		4	4	8	2	1	11
Percent		100	3.3	46.7	36.7	6.7	3.3	3.3	86.6	6.7	6.7		13.3	13.3	26.7	6.7	3.3	36.7

Figure 4-3. Water-Glycol Temperature Sensor Failure Matrix

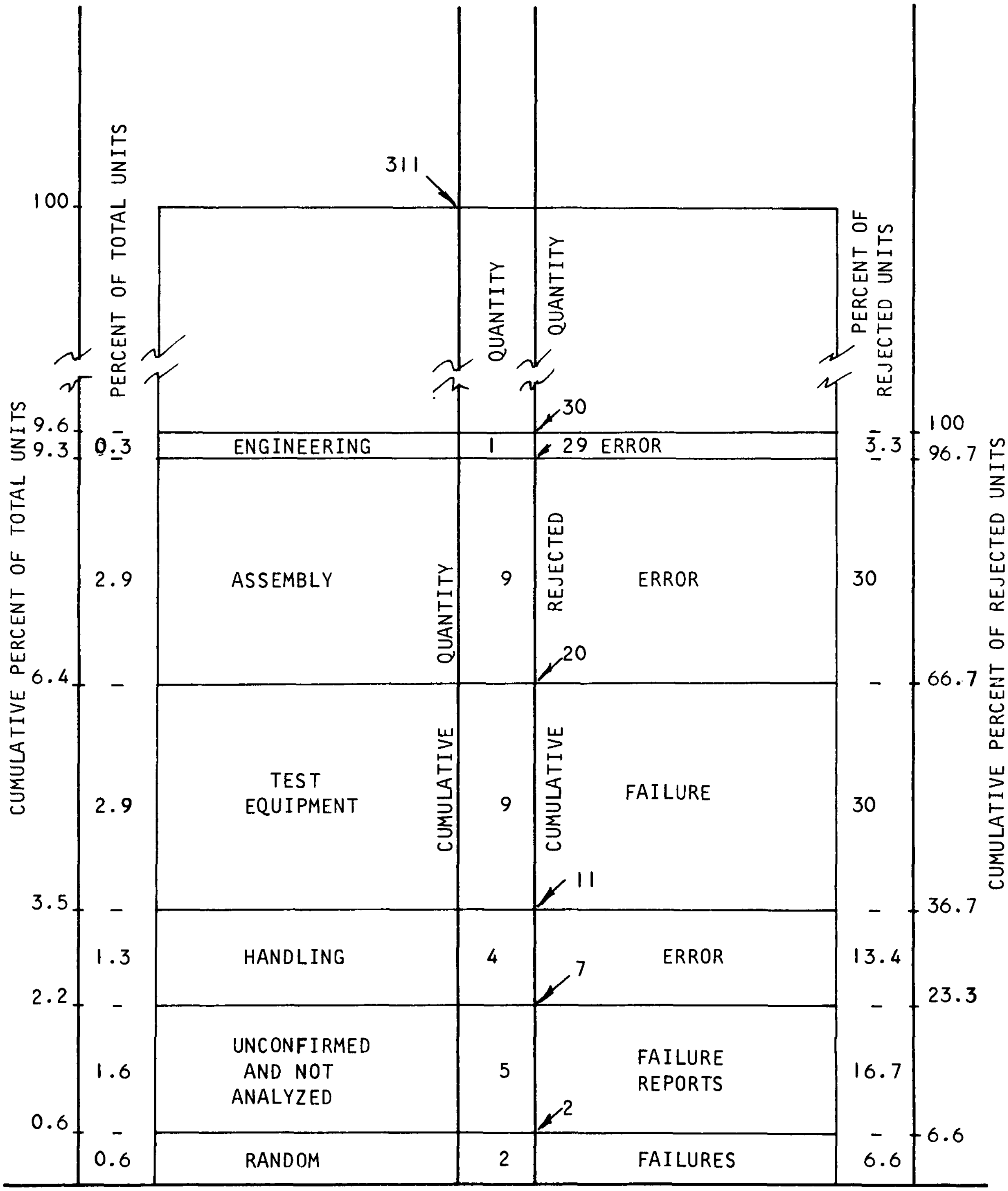


Figure 4-4. Distribution of Failures According to Problem Area

TABLE 4-1

PERFORMANCE AND DESIGN DATA FOR PN 820918-1
(Initial Design)

Performance requirements

(a) Thermistor resistance: Resistance is 1822 ohms $\pm 2\%$ at $45^{\circ}F$

(b) Time constant: 2 min when exposed to 200 lb/hr water-glycol flow rate

Operating pressures:

(a) Normal: 21 psig

(b) Max.: 60 psig

(c) Pressure drop across sensor: 0.5 in. water max. at 200 lb/hr glycol flow rate

Structural requirements:

(a) Proof pressure: 90 psig

(b) Burst pressure: 150 psig

External leakage: Zero with 60 psig internal pressure

Fittings: Per MS-33656-6, Style E

Environmental conditions: As specified in AiResearch Specification SS-1060-R; Type I equipment

Installation envelope: Per AiResearch Drawing 820918

Weight: 0.1 lb

Electrical connector: In accordance with MIL-C-26482C and gold-plated

TABLE 4-2

PERFORMANCE AND DESIGN DATA FOR PN 820918-2
(Initial Design)

Performance requirements:

(a) Thermistor resistance: 3677 ohms $\pm$2% at 50°F
2916 ohms $\pm$2% at 60°F
2330 ohms $\pm$2% at 70°F
1876 ohms $\pm$2% at 80°F

(b) Time constant: 2 min when exposed to 200 lb/hr water-glycol flow rate

Operating pressures:

(a) Normal: 21 psig

(b) Max.: 60 psig

(c) Pressure drop across sensor: 0.5 in. water max. at 200 lb/hr water-glycol flow rate and 45°F temperature

Structural requirements:

(a) Proof pressure: 90 psig

(b) Burst pressure: 150 psig

External leakage: Zero with 60 psig water-glycol pressure

Environmental conditions: Per AiResearch Report SS-1060-R; Type I equipment

Installation envelope: Per AiResearch Drawing 820918

Weight: 0.1 lb

Electrical connector: Per MIL-C-26482C and gold-plated

TABLE 4-3

PERFORMANCE AND DESIGN DATA FOR PN 820980-1
(Initial Design)

End fittings	Per MS33656-6
Operating pressure	60 psig maximum
Proof pressure	90 psig
Burst pressure	150 psig
External leakage	1.3×10^{-4} cc/hr water-glycol with 60 psig at 70°F
Weight	0.1 lb
Envelope	3.6 by 3.5 by 2.0 in.
Sensor resistance (each)	4670 ohms ±1% at 40°F 2001 ohms ±1% at 77°F 413.6 ohms ±1% at 160°F
Time constant	2 min when exposed to 200 lb/hr water-glycol flow rate

TABLE 4-4

PERFORMANCE AND DESIGN DATA FOR PN 820980-2
(Initial Design)

End fittings	Per MS33656-6
Operating pressure	60 psig
Proof pressure	90 psig
Burst pressure	150 psig
External leakage	1.3×10^{-4} cc/hr water-glycol with 60 psig at 70°F
Weight	0.1 lb
Envelope	3.6 by 3.5 by 2.0 in.
Sensor resistance (each)	3296 ±280 ohms at 20°F 2614 ±139 ohms at 30°F 2084 ±51 ohms at 40°F 1860 ±28 ohms at 45°F 1663 ±42 ohms at 50°F 1336 ±58 ohms at 60°F 1082 ±66 ohms at 70°F
Time constant	2 min when exposed to 200 lb/hr water-glycol flow rate
Qualification status	This glycol temperature sensor is a qualified Block II Apollo component.

TABLE 4-5

PERFORMANCE AND DESIGN DATA FOR PN 820980-3
(Initial Design)

End fittings	Per MS33656-6
Operating pressure	60 psig maximum
Proof pressure	90 psig
Burst pressure	150 psig
External leakage	1.3×10^{-4} cc/hr water-glycol with 60 psig at 70°F
Weight	0.1 lb
Envelope	3.6 by 3.5 by 2.0 in.
Sensor resistance (each)	4670 ohms $\pm1\%$ at 40°F 2001 ohms $\pm1\%$ at 77°F 413.6 ohms $\pm1\%$ at 160°F
Time constant	2 min when exposed to 200 lb/hr water-glycol flow rate

TABLE 4-6

PERFORMANCE AND DESIGN DATA FOR PN 820980-4
(Initial Design)

End fittings	Per MS33656-6
Operating pressure	60 psig maximum
Proof pressure	90 psig
Burst pressure	150 psig
External leakage	1.3×10^{-4} cc/hr water-glycol with 60 psig at 70°F
Weight	0.1 lb
Envelope	3.6 by 3.5 by 2.0 in.
Sensor resistance (each)	9356 ± 117 ohms at 40°F 7355 ± 92 ohms at 50°F 5835 ± 73 ohms at 60°F 4661 ± 58 ohms at 70°F 3752 ± 47 ohms at 80°F 3041' ± 38 ohms at 90°F 2482 ± 31 ohms at 100°F
Time constant	2 min when exposed to 200 lb/hr water-glycol flow rate
Qualification status	The glycol temperature sensor is a qualified Block II Apollo component.

Current Designs

The performance and design data for current designs PN's 836684-1 and 836684-2 are presented in Tables 4-7 and 4-8.

TABLE 4-7

PERFORMANCE AND DESIGN DATA FOR PN 836684-1
(Current Design)

Connector	AiResearch 223-022-9007
Proof pressure	150 psig
Burst pressure	200 psig
Sensor resistance	1860 $\pm$19 ohms at 45°F

TABLE 4-8

PERFORMANCE AND DESIGN DATA FOR PN 836684-2
(Current Design)

Connector	AiResearch 223-022-9007
Proof pressure	150 psig
Burst pressure	200 psig
Sensor resistance	9356 $\pm$94 ohms at 40°F 4661 $\pm$47 ohms at 70°F 2482 $\pm$25 ohms at 100°F

FAILURE AND DESIGN REVIEW

Initial Designs

1. Water-Glycol Temperature Sensor PN 820918-1

Table 4-9 is a summary of the four failure reports that were reviewed for this sensor evaluation. Two of the reports were determined to be due to test equipment errors and two reports were related to random failure of seals. Figure 4-5 summarizes this information in the failure matrix. Recommendations for actions that will reduce the quantity of rejections stemming from human errors are summarized in Section 2 of this report.

2. Water-Glycol Temperature Sensor, PN 820918-2

Table 4-10 is a summary of the only failure report that was reviewed for the evaluation of this sensor. The only problem was low insulation resistance caused by excessive use of potting compound which pressed the lead wire to the housing. Recommendations of actions that will reduce the quantity of this type of failures are presented in Section 2 of this report.

3. Water-Glycol Temperature Sensor, PN 820980-1

Table 4-11 is a summary of the two failure reports that were reviewed for the evaluation of this sensor. One unit was scrapped without analysis of the failed item. The second unit exhibited low insulation resistance because of water leakage into the case, which resulted from a defective solder joint in the thermistor-to-case seal. Recommendations of actions that will reduce the quantity of this type of failures are presented in Section 2 of this report.

4. Water-Glycol Temperature Sensor, PN 820980-2

Table 4-12 is a summary of the two failure reports that were reviewed for the evaluation of this sensor. One failure report was not relevant to the sensor and the rejection was found to be caused by a faulty battery in the test equipment. The second failure report was written on a unit with low resistance, which was caused by water leakage into the thermistor as a result of a crack caused by mishandling. Recommendations of actions that will reduce the quantity of such rejections and failures are presented in Section 2 of this report.

5. Water-Glycol Temperature Sensor, PN 820980-3

Table 4-13 is a summary of the only failure reported on this part number; however, the unit was scrapped before failure analysis was performed. Since this design is not being implemented and has been superseded, it is recommended that no further investigation be performed on this design.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE 4-9

WATER-GLYCOL TEMPERATURE SENSOR FAILURE EVALUATION

TRANSDUCER APPLICATION Glycol Temperature Sensor
BASIC PART NUMBER 820918-1
TRANSDUCER MANUF. AiResearch Mfg. Co.
TROUBLE REPORT SOURCE AiResearch

TRANSDUCER TYPE Temperature
OPERATING PRINCIPLE Thermistor
MEASUREMENT RANGE 50 - 80°F
MEASUREMENT MEDIA Glycol

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
820918-1-1	24-107	6-18-64	3370	Human	Drift	Faulty test equipment	Out-of-calibration test gages	Testing equipment	Replace faulty test equipment	Unit was good
820918-1-1	44-113	4-7-65	4785	Mech	Connector packing ("O" ring) damage	Isolated case	--	--	--	This packing was lost prior to analysis
820918-1-1	44-112	4-7-65	4785	Mech	Connector packing ("O" ring) damage	Isolated case	--	--	--	
820918-1-1	44-113	4-13-65	5890	Human	Explosion in test set-up	No	--	Not confirmed failure	--	Failure did not relate to unit. Unit was good.

FAILURE

PERCENT	MODE: DRIFT	DISINTEGRATION													NONE	TYPE: HUMAN	ELECTRICAL	MECHANICAL	MECHANISM: SENSING MECHANISM ELEC.		SENSING MECHANISM MECHANICAL					HOUSING AND SIGNAL TRANSMISSION MECHANISM: SEAL														NO FAILURE	PROBLEM AREA
																																									ENGINEERING
																																									MANUFACTURING
25	1															1																								1	TEST EQUIPMENT FAILURE
																																									FINAL ASSEMBLY
50		2																2								2															RANDOM FAILURE
25															1	1																								1	NOT CONFIRMED FAILURE
100	1	2													1	2		2								2														2	TOTALS
	25	50													25	50		50								50														50	PERCENT

FAILURE CAUSE

Figure 4-5. PN 820918-1 Failure Matrix

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE 4-10

WATER-GLYCOL TEMPERATURE SENSOR FAILURE EVALUATION

TRANSDUCER APPLICATION Glycol Temperature Sensor

BASIC PART NUMBER 820918-2

TRANSDUCER MANUF. AiResearch Manufacturing Co.

TROUBLE REPORT SOURCE AiResearch

TRANSDUCER TYPE Temperature

OPERATING PRINCIPLE Thermistor

MEASUREMENT RANGE 50 - 80°F

MEASUREMENT MEDIA Glycol

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
820918-2	24-105	6/18/64	3435	Human	Low insulation resistance	Potting compound provided a low resistance path wire to case	Excessive potting compound used in assembly	Manufacturing, assembly	Use a measured amount of potting compound	

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE 4-11

WATER-GLYCOL TEMPERATURE SENSOR FAILURE EVALUATION

TRANSDUCER APPLICATION Glycol Temperature Sensor

BASIC PART NUMBER 820980-1

TRANSDUCER MANUF. AiResearch Manufacturing Co.

TROUBLE REPORT SOURCE AiResearch

TRANSDUCER TYPE Temperature

OPERATING PRINCIPLE Thermistor

MEASUREMENT RANGE 40 - 100°F

MEASUREMENT MEDIA Glycol

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
820980-1	65-106	1/18/66	8234	Elect.	Drift	---	---	---	---	Unit scrapped with no failure analysis performed
820980-1	65-103	10/17/66	11372	Human	Low insulation resistance	Water leakage into sensor case	Defective solder joint in thermistor-to-case seal	Manufacturing	Add 90 psig water-glycol test during assembly	

TABLE 4-12

Water-Glycol Temperature Sensor Failure Evaluation

TRANSDUCER APPLICATION Glycol Temperature Sensor
BASIC PART NUMBER 820980-2
TRANSDUCER MANUF. AiResearch Manufacturing Co.
TROUBLE REPORT SOURCE AiResearch

TRANSDUCER TYPE Temperature
OPERATING PRINCIPLE Thermistor
MEASUREMENT RANGE 40 - 100°F
MEASUREMENT MEDIA Glycol

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
820980-2	16-113	2/16/72	13058	Human	Low insulation resistance	Water leakage into thermistor encapsulation	Cracked thermistor bead	Handling	Add notes to assembly instruction on fragility	
820980-2	76-137	7/29/67	15442	Human	Drift	Failed test setup	Failed battery	Testing, ATP	Replace battery	Unit was good

TABLE 4-13

WATER-GLYCOL TEMPERATURE SENSOR FAILURE EVALUATION

TRANSDUCER APPLICATION Glycol Temperature Sensor

BASIC PART NUMBER 820980-3

TRANSDUCER MANUF. AiResearch Manufacturing Co.

TROUBLE REPORT SOURCE AiResearch

TRANSDUCER TYPE Temperature

OPERATING PRINCIPLE Thermistor

MEASUREMENT RANGE 40 - 100°F

MEASUREMENT MEDIA Glycol

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
820980-3-1	65-112	11/29/65	7483	Elect.	Drift	---	---	---	---	Unit scrapped with no analysis performed

6. Water-Glycol Temperature Sensor, PN 820980-4

Table 4-14 is a summary of 12 failure reports written against 19 units that were reviewed for evaluation of this sensor. The information indicated in Table 4-14 is summarized in the failure matrix of Figure 4-6. One of the units was scrapped before failure analysis was performed. One failure was not confirmed. Four units had cracked beads as a result of mishandling. Seven units were rejected because of faulty test equipment. Five units were rejected because of water leakage as a result of poor soldering. Finally, one unit was rejected because of contamination as a result of inadequate posttesting cleaning instructions in the qualification test procedures. All of the test rejections are potentially avoidable, and recommendations for actions that will reduce drastically the quantity of such rejections is presented in Section 2 of this report.

Current Designs

1. Water-Glycol Temperature Sensor, PN 836684-1

This design does not have any failure report supplied by NASA for evaluation. This design, a qualified Block II Apollo component, is a good one for its specific application. An altered copy of the outline drawing of this temperature sensor is shown in Figure 4-7.

2. Water-Glycol Temperature Sensor, PN 836684-2

Table 4-15 is a summary of the only NASA-supplied failure report on this temperature sensor that was reviewed for evaluation of this sensor. Failure was caused by an inadequate solder joint. A single failure in a total population of 96 units is equivalent to a rejection rate of 1.04 percent. This design, a qualified Block II Apollo component, is a good one for its specific application. An altered copy of the outline drawing of this temperature sensor is shown in Figure 4-8.

TABLE 4-14

WATER-GLYCOL TEMPERATURE SENSOR FAILURE EVALUATION

TRANSDUCER APPLICATION Glycol Temperature Sensor
BASIC PART NUMBER 820980-4 (Page 1 of 2)
TRANSDUCER MANUF. AiResearch Manufacturing Company
TROUBLE REPORT SOURCE AiResearch

TRANSDUCER TYPE Temperature
OPERATING PRINCIPLE Thermistor
MEASUREMENT RANGE 40 - 100°F
MEASUREMENT MEDIA Glycol

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
820980-4-1	46-130	5-18-66	9197	Human	Failed high	-	-	-	-	Trouble report analysis does not relate to failure
820980-4-1	46-148	8-31-66	8845	Human	Low insulation resistance	Water leakage into sensor case	Solder pinhole in thermistor-to-case seal	Manufacturing	Clean and pressure test all solder seals	Leaks were sealed with flux during initial testing
820980-4-1	46-154	10-3-66	11330	Human	Low insulation resistance	Water leakage into thermistor encapsulation	Cracked thermistor bead	Handling	None	
820980-4-1	46-171	10-3-66	11330	Human	Low insulation resistance	Water leakage into sensor case	Cracks in solder thermistor-to-case seal	Manufacturing	Clean and inspect all solder seals	
820980-4-1	46-188	10-6-66	11334	Human	Low insulation resistance	Water leakage into sensor case	Cold solder joint in thermistor-to-case seal	Manufacturing	Clean and inspect all solder seals	
820980-4-1	46-189	10-6-66	11334	Human	Low insulation resistance	Water leakage into sensor case	Cold solder joint in thermistor-to-case seal	Manufacturing	Clean and inspect all solder seals	
820980-4-1	46-153	10-14-66	11365	Human	Low insulation resistance	Water leakage into sensor case	Cracked thermistor bead	Handling	None	
820980-4-1	46-163	10-14-66	11365	Human	Low insulation resistance	Water leakage into sensor case	Cold solder joint in thermistor-to-case seal	Manufacturing	Add low temperature and proof pressure tests during assembly	
820980-4-1	46-170	10-22-66	11391	Human	Low insulation resistance	-	-	-	-	Unit scrapped prior to performing analysis

TABLE 4-14 (Continued)

TRANSDUCER APPLICATION Glycol Temperature Sensor
BASIC PART NUMBER 820980-4 (Page 2 of 2)
TRANSDUCER MANUF. AiResarch Manufacturing Company
TROUBLE REPORT SOURCE AiResearch

TRANSDUCER TYPE Temperature
OPERATING PRINCIPLE Thermistor
MEASUREMENT RANGE 40 - 100°F
MEASUREMENT MEDIA Glycol

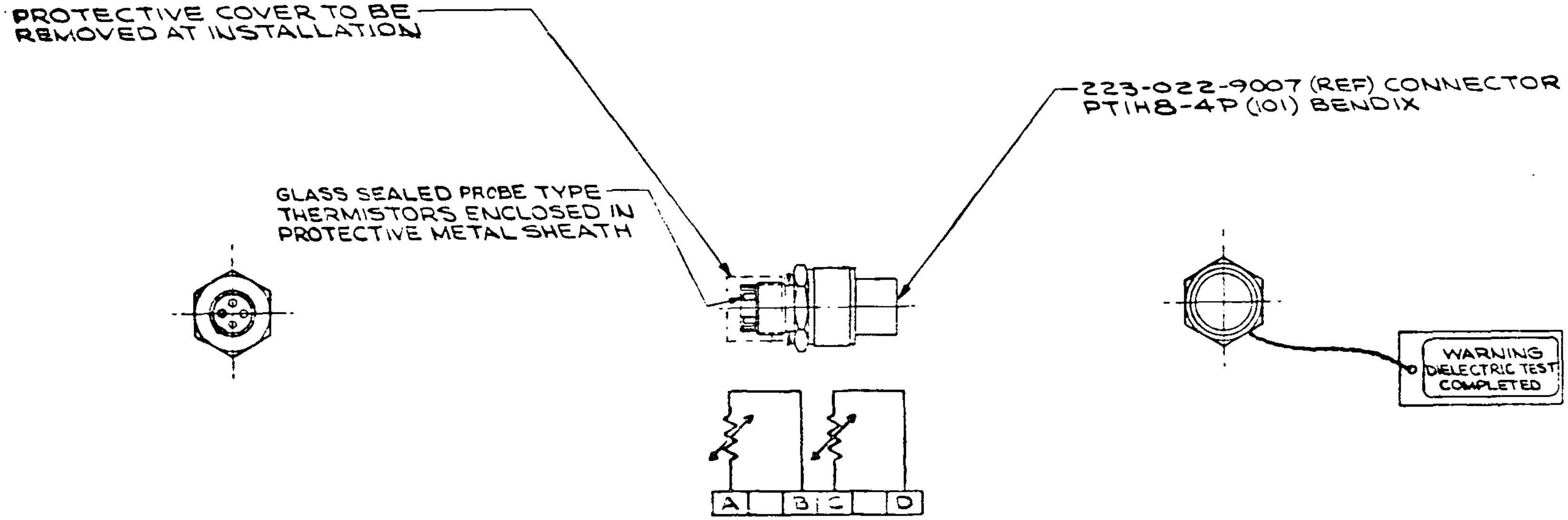
PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
820980-4-1	46-146	2-14-67	13099	Human	Low insulation resistance	Water leakage into thermistor encapsulation	Cracked thermistor bead	Handling	Add notes to assembly instructions on fragility	
820980-4-1	46-150	3-23-67	8871	Human	Low insulation resistance	Contamination of connector	Connector contamination during testing	QTP procedure design	None	No failure
820980-4-1	46-196 46-198 46-199 46-200	7-27-67	15439	Human	Drift	Failed test setup	Failed battery in test setup	Testing, ATP	Replace battery	Units were good
820980-4-1	46-142 46-179 46-185	7-29-67	15441	Human	Drift	Failed test setup	Failed battery in test setup	Testing, ATP	Replace battery	Units were good
820980-4-1	46-172	7-29-67	15440	Human	Low insulation resistance	Water leakage into thermistor encapsulation	Cracked thermistor bead	Handling	Add notes to assembly instructions on fragility	

PROBLEM AREA		PERCENT	FAILURE MODE: HIGH OUTPUT	MODE: LOW RESISTANCE	MODE: DRIFT	TYPE: HUMAN	TYPE: ELECTRICAL	TYPE: MECHANICAL	MECHANISM: SENSING ELEMENT ELEC.	SENSING ELEMENT MECHANICAL: CRACKED BEAD	HOUSING AND SIGNAL TRANSMISSION MECHANISM: UNKNOWN	HOUSING: POOR SOLDERING	HOUSING: NO FAILURE
DESIGN	ENGINEERING												
PROCEDURE, ATP (TESTING)	ENGINEERING												
ERROR (QTP, TESTING)	ENGINEERING												
PROCEDURE (QTP, TESTING)	ENGINEERING	5.3		1		1							1
PLANNING	MANUFACTURING												
FABRICATION	MANUFACTURING												
ASSEMBLY	MANUFACTURING	26.3		5		5						5	
Q.C.	MANUFACTURING												
INSPECTION	MANUFACTURING												
ATP TEST ERROR	MANUFACTURING												
TEST EQUIPMENT FAILURE		36.8			7	7							7
LOX CLEANING													
HANDLING		21.1		4		4				4			
	FINAL INSTALLATION												
	FINAL INSTALLATION												
RANDOM FAILURE													
UNCONFIRMED FAILURE		5.3		1		1					1		
NOT ANALYZED FAILURE REPORT		5.2	1			1					1		
TOTAL		100	1	11	7	19				4	2	5	8
PERCENT			5.3	57.9	36.8	100				21.1	10.5	26.3	42.1

FAILURE CAUSE

Figure 4-6. PN 820980-4 Failure Matrix

AIRESEARCH MANUFACTURING COMPANY
Los Angeles, California



WIRING DIAGRAM

TABLE		
TEMP °F	CIRCUIT RESISTANCE (OHMS)	± OHMS TOLERANCE
45	1860	19.0

ITEM NO.	QTY REQD	CODE IDENT NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	SYM
			SEE TAB		
	-1		← ASSY	PARTS LIST	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES.
MACHINE FILLET RADII .015 — .030
SURFACE ROUGHNESS PER MIL-STD-10
BURR CONTROL PER SC653
DIMENSION LIMITS HELD AFTER PLATING
IDENT MARKING PER MC16
DIMENSIONING AND TOL PER MIL-STD-8

HEAT TREATMENT	PROCESS
HARDNESS AND SPEC	NAME AND SPEC

REQD	NEXT ASSY	USED ON
APPLICATION		

CONTRACT NO.
DFT 8-27-67
CHK 8-30-67
VALUE ENGR 9-1-67
MATL
STRESS
APPD
APPD
AIRESEARCH APPD 8-31-67
OTHER ACTIVITY APPD

AIRESEARCH MANUFACTURING COMPANY
A DIVISION OF THE GARRETT CORPORATION
LOS ANGELES, CALIFORNIA

SENSOR, GLYCOL TEMPERATURE

SIZE	CODE IDENT NO.	DWG NO.
D	70210	836684

SCALE 1/1 SHEET 1 OF 1

Figure 4-7. Outline Drawing of the Water-Glycol Temperature Sensor PN 836684-1

TABLE 4-15

WATER-GLYCOL TEMPERATURE SENSOR FAILURE EVALUATION

TRANSDUCER APPLICATION Glycol Temperature Sensor

BASIC PART NUMBER 836684

TRANSDUCER MANUF. Fenwal Electronics Corp.

TROUBLE REPORT SOURCE AiResearch

TRANSDUCER TYPE Temperature

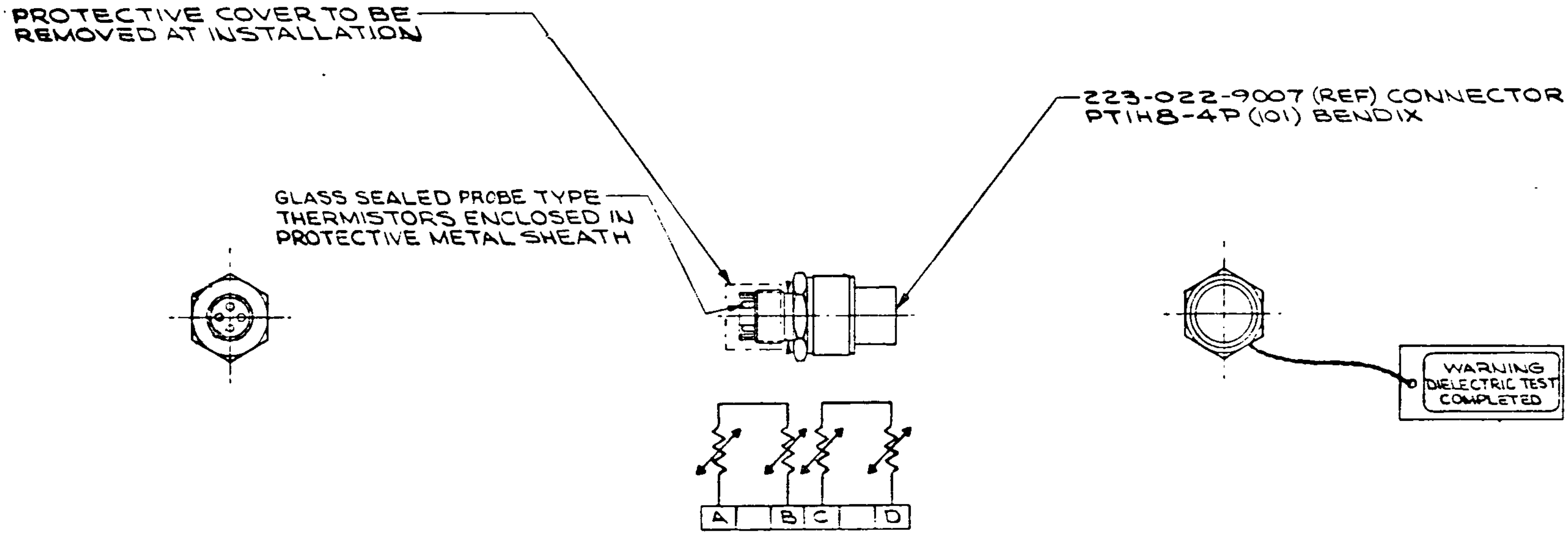
OPERATING PRINCIPLE Thermistor

MEASUREMENT RANGE

MEASUREMENT MEDIA Glycol

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
836684-2	36	11/17/68	16846	Elec.	Intermittent output	Poor lead conductor connection	Inadequate solder joint	Manufacturing	Add inspection of soldered connections	

AIRESEARCH MANUFACTURING COMPANY
Los Angeles, California



WIRING DIAGRAM

TABLE		
TEMP °F	CIRCUIT RESISTANCE (OHMS)	± OHMS TOLERANCE
40	9356	94
70	4661	47
100	2482	25

ITEM NO.	QTY REQD	CODE IDENT NO.	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	SYM
			SEE TAB		
	-2		← ASSY	PARTS LIST	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES.
MACHINE FILLET RADII .015 — .030
SURFACE ROUGHNESS PER MIL-STD-10
BURR CONTROL PER SC053
DIMENSION LIMITS HELD AFTER PLATING
IDENT MARKING PER MC16
DIMENSIONING AND TOL PER MIL-STD-8

HEAT TREATMENT — HARDNESS AND SPEC | PROCESS — NAME AND SPEC

REQD | NEXT ASSY | USED ON
APPLICATION

CONTRACT NO.
DFT Mitchell 8-23-67
CHK 8-30-67
VALUE ENGR
MATL
STRESS
APPD
APPD
AIRESEARCH APPD 8-31-67
OTHER ACTIVITY APPD

AIRESEARCH MANUFACTURING COMPANY
A DIVISION OF THE GARRETT CORPORATION
LOS ANGELES, CALIFORNIA

SENSOR, GLYCOL TEMPERATURE

SIZE	CODE IDENT NO.	DWG NO.
D	70210	836684

SCALE 1/1 — SHEET 1 OF 1

Figure 4-8. Outline Drawing of the Water-Glycol Temperature Sensor PN 836684-2

SECTION 5

CABIN TEMPERATURE SENSORS AND CABIN TEMPERATURE ANTICIPATOR (AIRESEARCH PN's 820100, 820964, 820110)

INTRODUCTION

The three part numbers listed above have identical functions and their design and performance specifications are very similar. The initial design of the cabin temperature sensor, PN 820100, which was an Apollo Block I ECS component, was replaced by a new design, PN 820964, in the Block II. The physical characteristics of the housing of these two sensors are different; however, their functions and principle of operation are identical. The temperature anticipator, PN 820110, also is very similar to the initial design of cabin temperature sensor PN 820100.

PURPOSE AND DESCRIPTION

Cabin Temperature Sensor

The cabin temperature sensor senses the gas temperature near the inlet of the cabin heat exchanger. This information is used by the cabin temperature control subsystem for temperature regulation.

Each sensor consists of a metal probe containing a glass-sealed, dual-bead thermistor. An outline drawing of the current design, PN 820964-1 is presented in Figure 5-1 for reference.

Cabin Temperature Anticipator

The cabin temperature anticipator senses the temperature of the gases at the outlet duct of the cabin heat exchanger. The anticipator reduces the amount of temperature overshoot and improves the dynamic characteristics of the cabin temperature control subsystem.

The anticipator consists of a metal probe, containing two glass-sealed, dual-bead thermistors. One thermistor is thermally lagged by encapsulation in a metal slug, while the other is in direct contact with the cabin air. An outline drawing of the current design, PN 820110, is presented in Figure 5-2 for reference.

The thermistors are connected to the cabin temperature controller to form two branches of a temperature-rate-of-change resistance bridge. The resistance ratio produced by the two thermistors corresponds to the rate of temperature change occurring at the cabin heat exchanger outlet. The change in thermistor resistance unbalances the bridge, causing an error rate of change signal to be produced. The error rate of change signal improves the dynamic performance of the cabin temperature subsystem.

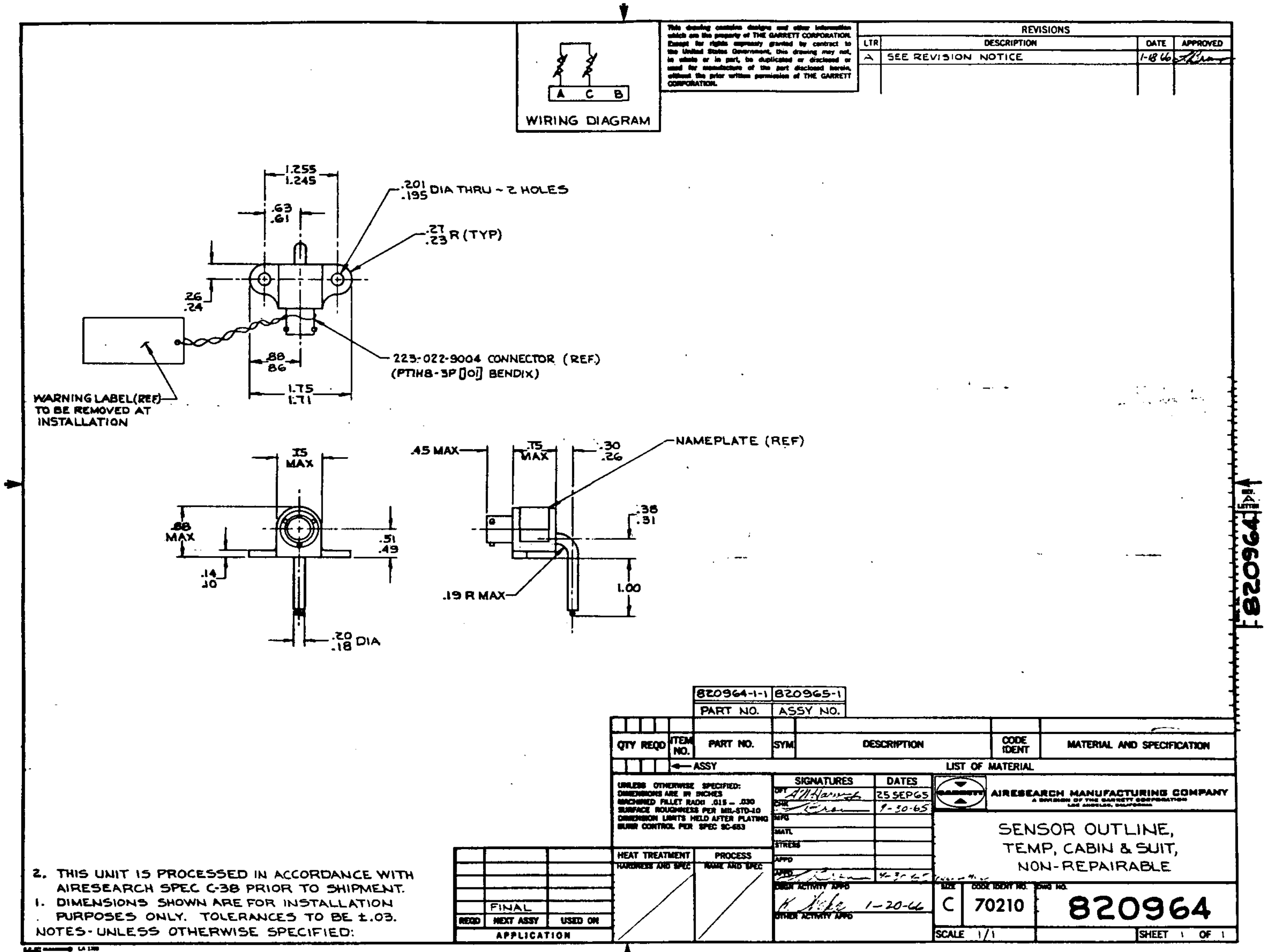


Figure 5-1. Outline Drawing of Cabin Temperature Sensor PN 820964-1

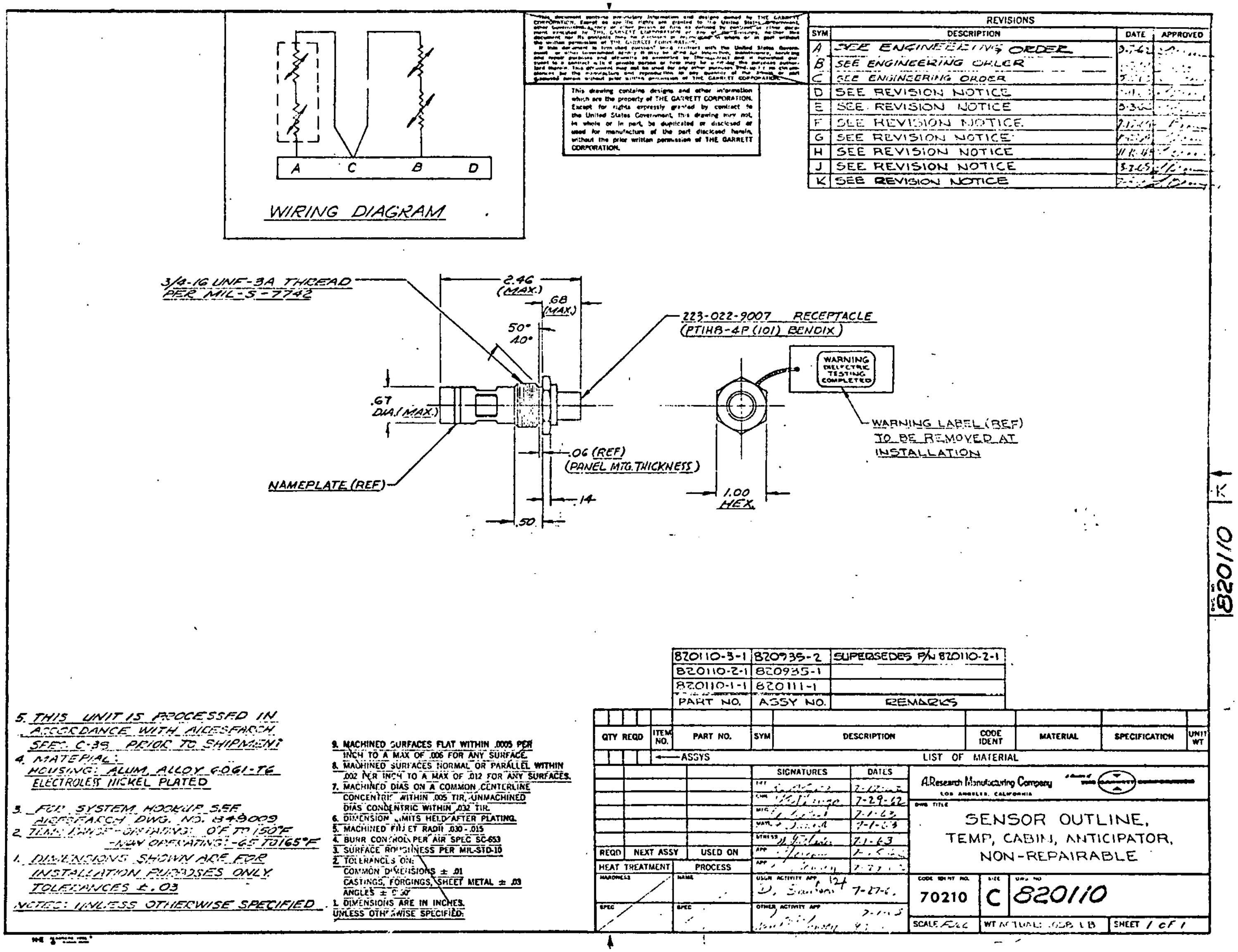


Figure 5-2. Outline Drawing of Cabin Temperature Anticipator

PROBLEM AREA		PERCENT	FAILURE MODE: NO OUTPUT	FIXED OUTPUT	ERRATIC	DAMAGED	NONE	FAILURE TYPE: HUMAN	ELECTRICAL	MECHANICAL	FAILURE MECHANISM / FAILURE CAUSE: SENSING ELEMENT ELEC.	SENSING ELEMENT MECHANICAL	HOUSING AND SIGNAL TRANSMISSION MECHANISM: UNKNOWN	NO FAILURE
ENGINEERING	DESIGN													
ENGINEERING – TESTING	PROCEDURE, ATP													
ENGINEERING – TESTING – QUAL	ERROR													
ENGINEERING – TESTING – QUAL	PROCEDURE													
MANUFACTURING	PLANNING													
MANUFACTURING	FABRICATION													
MANUFACTURING	ASSEMBLY													
MANUFACTURING	QUALITY CONTROL													
MANUFACTURING	INSPECTION													
MANUFACTURING	ATP TEST ERROR													
TEST EQUIPMENT FAILURE		28.6					2	2						2
LOX CLEANING														
HANDLING		14.3				1		1						1
FINAL INSTALLATION	RECEIVING INSPECTION													
FINAL INSTALLATION	INSTALLATION													
RANDOM FAILURE														
UNCONFIRMED FAILURE		42.8	1	1	1			3						3
NOT ANALYZED FAILURE REPORTS		14.3		1					1				1	
TOTAL			1	2	1	1	2	6	1				1	6
PERCENT			14.3	28.6	14.3	14.3	28.5	85.7	14.3				14.3	85.7

Figure 5-3. Cabin Temperature Sensor and Anticipator, AiResearch PN's 820100, 820969 and 820110, Failure Matrix

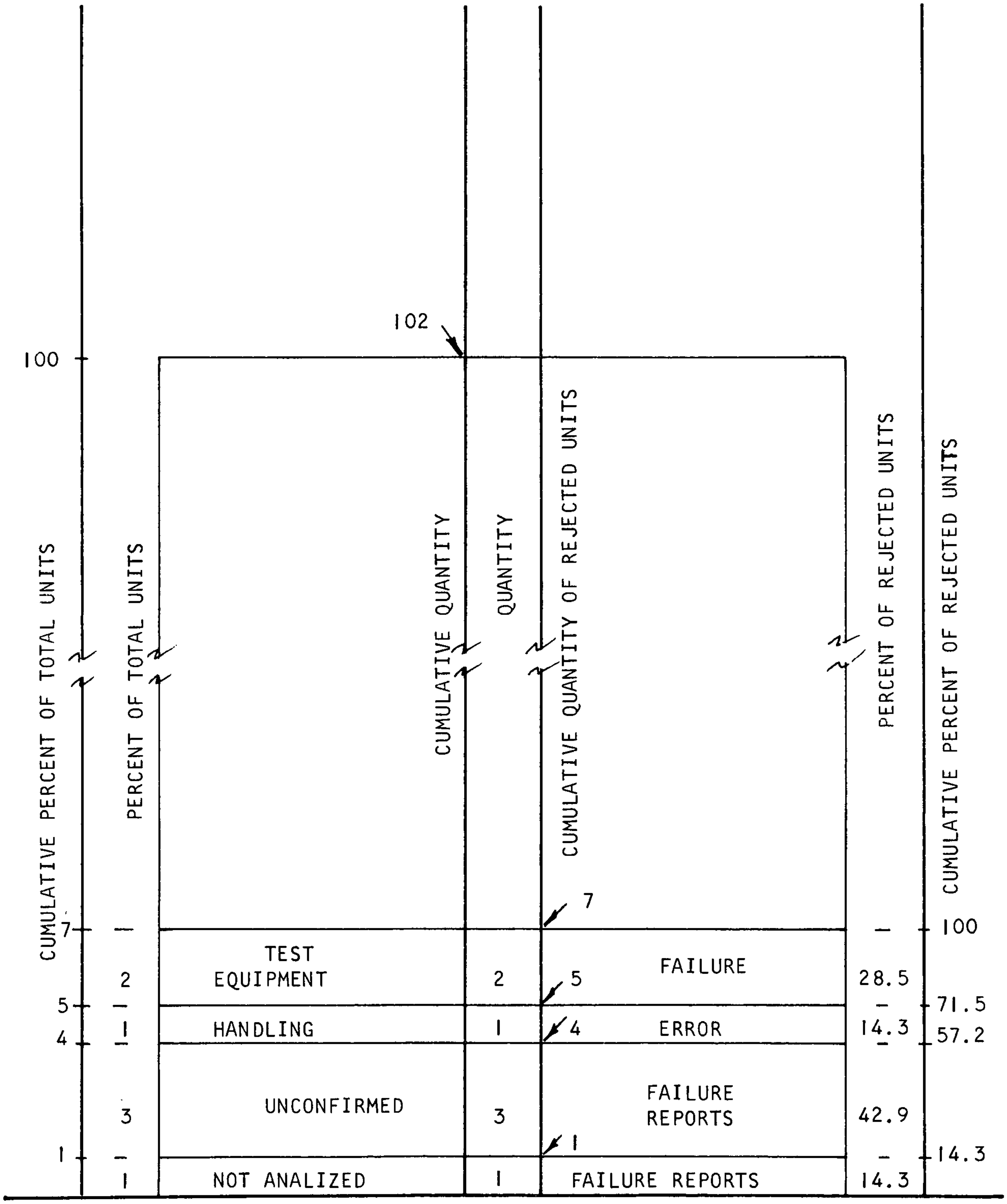


Figure 5-4. Distribution of Failures According to Problem Area for the Cabin Temperature Sensor and Anticipator

TABLE 5-1

PERFORMANCE AND DESIGN DATA FOR PN 820100-1
(Initial Design)

Performance Requirements:

(a) Thermistor resistance: 3677 ohms $\pm 2\%$ at $50^\circ F$
2916 ohms $\pm 2\%$ at $60^\circ F$
2330 ohms $\pm 2\%$ at $70^\circ F$
1876 ohms $\pm 2\%$ at $80^\circ F$

(b) Time constant: 6 sec max. when exposed to 35 cfm airflow rate.

Environmental Conditions: Per AiResearch Report SS-1060-R; Type I equipment.

Installation Envelope: Per AiResearch Drawing 820100.

Design:

(a) Weight: 0.1 lb.

(b) Thermistor: Bead type with a high negative temperature coefficient of resistance. Thermistor enclosed in end of glass cylinder.

(c) Mounting provision: The sensor probe is threaded for installation in the inlet air duct of the cabin heat exchanger.

Electrical Connector: Per MIL-C-26482C and gold-plated.

TABLE 5-2

PERFORMANCE AND DESIGN DATA FOR PN 820964-1

Thermistor resistance	2330 ohms ±2% at 70°F 2230 ohms ±2% at 72°F 2135 ohms ±2% at 74°F 2045 ohms ±2% at 76°F 1959 ohms ±2% at 78°F 1923 ohms ±2% at 80°F
Time constant	8 sec max. to reach 63.2% of applied ΔT when exposed to 35 cfm airflow rate at 14.7 psia in a 3-in. duct
Thermistor	Bead type with a high negative temp coefficient of resistance. Thermistor enclosed in end of a glass cylinder
Mounting provision	The sensor probe is threaded for installation in the inlet air duct of the cabin heat exchanger
Electrical connector	Per MIL-C-26482C and gold-plated
Weight, lb	0.05
Envelope, in.	0.9 in. dia by 2.16 in. long
Qualification status	The cabin temperature sensor is a qualified Apollo Block II item

TABLE 5-3

PERFORMANCE AND DESIGN DATA FOR PN 820110-3

Performance Requirements:

(a) Thermistor resistance:

3672 ohms ±2% at 50°F
2916 ohms ±2% at 60°F
2330 ohms ±2% at 70°F
1876 ohms ±2% at 80°F

(b) Time constants: 8 sec max to reach 63.2 percent of applied ΔT when exposed to 20 cfm airflow rate at 14.7 psia in a 3-in. dia duct

Thermally lagged thermistor, min: 4.0 ±1.0

Unlagged thermistor, sec: 6 max.

Environmental Conditions: Per AiResearch Report SS-1060-R; Type I equipment.

Installation Envelope: Per AiResearch Drawing 820110.

Design:

(a) Weight: 0.1 lb

(b) Thermistor: Bead type with a high negative temperature coefficient of resistance. Thermistor enclosed in end of glass cylinder.

(c) Mounting provision: The anticipator probe is threaded for Installation on the outlet air duct of the cabin heat exchanger.

Electrical Connector: Per MIL-C-26482C

TABLE 5-4

CABIN TEMPERATURE SENSOR FAILURE EVALUATION

TRANSDUCER APPLICATION Cabin Temperature Sensor
BASIC PART NUMBER 820100
TRANSDUCER MANUF. AiResearch
TROUBLE REPORT SOURCE AiResearch

TRANSDUCER TYPE Temperature
OPERATING PRINCIPLE Thermistor
MEASUREMENT RANGE 50-80°F
MEASUREMENT MEDIA Cabin Air

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
820100-1	93-103	7/1/64	3145	Human	Test setup explosion	---	Heater coil insulation breakdown due to heat	Testing	Revise test setup	Unit was good
820100-1	93-106	7/1/64	3146	Human	Test setup explosion	---	Heater coil insulation breakdown due to heat	Testing	Revise test setup	Unit was good
820100-1-2	65-116	9/27/65	6143	Human	Sensor shield damaged	Damaged by technician's wrench	Unit being used during test set buildup	Handling	Use dummy unit during buildup	

REJECTION SUMMARY

Figure 5-3 presents a matrix of all failure reports written against these three parts. The same information is presented in the histogram of Figure 5-4. Of the total of seven failure reports, two reports were concerned with test equipment failure, one report was written on a damaged unit, the failures indicated in three other reports were not confirmed, and one unit was scrapped before failure analysis was performed. Assuming the scrapped unit was actually a failed item, this type of temperature sensors exhibited a failure rate of one percent; the rest were avoidable.

PERFORMANCE AND DESIGN DATA

Performance and design data for cabin temperature sensors PN's 820100-1 (initial design) and 820964 (current design) are presented in Tables 5-1 and 5-2, respectively. Table 5-3 presents performance and design data for cabin temperature anticipator PN 820110-3.

FAILURE AND DESIGN REVIEW

Cabin Temperature Sensor PN 820100-1 (Initial Design)

Table 5-4 is a summary of three failure reports supplied by NASA-MSC, which were reviewed for evaluation of this sensor. Two of the reports were determined to have resulted from test equipment failure resulting in damage to the sensors. The other report described damage inflicted on the sensor housing by mishandling. All three reported cases were potentially avoidable. Figure 5-5 summarizes this information in the failure matrix. Since this sensor has been superseded, it is recommended that no further evaluation of it be made.

Cabin Temperature Sensor PN 820964-1 (Current Design)

No failure report was supplied by NASA-MSC for evaluation of this part. This part number supersedes the previous PN 820100-1 and is a very good component in its application.

Cabin Temperature Anticipator PN 820110 (Current Design)

Table 5-5 is a summary of four failure reports supplied by NASA-MSC, which were reviewed for this sensor evaluation. Three of the reported failures were not confirmed and one unit was scrapped after four consecutive failures before failure analysis was performed. Figure 5-6 summarizes this information in the failure matrix. The one failed item out of a total population of 47 units represents a rejection rate of 2.1 percent.

Problem Area		Percent	Failure Mode: Damaged	Failure Mode: None	Failure Type: Human	Failure Type: Electrical	Failure Type: Mechanical	Failure Mechanism: Sensing Element, Elec.	Failure Mechanism: Sensing Element, Mechanical	Failure Mechanism: Housing and Signal Transmission Mechanism	Failure Cause: No Failure
Engineering	Design										
Engineering	Testing: Procedure, ATP										
Engineering	Testing, Qual: Error										
Engineering	Testing, Qual: Procedure										
Manufacturing	Planning										
Manufacturing	Fabrication										
Manufacturing	Assembly										
Manufacturing	Quality Control										
Manufacturing	Inspection										
Manufacturing	ATP Test Error										
Test Equipment Failure				2	2						2
LOX Cleaning											
Handling			1		1						1
Final Installation	Receiving Inspection										
Final Installation	Installation										
Random Failure											
Unconfirmed Failure											
Not Analyzed Failure Reports											
Total											
Percent											

Figure 5-5. Cabin Temperature Sensor, PN 820100-1, Failure Matrix

TABLE 5-5

CABIN TEMPERATURE ANTICIPATOR FAILURE MATRIX

TRANSDUCER APPLICATION Cabin Temperature Anticipator (Sensor)
BASIC PART NUMBER 820110-3-1
TRANSDUCER MANUF. AiResearch
TROUBLE REPORT SOURCE AiResearch

TRANSDUCER TYPE Temperature Sensor
OPERATING PRINCIPLE Thermistor
MEASUREMENT RANGE 50-80^{o}F
MEASUREMENT MEDIA Electric Current

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
820110-3-1	26-140	9-23-66	11088	Elect.	Continuous Output	Unknown	Unknown	Unknown	None	Unit was scrapped after the fourth failure
820110-3-1	26-140	7-28-66	10718	Human	No output	Unknown	Unknown	Unknown	None	Failure not confirmed
820110-3-1	26-140	5-31-66	9273	Human	Continuous Output	Unknown	Unknown	Unknown	None	Failure not confirmed
820110-3-1	26-140	4-25-66	8711	Human	Erratic	Unknown	Unknown	Unknown	None	Failure not confirmed

PROBLEM AREA			FAILURE MODE: PERCENT	MODE: NO OUTPUT	MODE: FIXED OUTPUT	MODE: ERRATIC	TYPE: HUMAN	TYPE: ELECTRICAL	TYPE: MECHANICAL	MECHANISM / FAILURE CAUSE: SENSING ELEMENT ELEC.	SENSING ELEMENT MECHANICAL	HOUSING AND SIGNAL TRANSMISSION MECHANISM: UNKNOWN	HOUSING AND SIGNAL TRANSMISSION MECHANISM: NO FAILURE
ENGINEERING		DESIGN											
ENGINEERING	TESTING	PROCEDURE, ATP											
ENGINEERING	TESTING / QUAL	ERROR											
ENGINEERING	TESTING / QUAL	PROCEDURE											
MANUFACTURING		PLANNING											
MANUFACTURING		FABRICATION											
MANUFACTURING		ASSEMBLY											
MANUFACTURING		QUALITY CONTROL											
MANUFACTURING		INSPECTION											
MANUFACTURING		ATP TEST ERROR											
TEST EQUIPMENT FAILURE													
LOX CLEANING													
HANDLING													
FINAL INSTALLATION		RECEIVING INSPECTION											
FINAL INSTALLATION		INSTALLATION											
RANDOM FAILURE													
UNCONFIRMED FAILURE				1	1	1	3						3
NOT ANALYZED FAILURE REPORTS					1			1				1	
TOTAL													
PERCENT													

Figure 5-6. Cabin Temperature Anticipator Failure Matrix

AIRESEARCH MANUFACTURING COMPANY
Los Angeles, California

REPORT ON FAILURE AND DESIGN EVALUATION OF APOLLO ECS TEMPERATURE SENSOR, THERMISTOR BEAD AND COIL TYPE

CONTRACT NO. NAS 9-12452

72-8537-13, Rev. 1 February 10, 1973

Prepared by A. Saginian

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APPROVED: M. J. Brudnicki
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HOUSTON, TEXAS 77058

ABSTRACT

This report presents the results of a failure and design evaluation study conducted on the Apollo ECS transducers, the generic group of the combination of thermistor bead and coil type temperature sensors. The study was conducted for NASA-MSC by the AiResearch Manufacturing Company, a division of The Garrett Corporation under Contract NAS9-12452.

The study purpose was to evaluate the integrity of design of this type temperature sensor. Failure information is presented and summarized pertaining to two different transducer part numbers. A failure matrix is presented which describes the failure mode, type, mechanism, cause, and problem areas, for failures.

The integrity of the superseding design was confirmed. Recommendations are made to reduce the rejection rate of human induced failures.

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SECTION 1

INTRODUCTION

This report presents a summary of failure data of the generic group of the combination of bead-type thermistor and coil temperature sensors, one of several temperature sensor types that are described and categorized in AiResearch Report No. 72-8537-1. Four bead-type thermistor temperature sensors were evaluated.

All temperature sensors evaluated in this report have been used in the Apollo environmental control system (ECS). In general, they may be used to perform any other temperature sensing function with similar requirements.

The temperature sensors that are evaluated and summarized in this report are, by AiResearch part number:

PN	Nomenclature
820920-1	Glycol Temperature Sensor
820920-2	Glycol Temperature Sensor
820920-3	Glycol Temperature Sensor
836172-1	Glycol Temperature Sensor

Detailed failure data, a summary, and descriptive information on each of these temperature sensors are presented in Section 2 of this report.

SECTION 2

DESCRIPTION, FAILURE SUMMARY, AND RECOMMENDATIONS FOR THE COMBINATION OF THERMISTOR BEAD AND COIL TYPE TEMPERATURE SENSORS

INTRODUCTION

The initial design of glycol temperature sensor PN 820920-2 was implemented on the Apollo Block I and Block II ECS. Because of numerous failures this design was superseded by a new design, PN 836172, which was implemented on Apollo Block II ECS. Each of these designs is analyzed in this section.

PURPOSE AND DESCRIPTION

The outline of the current glycol temperature sensor which is a combination of thermistor bead and coil type sensor is presented in Figure 2-1. Subject glycol temperature sensor senses the temperature of the water-glycol coolant at the outlet of the glycol evaporator. The unit consists of a metal housing containing two glass-sealed thermistors, a coil type sensing element, a resistance-bridge circuit, and a transformer coupled output circuit.

The two glass-sealed thermistors, one of which is standby redundant, operate in conjunction with the backpressure control. The operating thermistor forms one leg of a resistance bridge in the control.

The coil type sensing element, which has a positive coefficient of resistance, forms the measured branch of the resistance-bridge circuit of this unit and is used for instrumentation purposes. The resultant signal is transmitted to the associated inflight temperature sensor amplifier through the transformer coupled output circuit of the glycol temperature sensor. This signal is amplified and the amplifier output signal is used for telemetry purposes.

PERFORMANCE AND DESIGN DATA

Table 2-1 presents the performance and design data for these temperature sensors. These data are identical for both of the designs. Human errors in design, assembly, testing, and handling of PN 820920 was the problem source for 29 rejections in a total population of 71 units which represents a rejection rate of 40.8 percent. This high rejection rate motivated the design effort for PN 836172 which was approved as a new part of the Apollo Block II ECS. There has been no reported failed unit of this new design which has a total population of 22 units.

FAILURE AND DESIGN REVIEW

Initial Design (PN 820920)

Table 2-2 is a summary of 30 failure reports written against 29 units of PN 820920. One of these failure reports was duplicating the information presented in another failure report. Six of the rejections (20 percent) were caused by engineering design error. Twelve units were rejected (41.4 percent) because of assembly errors. Four rejections (13.8 percent) were caused by ATP test errors. Three units were rejected (13.3 percent) because of test equipment failure. One unit was damaged in handling (3.5 percent) and three units were scrapped before failure analysis were performed. These information is presented in Figure 2-2 failure matrix.

Current Design (PN 836172)

There have been no failures in PN 836172 which replaces PN 820920. This is a design of proven integrity and, with assembly personnel who are well trained in up-to-date techniques of assembly, test, and application procedures the only failure source should be random failures.

RECOMMENDATIONS

Since the design problems of this temperature sensor were resolved and eliminated in the new design only the following recommendations are made to prevent human induced failures.

Manufacturing Criteria

(a) Provide detailed assembly and operations instructions to eliminate poor soldering and calibration problems

(b) Retrain assembly personnel at scheduled intervals.

Testing Criteria

(a) Provide detailed test equipment checkout procedures.

(b) Retrain test personnel at schedule intervals.

Usage

Use the superseding design which is trouble free.

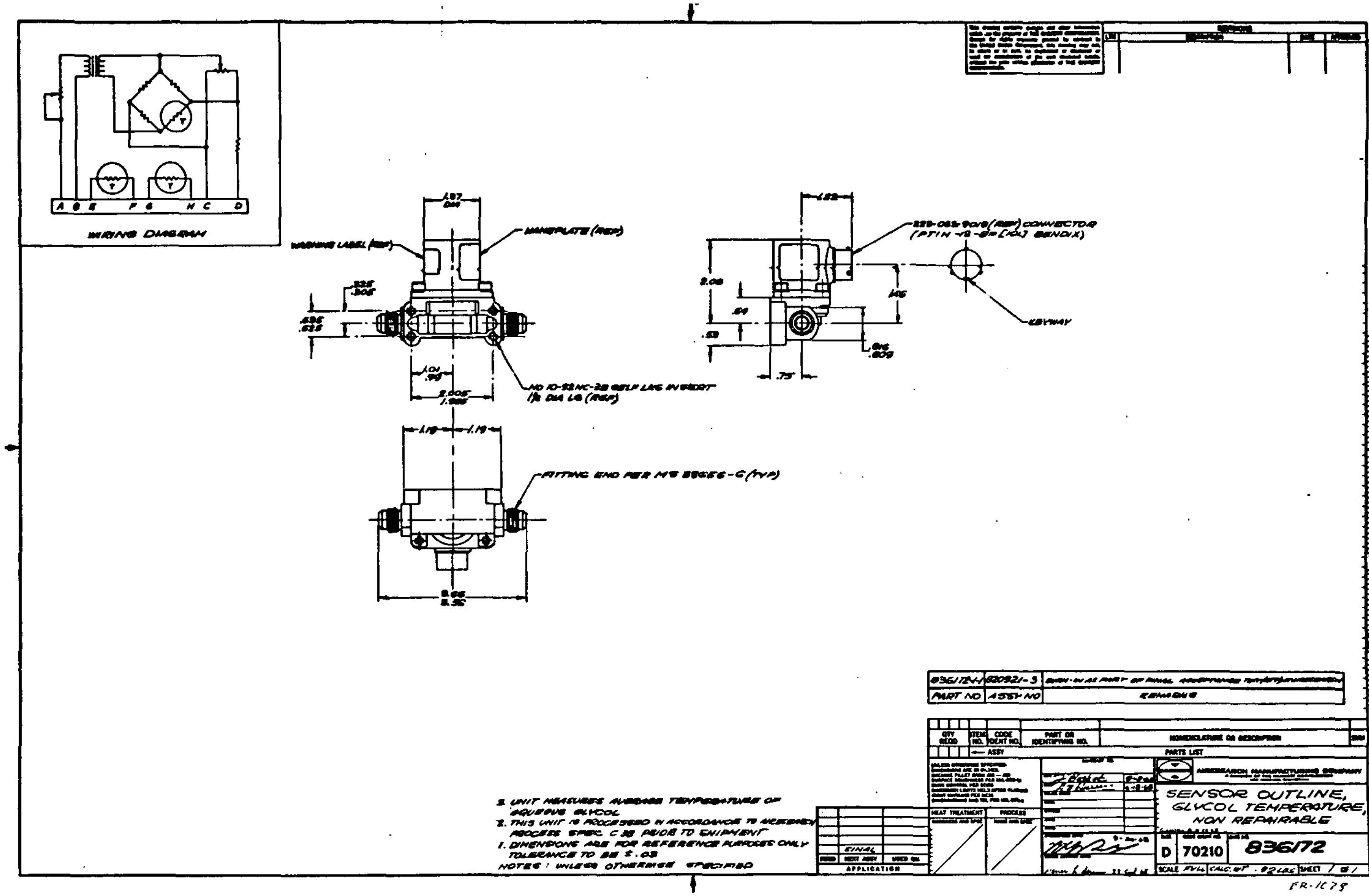

Figure 2-1. Outline Drawing of Glycol Temperature Sensor

Percent	Failure Mode: Drift	Mode: Leakage	Mode: Low Resistance	Mode: Calibration	Mode: High Output	Type: Human	Type: Electrical	Type: Mechanical	Mechanism – Sensing Mechanism, Elec.	Sensing Mechanism, Mechanical: Heat Transf.	Sensing Mechanism, Mechanical: Cracked Bead	Signal Conditioning and Transmission Mechanism: Seal	Signal Conditioning: Calibration	Signal Conditioning: Solder	Signal Conditioning: Unknown	No Failure	Problem Area	
20.7	1	5				6				1		5					DESIGN	ENGINEERING
																	PROCEDURE, ATP	ENGINEERING
																	ERROR	ENGINEERING
																	PROCEDURE	ENGINEERING
																	PLANNING	MANUFACTURING
																	FABRICATION	MANUFACTURING
41.4	1		5	5	1	12						1	6	5			ASSEMBLY	MANUFACTURING
																	QUALITY CONTROL	MANUFACTURING
																	INSPECTION	MANUFACTURING
13.8	4					4										4	ATP TEST ERROR	MANUFACTURING
10.3	1			2		3										3	TEST EQUIPMENT FAILURE	
																	LOX CLEANING	
3.5	1					1					1						HANDLING	
																	RECEIVING INSPECTION (TEST AND EQUIPMENT)	FINAL INSTALLATION
																	INSTALLATION	FINAL INSTALLATION
																	RANDOM FAILURE	
																	UNCONFIRMED FAILURE	
10.3	1	1	1			3									3		NOT ANALYZED FAILURE REPORTS	
	9	6	6	7	1	29				1	1	6	6	5	3	7	TOTAL	
100	31.0	20.7	20.7	24.1	3.5					3.5	3.5	20.7	20.7	17.2	10.3	24.1	PERCENT	

FAILURE CAUSE

Figure 2-2. Thermistor Bead and Coil Type Temperature Sensor Failure Matrix

TABLE 2-1

PERFORMANCE AND DESIGN DATA FOR PNs 820920 AND 836172

Performance Requirements

a. Thermistors:

(1) Resistance: 4220 ohms ±2.0% at 45°F only

(2) Time constant: Six sec max when exposed to 200 lb/hr water-glycol flow rate

b. Instrumentation part of sensor:

(1) Operating temperature range: 25°F to 75°F

(2) Accuracy: ±0.75°F (±1.5% of total operating range)

(3) Output signal: Proportional to sensed temperature. Zero at 25°F and 59 mv peak-to-peak sq wave (with 260 ±2.6 ohm load) at 75°F

(4) Output impedance: 200 ohms max

(5) Time constant: Same as thermistor time constant

(6) Bridge excitation voltage: 5.4 ±0.1v peak-to-peak, 300 cps, sq wave at 140 ma

(7) Power dissipation of sensing element: 46 mw max

Operating Pressure

a. Normal: 21 Psig (relative to cabin)

b. Max: 60 psig (relative to cabin)

c. Pressure drop across sensor: 0.50 in. water max at flow rate

0.50 in. water max at flow rate

TABLE 2-1 (Continued)

Structural Requirements:

a. Proof pressure: 90 psig

b. Burst pressure: 150 psig

External Leakage: Zero with 60 psig internal pressure

Environmental Conditions: Per AiResearch Specification SS-1060-R; Type I equipment

Installation Envelope: Per outline Drawing 820920

FOLDOUT FRAME 1

TABLE 2-2
GLYCOL TEMPERATURE TRANSDUCER FAILURE EVALUATION

FOLDOUT FRAME 2

TRANSDUCER APPLICATION WATER-GLYCOL TEMPERATURE
BASIC PART NUMBER 820920 (PAGE 1 OF 4)
TRANSDUCER MANUF. AIRESEARCH
TROUBLE REPORT SOURCE AIRESEARCH

TRANSDUCER TYPE TEMPERATURE
OPERATING PRINCIPLE THERMISTOR
MEASUREMENT RANGE
MEASUREMENT MEDIA WATER-GLYCOL

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
820920-1	14-106	1/4/65	5048	Human	Drift	ATP Test procedure not followed	Technician error	Testing	Re-emphasize test procedure to test personnel	Unit was good
820920-1	14-106	1/14/65	4766	Human	Drift	Metal cap which encapsulates the thermistor bead conducts too much heat.	Improper design of unit.	Design	Design revised	
820920-2-1	45-114	8/23/65	7008	Mech	Excessive external leakage	External leak from port connection	Defective "O" ring packings in assembly	Design	Replace packings	Blind assy. Fault found during leak check.
820920-2-1	45-113	8/23/65	7425	Human	Excessive external leakage	External leak from port connection	Damaged "O" ring	Design	Replace packings	Blind assy. Fault found during leak check.
820920-2-1	45-113	9/23/65	7499	Human	Excessive external leakage	External leak from port connection	Contamination	Design, blind assy	Replace packings	Blind assy. Fault found during leak check.
820920-2-1	85-120	2/21/66	8416	Human	Excessive external leakage	External leak from port connection	Damaged "O" ring	Design, blind assy	Replace packings	Blind assy. Fault found during leak check.
820920-2-1	85-120	7/21/66	10737	Human	Excessive external leakage	-	-	-	-	No teardown analysis performed on unit. Unit scrapped
820920-2-1	46-156	8/17/66	10268	Human	Low insulation resistance	-	-	-	-	No teardown analysis performed on unit. Unit scrapped
820920-2-1	46-154	9/8/66	10976	Human	Excessive external leakage	External leak from port connection	Defective "O" ring packings	manufacturing/ design	Replace packings	Blind assy. Fault found during ATP leak check.

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TRANSDUCER APPLICATION ______

BASIC PART NUMBER 820920 CONT'D (PAGE 2 OF 4)

TRANSDUCER MANUF. ______

TROUBLE REPORT SOURCE ______

TRANSDUCER TYPE ______

OPERATING PRINCIPLE ______

MEASUREMENT RANGE ______

MEASUREMENT MEDIA ______

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
820920-2-1	85-123	9/12/66	11029	Human	Drift	-	-	-	-	Unit scrapped prior to reliability analysis
820920-2-1	46-137	9/15/66	11046	Human	Out of calibration	-	Unit's original calibration done incorrectly	Manufacturing	Re-calibrate unit.	
820920-2-1	46-144	10/10/66	11336	Human	Out of calibration	-	Unit's original calibration done incorrectly	Manufacturing	Re-calibrate unit.	
820920-2-1	46-153	10/25/66	11397	Human	Out of calibration	-	Unit's original calibration done incorrectly	Manufacturing	Re-calibrate unit	
820920-2-1	46-159	10/26/66	11398	Human	Out of calibration	-	Unit's original calibration done incorrectly	Manufacturing	Re-calibrate unit.	
820920-2-1	46-138	10/27/66	12004	Human	Drift	Failed test setup	Battery in test setup failed	Testing	Replace battery in test setup	Unit was good
820920-2-1	46-153	11/30/66	11953	Human	Low insulation resistance	Fluid was able to enter unit	Defective hermetic seal	Manufacturing	Add more stringent in-process testing.	
820920-2-1	106-174	12/22/66	12554	Human	Drift	Cracked thermistor glass bead	Mishandling	Handling	-	
820920-2-1	106-167	12/28/66	12558	-	-	-	-	-	-	Refer to TR 14169

TRANSDUCER APPLICATION ______ TRANSDUCER TYPE ______

BASIC PART NUMBER 820920 CONT'D (PAGE 3 OF 4) OPERATING PRINCIPLE ______

TRANSDUCER MANUF. ______ MEASUREMENT RANGE ______

TROUBLE REPORT SOURCE ______ MEASUREMENT MEDIA ______

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
820920-2-1	85-126	3/24/67	13717	Human	Low insulation resistance	Leak between mandrel and housing	Faulty solder joint, which acts as seal.	Manufacturing	Evaluate other methods of producing this unit	
820920-2-1	46-158	4/19/67	14161	Human	Low insulation resistance	Leak between mandrel and housing	Faulty solder joint, which acts as seal.	Manufacturing	Evaluate other methods of producing this unit.	Found during re-test of all units to find units with faulty sealing.
820920-2-1	106-167	5/12/67	14169	Human	Drift	Unit incorrectly calibrated.	Thermission element out of tolerance and unit incorrectly calibrated	Manufacturing	Use more accurate calibration equipt. and re-educate personnel.	
820920-2-1	46-131	10/20/67	15114	Human	Out of calibration	Unit incorrectly calibrated.	Unit incorrectly calibrated	Manufacturing	Use more accurate calibration equipt. and re-educate personnel.	
820920-3-1	106-164	5/2/68	16623	Human	Out of calibration	Test equipt. fault	Weak battery in test equipt	Testing	None	Unit was good
820920-3-1	-	6/10/68	15148	Human	Out of calibration	Test equipt fault	Capacitor used in calib. equipt. was loading output	Testing	Revise test equipment	Unit was good
820920-3-1	85-125	7/12/68	16664	Human	Low insulation resistance	Leakage into unit	Faulty solder seal	Manufacturing	None. Fault found during re-test with revised procedures.	Unit was being upgraded to -3-1
820920-3-1	85-121	7/26/68	16699	Human	Low insulation resistance	Leakage into unit	Faulty solder seal	Manufacturing	None. Fault found during re-test with revised procedures.	Unit was being upgraded to -3-1
820920-3-1		7/30/68	16679	Human	Failed to high output	Failed open thermistor to lead wire joint	Faulty weld of lead wire	Manufacturing	None. Random failure.	

TRANSDUCER APPLICATION

BASIC PART NUMBER 820920 CONT'D (PAGE 4 OF 4)

TRANSDUCER MANUF.

TROUBLE REPORT SOURCE

TRANSDUCER TYPE

OPERATING PRINCIPLE

MEASUREMENT RANGE

MEASUREMENT MEDIA

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
820920-3-1	106-170	4/17/68	-	Human	Drift	-	Changed test methods from initial calibration	-	Re-calibrate unit.	Unit was good when tested with old method.
820920-3-1	106-166	4/18/68	17676	Human	Drift	-	Changed test methods from initial calibration	-	Re-calibrate unit	Unit was good when tested with old method.
820920-3-1	106-165	4/17/68	17685	Human	Drift	-	Changed test methods from initial calibration	-	Re-calibrate unit	Unit was good when tested with old method.

AIRESEARCH MANUFACTURING COMPANY
Los Angeles, California

REPORT ON FAILURE AND DESIGN EVALUATION OF APOLLO ECS CABIN TEMPERATURE SENSOR, THERMISTOR WITH ELECTRONICS TYPE

CONTRACT NO. NAS 9-12452

72-8537-14, Rev. 1 February 10, 1973

Prepared by A. Saginian

APPROVED:
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Program Manager

APPROVED:
M. J. Brudnicki
Principal Investigator

Prepared for

NASA MANNED SPACECRAFT CENTER
HOUSTON, TEXAS 77058

ABSTRACT

This report presents the results of a failure and design evaluation study conducted on Apollo ECS transducers, the generic group of the combination of thermistor bead with electronics type temperature sensors. This study was conducted for NASA-MSC by the AiResearch Manufacturing Company, a division of The Garrett Corporation under Contract NAS 9-12452.

The study purpose was to evaluate the integrity of design of this type temperature sensor. Failure information is presented and summarized. A failure matrix is presented which describes the failure mode, type, mechanism, cause, and problem areas, for failures.

The integrity of the final design configuration was confirmed. Recommendations are made for actions which will reduce the quantity of rejections resulting from human errors.

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SECTION 1

INTRODUCTION

This report presents a summary of failure data of the generic group of bead-type thermistors with electronics, one of several temperature sensor types that are described and categorized in AiResearch Report No. 72-8537-1.

The temperature sensor evaluated in this report was used in the Apollo environmental control system (ECS). This temperature sensor may be used to perform any other temperature sensing function with similar requirement.

The temperature sensor which is evaluated and summarized in this report is the Apollo cabin temperature sensor, PN 836930. Detailed failure data, a summary, and description information on this temperature sensor are presented in Section 2 of this report.

SECTION 2

DESCRIPTION, FAILURE SUMMARY, AND RECOMMENDATIONS FOR THERMISTOR BEAD WITH ELECTRONICS TYPE TEMPERATURE SENSOR

INTRODUCTION

The initial design of cabin temperature sensor PN 836064 was implemented on the Apollo Block I ECS. This sensor, which had a coil type sensing element, was replaced by a new design, PN 836930, which was implemented on Apollo Block II ECS. The new design is analyzed in this section. The previous design, which utilizes a coil type sensing element is analyzed with the other coil type sensors in a separate report.

PURPOSE AND DESCRIPTION

A typical isometric drawing of the current cabin temperature sensor is presented in Figure 2-1. This sensor senses the cabin temperature at the inlet duct of cabin heat exchanger. The unit consists of a metal housing containing power supply, temperature sensing element, and signal conditioner. The temperature sensing element consists of two series bead thermistors mounted at the end of a probe. An internal power supply provides the necessary operating voltages and isolates the unit from 28-vdc spacecraft power. The signal conditioner converts sensing element current changes (due to resistance changes) into an output voltage for telemetry or visual display.

PERFORMANCE AND DESIGN DATA

Table 2-1 presents the performance and design data for these temperature sensors.

QUALIFICATION STATUS

The cabin temperature sensor is a qualified Block II Apollo component.

FAILURE AND DESIGN REVIEW

Table 2-2 is a summary of eight failure reports written against the -1 and -3 versions of PN 836930. The -3 version design is identical to the -1. The only difference between the -1 and the -3 is that the -3 acceptance test procedure includes a burn-in instruction over and above the ATP requirement of the -1 version. Human errors in design, manufacturing and handling were the problem sources for the eight rejections in a population of 38 units which represents a rejection rate of 21 percent.

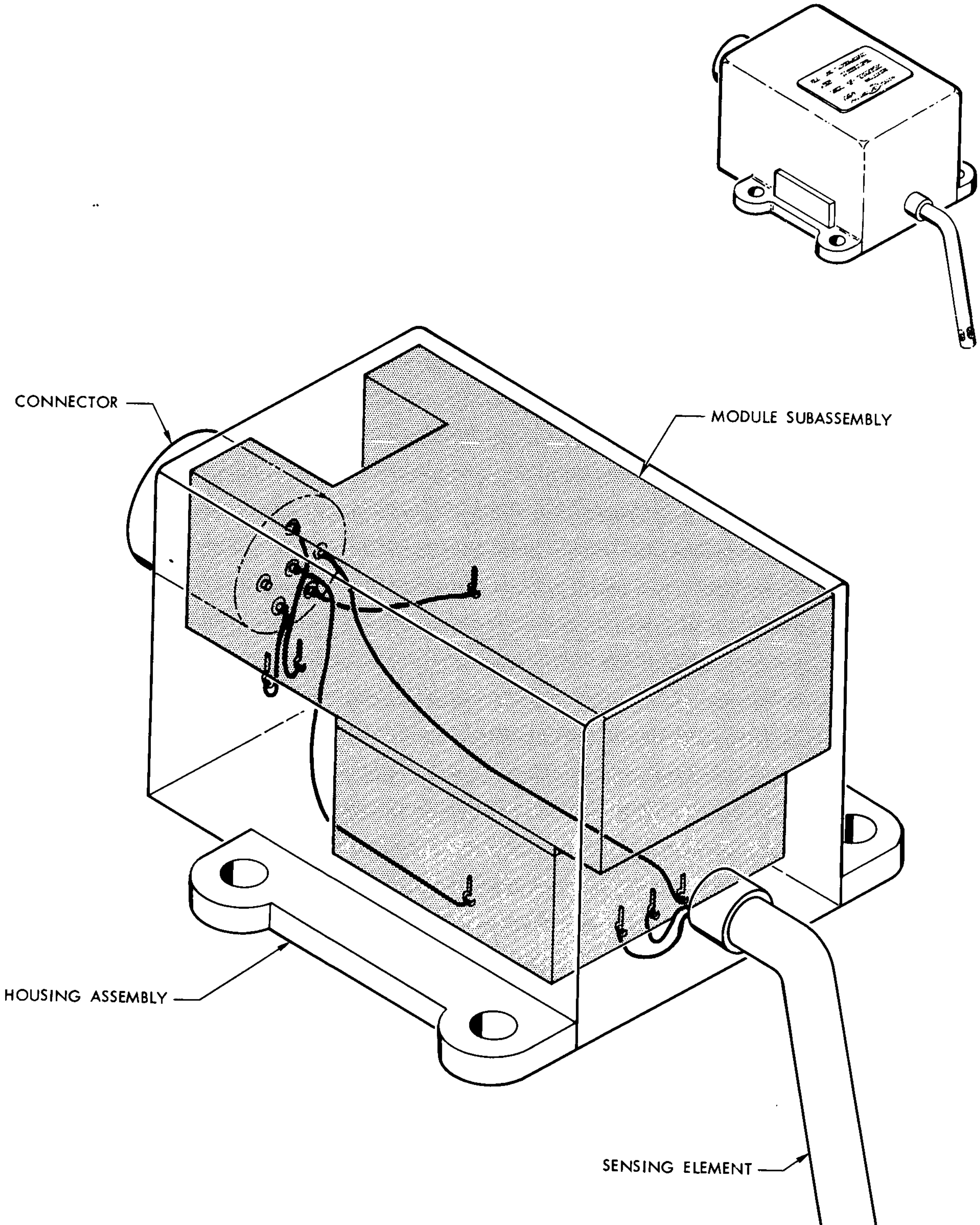

Figure 2-1. A Typical Isometric Drawing of Thermistor Bead With Electronics Temperature Transducer.

A-19700
S-32-250

TABLE 2-1

PERFORMANCE AND DESIGN DATA FOR PN 836930-1

Output signal	Proportional to sensed temperature 0 v at 40°F and 5 vdc at 125°F
Accuracy	±2.5 percent of full scale output (±0.125 vdc) at 60°F to 80°F
	±5 percent of full scale output (±0.25 vdc at 40°F to 60°F and 80°F to 125°F
Response time	10 sec max to 63.7 percent of total change in 20 cfm air flow at 14.7 psia in 3 in. dia duct
Output impedance	500 ohms maximum
Load resistance	30,000 ±6000 ohms
Power consumption	80 ma max at 28 +2, -3 vdc
Weight, lb	0.2

Two of the eight rejections (25 percent) were caused by design error. The unit was redesigned; and the problem area was eliminated. Four of the rejections (50 percent) were caused by erroneous assembly. The assembly MOT was revised; and the problem area was eliminated. One unit made a poor connection (12.5 percent) because of contamination. One unit was rejected (12.5 percent) because of a design criteria that is not evident in installation but produces a misleading signal on the test stand.

RECOMMENDATIONS

Since the design and manufacturing problems of this temperature sensor were resolved and eliminated in the development process of the unit, only the following recommendations are made to prevent human induced failures.

Manufacturing Criteria

a. Provide detailed and up-to-date assembly and operations instructions to eliminate assembly problems.

b. Retrain assembly personnel at scheduled intervals.

Design Criteria

Provide better protection for the probe to eliminate accidental damage.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE 2-2

CABIN TEMPERATURE TRANSDUCER FAILURE EVALUATION

TRANSDUCER APPLICATION CABIN TEMPERATURE SENSOR

BASIC PART NUMBER 836930

TRANSDUCER MANUF. AIRESEARCH

TROUBLE REPORT SOURCE AIRESEARCH

TRANSDUCER TYPE TEMPERATURE

OPERATING PRINCIPLE THERMISTOR WITH ELECTRONICS

MEASUREMENT RANGE 40 to 125°F, 0 - 29 mv RMS

MEASUREMENT MEDIA GAS TEMPERATURE

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
836930-3	108-135	11/27/68	19130	Human	Low insulation resistance	Short	Bad assembly	Manufacturing	Assembly not revised	
836930-3	36-109	1/15/69	NAA 61062	Human	Circuit breaker trips	Input diodes shorted	Erroneous assembly	Manufacturing	None	
836930-1	36-103	6-16-68	NAA A 91329	Human	Unstable	Burned	Overheated by heat gun	Manufacturing	None	
836930-1	37-126	6-21-68	NAA A 91338-B	Human	Low temp. reading	Insufficient base current	Resistor	Design	None	Once installed the low temp condition will never occur
836930-1	37-125	3-20-68	16613	Human	Inresponsive to temp. change	Low current draw	Bad connection	Manufacturing Q.C.	Q.C. notified	
836930-1	37-123	5-31-67	14179	Human	Low output	Low resistance	Low power	Engineering	Unit redesigned	
836930-1	37-124	5-31-67	14178	Human	High current output	Low resistance	Low power	Engineering	Unit redesigned	
836930-1	36-103	6-14-66	10382	Human	Low insulation resistance	Bad connection	Contamination	Manufacturing procedures	None	

FOLDOUT FRAME 1 FOLDOUT FRAME 2

PROBLEM AREA		PERCENT	FAILURE MODE: LOW RESISTANCE	MODE: C.B. TRIP	MODE: UNSTABLE	MODE: LOW OUTPUT	MODE: FIXED OUTPUT	MODE: HIGH OUTPUT	TYPE: HUMAN	TYPE: ELECTRICAL	TYPE: MECHANICAL	MECHANISM: SENSING ELEMENT: ELEC.	MECHANISM: SENSING ELEMENT: MECHANICAL	MECHANISM: SIGNAL CONDITIONING AND TRANSMISSION MECHANISM — FAILURE CAUSE: CONTAMINATION	LOW POWER	POOR ASSEMBLY	DAMAGED	NO FAILURE
ENGINEERING	DESIGN	25				1		1	2						2			
ENGINEERING — TESTING	PROCEDURE, ATP																	
ENGINEERING — TESTING — QUAL	ERROR																	
ENGINEERING — TESTING — QUAL	PROCEDURE																	
MANUFACTURING	PLANNING	12.5	1						1					1				
MANUFACTURING	FABRICATION																	
MANUFACTURING	ASSEMBLY	50	1	1	1		1		4							3	1	
MANUFACTURING	Q.C.																	
MANUFACTURING	INSPECTION																	
MANUFACTURING	ATP TEST ERROR																	
TEST EQUIPMENT FAILURE																		
LOX CLEANING																		
HANDLING																		
FINAL INSTALLATION	RECEIVING INSPECTION	12.5				1			1									1
FINAL INSTALLATION	INSTALLATION																	
RANDOM FAILURE																		
UNCONFIRMED FAILURE																		
NOT ANALYZED FAILURE REPORTS																		
TOTAL			2	1	1	2	1	1	8					1	2	3	1	1
PERCENT		100	25	12.5	12.5	25	12.5	12.5	100					12.5	25	37.5	12.5	12.5

Figure 2-2. Thermistor Bead with Electronics Type Temperature Sensor Failure Matrix

AIRESEARCH MANUFACTURING COMPANY
Los Angeles, California

REPORT ON FAILURE AND DESIGN EVALUATION OF APOLLO ECS TEMPERATURE SENSORS, COIL WITH ELECTRONICS TYPE

CONTRACT NO. NAS 9-12452

72-8537-15, Rev. 1 February 10, 1973

Prepared by A. Saginian

APPROVED: [signature]
R. E. Vesque
Program Manager

APPROVED: [signature]
M. J. Brudnicki
Principal Investigator

NASA MANNED SPACECRAFT CENTER
HOUSTON, TEXAS 77058

ABSTRACT

This report presents the results of a failure and design evaluation study conducted on the Apollo ECS temperature sensors, the generic group of coil with electronics type temperature sensors. The study was conducted for NASA-MSC by the AiResearch Manufacturing Company, a division of The Garrett Corporation under Contract NAS9-12452.

The study purpose was to evaluate the integrity of design of this type sensors. Failure information is presented and summarized pertaining to four sensor designs. A failure matrix is presented which describes the failure mode, type, mechanism, cause, and problem areas for 38 rejections out of a lot total of 167 units.

The integrity of the design was confirmed. Recommendations are made to reduce the failure rate from the current level of 15 percent.

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5	SUIT SUPPLY TEMPERATURE TRANSDUCER	5-1
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SECTION 1

INTRODUCTION

This report presents a summary of failure data of the generic group of coil with electronics type temperature transducer, one of several temperature sensor types that are described and categorized in AiResearch Report No. 72-8537-1. Four coil with electronics type temperature transducers were evaluated in one configuration group: (1) cabin temperature transducer, (2) suit supply temperature transducer, (3) steam duct temperature transducer, and (4) radiator water-glycol outlet temperature transducer.

One of the temperature transducers evaluated in this report was used in the Apollo environmental control system (ECS) Block I only was replaced by a bead with electronics type temperature transducer in the Block II ECS. A second transducer used to have a preceding part number which was changed during a design revision. These three temperature transducers have been used in the Apollo ECS Block I and Block II. All four of these transducers may be used to perform other temperature sensing functions with similar requirements.

The temperature transducers that are evaluated and summarized in this report are, by AiResearch part number:

PN	Nomenclature
836064-1	Cabin Temperature Sensor
836064-2	Cabin Temperature Sensor
836950-1	Suit Supply Temperature Sensor
836950-2	Steam Duct Temperature Sensor
836060-1	Steam Duct Temperature Sensor
836054-1	Suit Supply Temperature Sensor
836058-1	Radiator Water-Glycol Outlet Temperature Sensor
836058-2	Radiator Water-Glycol Outlet Temperature Sensor

Section 2 of this report presents a failure summary on all four transducers combined, descriptive information on a typical coil with electronics temperature transducer and recommendations for actions which will reduce the quantity of rejections. The reason for combination of analysis of four temperature transducers in Section 2 and their treatment as a single design is that in reality the principles of operation in all four transducers are identical and only slight variation of packaging and signal conditioning components constitutes the difference.

Detail design and failure data on each of these temperature transducers are presented in Sections 3 through 6 of this report.

SECTION 2

DESCRIPTION, FAILURE SUMMARY AND RECOMMENDATIONS FOR COIL AND ELECTRONICS TYPE TEMPERATURE TRANSDUCER

DESCRIPTION

The isometric drawing of a typical coil with electronics temperature transucer is presented in Figure 2-1. The unit consists of a metal housing containing a coil type sensing element, a resistance-bridge circuit, and a transformer coupled output circuit.

The coil type sensing element which is identical in all four of the subject transducers, is a coil of coated 40-gage platinum wire enclosed within a wall of 14K-gold tubular probe and has a positive coefficient of resistance, forms the measured branch of the resistance-bridge circuit of the transducer. The resultant signal is transmitted through the transformer coupled output circuit of the transducer for further signal treatment and eventual implementation.

FAILURE SUMMARY

Summaries of detail failure analysis of each of the four temperature transducers evaluated are presented in Sections 3 through 6 of this report. However, because all four of the transducers have the same principle of operation the failures of individual designs are combined to present the general value and reliability of this type of transducer in its temperature sensing and signal transmitting application.

Thirty nine failure reports, written against these transducers and furnished by NASA-MSC, were reviewed. The results of these reports are summarized in the failure matrix shown in Figure 2-2. This matrix is a summary of the individual matrixes presented in turn for each of these four temperature transducers. One of the failure reports was a duplication of another failure report. The remaining 38 rejections (100 percent) were determined to be due to human error. A total of 38 rejections from a population of 176 units represents a rejection rate of 22.8 percent.

A review of the failure matrix of Figure 2-2 indicates that there is no basic design problem area for this type of temperature transducer. This conclusion is based on the following observations on the failure matrix.

<u>Non-Specific Problem Area</u>

(a) There was no information concerning the failure cause of the transducers in the two failure reports which were not analyzed.

(b) Eight failures were not confirmed and the responsibility of the reports belongs to their initiators.

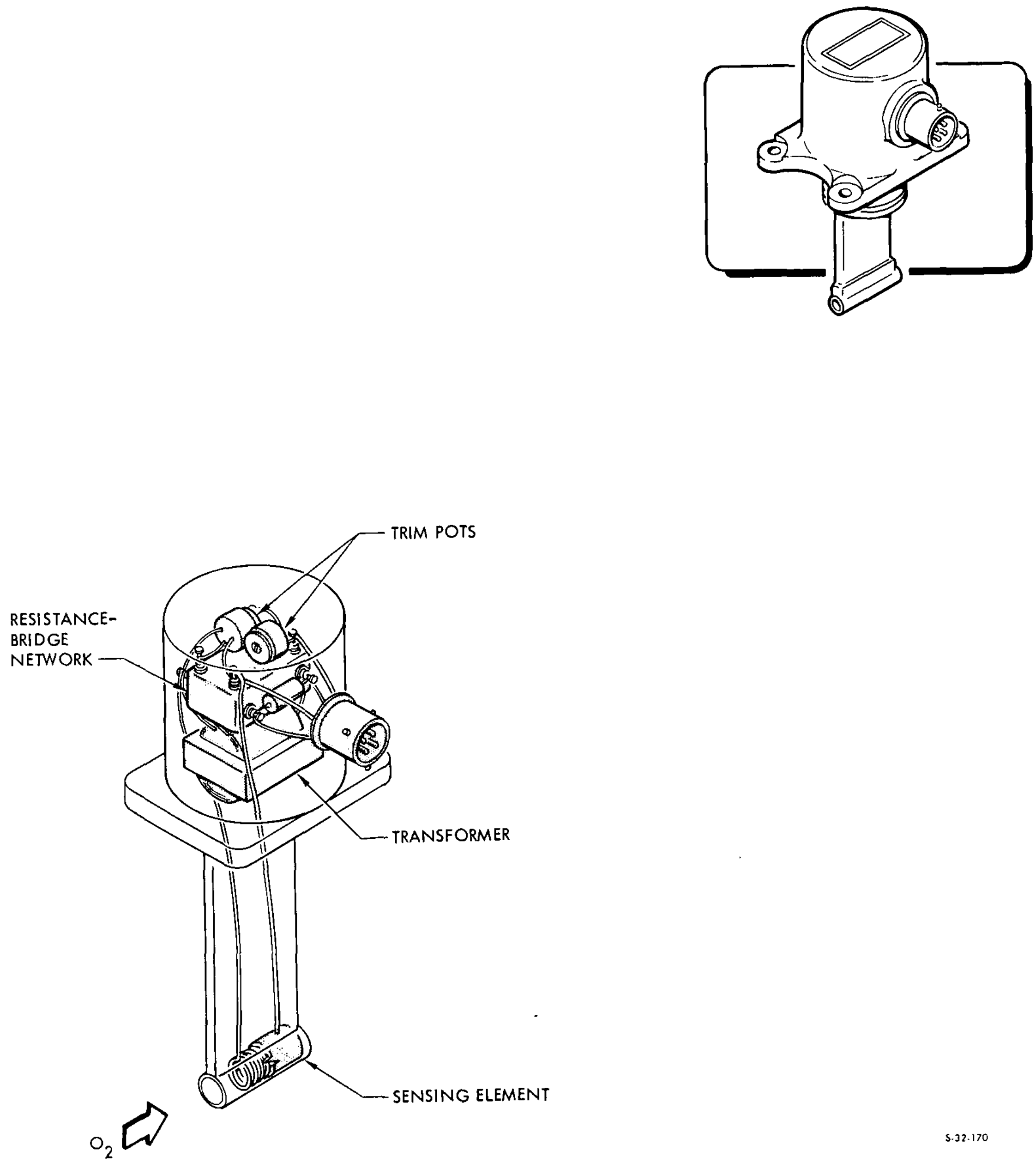

Figure 2-1. Isometric Drawing of a Typical Coil With
Electronics Type Temperature Transducer.

PROBLEM AREA		PERCENT	FAILURE MODE: DAMAGED	HIGH OUTPUT	RESISTANCE, INS	LEAKAGE	LOW OUTPUT	OUT OF CALIB.	NO FAILURE	FAILURE TYPE: HUMAN	ELECTRICAL	MECHANICAL	MECHANISM: SENSING MECHANISM, ELECT: SHORT	SENSING MECHANISM, MECHANICAL: DAMAGED	SIGNAL CONDITIONING AND TRANSMISSION MECHANISM: SEAL LEAKAGE	LOOSE PART	POOR ASSEMBLY	DAMAGED	CALIBRATION	UNKNOWN	NO FAILURE
ENGINEERING	DESIGN	10.5		1	2			1		4			2						1		1
ENGINEERING – TESTING	PROCEDURE, ATP																				
ENGINEERING – TESTING – QUAL	ERROR	2.6		1						1											1
ENGINEERING – TESTING – QUAL	PROCEDURE	2.6		1						1											1
MANUFACTURING	PLANNING																				
MANUFACTURING	FABRICATION																				
MANUFACTURING	ASSEMBLY	21.1		3	2	2	1			8					4	1	2	1			
MANUFACTURING	QUALITY CONTROL																				
MANUFACTURING	INSPECTION																				
MANUFACTURING	ATP TEST ERROR	26.3		1			5	3	1	10									9		1
TEST EQUIPMENT FAILURE		2.6						1		1											1
LOX CLEANING																					
HANDLING		7.9	3							3				1				2			
FINAL INSTALLATION	RECEIVING INSPECTION (TEST AND EQUIPMENT)																				
FINAL INSTALLATION	INSTALLATION																				
RANDOM FAILURE																					
UNCONFIRMED FAILURE		21.1		7		1				8											8
NOT ANALYZED FAILURE REPORT		5.3		2						2										2	
TOTALS			3	16	4	3	6	5	1	38			2	1	4	1	2	3	10	2	13
PERCENT		100	7.9	42.1	10.5	7.9	15.8	13.2	2.6	100			5.3	2.6	10.5	2.6	5.3	7.9	26.3	5.3	34.2

FAILURE CAUSE

Figure 2-2. Coil With Electronics Type Temperature Transducer Failure Matrix

There is no basic problem area to be dealt with; therefore, no corrective action is recommended.

Laboratory Equipment and Handling

(a) Three units were damaged in handling.

(b) One unit was rejected because of test equipment failure. Equipment failure has no reflection on the integrity of the transducer.

A problem source exists in handling which must be eliminated.

Manufacturing

(a) One unit was rejected because of test error while the unit had not failed.

(b) Nine units failed as a result of faulty calibration.

(c) Eight units failed because of various assembly problems.

A problem source exists in testing equipment and procedure as well as in manufacturing operations and tooling (MOT) which must be eliminated.

Engineering

(a) One unit was rejected because of qualification test procedure error while the unit had not failed.

(b) One unit was rejected because of qualification test error while the unit had not failed.

(c) four units were rejected because of design errors. One unit exhibited high output because of the sensor orientation in the assembly which the unit had not failed. Three units failed because of wrong choice of components.

All of the engineering problem sources have been eliminated by corrective actions.

Transducer Problem Area Evaluation

Since none of the open problem areas mentioned above are design problems, the conclusion is that the transducer design is trouble-free and is recommended to be considered for future applications.

Failure Distribution

Figure 2-3 illustrates the distribution of failures according to problem area. Figure 2-4 illustrates this distribution after design change which will eliminate the recurrence of engineering-error-related failures and after the discard of unconfirmed failures.

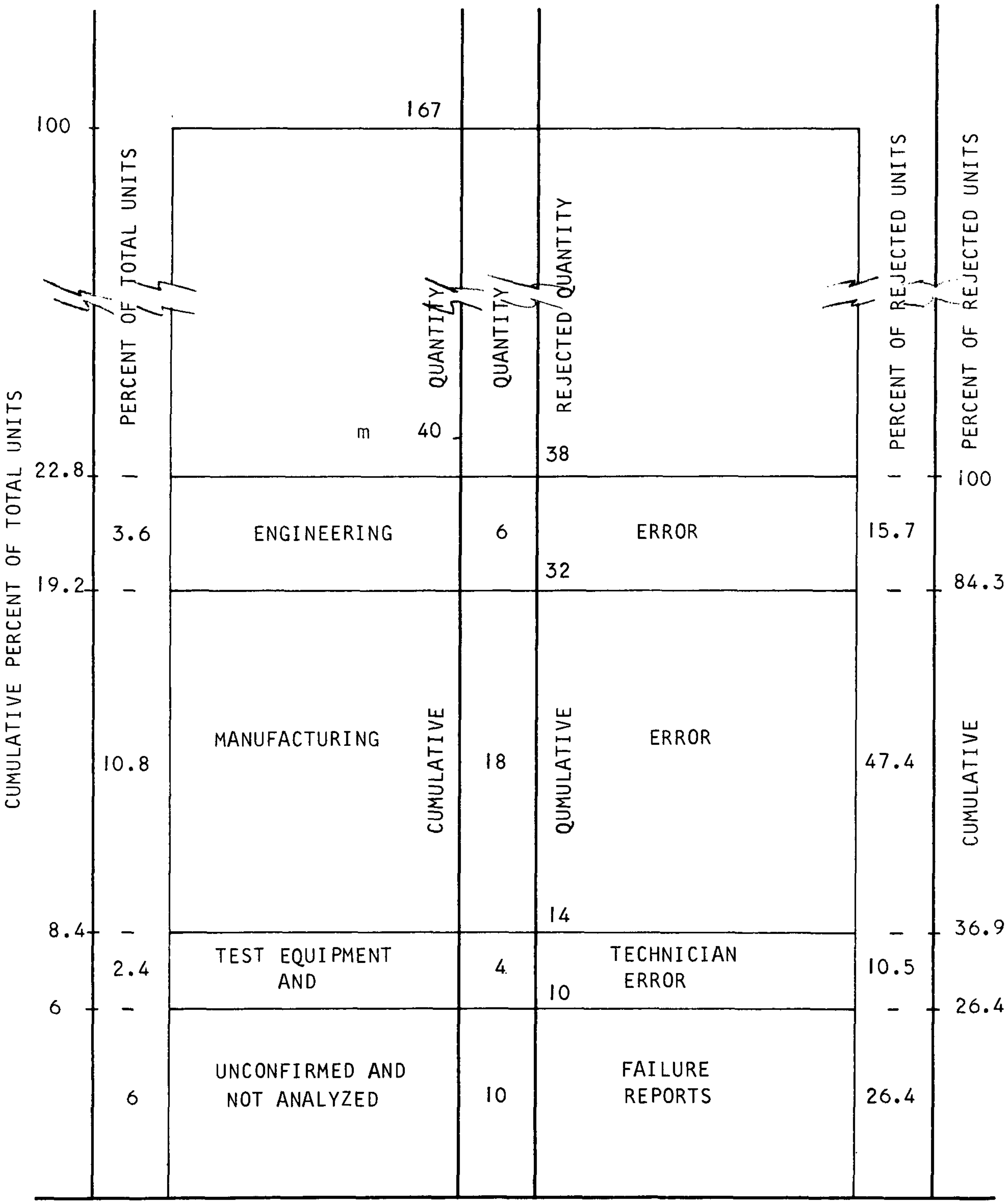

Figure 2-3. Distribution of Failures According to Problem Area.

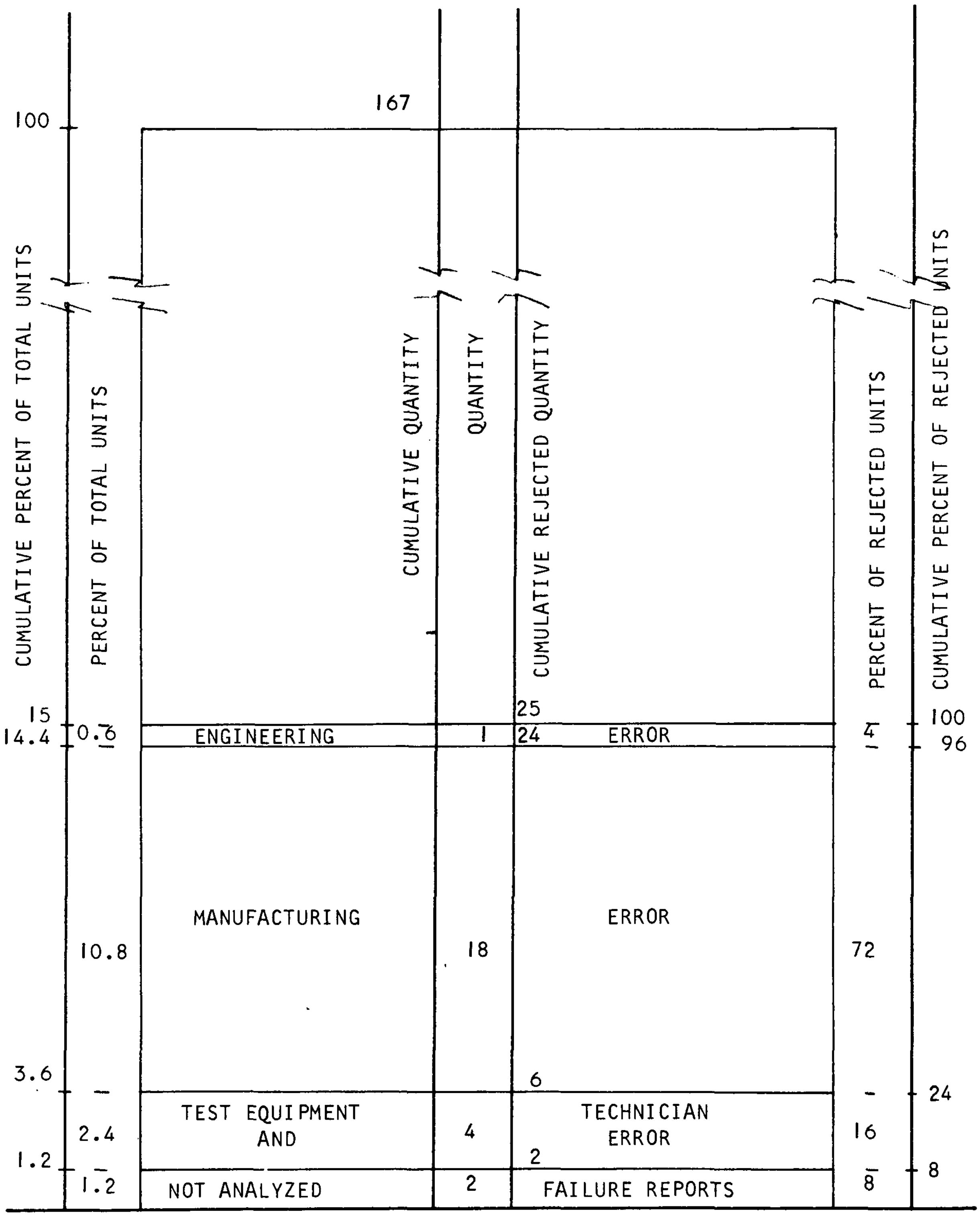

Figure 2-4. Distribution of Failures According to Problem Area After Elimination of Engineering Errors and Unconfirmed Failures

According to the data in Figure 2-4, from the total population of 167 units 15 percent were rejected. Of these, 72 percent were caused by manufacturing errors and none could be classified as random failure and all rejections were potentially avoidable.

RECOMMENDATIONS

Most failure reports on coil with electronics temperature transducers were the result of either manufacturing error or external damage in test and handling. As a result, the following recommendations are made with respect to design, manufacturing, test, and handling criteria:

Design Criteria

(a) Incorporate a protective open shell around the sensing element which will not disturb free flow and in the mean time will protect sensing element from external damage.

Manufacturing Criteria

(a) Necessary inspection requirements should be provided to prevent the passage of the faulty assembled components to the final assembly.

Test and Handling Criteria

(a) ATP and QTP documents should be reviewed and amended as necessary to minimize the possibility of test technician error in the conduct of the test and to provide adequate calibration tolerance without compromizing specification requirements.

(b) Protective covers or containers should be provided which will be removed at the assembly time to minimize the possibility of accidental damage to the part during various manufacturing processes.

SECTION 3

RADIATOR WATER-GLYCOL OUTLET TEMPERATURE TRANSDUCER (AIRESEARCH PN 836058)

PURPOSE AND DESCRIPTION

This transducer senses the water-glycol coolant temperature at the space radiator outlet and in conjunction with the associated in-flight signal amplifier it provides a signal proportional to the sensed temperature.

The unit consists of a metal housing containing a coil type sensing element, a resistance-bridge circuit, and a transformer coupled output circuit. The coil type sensing element, which has a positive coefficient of resistance, forms the measured branch of the resistance-bridge circuit of this unit. The resultant signal is transmitted to the associated in-flight temperature sensor amplifier through the transformer coupled output circuit of the radiator outlet temperature sensor. This signal is amplified and the amplifier output signal is used for telemetry purposes.

PERFORMANCE AND DESIGN DATA

Table 3-1 lists performance and design data and Figure 3-1 presents the outline for this transducer.

FAILURE REVIEW

Table 3-2 is a summary of 12 failure reports written against 14 units of this transducer. Two of the failure reports were not reported and information is not available. One failure report on unit leakage was not verified. One unit was shorted by faulty soldering. One unit was rejected because of improper location for certain vehicle orientations. Two units were rejected because of moisture entry into the electronic package. One unit was rejected because of moisture in the test equipment. Finally, six units were rejected because of calibration problems.

All of the above mentioned rejection causes were human induced. Calibration of the unit has been a problem source. However, revision of TI and ATP eliminated this problem source and provided for the screening of the leaking units.

TABLE 3-1

PERFORMANCE AND DESIGN DATA FOR PN 836058

Performance Requirements:

a. Operating temperature range: $-50^{\circ}F$ to $+100^{\circ}F$

b. Accuracy: $\pm1.0^{\circ}F$ ($\pm0.67\%$ of total operating range) between $25^{\circ}F$ and $60^{\circ}F$ and $\pm3.0^{\circ}F$ ($\pm2.0\%$ of total operating range) at $-50^{\circ}F$ and $+100^{\circ}F$

c. Output Signal: Proportional to sensed temperature: Zero at $-50^{\circ}F$ and 59 mv peak-to-peak, sq wave (with 260 ±2.6 ohm load) at $100^{\circ}F$

d. Output impedance: 1300 ohms max.

e. Time constant: 6.0 sec max.

f. Power dissipation of sensing element: 46 mw max.

Bridge Excitation Voltage: 5.4 v peak-to-peak, 300 cps, sq wave at 140 ma max.

Operating Pressures:

a. Max: 60 psig (relative to cabin)

b. Pressure drop across sensor: 0.25 in. water max. at flow rate of 200 lb/hr

Structural Requirements:

a. Proof pressure: 90 psig

b. Burst pressure: 150 psig

External Leakage: Zero with 60 psig internal pressure

Environmental Conditions: As per AiResearch Report SS-1060-R; Type I equipment

Installation Envelope: Per AiResearch Drawing 836058

Weight: 0.3 lb

Electrical Connector: In accordance with MIL-C-26482C

Radio Noise: In accordance with NAA Specification MC 999-0002A.

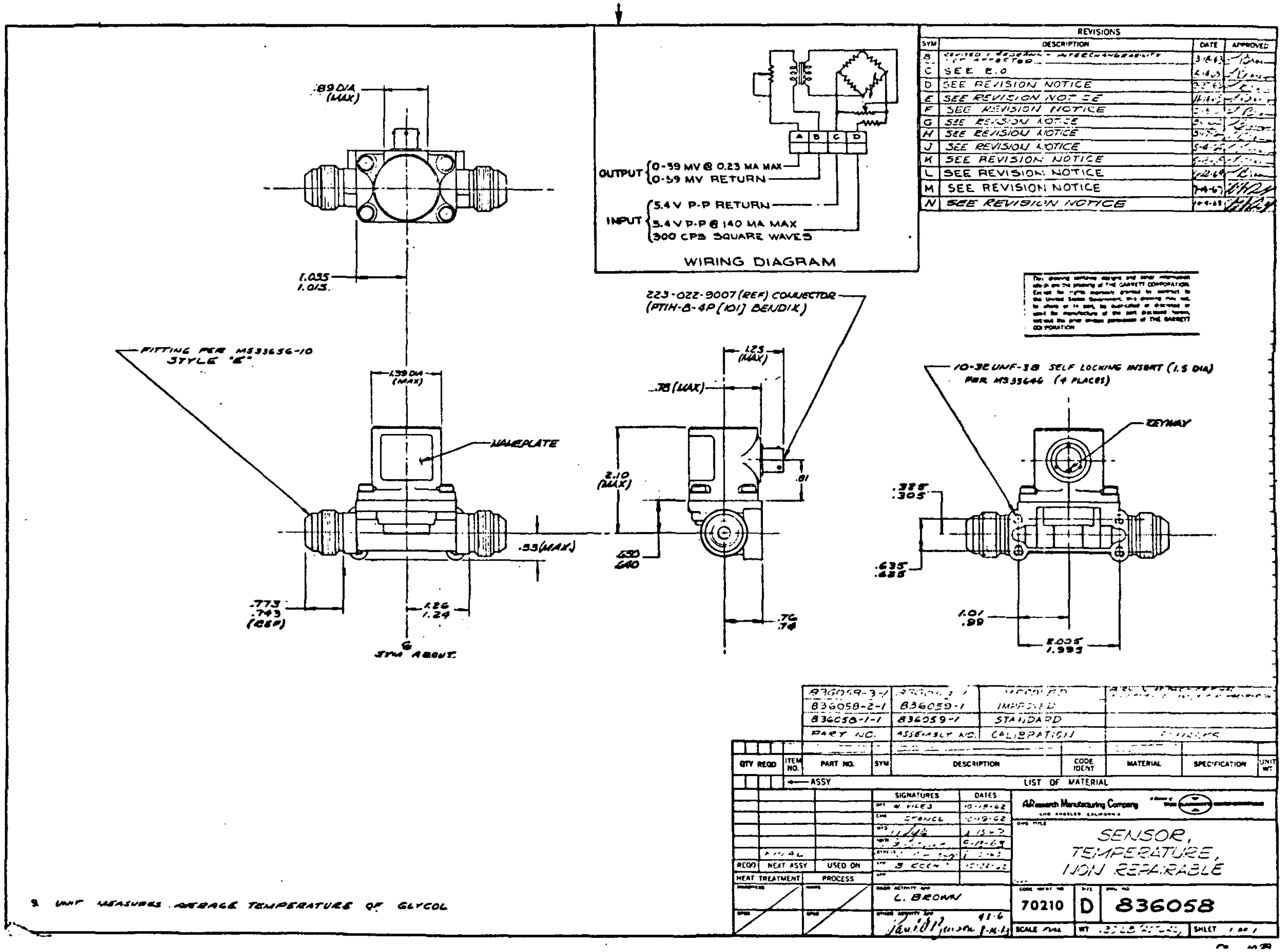

Figure 3-1. Altered Outline of Water-Glycol Outlet Temperature Transducer

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE 3-2

RADIATOR WATER-GLYCOL OUTLET TEMPERATURE TRANSDUCER FAILURE EVALUATION

TRANSDUCER APPLICATION RADIATOR WATER-GLYCOL OUTLET TEMP SENSOR

BASIC PART NUMBER 836058, ME431-0047 (NAR PN)

TRANSDUCER MANUF.

TROUBLE REPORT SOURCE AIRESEARCH

TRANSDUCER TYPE TEMPERATURE

OPERATING PRINCIPLE RESISTANCE BRIDGE

MEASUREMENT RANGE -50°F TO +100°F

MEASUREMENT MEDIA WATER-GLYCOL COOLANT

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
ME431-0047-0001	00400 0126138	11-22-69 FLIGHT	SD69-429-04	HUMAN	HIGH OUTPUT	SENSOR, IMPROPERLY LOCATED FOR SOME VEHICLE ORIENTATIONS	THERMAL STRATIFICATION OF MEDIA	DESIGN, PRIME RESPONSIBILITY	NONE	THIS IS NOT A FAILURE AREA PRIME RESPONSIBILITY
836058-2-1	88-145	4-10-69	19173	HUMAN	HIGH OUTPUT	ELECTRONICS PACKAGE	IMPROPER CALIBRATION AND TEST	MANUFACTURING	SURVEILLANCE FOR RECURRENCE OF PROBLEM	THIS IS NOT A FAILURE IMPROPER CALIBRATION OCCURRED AT MFG LEVEL
ME431-0047-0001	00400 46133	12-27-68 FLIGHT	PF103512	HUMAN	HIGH OUTPUT	ELECTRONICS PACKAGE	MOISTURE	IMPROPER INSTALLATION IN VEHICLE	INSTRUCT PERSONNEL IN PROPER HANDLING AND INSTALLATION PROCEDURES	PRIME RESPONSIBILITY
836058-2-1	46-123	11-20-68	19127	HUMAN	LOW IR	ELECTRONICS PACKAGE	SHORTED SOLDER JOINTS	MANUFACTURING	TI & ATP REVISIONS TO SCREEN OUT DEFECTIVE UNITS	UNIT RETURNED FROM PRIME-WAS SHIPPED PRIOR TO TI & ATP REVISIONS
836058-2-1	46-133	11-17-67	16514	HUMAN	HIGH OUTPUT	NONE - HIGH OUTPUT DUE TO MOISTURE IN TEST EQUIPMENT, THIS IS NOT A FAILURE				
836058-1-1	46-121	7-25-67	8884	HUMAN	LOW IR	ELECTRONICS PACKAGE	MOISTURE ENTRY THROUGH POROUS PORTIONS OF SOLDER JOINT	MANUFACTURING	TI AND ATP REVISIONS TO SCREEN OUT DEFECTIVE UNITS	
836058-1-1	14-102 45-114	10-16-66 8-12-67	M165612 MA22253	HUMAN	OUT OF CALIBRATION	ELECTRONICS PACKAGE	WRONG CALIBRATION LIMITS USED	MANUFACTURING	CALIBRATION PROCEDURES CHANGED	
836058-1-1	46-135 46-134	9-7-66 9-6-66	11089 10288	HUMAN	LOW OUTPUT	ELECTRONICS PACKAGE	IMPROPER INITIAL CALIBRATION	MANUFACTURING	NONE-UNIT RECALIBRATED	THESE ARE NOT FAILURES. IMPROPER CALIBRATION OCCURRED DURING MFG PRIOR TO ATP.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE 3-2 (Continued)

TRANSDUCER APPLICATION RADIATOR WATER-GLYCOL OUTLET TEMP SENSOR
BASIC PART NUMBER 836058, ME431-0047 (NAR PN)
TRANSDUCER MANUF.
TROUBLE REPORT SOURCE AIRESEARCH

TRANSDUCER TYPE TEMPERATURE
OPERATING PRINCIPLE RESISTANCE BRIDGE
MEASUREMENT RANGE $+50^{\circ}F$ TO $+100^{\circ}F$
MEASUREMENT MEDIA WATER-GLYCOL COOLANT

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
836058-1-1	46-122	6-12-66	9260	HUMAN	OUT OF CALIBRATION	THIS IS NOT A FAILURE - CALIBRATION AND VOLTAGE INPUT TEST REQUIREMENTS TOO STRINGENT FOR EQUIPMENT			ATP REVISED TO EXPAND ACCEPTABLE CALIBRATION & INPUT VOLTAGE PARAMETERS	
836058-1-1	14-102	6-7-66	7661	HUMAN	LEAKAGE	FAILURE COULD NOT BE VERIFIED				
836058-1-1	104-111	5-20-66	MA 17741	HUMAN	HIGH OUTPUT	NOT REPORTED	NOT REPORTED	NOT REPORTED	NOT REPORTED	
836058-1-1	104-109	4-9-65	5782	HUMAN	HIGH OUTPUT	NOT REPORTED	NOT REPORTED	NOT REPORTED	NOT REPORTED	

SECTION 4

STEAM DUCT TEMPERATURE TRANSDUCER (AIRESEARCH PN 836060-1 SUPERCEDED BY PN 836950-2)

PURPOSE AND DESCRIPTION

This transducer senses the steam temperature in the glycol evaporator steam discharge line, and in conjunction with the associated in-flight signal amplifier it provides a signal proportional to the sensed temperature.

The unit consists of a metal housing containing a coil type sensing element, a resistance-bridge circuit, and a transformer coupled output circuit. The coil type sensing element, which has a positive coefficient of resistance, forms the measured branch of the resistance-bridge circuit of this unit. The resultant signal is transmitted to the associated in-flight temperature sensor amplifier through the transformer coupled output circuit of the steam duct temperature sensor. This signal is amplified and the amplifier output signal is used for telemetry purposes.

PERFORMANCE AND DESIGN DATA

Table 4-1 lists performance and design data for this transducer, and Figures 4-1 and 4-2 present the outlines of these two designs.

FAILURE REVIEW

Table 4-2 is a summary of two failure reports on part number 836950-2. Table 4-3 is a summary of four failure reports on part number 836060-1. These NASA-MSC furnished failure reports were reviewed for this transducer evaluation.

The initial design of this transducer, PN 836060-1 had a heat generating electronics package. A design change effort was initiated as a result the new design PN 836950-2 supersedes the initial design. This design change eliminated the self heat generating problem of the electronics package of the superseded unit.

The two failure reports on the new design are results of technician errors. Recommendations to minimize the possibility of the recurrence of such failures are given in Section 2 of this report.

TABLE 4-1

PERFORMANCE AND DESIGN DATA FOR PN'S 836060-1
AND 836950-2

Performance Requirements:

a. Operating temperature range: 20°F to 95°F

b. Accuracy: ±1.5° (±2.0% of total operating range).

c. Output signal: Proportional to sensed temperature. Zero at 20°F and 59 mv peak-to-peak sq wave (with 260 ±2.6 ohm load) at 95°F

d. Output impedance: 500 ohms max.

e. Time constant: 6.0 sec max.

f. Power dissipation of sensing element: 46 mw max.

Bridge Excitation Voltage: 5.4 v peak-to-peak, 300 cps, sq wave at 140 ma max.

Operating Pressures:

a. Normal: 0 to 1 psia

b. Max: 20 psia

Environmental Conditions: As specified in AiResearch Specification SS-1060-R; Type I equipment

Installation Envelope: Per AiResearch Drawing 836060

Weight: 0.20 lb

Electrical Connector: In accordance with MIL-C-26482C

Radio Noise: In accordance with NAA Specification MC 999-0002A

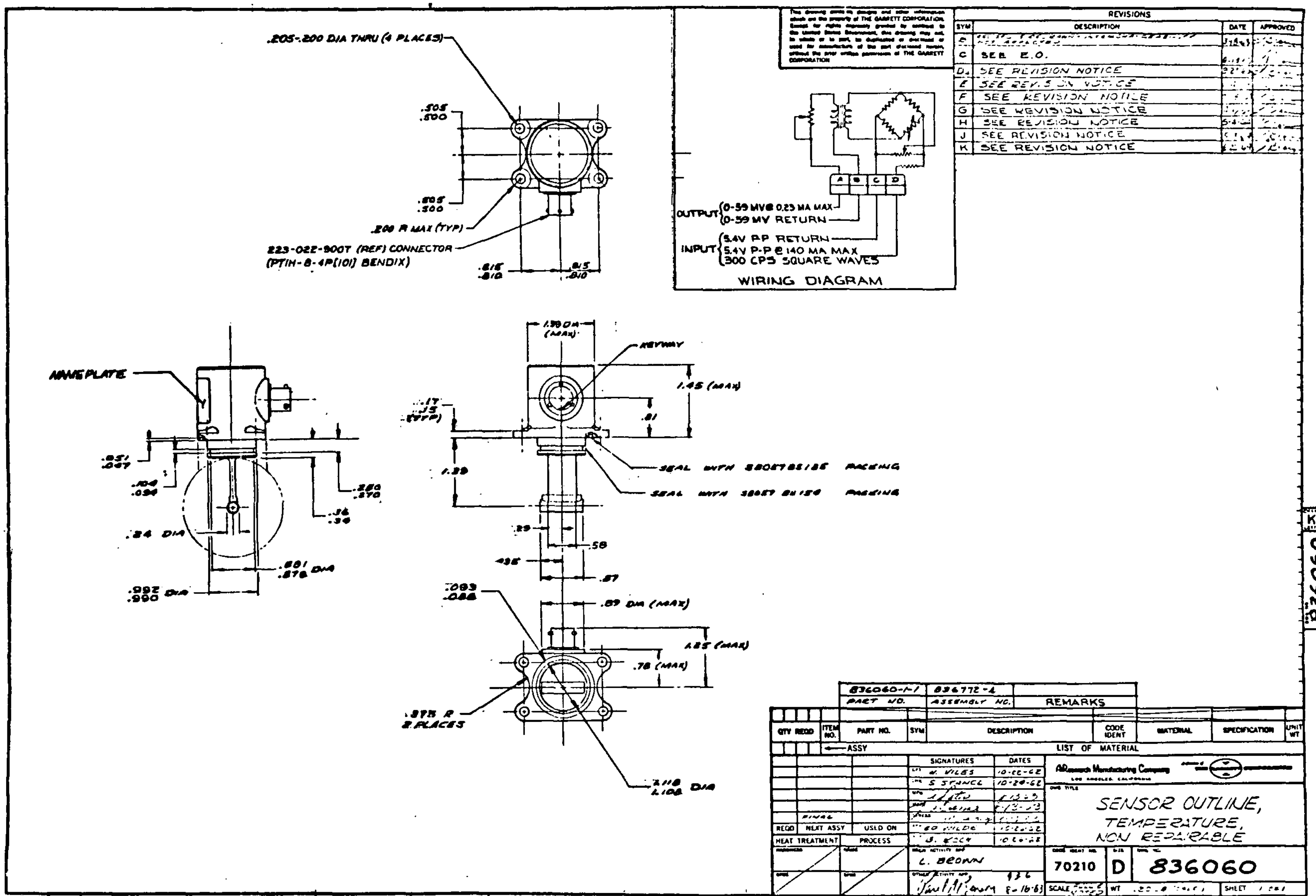

Figure 4-1. Altered Outline Of Steam Duct Temperature Transducer.

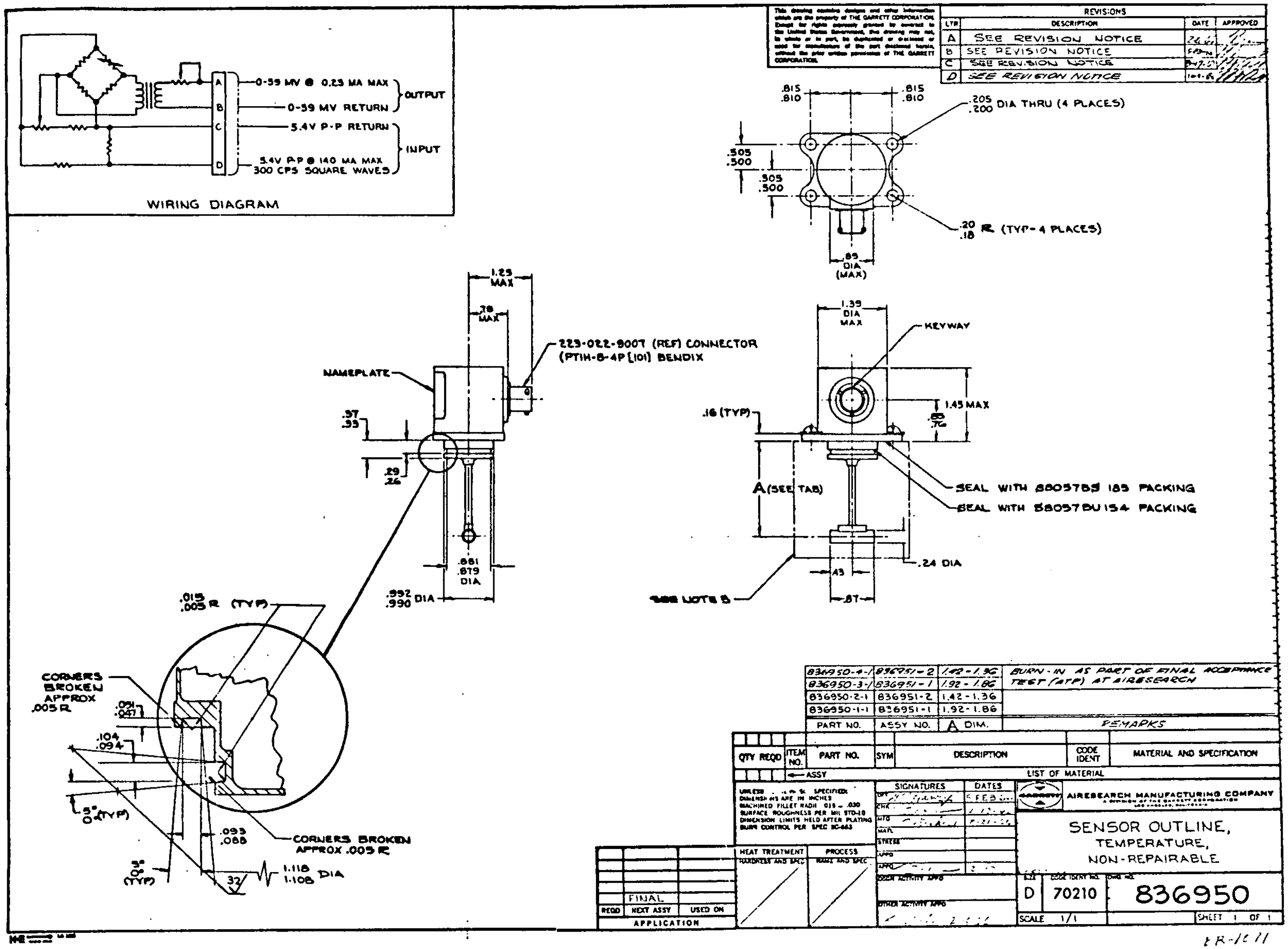

Figure 4-2. Altered Outline of Steam Duct Temperature Transducer.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE 4-2

STEAM DUCT TEMPERATURE TRANSDUCER FAILURE EVALUATION

TRANSDUCER APPLICATION: STEAM DUCT TEMPERATURE TRANSDUCER

BASIC PART NUMBER: 836950-2

TRANSDUCER MANUF.:

TROUBLE REPORT SOURCE: AIRESEARCH

TRANSDUCER TYPE: TEMPERATURE

OPERATING PRINCIPLE: WHEATSTONE BRIDGE WITH SENSING ELEMENT AS ONE ARM

MEASUREMENT RANGE:

MEASUREMENT MEDIA: STEAM AND FREE H_2O EXHAUSTED TO SPACE

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
836950-2-1	88-134	5-21-69	19183	HUMAN	LOW OUTPUT	USE OF INCORRECT TEST EQUIPMENT	WRONG LOAD RESISTANCE	TEST	NONE	
836950-2-1	46-101	4-27-67	8896	HUMAN	OUT OF CALIBRATION	ELECTRONIC PACKAGE	R5 DAMAGED	PLANNING	NONE	R5 DAMAGED BY DRILL BIT DURING MODIFICATION

TABLE 4-3

STEAM DUCT TEMPERATURE TRANSDUCER FAILURE EVALUATION

TRANSDUCER APPLICATION STEAM DUCT TEMPERATURE TRANSDUCER

BASIC PART NUMBER 836950, 836060 (BLOCK I)

TRANSDUCER MANUF.

TROUBLE REPORT SOURCE AIRESEARCH

TRANSDUCER TYPE TEMPERATURE

OPERATING PRINCIPLE WHEATSTONE BRIDGE WITH SENSING ELEMENT AS ONE ARM

MEASUREMENT RANGE

MEASUREMENT MEDIA STEAM AND FREE H_2O EXHAUSTED TO SPACE

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
836060-1-1 (BLK I)	14-103	10-13-66	11364	HUMAN	LOW INSULATION RESISTANCE	ELECTRONIC PACKAGE SHORT CIRCUIT	SENSE ELEMENT CORRODED	DESIGN	REDESIGN TO USE SENSOR ELEMENT WITH BETTER CORROSION RESISTANCE	
836060-1-1	14-104 (BLK 1)	10-21-65	6602	HUMAN	OUT OF CALIBRATION	ELECTRONIC PACKAGE RESISTANCE CHANGE	THERMAL CONDUCTION	DESIGN	REDESIGN	
836060-1-1 (BLK I)	14-104	5-14-65	N.R. TR 313 A/R TR 6056	HUMAN	OUT OF CALIBRATION AT LOW TEMP.	TEST EQUIPMENT	TEST EQUIPMENT	TESTING	REVISE TEST HOOK-UP AND CRITERIA	
836060-1-1 (BLK I)	14-104	5-1-65	6057	NOT REPORTED, DUPLICATION OF TR #6056						TR VOID

SECTION 5

SUIT SUPPLY TEMPERATURE TRANSDUCER
(AIRESEARCH PN'S 836950-1 AND 836054-1)

PURPOSE AND DESCRIPTION

These transducers sense the oxygen temperature at the suit inlet and in conjunction with the associated in-flight signal amplifier they provide signals proportional to the sensed temperature.

The unit consists of a metal housing containing a coil type sensing element, a resistance-bridge circuit, and a transformer-coupled output circuit. The coil type sensing element, which has a positive coefficient of resistance, forms the measured branch of the resistance-bridge circuit of this unit. The resultant signal is transmitted to the associated in-flight amplifier through the transformer coupled output circuit of the suit supply temperature sensor. This signal is amplified and the amplifier output signal is used for telemetry purposes and visual readout.

PERFORMANCE AND DESIGN DATA

Table 5-1 lists performance and design data for this transducer, and Figures 5-1 and 5-2 present the outlines of these two designs.

FAILURE REVIEW

Table 5-2 is a summary of six failure reports on PN 836950-1. Table 5-3 is a summary of five failure reports on PN 836054-1. These NASA-MSC furnished reports were reviewed for this transducer evaluation.

The initial design of this transducer, PN 836054-1, had a heat generating electronics package. A design change effort was initiated and as a result the new design PN 836950-1 supersedes the initial design. This design change eliminated self heat generating problem of the electronics package of the superseded unit.

The five failure reports on the new design are results of technician errors. Recommendation to minimize the possibility of the recurrence of such failures are given in Section 2 of this report.

TABLE 5-1

PERFORMANCE AND DESIGN DATA FOR
PN'S 836054-1 AND 836950-1

Performance Requirements:		
a.	Operating temp range, $^{\circ}F$	20 to 95
b.	Accuracy, mv rms	±0.59 (±1.5°F) of sensed suit-gas temp
c.	Output signal, cps	300 sq-type wave with wave magnitude proportional to sensed temp 0 at 20°F and 29.5 rms, sq wave (with 270 ±2.7 ohms load) at 95°F
d.	Output impedance, ohms	500 (max.)
e.	Time constant, sec	6.0 max. in quiescent water
f.	Power consumption	Corresponding to 140 ma current with specified bridge excitation voltage
Bridge Excitation Voltage:		2.70 ±0.05 vrms, 300 cps, sq-type waves
Operating Pressures:		
a.	Normal, psia	5.22
b.	Max, psia	17
c.	Pressure drop	0.25 in. water max.
Structural Requirements:		
a.	Proof pressure, psig	6
b.	Burst pressure, psig	10
External Leakage:		6×10^{-6} lb/hr O_2, installed in duct, at 4 psig and 70°F
Environmental Conditions:		Per AiResearch Report Ss-1060-R; Type I equipment
Installation Envelope:		Per AiResearch Drawing 836054

TABLE 5-1 (Continued)

Electrical Connector:	In accordance with MIL-C-26482C
Radio Noise:	In accordance with NAA Specification MC 999-002A
Weight:	0.2 lb
Qualification Testing:	This unit is a qualified Block II Apollo component

AIRESEARCH MANUFACTURING COMPANY
Los Angeles, California

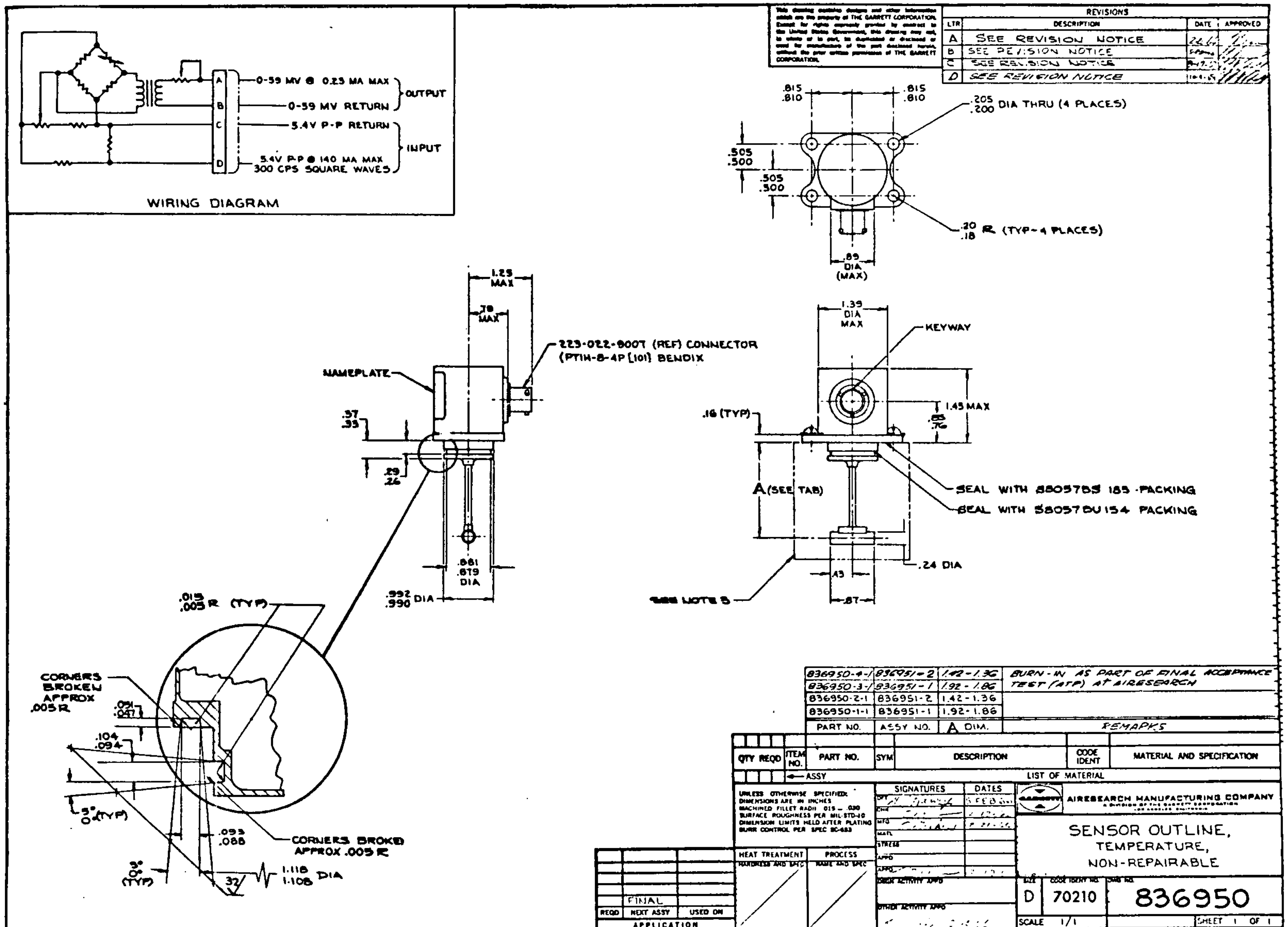

Figure 5-1. Altered Outline of Suit Supply Temperature Transducer

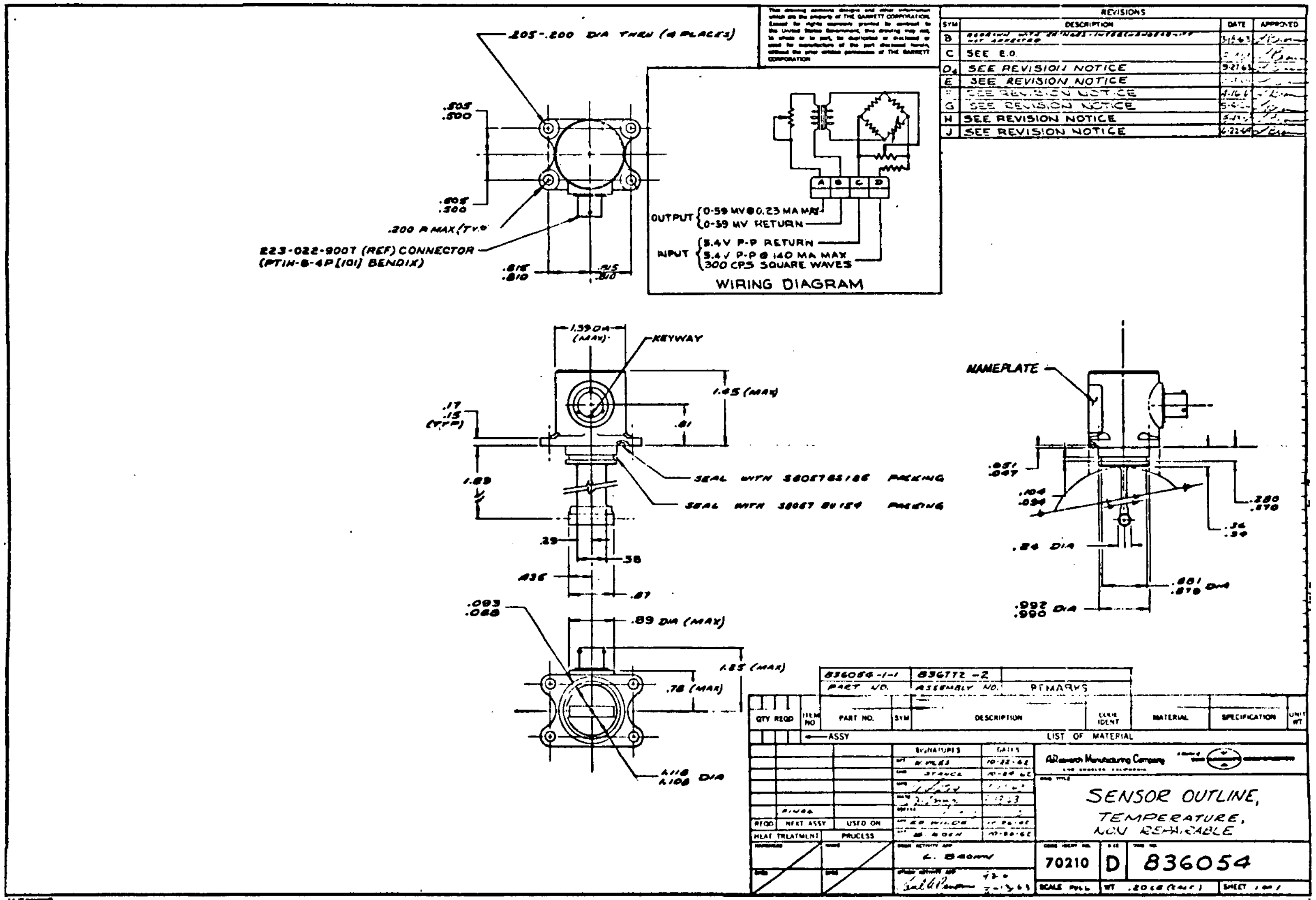

Figure 5-2. Altered Outline of Suit Supply Temperature Transducer

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE 5-2

SUIT SUPPLY TEMPERATURE TRANSDUCER FAILURE EVALUATION

TRANSDUCER APPLICATION SUIT SUPPLY TEMP SENSOR

BASIC PART NUMBER NR:ME431-0074 A/R 836950

TRANSDUCER MANUF. AIRESEARCH

TROUBLE REPORT SOURCE

TRANSDUCER TYPE

OPERATING PRINCIPLE

MEASUREMENT RANGE

MEASUREMENT MEDIA

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
836950-1-1	46-111	8-15-66	A/R 10904-9	HUMAN	LOW OUTPUT	CALIBRATION	CALIBRATION ERROR	TEST	UNIT RECALIBRATED	
836950-1-1	46-101	10-14-66	11369	NOT REPORTED, TECHNICIAN ERROR IN READING						
836950-1-1	46-118	10-14-69	A/R 20306	HUMAN	HIGH OUTPUT	LOOSE TRIM POT RESISTANCE CARD	RESISTANCE CARD IN TRIM POT WAS NOT CEMENTED	RANDOM HUMAN ERROR	SPECTRAL TRIM POT MODIFIED TO ELIMI-NATE HUMAN ERROR	
836950-1-1	46-101	7-25-67	A/R 15456-9	HUMAN	HIGH EXTERNAL LEAKAGE	CASE LEAKAGE	SPECIAL INSTRUMENTA-TION HOLE FOR QUAL TEST NOT PLUGGED	TEST	XDUCER REMOVED AND IDENTIFIED AS SPECIAL FOR QUAL TEST	
836950-1-1	46-101	10-14-66	A/R 11369-9	HUMAN	HIGH OUTPUT	---	---	TECHNICIAN ERROR	---	NOT A FAILURE
836950-1-1	46-110	8-19-66	A/R 10925-9	HUMAN	LOW OUTPUT	CALIBRATION	CALIBRATION ERROR	TEST	UNIT RECALIBRATED	

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE 5-3

SUIT SUPPLY TEMPERATURE TRANSDUCER FAILURE EVALUATION

TRANSDUCER APPLICATION SUIT SUPPLY TEMP SENSOR

BASIC PART NUMBER NR ME431-0074 AIRESEARCH 836950

TRANSDUCER MANUF. AIRESEARCH

TROUBLE REPORT SOURCE

TRANSDUCER TYPE

OPERATING PRINCIPLE

MEASUREMENT RANGE

MEASUREMENT MEDIA

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
836054-1	104-108	4-26-65	NR 305	HUMAN	OUTPUT HIGH (SPIKE OF 17.82 MV SHOULD NOT BE OVER 16.32 MV)	---	TEST METER READS HIGH BECAUSE IT INTEGRATES THE SPIKE INTO THE RMS READING	TEST EQUIPMENT	REVISE QTP SS-1232R TO ACCOMMODATE SCALE ERROR	
836054-1	14-103	7-16-64	A/R 3524	HUMAN	FAILED INSULATION RESISTANCE TEST	ELEC SHORT (WIRE TO CASE)	METAL JOINING TEMP OF HOUSING & MANDREL MELTED THE INSULATION	DESIGN	USE HI SILVER 14K GOLD FOR JOINING AT TEMP	
ME431-0074-0001	46-117	10-29-69	NR A146407A	HUMAN	EXCESSIVE LEAKAGE (INTERFACE LEAK WAS 5.12×10^{-7} SHOULD BE 1×10^{-7} MAX.)	O-RING (BETWEEN SENSOR AND DUCT)	DAMAGED O-RING	INSTALLATION	REPLACE O-RING AND LEAKAGE TEST	
836054-1-1	84-120	9-20-66	TR 8849	HUMAN	ELEC CONNECTOR DAMAGED	ELEC CONNECTOR PARTIALLY SEPARATED FROM FLANGE BASE	UNKNOWN	---	---	
836054-1-1	104-109	9-2-66	NR 22287	HUMAN	MECHANICAL DAMAGE	PROTECTIVE TUBE PULLED LOOSE	CORROSION AND MISHANDLING DURING DISASSEMBLY	HANDLING	PERSONNEL CAUTIONED	

SECTION 6

CABIN TEMPERATURE TRANSDUCER
(AIRESEARCH PN 836064-1)

PURPOSE AND DESCRIPTION

This transducer, before it was superseded in Apollo Block II, sensed the cabin temperature and in conjunction with in-flight signal amplifier it provided a signal proportional to the sensed temperature.

The unit consists of a metal housing containing a coil type sensing element, a resistance-bridge circuit, and a transformer coupled output circuit. The coil type sensing element, which has a positive coefficient of resistance, forms the measured branch of the resistance-bridge circuit of this unit. The resultant signal is transmitted to the associated in-flight temperature sensor amplifier through the transformer coupled output circuit of the cabin temperature sensor. This signal is amplified and the amplifier output signal is used for telemetry purposes.

PERFORMANCE AND DESIGN DATA

Table 6-1 lists performance and design data and Figure 6-1 presents the outline for this transducer.

FAILURE REVIEW

Table 6-2 is a summary of five failure reports against eight units of this transducer. One of the units was damaged in handling. The remaining units had not failed and because this design was superseded no further action was taken. Design change was initiated because of end assembly design change which created new physical and functional requirements for this transducer.

TABLE 6-1

PERFORMANCE AND DESIGN DATA FOR
PN 836064-1

Performance Requirements:

a. Operating temperature range: 20°F to 95°F

b. Accuracy: ±1.0°F (±1.33% of total operating range) between 60°F and 90°F and ±1.5°F (±2.0% of total operating range) at 20°F and 95°F

c. Output signal: Proportional to sensed temperature. Zero at 20°F and 59 mv peak-to-peak, sq wave (with 260 ±2.6 ohm load) at 95°F

d. Output impedance: 500 ohm max.

e. Time constant: 6.0 sec max.

f. Power dissipation of sensing element: 46 mw max.

Bridge Excitation Voltage: 5.4 v peak-to-peak, 300 cps, sq wave at 140 ma max.

Operating Pressure:

a. Max: 16 psia

b. Normal: 5 psia

Environmental Conditions: Per AiResearch Report SS-1060-R; Type I equipment

Installation Envelope: Per AiResearch Drawing 836064

Weight: 0.2 lb

Electrical Connector: In accordance with MIL-C-26482C

Radio Noise: In accordance with NAA Specification MC 999-0002A

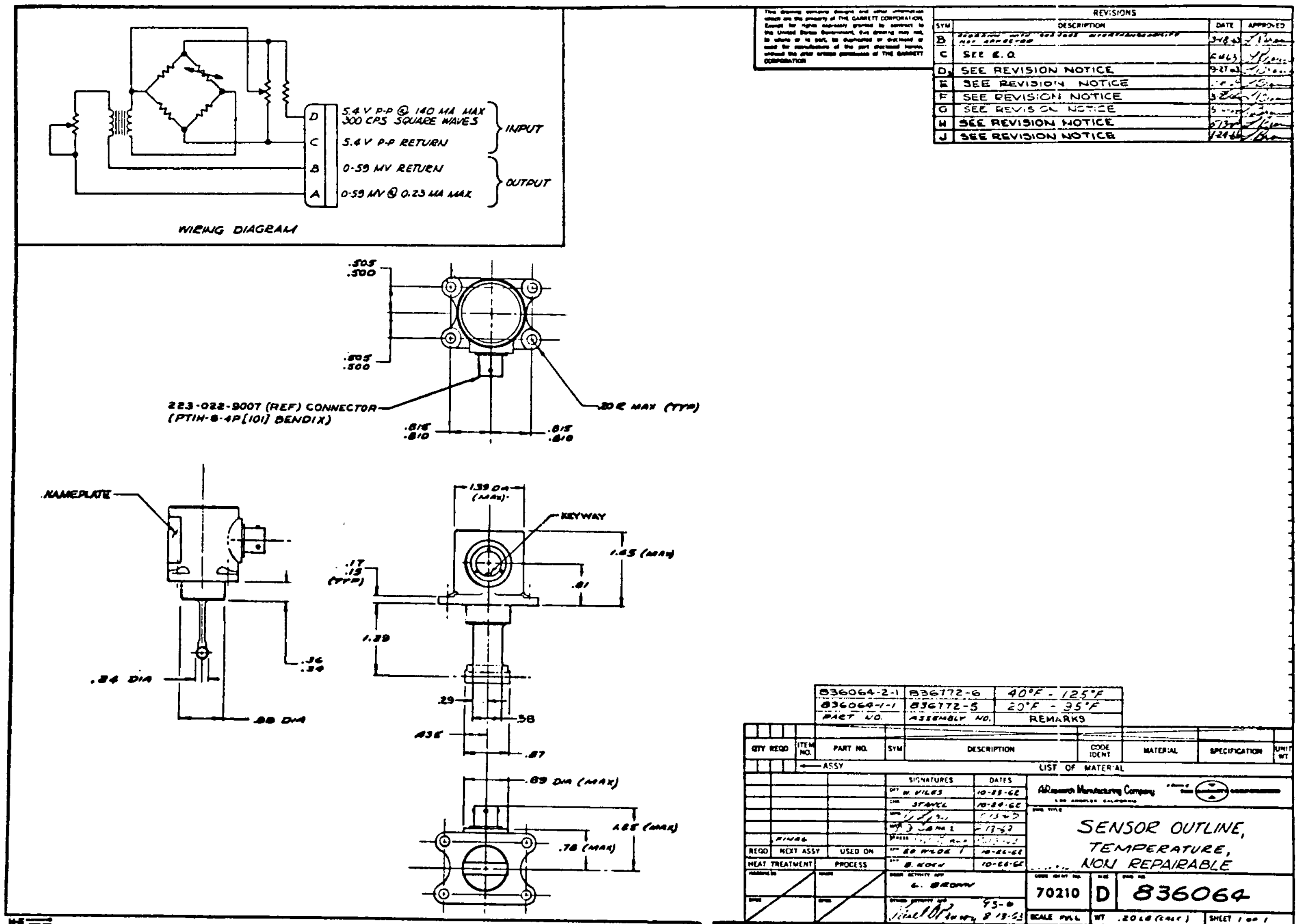

Figure 6-1. Altered Outline of Cabin Temperature Transducer.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE 6-2

CABIN TEMPERATURE TRANSDUCER FAILURE EVALUATION

TRANSDUCER APPLICATION CABIN TEMPERATURE TRANSDUCER (BLOCK I)

BASIC PART NUMBER 836064

TRANSDUCER MANUF. AIRESEARCH

TROUBLE REPORT SOURCE AIRESEARCH

TRANSDUCER TYPE TEMPERATURE

OPERATING PRINCIPLE RESISTANCE BRIDGE

MEASUREMENT RANGE 20° - 95°F

MEASUREMENT MEDIA GAS

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
836064-1	104-107 & 104-108	10-29-65	6601	NONE	HIGH OUTPUT VOLTAGE	NOT A FAILURE				
836064-1	104-107 & 104-108	6-4-65	7201	NONE	HIGH OUTPUT VOLTAGE	NOT A FAILURE				
836064-1	104-107	6-4-65	5897	NONE	HIGH OUTPUT VOLTAGE	NOT A FAILURE				
836064-1	104-107	1-4-65	5044	NONE	HIGH OUTPUT VOLTAGE	NOT A FAILURE				
836064-2	16-128	2-24-66	8427	HUMAN	DAMAGED	MISHANDLING	ACCIDENT	HANDLING	NONE	

AIRESEARCH MANUFACTURING COMPANY
Los Angeles, California

REPORT ON FAILURE AND DESIGN EVALUATION OF
APOLLO ECS OXYGEN FLOW TRANSDUCER
TEMPERATURE SENSOR WITH ELECTRONICS TYPE

CONTRACT NO. NAS 9-12452

72-8537-22, Rev. 1 February 10, 1973

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ABSTRACT

This report presents the results of a failure and design evaluation study conducted on the Apollo ECS oxygen flow transducer, the generic group of temperature sensor with electronics type flow transducer. The study was conducted for NASA-MSC by the AiResearch Manufacturing Company, a division of The Garrett Corporation under Contract NAS9-12452.

The study purpose was to evaluate the integrity of design of this type transducers. Failure information is presented and summarized pertaining to one transducer design. A failure matrix is presented which describes the failure mode, type, mechanism, cause, and problem areas for 37 rejections out of a lot total of 63 units.

This unit has had and continues to have much problems with its flow sensing and signal conditioning package designs. A critical design review and redesign effort for this transducer is warranted.

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SECTION 1

INTRODUCTION

This report presents a summary of failure data of the generic group of temperature sensor with electronics type flow transducers, one of several flow transducer types that are described and categorized in AiResearch Report No. 72-8537-21.

The flow transducers evaluated in this report were used in the Apollo environmental control system (ECS). This flow transducer may be used to perform any other flow sensing function with similar requirements.

The flow transducer which is evaluated and summarized in this report is the Apollo oxygen flow transducer, PNs 836112 and 836136. These two part numbers are identical in design with the only difference that PN 836136 has an epoxy and bonding material used in its seal installation while PN 836112 does not use this bonding agent. Detail failure data, a summary, and description information on this flow transducer are presented in Section 2 of this report.

SECTION 2

DESCRIPTION, FAILURE SUMMARY, AND RECOMMENDATIONS FOR TEMPERATURE SENSOR WITH ELECTRONICS TYPE FLOW TRANSDUCER

INTRODUCTION

The initial design of oxygen flow transducer PN 836028 was implemented at early stages of Apollo Block I ECS. Only five units of this part number were delivered. This transducer, which had a venturi tube sensing element, was replaced by a new design, PN 836112, which was implemented on Apollo Block I ECS. This design was later modified to PN 836136 by incorporation of epoxy bonding agent in its seal installation. This modified transducer was implemented on Apollo Block II ECS. The new design is analyzed in this section. The previous design which utilizes a venturi tube and sensor will not be analyzed because of its limited population and lack of data. Engineering data on this transducer is presented in Addendum A of this report.

PURPOSE AND DESCRIPTION

A typical isometric drawing of the current oxygen flow transducer is presented in Figure 2-1. The subject flow rate transducer, in Apollo ECS application, measures the rate-of-flow from the main oxygen supply. The flow sensing element is located at the outlet of the oxygen pressure regulator assembly. This transducer is powered by the 28 vdc supply of the spacecraft and operates over a flow range of 0.2 to 1.0 pounds per hour. An electrical signal (0 to 5 vdc) proportional to the oxygen flow-rate is provided by the transducer. This signal is used for ground checkout, for the crews visual information, via an indicator for telemetry data to be transmitted to a ground station. A static switch is actuated in the event of an overflow condition (at 2 pound per hour), which turns on an indicator light.

PERFORMANCE AND DESIGN DATA

Table 2-1 presents the performance and design data and Figure 2-2 presents the altered outline drawing of this flow-rate transducer.

QUALIFICATION STATUS

The oxygen supply flow rate transducer is a qualified Block II Apollo component.

FAILURE AND DESIGN REVIEW

Table 2-2 is a summary of 38 failure reports written against 37 units of 836112 and 836136 configurations of this transducer. As it was mentioned above, the 836136 design is identical to 836112. The only difference between the two part numbers is that 836136 includes on epoxy adhesive in its seal installation

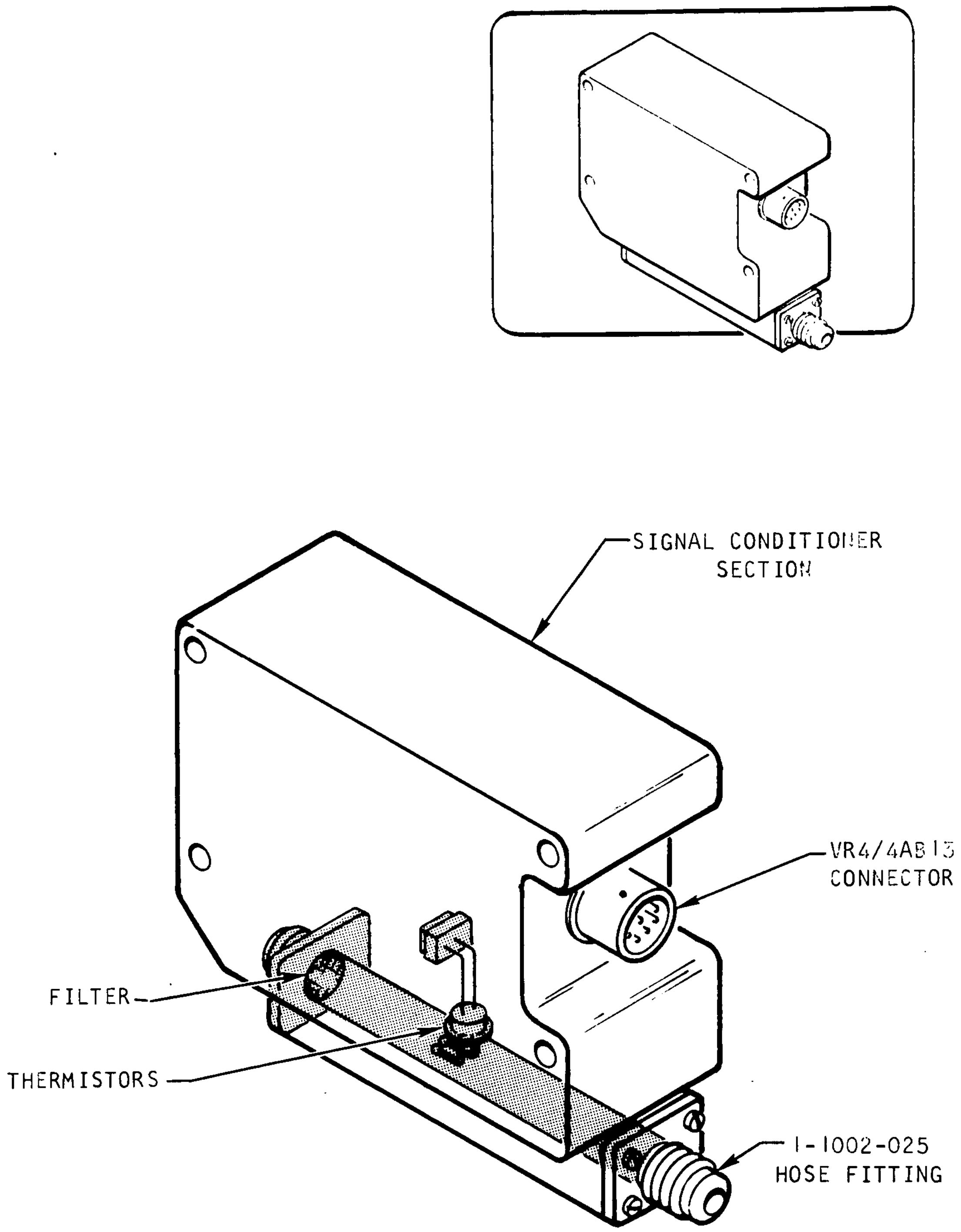


Figure 2-1. Isometric Drawing of a Current Oxygen Flow Transducer

TABLE 2-1

Operating flow range, lb/hr	0.2 to 1.0
Max. overflow, lb/min	0.7 (42 lb/hr)
Accuracy, lb/hr	±0.048 (±0.30 v) 0 to 150°F
Differential pressure	1.0 psi max. at 2.0 lb/hr and 100 psig inlet 8.0 psi max. at 0.7 lb/min and 100 psig inlet
Operating temperature range, $^{\circ}$F	-40 to +165 (ambient 0 to 150)
Time constant, sec	15 max. (to 63.2% with applied step flow rate)
Output signal	0 v at 0.2 lb/hr at 5.0 vdc at 1.0 lb/hr 6.5 vdc max. at greater flow
Output ripple, mv rms	Ripple component of output signal shall not exceed 20
Output load, ohm	30,000
Output impedance, ohm	500 (max.)
Fitting ends	MS 33656-4 (1/4 in. OD tube)
Line pressure, psig	85 to 140 (100 nominal)
Proof pressure, psig	210
Burst pressure, psig	350
External leakage	6×10^{-6} lb/hr O_2 max. with 140 psig internal pressure at 70°F
Electrical power requirements	
Input voltage, vdc	28 per S-1070
Excitation current, ma	80 (max.)
Weight, lb	1.0

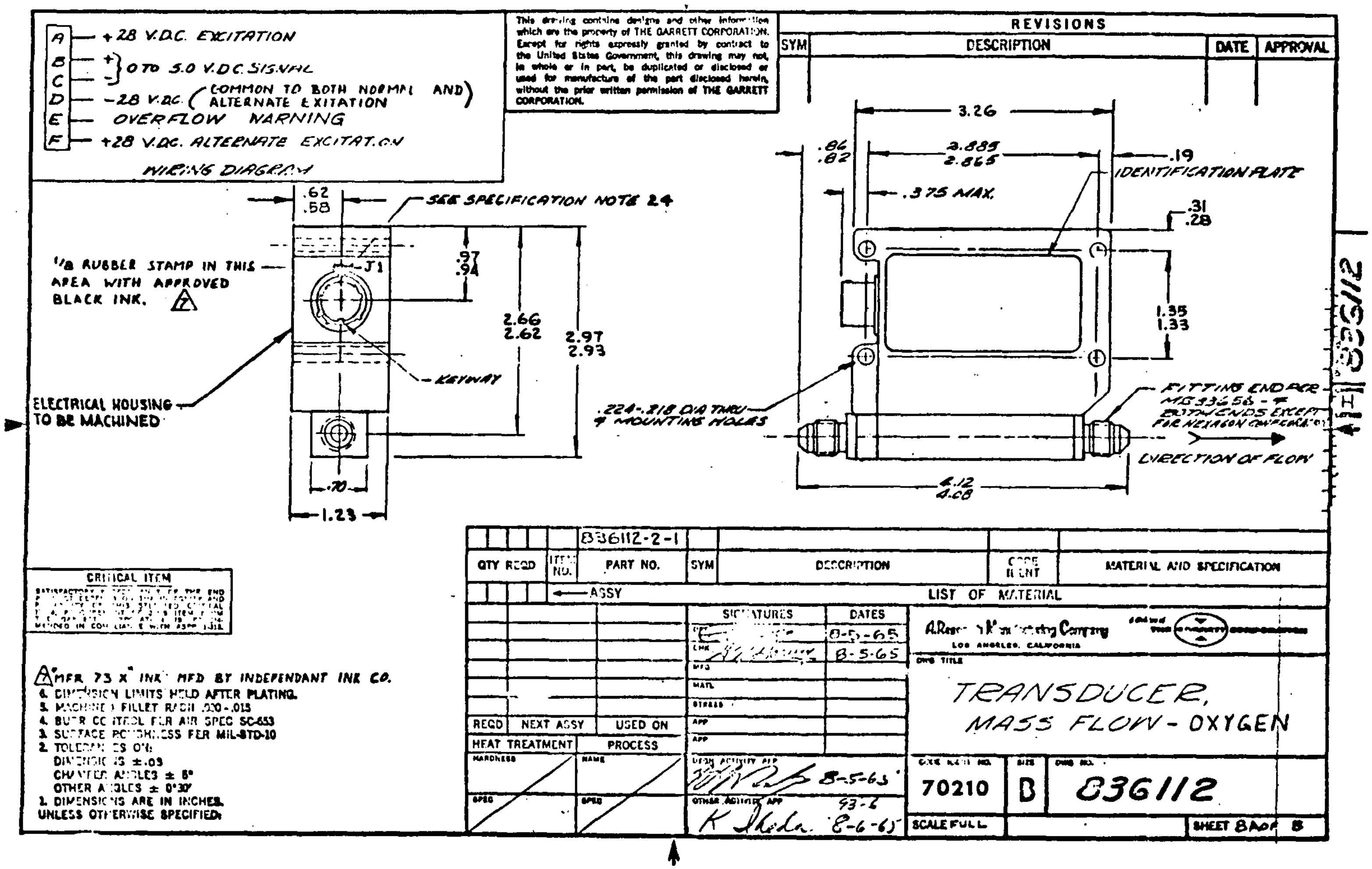


Figure 2-2. Outline Drawing of Oxyger Flow Transducer

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE 2-2

OXYGEN FLOW-RATE TRANSDUCER FAILURE EVALUATION

TRANSDUCER APPLICATION O_2 FLOW TRANSDUCER
BASIC PART NUMBER 836112-2-1
TRANSDUCER MANUF. TYLAN PN 311-2
TROUBLE REPORT SOURCE AIRESEARCH/NORTH AMERICAN ROCKWELL

TRANSDUCER TYPE O_2 FLOWMETER
OPERATING PRINCIPLE TEMPERATURE CHANGE
MEASUREMENT RANGE 0 to 1 lb/hr
MEASUREMENT MEDIA OXYGEN

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
836112-2-1	0040	6-7-67	14181	Human	High output	Sensing probe	Out of position	Manufacturing	Improve Manufacturing Quality Control and all parts photographed before delivery.	
836112-2-1	0045	4-12-67	14158	Elect.	Out of tolerance	Electronics package	Faulty thermistor	Unknown	None.	
836112-2-1	0038	2-13-57	13098	Human	Out of tolerance	Wrong part sensing probe	Block I part should be Block II	Manufacturing	Replace Block II part and assembly passed test	
836112-2-1	0039	12-22-66	12556	Human	Low output	Sensing probe	Out of position	LOX cleaning	Tylan (sub) improve QC of part during cleaning	
836112-2-1	0030	12-22-66	12555	Human	Low output	Sensing probe	Out of position	LOX cleaning	Tylan (sub) improve QC of part during cleaning	
836112-2-1	0041	12-17-66	12547	Human	Low output	Sensing probe	Out of position	LOX cleaning	Tylan (sub) improve QC of part during cleaning	
836112-2-1	0046	12-8-66	11990	Human	Intermittant output	Short	Moisture leakage from excessive external pressure.	Design	Unit redesign to withstand higher spacecraft external pressure	
836112-2-1	0041	11-18-66	11935	Human	Out of tolerance	None!	Excessively tight tolerance	Design	SCD revised to open up tolerance	PART DID NOT FAIL
836112-2-1	0024	9-20-66	11301	Human	Low output	Altered flow path	Inlet screen damage change flow path cause pressure drop	Design	Inlet screen redesign to minimize installation damage	

TRANSDUCER APPLICATION O_2 FLOW TRANSDUCER

BASIC PART NUMBER 836112-2-1

TRANSDUCER MANUF. TYLAN PN 311-2

TROUBLE REPORT SOURCE AIRESEARCH/NORTH AMERICAN ROCKWELL

TRANSDUCER TYPE O_2 FLOWMETER

OPERATING PRINCIPLE TEMPERATURE CHANGE

MEASUREMENT RANGE 0 to 1 lb/hr

MEASUREMENT MEDIA OXYGEN

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
836112-2-1	0030	9-8-66	11122	Human	No flow	Electronics package	Subjected to out of specification voltage	Testing	None	
836112-2-1	0020	8-31-66	11110	Mechanical	Fixed output	Electronic package	Stuck relay	Random	None	
836112-2-1	0039	8-12-66	10902	Human	Low output	None	Impediment in flow path by test equipment	Test	Seal extruded in flow path. Replace seal with one that does not extrude	No failure
836112-2-1	0017	1-10-66	8219	Human	High output	Unknown	Unknown	Unknown	None	Unconfirmed failure
736112-2-1	0018	1-4-66	6620	Human	Output out of tolerance	Unknown	Unknown	Specification (design)	Waiver grant to accept part	
836112-2-1	0017	10-27-65	7464	Human	High output	Unknown	Unknown	Unknown	None	Unconfirmed failure
836112-2-1	0019	10-27-65	7463	Human	No output	Electronics package	Shorted diodes	Testing	None. Random test procedure renewed	Input power inadvertently applied to output.
836112-2-1	0019	12-11-65	6613	Human	Out of calibration	None	Test equipment	Testing	Test equipment corrected	
836112-2-1	0016	10-24-65	7204	Human	Excessive EMI generated	EMI filters	Inadequate filter	Design	None	Waiver qualified to continue testing

FOLDOUT FRAME 1

TABLE 2-2 (CONTINUED)

FOLDOUT FRAME 2

TRANSDUCER APPLICATION O_2 FLOW TRANSDUCER

BASIC PART NUMBER 836112-2-1

TRANSDUCER MANUF. TYLAN PN 311-2

TROUBLE REPORT SOURCE AIRESEARCH/NORTH AMERICAN ROCKWELL

TRANSDUCER TYPE O_2 FLOWMETER

OPERATING PRINCIPLE TEMPERATURE CHANGE

MEASUREMENT RANGE 0 to 1 lb/hr

MEASUREMENT MEDIA OXYGEN

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
836112-1	0013	7-20-65	5761	Human	Fixed output	Electronics package	Overvoltage spikes	Design	Design change to incorporated high voltage spike	Detail was for lowered peak to peak spikes is 50 should be 78 volts
836112-1	0011	6-26-65	6758	Human	Insulation resistance too low	Solder joint case	Imperfect case seal	Design	Design improved PN 836112-2 replace -1	
836112-1	0007	6-7-65	6284	Human	Low output	Altered flow path	Inlet screen damage cause pressure drop	Design	Revised test procedure - increasing ΔP	
836112-1	009	6-7-65	6283	Human	Insulation resistance	Leaky case	Imperfect case joint	Design	Redesign in progress	836112-2 replaces 836112-1
836112-1	0006	4-7-65	6779	Unknown	Low insulation resistant to ground connector pins	Unknown	Unknown	Unknown	None	Uncomfirmed failure
836136-1-1	0054	9-30-67	15177	Human	Low output	Distortion	Overtorques	Manufacturing	Torque stripe used with revised test procedure	
836136-1-1	0039	9-6-67	15163	Human	Low output	Distortion	Overtorques	Manufacturing	Torque stripe used with revised test procedure	
836136-1-1	0029	8-25-67	14619	Human	Fixed output	Signal condition	Input power applied to output	Testing	Test adaptor changed so that they are dissimilar to misapplication of power source	

TRANSDUCER APPLICATION O_2 FLOW SENSOR

BASIC PART NUMBER 836136-2

TRANSDUCER MANUF. TYLAN (FMS 339-2 for 836136-2)*

TROUBLE REPORT SOURCE AIRESEARCH AND NORTH AMERICAN ROCKWELL

TRANSDUCER TYPE O_2 FLOWMETER

OPERATING PRINCIPLE TEMPERATURE CHANGE

MEASUREMENT RANGE 0 to 1 lb/hr

MEASUREMENT MEDIA OXYGEN

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
836136-2	0071	2-9-70	20336	Elect.	Low output	Signal conditioners amplifier temperature shift	Resistor failed	None	None. Failure occurred during burnin	
836136-2	56	11-4-69	18772	Elect.	Open	Signal conditioners amplifier converter	Transistors	Testing	None	Support transistor burst, opens incorrect circuit
(836136-2) ME449-0129 -0001 MEM9.2	54 or 4000	7-17-69	PF 107500	Elect.	Open	Signal conditioners amplifier signal shifted	Open capacitor	Apollo Flight #12	None	
836136-2	68	4-28-69	19171	Human	Low output	North American has stopped all activity on this part			None	Occurred during burnin.
836136-2-1	57	4-8-69	61243 (NR)	Human	No output	Signal conditioner	Transitor burnt open	Manufacturing or Testing	None. Design change in progress	Suspect was applied voltage
836136-2-1	70	2-5-69	19152	Human	No output	Signal conditioner	Weld from chip to emitters failed open	Manufacturing	Non. Occurred during burnin test	
836136-2-	70	12-17-68	19137	Human	Improper signal (erratic)	None	None	Incorrect test setup	None	
836136-2	64	10-13-68	19196	Human	No output	Signal conditioner	Output zenier diode failed open	Testing	None. Purpose of burnin test	Overvoltage applied.
836136-2	56	5-1-68	16622	Human	Output High	Signal conditioner	Stabilization	Design		Part burnin stabilizes output however, failed in this case. Design is susceptible to shift

* 836136-1 Tylan FMS 311-37
836136-2 Ident. TO836136-1 except for testing.

which is not included in 836112 design. Random failures were responsible for five (5) rejections (13.5%), unconfirmed failures were responsible for three rejections (8.1%), and one rejected unit (2.7%) was not analyzed. Design problems, manufacturing errors, and testing errors were responsible for the remaining 28 rejections (75.7%). Figure 2-3 presents the failure matrix of this transducer. The major problem of this transducer is with its sensing elements and signal conditioning package design which has been responsible for 12 failures (32.5%). Figure 2-4 presents the distribution of all rejections according to problem area. Figure 2-5 presents the distribution of relevant failure reports according to problem area.

RECOMMENDATIONS

Most of the design problems of this flow transducer are not resolved. Therefore a meticulous design review and careful redesign effort is recommended. The manufacturer of this transducer, the Tylan Corp., has developed a commercial type flow transducer which utilizes three coils as the sensing element and a newly designed and improved signal conditioning package. The principle of operation of the sensing element is the analogy of the increase in the sensed temperature level by the downstream coil as compared to the indication of the temperature level by the upstream coil as a result of premeasured amount of heat input to the media by the heating coil which is located between the two sensing coils. Of this new design, during the past 4 year period, over 2000 units have been in commercial applications with very satisfactory results. It is recommended to have this commercial design studied for possible aerospace packaging, correction of "g" sensitivity, and demonstration of compliance with SSV vibration requirements.

PROBLEM AREA	PERCENT	MODE: HIGH OUTPUT	TOLERANCE	LOW OUTPUT	INTERMITTENT	NO OUTPUT	FIXED OUTPUT	CALIBRATION	EXCESSIVE EMI	INSULATION	ERRATIC OUTPUT					NONE	TYPE: HUMAN	ELECTRICAL	MECHANICAL
ENGINEERING: DESIGN	32.5	3	2	2	1		1		1	2							12		
ENGINEERING: TESTING: PROCEDURE, ATP																			
ENGINEERING: TESTING: QUAL: ERROR																			
ENGINEERING: TESTING: QUAL: PROCEDURE																			
MANUFACTURING: PLANNING	2.7		1														1		
MANUFACTURING: FABRICATION																			
MANUFACTURING: ASSEMBLY	8.1			2		1											3		
MANUFACTURING: QUALITY CONTROL	2.7	1															1		
MANUFACTURING: INSPECTION																			
MANUFACTURING: ATP TEST ERROR	13.5					4	1										5		
TEST EQUIPMENT FAILURE	8.1							1			1					1	3		
LOX CLEANING	8.1			3													3		
HANDLING																			
FINAL INSTALLATION: RECEIVING INSPECTION																			
FINAL INSTALLATION: INSTALLATION																			
RANDOM FAILURE	13.5		1	1		2	1											4	1
UNCONFIRMED FAILURE	8.1	2							1								3		
NOT ANALYZED FAILURE REPORTS	2.7			1													1		
TOTAL		6	4	9	1	7	3	1	2	2	1					1	32	4	1
PERCENT	100	16.3	10.8	24.3	2.7	18.9	8.1	2.7	5.4	5.4	2.7					2.7	86.5	10.8	2.7

PROBLEM AREA	MECHANISM: SENSING ELEMENT: ELEC		MECHANICAL: LOCATION	WIRING PART	DISTORTION			SIGNAL CONDITIONING AND TRAMISSION MECHANISM: FAULTY COMP	SHORT	TIGHT TOLL	DAMAGED	HIGH INPUT VOLT	UNKNOWN	MISCONNECTED	INADEQUATE PART	VOLTAGE SPIKES	SEAL	FAULTY WELD	STABILIZATION		UNKNOWN	NO FAILURE
ENGINEERING: DESIGN									1	1	2		1		1	1	2		3			
ENGINEERING: TESTING: PROCEDURE, ATP																						
ENGINEERING: TESTING: QUAL: ERROR																						
ENGINEERING: TESTING: QUAL: PROCEDURE																						
MANUFACTURING: PLANNING				1																		
MANUFACTURING: FABRICATION																						
MANUFACTURING: ASSEMBLY					2													1				
MANUFACTURING: QUALITY CONTROL			1																			
MANUFACTURING: INSPECTION																						
MANUFACTURING: ATP TEST ERROR								1				1	1	2								
TEST EQUIPMENT FAILURE																						3
LOX CLEANING			3																			
HANDLING																						
FINAL INSTALLATION: RECEIVING INSPECTION																						
FINAL INSTALLATION: INSTALLATION																						
RANDOM FAILURE								5														
UNCONFIRMED FAILURE																						3
NOT ANALYZED FAILURE REPORTS																					1	
TOTAL			4	1	2			6	1	1	2	1	2	2	1	1	2	1	3		1	6
PERCENT			10.8	2.7	5.4			16.3	2.7	2.7	5.4	2.7	5.4	5.4	2.7	2.7	5.4	2.7	8.1		2.7	16.2

Figure 2-3. Flow Transducer Failure Matrix.

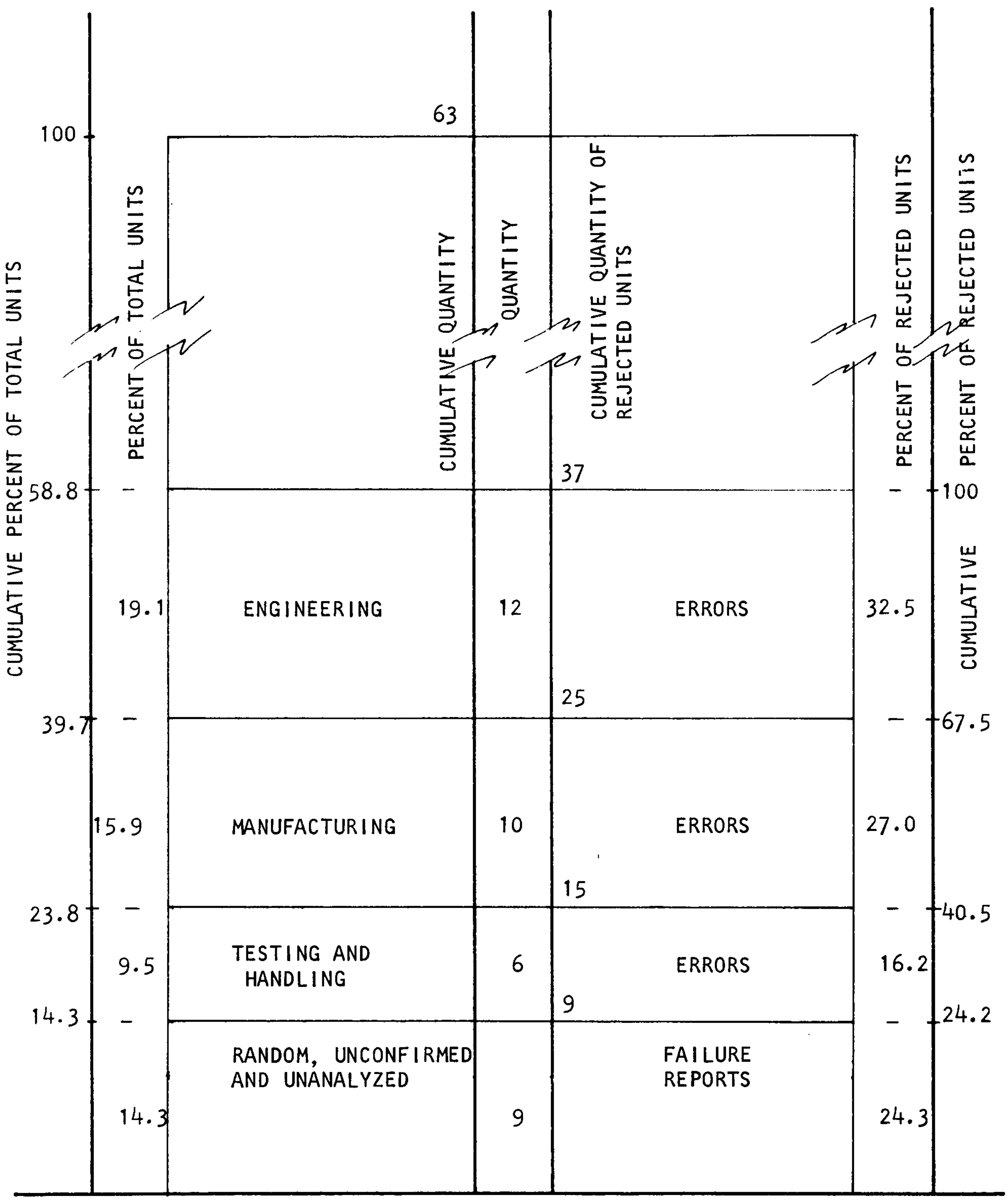


Figure 2-4. Distribution of all Failure Reports According to Problem Area for Oxygen Flow-Rate Transducer.

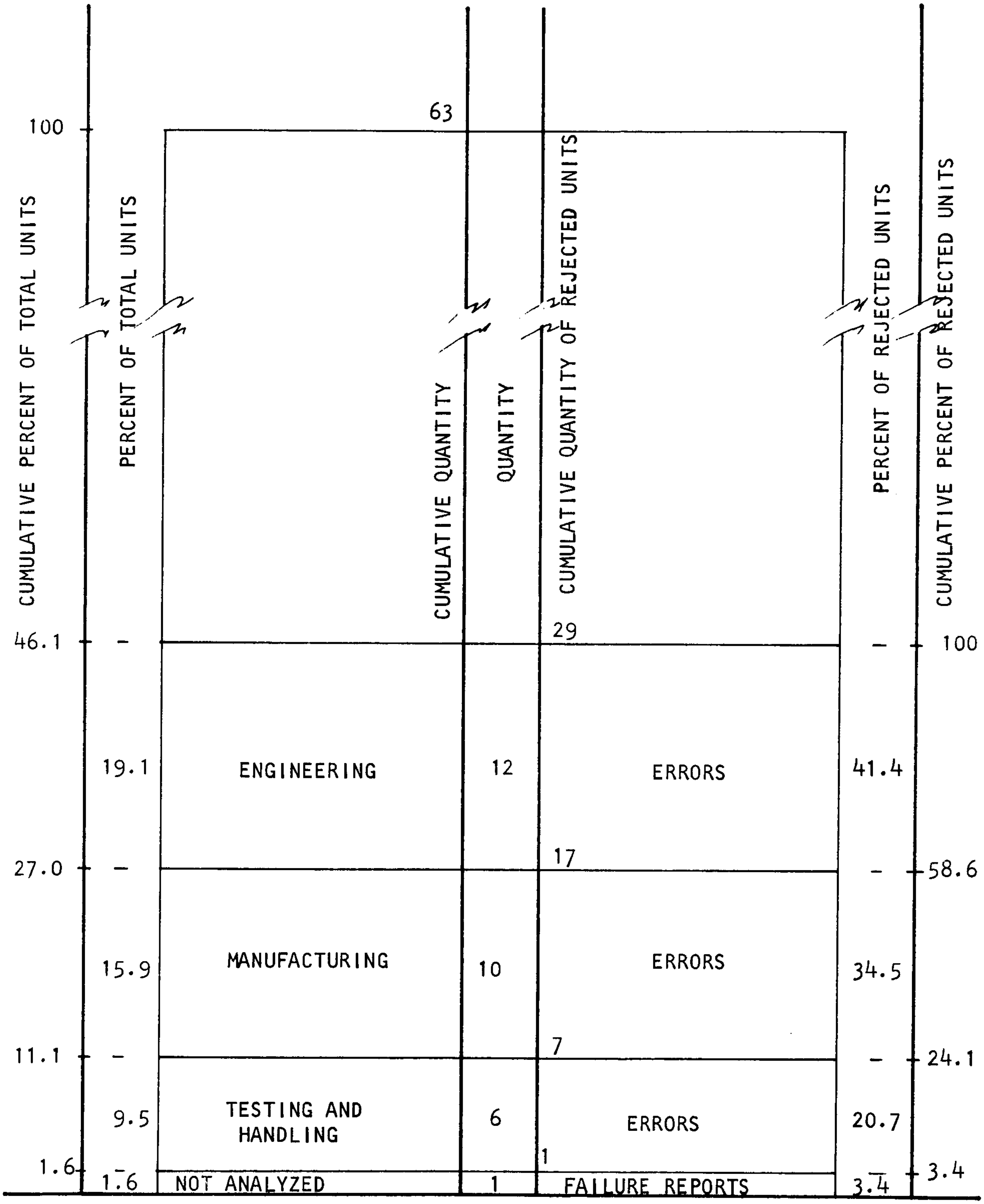


Figure 2-5. Distribution of Relevant Failures According to Problem Area for Oxygen Flow-Rate Transducer.

ADDENDUM A

OXYGEN SUPPLY FLOW-RATE TRANSDUCER
PN 837028-1

FUNCTION AND DESCRIPTION

The flow-rate transducer measures the rate-of-flow from the main oxygen supply. The flow-sensing element is located at the outlet of the oxygen pressure regulator assembly.

In its early Apollo ECS application, the transducer was powered by the 28 vdc supply of the spacecraft and operated over a flow range of 0.2 to 0.5 lb/hr. An electrical signal (0 to 5 vdc) proportional to the oxygen flow-rate was provided by the transducer. This signal was used for ground checkout, for the crew's visual information, via an indicator, and for telemetry data to be transmitted to a ground station.

PERFORMANCE AND DESIGN DATA

Table A-1 presents the performance and design data and Figure A-1 presents a typical isometric drawing of this flow rate transducer.

TABLE A-1

Performance Requirement:

a. Operating flow range: 0.2 to 0.5 lb/hr

b. Max. overflow: 0.7 lb/min (42 lb/hr)

c. Accuracy: ±0.018 lb/hr. Also refer to k

d. Differential pressure: 1.0 psi max. at 0.5 lb/hr. 2.0 psi max. at 0.7 lb/min

e. Operating temperature range: $-110^{\circ}F$ to $+25^{\circ}F$ (ambient 0 to $200^{\circ}F$)

f. Time constant: Within 30 ms

g. Output signal: 0 v at 0.2 lb/hr to 5.0 vdc at 0.5 lb/hr

h. Output ripple: Ripple component of output signal shall not exceed 10 mv, rms.

i. Output load: 30,000 ohm

j. Output impedance: 500 ohm max.

k. Environmental error band: Output signal error resulting from the combined effects of non-linearity, repeatability, and input voltage fluctuation during any rational combination of environmental conditions specified in AiResearch Specification SS-1060-R shall not exceed ±6.0% (±0.3 v) of full scale from 0 to 100% of flow range.

Structural Requirements:

a. Line pressure: 85 to 140 psig (100 psig nominal)

b. Proof pressure: 210 psig

c. Burst pressure: 350 psig

External Leakage: Zero with 140 psig internal pressure

Electrical Power Requirements:

a. Input voltage: 28 ±4 vdc

b. Excitation current: 60 ma max.

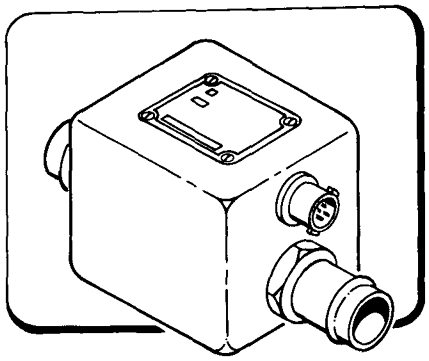
TABLE A-1 (Continued)

Environmental Conditions: Per AiResearch Report SS-1060-R; Type I equipment

Installation Envelope: Per AiResearch Drawing 837028

Weight: 1.0 lb max.

Electrical Connector: In accordance with MIL-C-26482C



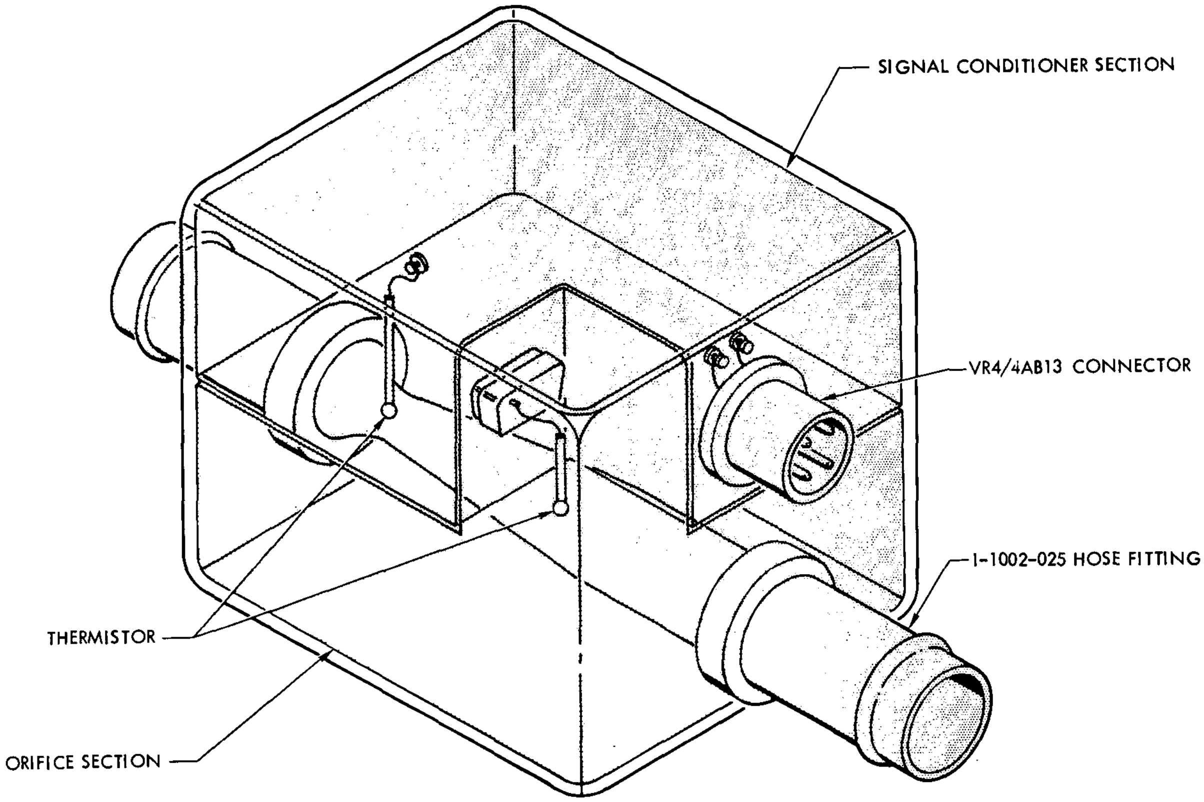


Figure A-1. Typical Isometric of Oxygen Flow Transducer Venturi Tube With Electronics Type.

AIRESEARCH MANUFACTURING COMPANY
Los Angeles, California

REPORT ON FAILURE AND DESIGN EVALUATION
OF APOLLO ECS VALVE POSITION
INDICATOR SWITCHES
CONTRACT NO. NAS 9-12452

72-8537-51, Rev. 1 February 10, 1973

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ABSTRACT

This report presents the results of a failure and design evaluation study conducted on precision switches that were used in the Apollo Lunar Module ECS. The switches were assembled to valves, regulators and other components in the ECS for the purpose of providing a telemetry signal that was indicative of valve position. The Valve Position Indication (VPI) switches were also used as control switches to open or close electrical circuits for remote actuation of other components in the system.

The failure and design evaluation study of VPI switches is part of the Apollo ECS Transducer Study Program being conducted for NASA-MSC by the AiResearch Manufacturing Company, a division of The Garrett Corporation under Contract NAS 9-12452.

The purpose of this study was to evaluate the history of VPI switch failures and associated design documents and to make recommendations to reduce the failures of these switches for possible use in future Aerospace Programs. The failure reports, diagrams and technical information contained in this report were taken from NASA furnished documents that were supplied as an input to this study.

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4	RECOMMENDATIONS AND CONCLUSIONS	4-1

SECTION 1

INTRODUCTION

This report presents a summary of the failures experienced with the use of precision switches for monitoring value position and for switching other system valves and controls in the Lunar Module ECS. Fourteen (14) Valve Position Indicator (VPI) switches and nine (9) control switches were used in eight (8) different component items in each Environmental Control System (ECS) for the Lunar Module.

The VPI switches provide an open or closed signal to stimulate a telemetry signal and also cause panel lights to illuminate on the crew monitoring panels. The application of the VPI switches were found to be troublesome because the mechanical displacement required for switch actuation was transmitted through several component parts in their next assembly valves. The tolerance and gaps associated with the component parts required each VPI switch to be shimmed to its next assembly valve. In spite of this, switch operation was reported to be intermittent and frequently the VPI would stay actuated even after the valve handle was restored to the original (switch open) position.

The addition of the VPI switches required the component parts of the next assembly valves to be made to closer tolerances and also required acurate cam surfaces to be made for actuating the switches. These costs plus the cost of the VPI switches could have been better spent on flow, pressure or temperature transducers that could be used to provide continuous performance monitoring of the ECS. The VPI switches were redundant to visual inspection by the crew and also to the voice link for verification of proper subsystem configuration.

SECTION 2

DESCRIPTION AND APPLICATION OF PRECISION SWITCHES

The precision switches are position indicating and control switch assemblies used to indicate the position of ECS component controls and to control component electrical power. The valve position indicating (VPI) switch assemblies develop a switch closure (or opening) as an input to the telemetry system.

The switch assemblies were made by Texas Instruments, Inc., Control Products Division, and are identified by Klixon part numbers. These switches were procured in accordance with Hamilton Standard (HS) specifications and are identified by the following HS part numbers:

Hamilton Standard PN	Klixon PN
SV 700952	AT225-1
SV 707744	AT200
SV 715076	AT250
SV 715077	AT249
SV 712948	10AT52-1 and 10AT53-1
SV 730077	AT298-1

Figure 2-1 is a photograph of position switch SV 715077-2 (AT249-2) and Figure 2-2 contains the outline dimensions for position switch SV 730077 (AT298-1). The size and shape of the other VPI switches used in the LM ECS are similar. The operational characteristics of the VPI switches and their next assembly requirements are summarized in Table 2-1.

A review of the VPI and control switch requirements show them to be unique to the Lunar Module ECS. A total of fourteen VPI switches and nine control switches are used in the valves described below in each LM ECS. Failure reports recorded against the next assembly valves were reviewed to isolate the failure reports that pertained to the precision VPI switches. Table 2-2 describes the LM ECS hardware items that include VPI and control switches.

The following describes the application of the VPI and control switches in the ECS hardware for the Grumman Aircraft Engineering Corp. (GAEC) LM Vehicle:

Item 112 Suit Gas Diverter Valve (GAEC PN 330-112)

The SUIT GAS DIVERTER valve is a manually operated, two-way valve (one inlet and two outlets) with a solenoid override in one direction. When the valve handle is pushed into CABIN position, oxygen is directed into the cabin.

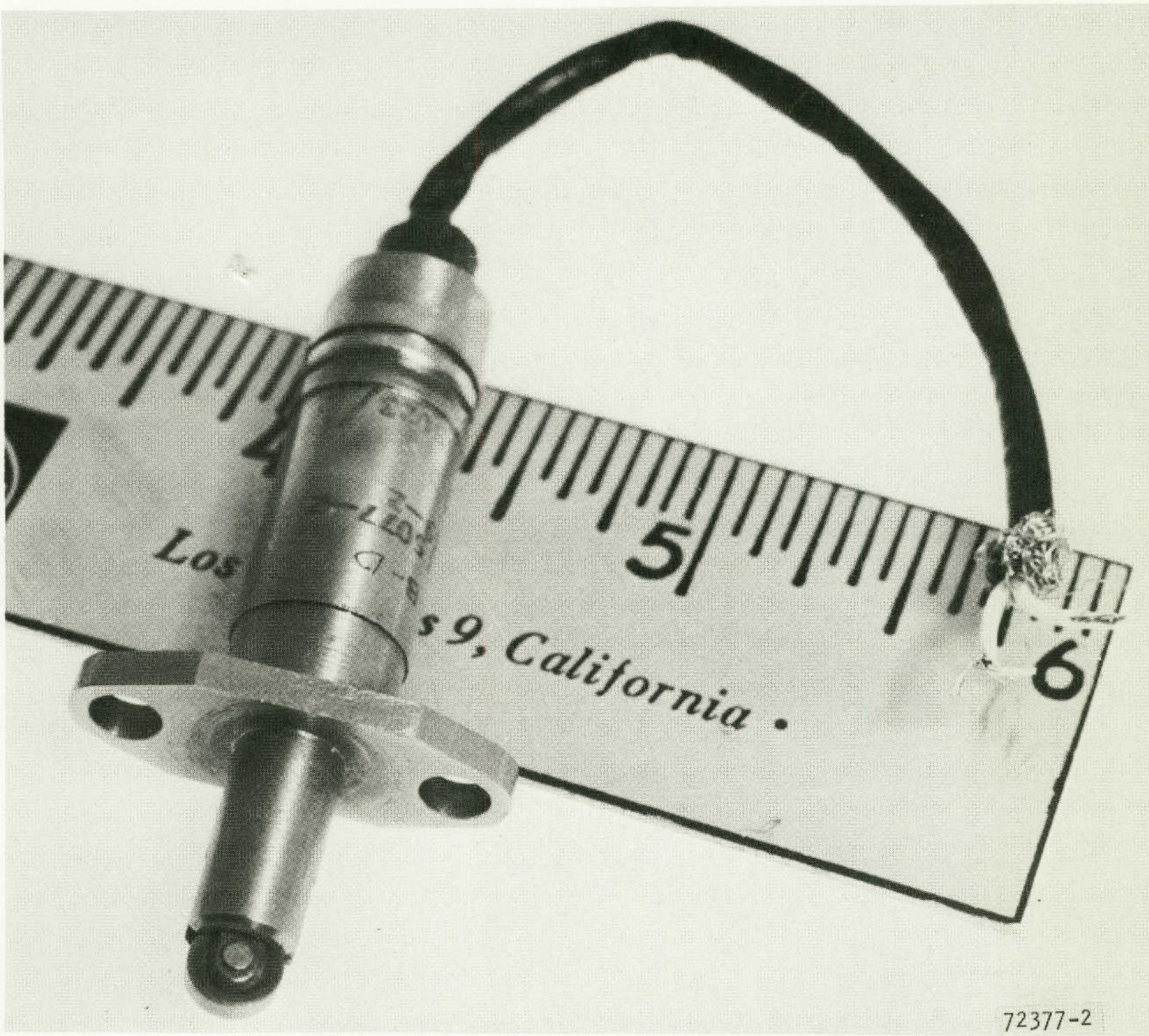


Figure 2-1. Valve Position Switch SV 715077-2(AT249-2)

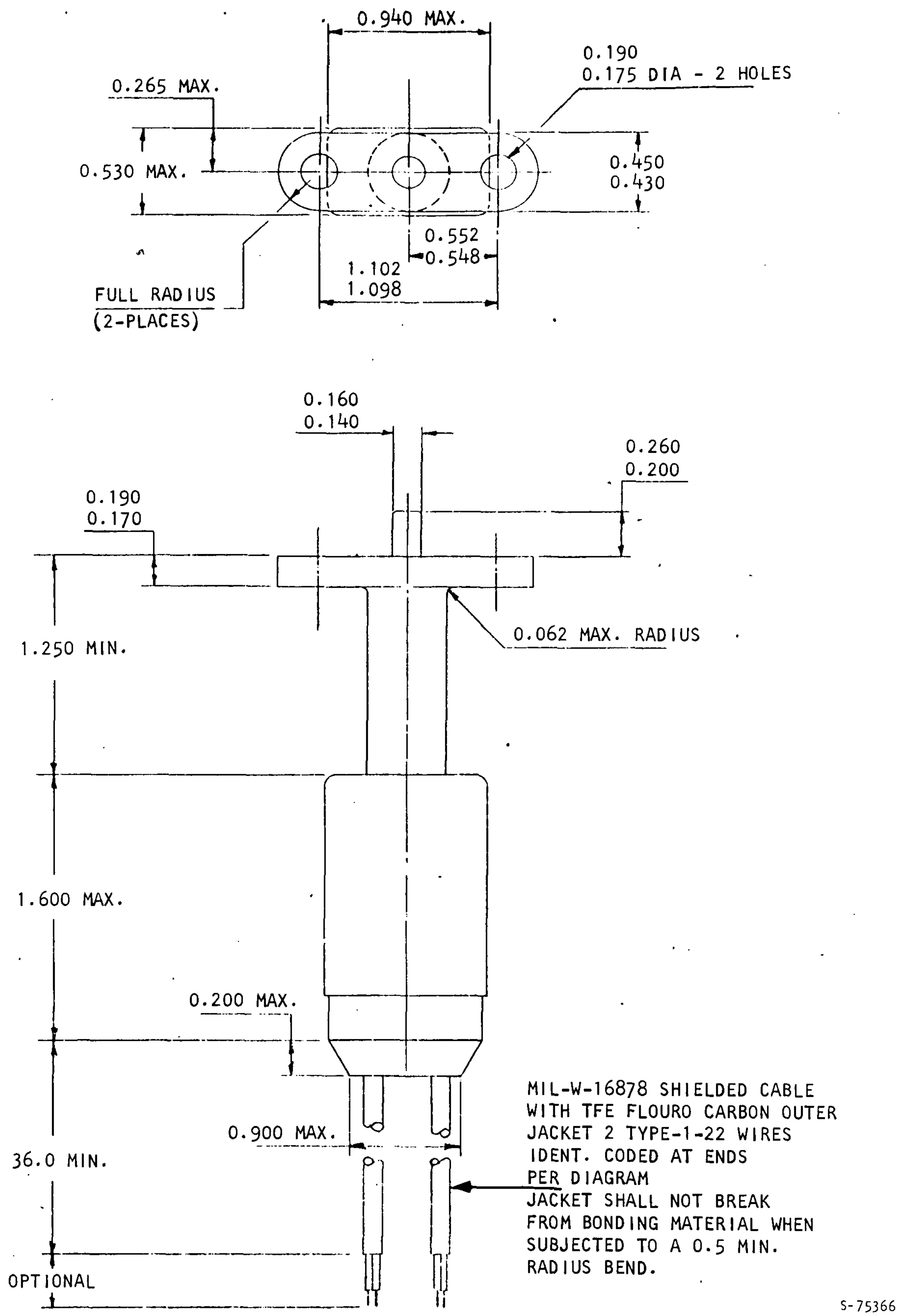


Figure 2-2. Value Position Switch (AT 298-1)

TABLE 2-1

OPERATIONAL CHARACTERISTICS OF VPI AND CONTROL SWITCHES

Application	Lo Level Indicator	VPI	Control Switch	VPI	VPI	VPI	Control Switch	Control Switch (two per unit)
Type	SPST NC	SPST NC	SPST NO	SPST NC	SPST NO	SPST NC	SPST NC	NC NO
Used in GAEC P/N's 330-	210	113	112	112 309 114	128 117 114	306 138	306 138	306
Amps at rated load	0.002	0.002	3.00	0.002	0.002	0.002	3.00	3.00/switch
Contact resistant at rated load - ohms	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2/switch
Voltage rating-vdc	20-32	20-32	20-32	20-32	20-32	20-32	20-32	20-32/switch
Actuation force-max oz	24	24	24	24	24	24	24	8 lb
Release force-min oz	1	1	1	1	1	1	1	2 lb
Overtravel force-min lb	20	20	20	20	20	20	20	20
Pretravel-max inches	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.025
Movement differential-max in.	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.020
Overtravel-min inches	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Weight-ounces	3.2	2.0	3.1	3.1	3.1	3.3	3.3	4.0 per unit

TABLE 2-2

LUNAR MODULE ECS EQUIPMENT
CONTAINING POSITION SWITCHES

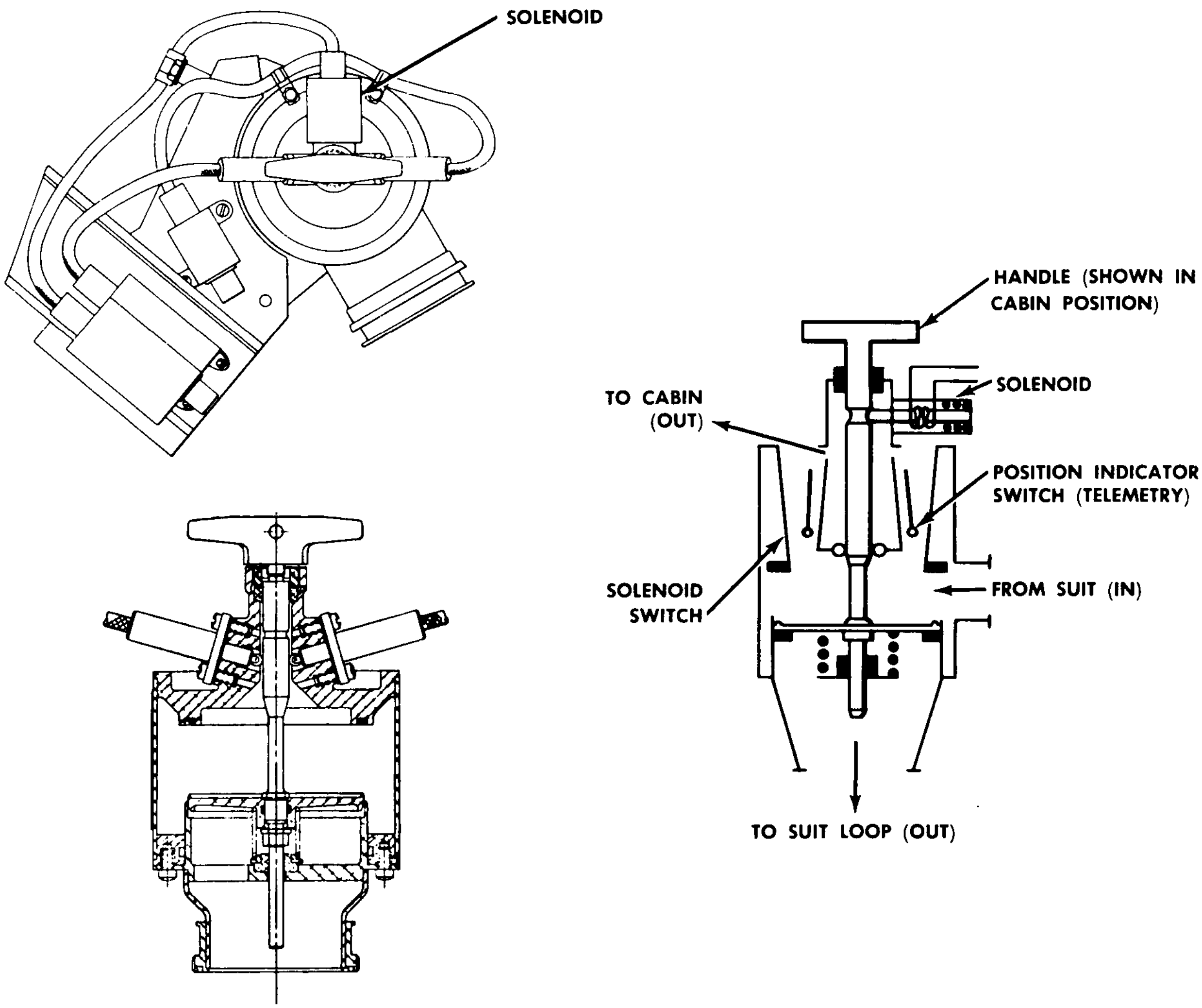
GAEC No. LSC	Component Description	VPI Switch Ham-Std.No.	Measurement, Description and Range
330-112	Suit gas diverter valve	SV 715077-2	Suit diverter VPI closed
		SV 707744-2	Open - closed
330-113	Cabin gas return check valve	SV 715077-2	Cabin gas return VPI closed
		SV 707743-2	Open - closed
330-114	LiOH canister selector valve	SV 715077-2	CO_2 cartridge in sec position
		SV 707744-2	No - yes
330-117	Suit circuit relief valve	SV 715077-3	Suit pressure relief VPI open
		SV 707744-3	Open - closed
330-138	Solenoid valve	SV 715077-3	Suit flow control disconnect Open - closed
330-210	Glycol accumulator	SV 707741	Coolant accum. low level ABS - PRS
330-306	Oxygen inflow regulator	SV 715077-4	Oxygen regulator valve locked closed
		SV 707744-4	No - yes
330-309	Cabin repressurization	SV 715077-2	Emergency O_2 valve elec. open
	Solenoid Valve	SV 707744-2	No - yes

The valve is maintained in this position, against main valve spring pressure, by a deenergized solenoid. Pulling the valve handle to EGRESS position overrides the solenoid and permits the valve to reposition to its upper seat, blocking flow to the cabin.

This valve incorporates a normally closed (NC) VPI switch and a normally open (NO) control switch. These switches are shown mounted on each side of the valve shown in the Figure below.

Handle positions - Normal - suit circuit flow open to cabin

Closed - suit circuit flow closed to cabin



Suit Circuit Diverter Valve-Item 112

Item 113 Cabin Gas Return Check Valve (GAEC PN 330-113)

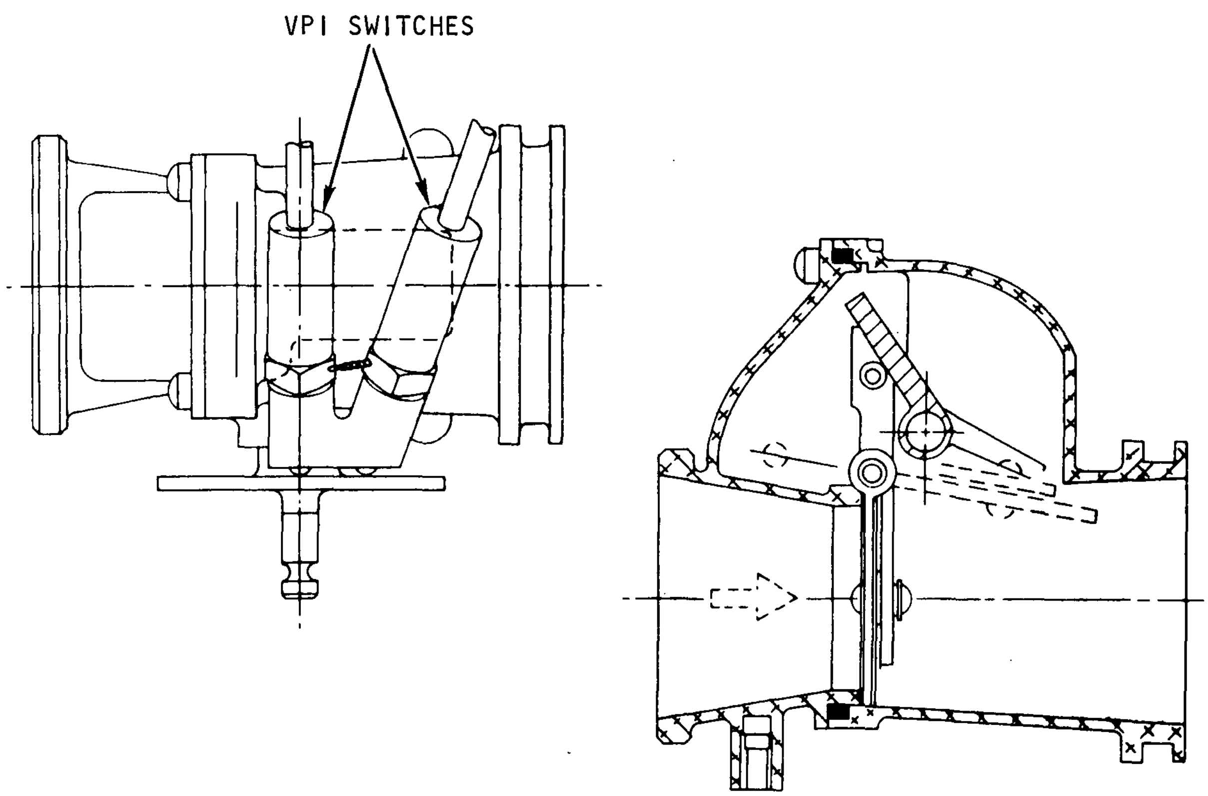
The CABIN GAS RETURN check valve is a spring-loaded, flapper-type valve. The valve has AUTO, OPEN, and EGRESS (closed) positions. In the AUTO position, the valve automatically permits cabin gas to return to the suit circuit. When the cabin is depressurized, the suit circuit pressure closes the valve, preventing backflow into the cabin. The OPEN and EGRESS positions provide manual override of the AUTO position. Valve-position-indicating switches provide telemetry signals when the valve is set to OPEN or EGRESS.

Handle positions - full counterclockwise - valve locked "OPEN"

mid-position - normal operation "AUTO"

full clockwise - valve locked closed "EGRESS"

The figure below shows a sketch of the cabin gas return check valve including the two VPI switches.



Cabin Gas Return Check Valve Item 113

Item 114 LiOH Canister Selector Valve (GAEC PN 330-114)

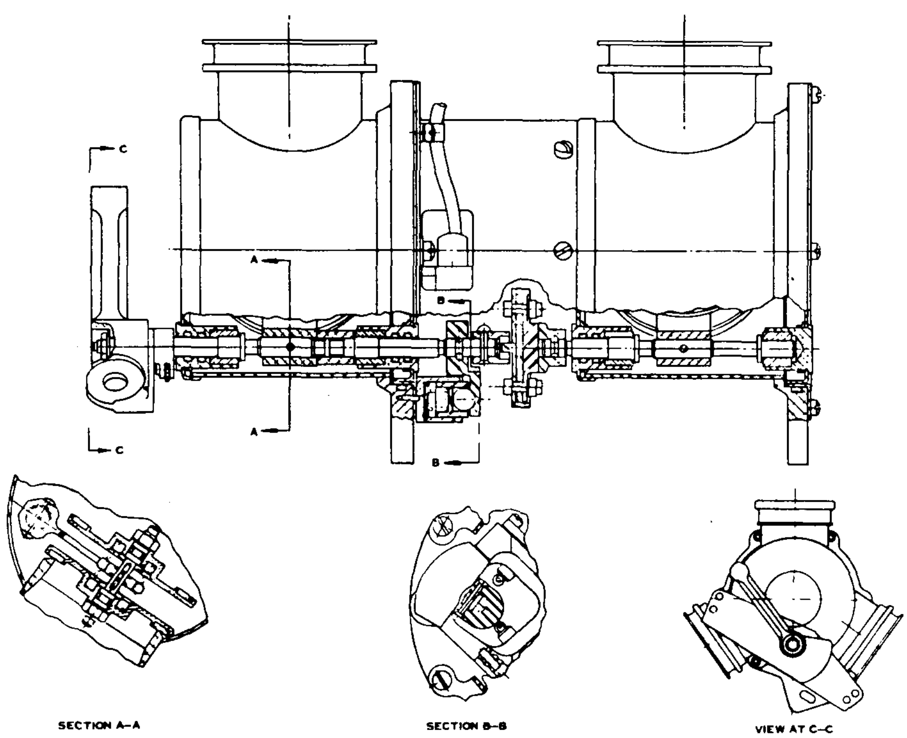
The CO_2 canister selector valve is a dual-flapper-type valve that routes flow through the CO_2 and odor removal canisters. The valve has PRIM and SEC positions. One flapper is at the inlet to the canisters: the other, at the outlet.

Two VPI switches are incorporated on the valve to indicate the position of the selector. One switch is normally opened and the other is normally closed.

Handle positions: Full clockwise - O_2 flow is through the primary LiOH canister

Full counterclockwise - O_2 flow is through the secondary (small) LiOH canister

The roller ends of the VPI switches are shown in Section B-B of the figure below.



Sectional View of Lithium Hydroxide Selector Valve Item 114

Item 117 Suit Circuit Relief Valve (GAEC PN 330-117)

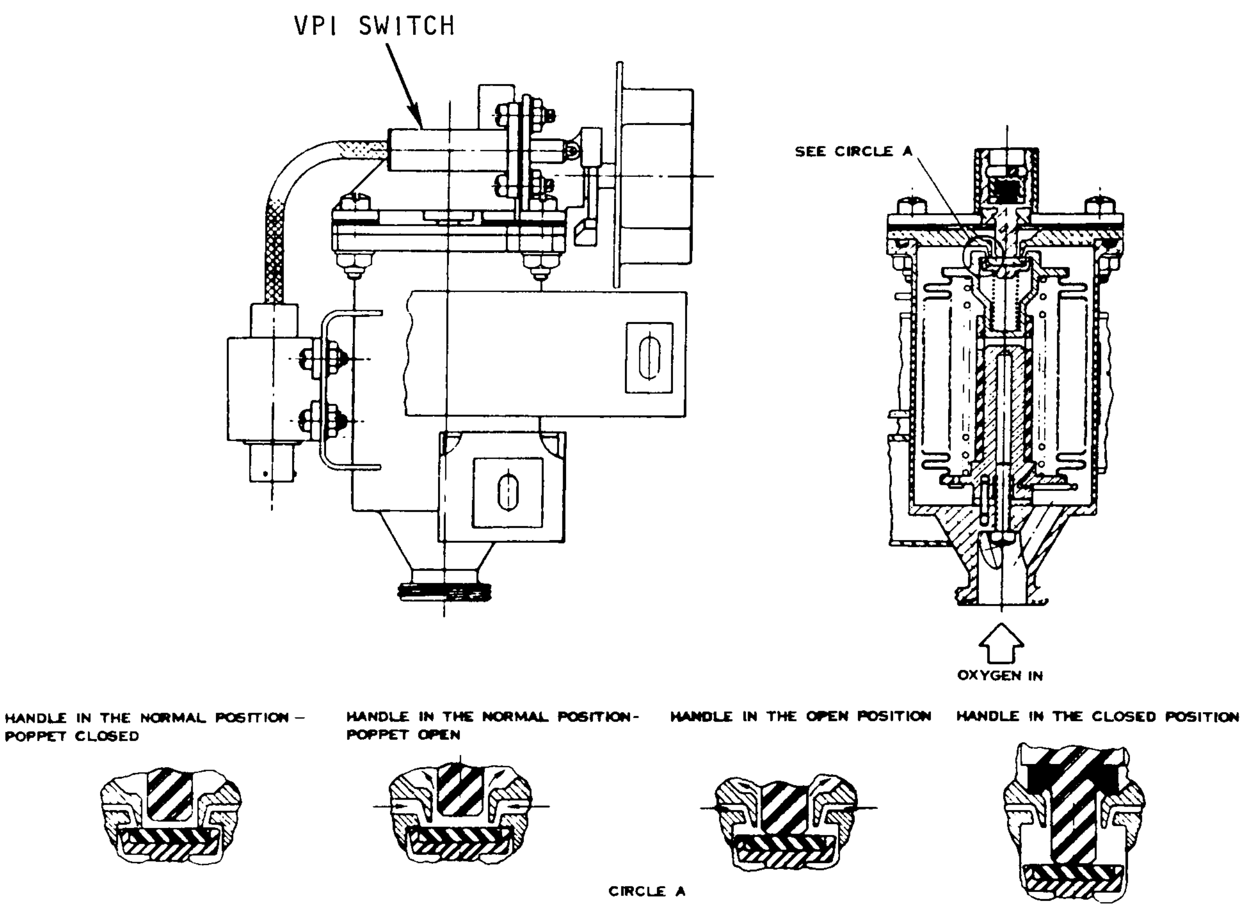
The SUIT CIRCUIT RELIEF valve is an aneroid-operated, poppet-type valve that protects the suit circuit against overpressurization. The valve has AUTO, OPEN, and CLOSE positions. Two externally mounted microswitches provide telemetry signals when the OPEN or CLOSE position is selected.

Handle positions: 180 deg handle rotation

Normal position - relief valve actuated by pressure of an aneroid bellows. Discharge is vented into the cabin.

Closed position - Manual override closes valve to cabin.

The figure below shows one of the two VPI switches mounted on the valve.



Sectional View of Suit Circuit Relief Valve Item 117

Item 138 Solenoid Valve (Suit Isolation Valve) (GAEC PN 330-138)

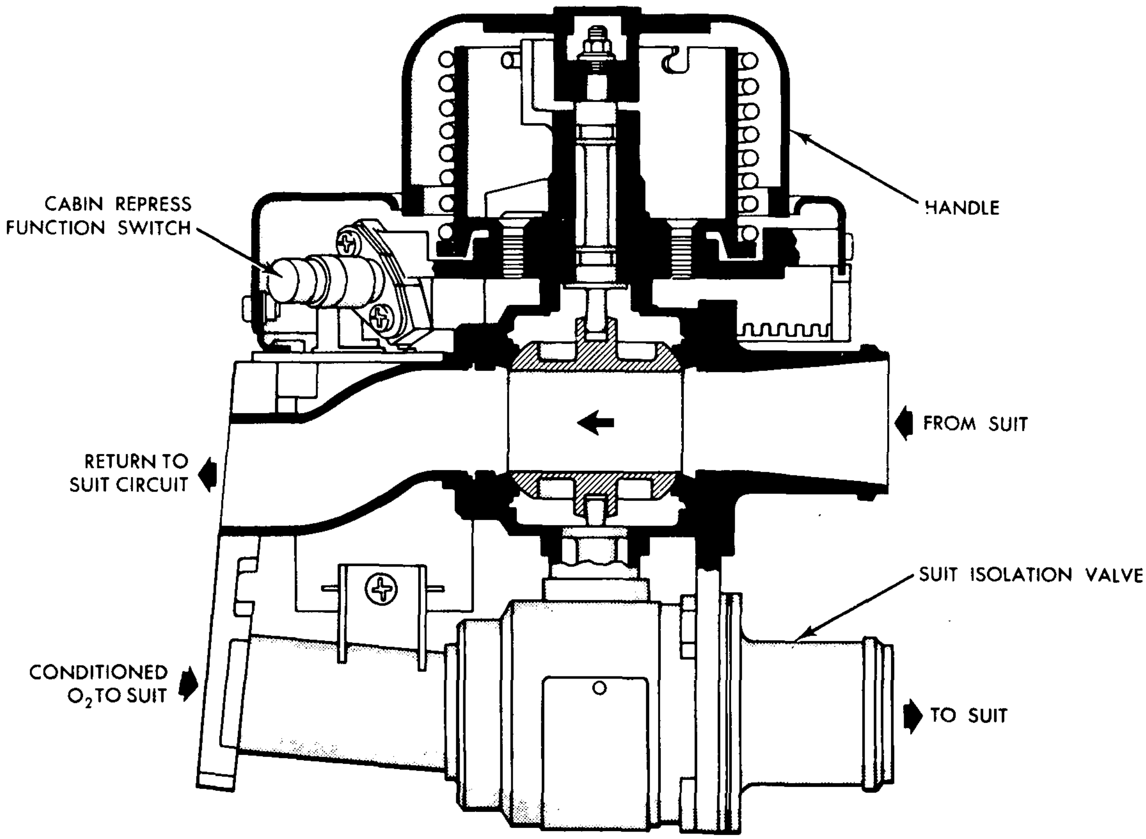
Two of these valves are utilized in the LM ECS. Each valve incorporates a normally closed VPI switch and a normally closed control switch.

The suit isolation valves are manually operated, two-position dual-ball valves. In the SUIT FLOW position, suit-circuit gas is directed through the valve into the Pressure Garment Assembly (PGA), and from the PGA back into the suit circuit. In the SUIT DISC position, the valves keep the gas in the suit circuit bypassing the PGA's and preventing flow in either direction between the suit circuit and PGA's.

Handle positions: Normal - Full counterclockwise and locked. Flow is through the suit.

Bypass - 90 deg clockwise from normal. Flow bypasses the suit.

One of the two switches is shown in the figure below.

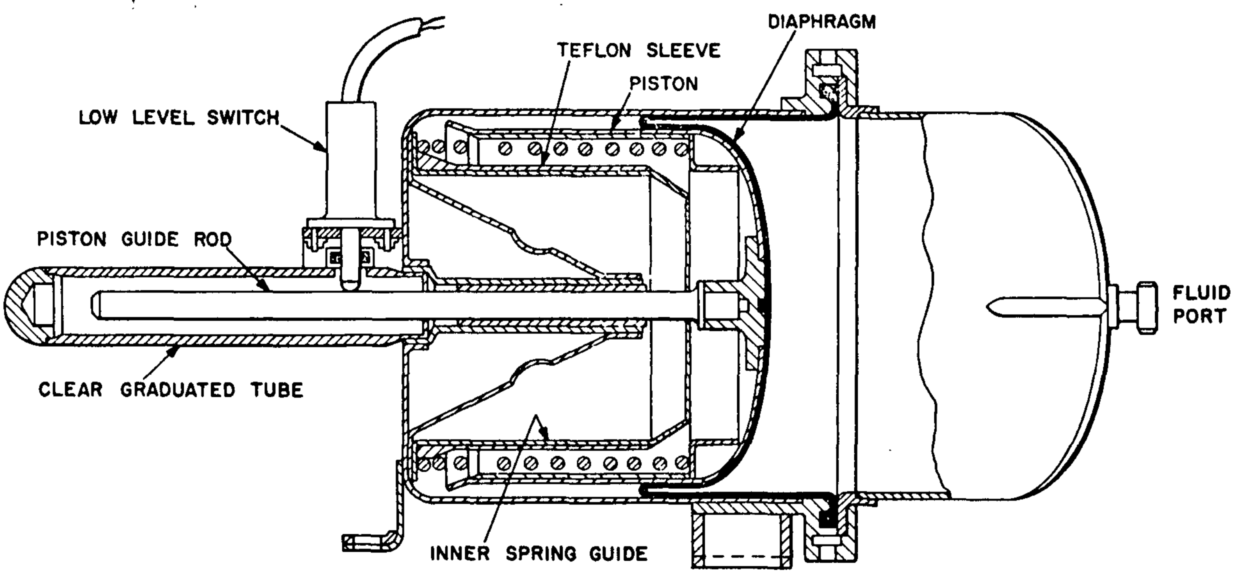


VALVE IN SUIT FLOW (OPEN) POSITION

Solenoid Valve (Suit Isolation Valve), Item 138

Item 210 Glycol Accumulator (GAEC PN 330-210)

Each of the two glycol accumulators incorporate a position switch that is actuated by the piston at a point when 10 ±5 percent of the usable capacity of coolant remains within the accumulator. The figure below shows the position switch and actuator.



Glycol Accumulator, Item 210

Item 306 Oxygen Inflow Regulator (GAEC PN 330-306)

Two oxygen inflow regulators are used in the LM ECS. Each regulator incorporates two NC control switches, a NO control switch and an NC VPI switch. The regulator handle actuates each of the four switches, which control the arming of the electrical switching logic associated with the cabin repressurization solenoid valve (Item 309), the suit circuit diverter solenoid valve (Item 112) and the two cabin air recirculation fans.

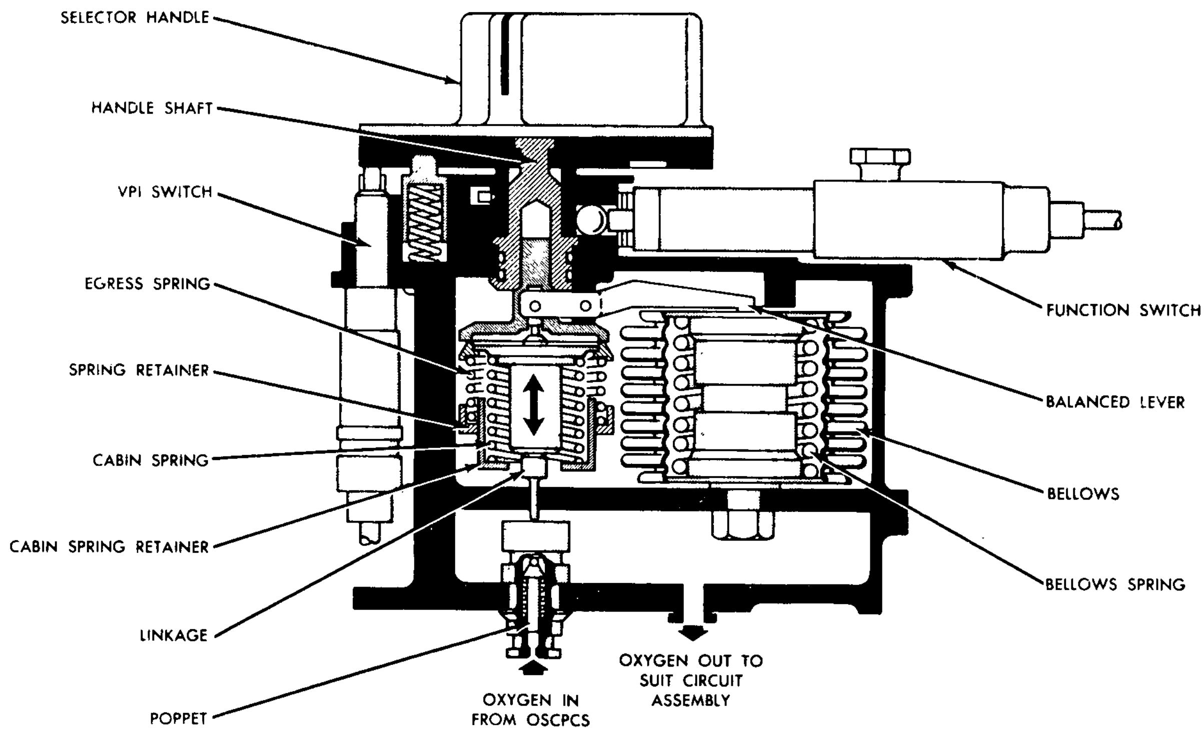
Handle positions: Egress - Valve fully counterclockwise - suit pressure maintained at 3.8 psia.

Normal - 90 deg from egress position - suit pressure maintained at 4.8 psig, cabin maintained at nominal 4.8 psia.

Open - 180 deg from egress position.

Closed - 270 deg from egress position.

Two of the four switches are shown installed on the oxygen inflow regulator in the figure below.



Oxygen Inflow Regulator, Item 306

Item 309 Cabin Repressurization Solenoid Valve (GAEC PN 330-309)

The cabin repressurization and emergency oxygen (CABIN REPRESS) valve is a solenoid-operated valve with manual override (MANUAL and CLOSE positions). It is used to repressurize the cabin after a deliberate decompression and provides an emergency flow of oxygen if the cabin is punctured.

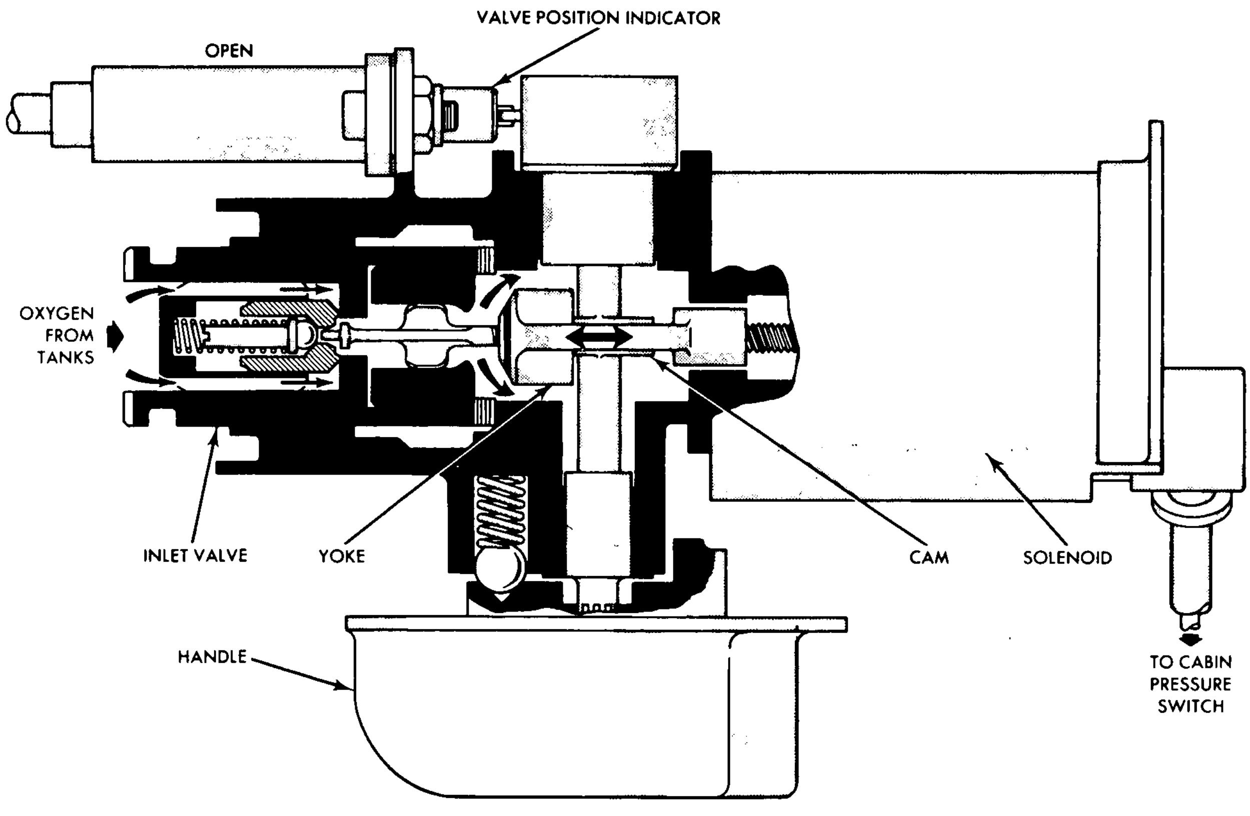
This valve incorporates a single normally closed VPI switch.

Handle positions: Manual open - Full counterclockwise

Automatic - 90 deg clockwise from open

Manual closed - 180 deg clockwise from open

The position switch is shown attached to the cabin repressurization solenoid valve in the figure below.



Cabin Repressurization Solenoid Valve, Item 309

SECTION 3

FAILURE EVALUATION

The NASA furnished failure reports on the precision switches used in the Lunar Module ECS were reviewed to determine if the failure modes and/or causes were repetitive. The most common failure mode was "intermittant switching" resulting from improper shimming of the switch to the next assembly valve. Only 28 failure reports were received from NASA that are summarized on Table 3-1. Several of these reports refer to numerous similar failures giving cause to suspect that the 28 reports do not represent the total failures experienced. Some of the failure reports state that the switching malfunction is a nuisance failure and that inadvertent actuation or de-actuation of the switch is not catastrophic because the valve position can be visually inspected and manually positioned by the crew. In this sense the VPI switches are redundant to the voice link for verification of proper subsystem configuration.

The corrective action stipulated on the failure reports generally specified a re-shimming of the switch to the next assembly valve. Factory shimming procedures were sent out to cover rework to systems delivered. Changes were made to these procedures with little apparent success, since intermittent switching was reported soon after re-shimming was completed and verified.

Very small plunger travel is required to cause the VPI switches to be actuated. Table 2-1 shows that the switch pretravel is 0.010 inches and that a movement differential of only 0.005 inches is required for actuation of the switch. In one application (suit isolation valve item 138 shown in Section 2), more than a half dozen indirect measurements (with cumulative tolerances) are required for the switch installation. In another application (oxygen inflow regulator item 306), a review of the cross sectional drawing in Section 2 of this report shows the housing of the switch to be attached to the lower surface of the upper housing of the valve. The roller/plunger of the switch rides along the lower surface of the selector knob. Any looseness between the knob and the shaft and the shaft and the housing will allow the knob to wobble causing the roller/plunger to change position. This condition is further complicated by the addition of allowable tolerances for imperfections of the cam surface, the lack of normality between the cam surface and the centerline of the shaft, eccentricity of the rotary parts and variations in the pretravel and switch actuation travel of the VPI switches. It is highly conceivable that a dimensional analyses of the component parts of the next assembly valve would show that variations caused by the above described tolerances could result in intermittent switch operation.

The failure reports reviewed indicate that at least three of the switches suspect of failure were returned to Texas Instruments for a tear-down analysis. The performance tests, x-ray analysis and detail dimensional check revealed that the switches were not at fault.

One failure was reported where the switch contacts remained closed, regardless of plunger position. A tear-down analysis revealed that the positive stop was not properly staked in place resulting in movement of the internal parts such that the switch contacts remained closed. X-rays taken of all delivered parts proved this to be an isolated failure.

A breakage of the insulation and fraying of wires was found at the point where the pigtail wires emerge from the hard stycast potting. An ECP E31486 was processed in March 1968 for incorporating a soft EC1663 potting. No failures of this type were reported following the change except for the case of improper handling.

NASA technical report "Apollo Experience Report - Lunar Module Environmental Control Subsystem" NASA TN D-6724 dated March 1972 indicated that the VPI switches were found to be susceptible to a change in performance (actuation force) with a change in ambient pressure. The control specification SV HS 3023 requires that certain of the VPI switches are to contain a sealed roller/plunger. An actuation force change of approximately 0.25 lb (4 oz) can result when dumping cabin pressure from 14.7 psia ambient to a high vacuum during a chamber test. Less severe; however similar differential pressures can be experienced across the sealed plunger during various mission modes of the LM vehicle. Table 2-1 herein shows that the switches were required to meet a 24 oz max force to actuate the switch with a 1 oz min force for release of the switch point. If the differential pressure acting across the sealed plunger is acting in the direction of keeping the switch depressed, it is possible the return spring force may not be able to deactuate the switch. This condition may explain why certain switches displayed intermittent operation during some of the chamber test runs and later performed satisfactorily when cycled by the failure evaluation committee.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE 3-1

VPI SWITCH FAILURE EVALUATION

TRANSDUCER APPLICATION VPI SWITCH SV 715077-3

BASIC PART NUMBER LSC 330-114 CANISTER SELECTOR VALVE

TRANSDUCER MANUF. TEXAS INSTRUMENTS (AT 249-3)

TROUBLE REPORT SOURCE NASA

TRANSDUCER TYPE PRECISION VALVE POSITION SWITCH

OPERATING PRINCIPLE MECHANICAL ROLLER/PLUNGER

MEASUREMENT RANGE ON-OFF

MEASUREMENT MEDIA MECHANICAL FORCE

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
LSC 330-114	VPI S/N 063	8-18-69	FGAH 5688	HUMAN	INTERMITTENT SWITCHING	IMPROPER SHIMMING	SHORT SPRING IN SWITCH CAUSES 0.008 OF SHIMMING	INSTALLATION	NONE CONSIDERED NUISANCE FAILURE	NOT CRITICAL SINCE CREW CAN VERIFY POSITION OF CO_2 SELECTOR VALVE

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE 3-1 (Continued)

TRANSDUCER APPLICATION VPI SWITCH

BASIC PART NUMBER LSC 330-117 SUIT CIRCUIT RELIEF VALVE

TRANSDUCER MANUF. TEXAS INSTRUMENTS

TROUBLE REPORT SOURCE NASA

TRANSDUCER TYPE PRECISION VALVE POSITION SWITCH

OPERATING PRINCIPLE MECHANICAL ROLLER/PLUNGER

MEASUREMENT RANGE ON-OFF

MEASUREMENT MEDIA MECHANICAL FORCE

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
LSC 330-117	NOT SPECI-FIED	3-11-71	FHAA 72608	MECH	EXCESS HANDLE TORQUE	VPI SWITCH PLUNGER CONTAINS SEVERAL AXIAL SCRATCHES	HIGH SURFACE ROUGHNESS ON SWITCH PLUNGER	MANUFACTURING	NONE SINCE SWITCH FORCE WAS ON THE HIGH SIDE OF THE ALLOWABLE	ACTUATING FORCE OF 21.6 OZ VS REQUIRED MAX. OF 24 OZ
330-117	129	9-22-70	FGAJ 5156	HUMAN	VPI DEACTUATION IS 7° BEFORE TRUE DETENT SHOULD BE 5°	IMPROPER SHIMMING	INCORRECT ASSEMBLY	INSTALLATION	VALVE RESHIMMED AS REQUIRED	
330-117	SV715077-3 S/N 066	9-24-68	FHAA 44895	MECH	SWITCH FAILED IN CLOSED POSITION	SWITCH OVERTRAVEL STOP MOVED	POSITIVE STOP WAS NOT STAKED	MANUFACTURING	ALL SWITCHES X-RAYED NO OTHER DISCREP-ANCIES FOUND	
LSC 330-117	127	3-31-71	FGAJ 6012	HUMAN	INTERMITTENT SWITCHING	IMPROPER SHIMMING	INCORRECT SHIMMING PROCEDURE	INSTALLATION	REVISED SHIMMING PROCEDURE	
LSC 330-117	122	12-27-68	FGAG 6293	HUMAN	SWITCH FAILED IN OPEN POSITION	IMPROPER SHIMMING	INCORRECT ASSEMBLY	INSTALLATION	SWITCH RESHIMMED	

TABLE 3-1 (Continued)

TRANSDUCER APPLICATION VPI SWITCH SV 715077-4

BASIC PART NUMBER LSC 330-138, SUIT ISOLATION VALVE

TRANSDUCER MANUF. TEXAS INSTRUMENTS

TROUBLE REPORT SOURCE NASA

TRANSDUCER TYPE PRECISION VALVE POSITION SWITCH

OPERATING PRINCIPLE MECHANICAL ROLLER/PLUNGER

MEASUREMENT RANGE ON-OFF

MEASUREMENT MEDIA MECHANICAL FORCE

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
LSC 330-138-1-5	UNKNOWN	11-6-69	FGAH 7929	MECH	INTERMITTENT SWITCHING	WAS NOT ESTABLISHED	RANDOM MECHANICAL SWITCH FAILURE	NOT DETERMINED	NONE	
LSC 330-190-3-21	0004	4-1-70	FGAK 1068	HUMAN	INTERMITTENT SWITCHING	VALVE HANDLE	INTERFERENCE BETWEEN VALVE HANDLE AND VPI PLUNGER	DUE TO BUILD-UP OF TOLERANCES	HANDLE REPLACED	
SWITCH SV715077-4 LSC 330-138	UNKNOWN	5-3-69	FGAH 8408	HUMAN	INTERMITTENT SWITCHING	SUSPECT HANDLE BAD	TOLERANCE BUILD-UP	LOOSENESS OF COMPONENT PARTS GREATER THAN SWITCH THROW	HANDLE REPLACED AND SWITCH RESHIMMED. HANDLE LATER FOUND TO BE OK	CONSIDERED A NUISANCE FAILURE
LSC 330-138	UNKNOWN	4-29-69	FGAH 6440	HUMAN	INTERMITTENT SWITCHING	IMPROPER SHIMMING OF SWITCH	SHIMMING PROCEDURE INCORRECT	INSTALLATION	SHIM SWITCH PER PER NEW PROCEDURE LCD 3894	
LSC 330-138	12	5-7-68	FHAA 43417	HUMAN	HANDLE TORQUE HIGH	VPI SWITCH ROLLER WORE GROOVE IN VALVE HANDLE	EXCESS CYCLING DURING QUAL TEST	2850 VALVE CYCLES SHOULD BE 1000 MAX	NONE	
LSC 330-138	00015	3-5-69	FHAA 56204	HUMAN	INTERMITTENT SWITCHING	IMPROPER SHIMMING OF VPI SWITCH	HANDLE WAS CHANGED AT KSC	INSTALLATION	NONE	
LSC 330-138	12	5-9-68	FHAA 43418	ELEC	SWITCH REMAINED OPEN SHOULD BE CLOSED	BREAK IN LEAD WIRES	STYCAST (HARD) POTTING CAUSED BREAK IN LEAD WIRES	HANDLING	CHANGED TO SOFT POTTING EC 1663	
LSC 330-138	10	1-23-68	FHAA 38849	HUMAN	INTERMITTENT SWITCHING	IMPROPER SHIMMING OF VPI SWITCH	SWITCH IMPROPERLY SHIMMED TO VALVE	INSTALLATION	NONE	

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE 3-1 (Continued)

TRANSDUCER APPLICATION VPI SWITCH

BASIC PART NUMBER LSC 330-210 GLYCOL ACCUMULATOR

TRANSDUCER MANUF. TEXAS INSTRUMENTS

TROUBLE REPORT SOURCE NASA

TRANSDUCER TYPE PRECISION VALVE POSITION SWITCH

OPERATING PRINCIPLE MECHANICAL ROLLER PLUNGER

MEASUREMENT RANGE ON-OFF

MEASUREMENT MEDIA MECHANICAL FORCE

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
LSC 330-210	108	8-23-68	FGAF-6525	HUMAN	DEFECTIVE ELECTRICAL WIRING	BROKEN WIRE INSULATION AND WIRE KINKED	MISHANDLING	ASSEMBLY	LOW LEVEL SWITCH IS NOT REQUIRED TO FUNCTION ON LM4, 5, AND 8	
LSC 330-210	39	7-25-66	A52900	HUMAN	LOW LEVEL SWITCH FAILED TO OPERATE	MISALIGNED SWITCH MOUNTING BRACKET	BRKT WAS NOT DESIGNED TO HOLD SWITCH PARALLEL TO ACCUMULATOR TUBE	DESIGN	BRKT REDESIGNED	
LSC 330-210	42	10-1-66	A33928	HUMAN	LOW LEVEL SWITCH FAILED TO OPERATE	MISALIGNED SWITCH MOUNTING BRACKET	BRKT WAS NOT DESIGNED TO HOLD SWITCH PARALLEL TO ACCUMULATOR TUBE	DESIGN	BRKT REWORKED	
LSC 330-210	3	1-4-67	A35094	HUMAN	LOW LEVEL SWITCH FAILED TO OPERATE	MISALIGNED SWITCH MOUNTING BRACKET	BRKT WAS NOT DESIGNED TO HOLD SWITCH PARALLEL TO ACCUMULATOR TUBE	DESIGN	BRKT REWORKED	
LSC 330-210	041	12-21-67	UNABLE TO READ	HUMAN	LOW LEVEL SWITCH FAILED TO ACTUATE AT 5-15%	ACCUMULATOR TUBE WAS NOT MARKED CORRECTLY	PREVIOUS REWORK OF ACCUMULATOR LEFT TUBE INCORRECTLY MARKED	ASSEMBLY	UNIT CORRECTLY MARKED	
LSC 330-210	121	8-16-68	FHAA 44869	HUMAN	LOW LEVEL SWITCH FAILED TO ACTUATE	SWITCH IMPROPERLY SHIMMED TO ACCUMULATOR	EXCESSIVE AMOUNT OF SHIMS USED	ASSEMBLY	UNIT CORRECTLY SHIMMED	
LSC 330-210	039	8-30-67	A45978	ELEC	FAILED CONTINUITY TEST	NO ANALYSIS	NO ANALYSIS	NO ANALYSIS	NO ANALYSIS	

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE 3-1 (Continued)

TRANSDUCER APPLICATION VPI SWITCH SV 715077

BASIC PART NUMBER LSC 330-306, OXYGEN INFLOW REGULATOR

TRANSDUCER MANUF. TEXAS INSTRUMENTS

TROUBLE REPORT SOURCE NASA

TRANSDUCER TYPE PRECISION VALVE POSITION SWITCH

OPERATING PRINCIPLE MECHANICAL ROLLER/PLUNGER

MEASUREMENT RANGE ON-OFF

MEASUREMENT MEDIA MECHANICAL FORCE

PART NUMBER	SERIAL NUMBER	FAILURE DATE	T/R NUMBER	FAILURE TYPE	FAILURE MODE	FAILURE MECHANISM	FAILURE CAUSE	PROBLEM AREA	CORRECTIVE ACTION	COMMENTS
LSC 330-306-1-8	0015	6-8-70	FGAK 9928	HUMAN	INTERMITTENT SWITCHING	IMPROPER SHIMMING	SWITCH TRANSFERRED TO NEW NEXT ASSY WITH RESHIMMING	INSTALLATION	NONE SWITCH USED ONLY FOR TELEMETRY INDICATION	O_2 DEMAND REGULATOR EVENT LIGHT IS NOT ON WITH REG IN LOCKED/ CLOSE POSITION
306-1-6	330-390-1-11	9-26-68	FGAD 4823	HUMAN	INTERMITTENT SWITCHING	IMPROPER SHIMMING	SWITCH NOT SHIMMED PER FACTORY INSTRUCTIONS	INSTALLATION	RESHIM IN PLACE	
330-306 SV730077	011	11-29-68	FGAD 4861	HUMAN	FAILED TO TURN OFF O_2 SUPPLY WITH REGULATOR IN EGRESS POSITION	LOOSE INTERNAL NUT CRACKED EXTERNAL SOLDER JOINT	MISHANDLING	INSTALLATION	INSPECT ALL INSTALLATIONS FOR CRACKED SOLDER JOINT	
330-306 SV730077	006	12-8-68	FGAD 4872	HUMAN	FAILED TO TURN OFF O_2 SUPPLY WITH REGULATOR IN "CLOSE" POSITION	NONE FOUND	NOT FOUND	NOT FOUND	REPLACE POSITION SWITCH	SWITCH DISASSEMBLED BY VENDOR - NO DISCREPANCY FOUND
330-306	106	6-15-67	FGAA 2755	HUMAN	INTERMITTENT SWITCHING	HANDLE DEFLECTION CAUSED SWITCH TO ACTUATE OR DEACTUATE	NOT REPORTED	NOT REPORTED	NOT REPORTED	
330-306	106	7-12-67	FGAA 5377	HUMAN	POS'N SWITCH NOT SYNCHRONIZED WITH VALVE HANDLE POS'N	HANDLE NOT INDEXED CORRECTLY	INCORRECT ASSEMBLY	INSTALLATION	HANDLE RE-INDEXED	
LSC 330-306		8-31-67	FGAA 45980	ELEC	FAILED ELEC CONTINUITY TEST	--	WIRING LOGIC DIAGRAM CHANGED	HDWE NOT PER LATEST CHANGE		

SECTION 4

RECOMMENDATIONS AND CONCLUSIONS

Most of the failures associated with the precision switches that were used to indicate valve position in the Lunar Module ECS were attributed to improper shimming of the switch to the next assembly valve. Several of the switches were returned to the manufacturer (Texas Instruments) for a tear down analysis. In only one case where the internal positive stop came loose due to improper staking was the switch found to be at fault. All other failures except for improper handling of the pigtail wires can be attributed to the method by which the switches are actuated in the next assembly valves. This method involves transferring the switch actuating displacement/force through several component parts in the next assembly valve. Section 2 of this report describes these conditions in greater detail.

The following design criteria is suggested for future use of the precision switches described in this report:

Design Criteria

(a) Design the precision switch next assembly so that there are a minimum number of component parts between the part that supports the body of the switch and the part that actuates the roller/plunger of the switch.

(b) Incorporate springs or similar means to bias all of the next assembly component parts against known surface(s) so that the looseness of parts do not inadvertently actuate the precision switch(es).

(c) Provide high rise cams (within good design practices) to ensure overstroke of the switch at the desired valve position.

(d) Cam surfaces for actuating the roller/plunger on the switch should contain a 32 finish or better and should be hardened to a Rockwell C of 40 to 60 to minimize side loading of the switch plunger and minimize wear of the cam surface.

The following design criteria is suggested for possible re-design of the precision position indicating switches:

(a) Control maximum and minimum forces for switch actuation, release and overtravel. Control maximum and minimum switch stroke for pre-travel, switch actuation and overtravel. These values as shown in Table 2-1 are only held to one side of the tolerance allowed.

(b) Design pressure balanced switch seals so that the switch actuation force is not affected by changes in ambient pressure.

(c) Design the switch with dual rollers such that the switch is actuated by differential movement of the two rollers. Both rollers should be spring loaded by a single spring acting against two adjacent cams that are machined relative to each other on a common part. Any movement of the cam surfaces due to tolerances and clearances of the component parts of the next assembly valve would act on both cams simultaneously. The movement would be taken up by the common spring however the differential movement of the two rollers would not be disturbed. This type of design would allow the component parts to be manufactured to standard tolerances at a lower resultant cost.