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FLUIDICALLY CONTROLLED CARGO HOOK

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A program to design, fabricate, and test a fluidically controlled cargo hook for a CH-54 type helicopter was conducted.

The existing cargo system uses an electrically controlled cargo hook which is attached to a 100-foot length of cable wound on a hoist drum. The existing hoist system was modified to permit a prototype pneumatic/fluidic

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system to be used in place of the electrical system.

The system was tested and, though only 559 of the proposed 1000 cycles of testing were successfully completed, the concept proved to be feasible.

It is recommended that further testing be conducted after the incorporation of relatively minor improvements shown to be necessary during the 559 cycle testing.

EUSTIS DIRECTORATE POSITION STATEMENT

This report documents an in-depth research and development effort pertaining to the design, fabrication, and testing of a fluidically controlled cargo hook compatible with the CH-54 helicopter cargo hoist system. Major problem areas developed during testing which prevented completion of project goals.

Results of this program are inconclusive. However, indications are that the basic cable and pneumatic core concept has merit. With further design effort, technical modifications, improvement in materials and components, and more advanced manufacturing techniques, an effective, reliable fluidically controlled cargo hook system appears to be feasible.

Mr. S. G. Riggs, Jr., of the Military Operations Technology Division served as Project Engineer for this effort.

PREFACE

This program was conducted by the Sikorsky Aircraft Division of United Aircraft Corporation, Stratford, Connecticut, under Contract DAAJ02-73-C-0043 with the Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory (USAAMRDL), Fort Eustis, Virginia. USAAMRDL technical monitor for this effort was Mr. S. G. Riggs, R&M Analysis and Maintenance, Military Operations Technology Division.

The authors acknowledge the contributions made by Mr. D. O. Adams, upon whose basic concepts the program was based. Significant contributions to the program were also made by Mr. A. L. Sivigny and Mr. W. J. Mulvey.

TABLE OF CONTENTS

Page

PREFACE 1

LIST OF ILLUSTRATIONS 4

LIST OF TABLES 6

INTRODUCTION 7

Background 7
Objective ....
Concept 7

BASIC DATA 8

Establish Requirements 8
Breadboard Fluidic Circuit Design 13
Breadboard Fluidic Circuit Fabrication 18
Determination of System Characteristics 19
Design and Fabrication 24

TEST PROGRAM 31

Scope 31
Date and Place 31
Procedures and Results 31
Discussion of Results 62

CONCLUSIONS 71

RECOMMENDATIONS 72

APPENDIXES

A. Fluidic Circuit Procurement Specification 73
B. Test Plan 77

LIST OF SYMBOLS 83

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LIST OF ILLUSTRATIONS

Figure		Page
1	JFTD12A-5A Engine Bleed Air Pressure	9
2	JFTD12A-5A Engine Bleed Air Temperature	10
3	Tubing Cross Section	12
4	Logic Circuit Diagram	15
5	Final Breadboard Fluidic Circuit	17
6	External Cargo Handling System - CH-54 Type Aircraft	18
7	Back Pressure Switch Response Time - Switching On	20
8	Back Pressure Switch Response Time - Switching Off	21
9	Hook Actuator - Pressure Rise Rate	22
10	Breadboard Fluidic System Component Location	23
11	Schematic of Fluidically Controlled Cargo Hook System	25
12	Final Integrated Fluidic Circuit	27
13	Bonding Fixture and Specimen	28
14	Schematic of "Electroline" Type Cable End Fitting	29
15	Hoist Slip Ring Vibration Test Setup	35
16	Interface Valve Vibration Test Setup	37
17	System Vibration Test Setup	38
18	Block Diagram - Extreme Temperature Test Setup	39
19	Extreme Temperature Test Setup	41
20	Condition of System Filters After Contaminated Air Test	43
21	Sand Accumulation in Pressure Regulator and Interface Valve	45
22	Sand and Dust Test Setup - Front View	46
23	Sand and Dust Test Setup - Side View	47
24	Completion of Sand and Dust Test	48

LIST OF ILLUSTRATIONS (Continued)

Figure		Page
25	Interface Valve Installation in Hoist Well	49
26	Fluidic Control Module Installation	51
27	Cable Installation on Cargo Hoist	53
28	Cable Core Termination on Cargo Hoist	54
29	Displacement of Strands on Cable Assembly	57
30	Waves on Cable Assembly	58
31	Installation of Repaired Cable	59
32	Cable Disassembly	61
33	Pattern of Deformation at Cable Core	62
34	Core Leakage	64
35	Core Damage - Leaky Section	65
36	Interface Valve Operation	67
37	Technique Used in Restoring Indicator Operation	68
38	Cable Reaction to Airdrop	69
A-1	Integrated Fluidic Circuit	74
B-1	Test Matrix	82

LIST OF TABLES

Table Page

1 Input/Output Variable and Logic Assignments 14

2 Major Component Location Matrix 19

3 Automatic Touchdown Signal Time 19

4 Interface Valve Signal Time 20

5 Prototype Control System Release Time Evaluation 22

INTRODUCTION

BACKGROUND

Since 1961 Sikorsky Aircraft has been involved in the design and operation of crane type helicopters. Operation of this type of aircraft by both military and commercial operators has been closely monitored during these years. One of the primary problem areas encountered in the external cargo handling system has been the reliability of the cargo hook release system. The cargo handling system on crane type aircraft is unique in that the hook is attached to a hoist mounted in the aircraft. To permit hook release, an electrical conductor is buried in the core of the load suspension cable. The use of hoist and hook mounted slip rings permits use of an electrical solenoid to open the cargo hook. The primary cause of hook release unreliability has been a problem with slip rings and electrical switches.

With the advent of turbine-powered helicopters and fluidic controls, a new cargo hook release system using a pneumatic/fluidic system would appear to offer greater reliability than the existing electrical system. A pneumatic/ fluidic system would offer the following advantages over an electrical system:

- more reliable slip rings since slight amount of air leakage tends to keep rings clean and does not affect operation of sensors or actuator.
- constant airflow through fluidic sensors avoids contamination of contacts with resultant failure to operate.
- small break in air line does not mean system failure as does a break in an electrical wire.

In 1970 Sikorsky Aircraft designed, built and tested a fluidically controlled cargo hook to prove the feasibility of this concept. Three small diameter nylon tubes of appropriate length were used to simulate the conductor in the core of the load suspension cable. The program proved to be a success and provided the foundation upon which this program is based.

OBJECTIVE

The objective of this program was to design, fabricate, and test a pneumatic/fluidic cargo hook release system for use on a CH-54B helicopter.

CONCEPT

The basic concept requires the use of engine bleed air as a source of power and control. A three channel plastic tube is to be buried in the core of the load suspension cable. Pneumatic slip rings at cable and hoist are to be developed. Fluidic sensors and a pneumatic actuator are to be provided. A fluidic logic control circuit to permit hook actuation and to provide hook open, loaded and release malfunction indication is to be developed.

BASIC DATA

ESTABLISH REQUIREMENTS

General

The basic requirement was to design, fabricate, and test a pneumatic/ fluidic system capable of operating the cargo hook in a CH-54B helicopter. The system was to be built using existing major components with minimum modifications required. It was also specified that the fluidic logic circuit perform the following functions:

- sense and indicate a hook open condition.
- sense and indicate a hook loaded condition.
- sense and indicate a malfunction of the release system.
- open the hook on pilots command.
- open the hook when automatic touchdown mode is selected and the load reaches a designated value.

Note: the existing system on the CH-54B does not sense and indicate a hook loaded condition, nor does it have a release malfunction indicator.

To complete the system it was required that the following parameters be established:

- the range of allowable temperatures and pressures of operating air in the fluidic circuit.
- force and stroke requirements for the hook load release actuator.
- requirements for the conditioning of air (cooling, filtration and drying).
- size requirements for the pneumatic/fluidic tubing.
- pressure drop in the pneumatic/fluidic tubing.

In addition, the source of bleed air was to be determined, as was a redundant bleed air system.

Bleed Air

A survey of the bleed air temperature and pressure variation with actual shaft horsepower for the JFTD 12A-5A engine at altitudes from sea level to 15,000 feet and ambient temperatures of -65°F, 60°F, and 120°F was made. Figure 1 shows bleed air pressure variations with shaft horsepower and Figure 2 shows bleed air temperature variations with shaft horsepower. These curves represent engine only data.

With both engines installed in the aircraft, the maximum power required could not reach the 4800 hp shown on the curves. However, single engine

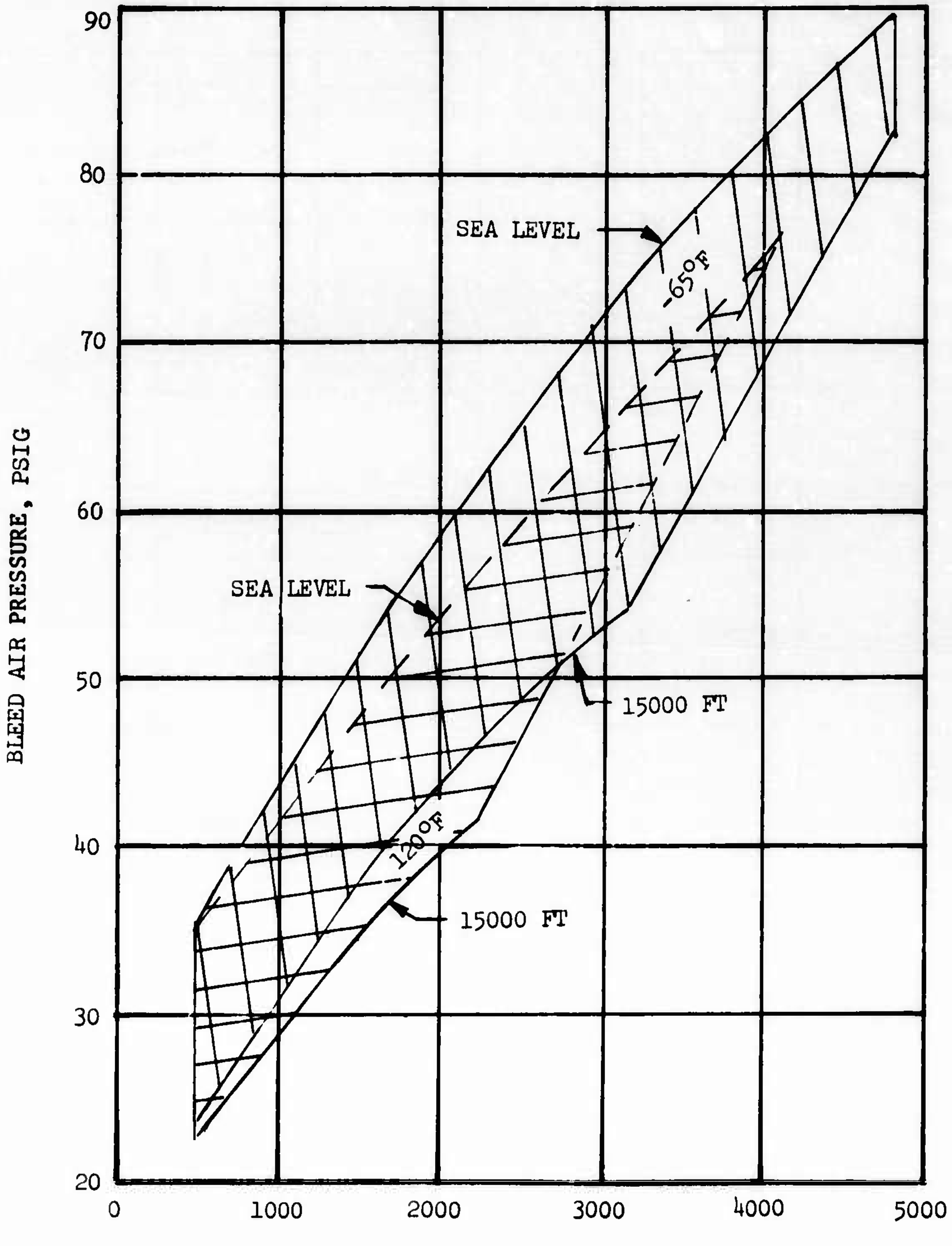


Figure 1. JFTD12A-5A Engine Bleed Air Pressure.

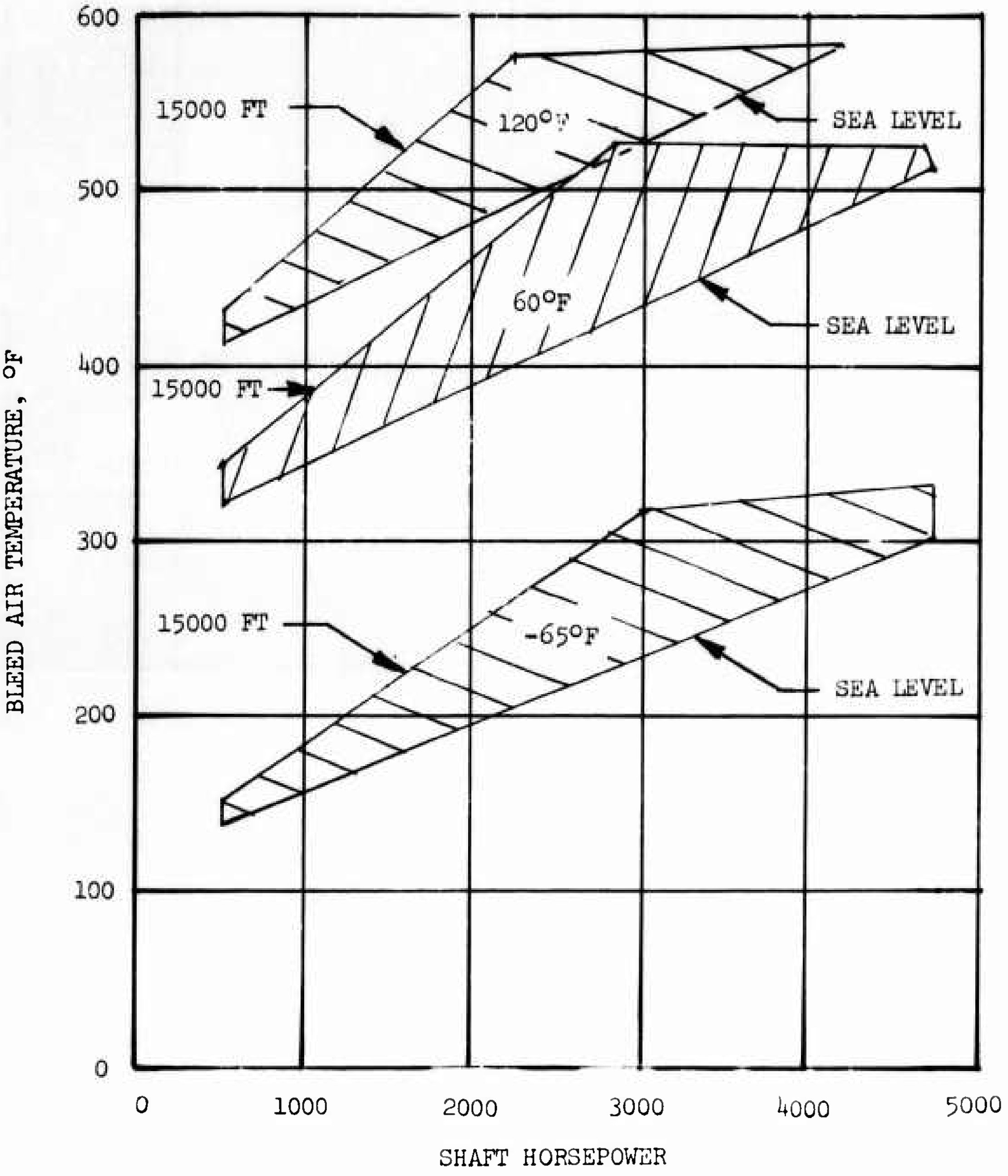


Figure 2. JFTD12A-5A Engine Bleed Air Temperature.

operation could easily require this power; hence the values at 4800 hp were considered. Design limits, as taken from these curves, were temperatures from 140° to 582°F and pressures from 42.7 to 103.7 psia.

Since these values are measured at the bleed air port of the engine, lesser values can be expected at the interface valve and the fluidic control box (see Determination of Fluidic System Characteristics section).

Cargo Hook

Modification of the existing CH-54B Cargo Hook and Swivel Assembly to utilize a pneumatic/fluidic control system instead of the normal electrical system was considered to be feasible. The seven-channel electrical slip ring, designed as a replaceable module, was replaced by a pneumatic/fluidic slip ring. Existing electrical sensors (micro switches) were replaced by fluidic sensors. The electrical solenoid was replaced by a diaphragm type air cylinder of equivalent output power.

Conditioning of Air

Based on the requirements of F.A.R. Part 25 and MIL-E-5007E, with judgement factors, the following values were used for design purposes.

Sand:

$44 \times 10^{-6}\ \frac{\text{lb of sand/sec}}{\text{lb of bleed air/sec}}$ without EAPS (Engine Air Particle Separator)

$6.6 \times 10^{-6}\ \frac{\text{lb of sand/sec}}{\text{lb of bleed air/sec}}$ with EAPS

Sand Particle Size:

Particle Diameter (microns)	Quantity (% by weight finer than size indicated)
1000	100
900	98 - 99
600	93 - 97
400	82 - 86
200	46 - 50
125	18 - 22
75	3 - 7

Water Concentration:

$9.2 \times 10^{-4}\ \frac{\text{lb of water/sec}}{\text{lb of bleed air/sec}}$

Temperature and pressure requirements were based on the bleed air temperature and pressures and on the pneumatic/fluidic system characteristics (see Breadboard Fluidic Circuit Design).

Pneumatic/Fluidic Tubing

Both length and diameter were established by the requirement that the tubing be buried inside a spin resistant cable with a minimum breaking strength of 75,000 pounds, a length of 100 feet, and a maximum diameter of 0.923 inch (to permit use on the existing CH-54B hoist drum). Previous work by the Contractor had indicated that 1/8-inch I.D. tubing would be adequate to provide the required air at the hook actuator. Thus, since three passages were required to perform the required functions, a cross section as shown by Figure 3 was established. Operating air (and ambient air) temperature limits of -65°F (ambient) and 582°F (engine bleed air maximum temperature) were too severe to be met by any known material.

Figure 3. Tubing Cross Section.

Preliminary calculations, based on use of stainless steel tubing from the engine bleed air port to the hoist interface valve, indicated that the bleed air temperature, with a flow of 1.5 scfm, would drop from 580°F to ambient in approximately 14.6 feet. Subsequent testing (see Test Program) indicated that this calculation was extremely conservative. With the temperature problem resolved, the core upper temperature limit was established at 165°F, which provided an adequate margin over the required maximum ambient air temperatures.

Redundant System

Since the CH-54B is a twin engine aircraft, a redundant bleed air system would only require that both engines be tapped for bleed air. Automatic switching would be provided to permit bleed air to be drawn from the "live" engine in case one engine fails or is shut down. For single engine aircraft, it would be necessary to provide an alternate source of penumatic power - perhaps a rotor gearbox driven compressor would suffice - as well as automatic switching controls.

BREADBOARD FLUIDIC CIRCUIT DESIGN

The fluidic circuit used in the breadboard test program is based on a circuit developed at Sikorsky in 1970. A few changes were evolved as a result of the limited breadboard testing done on that circuit. In addition, a "combinational logic" circuit synthesis procedure was used to evaluate and improve the early circuit design.

Circuit Requirements

The following are the basic requirements for the cargo hook fluidic control system circuit:

- Release the hook load from any or all of the pilot's, copilot's or aft pilot's stations.
- Automatic touchdown release to occur when the load on the hook is reduced to a prescribed value and automatic touchdown release mode has been selected.
- A separate safety control to disable all release functions while leaving the system powered-up.
- Indicators to come on when the hook is open or when the hook is loaded.
- A release malfunction feature which causes an indicator to come on when release does not occur within a specific time period after either type of release is initiated. The minimum time delay to be determined by experiment.
- Interface with the existing CH-54B cargo hook design, which provides two mechanical devices (suitable for fluidic switch installations) that provide hook status signals. One mechanical motion occurs when the hook load beam is open and the other occurs when the hook load beam is closed and unloaded.

The above requirements may be interpreted as input/output variables and assigned symbols as shown in Table 1. Each variable, which may have only two levels (ON or OFF), is also assigned a sign convention. For example, the hook open status is defined as positive or ON. The physical hardware (the fluidic back pressure switches) could be arranged either way - ON when the hook is open, or ON when the hook is closed. The choices in the case of the two hook status signals were based on experience with the earlier development of a cargo hook release system, where the opposite choices were made and some false indication problems were encountered due to the long line lengths between the fluidic elements and the hook. The sign conventions for the other input/output variables are simply the most logical choice.

TABLE 1. INPUT/OUTPUT VARIABLE AND LOGIC ASSIGNMENTS

VARIABLE TYPE	NAME	LETTER SYMBOL	POSITIVE OR ON WHEN:
Input	Hook Open Status	A	Hook Open
	Hook Load Status	B	Hook Closed & Unloaded
	Auto Touchdown	C	Auto T.D. Selected
	Release Mode	D	ON Selected
	Pilot's Release	E	Release Selected
	Copilot's Release	F	Release Selected
	Aft Pilot's Release	G	Release Selected
Output	Release	H	Release Actuation
	Rel. Malf. Indicator	I	Rel. Malf. Occurs
	Hook Loaded Indicator	J	Hook Loaded
	Hook Open Indicator	K	Hook Open

Circuit Logic Design

A circuit may be formulated without the use of the following analysis; in fact, the original circuit was done without formal analysis. However, the use of Boolean algebra and the logic circuit assures that the final result is the simplest and most efficient.

The Boolean equations relate each output variable to the input variables using the desired functions of the system. In these equations, the symbol + means OR, the symbol • means AND, and a bar drawn over a variable or variable groups means negate or NOT. Note that each variable has only two states, ON or OFF, and each is the negation of the other.

The equation for hook release expresses that release is to occur whenever (1) the release mode switch is ON, or (2) any one of the three pilots selects release OR whenever the hook unloads with auto touchdown ON. Using the symbols and logic assignments of Table 1, this equation is:

$$H = D \cdot \left[E + F + G + (B \cdot C) \right] \qquad (1)$$

The equation for the release malfunction indicator must also show the time delay whereby the system gives the hook a short time to achieve a release once a release has been initiated. If a release does not occur within the time delay, the indicator is to come on. The symbol T is used to signify "the time since release initiation has exceeded the pre-set value". As a simplification, the output variable H can be used as an input to the release malfunction logic. The Boolean equation which meets the requirements for this system is therefore

$$I = H \cdot \overline{A} \cdot T \qquad (2)$$

The hook loaded equation takes into account the mechanical oddity of the CH-54B hook in that the available ON signal is "hook closed and unloaded". The OFF signal occurs when the hook is either open OR loaded. Two signals can be combined to give the correct indication as follows:

$$J = \overline{A} \cdot \overline{B} \tag{3}$$

Finally, the hook open indicator is an identity:

$$K = A \tag{4}$$

The logic circuit diagram, Figure 4, follows from the Boolean equations by connecting inputs and outputs using pictorial symbols, connected by lines, for the mathematical symbols.

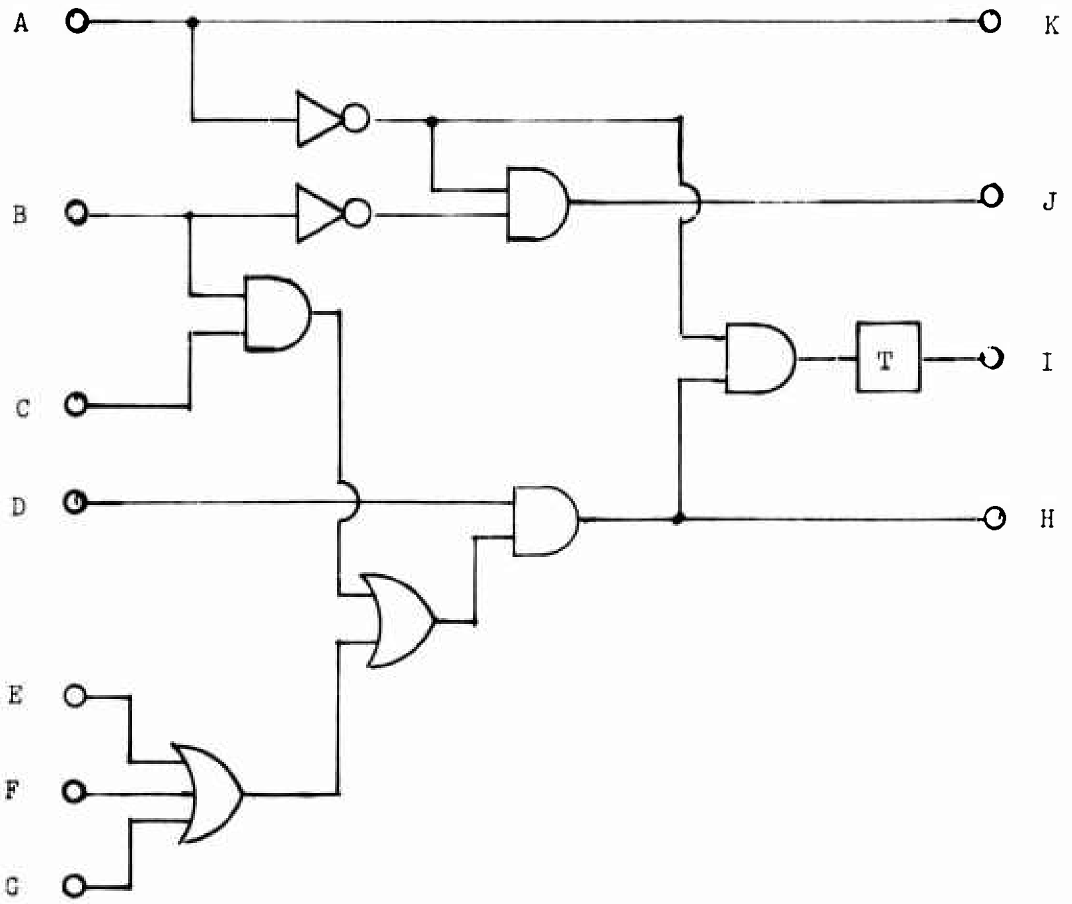


Figure 4. Logic Circuit Diagram.

Final Breadboard Circuit Design

The final circuit design is shown in Figure 5. The design and understanding of the circuit operation by derivation from the logic circuit, Figure 4, is presented below. The practical abilities and limitations of available fluidic logic elements are primary design considerations.

The logic used in the final circuit is the same as derived in Figure 5, and in some cases, fluidic elements replace exactly the symbols of Figure 4.

A primary addition in Figure 5 is the input interface devices labled No.'s 1 through 7. These are back pressure switches, which change state (OFF to ON) when their control port is blocked. These devices provide the actual input signals to the logic, in fact since both OFF and ON signals are available from the backpressure switches, the two NOT elements of Figure 4 are not required in Figure 5.

In case of the pilot's input controls, open holes are blocked, either within a special switch or by direct touch, in order to initiate a command. In the case of the hook signals, the ends of tubes running down through the hoist cable are blocked or unblocked according to hook status. One signal tube end is blocked when the hook is open, and is unblocked when the hook is closed. A second tube end is blocked when the hook is closed and unloaded. It is unblocked when the hook is either open or loaded. This second arrangement is inherent in the basic CH-54B Cargo Hook design, but an indication of hook load status alone is easily obtained by using element 9 to perform the function $J = \overline{A} \cdot \overline{B}$

Element 12, an inhibited OR, in Figure 5, replaces an OR and an AND in the release circuit of Figure 4. The inhibited OR element functions as an OR element as long as the inhibit signal is OFF. When the inhibit signal is ON (SAFE position on the RELEASE MODE switch), element 12 cannot switch ON and therefore no release can take place, element 12 being the final input to the interface valve.

Element 10 is a digital amplifier that is required to boost the output of element 4 to meet the low input impedance requirements of element 12, the inhibited OR.

Element 13, an OR gate, serves the same function as one of the ANDs of Figure 4. This substitution is expressed logically in Boolean algebra as $\overline{A} \cdot H = A + \overline{H}$. This does not reduce the number of elements, but the circuit is simplified by the use of the otherwise unused OFF output of element 13. The full output of the ON port of element 12 is therefore available to drive the interface valve. Also note that there is only one Tee connection, the ON port of element 2 fanning out to both element 13 and the hook open indicator.

The four system outputs - three indicators and the fluidic/pneumatic interface valve - are designed to operate directly on fluidic element output pressures. The interface valve drives the actuator on the cargo hook via

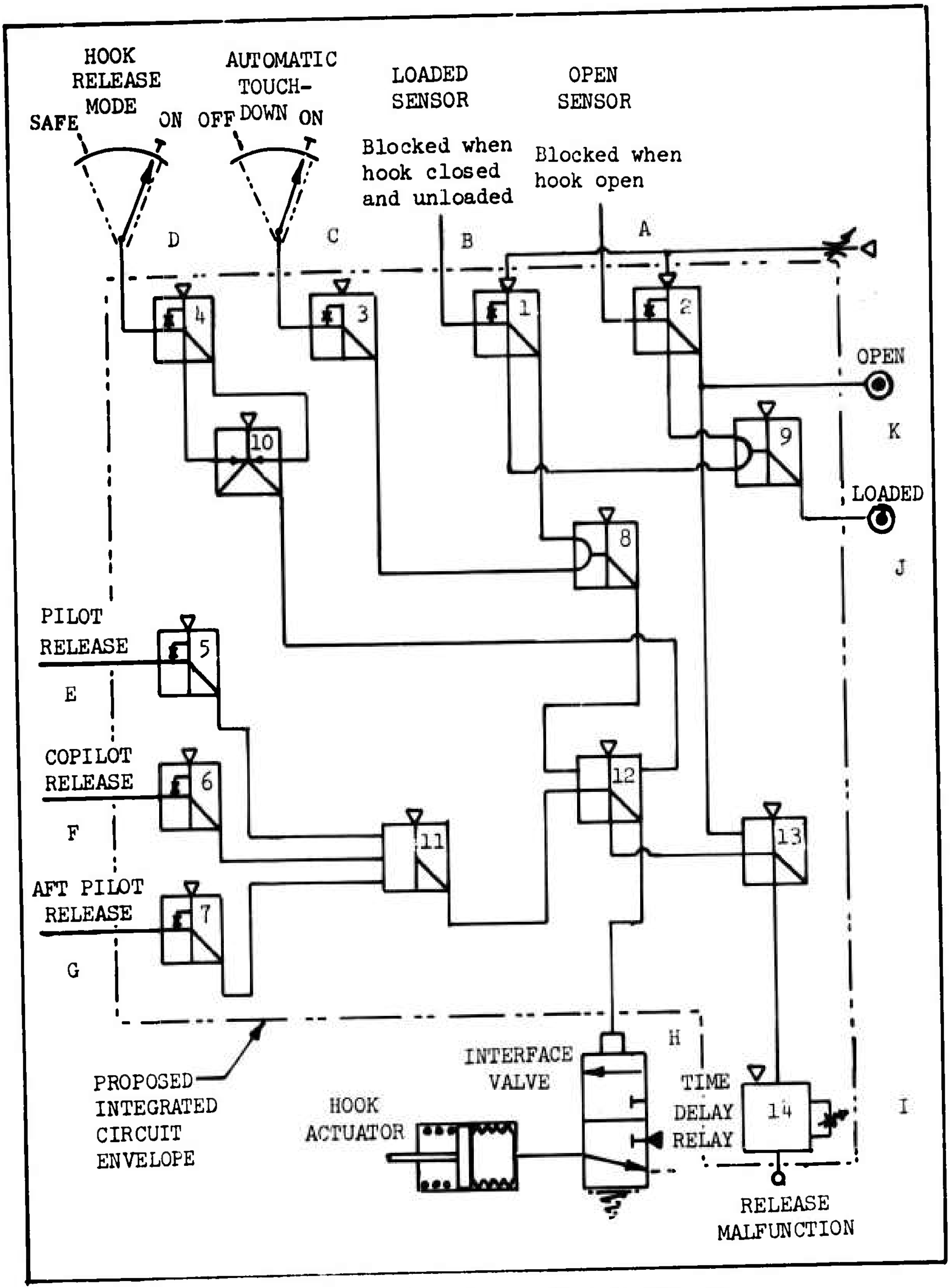


Figure 5. Final Breadboard Fluidic Circuit.

a third channel in the tube buried in the core of the load suspension cable.

BREADBOARD FLUIDIC CIRCUIT FABRICATION

The final breadboard fluidic circuit, Figure 5, was fabricated using the components listed below:

- a cargo hook modified by addition of fluidic sensors and a pneumatic actuator
- an interface valve
- a fluidic logic module
- a fluidic control module
- various lengths of 1/8 inch I. D. tubing

The lengths of tubing used to connect the major system components were determined by their physical size and location of components in the aircraft. Figure 6 shows the general aircraft configuration.

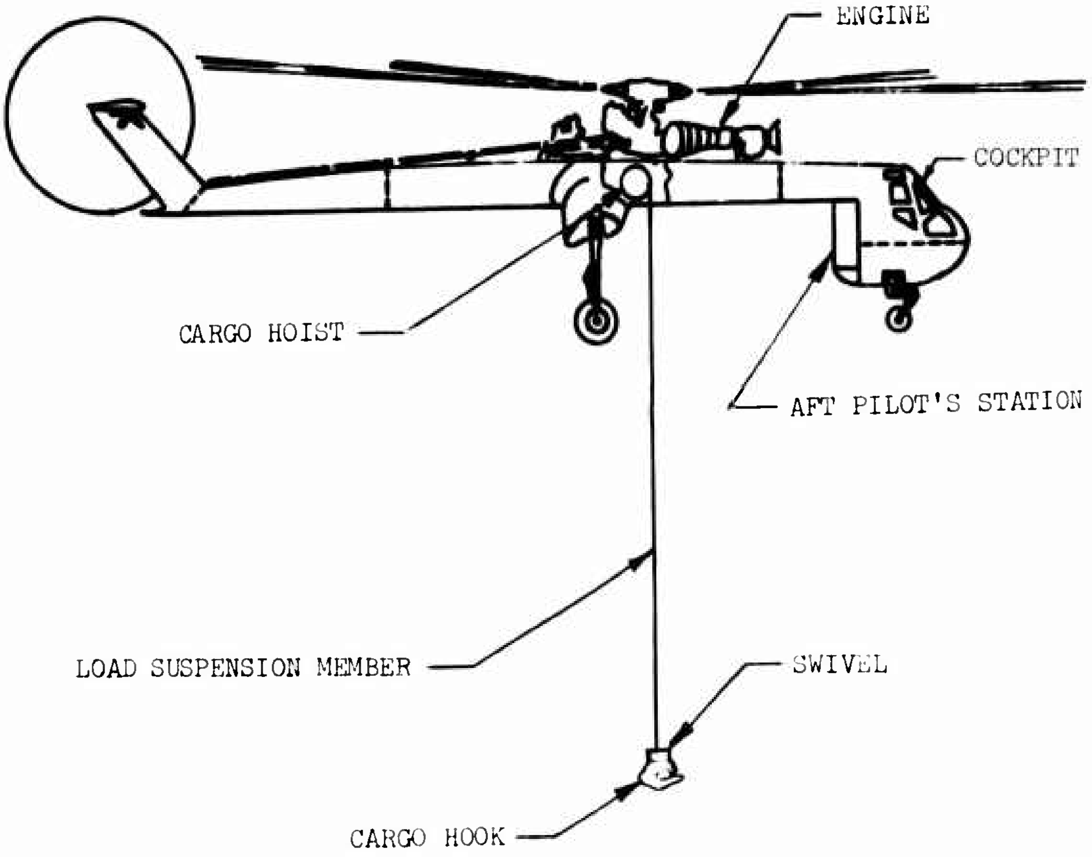


Figure 6. External Cargo Handling System - CH-54 Type Aircraft.

With this basic configuration, the various possible locations of the major components that are feasible are shown in Table 2. Line lengths were varied so that each of the above schemes could be evaluated.

TABLE 2. MAJOR COMPONENT LOCATION MATRIX

SCHEME NO.	COMPONENT LOCATION		
	SWITCH MODULE	LOGIC MODULE	INTERFACE VALVE
1	Cockpit	Cockpit	Cockpit
2	Cockpit	Cockpit	Cockpit
3	Cockpit	Hoist	Hoist
4	Cockpit	Midway	Hoist

Standard off-the-shelf fluidic components were used to fabricate the logic and control modules. Micro switches on the hook were replaced with air jets which, when blocked by the micro switch actuators, provided hook closed and hook loaded signals. A standard pneumatic rotary actuator was modified to reduce friction and replaced the rotary solenoid on the hook.

DETERMINATION OF SYSTEM CHARACTERISTICS

Optimization Studies

Since back pressure switches are used to interface sensors to the fluidic logic system, their characteristics of operation at varying pressures and distances from a power source were among the first data to be determined. Figure 7 shows the variation in switching ON response time at various lengths of 1/8-inch-I.D. line and supply pressures.

Figure 8 shows the variation in switching OFF response time at various lengths of 1/8-inch-I.D. line and supply pressures.

Hook actuator characteristics were established by measuring the pressure rise rate with air supplied at varying pressures through 100 feet of 1/8-inch-diameter tubing. Figure 9 indicates the results obtained. Automatic touchdown signal times were determined at various supply pressures and with a line length of 138 feet. Results are shown in Table 3.

TABLE 3. AUTOMATIC TOUCHDOWN SIGNAL TIMES

SUPPLY PRESSURE, PSIG	ELAPSED TIME, SEC
4	0.45
7	0.83
10	0.96

The time required for a signal to travel from the interface valve to the logic circuit at varying line lengths and pressures was determined. Results are shown in Table 4.

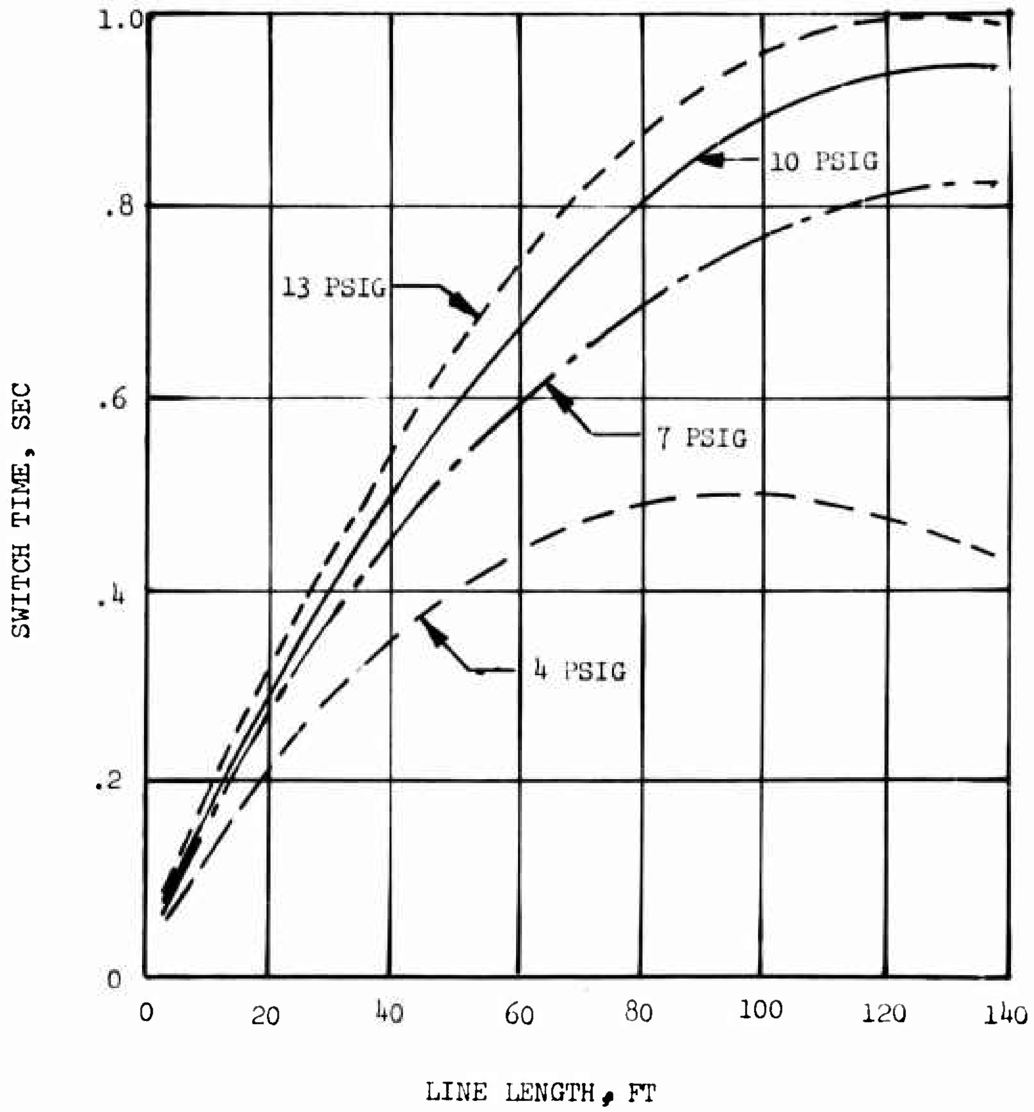


Figure 7. Back Pressure Switch Response Time - Switching On.

TABLE 4. INTERFACE VALVE SIGNAL TIME

LENGTH, FEET	TIME, SEC.		
	AT 4 PSIG	AT 7 PSIG	AT 10 PSIG
.33	.048	.050	.06
10	.06	.07	.07
24	.09	.09	.09
34	.13	.12	.13

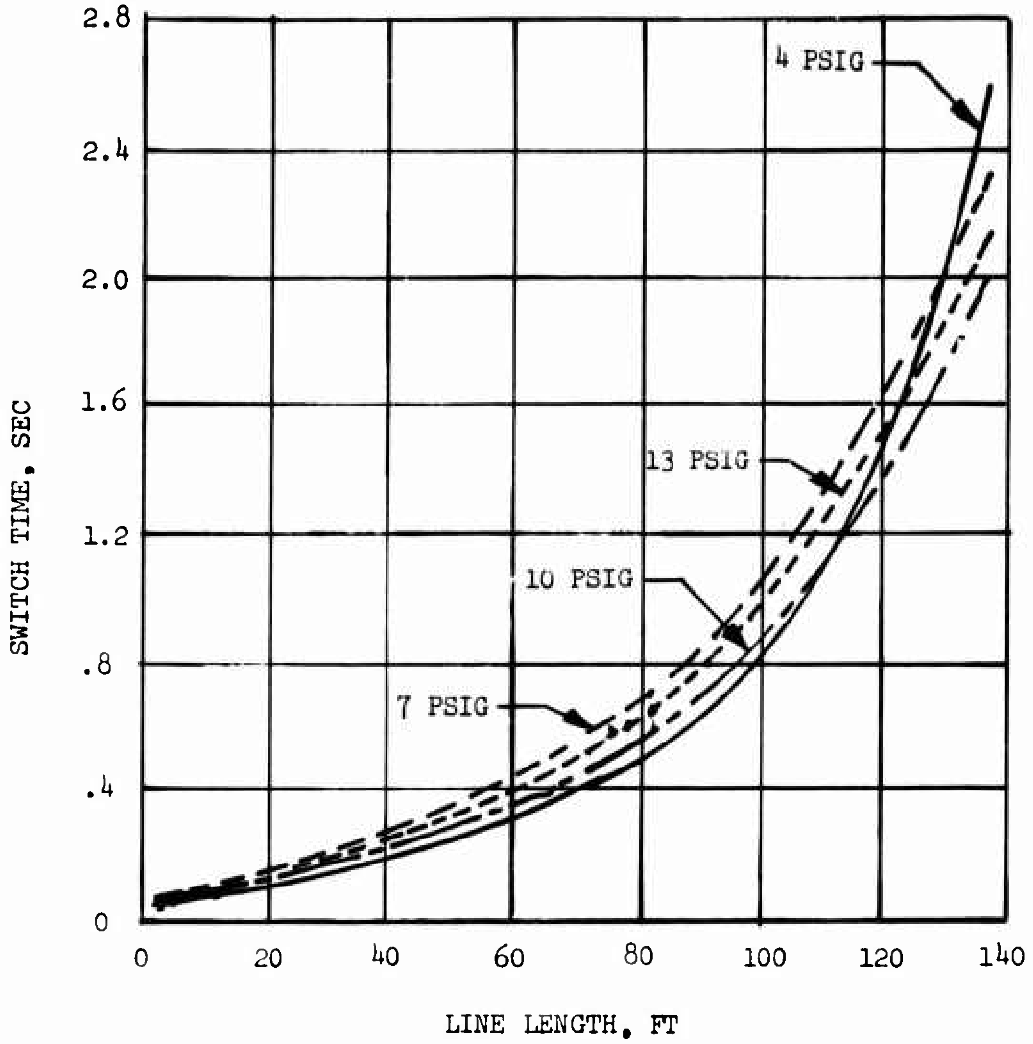


Figure 8. Back Pressure Switch Response Time - Switching Off.

Signal propagation times within the logic system were on the order of milliseconds and thus do not significantly add to the overall release times nor do they vary significantly with supply pressure.

Location of the various fluidic system components is limited, to a great extent, by the location of personnel and equipment in the aircraft. Four configurations were evaluated and the results obtained are described in Table 5.

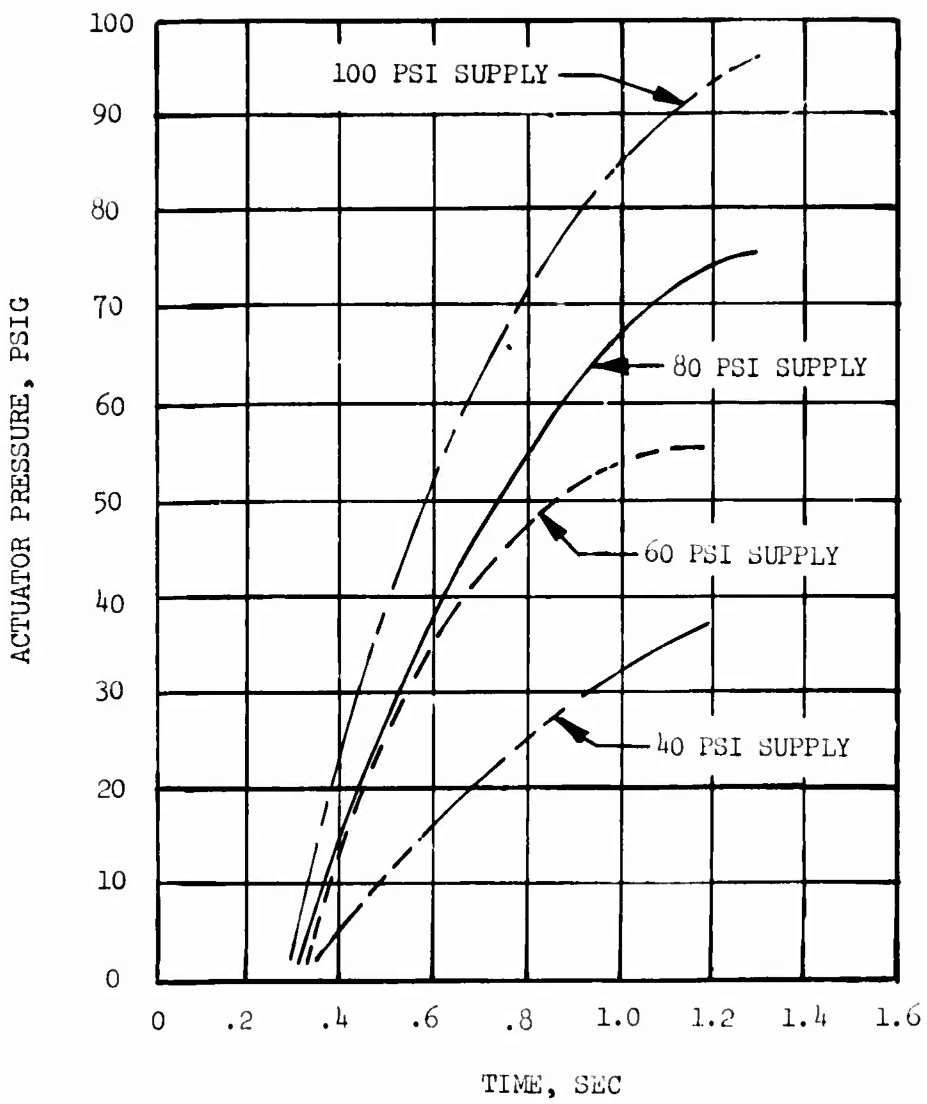


Figure 9. Hook Actuator - Pressure Rise Rate.

TABLE 5. PROTOTYPE CONTROL SYSTEM RELEASE TIME EVALUATION

COMPONENT LOCATION			RELEASE TIME, SEC.	
SWITCH MODULE	LOGIC MODULE	INTERFACE VALVE	NORMAL	AUTO TOUCHDOWN
Cockpit	Cockpit	Cockpit	1.23	2.33
Cockpit	Cockpit	Hoist	0.88	1.88
Cockpit	Hoist	Hoist	1.27	1.78
Cockpit	Midway	Hoist	1.03	1.80

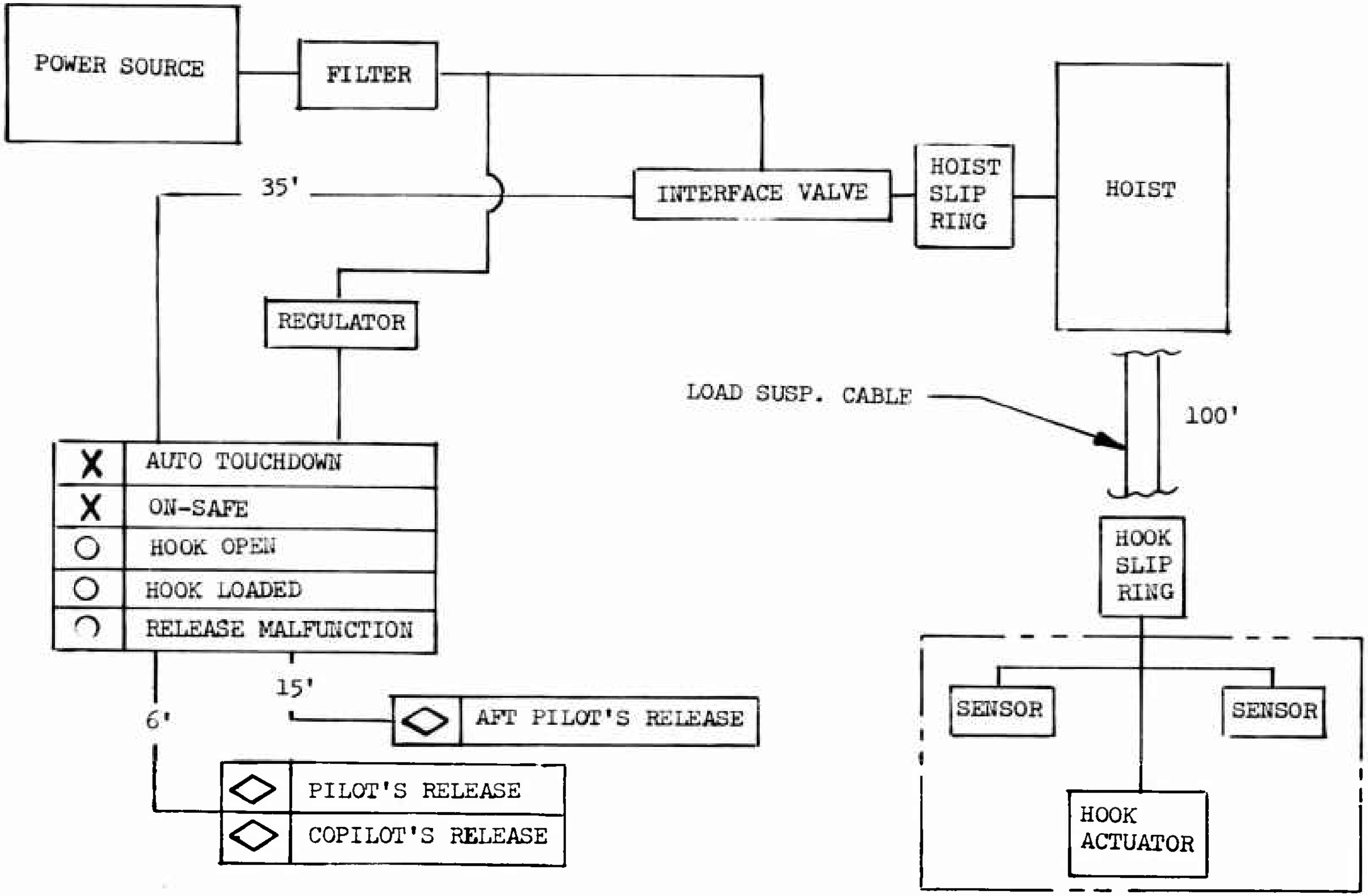


Figure 10. Breadboard Fluidic System Component Location.

The final breadboard circuit, shown in Figure 5, has the switch and logic modules integrated and located in the cockpit. The interface valve is located in the hoist well. Figure 10 shows the final breadboard system component locations.

DESIGN AND FABRICATION

Design of all the components of the system was based on the requirement that they conform to the physical limiations imposed by the existing CH-54B external cargo handling system. The existing hoist cable, with its seven-conductor electrical core, was replaced by a hoist cable with a three-channel plastic tube. The solenoid used to actuate the hook release mechanism was replaced by a pneumatic actuator. Electrical sensors in the hook were replaced with fluidic back pressure switches. Electromechanical slip rings at the hook and the hoist were replaced with pneumatic mechanical types. The existing electrical control circuitry was replaced by a fluidic circuit based on the data gathered during the development and testing of the breadboard fluidic circuit. The system is shown schematically in Figure 11. A bleed air port on the engine provides the air required. Power air is then piped to an interface valve, after passing through a pneumatic filter. Control air is piped to the fluidic logic control unit via appropriate filters and regulators from whence it is transmitted by the hoist slip ring to a three-chambered tube imbedded in the center of the 7/8-inch-diameter load suspension cable. A slip ring located in the hook swivel transmits the air from the three-chambered tube to the hook status sensors and the actuator located on the hook. The mode selector switch, controls, and indicators are taken from the fluidic logic control unit located in the cockpit.

INTEGRATED FLUIDIC CIRCUIT

Information gathered during the Basic Data phase of the program was used to prepare a procurement specification for the fluidic circuit, see Appendix A. As a result of conferences between Sikorsky and vendor personnel several modifications to this circuit were made, resulting in the final integrated circuit schematic as shown in Figure 12. The basic changes involved replacing AND logic elements with OR elements. This change was made to increase circuit reliability, since AND elements require closely balanced control inputs to produce the correct outputs. This change also required some relocation of elements. The time delay relay was also separated from the integrated module.

Pneumatic Slip Rings

Two three channel slip rings were fabricated: one for installation in the hoist, the other for use in the hook swivel. Space limitations required fabrication of adapter links between the swivel and hook to provide the required space. Both slip rings had the same sealing element design. A unique solution was developed to permit attachment of the polyethylene tubing to the slip rings.

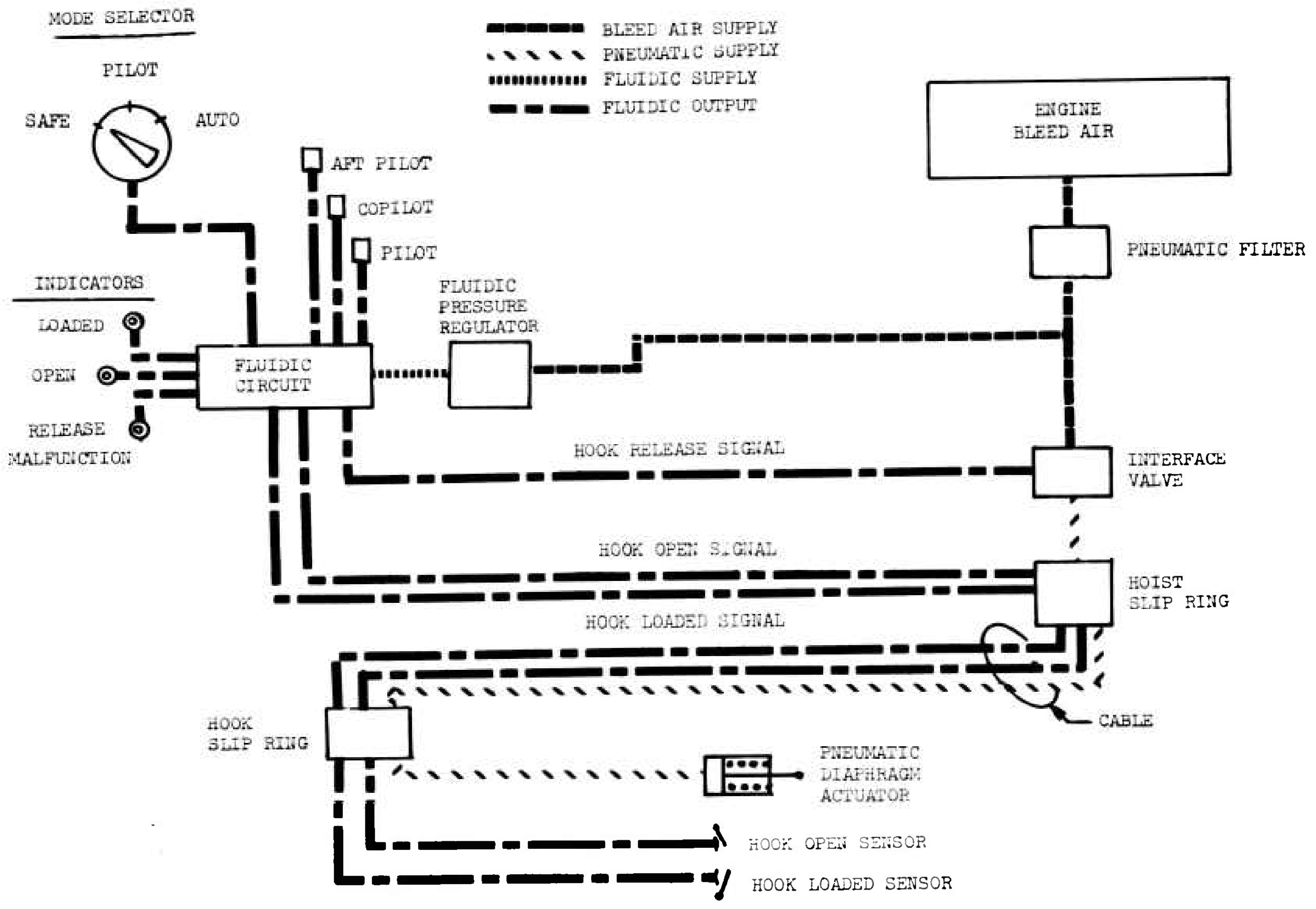


Figure 11. Schematic of Fluidically Controlled Cargo Hook System.

Hook Slip Ring

The existing swivel assembly used on the CH-54B contains a seven-channel pancake type modularized electrical slip ring. The size limitations imposed by this design could not be met by a pneumatic, three-channel slip ring, at least at this stage of the program. Hence steel links were fabricated to provide added clearance between the swivel and the hook for the slip ring. A major problem that required solution at this stage was to find a method of attaching the polyethylene tube to the slip ring housing. There is no known adhesive compatible with polyethylene, hence this concept had to be abandoned. This problem was eventually solved by developing a method of casting a block of polyurethane around the tubing. Figure 13 shows the prototype specimen. With this method it was possible to design adaptors to transmit the air from the tubing to the housing of the slip ring.

Hoist Slip Ring

Replacement of the electrical hoist slip ring proved to be far simpler. Space available was more than adequate and required only the appropriate adaptors be used. Sealing element design was identical with that used on the hook swivel, and the tube/housing attachment problem had been resolved during the design of the hook slip ring.

HOOK ACTUATOR

The hook actuator release torque requirements had been established during the Basic Data phase. Subsequent testing during the determination of system characteristics phase (see Figure 9) indicated that hook release times would be unacceptably long with the pneumatic pressures available unless actuator efficiency could be significantly increased. To achieve this goal a diaphragm type linear actuator was selected rather than the rotary (gland seal) type originally intended. The linear type actuator was attached to a crank arm on the hook actuator shaft.

CABLE/CORE ASSEMBLY

A cable/core assembly that would meet the constraints imposed by size (.923 inch maximum O.D.), strength (75,000-lb minimum breaking strength), construction (spin resistant), and material (corrosion resistant), and a core capable of being "buried" inside and of sufficient size and strength, proved to be the major design problems encountered.

One of the most difficult parts of the design effort was that of providing end fittings through which the three-channel polyethylene tube could be passed. This problem was solved at the hook end by the use of an "Electro-line" type fitting (see Figure 14). With this type of fitting the cable is installed between the wire strands of the cable and the core (polyethylene) tubing. The sleeve thus protects the core from damage (see Figure 14). At the drum end, where outside diameter limitations existed, and loads were considerably lower, a different concept was used.

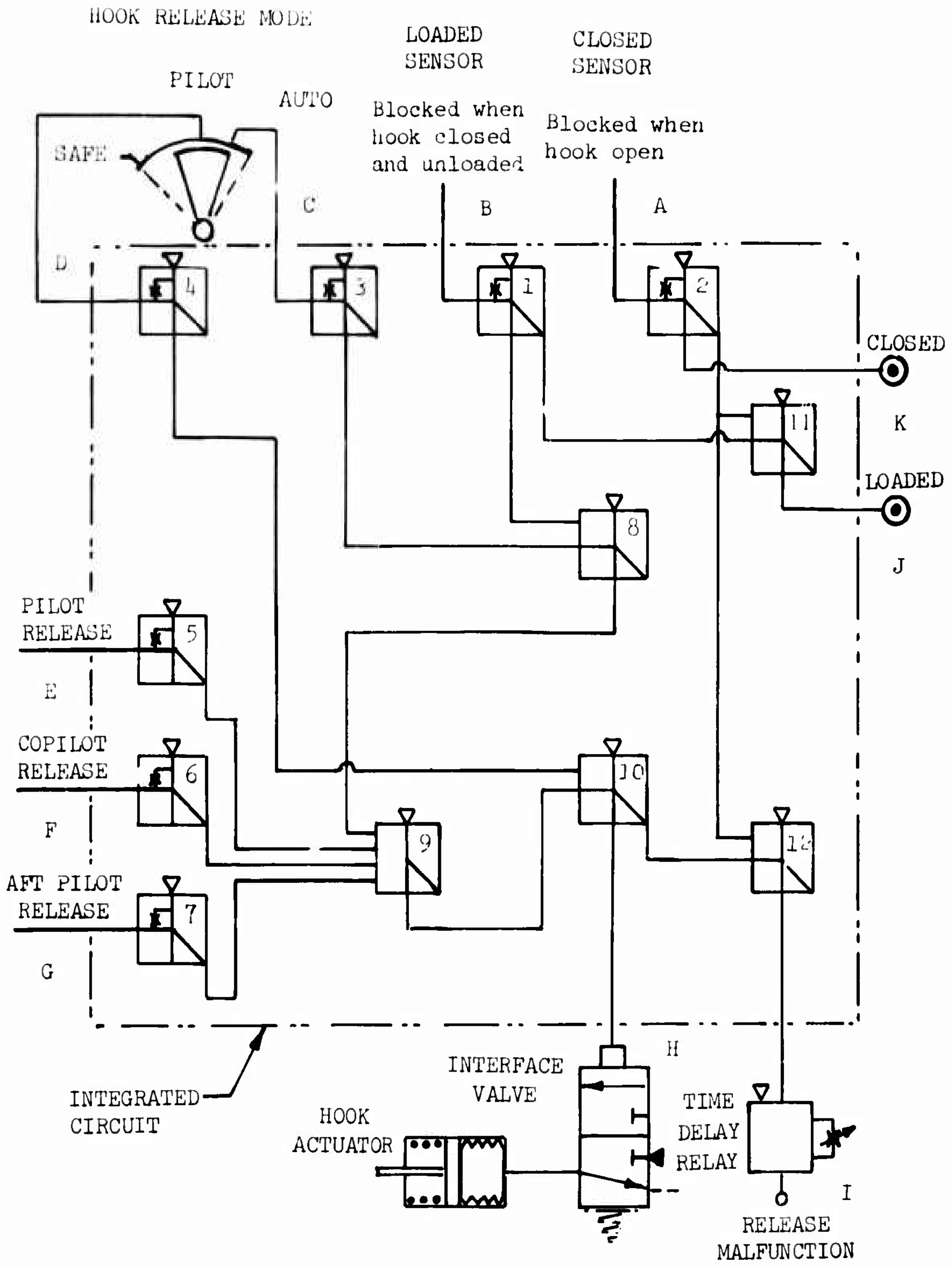


Figure 12. Final Integrated Fluidic Circuit.

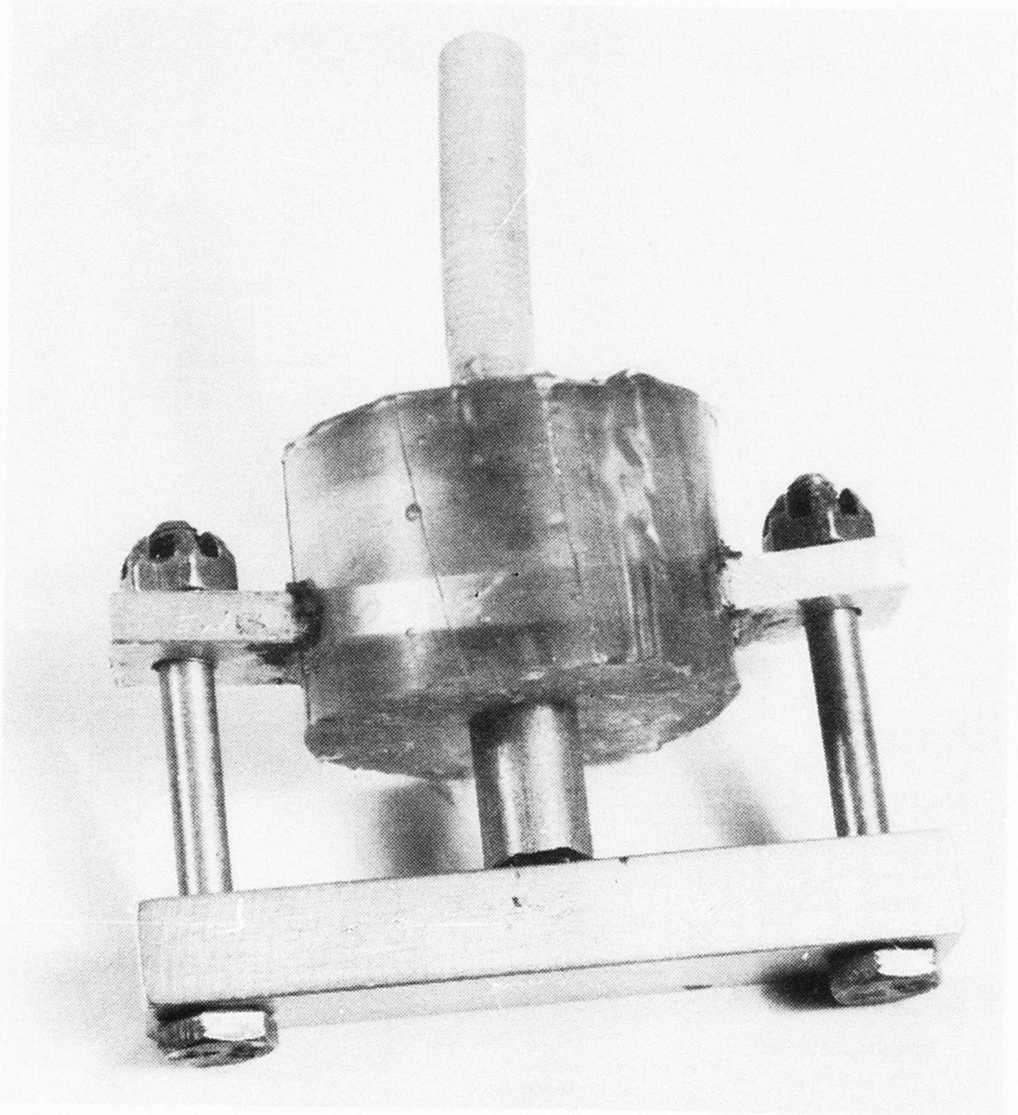
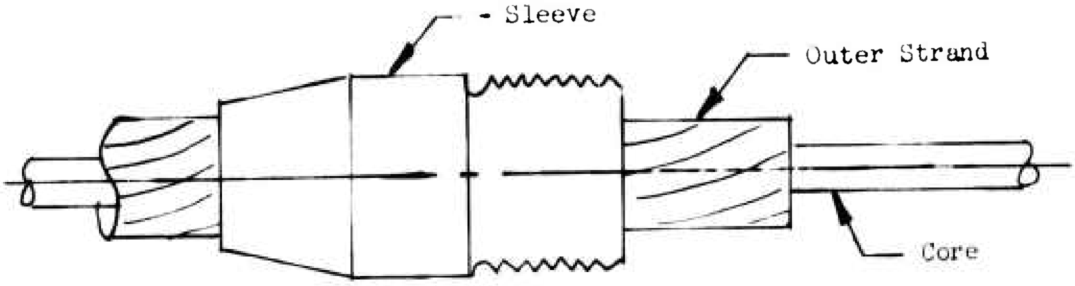
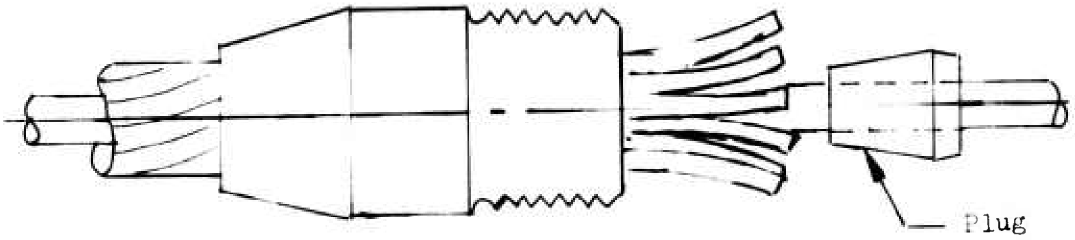


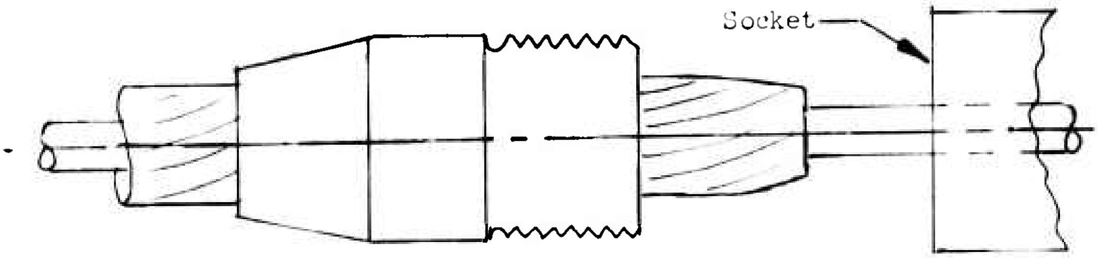
Figure 13. Bonding Fixture and Specimen.



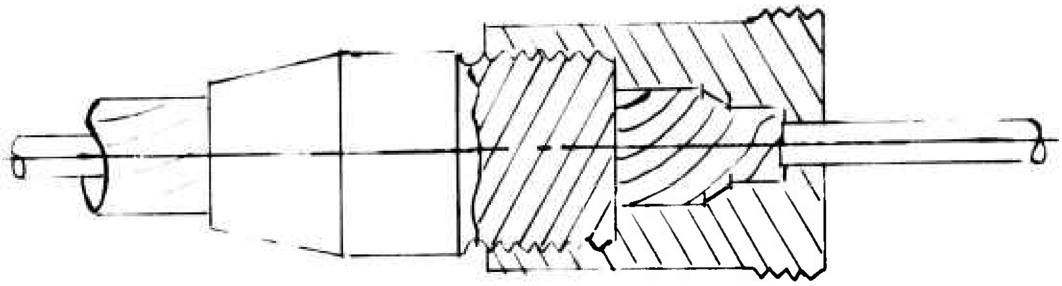
Stranding passed thru sleeve.



Wires fanned out for insertion of plug.



Plug driven in and wires closed to apply socket.



Socket applied - assembly completed.

Figure 14. Schematic of "Electroline" Type Cable End Fitting.

The strength, diameter and non-spin requirements also presented problems. These were overcome by developing a special cable construction. It consists of an inner layer of 8 strands of 26 wires wrapped in a left-hand Lang lay around the core and an outer layer of 14 strands of 26 wires wrapped in a right-hand Regular Lay. The eight inner strands were preformed but the fourteen outer strands were not. Although normal practice would utilize preformed wire in the outer strands also, they were not preformed because tooling for the special diameters and construction did not exist. In the time available it was impossible to obtain preformed strands. Also, it was not realized at the time that this compromise would affect the function of the cable (see Conclusions).

Assembly

A GFAE Cargo Hoist (FSN 1680-168-5739) was modified by the installation of a pneumatic/fluidic slip ring in place of the electrical slip ring and the installation of a cable assembly with a pneumatic/fluidic core in place of the standard cable with a seven-conductor electrical core.

A GFAE Cargo Hook/Swivel Assembly (FSN 1680-484-3223) was modified as described below:

- replaced electrical slip ring with pneumatic slip ring
- installed adapter links between hook and swivel
- replaced electrical solenoid with pneumatic actuator
- removed micro switches and replaced with flapper to indicate hook open status

The above major components, along with the fluidic logic and control units and interface valve, were then assembled in the Sikorsky Hoist Test Facility (see System Assembly section of Test Program).

TEST PROGRAM

SCOPE

This test program was performed to meet the requirements of Task III of the Fluidically Controlled Cargo Hook Program. The approved test plan is presented in Appendix B. All tests performed were accomplished in accordance with this plan, except where noted in the following procedures.

DATE AND PLACE

These tests were performed between November 1973 and August 1974.

Sand and dust tests were performed at the York Research Corporation, Stamford, Connecticut.

All other testing was performed in the test laboratories and the Hoist Test Facility at Sikorsky Aircraft, Stratford, Connecticut.

PROCEDURES AND RESULTS

Component Checkout and Assembly

Each of the following system components was subjected to performance and acceptance tests prior to assembly.

Integrated Circuits

Bench tests were performed on the three integrated circuits purchased for this program. Logic and function checks of the circuits showed operation to be in accordance with the procurement specification, Appendix A, for supply pressures of 1 to 14 psig. Quiescent flow or air consumption was measured and recorded. It was 1.4 ± 0.1 scfm at the maximum rated supply pressure of 10 psig. External output pressures or losses ranged from 45 to 55% of the supply pressure applied throughout the operating range. Frequency response was determined by measurement of the signal propagation time through each function of the units. The maximum response time recorded was 17.9 ms in the copilot's release function. Similarly, the minimum response time was recorded as 7.7 ms in the pilot's release function. All times varied through these extremes, increasing as supply pressure increased through the operating range of 3 to 10 psig.

Hoist Cable Assembly

Difficulities were encountered in making pressure tight connections to the three triangular passages of the polyethylene cable core. In order to perform pressure and leakage tests, the cable was assembled with the hook and hoist slip rings. This provided the most adequate connections for application of test pressures through the cable-slip ring adapters developed in the fabrication stage of this program. Following this assembly, the cable core passages were arbitrarily numbered 1, 2, and 3. The corresponding passages of both slip rings and their adapters were similarly identified.

Leakage tests were performed by applying 100 psig to each assembly passage individually. One external leak was detected from passage 2. This was slight and well below the range of available flow measurement equipment. It was suspected that the leakage was in the cable, but the exact location could not be determined. Leakage was observed between adjacent assembly passages as follows:

Passages	Observed Leakage
1 ↔ 2	0.02 scfm
1 ↔ 3	None
2 ↔ 3	Slight (unmeasurable)

Pressure drop through the assembly passages was measured as follows:

PSID	Passage Flow, SCFM		
	1	2	3
1.6	0.04	0.06	0.06
10.0	0.21	0.28	0.27
50.0	0.79	0.99	0.92
100.0	1.61	2.01	1.87

At this point in the test program, some concern existed for the strength of the connection between the cable core and the hook slip ring adapter. Therefore, proof pressure testing of the cable was deferred to the assembly proof pressure test to be performed during System Assembly and Checkout. At that time, in the complete assembly, the hook slip ring, the adapter, and the cable would be additionally contained by the hook swivel and eliminate the risk of damage to the one-of-a-kind cable.

To demonstrate structural adequacy of the cable core, burst pressure tests were performed on a sample of the core. A short piece was pressurized through passage 3 of the hoist slip ring adapter while the other end of the polyethylene core was welded closed. Passage 3 broke through to passage 2 at 400 psi. Upon a second application of pressure, passage 3 broke through to passage 1 at 350 psi. At 500 psi the core separated from the adapter fitting.

Cargo Hook Assembly

The hook sensors were checked for leakage in the blocked position. No leakage was detected at pressures to 10 psi. Pressure drop through the hook sensors in the unblocked position was measured as follows:

Pressure Inches of Water	FLOW, SCFM Hook Open Sensor	 Hook Loaded Sensor
1	0.1	0.09
2	0.15	0.14
3	0.19	0.17
4	0.22	0.20

The hook actuator is spring-loaded to the retracted position and is of the rolling diaphragm type. Operation was smooth with no binding. Spring rate was measured and recorded as 4.5 lb/in. with a 6.5-lb preload. Hook slip ring breakout torque was found to vary with the length of time the unit remained stationary. Breakout torque was 25 in.-lb after repeated cycling and 60-70 in.-lb initial breakout following extended static periods. Hook swivel breakout torque was 50-60 in.-lb.

A pressure of 100 psig was applied to all three ports of the hook slip ring simultaneously and the unit was immersed in water. Some slight leakage was noted coming from both ends of the hook slip ring at the bearings. This leakage was well below the threshold of the flow measurement equipment available.

Similarly, some slight inter-port leakage was found when 100 psig was applied to the individual ports. Pressure drop tests were performed on the individual passageways. Results are tabulated below:

	Passage Flow, SCFM		
PSID	1	2	3
0.25	0.43	0.43	0.43
1.00	0.90	0.90	0.90
2.00	1.30	1.30	1.33
4.00	1.90	1.90	1.95
6.00	2.35	2.35	2.42

Hoist Slip Ring

The hoist slip ring was tested to determine breakout torque. Breakout torque was 27 in.-lb for repeated motion applications and 60-70 in.-lb for initial breakout following extended static periods.

Pressure drop through the three slip ring passages, including the slip ring-cable adapter, was measured and recorded as follows:

	Passage Flow, SCFM		
PSID	1	2	3
0.25	0.20	0.20	0.20
1.00	0.46	0.46	0.40
4.00	0.98	0.98	0.92
6.00	1.22	1.22	1.17
8.00	1.47	1.47	1.42

Leakage tests were performed on the hoist slip ring by both individual and collective passage pressurization. The slip ring assembly was immersed in water during pressurization. Leakage observed varied from none at low pressure to very slight at 100 psig. This leakage was well below the range of available flow measurement equipment and amounted to only a few bubbles in the water tank.

Interface Valve

Testing of the breadboard system revealed that the threshold pressure of the interface valve was too low. For the final system a spring and retainer were installed under the interface valve diaphragm, which boosted the threshold pressure to the desired level of 0.5 psig.

Frequency response tests were performed on the interface valve, and when results were tabulated, it was found that the valve was relatively insensitive to orientation and supply pressure variations. Response times varied between 18 and 28 ms.

Quiescent flow of the valve was measured and found to be dependent on supply pressure as follows:

Supply Pressure PSIG	Quiescent Flow SCFM
30	0.05
60	0.10
90	0.13

Pressure drop was measured across the valve between the supply port and the outlet port when the valve was actuated open. Results are tabulated below:

PSID	FLOW, SCFM (supply to load)
2	1.2
6	2.4
10	3.4
14	4.4
18	5.5

Control Box Components

A control valve, for the pilot's release mode selection on the control box, was not readily available with porting exactly as required for the fluidic cargo hook circuit. A valve meeting all other requirements with similar porting was purchased. Upon receipt of the valve, porting was modified to meet the system requirements. Functional acceptance tests of the modified valve disclosed no problems.

All other control box indicators and controls were bench tested to manufacturer's specifications and were found to be acceptable.

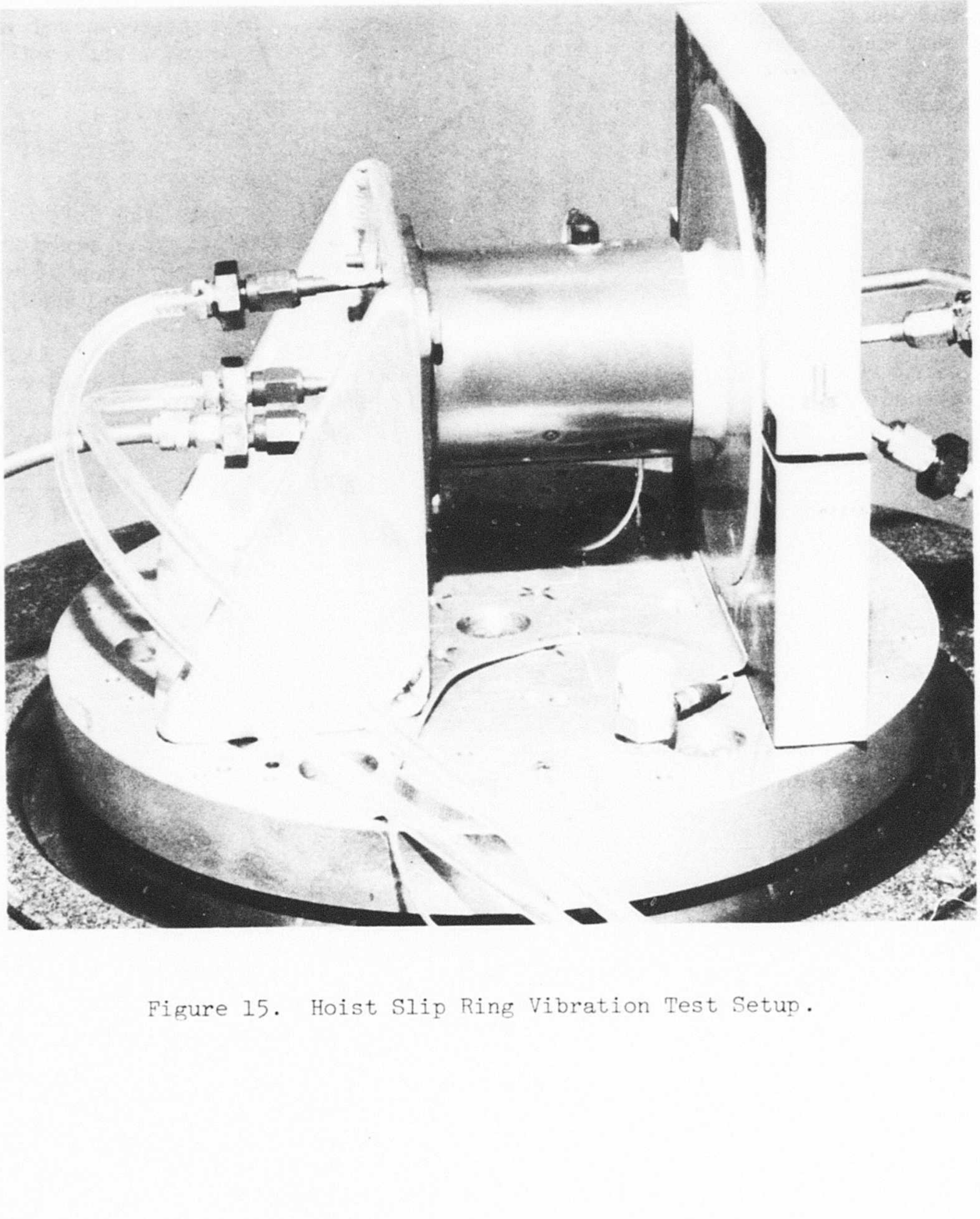


Figure 15. Hoist Slip Ring Vibration Test Setup.

Air Supply System

The air supply system filters and fluidic system supply pressure regulator were tested. The filters adequately removed solid contaminants injurious to fluidic system operation. The regulator was adjusted to 9 psig and was functionally tested without malfunction. Cooling loop development and evaluation were accomplished during extreme temperature tests.

Environmental Tests

Vibration Tests

Vibration tests were performed on the fluidic control box, the hoist slip ring and the interface valve. During all vibration tests, the cargo hook and other functional components were connected by flexible tubing to other system components, including the cargo hook, to permit functional checks.

Each component was tested in accordance with MIL-STD-810B, Method 514, Category C, Procedure I-1, Curve M (equipment installed in helicopters, without vibration isolators). The fluidic control box was tested in three mutually perpendicular axes. The hoist slip ring and interface valve were each tested in two axes since both are symetric about one axis. Typical test setups are shown for the hoist slip ring in Figure 15, and the interface valve in Figure 16.

Following these tests, the three components were collectively subjected to 3 hours of continuous vibration at 3 Hz and 0.10 inch double amplitude and 3 hours at 18 Hz and 0.10 inch double amplitude. This test setup is shown in Figure 17.

During all testing the components and system were subjected to periodic functional checks. Throughout the vibration tests, no malfunctions occurred. Upon disassembly and inspection of the system following these tests, no evidence of damage was observed.

Extreme Temperatures

The system components, including cooling loop, filters, fluidic supply pressure regulator, fluidic control module, hook slip rings, hoist slip rings, cargo hook assembly, and interface valve, were assembled in the environmental chamber. The hoist slip ring and the hook slip ring were connected with 100 feet of polyethylene cable core conductor. Provisions were made to meter controlled amounts of water into the supply air.

A pressure regulator and heater were installed in the air supply line to simulate engine bleed air conditions. A pneumatic actuator was installed on the hook load beam to simulate hook loaded or unloaded conditions. This actuator was controlled by a manually controlled three-way valve located outside of the chamber. A tee fitting was installed in the hook closed line and the leg of the tee was plumbed to a manually operated two-way valve located outside of the chamber. This was done so that a hook release malfunction could be simulated as part of the functional check-

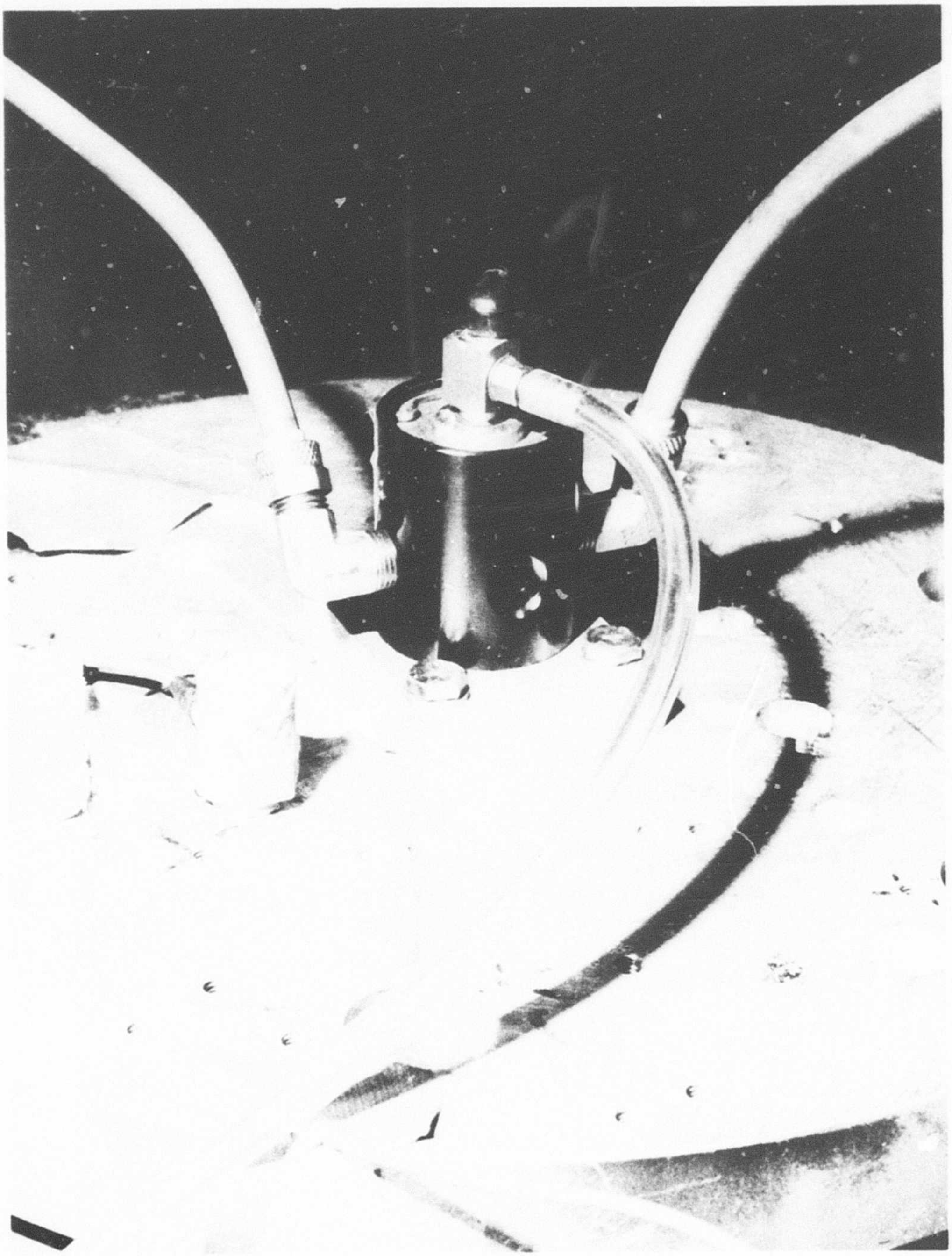


Figure 16. Interface Valve Vibration Test Setup.

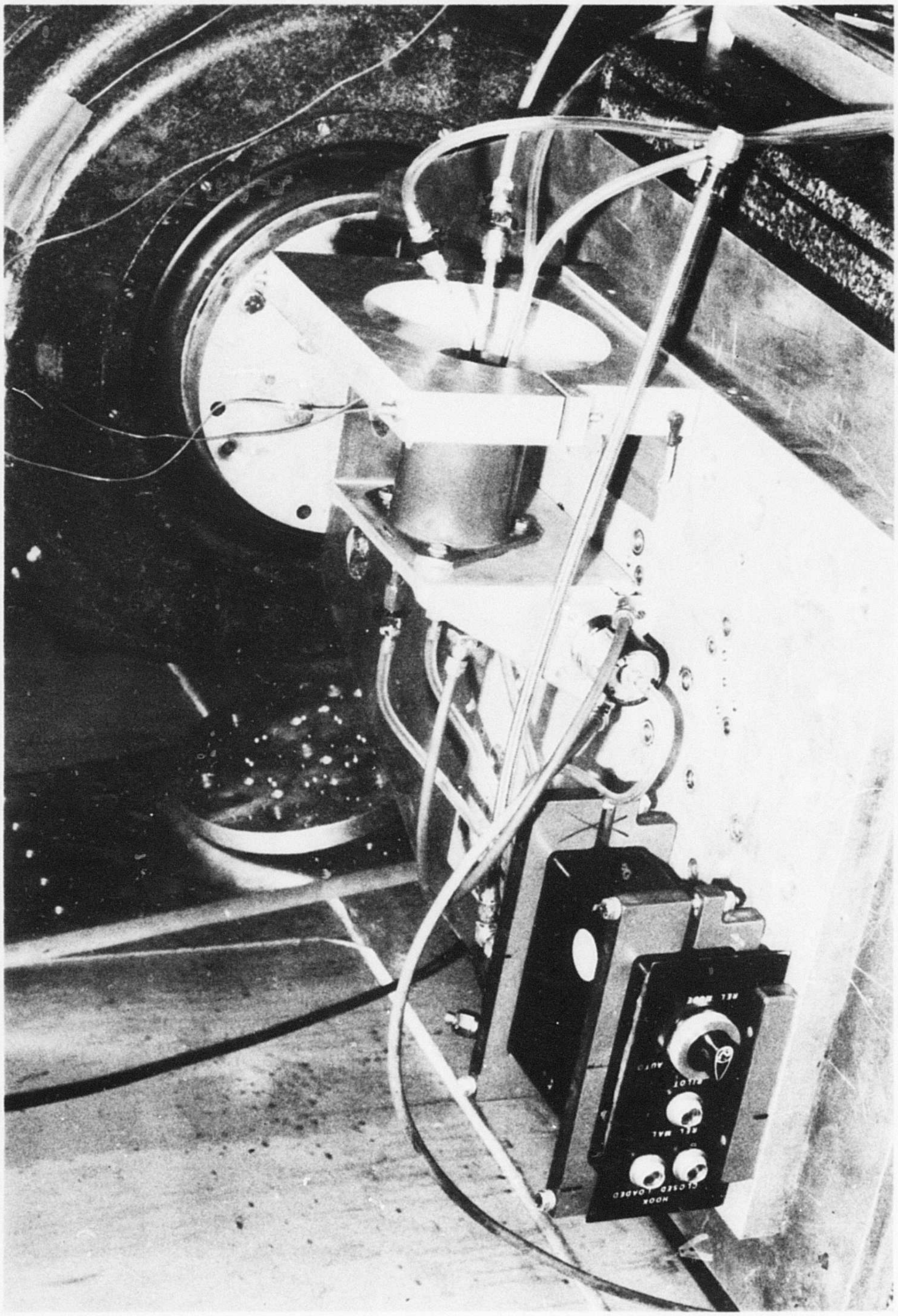


Figure 17. System Vibration Test Setup.

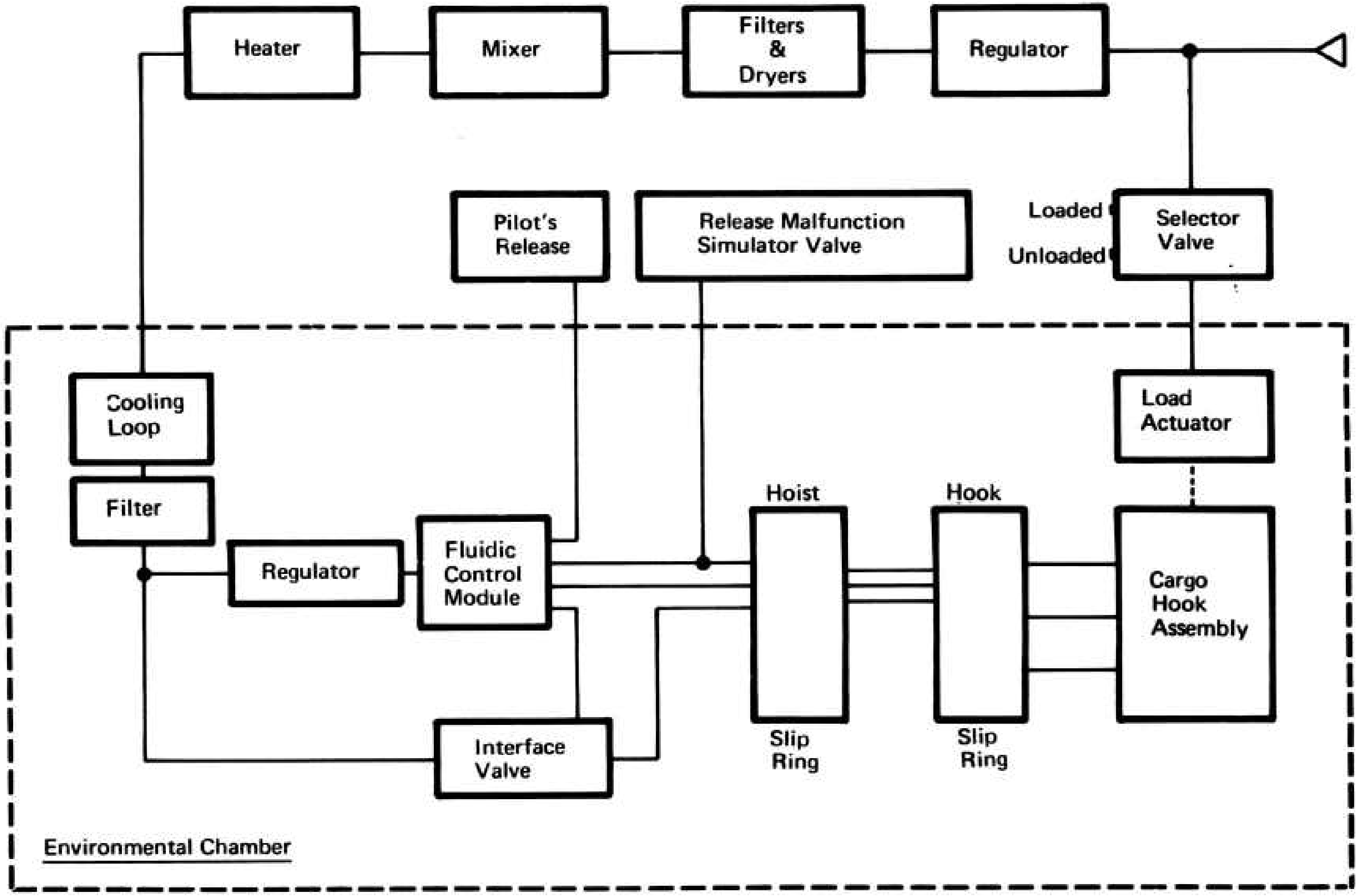


Figure 18. Block Diagram - Extreme Temperature Test Setup.

out of the system.

It was estimated that the length of line required to form the cooling loop would be 15 feet. Tests were performed to ascertain cooling loop effectiveness before beginning extreme temperature tests. A restrictor was installed at the end of the cooling loop to simulate the load of the fluidic system. The supply air conditioning system was adjusted to maintain cooling loop inlet conditions of 500°F and 9 psig. Cooling loop outlet temperature was measured and found to be equal to ambient temperature. The length of the cooling loop was then gradually reduced until outlet temperature was a few degrees above ambient. The final length of the cooling loop was 7 feet. A block diagram and a photograph of the extreme temperature test setup are shown in Figure 18 and Figure 19 respectively.

The hook release mode switch on the fluidic controls module was positioned to the automatic touchdown position. One pilot's release control was set up outside of the chamber. The cargo hook assembly was oriented inside the chamber so that the manual release knob could be observed through the window. The manual release knob is mechanically in series with the hook actuator and thus provides an indication of hook actuator operation. Similarly, the fluidic control module was oriented so that indicator operation could be observed through the chamber window.

Low Temperature Test

The supply air was adjusted to maintain a condition of 40 psig, 132°F, and 0.75 $in.^3$/hr water flow. The fluidic supply pressure regulator was set to 9 psig. The chamber controls were set to rapidly reduce temperature to -65°F. During the cool-down period the following observations were made: At 32°F and 10 minutes into the cool-down period, the release malfunction indicator came on briefly during each release cycle; the period of time that the indicator remained on increased with decreasing temperature. At -10°F and 1 hour into the cool-down period, the interface valve did not respond to an input signal. At -40°F and 1.7 hours into the cool-down period, the supply pressure began dropping off. At -58°F and 2 hours into the cool-down period, the supply pressure had dropped to 0 psig. A temperature of -65°F was maintained for 6 hours. During this time the supply pressure remained at 0 psig and functional tests could not be performed. The chamber controls were set for a rapid warm-up to 70°F. During the warm-up period the supply pressure remained at 0 psig until a temperature of +58°F was reached. At this time the supply pressure suddenly returned to 40 psig and the fluidic supply pressure suddenly returned to 9 psig. A functional check of the system was immediately performed, and the only problem encountered was that the release malfunction indicator again came on briefly during release cycles. The period of time that the release malfunction indicator remained on gradually decreased to zero as the system stabilized at 70°F. All components were visually inspected for damage. No damage was found. The problem encountered with the interface valve is discussed in DISCUSSION OF RESULTS.

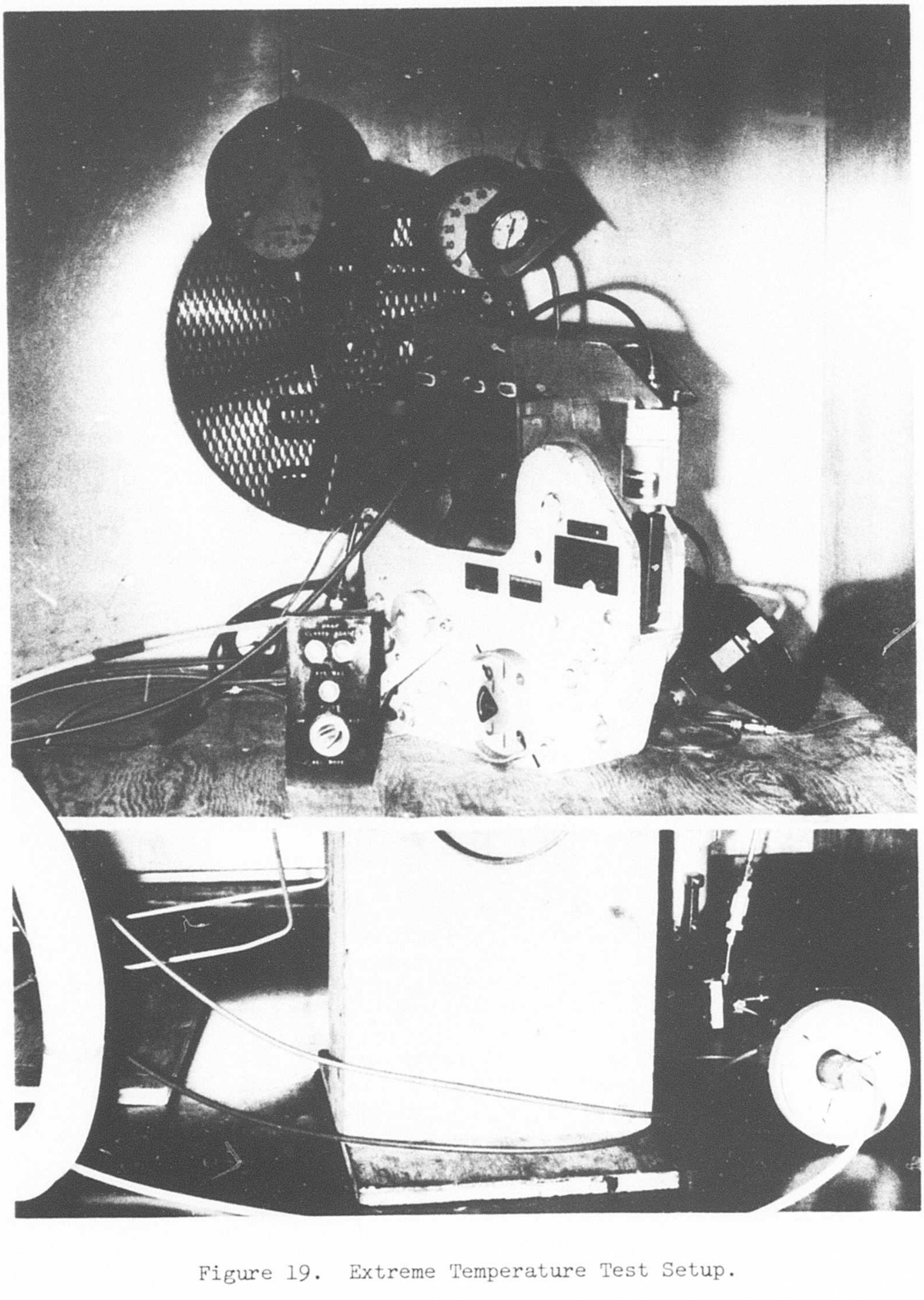


Figure 19. Extreme Temperature Test Setup.

High Temperature Test

The cooling loop was relocated outside of the chamber and the supply air was maintained at 76 psig, $500^{\circ}F$, and 0.75 $in.^3$/hr water flow. The chamber controls were set to rapidly increase the temperature to $+160^{\circ}F$. The cargo hook system functioned properly during the warm-up period. The chamber controls were set to maintain a temperature of $+160^{\circ}F$ for 6 hours.

After 1 hour, a functional check was performed, and it was noted that both the closed and loaded indicators were sticking in the "on" position. After several cycles the indicators began to function properly. The functional check performed on the third hour revealed that the system would not respond to an automatic touchdown release and that the fluidic system supply pressure had decreased to 7.5 psi. The soak period was interrupted to determine the cause of the malfunction.

The plastic tube supplying air to the integrated circuit had come loose. The tube was reconnected and securely clamped. The remaining tubing connections showed evidence of softening and slipping, so their clamps were tightened. The indicators were disassembled, cleaned and reinstalled in the control module. The high temperature test was repeated. No problems occurred during the warm-up period. During the 6-hour soak, the sticking indicator problem persisted. At the conclusion of the rapid cool down to room temperature, all components were visually inspected. No damage was found. The high temperature test was repeated with the cooling loop installed inside the chamber and the chamber controls set for $120^{\circ}F$. No new problems were encountered.

Contaminated Air Test

The extreme temperature test setup was utilized for the contaminated air test. The heater was removed from the circuit and provision was made to meter controlled amounts of sand into the supply air. The sand was the same as that specified in MIL-E-5007C, paragraph 3.25 (Mikel's Mix). The supply air system was adjusted to deliver 0.75 $in.^3$/hr water flow and 3×10^{-4} lb/hr sand flow at 76 psi. The system was operated using this contaminated air supply for 64.5 hours. Functional checks of the system revealed no problems. The filters were not drained during the test. At the conclusion of the test the filters were removed and disassembled. The first (pre-filter) filter element and bowl were heavily coated with sand. The pre-filter bowl was half full of water. The second filter element and bowl appeared to be clean and dry. Figure 20 shows the condition of these filters. The cargo hook system was then operated for an additional 2 hours with the same contaminated air supply conditions, but with the filters removed from the system.

Soon after the system was turned on, a functional check was performed. The hook released properly, but the interface valve did not return completely to the off mode. That is, the interface valve began to bypass

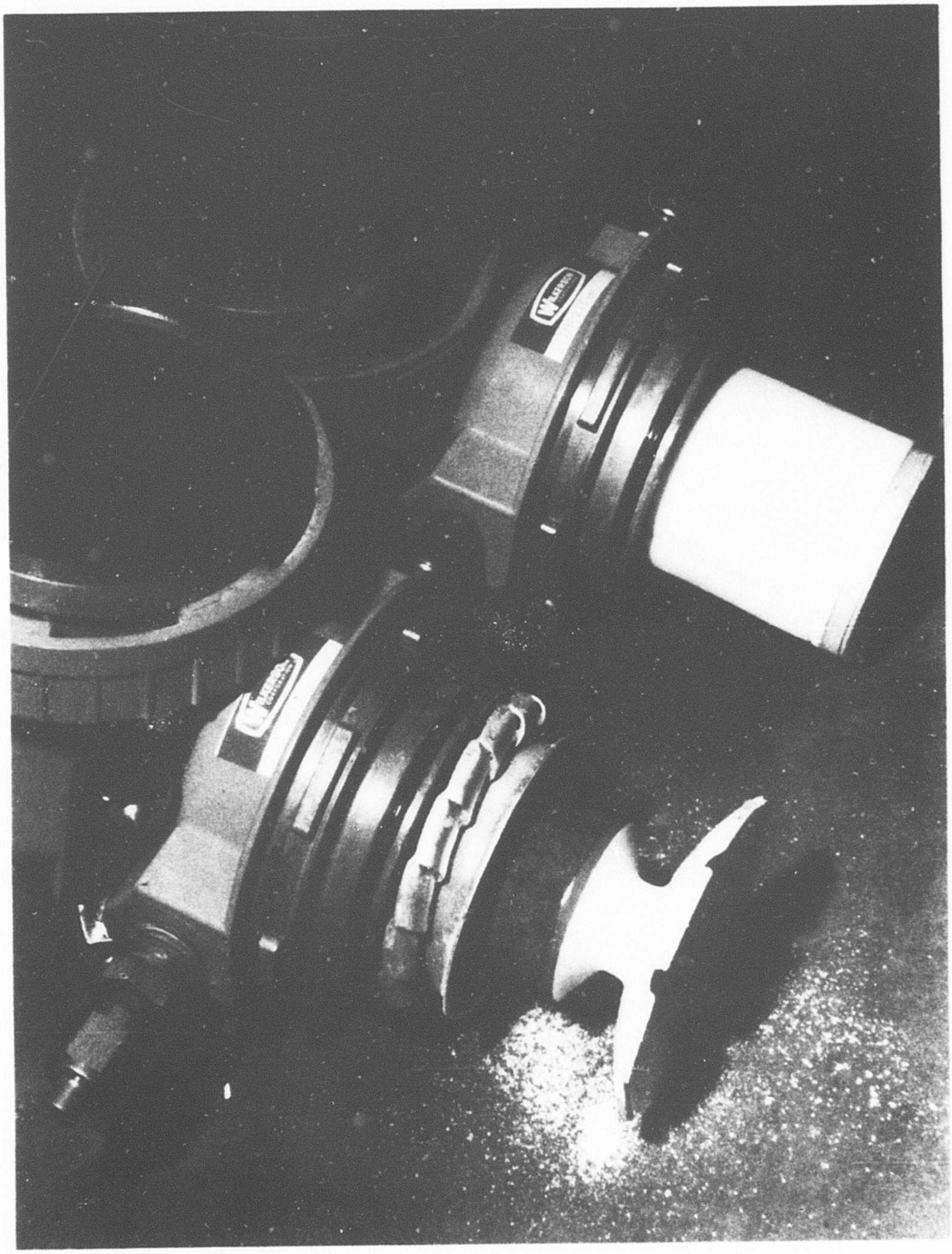


Figure 20. Condition of System Filters After Contaminated Air Test.

flow from the supply port to the exhaust port. Functional tests were performed every 10 minutes thereafter. During the second functional check, the fluidic supply pressure was noted to be 7.5 psig. During the seventh functional check, the fluidic supply pressure had decreased to 6.5 psig. During the ninth functional check, the interface valve internal leakage ceased. At the completion of the test, the system was inspected for evidence of contamination. A heavy quantity of sand was found inside the interface valve body and on its poppets. Large quantities of sand were found in the regulator. Figure 21 shows the sand accumulation. No evidence of contamination was found in the fluidic controls module. Traces of sand and water were found in the hoist slip ring. No evidence of contamination was found in the hook slip ring or hook actuator.

Sand and Dust Tests

The sand and dust test was set up as shown in Figures 22 and 23. Testing was performed in accordance with MIL-STD-810B, Method 510 as follows:

The system was placed in the sand and dust chamber. An air supply and one pilot's release control was connected outside of the chamber and the chamber was sealed. The chamber temperature was set at +23°C with the relative humidity at less than 22%. Sand and dust density was raised to 0.3 ± 0.2 gm/ft^3 and the air velocity was maintained at 1750 fpm. The above conditions were maintained for 6 hours. The fluidic power remained on during this period. Fluidic power was then turned off and the chamber temperature was increased to +63°C. The air velocity was reduced to 300 ± 200 fpm. These conditions were maintained for 16 hours with fluidic power off.

The system was then subjected to an on-off functional test in the normal release mode, the slip rings were rotated, and the hook was cycled 10 times.

The chamber temperature was set at +63°C and the air velocity was maintained at 1750 fpm for a 6-hour period. The fluidic power remained on during this period.

The chamber controls were turned off and the system was allowed to return to ambient conditions. No attempt was made to remove accumulated sand and dust. Figure 24 shows the system at this time.

At ambient conditions, the system was subjected to an on-off functional test in the normal release mode, the slip rings were rotated, and the hook was cycled 10 times.

Examination and inspection of the components following these tests disclosed no physical damage or deterioration of the system.

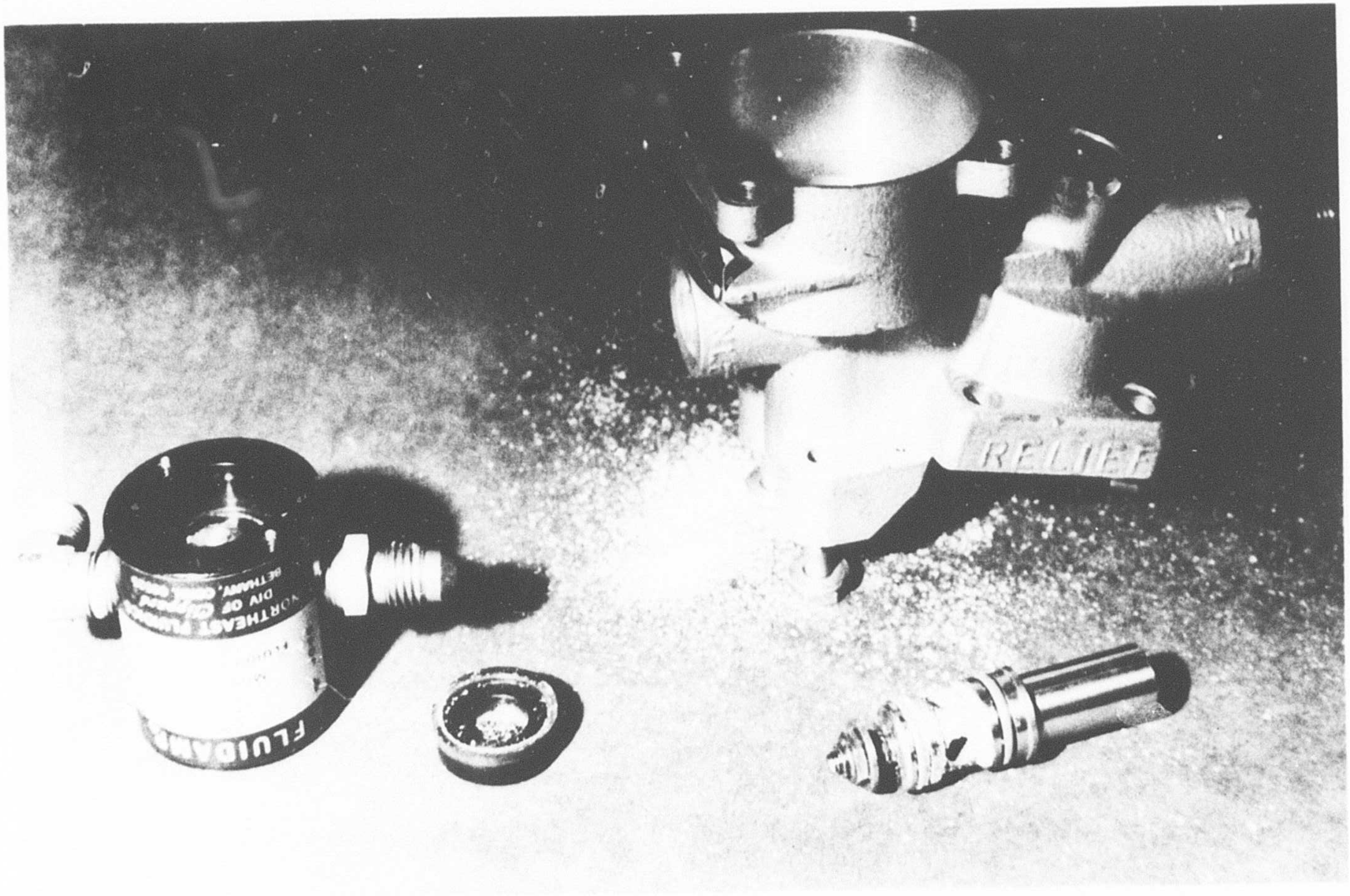


Figure 21. Sand Accumulation in Pressure Regulator and Interface Valve.

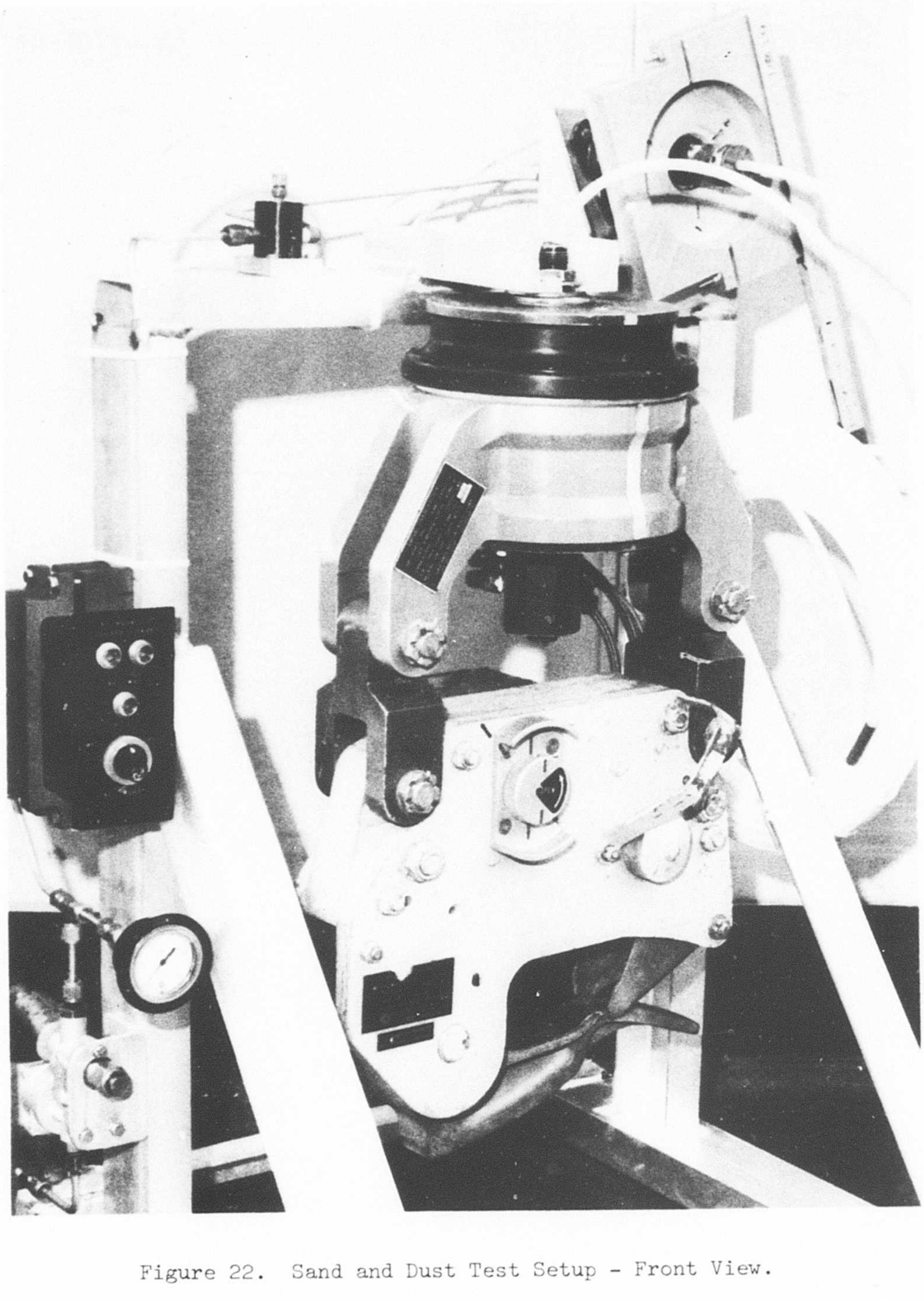


Figure 22. Sand and Dust Test Setup - Front View.

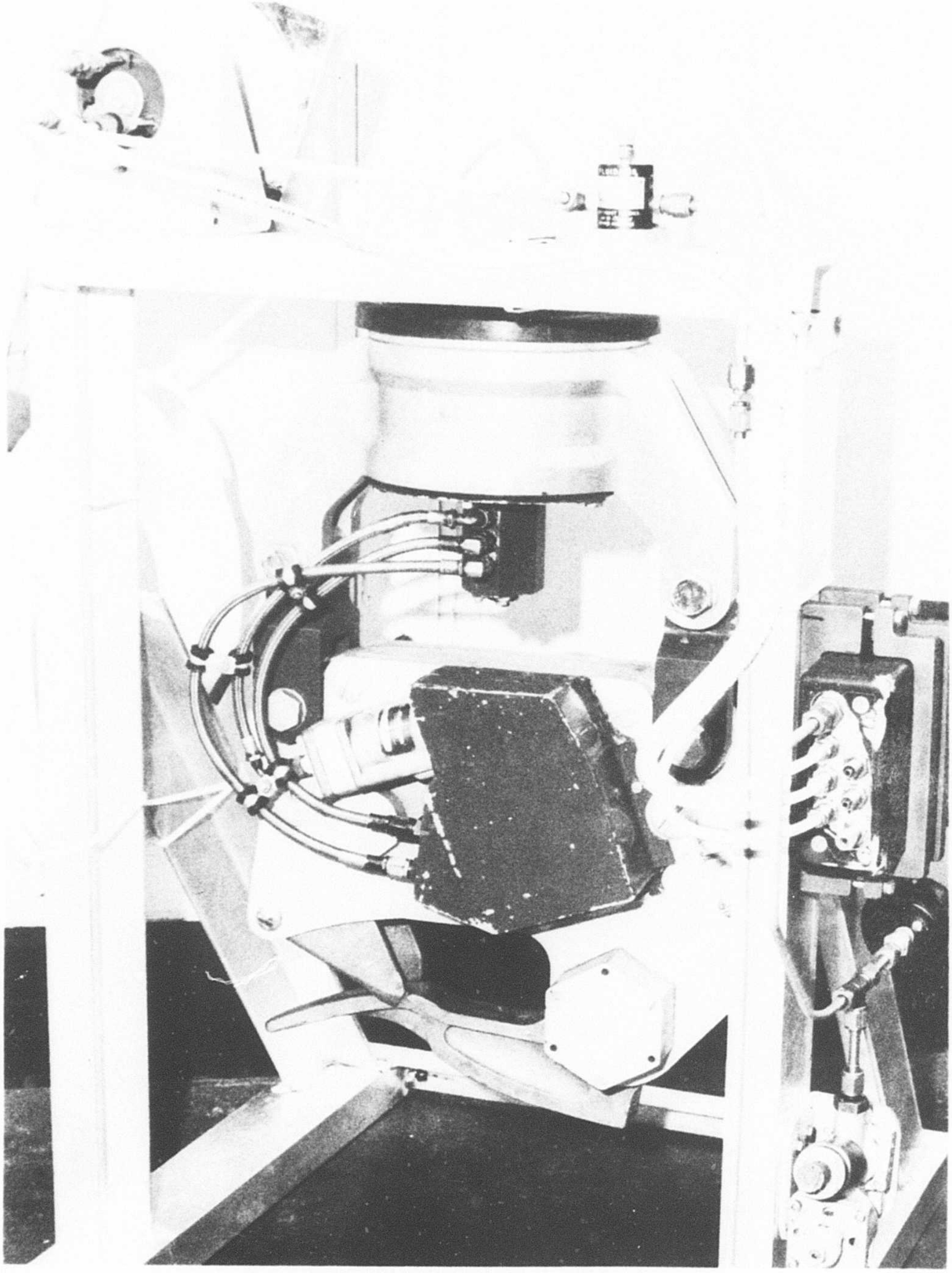


Figure 23. Sand and Dust Test Setup - Side View.

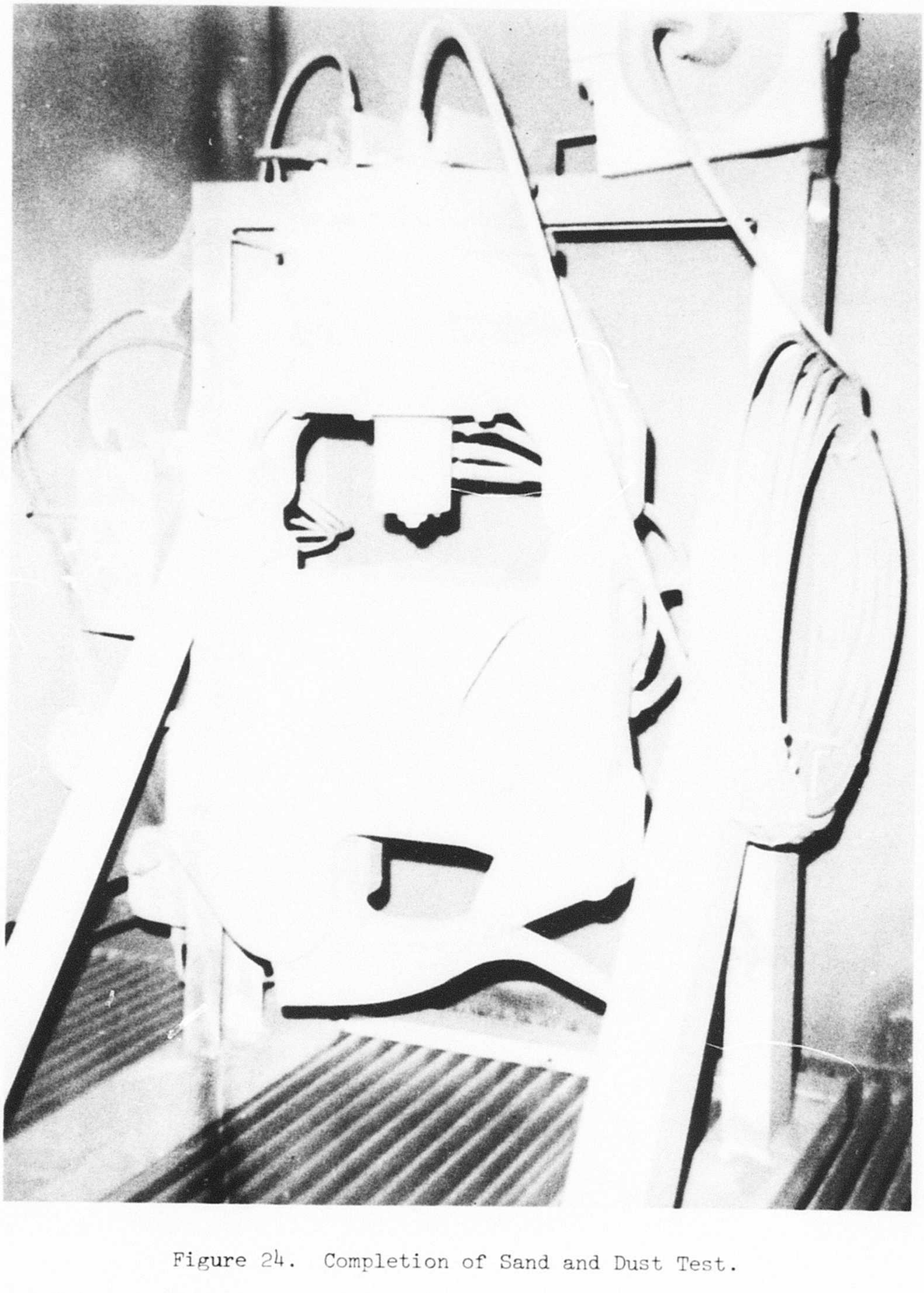


Figure 24. Completion of Sand and Dust Test.

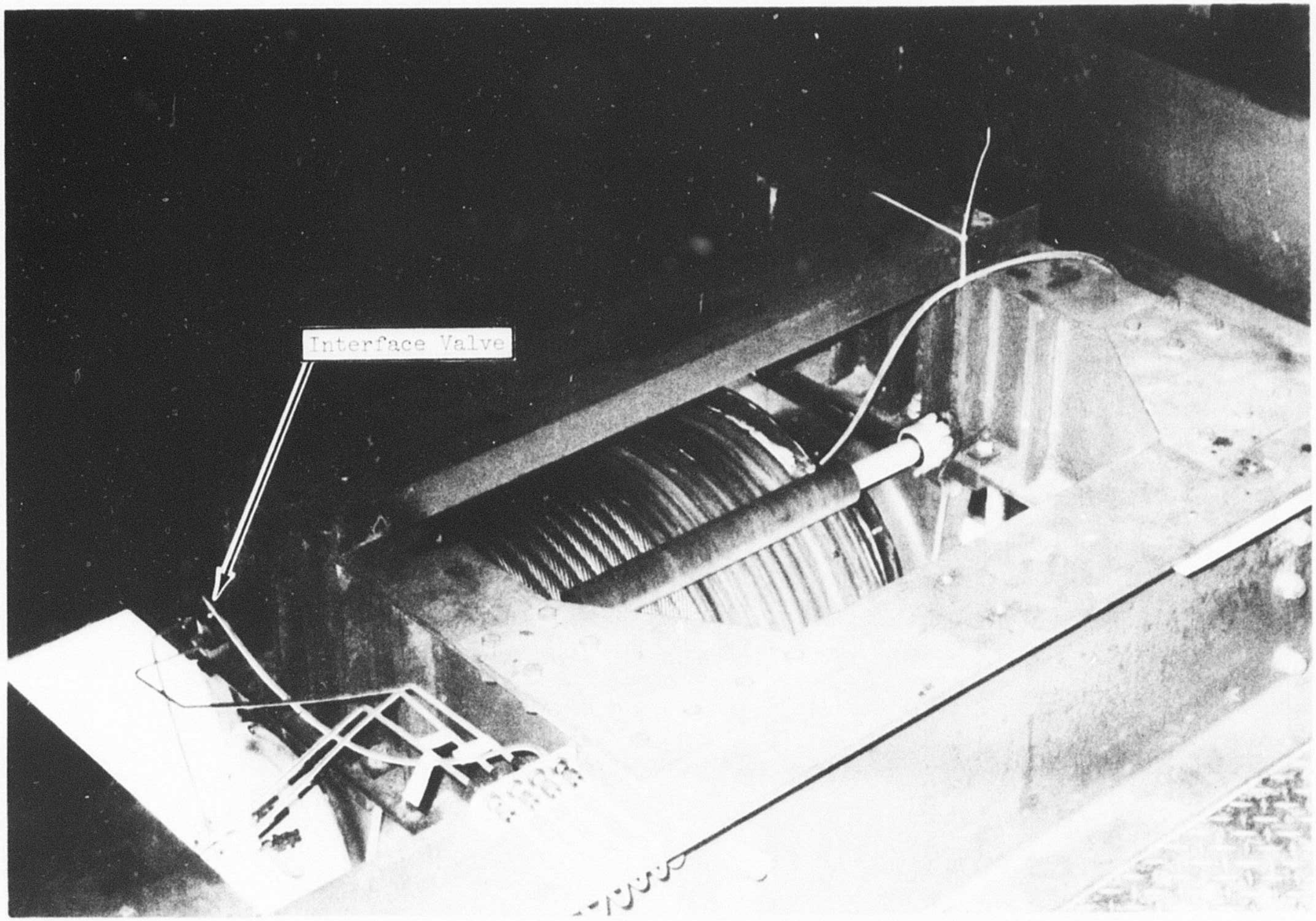


Figure 25. Interface Valve Installation in Hoist Well.

Installed System Functional and Endurance Tests

System Assembly and Checkout

System Assembly

The entire cargo hook system was assembled in the Sikorsky Hoist Test Facility. Components were located in accordance with the optimized locations determined in the breadboard phase of this program. The interface valve was mounted in the hoist well approximately 16 inches away from the hoist slip ring. This installation is shown in Figure 25. The fluidic control module was located in the facility control room and is shown in Figure 26.

Interconnections between the hoist slip ring and the control room were accomplished with ¼-inch aluminum and nylon tubing. Total line lengths are tabulated below:

	Hook Closed Indicator	Hook Loaded Indicator	Interface Valve Input Signal
Length, ft	48.6	48.3	47.2

Pressure drop tests were performed on the plumbing between the hoist slip ring and the fluidic controls module. Results are tabulated below:

	PASSAGE FLOW, SCFM		
PSID	Hook Closed Indicator	Hook Loaded Indicator	Interface Valve Input Signal
0.49	0.19	0.17	0.12
0.98	0.29	0.28	0.23
1.96	0.46	0.45	0.35
2.95	0.58	0.56	0.47

A reciprocating air compressor of 10 cfm flow capacity and 4 ft^3 receiver tank volume was used as the system air source. The bleed air pressure regulator and air conditioning system filters were connected to the air compressor through 29 feet of 3/8-inch tubing. Immediately downstream of the filters a tee fitting directed supply air to the interface valve and to the fluidic controls module pressure regulator. Supply pressure line lengths, all of ¼-inch tubing, are tabulated below:

Tee fitting to interface valve	27.6 feet
Tee fitting to fluidic supply pressure regulator	18 feet
Fluidic supply pressure regulator to fluidic controls module	2 feet

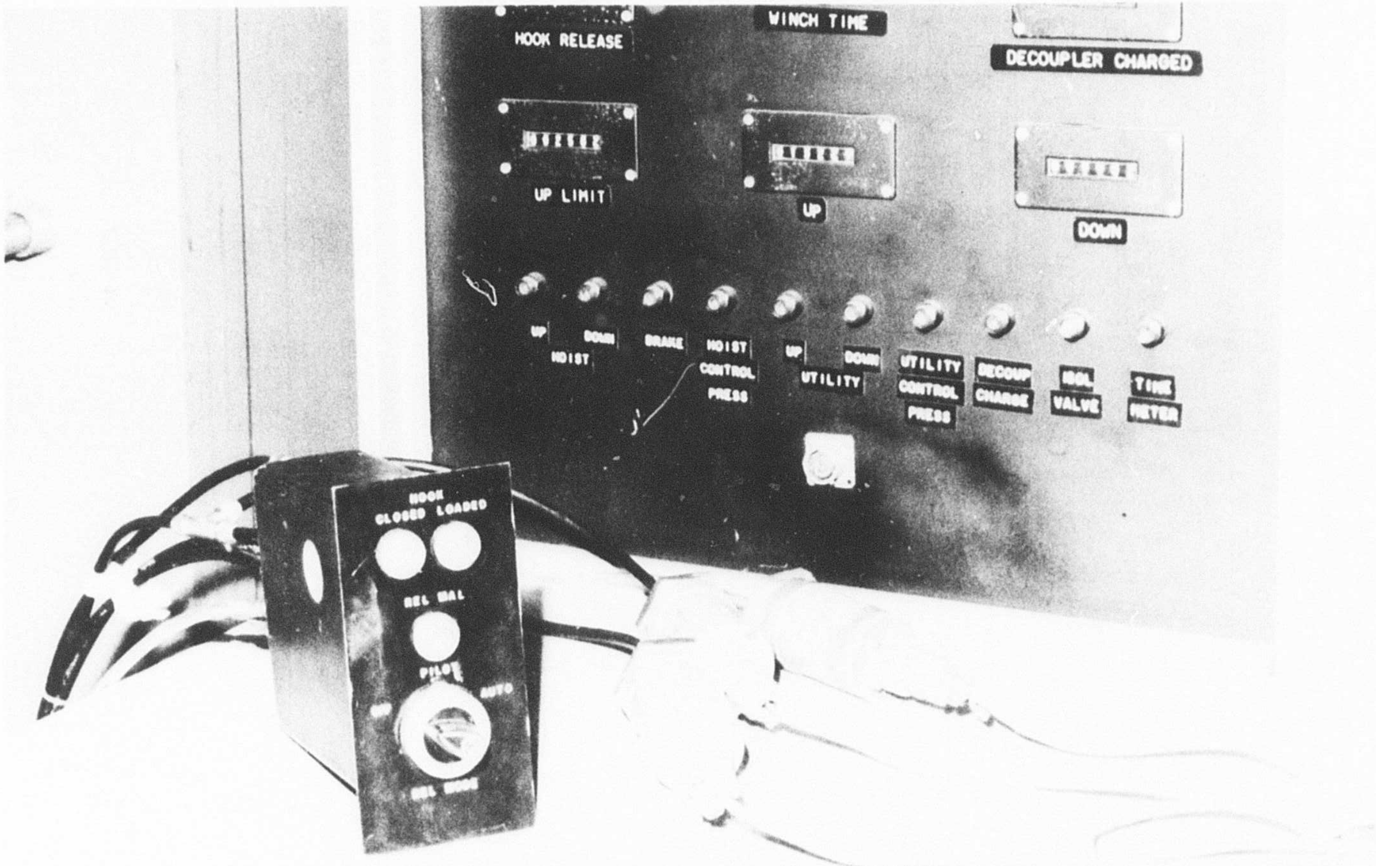


Figure 26. Fluidic Control Module Installation.

In the control room, a two-hand release system was installed to lessen the probability of an accidental release.

The cable assembly and hoist slip ring were installed on a Sikorsky CH-54B Cargo Hoist. No difficulties were encountered, although care was required to avoid kinking the exposed ends of the polyethylene cable core. This installation is illustrated in Figures 27 and 28.

Proof Pressure

A proof pressure test of 150% of maximum operating pressure was applied to the installed system. All lines and components that normally operate at 35-89 psig were pressurized to 135 psig. A pressure of 15 psig was applied to all fluidic system lines and components that normally operate at 7-10 psig. Proof pressures were maintained for 5 minutes, and inspection of the system revealed no evidence of failure, excessive leakage, or deformation.

Functional Checks

Operational tests were performed using a 1,000-lb test weight. In the pilot's release mode, the system opened the hook in response to a pilot's release input. The system opened the hook when the test weight was lowered to the ground with the automatic touchdown mode selected. The test weight was then lifted to height of approximately 6 inches, and attempts were made to induce an inadvertent release by varying supply pressures and by simulating catastrophic leaks such as might be encountered by line rupture. Only one set of conditions was found that would induce an inadvertent release. With the automatic touchdown release mode selected, a release occurred when the fluidic supply pressure was gradually decreased to zero. Further checks showed that decreasing both bleed air and fluidic supply pressure would not result in a release. This indicates that inadvertent release would occur only if the fluidic supply pressure reducer malfunctioned to cause loss of fluidic supply pressure while in the automatic touchdown mode. Normal release times were measured and the results are tabulated below:

Bleed Air Pressure PSIG	Release Time, SEC, at Fluidic Supply Pressure, PSIG					
	8		10		12	
	Pilot	Auto	Pilot	Auto	Pilot	Auto
35	1.0	2.4	1.0	2.9	1.0	3.3
89	0.9	2.5	0.9	2.7	0.9	3.1

System flow remained at 1.5 SCFM.

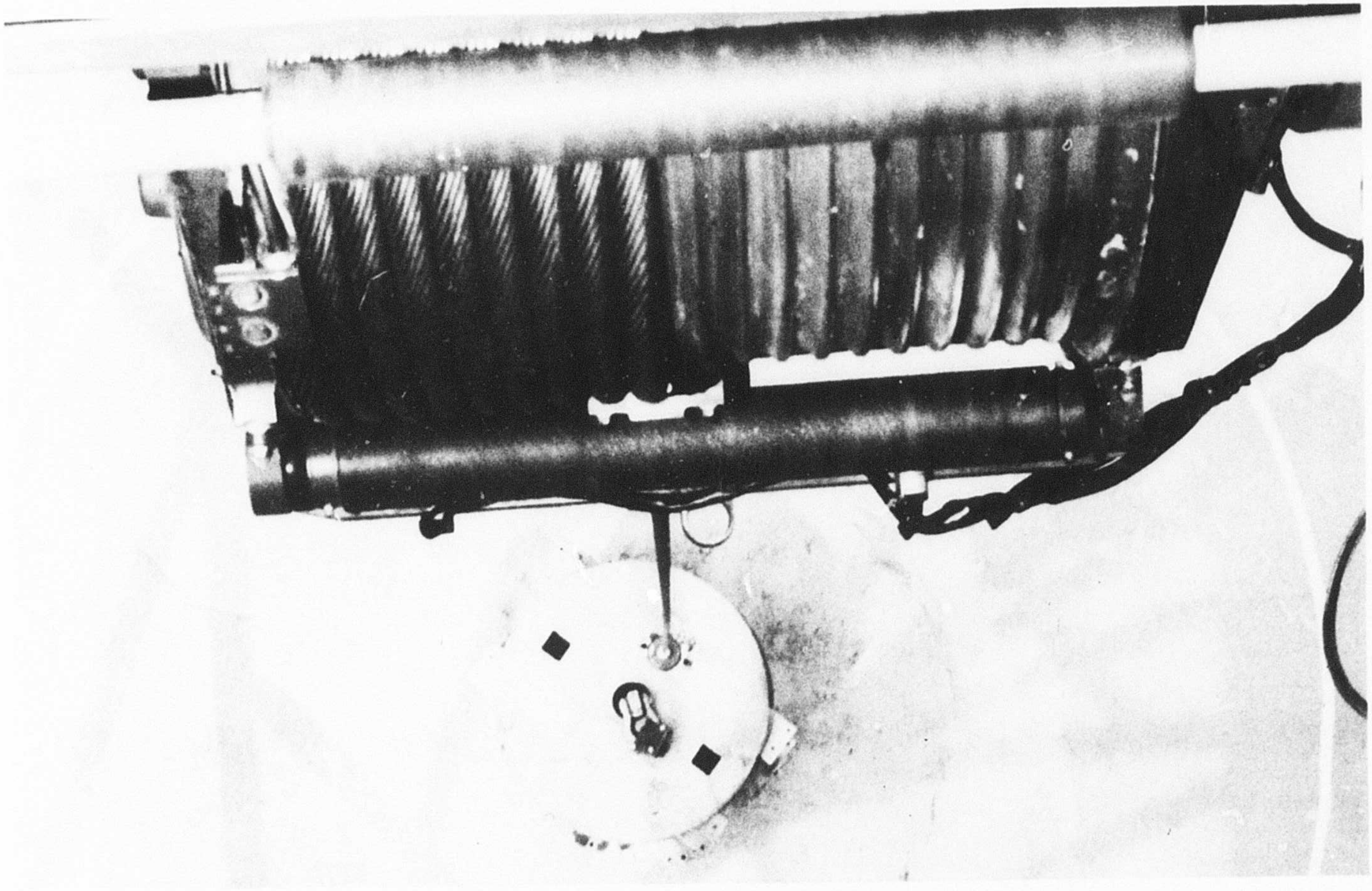


Figure 27. Cable Installation on Cargo Hoist.

Figure 28. Cable Core Termination on Cargo Hoist.

Installed System and Endurance Tests

Start of Endurance Tests

Initial endurance cycling started with 10 cycles at a test load of 10,000 pounds. Each cycle consisted of raising the load to the hoist up limit, stopping, lowering the load to the ground, and releasing the hook in the pilot's release mode. At the end of the 10th cycle, the load was stopped just off the ground and allowed to air-drop as the hook was opened. The system performed well and no discrepancies were noted.

Before proceeding to the next planned test load of 20,000 pounds, system operation was observed at 15,000 pounds. During the third cycle, erratic operation of the hook loaded and closed indicators was noted. Initially these indicators flickered only while the 15,000-pound load was in the air, but after additional cycles the condition continued with the load on the ground. Pressure measurements at the control module of both sensor lines indicated an increase in line restriction. Indicator operation was restored with the incorporation of bleed flow in the sensor lines. This technique is described in DISCUSSION OF RESULTS.

Endurance cycling was continued until a total of 10 cycles, including one airdrop, was accomplished at each test load of 10,000, 20,000, and 25,000 pounds. No new difficulties were encountered. The cable core restriction appeared to increase very slightly with cycling. Proper indicator operation continued with bleed flow compensation. Inspection of the hook assembly revealed that the three ¼-inch aluminum tubes, bonded into the hook slip ring housing, and providing connection to the three flex hoses from the hook to the slip ring, were damaged. Two were bent and the third had broken the bond joining the tube and the slip ring housing. The tubes were removed and the slip ring housing was tapped to accept steel pipe to flex hose adapter fittings. The flex hoses were then connected to these adapter fittings.

Installed System Functional Tests

Functional tests were performed as defined by the test matrix of Figure B-1 in the Test Plan, Appendix B. The matrix includes testing at various hook loads, cable lengths, dynamic conditions, and bleed air pressures. Experience with degradation of the cable core when operating with high load, led to the decision to limit the matrix tests to test loads of 0, 5,000, and 10,000 pounds at this time. Tests at 15,000, 20,000, and 25,000 pounds would be performed when the endurance goal of 1000 cycles had been accomplished. Measurement of actual available working height showed that the sand used to cushion the weight when air-dropped, the height of the weight, and the hoist mounting structure limited the payed out cable length to a maximum of 48 feet. Hoist cable payed out lengths were therefore adjusted in the matrix to be 48, 40.4, 33, 18, and 3 feet.

Release times recorded were found to vary slightly with bleed air pressure. Increasing pressure from 35 to 89 psig resulted in decreasing response time by 0.1 to 0.2 second. Other variables showed no trend, and average response time was 1.3 + 0.1 seconds. Forty-five matrix conditions were included.

Continued Endurance

Endurance testing was resumed. Cycling was now scheduled into test blocks as follows:

Load (lb)	Cycles
10,000	30
20,000	50
25,000	20

Again, one cycle in ten was terminated with an airdrop.

At 130 total endurance cycles, it was noted that the cable had begun to take on a wavy appearance. Testing continued to complete 164 total cycles. In an attempt to air-drop 20,000 pounds at the end of cycle 165, the hook would not release. Examination of the cable revealed a severe displacement of the lay of cable strands just above the hook swivel. The waves appearing in the cable outside diameter had become more pronounced. These conditions are visible in Figures 29 and 30. The hook would still release with no cable load when supply pressure was increased from the normal 40 psig to 55 psig. The hook closed indicator was still operational, but the hook loaded indicator was inoperative. The cable was removed and returned to its manufacturer for repair.

In summary, total cycles at each test load were:

Load (lb)	Cycles	Included Airdrops
10,000	60	6
20,000	84	8
25,000	20	2

Continued Endurance with Repaired Cable

The repaired cable was installed in the test facility. The repairs consisted of cutting off about 10 feet of the damaged end of the cable and replacing the swaged end fitting. In addition, the outside diameter of the cable was whipped with wire for a length of about 6 feet above the end fitting. The installed cable is shown in Figure 31. A functional check of the system demonstrated operation to be normal. Both hook condition indicators were operable, but required bleed flow to eliminate flickering.

Figure 29. Displacement of Strands on Cable Assembly.

Figure 30. Waves on Cable Assembly.

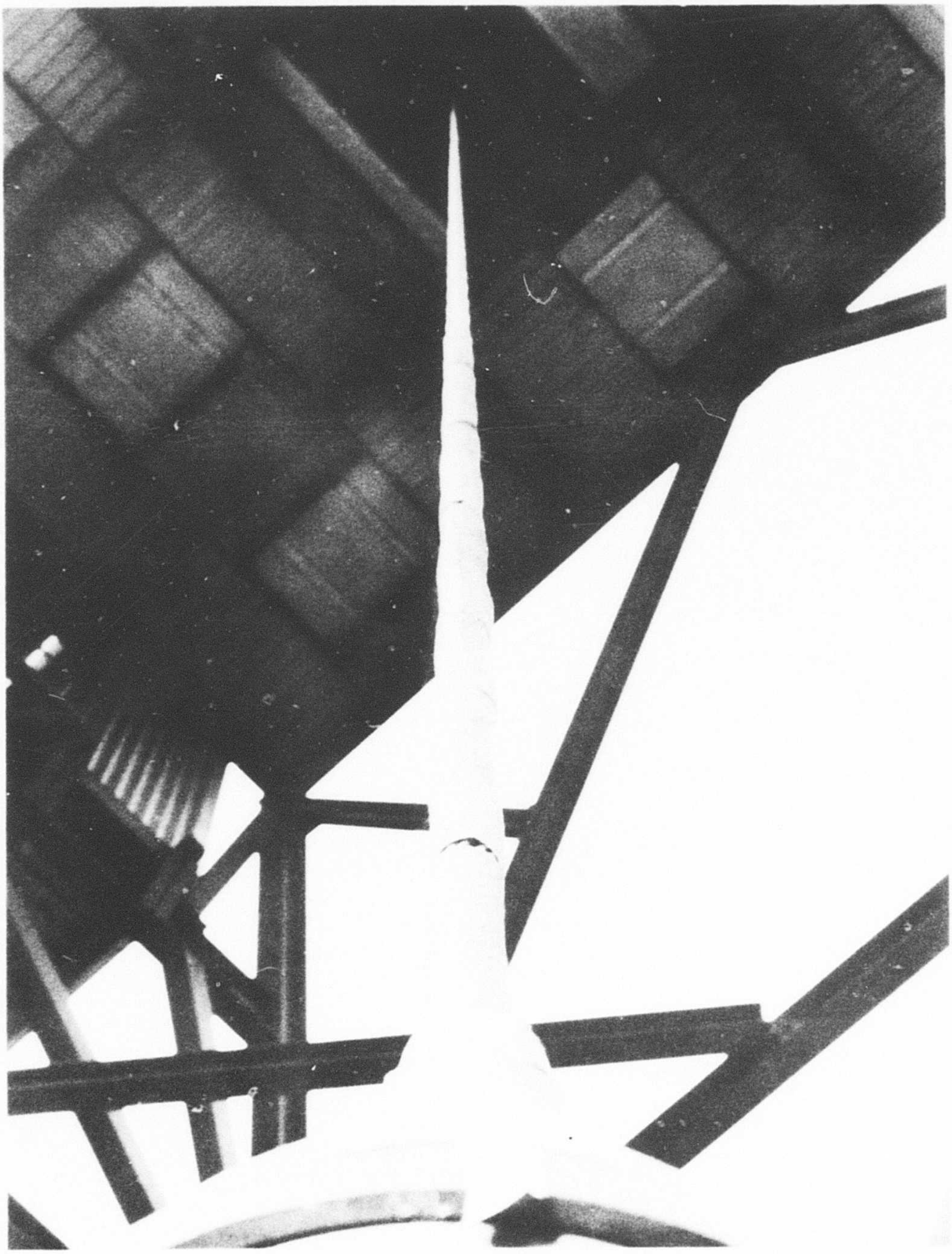


Figure 31. Installation of Repaired Cable.

Cycling was resumed at 10,000 pounds and continued with the objective of accomplishing the goal of 300 cycles at this load.

As endurance cycling approached 300 total cycles, the cable loaded indicator operation became erratic and finally inoperative.

Cycling continued and the goal of 300 cycles at 10,000 pounds was accomplished. Total cycles were 404.

The test load was increased to 20,000 pounds and continuous cycling resumed. Cycling continued to complete 454 total cycles. In an attempt to air-drop 20,000 pounds at the end of cycle 455, the hook would not release. It was also noted that the hook closed indicator became inoperative with the 20,000-pound load. The hook closed indicator was found to be operational when the load was set on the ground, unloading the cable. It was suspected that internal strand displacement in the cable was pinching the core when loaded and releasing when unloaded. In summary, total cycles at each test load were:

Load (lb)	Cycles	Included Airdrops
10,000	300	30
20,000	134	13
25,000	20	2

Endurance cycling at 20,000 pounds continued. Airdrops were attempted, without success, at the end of every tenth cycle. The hook continued to operate when unloaded. Release times began to increase. Times as high as 20 seconds were observed. At 519 total cycles the hook would not release when unloaded, with bleed pressure at the normal setting of 40 psig. Increasing pressure to 50 psig accomplished a hook release. Tests continued to complete 559 cycles. At the end of cycle 560, the hook would not operate at any pressure applied. Pressures up to 95 psig were applied. Endurance testing was abandoned and the cable was removed for inspection. Total endurance cycles accomplished were:

Load (lb)	Cycles	Included Airdrops
10,000	300	30
20,000	239	13
25,000	20	2

Fluidic Power System

Throughout all of the foregoing endurance tests, fluidic power was maintained on for a duration of 1106 hours of continuous operation. No maintenance was performed on the air supply system.

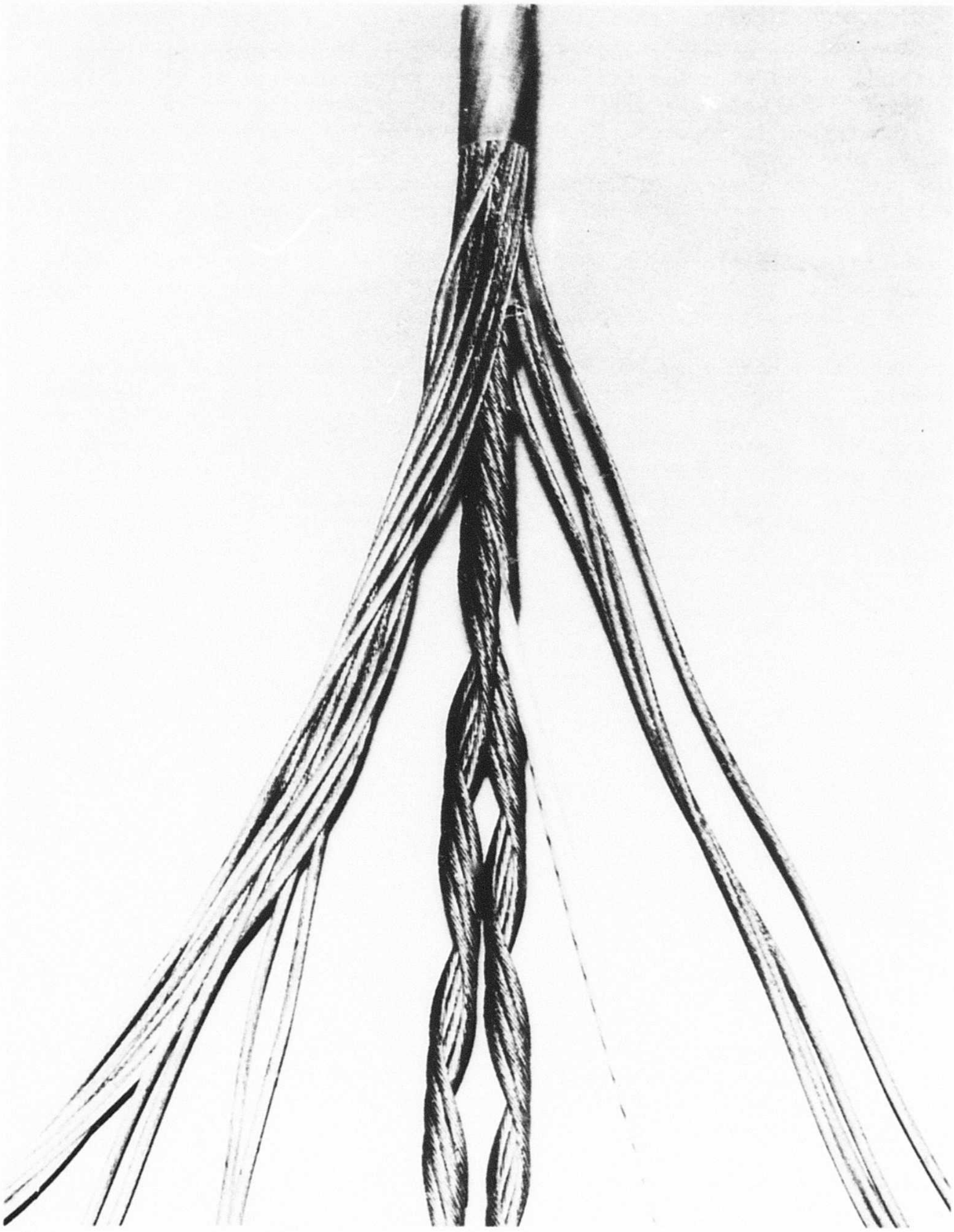


Figure 32. Cable Disassembly.

Teardown Inspection

The hoist cable assembly was disassembled in the Sikorsky experimental test laboratory with the assistance of a representative of the cable manufacturer. The hook and swage fitting were removed and the cable strands were unwrapped to expose a 30-foot section of the polyethylene core. See Figure 32. Severe deformation of the core became more obvious near the hook end. The pattern of deformation was a mirror image of the spiral wrapping of the inner strands of the cable. See Figure 33.

Conductor deformation decreased in magnitude moving away from the hook end of the cable. A section of cable near the hoist end was unwrapped, revealing no deformation of the conductor.

Air was introduced into the conductor at the hoist end at a pressure of 30 psig. Leakage in the conductor was located by immersing successive sections under water. Photographs of leakage appear in Figure 34. All leakage was located in the last 2 feet of conductor at the hook end. A closer inspection of one of the larger leaks, Figure 35, revealed that it was a break adjacent to the dividing wall separating the passages. The inner strands of the cable were in good condition and showed no evidence of damage. The outer strands of the cable were nicked, scratched, and showed signs of abrasive wear incurred during hoisting operations and ground handling. This damage was not excessive or abnormal.

DISCUSSION OF RESULTS

Checkout and Assembly

Generally, all components met anticipated performance requirements. The slight leakages observed during testing of the cable and slip rings were considered to be insignificant when related to overall system performance. Measurement equipment would indicate flows as low as 0.01 scfm. Observed leakage was well below this level.

Environmental Tests

Environmental test malfunctions never resulted in conditions that would result in an inadvertent release.

Vibration tests dispelled preliminary suspicions that moving parts in the interface valve might resonate and cause inadvertent releases. The entire cargo hook system functioned properly during all phases of vibration testing.

Low temperature test results demonstrated that exposure to cold environment has no permanent adverse effect on the integrity of the components. Momentary actuation of the release malfunction indicator during cycling was attributed to the slow mechanical response of the hook due to low temperature effects on hook lubricants. An increase in the time delay of the circuit would compensate for this condition.

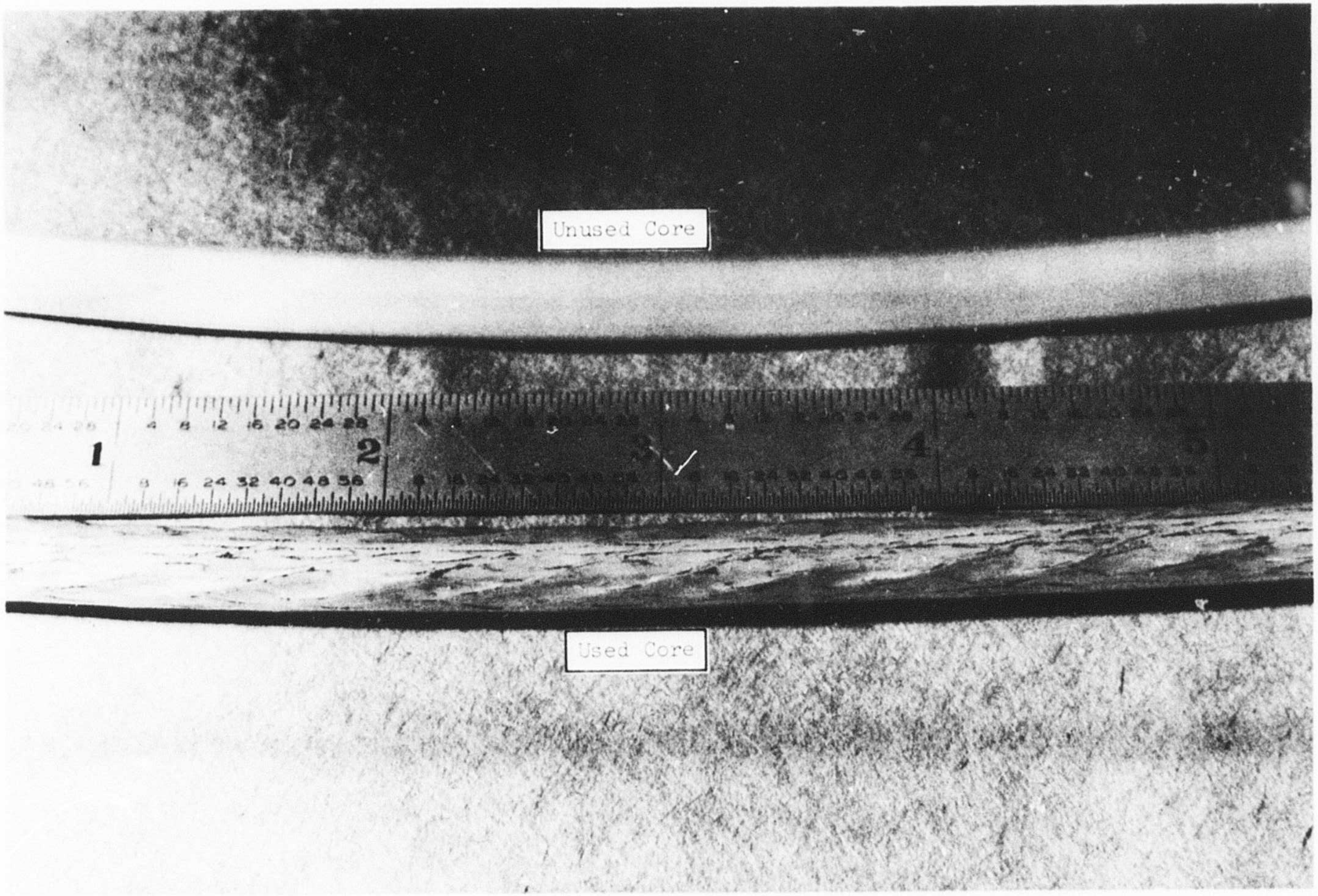


Figure 33. Pattern of Deformation at Cable Core.

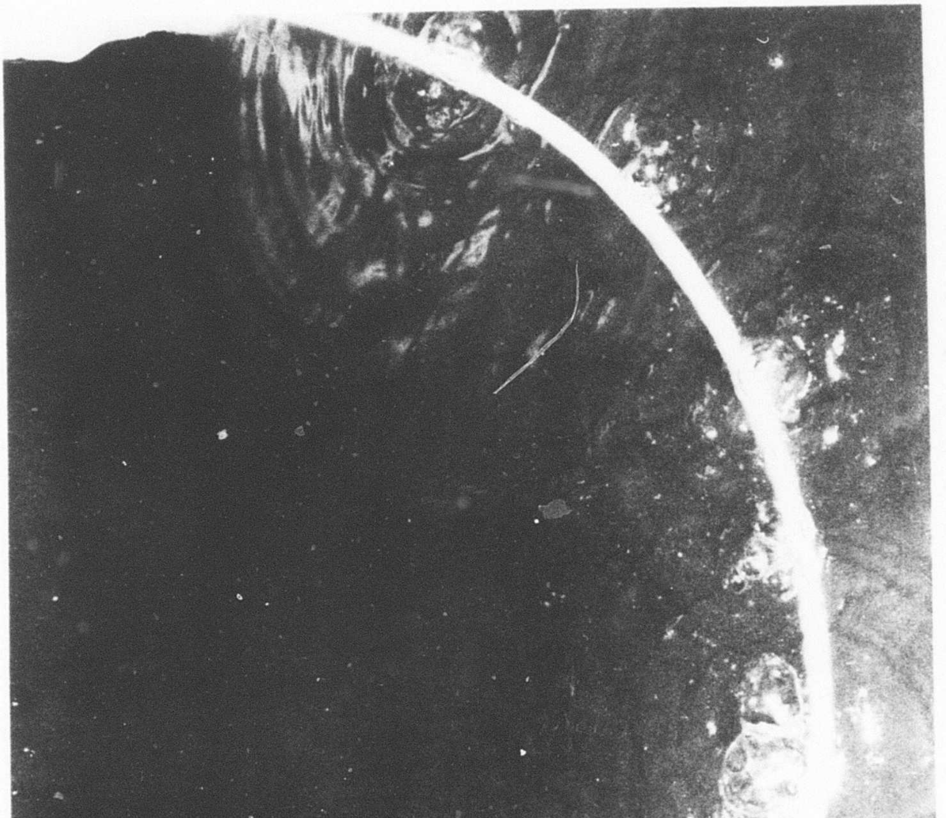


Figure 34. Core Leakage.

Figure 35. Core Damage - Leaky Section.

Problems encountered with interface valve operation during low temperature testing were attributed to valve construction. This valve is pilot operated, pilot pressure being provided by a small primary orifice. A secondary orifice in series with the primary orifice is normally vented to atmosphere. Normal operation of the valve is initiated by the input control signal, which through a diaphragm, blocks the secondary orifice. Pilot pressure then builds up to actuate the valve mechanism. This operation is illustrated in Figure 36. It was felt that the small primary orifice was being blocked by ice, thereby preventing proper operation of the valve. Solutions for this problem are suggested in RECOMMENDATIONS.

Investigation of the loss of supply pressure occurring during low temperature testing proved that the malfunction was due to simple ice blockage of the cooling loop. Several attempts were made to cure the problem by repositioning the cooling loop in the chamber and installing moisture traps in the supply line. These attempts were not successful.

The problems encountered during high temperature testing indicate the need for better indicators and an improved method of tubing connections. The indicators used in this prototype system were industrial and their materials not suitable for the extreme temperatures experienced.

Operation of the system with contaminated air and filters removed revealed that the fluidic system enjoyed a great deal of protection by the intricate passages in the fluidic system supply pressure regulator. The system tolerated intentionally introduced contamination, and subsequent cleaning restored proper operation. It should be noted that vibration, shock, or different regulator design might have resulted in intrusion of the sand into the fluidic system.

Installed System Tests

The single inadvertent release mode observed during tests performed at the hoist test facility was caused by a very special set of conditions. This problem could be avoided by a simple interlock that would reduce the interface valve supply pressure to zero whenever the fluidic system supply pressure decreased to a preset minimum.

Cable core damage ultimately resulted in loss of remote release capability. Before this occurred, core damage in the form of increased restriction was evidenced first by faulty operation of the hook loaded and then the hook closed indicators. Blocked line pressures were unchanged, but unblocked levels had increased. It was demonstrated that correct indicator operation resumed after incorporation of a bleed flow to atmosphere through a tee fitting installed in each sensor line behind the control module. This technique is illustrated in Figure 37.

Observation of system operation indicated that the life of the cable core was greatly affected by the number of heavy load airdrops performed. The core damage incurred during testing, specifically the leakage found in the last 2 feet of conductor, was directly related to violent bending of

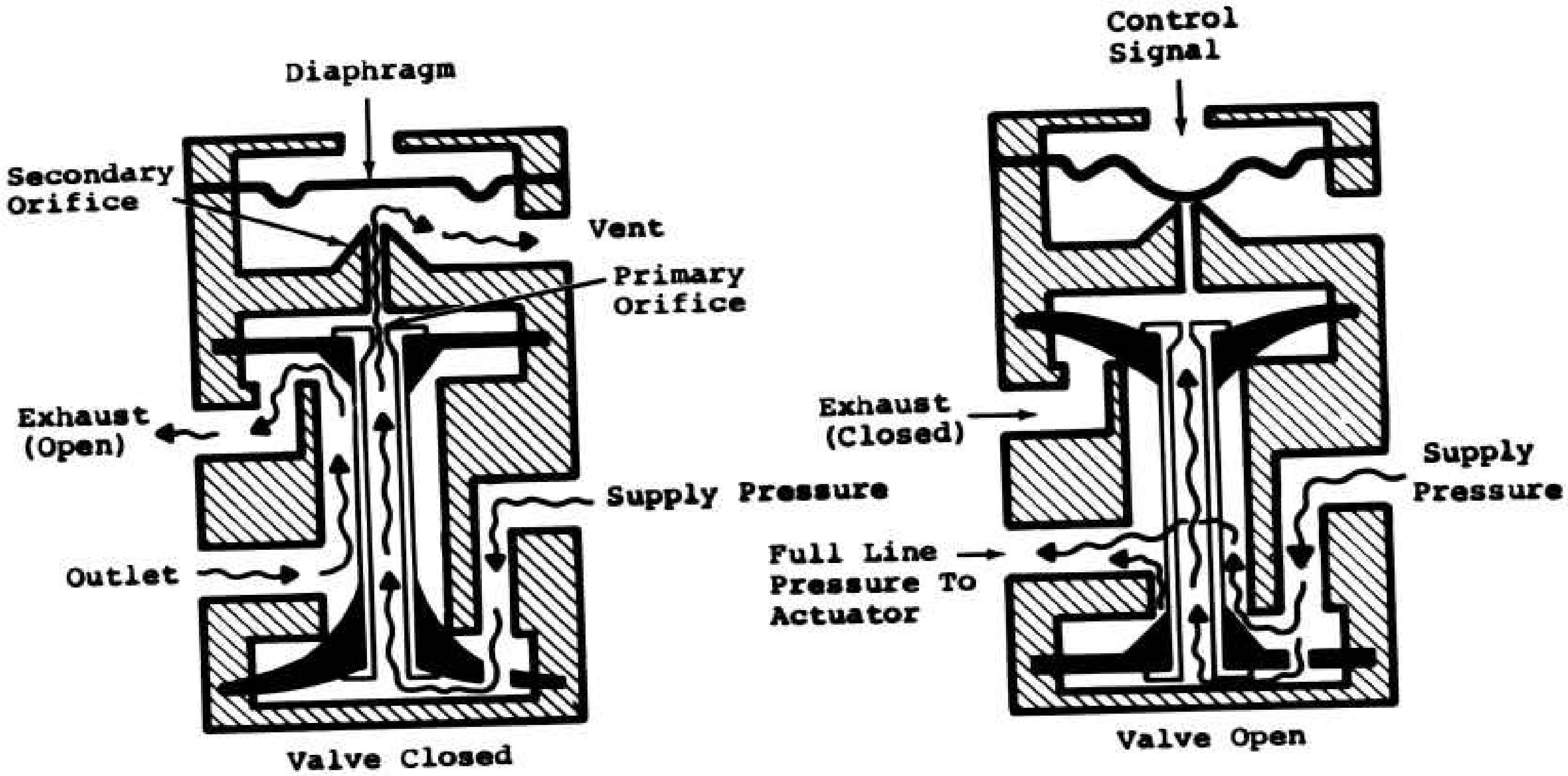


Figure 36. Interface Valve Operation.

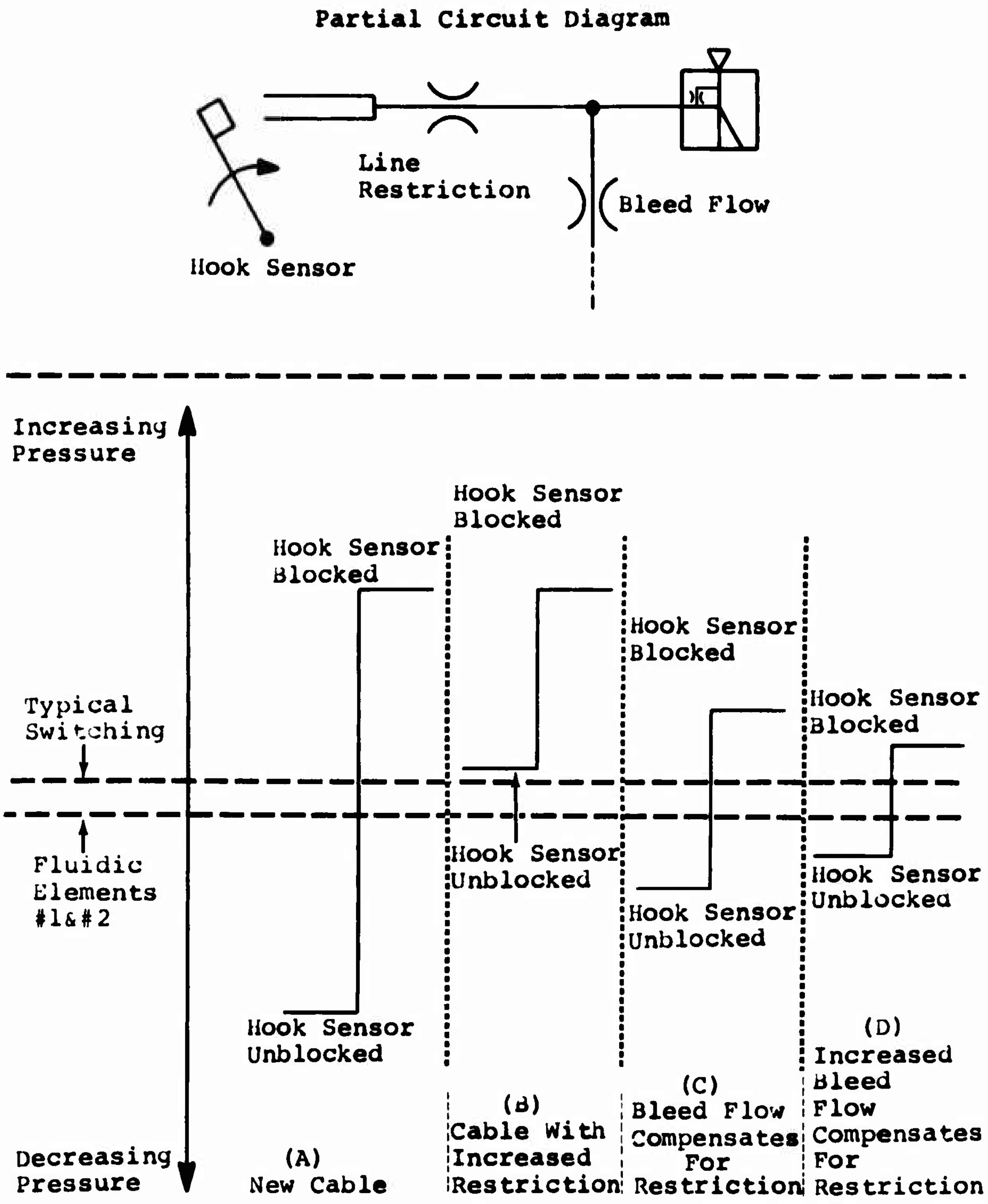


Figure 37. Technique Used in Restoring Indicator Operation.

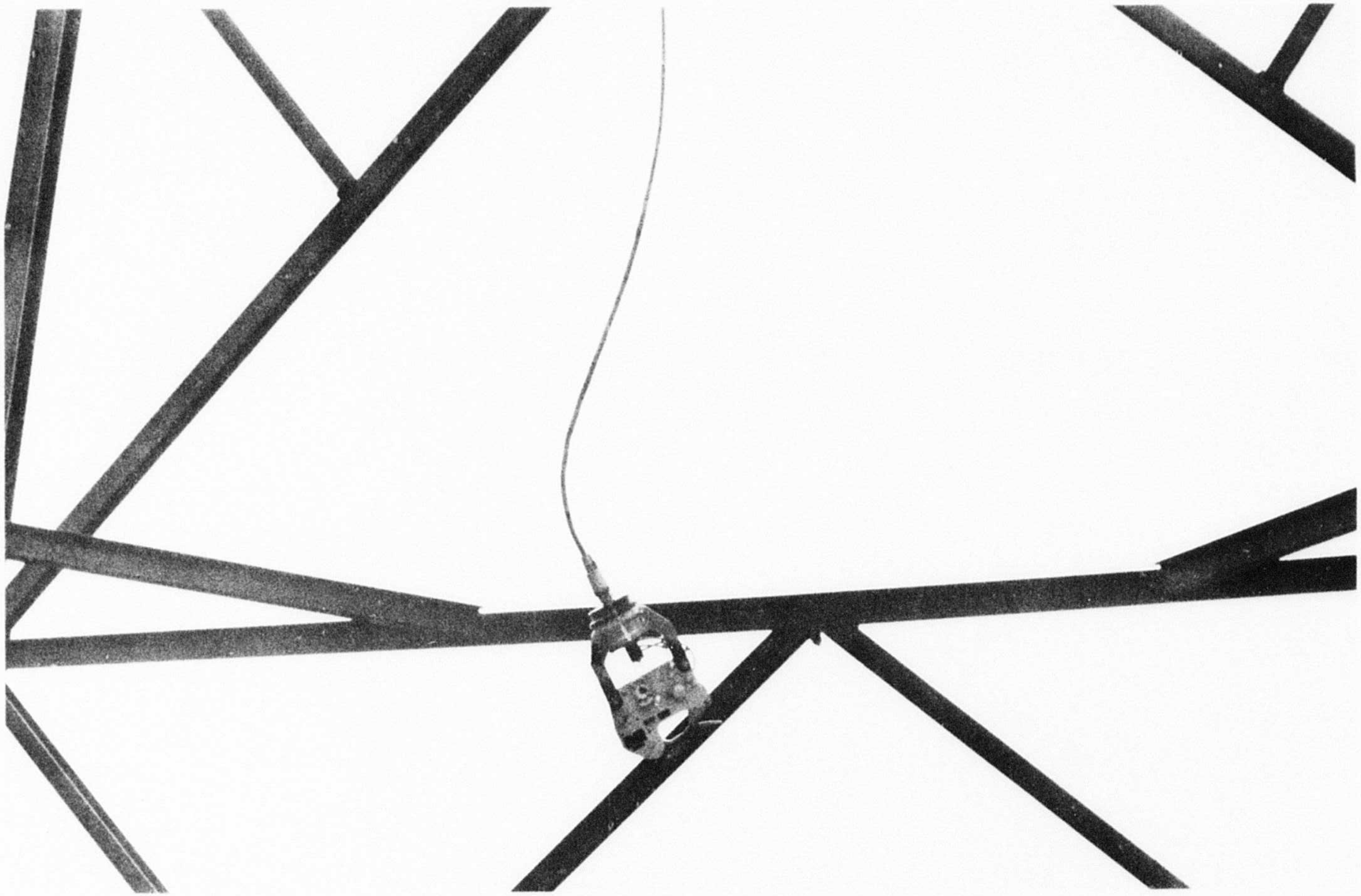


Figure 38. Cable Reaction to Airdrop.

the cable in this area. Immediately following a typical heavy load airdrop, the following sequence occurs: The hook travels straight up, turning over and curling the cable behind it, for a distance of approximately 30 feet. Figure 38 shows the hook starting this upward excursion immediately after the load was released. The hook then plummets straight down, in the inverted position, until the end of the cable is reached. It then, violently, snaps around through the upright position, to the inverted position again. This action continues for several cycles with diminishing amplitude. At least three must be considered severe. Other operations performed during hoisting do not abuse this area of the cable. Normally, this section never even wraps on the drum.

CONCLUSIONS

A prototype pneumatic/fluidic cargo hook release system for a CH-54B helicopter was designed, fabricated and tested for 454 load release cycles with minimal major or significant problems.

The system also passed vibration, sand and dust, and contaminated air tests with no problems.

The inability of the system to reach the goal of 1000 load releases was primarily due to the damage sustained by the conductor core immediately following air dropping of loads. The airdrop requirement was included in the test program to accelerate the test program - that is to cause failure/malfunction far sooner than they would occur under normal operating conditions.

It is understood that elimination of the airdrop requirement has been considered for some time because of the relatively large number of accidental hook releases that have occurred in flight on aircraft configured to permit airdrops. As a point of fact future cargo system requirements (e.g. HLH cargo system) have required that airdrops shall be prohibited. Therefore, it is felt that the basic cable/core concept has been proven; and with minor improvements (see RECOMMENDATIONS), it will prove to be more reliable than the existing electrical conductor core cable.

The problems encountered during elevated temperature testing (sticking indicators) were minor and can be solved by using materials and bonding agents with improved resistance to high temperatures.

The failure of the interface valve to operate at low temperatures was caused by ice blocking the primary orifice of the valve. Two possible solutions to the problem are described in the RECOMMENDATIONS section.

RECOMMENDATIONS

It is recommended that the design improvements described below be incorporated and that further testing with a goal of 5000 cycles (with no airdrops) be performed.

- Improve cable/conductor, using preformed wire strands in the outer wrap and higher density material in the conductor core. These changes should improve the wear resistance of the conductor core.
- Improve indicators, using materials and adhesives capable of withstanding elevated temperatures to eliminate the "sticking" problem.
- Replace the interface valve with a fluidic valve of different design which has exhibited less sensitivity to clogging. Also it is recommended that an electrically operated valve be procured as a backup. The use of such a valve would reduce the hook opening time significantly, reduce system weight, and ensure operation at -65°F. Low temperature testing will be used to evaluate the better of the two valves.

The modified test program would delete all requirements for air-dropping loads and would have a goal of 5000 release cycles.

APPENDIX A

FLUIDIC CIRCUIT PROCUREMENT SPECIFICATION

1.0 SCOPE

1.1 Description and requirements for the procurement of an integrated fluidic circuit for the fluidically controlled/pneumatically operated cargo hook.

2.0 DEFINITIONS

2.1 The word 'element' is used herein to define individual logic functions and their interconnections within the circuit. The intent is not to limit the use of other fluidic devices but to define the logic involved.

3.0 CIRCUIT DESCRIPTION

3.1 The circuit shall consist of pure fluid elements with the exception of diaphragms.

3.2 The circuit shall consist of one-piece construction with the exception of provisions to replace any diaphragms used.

3.3 The circuit shall be integrated as shown in Figure A-1.

3.4 Elements of the circuit shall be as follows:

3.4.1 Elements 1 through 7 shall be back-pressure switches with normal output at 02. The output shall switch to 01 when the sensing port is blocked.

3.4.2 Elements 8 and 13 shall be or-nor switches with normal output at 02. An input at any one or combination of control ports shall switch the output to 01.

3.4.3 Elements 9 and 12 shall be and-nand switches with normal output at 02. Inputs at both control ports shall switch the output to 01. An input at one control port but not the other shall result in an output at 02.

3.4.4 Element 10 shall be a digital amplifier. It shall have no memory or hysteresis. A control signal at 01 shall result in an output at 01. A control signal at 02 shall result in an output at 02.

3.4.5 Element 11 shall be an or-nor switch with an override capability. The normal output shall be at 02. A control signal at C1 shall always result in an output at 02. With no input at C1 and an input at C2 and/or C3 the output shall switch to 01.

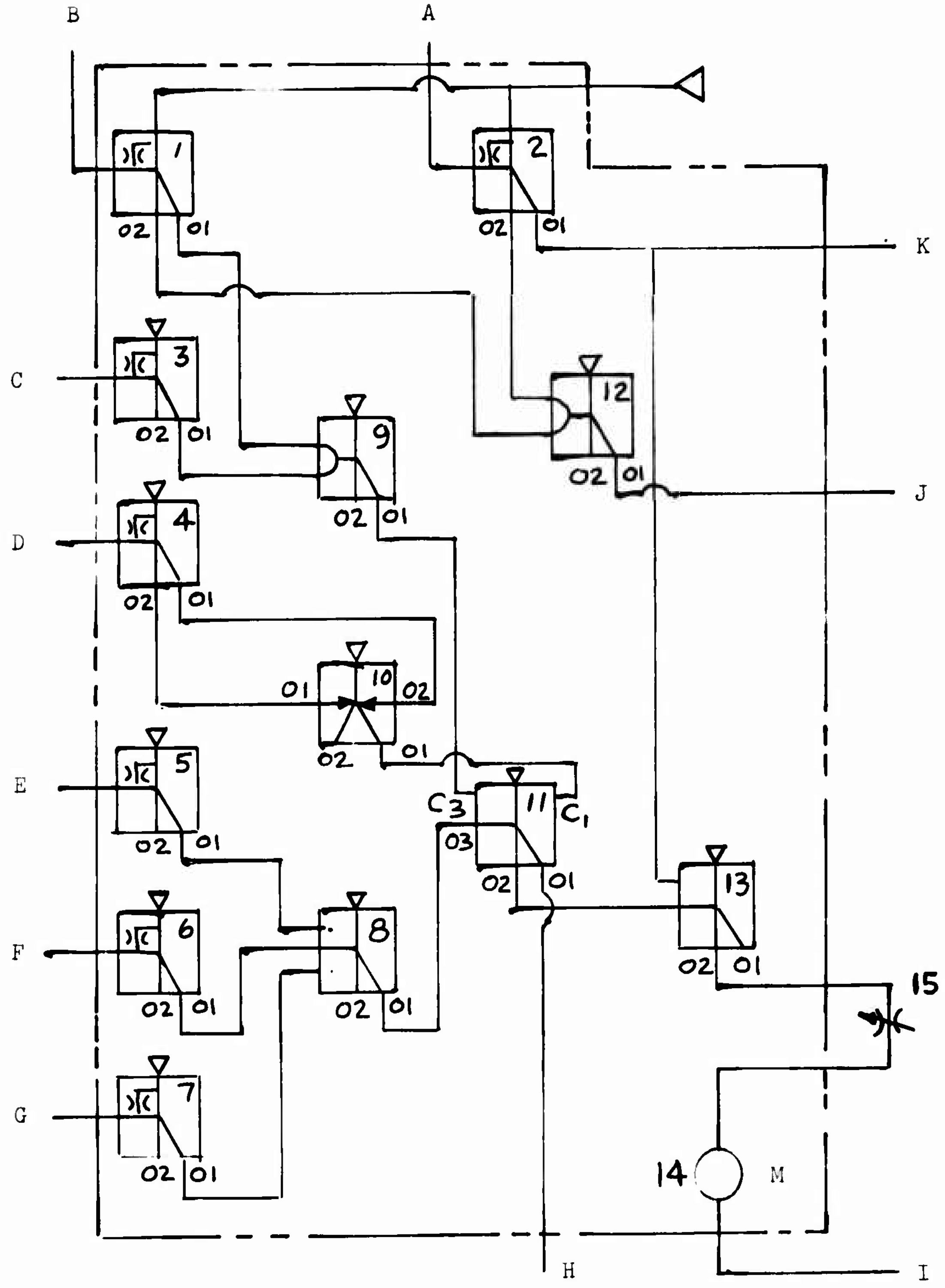


Figure A-1. Integrated Fluidic Circuit.

3.4.6 Element 14 shall be a capacitor and element 15 shall be a variable resistor. This combination shall be such that a time delay occurs between the output 02 of element 13 and the external output point 'I'. The delay shall be varied by the external restrictor and shall have a range of 1 to 10 seconds.

3.5 Elements 3 through 14 shall be supplied by a single external port. Elements 1 and 2 shall be supplied an additional single supply port.

3.6 Output ports 'H' through 'K' shall be adaptable for the connection of transmission lines. All other output ports shall be either properly vented or connected internally to the respective control port, as required.

3.7 Back-pressure sensing ports 'A' through 'G' shall be adaptable for the connection of transmission lines.

3.8 The circuit shall operate at supply pressures of 3 to 10 psig without any noise or malfunction.

3.9 All input and output impedances shall be matched such that no malfunctions will occur.

3.10 Air consumption of the circuit shall be less than 1.5 scfm at a supply pressure of 10 psig.

4.0 CIRCUIT REQUIREMENTS

4.1 The circuit shall be capable of a complete functional checkout without malfunction.

4.2 The circuit shall be capable of operating at sea level to an altitude of 16,000 feet without malfunction.

4.3 The circuit shall be capable of operating without malfunction and show no evidence of damage after completion of the following environmental tests.

4.3.1 Extreme temperatures of -65°F to 165°F for periods of 6 hours. The circuit shall operate without malfunction during the test.

4.3.2 The sand and dust test of MIL-STD-810B with the exceptions that supply pressure will be on during steps 1 and 3 of the test, the circuit will be periodically operated and accumulated sand and dust will not be removed.

4.3.3 The vibration test of MIL-STD-810B, Category C, Procedure 1, Part 1, Curve M.

4.3.4 Contaminated air for a period of 1 hour.

4.4 The circuit shall be capable of being purged of contaminants without resulting in damage or future malfunction.

APPENDIX B

TEST PLAN

SCOPE

This test plan documents the test program requirements for Task III of the Fluidically Controlled Cargo Hook Program. The testing includes system functional tests, environmental tests, and endurance tests of the final system configuration. A test data log shall be maintained for each test. It shall contain test procedure/description, actual procedure results, conclusions, observations and comments.

APPLICABLE DOCUMENTS

Contract No. DAAJ02-73-C-0043
Fluidic Circuit Procurement Specification
Manufacturer's Specifications for Purchased Parts

REQUIREMENTS

System Functional Tests

Component Checkout and Assembly

Each of the following components will be subjected to performance and acceptance tests prior to assembly.

- Integrated Circuits - Check for logic and function per procurements specification; record flow, losses, and pressure output; and measure frequency response.
- Hoist Cable Assembly - Record leakage and pressure drop, and proof pressure test each passage to twice its maximum operating pressure.
- Cargo Hook Assembly - Check operation of backpressure switches and record pressure drop and leakage, check operation of actuator, record slip ring and swivel breakout torque, and check leakage across slip ring.
- Hoist Slip Ring - Record breakout torque, pressure drop, and leakage.
- Interface Valve - Check operation and record bleed flow, pressure drop, and maximum flow.
- Control Box Components - Test each indicator and control to manufacturer's specification.
- Air Supply System - Test cooling effectiveness at high inlet condition, check ability of system to remove contaminants.

System Assembly and Checkout

The entire system will be assembled in the laboratory and subjected to the following tests.

- Proof Pressure - Apply a proof pressure equal to 150% of maximum operating pressure to each flow path in the system for a period of 2 minutes. There shall be no evidence of failure, excessive leakage, or deformation, and results shall be recorded.
- Functional Test - Perform operational tests in the normal release mode and automatic touchdown mode. Observe for inadvertent release when supply pressure is changed over the full permissible range at various rates. Record release times in each mode between 35 psig and 89 psig supply pressure. Perform adjustments as required to optimize system performance. Record system flow.

Installed System Tests

The complete fluidic cargo hook system and cargo hoist will be installed at the Sikorsky Hoist Tower and subjected to functional checkout. Instrumentation will be installed to record hook release times. Release time will be measured and operation observed at least once in each of the configurations marked "X" in Figure B-1.

Environmental Tests

Sand and Dust

The system tested will be the fluidic control box, the hoist slip ring, the interface valve, and the cargo hook and swivel assembly, connected by short lengths of tubing.

The test will be conducted in accordance with MIL-STD-810B, Method 510, with the following exceptions: fluidic power will be on during steps 1 and 3 of the test, and off during step 2; the system will be subjected to an on-off functional test in the normal release mode, the slip rings will be rotated, and the hook will be cycled 10 times as a minimum at the end of step 2 and in step 5; and accumulated dust will not be intentionally cleaned off in step 4.

Extreme Temperature

The system tested will include the air supply system, the fluidic control box, the hoist slip ring, the interface valve, the hoist cable, and the cargo hook and swivel assembly. All of these components will be assembled in an environmental chamber. Provisions will be made to operate the system controls and to open and close the hook load beam from outside the chamber.

The tests will be conducted in general accordance with MIL-STD-810B, Methods 501 and 502. The shop air supply to the fluidic system will incorporate provisions to vary pressure, temperature and water content.

Low Temperature Test

The chamber will be reduced to -65°F as rapidly as possible while system supply air is maintained at a condition of 40 psig, 132°F, and 0.5 in.^3/hr water flow per scfm of airflow (estimated to be the most critical bleed air condition at -65°F ambient air). This bleed air condition will be maintained for the duration of the low temperature test. The cargo hook system will be operated a minimum of five times at equal intervals during the cool-down period. The temperature of -65°F will be maintained for 6 hours and the cargo hook system operated and functionally checked at the end of each hour.

At the end of the 6-hour period, the chamber temperature will be raised as rapidly as possible to ambient. The cargo hook system will be operated and functionally checked a minimum of five times at equal intervals during the warming period, until the system component temperatures have reached at least 32°F. All components will then be visually inspected.

High Temperature Test

The system tested will be the same as that used in the cold test, except that the bleed air cooler part of the air supply system will be set-up outside the test chamber. This is required since on the aircraft, the cooler would not be subjected to the "closed compartment" extreme temperature of 160°F, but rather to a temperature lower than the maximum ambient temperature of 120°F. The chamber temperature will be raised as rapidly as possible to +160°F while system supply air is maintained at 76 psig, 500°F and 0.5 in.^3/hr water flow per scfm of airflow (estimated to be the most critical bleed air condition at 120°F outside air temperature). This bleed air condition will be maintained for the duration of the high temperature test. The cargo hook system will be operated a minimum of five times at equal intervals during the warming period. The temperature of 160°F will be maintained for 6 hours, and the cargo hook system will be operated and functionally checked at the end of each hour. At the end of the 6-hour period, the chamber temperature will be lowered as rapidly as possible to ambient. The cargo hook system will be operated a minimum of five times at equal intervals during the cooling period, until the system component temperatures have dropped to at least 100°F. All components will then be visually inspected. The temperature test will be repeated. This time the air supply system will be included and the chamber temperature will be brought up to 120°F as rapidly as possible. The system supply will be maintained at 76 psig, 500°F and 0.5 in.^3/hr water flow per scfm of airflow.

Contaminated Air Test

The system tested will include the air supply system, the fluidic control box, the interface valve, the hoist slip ring, and the cargo hook and swivel assembly, connected by short pieces of tubing. Provisions will be made to inject controlled amounts of water and sand into the supply air.

The supply air system will be tested and adjusted to deliver 0.5 $\text{in.}^3/\text{hr}$ water flow per scfm of airflow, and 2×10^{-4} lb/hr sand flow per scfm of airflow (estimated to be worst conditions of bleed air). The sand will be that specified in MIL-E-5007C, paragraph 3.25 (Mikel's Mix).

The system will then be run using this contaminated supply air for at least 50 hours. The system will be functionally checked and operated at least every 2 hours. The air supply system will receive no maintenance during the test except for draining of manually operated moisture traps, if incorporated, after each 8 hours of test time. At the end of the test, the system will be inspected for evidence of contamination and the air supply system disassembled for evaluation of effectiveness.

The system filters and moisture traps will then be removed and the system run for an additional hour using the same rate of supply air contamination as established earlier. The system will be functionally checked and operated a minimum of five times at equal intervals during the hour. At the completion of the test, the system will be inspected for evidence of contamination and cleaning procedures will be evaluated.

Vibration Test

The system tested will be the fluidic control box and the interface valve. The cargo hook will be connected to the test system in order to perform functional checks, but will not be subjected to the vibratory environment.

The test will be conducted in general accordance with MIL-STD-810B, Method 514, Category C, Procedure I-1, Curve M (equipment installed in helicopters, without vibration isolators). At the conclusion of this test, the system will be subjected to 3 hours of continuous vibration at 3 cps and 0.10 inch double amplitude, and 3 hours at 18 cps and 0.10 inch double amplitude.

During all of the above testing, the system will be functionally checked and operated at least every hour. At the conclusion of the test, the system will be disassembled and inspected for damage.

Endurance Test

At the conclusion of all other testing, all components of the fluidic cargo hook system and cargo hoist will be reassembled on the Sikorsky Hoist Tower. Fluidic supply will be a compressor, which will not be turned off until the tests are complete with a goal of 600 hours. No maintenance will be performed on the air supply system except for draining of manually operated moisture traps.

The system will be operated as a minimum through 1000 of the following cycles:

Manually secure load onto hook

Hoist load to up limit and hold

Lower load to ground (or just off ground for airdrop)

Release load

300 cycles will be done at 25,000 pounds, 500 cycles at 20,000 pounds, and 200 cycles at 10,000 pounds. Every tenth release will be an airdrop. At the conclusion of all testing, all components will be subjected to a teardown inspection. Any evidence of structural failure, distortion, abnormal wear, or contamination will be documented and reported.

QUALITY ASSURANCE PROVISIONS

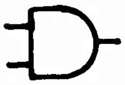
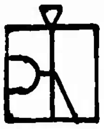
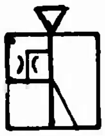
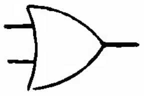
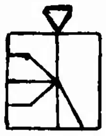
All measurement instruments and timing devices will be subjected to periodic calibration and maintained within the calibration date.

The Eustis Directorate will be notified of the date for each test segment in order to provide for witnessing.

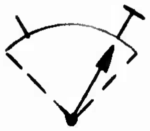
			HOIST CABLE PAYED OUT, FEET														
			60			45			30			15			0		
			BLEED AIR PRESSURE, PSIG														
DYNAMIC CONDITION.		CABLE LOAD, POUNDS	35	62	89	35	62	89	35	62	89	35	62	89	35	62	89
	STEADY	0	x	x	x		x		x		x		x		x		x
		5000	x	x	x	x		x		x		x		x		x	
		10000	x	x	x		x		x		x		x		x		x
		15000	x	x	x	x		x		x		x		x		x	
		20000	x	x	x		x		x		x		x		x		x
		25000	x	x	x	x		x		x		x		x		x	
	DECEL	0	x			x			x			x					
		5000		x			x			x			x				
		10000			x			x			x			x			
		15000	x			x			x			x					
		20000		x			x			x			x				
		25000			x			x			x			x			
	SWAY	0	x			x											
		5000		x			x										
		10000			x			x									
		15000	x			x											
		20000		x			x										
		25000			x			x									

Figure B-1. Test Matrix.

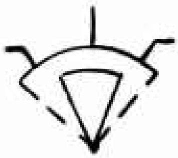
LIST OF SYMBOLS

	air source, low pressure
	air source, high pressure
	AND - logic symbol
	AND gate - fluidic symbol
	back pressure switch - fluidic symbol
	indicator, visual position type
	NOT - logic symbol
	OR - logic symbol
	OR gate - fluidic symbol
	restrictor, variable - fluidic symbol

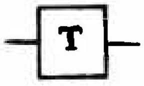
LIST OF SYMBOLS (Continued)



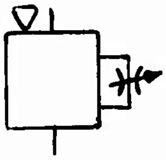
switch, two position - fluidic symbol



switch, three position - fluidic symbol



time delay



time delay relay, variable - fluidic symbol