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ROCKWELL INTERNATIONAL COLUMBUS OH NORTH AMERICAN AI--ETC F/G 13/7  
DESIGN, DEVELOPMENT, AND EVALUATION OF LIGHTWEIGHT HYDRAULIC SY--ETC(U)  
JAN 81 J N DEMARCHI, R K HANING N62269-78-C-0363

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DESIGN, DEVELOPMENT, AND  
EVALUATION OF  
LIGHTWEIGHT HYDRAULIC SYSTEM  
HARDWARE - PHASE I



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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br><br>The Lightweight Hydraulic System (LHS) program assesses the advantages of using an 8000 psi operating pressure level in Navy aircraft instead of the conventional 3000 psi level. This report presents the results of Phase I of a program to design, fabricate, and test a full scale 8000 psi system in a ground simulator and A-7E flight test aircraft. Two independent lightweight hydraulic systems, powered by variable delivery 8000 psi pumps, utilize twenty 8000 psi actuators and fourteen types of LHS minor hardware items. A steel framework |                                     |                                                                                        |

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20. ABSTRACT (Continued)

ground simulator was designed with LHS component installation and hydraulic distribution systems similar to the A-7E aircraft. Laboratory tests conducted on components fabricated in Phase I include rod seal development, servo valve erosion, compatibility, pressure impulse, and endurance. A math model of the compatibility system was verified. Test results demonstrated that the Phase II simulator will function as designed. Weight and space analyses made on LHS components projected the 30% weight and 40% space saving goals can be achieved. Based on preliminary R&M assessments of the development hardware, the MFHBF and MMH/FH improvements goal of 15% will be obtained.

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EXECUTIVE SUMMARY

1.0 PURPOSE OF THE PROGRAM

Aircraft hydraulic power requirements have increased significantly in recent years due to higher aerodynamic loading and expanded hydraulic functions. Weight and space allocations available for hydraulic system components have decreased because of thinner airfoil designs and the increasing number of on-board systems. Substantial reductions in the weight and space requirements of hydraulic components must be accomplished to meet mission and performance demands of future Navy aircraft. The Lightweight Hydraulic System (LHS) program investigates the concept of using higher operating pressures to achieve smaller and lighter weight hydraulic components.

2.0 BENEFITS TO THE NAVY

The LHS Advanced Development Program will assess the advantages of using an 8000 psi operating pressure level instead of the conventional 3000 psi level. This will be accomplished by (1) demonstrating the reliability and maintainability of 8000 psi hydraulic systems, and (2) substantiating the predicted weight and space savings achieved by operating at 8000 psi.

Ultimate goals for lightweight hydraulic systems in Navy aircraft are:

- (1) Weight savings of 30% over conventional 3000 psi systems
- (2) Space savings of 40% over conventional 3000 psi systems
- (3) A 15% improvement in MFHBF for development hardware over current fleet 3000 psi systems
- (4) A 15% improvement in MMH/FH for development hardware over current fleet 3000 psi systems

3.0 BACKGROUND INFORMATION

The Navy initiated an Exploratory Development Program in 1966 to investigate the areas of operational practicality and potential weight and space savings achieved by using a pressure level higher than 3000 psi. The program included a feasibility study, component development and testing, selection of the operating pressure level (8000 psi), laboratory systems testing, and brief flight testing. The program established: (1) that 8000 psi lightweight hydraulic systems can be designed, fabricated, and maintained without special techniques or state-of-the-art advances; and (2) that the overall weight and volume of aircraft hydraulic systems can be reduced up to 30% and 40%, respectively, for systems delivering more than approximately 100 horsepower.

The LHS Advanced Development Program will design, fabricate, and test a full scale 8000 psi lightweight hydraulic system on a ground simulator. The system will then be installed on an A-7E test aircraft and flown to assess in-flight performance. The program is anticipated to be performed in three phases:

- Phase I      Design, fabricate, and test 8000 psi components
- Phase II     Fabricate ground simulator. Conduct performance and endurance tests
- Phase III    Install 8000 psi hydraulic system in an A-7E aircraft and conduct flight test program

This report covers Phase I.

#### 4.0            PHASE I SUMMARY

##### 4.1            System, Component, and Simulator Design

Hydraulic circuitry in the A-7E flight test aircraft was reconfigured from three independent power control systems operating at 3000 psi (PC-1, PC-2, and PC-3) to two independent 8000 psi flight control systems (FC-1 and FC-2) and one 3000 psi utility system. FC-1 and FC-2 have the following primary flight control actuators: aileron, spoiler/deflector, roll feel, rudder, and unit horizontal tail (UHT). Secondary flight controls include the speed brake and wing leading edge flaps. The automatic flight control system (AFCS) has three actuators: roll, pitch, and yaw. The A-7E emergency power package (ram air turbine) pump provides emergency power at 3000 psi for FC-2 system.

The lightweight hydraulic system contains a total of 20 actuators; five were fabricated in Phase I. The LHS actuators were designed for the same end attach points, kinematics, load, stroke, and rate requirements as the equivalent 3000 psi actuators. Conventional design techniques and fabrication procedures were employed for all the test units. The 8000 psi pump is a typical variable delivery in-line piston design with several unique features to optimize performance at 8000 psi. LHS minor components such as check valves, filters, and solenoid valves utilized conventional designs modified for 8000 psi service. FC-1 and FC-2 tubing and fittings were sized to reflect the lower flow requirements which result from operating at 8000 psi.

Development of the various LHS components was completed satisfactorily with the exception of the pump. The pump problems were principally quality control and transfer tube sealing.

A full scale ground simulator was designed. The simulator will be a steel frame structure with LHS component installations and hydraulic distribution systems similar to the flight test aircraft. Modular construction provides cost effectiveness and program flexibility. Two types of modules are employed: (1) power system modules, and (2) actuator load modules. Six modules were fabricated in Phase I.

#### 4.2 Specifications

A total of 34 preliminary specifications were written to establish requirements for lightweight hydraulic systems. General, component, and process specifications were prepared in accordance with MIL-STD-961.

#### 4.3 Component Testing

4.3.1 Seal Development - A 400 hour test was conducted to evaluate and select candidate rod seals for the LHS actuators. The investigation considered single stage seals and two-stage unvented seals. Five seal configurations completed the test with acceptable leakage rates. A two-stage seal was selected for use in flight control actuators; a single stage seal was chosen for utility applications. A concurrent evaluation of servo valve erosion was made during the seal test. Erosion should not be a problem in 8000 psi systems using MIL-H-83282 fluid.

4.3.2 Compatibility Test - The compatibility test integrated major sections of the 8000 psi system to be assembled on the full scale simulator in Phase II. Primary purposes of this test were:

- (1) Permit preliminary LHS component compatibility testing.
- (2) Provide a means for realistically endurance testing the LHS pumps, reservoirs, actuators, valves, etc.

The test was performed in three blocks of 50 hours duration (150 hours total). Actuator cycling was based on the load/stroke schedule given in MIL-C-5503. A total of 1,000,000 cycles were run. Component performance checks were made at 0, 50, 100, and 150 hours.

Because of development difficulties, "interim pumps" were used. These units functioned well but had performance areas which could be improved with design changes. Full performance pumps are anticipated for Phase II.

The compatibility test was completed satisfactorily except for a number of minor problems. The test systems were stable, actuator operation was satisfactory, and pressure fluctuations were low. The results provided convincing evidence that the Phase II simulator will function as designed.

4.3.3 Pressure Impulse Test - A system containing an LHS solenoid valve, quick disconnect, hose, tubing, and 17 fittings was built. Difficulty was experienced in developing the required surge with this setup. After several setup modifications and elimination of the hose, the correct surge was attained (135% of system pressure). A 40,000 cycle test was run. No significant failures occurred.

4.3.4 Component Endurance Test - A 10,000 cycle endurance test was conducted on nine LHS components: accumulator, 3 check valves, hose, manifold, pressure gage, relief valve, and solenoid valve. Pressure was cycled up to 9000 psi to operate the relief valve. All components successfully withstood the test except the solenoid valve and two check valves. Design changes are expected to correct the performance deficiencies.

#### 4.4 Math Model

A computer program based on one developed by the Air Force was used to model the test system and predict pressure pulsation amplitudes. Spectrum scans were run on the compatibility setup. The test data compared well with the predicted values. Pressure pulsation amplitudes were less than the maximum allowable +200 psi. The data were subsequently corroborated by the Air Force Flight Dynamics Laboratory using their test equipment.

#### 4.5 Weight and Space Analysis

Weight savings achieved in the A-7E lightweight hydraulic system were:

|                                               |          |       |
|-----------------------------------------------|----------|-------|
| Total weight of<br>EQUIVALENT 3000 psi system | 644.4 lb |       |
| Total weight of<br>LHS system                 | 449.7 lb |       |
|                                               | <hr/>    |       |
| Weight reduction                              | 194.7 lb |       |
| Weight savings                                |          | 30.2% |

Space savings achieved were:

|                                               |                      |       |
|-----------------------------------------------|----------------------|-------|
| Total volume of<br>EQUIVALENT 3000 psi system | 8173 in <sup>3</sup> |       |
| Total volume of<br>LHS system                 | 5207 in <sup>3</sup> |       |
|                                               | <hr/>                |       |
| Volume reduction                              | 2966 in <sup>3</sup> |       |
| Space savings                                 |                      | 36.3% |

#### 4.6 R&M Assessment

Based on analysis of the development hardware, improvements of 44% in system MFHBF and 17% in MMH/FH were projected. Although the program goal of 15% improvement in system R&M for development hardware appears to have been exceeded, the predicted values must be considered as preliminary.

#### 4.7 GSE Interface Requirements

Hydraulic ground support equipment requirements for aircraft with lightweight hydraulic systems are the same as for aircraft with 3000 psi systems except for operating pressure level. For cost effectiveness, existing and modified equipment are planned to be utilized to the maximum extent possible.

#### 5.0 CONCLUSIONS

Major advances toward attaining the goals of the LHS program were made in Phase I. A principal achievement was the successful operation of two 8000 psi hydraulic systems containing many of the components to be installed in the Phase II full scale simulator. The 150 hour compatibility test demonstrated that an 8000 psi operating pressure level is a practical concept. Weight and space savings--the basic purpose of the LHS program--were determined to be close to predicted values. Work accomplished in Phase I will provide a sound basis for successful implementation of the tasks planned in Phase II.

#### 6.0 RECOMMENDATIONS

Preparations for the construction of an A-7E full scale lightweight hydraulic system simulator were completed in Phase I. Tasks recommended to be performed in Phase II are:

|           |                                     |
|-----------|-------------------------------------|
| Task I    | Fabricate remaining LHS components  |
| Task II   | Fabricate LHS simulator             |
| Task III  | Conduct simulator tests             |
| Task IV   | Component redesign/retest           |
| Task V    | Math model development/verification |
| Task VI   | System weight and space analysis    |
| Task VII  | Specification update                |
| Task VIII | R&M assessment                      |
| Task IX   | GSE requirements                    |
| Task X    | LHS Pump Development                |

PREFACE

This report documents a development program conducted by Rockwell International Corporation, North American Aircraft Division, Columbus, Ohio, under Contract N62269-78-C-0363 with the Naval Air Development Center, Warminster, Pennsylvania. Technical direction was administered by Mr. J. Ohlson, Head, Materials Application Branch, Aircraft and Crew Systems Technology Directorate, Naval Air Development Center (6061), and Mr. S. Hurst, Assistant Technology Administrator, Naval Air Systems Command (AIR-340C).

This report presents the results of Phase I of a program to design, fabricate, and test a full scale 8000 psi Lightweight Hydraulic System in a ground simulator and A-7E flight test aircraft. This work is related to tasks performed under Contracts NOW-65-0567-d, N00019-68-C-0352, N00156-70-C-1152, N62269-71-C-0147, N62269-72-C-0381, N62269-73-C-0700, N62269-74-C-0511, N62269-75-C-0422, N62269-76-C-0254, and N62269-78-C-0005.

Vought Corporation, Dallas, Texas, and Sperry-Vickers, Jackson, Mississippi, were major subcontractors on the program.

Project engineers in Phase I of the LHS Advanced Development Program were:

|                 |                                  |
|-----------------|----------------------------------|
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| Mr. K. Fling    | Vought Corporation               |
| Mr. F. Perian   | Sperry-Vickers                   |

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## 1.0 INTRODUCTION

### 1.1 BACKGROUND INFORMATION

Most military and commercial aircraft flying today have hydraulic systems which operate at 3000 psi. This pressure level was flown for the first time in the early 1940's and has remained at that level despite significant advances in sealing technology, pump and actuator design, fluids, and materials. Aircraft hydraulic power requirements have increased from less than 10 horsepower in early systems to 300 hp on the Navy F-14 fighter, and 1000 hp on the Air Force B-1 bomber. This growth has resulted primarily from higher aerodynamic loading combined with increased hydraulic functions and responsibilities. As airfoil designs have become thinner and mission requirements have continued to expand, internal volume available for the installation of all systems has decreased. Thus, while more and more power is allocated for hydraulic functions, smaller weight and space allocations are available for system components. Significant reductions in the weight and space requirements of hydraulic components must be accomplished to meet mission and performance demands of future Navy aircraft.

The concept of using higher operating pressures to achieve smaller and lighter weight hydraulic components is logical and warranted an in-depth investigation. The Navy initiated an exploratory development program in 1966 to assess the areas of operational practicality and potential weight and space savings. The program included a feasibility study, component development and testing, selection of the operating pressure level (8000 psi), laboratory systems testing, and brief flight testing, References 1 through 10. The program established: 1) that 8000 psi lightweight hydraulic systems can be designed, fabricated, and maintained without special techniques or state-of-the-art advances; and 2) that the overall weight and volume of aircraft hydraulic systems can be reduced up to 30% and 40%, respectively, for systems delivering more than approximately 100 horsepower.

### 1.2 PROGRAM OBJECTIVES

The program overall objectives are: 1) to demonstrate the reliability and maintainability of 8000 psi hydraulic systems; and 2) to substantiate the predicted weight and space savings achieved by operating at 8000 psi. These objectives are to be accomplished by designing, fabricating, and testing a full scale 8000 psi lightweight hydraulic system on a ground simulator to assure satisfactory operation. The system will then be installed on an A-7E test aircraft and flown to assess in-flight performance.

Ultimate goals for lightweight hydraulic systems in Navy aircraft are:

- (1) Weight savings of 30 percent over conventional 3000 psi systems
- (2) Space savings of 40 percent over conventional 3000 psi systems

- (3) A 15 percent improvement in MFHBF for LHS development hardware over current fleet 3000 psi systems
- (4) A 15 percent improvement in MMH/FH for LHS development hardware over current fleet 3000 psi systems.

The program is anticipated to be performed in three phases:

- Phase I - Design, fabricate, and test 8000 psi components
- Phase II - Fabricate ground simulator. Conduct performance and endurance tests
- Phase III - Install 8000 psi hydraulic system in an A-7E aircraft and conduct flight test program.

### 1.3 PHASE I SCOPE OF WORK

The scope of work in Phase I is summarized below:

- |           |                                                                                                                         |
|-----------|-------------------------------------------------------------------------------------------------------------------------|
| Task I    | Design the 8000 psi flight control system to be tested in an A-7E aircraft.                                             |
| Task II   | Prepare preliminary military specifications for 8000 psi components and systems.                                        |
| Task III  | Design 8000 psi components. Fabricate selected components.                                                              |
| Task IV   | Conduct component testing including seal development, valve erosion, acceptance, endurance, impulse, and compatibility. |
| Task V    | Assess R&M from test program data.                                                                                      |
| Task VI   | Design ground simulator. Design and fabricate selected subsystem modules.                                               |
| Task VII  | Develop preliminary math models for hydraulic and thermal system characteristics.                                       |
| Task VIII | Verify projected weight and space savings to be achieved.                                                               |
| Task IX   | Determine GSE interface requirements and make recommendations for equipment to be utilized in follow-on phases.         |

Drawings and specifications developed in Tasks I, II, III, and VI were submitted to the Navy Project Office under separate cover, References 11 and 12.

1.4      SUBCONTRACTING

Fifteen suppliers were awarded subcontracts to support the LHS Advanced Development Program in Phase I. Two firms provided major support: Vought Corporation, Dallas, Texas, and Sperry-Vickers, Jackson, Mississippi.

Vought Corporation is a prime manufacturer of military aircraft and built the flight test aircraft to be used in the LHS program. Vought provided important support in several areas:

- Supplied technical information on the A-7E
- Conducted seal development and servo valve erosion tests
- Designed and fabricated flight control actuators and system reservoirs
- Conducted acceptance testing of actuators and reservoirs
- Conducted limited endurance testing of actuators

Sperry-Vickers is a major manufacturer of aircraft hydraulic pumps. This firm developed the variable delivery pumps used to power the 8000 psi test systems.

## 2.0 SYSTEM DESIGN

2.1 A-7E AIRCRAFT2.1.1 General Description

The A-7E Corsair II is a single-place light attack aircraft powered by a turbojet engine, Figure 1. It is designed for both land and carrier based operations and employs advanced radar, navigation, and weapons systems. The aircraft has sweptback wings with a marked degree of negative dihedral. The primary flight control surfaces are ailerons, spoiler/deflectors, rudder, and unit horizontal tail (UHT). Secondary flight controls include the speed brake and wing leading and trailing edge flaps. Automatic flight control systems (AFCS) are provided for the roll, pitch, and yaw axes.

2.1.2 Hydraulic System

Prior to Airframe Change No. 73, the A-7E had two independent hydraulic systems, PC-1 and PC-2, which performed both flight control and utility functions. After Airframe Change No. 73, the A-7E contained three systems, PC-1, PC-2, and PC-3, which were integrated to power the flight control and utility systems. The objective of this configuration was to provide improved aircraft survivability. The flight test aircraft will have the 3-system configuration.

The A-7E hydraulic systems operate at 3000 psi and are designed to MIL-H-5440 Type II (-65 to +275°F) requirements. The primary flight control surfaces are powered by dual tandem hydraulic actuators. Each half of the tandem actuators is pressurized by two of the three power control systems as shown in Figure 2. If one PC system fails, the other two systems continue to supply hydraulic power for flight. An emergency power package (EPP) hydraulic pump provides emergency power for the PC-3 system.

The flight control system pumps are constant pressure, variable delivery, in-line piston designs with the following capacities:

|      |                      |
|------|----------------------|
| PC-1 | 24.1 gpm at 5650 rpm |
| PC-2 | 40.3 gpm at 5650 rpm |
| PC-3 | 15.6 gpm at 4400 rpm |

MIL-H-5606 hydraulic fluid is supplied to each pump by airless, bootstrap type reservoirs pressurized by system pressure (3000 psi). Fluid cleanliness is maintained by 5 micron absolute filters. Reservoir and system fluid capacities are:

|      | <u>Reservoir</u> | <u>System</u> |
|------|------------------|---------------|
| PC-1 | 0.8 gal.         | 3.5 gal.      |
| PC-2 | 4.0 gal.         | 12.4 gal.     |
| PC-3 | 0.8 gal.         | 3.5 gal.      |



FIGURE 1. A-7E Corsair II

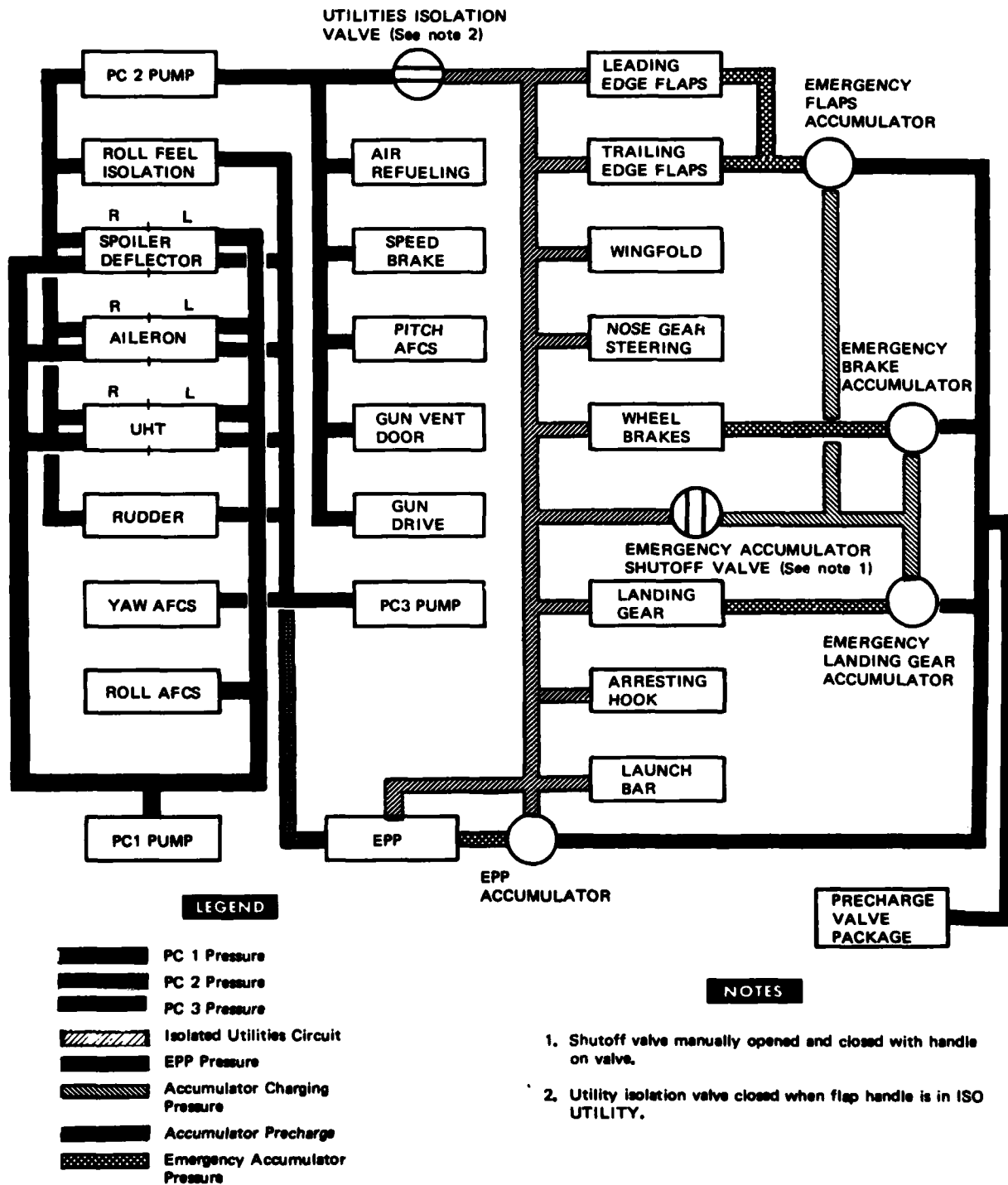


FIGURE 2. A-7E hydraulic system

## 2.2 A-7E LIGHTWEIGHT HYDRAULIC SYSTEM

Hydraulic circuitry in the A-7E flight test aircraft was re-configured from three independent power control systems operating at 3000 psi (PC-1, PC-2, and PC-3) to two independent 8000 psi flight control systems (FC-1 and FC-2) and one 3000 psi utility system. A simplified block diagram of the test installation is shown in Figure 3. A detail schematic diagram is presented as Figure 5. Major changes made in the A-7E hydraulic systems were:

- MIL-H-5606 fluid replaced with MIL-H-83282 fluid.
- PC-1 and PC-2 3000 psi pumps replaced with FC-1 and FC-2 8000 psi pumps. FC-1 and FC-2 pumps power flight control functions only.
- PC-3 3000 psi pump powers utility functions only.
- PC-2 reservoir converted to utility system reservoir.
- PC-3 reservoir converted to FC-2 reservoir.
- Speed brake hydraulic circuitry moved from PC-2 to FC-1.
- EPP supplies emergency 3000 psi power to FC-2.
- Seven primary and thirteen secondary flight control 3000 psi actuators replaced with 8000 psi actuators.

All FC-1 and FC-2 tubing and fittings were sized to reflect the lower flow requirements which result from operating at 8000 psi. Pressure tubing used in Phase I was 21-6-9 CRES; return tubing was 6061-T6 aluminum. Standard MS 28778 O-rings were used in all static (boss) seals. Component details are discussed in Section 3.0.

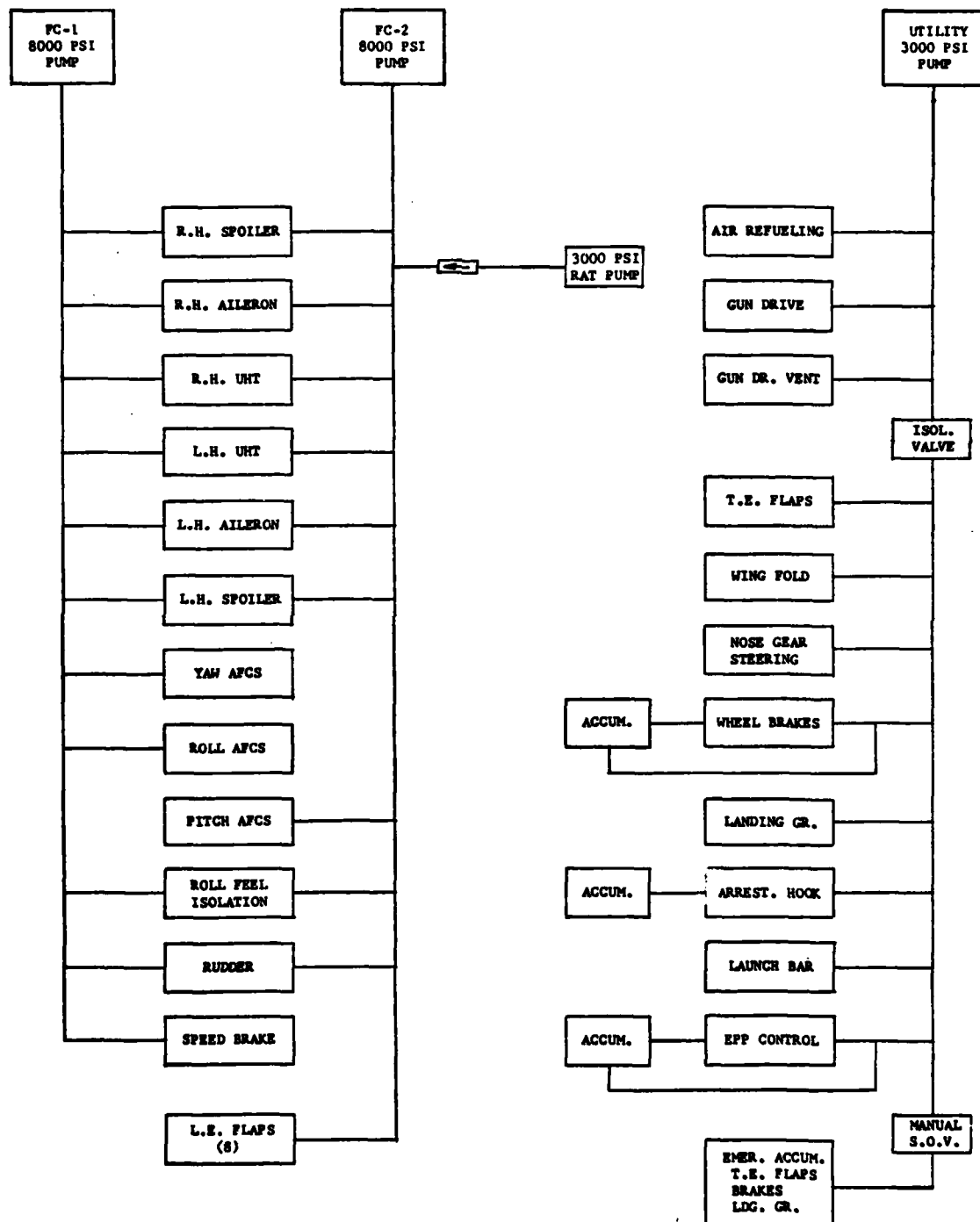


FIGURE 3. A-7E lightweight hydraulic system

## 3.0 COMPONENT DESIGN

3.1 MAJOR COMPONENTS3.1.1 Pump

The LHS pump was designed and fabricated by Sperry-Vickers in Jackson, Mississippi, and is identified as M/N PV3-047-2, P/N 570937. The unit is a variable delivery pressure compensated in-line piston design, Figure 4. Rated output at 5900 rpm and +220°F inlet fluid temperature is 10 gpm at 7700 psig; full displacement is 0.47 CIPR. Port sizes are: -10 inlet, -8 discharge, and -6 case drain.

The pump is basically a conventional design with several unique features to optimize performance at 8000 psi, Figure 6. Thick walled pistons are used to reduce unswept volume. The heavier pistons produce higher centrifugal moments than those occurring in 3000 psi pumps. In order to reduce the drive shaft bending stresses, meet the allowable shaft slope through the pump bearings, and absorb piston inertia moments, the cylinder block and drive shaft are integrated into a single piece. Because of the stiffness of the cylinder block drive shaft, a floating plate is used for valving the cylinders into the valve block. This plate is driven by the cylinder block through nine transfer tubes. The swash plate/piston shoe configuration in essentially a conventional design.

3.1.2 Actuators

LHS actuators designed and fabricated in Phase I were as follows:

| Part No.    | Total Number<br>In Test<br>System | Quantity<br>Fabricated<br>In Phase I | LHS<br>Actuator                                        | Type               | Mfr.   |
|-------------|-----------------------------------|--------------------------------------|--------------------------------------------------------|--------------------|--------|
| 8696-587100 | 1                                 | 1                                    | Rudder<br>(see Figure 7)                               | Dual<br>Tandem     | NAAD   |
| 83-00201    | 1                                 | 1                                    | Speed Brake<br>(see Figure 8)                          | Single<br>Cylinder | Vought |
| 83-00211    | 2                                 | 1                                    | Unit Horizontal<br>Tail (UHT)<br>(see Figure 9)        | Dual<br>Tandem     | Vought |
| 83-00221    | 2                                 | 1                                    | Aileron<br>(see Figure 10)                             | Dual<br>Tandem     | Vought |
| 83-00231    | 3                                 | 1                                    | Automatic Flight<br>Cont.Sys.(AFCS)<br>(see Figure 11) | Dual<br>Parallel   | Vought |
| 83-00251    | 1                                 | 0                                    | Roll Feel<br>Isolation                                 | Dual<br>Tandem     | Vought |
| 83-00261    | 8                                 | 0                                    | Leading Edge<br>Flap                                   | Single<br>Cylinder | Vought |
| 83-00271    | 2                                 | 0                                    | Spoiler/<br>Deflector                                  | Dual<br>Tandem     | Vought |

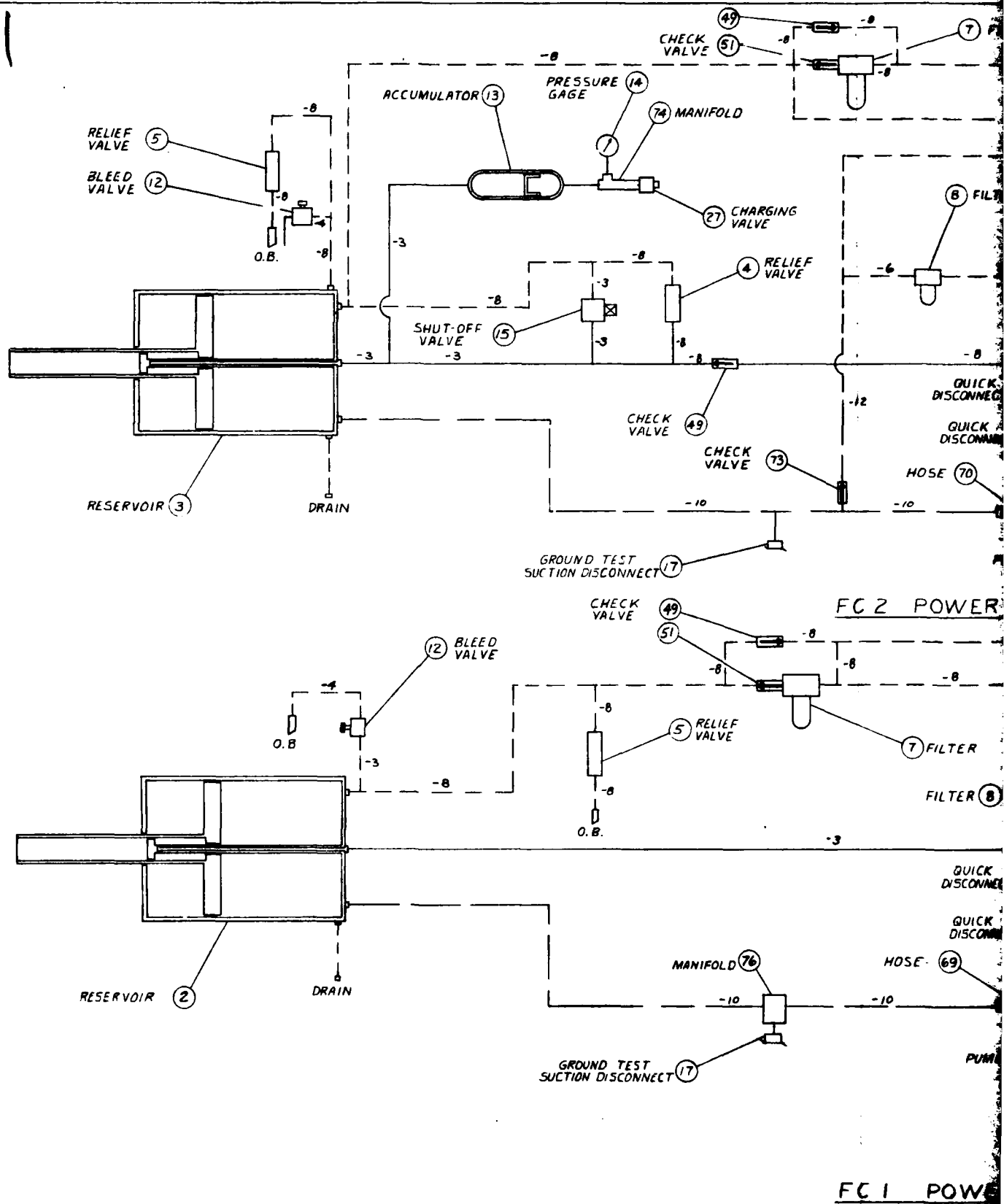


Sperry Vickers P/N 570937, M/N PV3-047-2

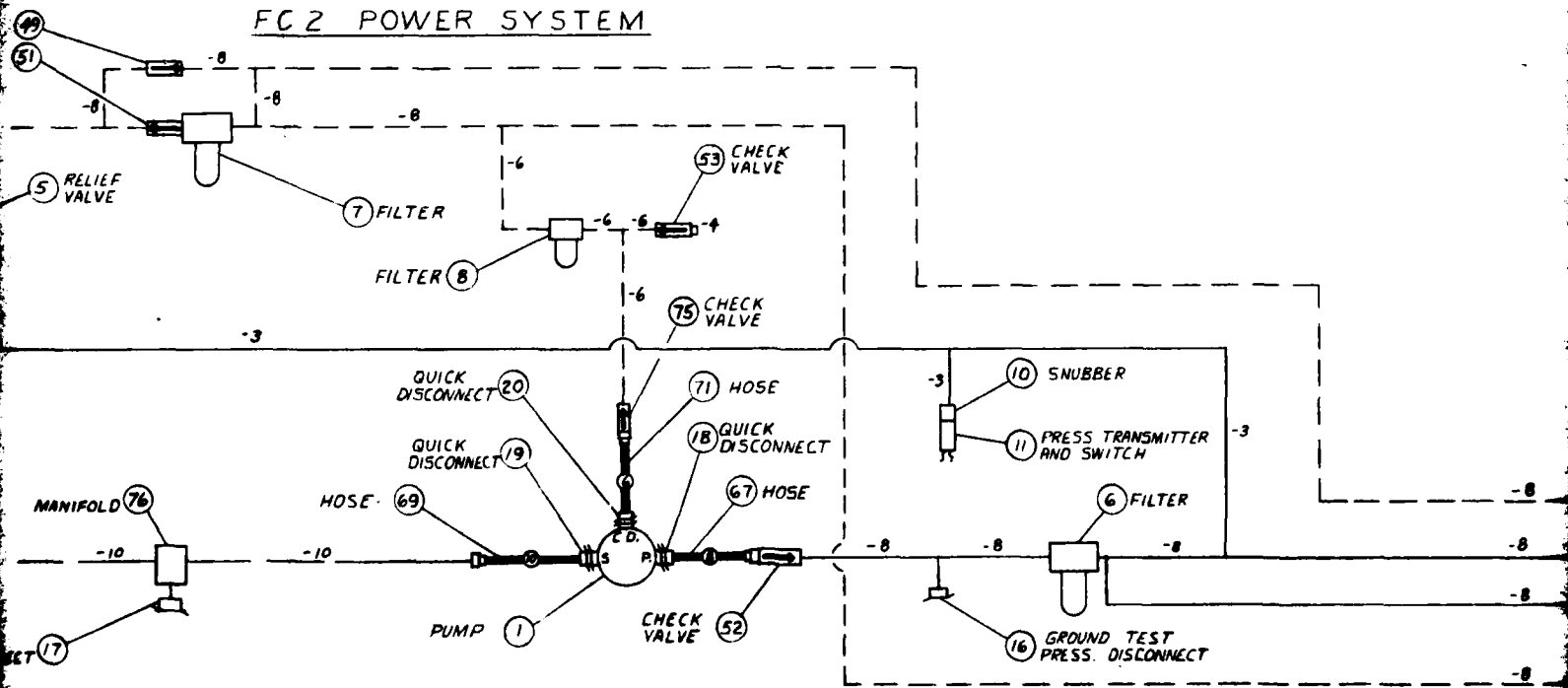
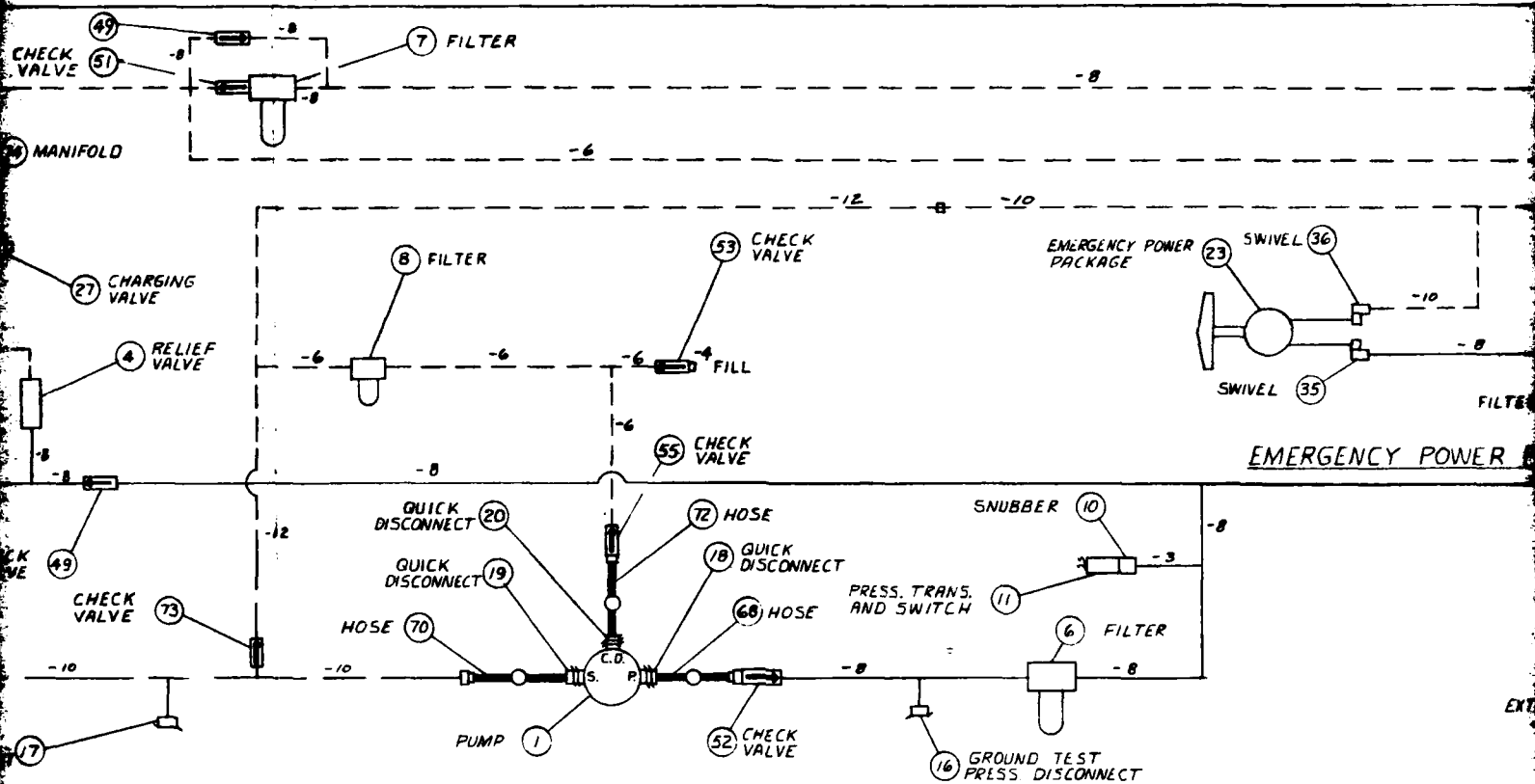
FC-1 S/N 346581

FC-2 S/N 348168

FIGURE 4. LHS pump

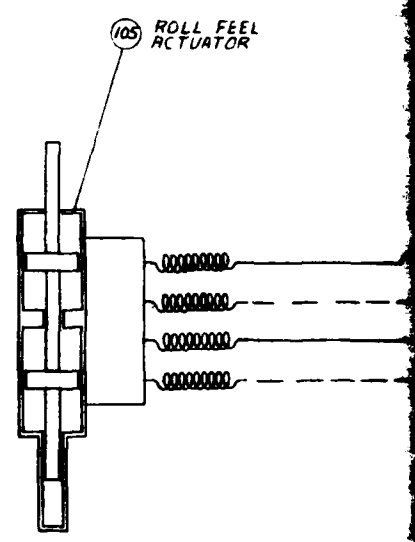
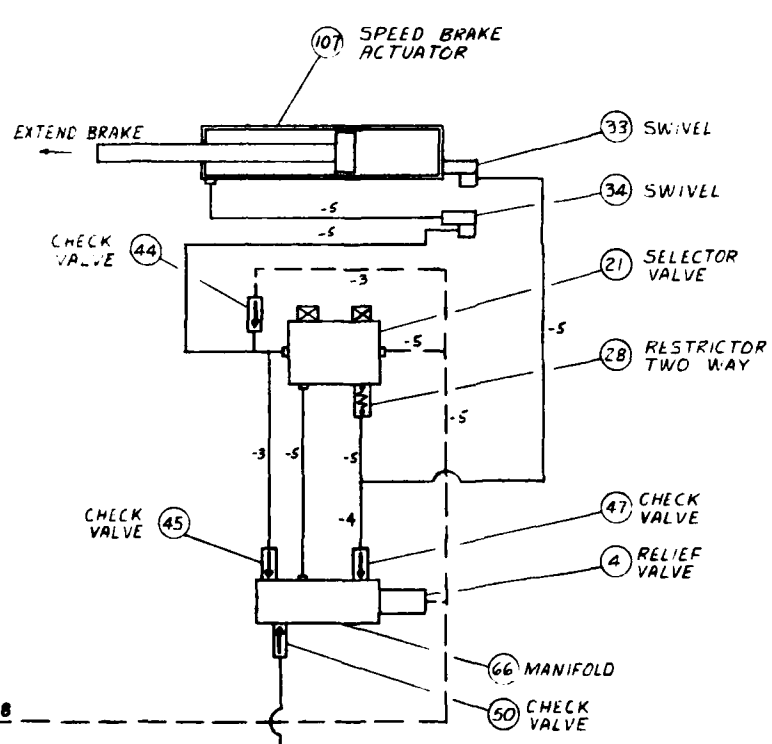
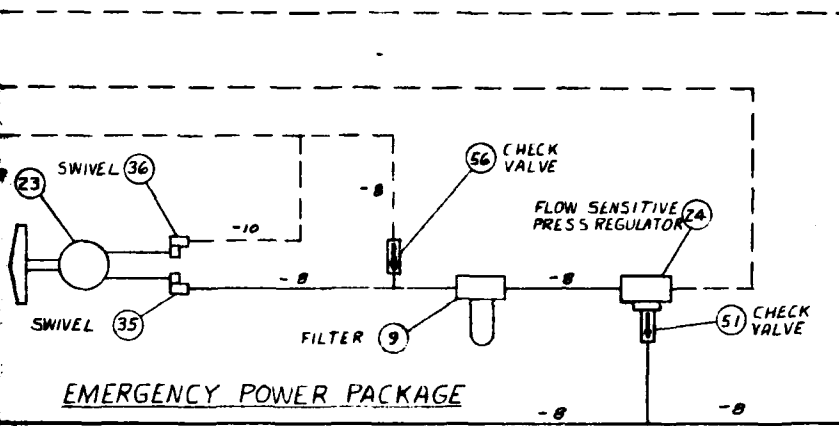


2 1



8696-580001

31

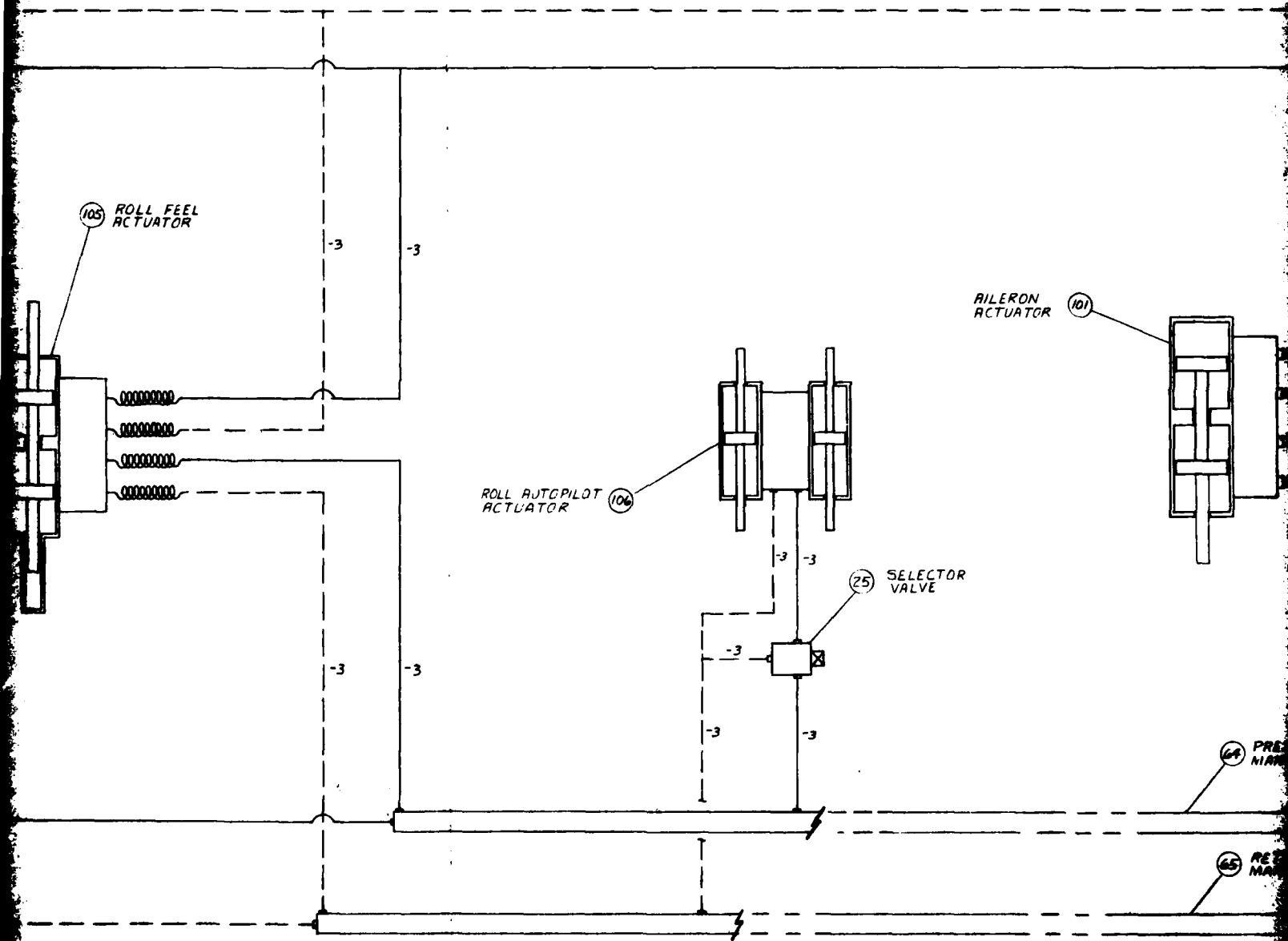


8696-580001

SPEED BRAKE

ROLL FEEL ISOLATION

4 1



FEEL ISOLATION

ROLL AUTOPILOT

5.

CHECK  
VALVE

-6

-6

AILERON  
ACTUATOR

(101)

(77)

(78)

(79)

(80)

SPOILER  
ACTUATOR

(102)

(37) (REF)

-3

-3

-3

-3

-3

-3

-3

-3

(37) WING FOLD  
SWIVEL

(64) PRESSURE  
MANIFOLD

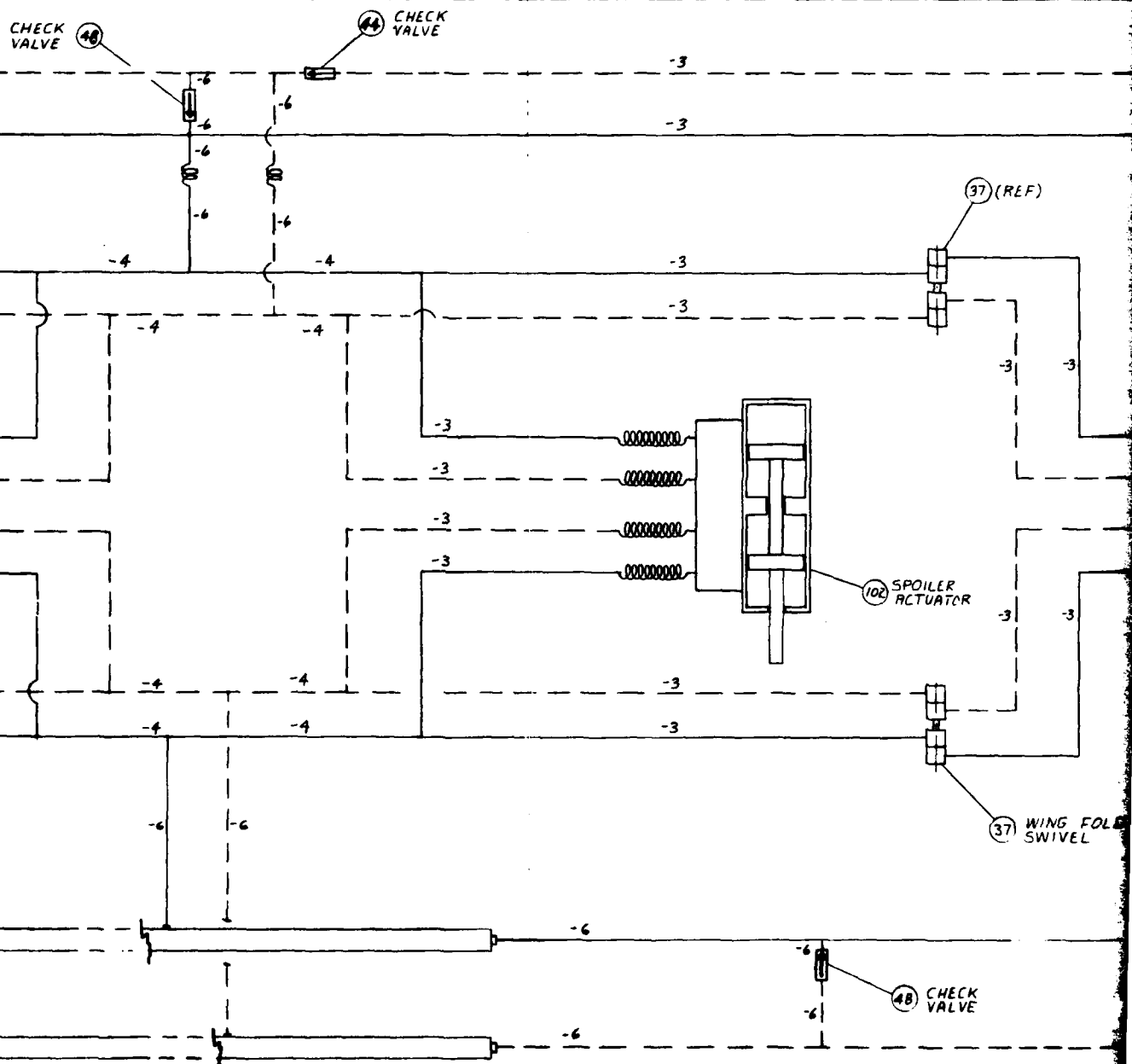
(65) RETURN  
MANIFOLD

8696-580001

1

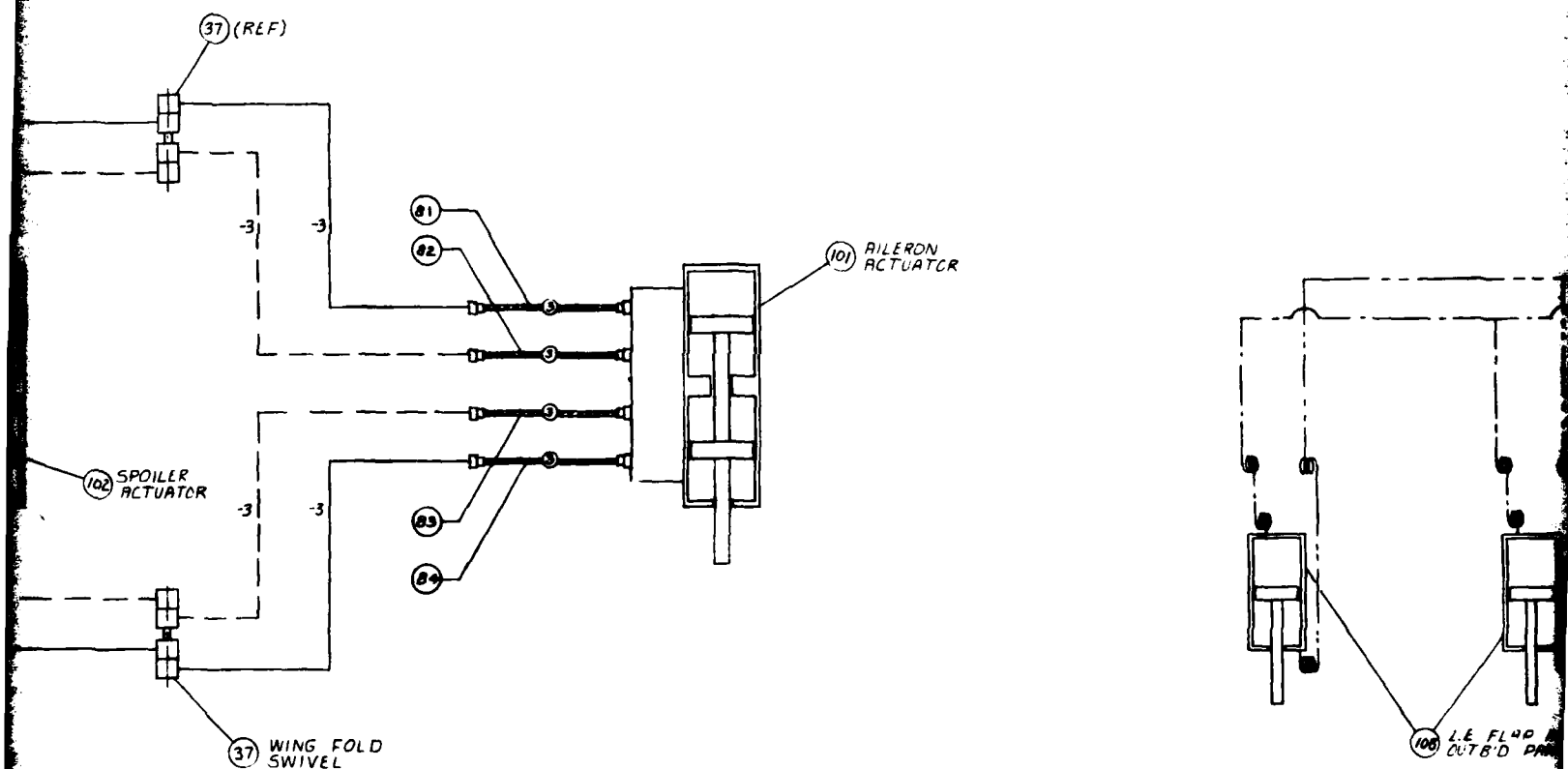
AILERON AN

6

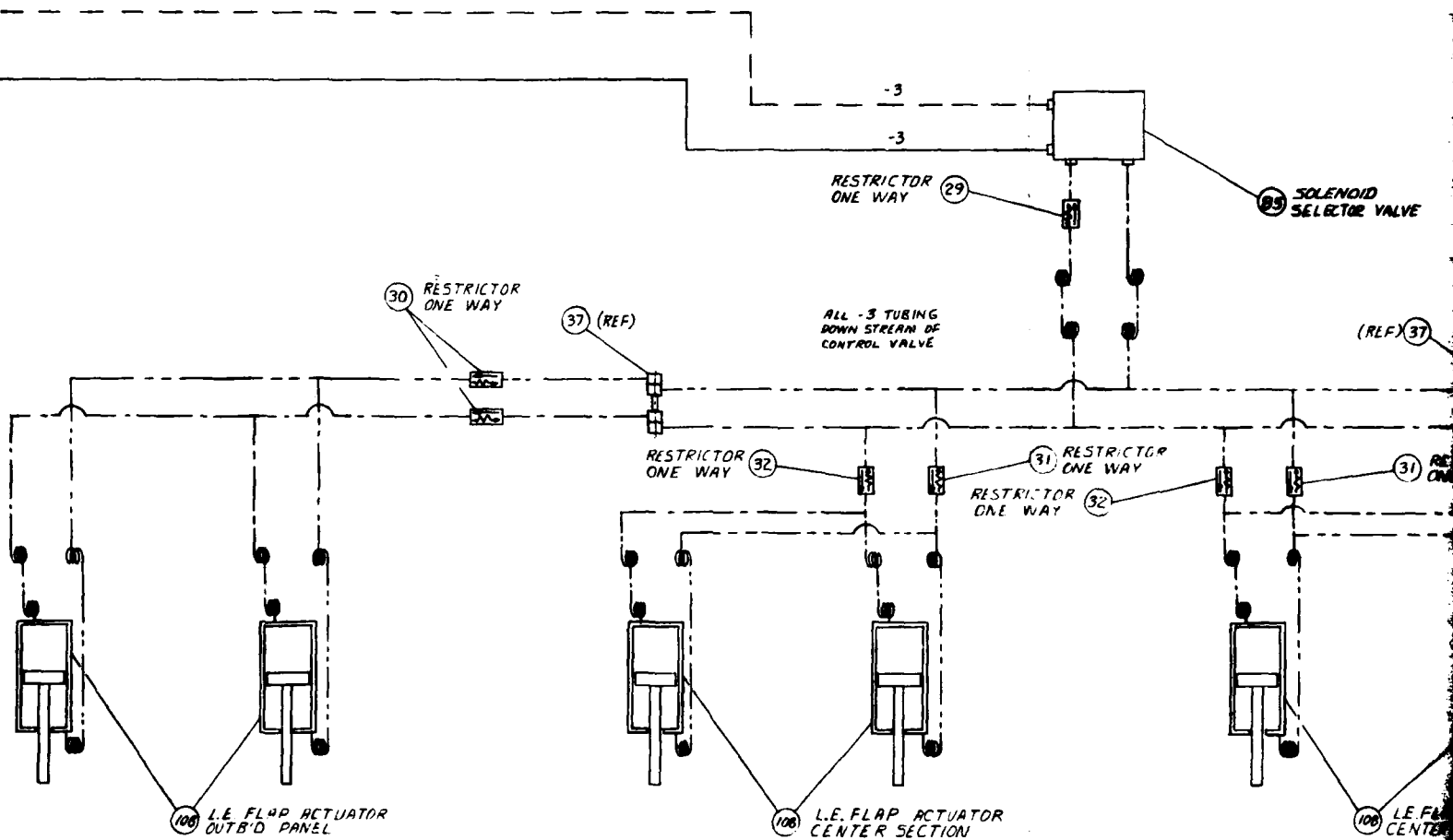


AILERON AND SPOILER

71



8



8696-580001

1

LEADING EDGE FLAP

9

-6

-6

SOLENOID  
SELECTOR VALVE

(REF) 37

RESTRICTOR  
ONE WAY

YAW AUTOPILOT  
ACTUATOR

106

RESTRICTOR  
ONE WAY

31

SELECTOR  
VALVE

25

LE FLAP ACTUATOR  
CENTER SECTION

108

LE FLAP ACTUATOR  
OUTB'D PANEL

108

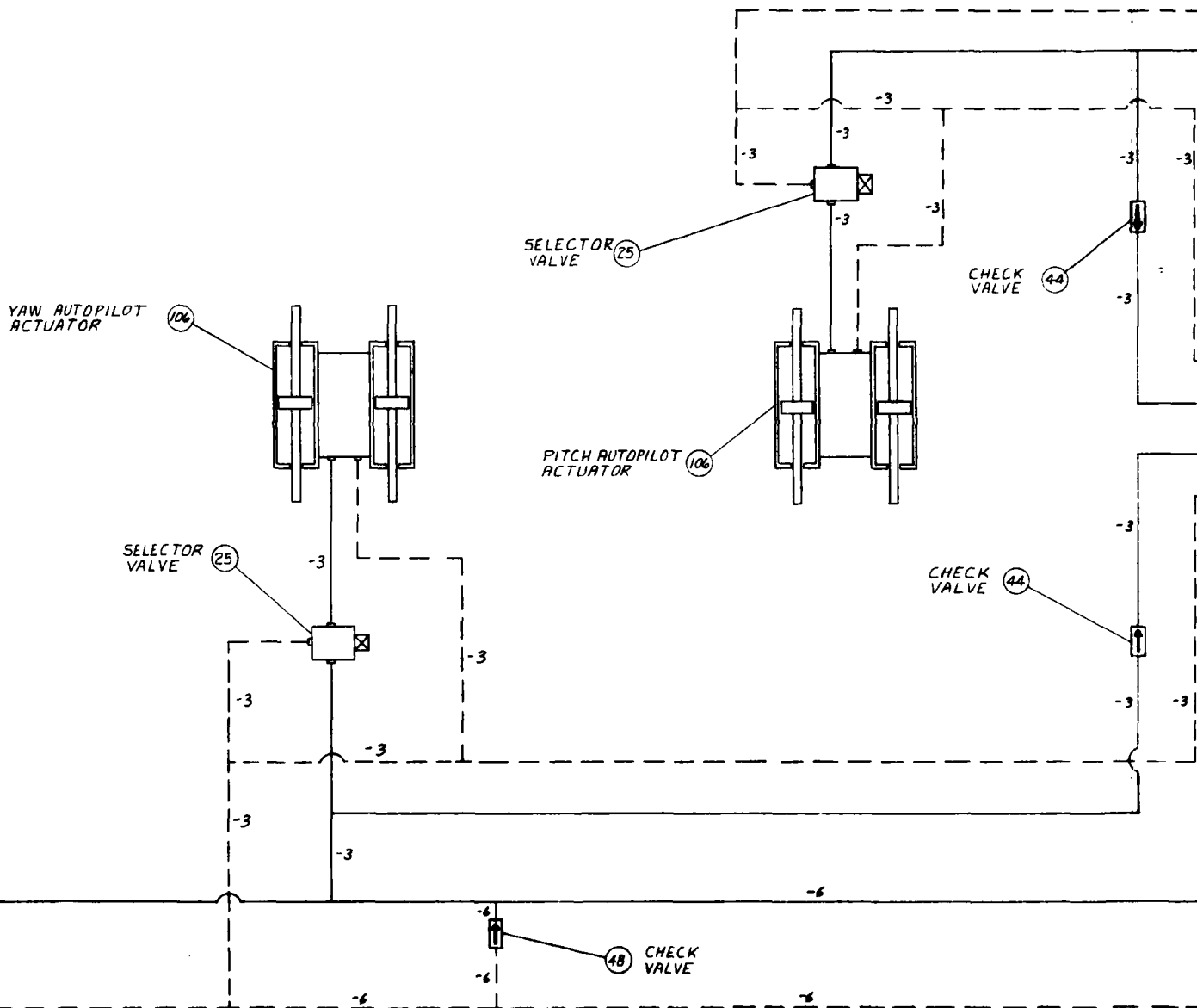
-3

-3

E FLAP

Y

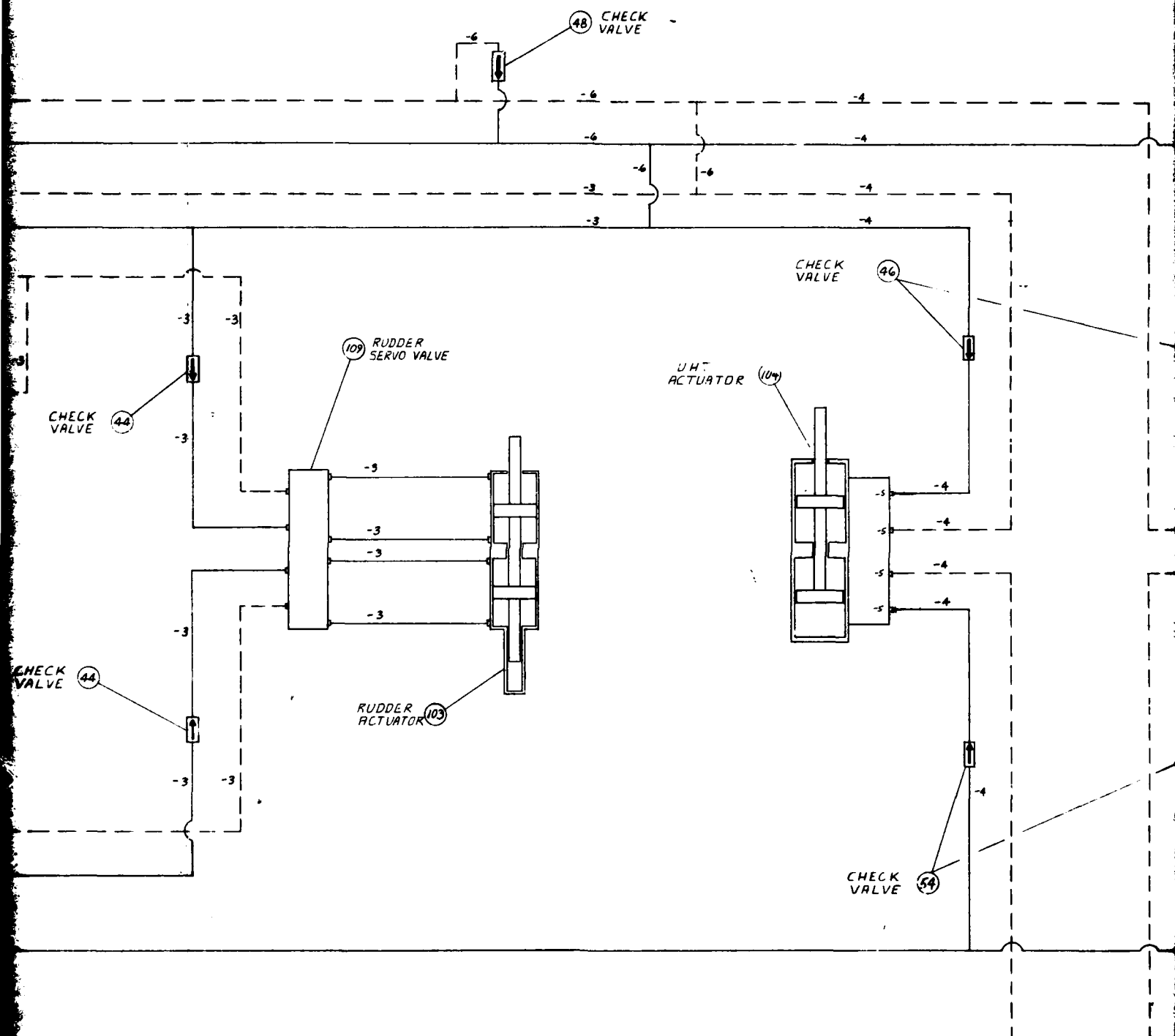
10



YAW AUTOPILOT

PITCH AUTOPILOT

11



PILOT

RUDDER

8696-580001

UNIT HORIZONTAL

12

| REVISIONS |                                                                                                  | DATE | APPROVED                   |
|-----------|--------------------------------------------------------------------------------------------------|------|----------------------------|
| NO.       | DESCRIPTION                                                                                      |      |                            |
| 1         | MAY BE REWORKED                                                                                  |      |                            |
| 2         | CANNOT BE REWORKED                                                                               |      |                            |
| 3         | RECORD CHANGE                                                                                    |      |                            |
| 4         | HOW SHIP PRACTICE                                                                                |      |                            |
| 5         | PARTS MADE OK                                                                                    |      |                            |
| A         | 1. REPLACED LEADING EDGE SWIVELS WITH COILED TUBE (ITEMS 41, 42, 43)                             | 3    |                            |
|           | 2. REPLACED WING/FUS. SWIVELS WITH COILED TUBE (ITEMS 38, 39, 40)                                | 3    |                            |
|           | 3. REPLACED LINE EXTENSION UNITS (ITEMS 57 THRU 63) WITH COILED TUBE AND NOSE (ITEMS 77 THRU 84) | 3    |                            |
|           | 4. DELETED SPEED BRAKE MANUAL UNLOADING VALVE (ITEM 22)                                          | 3    |                            |
|           | 5. REPLACED MANUALLY OPER. VALVE (ITEM 26) WITH SOLENOID OPER. VALVE (ITEM 85) ADDED ITEM 76     | 3    |                            |
|           | 6. REVISED CHECK VALVE CALLOUTS                                                                  | 3    |                            |
|           | 7. UPDATED SHT 2 TABLES                                                                          | 3    |                            |
|           | 8. ADDED FCI PUMP CASE DRAIN FILTER                                                              | 3    |                            |
|           |                                                                                                  |      | R. HOLLAND<br>12 DEC. 1980 |

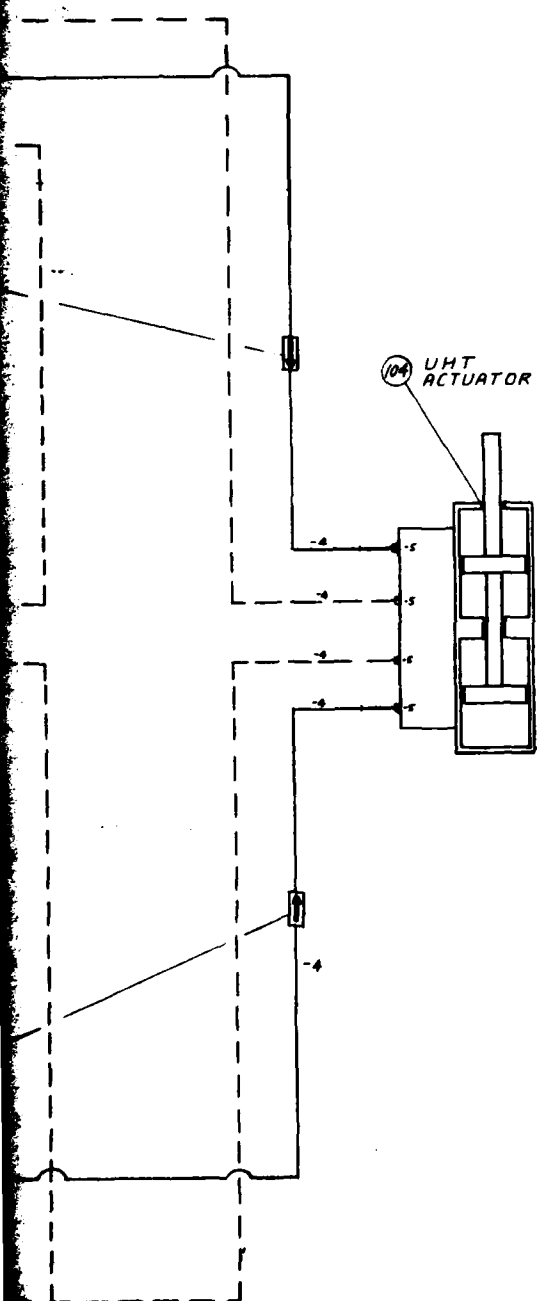


FIGURE 5

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HORIZONTAL TAIL

|          |            |                                                                  |             |
|----------|------------|------------------------------------------------------------------|-------------|
| CMTN NO. |            | Rockwell International Corporation<br>Columbus Aircraft Division |             |
| OWN BY   | R. HOLLAND | 3-14-79                                                          |             |
| CHK BY   |            |                                                                  |             |
| APVD     | L. PRIAPER | 12-19-80                                                         |             |
|          |            | SCHEMATIC DIAGRAM FCI/FC2<br>HYDRAULIC SYSTEM                    |             |
| SIZE     |            | CODE IDENTIFY                                                    | 8696-580001 |
| L        |            | 89372                                                            |             |
| SCALE    |            | PAGE 1 OF 2                                                      |             |

8696-580001

8000-280001

| ITEM | ZONE | QTY    | PART NUMBER<br>DWS. NUMBER  | NOMENCLATURE                                                                 | REMARKS                                                                        | NEXT<br>ASSEMBLY           | ENV. DRAWINGS<br>PROC. SPEC.<br>TEST SPEC. |
|------|------|--------|-----------------------------|------------------------------------------------------------------------------|--------------------------------------------------------------------------------|----------------------------|--------------------------------------------|
| 1    |      | 2      | PV3-47-2                    | PUMP-FC1 &<br>FC2 SYSTEMS                                                    | 100 GPM AT 7700 PSI AND<br>5700 RPM                                            |                            | HE 281-5015<br>LHS-8100                    |
| 2    |      | 1      | 83-00241-                   | RESERVOIR-FC1                                                                | 318.4 IN <sup>3</sup> MAX SWEPT VOL.<br>BOOTSTRAP TYPE-98.6 PSI<br>AT 8000 PSI | 8696-580016                |                                            |
| 3    |      | 1      | 83-00241-                   | RESERVOIR-FC2                                                                | 318.4 IN <sup>3</sup> MAX SWEPT VOL.<br>BOOTSTRAP TYPE-98.6 PSI<br>AT 8000 PSI | 8696-580020                |                                            |
| 4    |      | 2      | 1257<br>1258                | RELIEF VALVE-<br>FC1 & FC2 SYSTEMS                                           | FC1 100 GPM AT 8800 PSID<br>FC2 8200 PSI RESEAT PRESS                          | 8696-580017<br>8696-580020 | LHS-8029                                   |
| 5    |      | 2      |                             | RELIEF VALVE-<br>RESERVOIR, FC1 &<br>FC2 SYSTEMS                             |                                                                                | 8696-580016<br>8696-580020 |                                            |
| 6    |      | 2      | AD-4440-03Y1                | FILTER-PRESSURE,<br>FC1 & FC2 SYSTEMS                                        | 5μ ABS., NON-BYPASS TYPE                                                       | 8696-580016<br>8696-580020 | LHS-8115-1                                 |
| 7    |      | 2      | M8815/4A-B                  | FILTER-RETURN,<br>FC1 & FC2 SYSTEMS                                          | 5μ ABS., BYPASS TYPE                                                           | 8696-580016<br>8696-580020 | MIL-F-8815                                 |
| 8    |      | 1      | M8815/4A-G                  | FILTER-PUMP<br>BYPASS, FC2 SYSTEM                                            | 5μ ABS., BYPASS TYPE                                                           | 8696-580020                | MIL-F-8815                                 |
| 9    |      | 1      | AD3258-8HV                  | FILTER-EMERGENCY<br>POWER PACKAGE,<br>FC2 SYSTEM                             | RATED FLOW-6 GPM                                                               | 215-02011                  | 215-32484<br>205-15-2081<br>204-15-360     |
| 10   |      | 2      | 95239                       | PRESSURE SNUBBER<br>FC1 & FC2 SYSTEMS                                        |                                                                                | 8696-580016<br>8696-580020 | LHS-8024                                   |
| 11   |      | 2      | 18-8143                     | PRESSURE TRANSMITTER<br>& SWITCH-FC1 &<br>FC2 SYSTEMS                        | SWITCH 'OPENS' @ 4900 PSI (INCR. PR.)<br>'CLOSES' @ 4000 PSI (DECR. PRESS)     | 8696-580016<br>8696-580020 | LNS-8026                                   |
| 12   |      | 2      | 4DIR1                       | BLEED VALVE, FC1<br>& FC2 SYSTEMS                                            |                                                                                | 8696-580016<br>8696-580020 | -                                          |
| 13   |      | 1      | 3321471                     | ACCUMULATOR-FC2<br>SYSTEM                                                    | 9 IN <sup>3</sup> SWEPT OIL VOLUME<br>2 IN <sup>3</sup> MIN. GAS VOLUME        | 8696-580020                | HE-282-5001<br>LHS-8011                    |
| 14   |      | 1      | 1218-63-1                   | PRESSURE GAGE,<br>FC2 SYSTEM                                                 |                                                                                | 8696-580017                | LHS-8122-1                                 |
| 15   |      | 1      |                             | SHUT-OFF VALVE,<br>SOLENOID OPERATED,<br>FC2, PRESS. DUMP                    |                                                                                | 8696-580020                | HE-284-5059<br>LNS-8037                    |
| 16   |      | 2      | RE80942H                    | QUICK DISCONNECT, PRESS.<br>GROUND-COUPLING HALF<br>AND DUST CAP, FC1 & FC2  |                                                                                | 8696-580016<br>8696-580020 | LNS-8028                                   |
| 17   |      | 2      | 3018-54-12D<br>01553-57-12D | QUICK DISCONNECT, SUCTION<br>GROUND-COUPLING HALF<br>AND DUST CAP, FC1 & FC2 |                                                                                | 8696-580016<br>8696-580020 | 210-32587<br>205-10-2074                   |
| 18   |      | 2<br>2 | RE80943H<br>RE80944H        | QUICK DISC. PUMP PRESS.<br>HOSE HALF & BULKHEAD<br>HALF, FC1 & FC2           | HOSE HALF W/DUST CAP<br>PUMP HALF W/DUST CAP                                   | 8696-580020                | LNS-8028                                   |
| 19   |      | 2<br>2 | RE94251J<br>RE94952J        | QUICK DISC. PUMP SUCTION,<br>HOSE HALF & BULKHEAD<br>HALF, FC1 & FC2         | HOSE HALF<br>PUMP HALF                                                         | 8696-580020                | LNS-8028                                   |
| 20   |      | 2<br>2 | RE94951G<br>RE94952G        | QUICK DISC. PUMP C.D.R.,<br>HOSE HALF & BULKHEAD<br>HALF, FC1 & FC2          | HOSE HALF<br>PUMP HALF                                                         | 8696-580020                | 218-42335<br>205-18-2005<br>204-18-28      |
| 21   |      | 1      | 3321472                     | SELECTOR VALVE<br>SOLENOID OPERATED<br>FC1, SPEED BRAKE                      | 4.5 GPM @ 50 PSID                                                              | 8696-580017                | HE 284-5061<br>LNS-8037                    |
| 22   |      | 1      |                             | VALVE, LANDING-<br>MANUALLY OPERATED-<br>FC1, SPEED BRAKE                    |                                                                                |                            |                                            |
| 23   |      | 1      | 953012-4-1                  | EMERGENCY POWER<br>PACKAGE, FC2                                              |                                                                                | 218-02011                  | 216-27220<br>205-18-5002<br>204-16-71      |
| 24   |      | 1      | EA30002-24                  | FLOW SENSITIVE PRESS.<br>REGULATOR EMERGENCY<br>POWER PACKAGE, FC2           | INCLUDES RELIEF VALVE                                                          | 8696-580020                | 215-22131<br>205-15-2040<br>204-15-156     |
| 25   |      | 3      | 3321473                     | SELECTOR VALVE,<br>SOLENOID OPERATED-<br>SAS, FC1 & FC2                      | 1.4 GPM @ 50 PSID                                                              | 8696-580022                | HE 284-5060<br>LNS-8037                    |
| 26   |      | 1      |                             | SELECTOR VALVE,<br>MANUALLY OPERATED-<br>S.F.F.A.P., FC2                     |                                                                                |                            |                                            |

2 1

| NEXT ASSEMBLY              | ENV. DRAWING PROC. SPEC. TEST SPEC.    | VENDOR AND (CODE IDENT.)                            | SOURCE       |
|----------------------------|----------------------------------------|-----------------------------------------------------|--------------|
|                            | ME 281-3015 LNS-8100                   | SPERRY-VICKERS JACKSON, MISS (62983)                | NEW PURCHASE |
| 8696-580016                |                                        | VOUGHT CORP. DALLAS, TEXAS (80378)                  |              |
| 8696-580020                |                                        | VOUGHT CORP. DALLAS, TEXAS (80378)                  |              |
| 8696-580017<br>8696-580020 | LNS-8029                               | PNEUDRAULICS MONTCLAIR, CA. (06177)                 | NEW PURCHASE |
| 8696-580016<br>8696-580020 |                                        |                                                     |              |
| 8696-580016<br>8696-580020 | LNS-8115-1                             | AIRCRAFT POROUS MEDIA NORTH PINELLAS PK, FL (18350) | NEW PURCHASE |
| 8696-580016<br>8696-580020 | MIL-F-8815                             | SEE QPL                                             |              |
| 8696-580020                | MIL-F-8815                             | SEE QPL                                             |              |
| 215-02011                  | 215-32484<br>205-15-2081<br>204-15-360 | AIRCRAFT POROUS MEDIA INC. GLEN COVE N.Y. (01414)   | A-7 ASSETS   |
| 8696-580016<br>8696-580020 | LNS-8024                               | GAR KENTON NEW HAVEN, CT (26044)                    | NEW PURCHASE |
| 8696-580016<br>8696-580020 | LNS-8026                               | BENDIX CORP. COURTER INC. BOYNE CITY MICH. (96774)  | NEW PURCHASE |
| 8696-580016<br>8696-580020 | -                                      | ALLEN AIRCRAFT PROD. RAVENNA, OHIO (82829)          |              |
| 8696-580020                | ME-282-5001<br>LNS-8011                | BENDIX ELECTRODYNAMICS N. HOLLYWOOD, CA.            | NEW PURCHASE |
| 8696-580017                | LNS-8122-1                             | GED/INC. SANTA ANNA, CA. (24708)                    | NEW PURCHASE |
| 8696-580020                | ME-284-5059<br>LNS-8037                |                                                     | NEW PURCHASE |
| 8696-580016<br>8696-580020 | LNS-8028                               | AEROQUIP CORP. JACKSON, MICH. (00624)               | NEW PURCHASE |
| 8696-580016<br>8696-580020 | 210-32587<br>205-10-2074               | AEROQUIP CORP. JACKSON, MICH. (00624)               | A-7 ASSETS   |
| 8696-580020                | LNS-8028                               | AEROQUIP CORP. JACKSON, MICH. (00624)               | NEW PURCHASE |
| 8696-580020                | LNS-8028                               | AEROQUIP CORP. JACKSON, MICH. (00624)               | A-7 ASSETS   |
| 8696-580020                | 218-42335<br>205-18-2005<br>204-18-28  | AEROQUIP CORP. JACKSON, MICH. (00624)               | A-7 ASSETS   |
| 8696-580017                | ME 284-5061<br>LNS-8037                | BENDIX ELECTRODYNAMICS N. HOLLYWOOD, CA.            | NEW PURCHASE |
|                            |                                        |                                                     |              |
| 218-02011                  | 216-27220<br>205-18-5002<br>204-16-71  | GARRETT AIR RESEARCH L.A. CALIF. (70210)            | A-7 ASSETS   |
| 8696-580020                | 215-22131<br>205-15-2040<br>204-15-156 | SPERRY-VICKERS JACKSON, MISS. (62983)               | A-7 ASSETS   |
| 8696-580022                | ME 284-5060<br>LNS-8037                | BENDIX ELECTRODYNAMICS N. HOLLYWOOD, CA.            | NEW PURCHASE |

| ITEM | ZONE | QTY | PART NUMBER DWG. NUMBER | NOMENCLATURE                                             |
|------|------|-----|-------------------------|----------------------------------------------------------|
| 27   | 1    |     |                         | CHARGING VALVE, PNEUMATIC FC2, ACCUMULATOR               |
| 28   | 1    |     | REFX0380250A            | RESTRICTOR- TWO WAY, SPEED BRAKE, FC1                    |
| 29   | 1    |     |                         | RESTRICTOR- ONE WAY, L.E. FLAP, FC2                      |
| 30   | 4    |     |                         | RESTRICTOR- ONE WAY, L.E. FLAP OUTBD PANEL, FC2          |
| 31   | 2    |     |                         | RESTRICTOR- ONE WAY, L.E. FLAP, INBD PANEL, RETRACT, FC2 |
| 32   | 2    |     |                         | RESTRICTOR, ONE WAY, L.E. FLAP, INBD PANEL, EXTEND, FC2  |
| 33   | 1    |     |                         | SWIVEL JOINT- SPEED BRAKE EXTEND, FC1                    |
| 34   | 1    |     |                         | SWIVEL JOINT- SPEED BRAKE RETRACT, FC1                   |
| 35   | 1    |     | 141950                  | SWIVEL JOINT- EMER. POWER PACKAGE (RAT) FC2              |
| 36   | 1    |     | 141955                  | SWIVEL JOINT- EMER. POWER PACKAGE (RAT) FC2              |
| 37   | 2    |     |                         | SWIVEL JOINT- WINGFOLD, FC1 & FC2                        |
| 38   | 2    |     |                         | SWIVEL JOINT- WING CONNECTION, FC2 PRESS & RETURN        |
| 39   | 2    |     |                         | SWIVEL JOINT- L.E. FLAP WING CONNECT, FC2                |
| 40   | 2    |     |                         | SWIVEL JOINT- L.E. FLAP WING CONNECT, FC2                |
| 41   | 8    |     |                         | SWIVEL JOINT- L.E. FLAP ACTR. CONNECT, OUTBD PANEL, FC2  |
| 42   | 8    |     |                         | SWIVEL JOINT- L.E. FLAP ACTR. CONNECT, OUTBD PANEL, FC2  |
| 43   | 8    |     |                         | SWIVEL JOINT- L.E. FLAP ACTR. CONNECT, INBD PANEL, FC2   |
| 44   | 4    |     | 95202-1                 | CHECK VALVE, PRESSURE & RETURN                           |
| 45   | 1    |     | 95200-1                 | CHECK VALVE, PRESSURE & RETURN                           |
| 46   | 2    |     | 95202-2                 | CHECK VALVE, PRESSURE & RETURN                           |
| 47   | 1    |     | 95200-2                 | CHECK VALVE, PRESSURE & RETURN                           |
| 48   | 4    |     | 95202-4                 | CHECK VALVE, PRESSURE & RETURN                           |
| 49   | 3    |     | 95202-5                 | CHECK VALVE, PRESSURE & RETURN                           |
| 50   | 1    |     | 95200-5                 | CHECK VALVE, PRESSURE & RETURN                           |
| 51   | 3    |     | 952xx-5                 | CHECK VALVE, PRESSURE & RETURN                           |
| 52   | 2    |     | 95201-5                 | CHECK VALVE, PRESSURE & RETURN                           |

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| PART NUMBER<br>WG. NUMBER | NOMENCLATURE                                                               | REMARKS                                                               | NEXT<br>ASSEMBLY                          | ENV. DRAWING<br>PROC. SPEC.<br>TEST SPEC | VENDOR AND<br>(CODE IDENT.)                      | SOURCE       |  |
|---------------------------|----------------------------------------------------------------------------|-----------------------------------------------------------------------|-------------------------------------------|------------------------------------------|--------------------------------------------------|--------------|--|
|                           | CHARGING VALVE,<br>PNEUMATIC FC2,<br>ACCUMULATOR                           |                                                                       |                                           |                                          |                                                  |              |  |
| 95200-1                   | RESTRICTOR- TWO<br>WAY, SPEED BRAKE,<br>FC1                                | 4.0 GPM AT 7800 PSID<br>TYPE IIB                                      |                                           | LHS-8131-1                               | LEE CO.<br>WESTBROOK CT.<br>(92555)              | NEW PURCHASE |  |
|                           | RESTRICTOR- ONE<br>WAY, L.E. FLAP, FC2                                     | TYPE IIB                                                              |                                           | LHS-8031                                 |                                                  |              |  |
|                           | RESTRICTOR- ONE<br>WAY, L.E. FLAP OUTBD<br>PANEL, FC2                      | TYPE IA                                                               |                                           | LHS-8031                                 |                                                  |              |  |
|                           | RESTRICTOR - ONE<br>WAY, L.E. FLAP, INBD<br>PANEL, RETRACT, FC2            | TYPE IA                                                               |                                           | LHS-8031                                 |                                                  |              |  |
|                           | RESTRICTOR, ONE<br>WAY, L.E. FLAP, INBD<br>PANEL, EXTEND, FC2              | TYPE IA                                                               |                                           | LHS-8031                                 |                                                  |              |  |
|                           | SWIVEL JOINT- SPEED<br>BRAKE EXTEND, FC1                                   |                                                                       |                                           | ME278-5001-0003<br>LHS-8038              |                                                  |              |  |
|                           | SWIVEL JOINT- SPEED<br>BRAKE RETRACT, FC1                                  |                                                                       |                                           | ME278-5001-0001<br>LHS-8038              |                                                  |              |  |
| 141950                    | SWIVEL JOINT-EMER.<br>POWER PACKAGE (RAT)<br>FC2                           | PRESSURE LINE (3000 PSI)                                              |                                           | 215-22307<br>205-15-2036<br>204-15-143   | DUMONT ENGRG CO.<br>LONG BEACH CALIF<br>(97928)  | A-7 ASSETS   |  |
| 141955                    | SWIVEL JOINT-EMER.<br>POWER PACKAGE (RAT)<br>FC2                           | SUCTION LINE                                                          |                                           | 215-22307<br>205-15-2036<br>204-15-143   | DUMONT ENGRG CO.<br>LONG BEACH CALIF.<br>(97928) | A-7 ASSETS   |  |
|                           | SWIVEL JOINT-<br>WINGFOLD, FC1 &<br>FC2                                    | FC1 & FC2 PRESS. & RETURN.<br>L.E. FLAP EXTEND & RETRACT              |                                           | LHS-8038                                 |                                                  |              |  |
|                           | <del>SWIVEL JOINT- WING<br/>CONNECTION- FC2<br/>PRESS. &amp; RETURN</del>  |                                                                       |                                           | <del>LHS-8038</del>                      |                                                  |              |  |
|                           | <del>SWIVEL JOINT- L.E.<br/>FLAP- WING CONNECT,<br/>FC2</del>              | <del>FUSELAGE SIDE</del>                                              |                                           | <del>LHS-8038</del>                      |                                                  |              |  |
|                           | <del>SWIVEL JOINT- L.E.<br/>FLAP- WING CONNECT,<br/>FC2</del>              | <del>WING SIDE</del>                                                  |                                           | <del>LHS-8038</del>                      |                                                  |              |  |
|                           | <del>SWIVEL JOINT- L.E.<br/>FLAP ACTR. CONNECT,<br/>OUTBD PANEL, FC2</del> | <del>WING SIDE</del>                                                  |                                           | <del>LHS-8038</del>                      |                                                  |              |  |
|                           | <del>SWIVEL JOINT- L.E.<br/>FLAP ACTR. CONNECT,<br/>OUTBD PANEL, FC2</del> | <del>ACTUATOR SIDE</del>                                              |                                           | <del>LHS-8038</del>                      |                                                  |              |  |
|                           | <del>SWIVEL JOINT- L.E.<br/>FLAP ACTR. CONNECT,<br/>INBD PANEL, FC2</del>  | <del>WING SIDE</del>                                                  |                                           | <del>LHS-8038</del>                      |                                                  |              |  |
| 95202-1                   | CHECK VALVE,<br>PRESSURE & RETURN                                          | TYPE I, -3 SIZE<br>RUDDER SP. BRAKE, FLAP RETURN                      | 8696-580017<br>8696-580021<br>8696-580011 | LHS-8114-1                               | GAR-KENYON<br>NEW HAVEN, CT.<br>(26044)          | NEW PURCHASE |  |
| 95200-1                   | CHECK VALVE,<br>PRESSURE & RETURN                                          | TYPE IIB-3 SIZE<br>SPEED BRAKE                                        | 8696-580017                               | LHS-8114-1                               | GAR-KENYON<br>NEW HAVEN, CT.<br>(26044)          | NEW PURCHASE |  |
| 95202-2                   | CHECK VALVE,<br>PRESSURE & RETURN                                          | TYPE I, -4 SIZE<br>UHT                                                | 8696-580020                               | LHS-8114-1                               | GAR-KENYON<br>NEW HAVEN, CT.<br>(26044)          | NEW PURCHASE |  |
| 95200-2                   | CHECK VALVE,<br>PRESSURE & RETURN                                          | TYPE IIB-4 SIZE<br>SP. BRAKE                                          | 8696-580017                               | LHS-8114-1                               | GAR-KENYON<br>NEW HAVEN, CT.<br>(26044)          | NEW PURCHASE |  |
| 95202-4                   | CHECK VALVE,<br>PRESSURE & RETURN                                          | TYPE I, -6 SIZE<br>FC1 & FC2 RUN AROUND &<br>WING RUN AROUND          | 8696-580020<br>8696-580022                | LHS-8114-1                               | GAR-KENYON<br>NEW HAVEN, CT.<br>(26044)          | NEW PURCHASE |  |
| 95202-5                   | CHECK VALVE,<br>PRESSURE & RETURN                                          | TYPE I, -8 SIZE<br>ACCUM ISOL, FC1 & FC2 FILTER<br>RUN AROUND         | 8696-580020<br>8696-580016                | LHS-8114-1                               | GAR-KENYON<br>NEW HAVEN, CT.<br>(26044)          | NEW PURCHASE |  |
| 95200-5                   | CHECK VALVE,<br>PRESSURE & RETURN                                          | TYPE IIB, -8 SIZE<br>SP. BRAKE                                        | 8696-580017                               | LHS-8114-1                               | GAR-KENYON<br>NEW HAVEN, CT.<br>(26044)          | NEW PURCHASE |  |
| 95200-5                   | CHECK VALVE,<br>PRESSURE & RETURN                                          | TYPE IIA, -8 SIZE<br>RAT REGULATOR OUTLET,<br>FC1 & FC2 RETURN FILTER | 8696-580020<br>8696-580016                | LHS-8114-1                               | GAR-KENYON<br>NEW HAVEN, CT.<br>(26044)          | NEW PURCHASE |  |
| 95201-5                   | CHECK VALVE,<br>PRESSURE & RETURN                                          | TYPE IIB, -8 SIZE<br>PUMP PRESS.                                      | 8696-580020                               | LHS-8114-1                               | GAR-KENYON<br>NEW HAVEN, CT.<br>(26044)          | NEW PURCHASE |  |

8696-580001

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| SOURCE         |  |
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| CO. A-7 ASSETS |  |
| CO. A-7 ASSETS |  |
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| NEW PURCHASE   |  |
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| NEW PURCHASE   |  |

| ITEM | ZONE | QTY | PART NUMBER<br>DWG NUMBER            | NOMENCLATURE                                                               | REMARKS                                           | NEXT<br>ASSEMBLY           | ENV. DRAWING<br>PROC. SPEC.<br>TEST SPEC. |
|------|------|-----|--------------------------------------|----------------------------------------------------------------------------|---------------------------------------------------|----------------------------|-------------------------------------------|
| 53   |      | 2   |                                      | CHECK VALVE,<br>RETURN                                                     | -4/-6 SIZE, MS/DYN BLKHD-<br>SYS. FILL, FC1 & FC2 | 8696-580016<br>8696-580020 |                                           |
| 54   |      | 2   | 95201-2                              | CHECK VALVE<br>PRESSURE & RETURN                                           | TYPE III B, -4 SIZE<br>UHT PRESS (FC1)            | 8696-580020                | LHS-8114-1                                |
| 55   |      | 1   |                                      | CHECK VALVE,<br>RETURN                                                     | TYPE III A-6 SIZE<br>CASE DRAIN, FC2              | 8696-580020                | LHS-8114-1                                |
| 56   |      | 1   | CVC-4124-B                           | CHECK VALVE,<br>RETURN                                                     | -8 SIZE<br>RAT BYPASS                             | 218-02011 LTV              |                                           |
| 57   |      | 2   |                                      | <del>EXTENSION UNIT-<br/>ROLL FEEL, FC2<br/>PRESS &amp; RETURN</del>       |                                                   |                            |                                           |
| 58   |      | 1   |                                      | <del>EXTENSION UNIT-<br/>ROLL FEEL, FC1<br/>RETURN</del>                   |                                                   |                            |                                           |
| 59   |      | 1   |                                      | <del>EXTENSION UNIT-<br/>ROLL FEEL, FC1<br/>PRESS</del>                    |                                                   |                            |                                           |
| 60   |      | 1   |                                      | <del>EXTENSION UNIT-<br/>SPOILER, FC1 PRESS<br/>&amp; RETURN</del>         |                                                   |                            |                                           |
| 61   |      | 1   |                                      | <del>EXTENSION UNIT-<br/>SPOILER, FC2 PRESS<br/>&amp; RETURN</del>         |                                                   |                            |                                           |
| 62   |      | 6   |                                      | <del>EXTENSION UNIT-<br/>AILERON, FC1 PRESS<br/>FC1 &amp; FC2 RETURN</del> |                                                   |                            |                                           |
| 63   |      | 2   |                                      | <del>EXTENSION UNIT-<br/>AILERON, FC2 PRESS</del>                          |                                                   |                            |                                           |
| 64   |      | 1   | 8696-581002                          | MANIFOLD - FC1<br>PRESS.                                                   |                                                   | 8696-580022                |                                           |
| 65   |      | 1   | 8696-58003                           | MANIFOLD - FC1<br>RETURN                                                   |                                                   | 8696-580022                |                                           |
| 66   |      | 1   | 8696-581201                          | MANIFOLD - FC1<br>RELIEF VALVE                                             |                                                   | 8696-580017                |                                           |
| 67   |      | 1   |                                      | HOSE ASSEMBLY-<br>PUMP PRESSURE, FC1                                       | -8 SIZE                                           | 8696-580020                | LHS-8018                                  |
| 68   |      | 1   |                                      | HOSE ASSEMBLY-<br>PUMP PRESSURE, FC2                                       | -8 SIZE                                           | 8696-580020                | LHS-8018                                  |
| 69   |      | 1   |                                      | HOSE ASSEMBLY-<br>PUMP SUCTION, FC1                                        | -10 SIZE                                          | 8696-580020                |                                           |
| 70   |      | 1   |                                      | HOSE ASSEMBLY-<br>PUMP SUCTION, FC2                                        | -10 SIZE                                          | 8696-580020                |                                           |
| 71   |      | 1   |                                      | HOSE ASSEMBLY-<br>PUMP CASE DRAIN,<br>FC1                                  | -6 SIZE                                           | 8696-580020                |                                           |
| 72   |      | 1   |                                      | HOSE ASSEMBLY-<br>PUMP CASE DRAIN,<br>FC2                                  | -6 SIZE                                           | 8696-580020                |                                           |
| 73   |      | 1   | (400010 OR<br>400011)<br>(FC1 & FC2) | CHECK VALVE,<br>RETURN                                                     | -10 1/2 SIZE, RAT SUCTION                         | 8696-580020                |                                           |
| 74   |      | 1   | 8696-581004<br>VIA S.A.T.            | MANIFOLD - FC2<br>ACCUMULATOR                                              |                                                   | 8696-580017                |                                           |
| 75   |      | 1   | 95201-4                              | CHECK VALVE,<br>PRESSURE & RETURN                                          | TYPE III B, -6 SIZE,<br>FC1 CASE DRAIN            | 8696-580020                | LHS-8114-1                                |
| 76   |      | 1   | 8696-581001                          | MANIFOLD, FC1<br>SUCTION DISC.                                             |                                                   | 8696-580016                |                                           |
| 77   |      | 1   |                                      | HOSE ASSEMBLY-<br>AILERON PRESSURE,<br>FC2                                 | -3 SIZE                                           |                            | LHS-8018                                  |
| 78   |      | 1   |                                      | HOSE ASSEMBLY-<br>AILERON RETURN,<br>FC1                                   | -3 SIZE                                           |                            | LHS-8018                                  |

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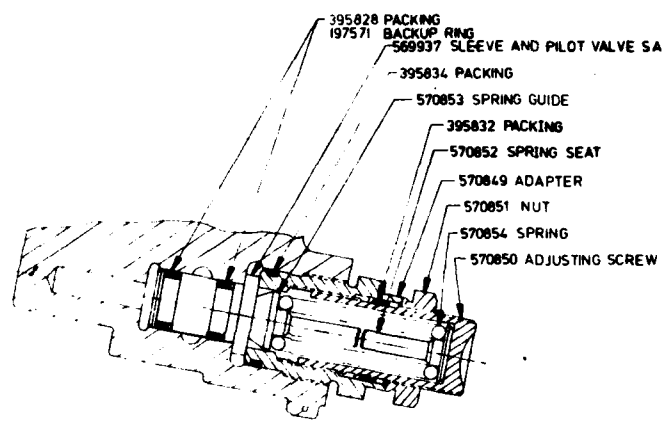
FIGURE 5 (CONT.)

8696-580004

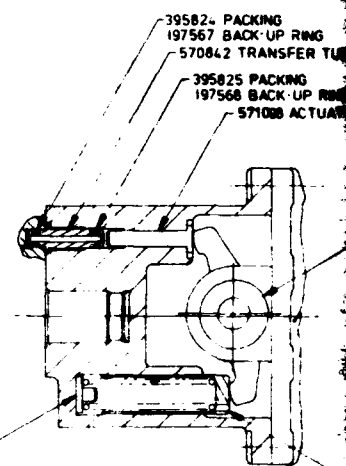
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| L     | CODE IDENT NO. | 8696-580004  |
|       | 89372          |              |
| SCALE |                | FIGURE 2 - 2 |

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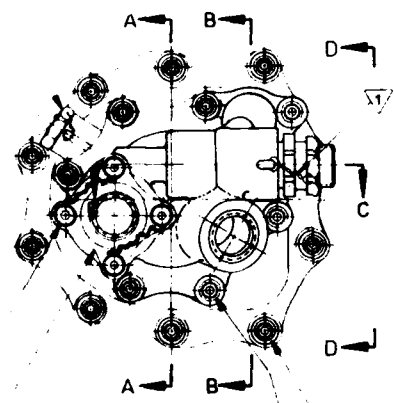


SECTION C-C  
SCALE 2/1  
ROTATED 11° CLOCKWISE



SECTION B-B

AN814-6DL (89276) PLUG  
396096 PACKING  
MS 20995C32 (28982) LOCKWIRE



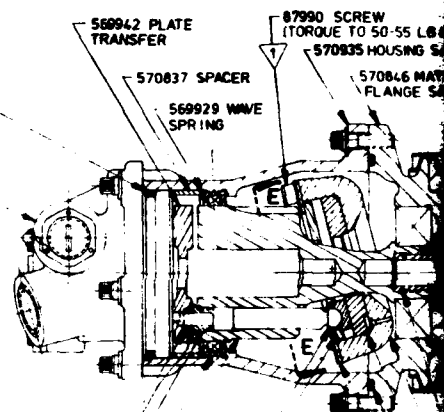
570843 DISCHARGE ADAPTER  
395875 PACKING  
197596 BACK-UP RING  
MS24678-21 (28580) SCREW  
(TORQUE TO 11-12 LB FT)

MS21098-50 (580555) SCREW  
AN960-416 (32261) WASHER  
(TORQUE TO 100-108 IN-LB)

TORQUE TO 75-80 IN-LB  
7 SCREWS

395958 PACKING

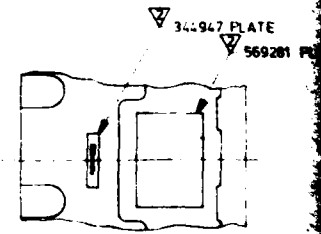
569938 VALVE BLOCK SA



87990 SCREW  
(TORQUE TO 50-55 LB FT)  
570835 HOUSING SA  
570846 MAT FLANGE SA

570832 CYLINDER BLOCK  
571110 PISTON & SHOE SA

577738 BEARING  
569940 RING, PISTON-LARGE  
569939 RING, PISTON-SMALL  
569941 TRANSFER TUBE



VIEW D-D

ADHESIVE BOND PER VS1 3-4-14.  
LOCKWIRE PER MS33540.

| REVISED             |               | DATE   | APPROVED |
|---------------------|---------------|--------|----------|
| A                   | EC62983-16208 | 1/1/70 | AE       |
| REVISED AND REDRAWN |               | G.E.S. | 1/1/70   |

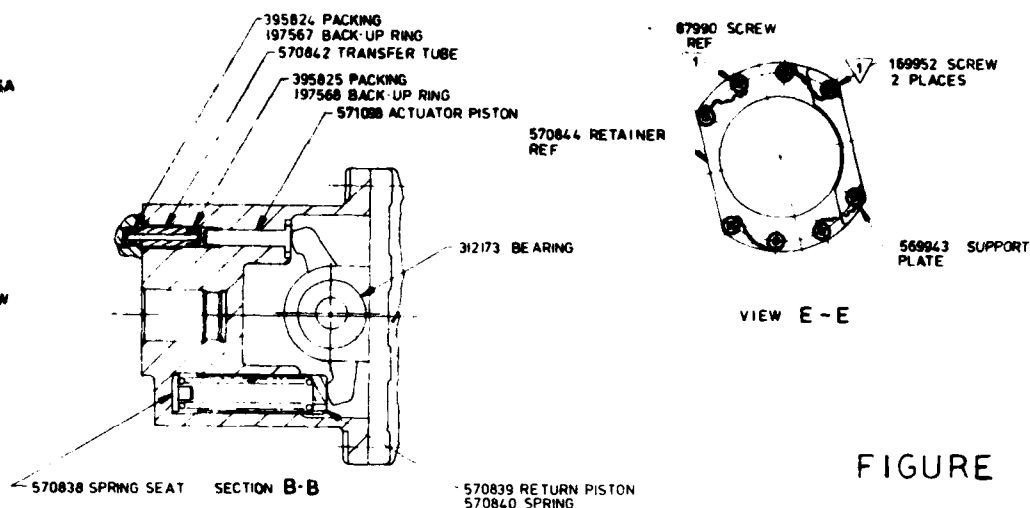
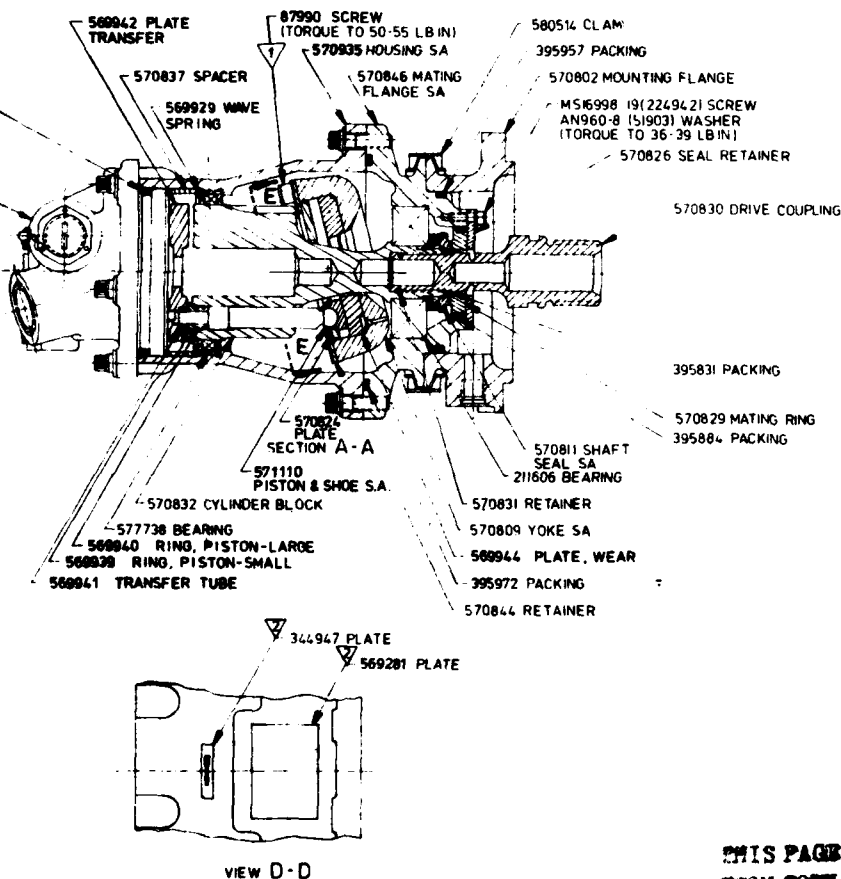


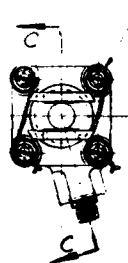
FIGURE 6



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|                                                                            |  |                               |  |                              |  |
|----------------------------------------------------------------------------|--|-------------------------------|--|------------------------------|--|
| DRAWING NUMBER<br>EC62983-16208                                            |  | PART NUMBER<br>PV3-047-2      |  | REV. N-00                    |  |
| TITLE<br>PUMP AXIAL PISTON<br>VARIABLE DISPLACEMENT<br>PRESSURE CONTROLLED |  | DESIGNED BY<br>PEDERSEN-27-75 |  | CHECKED BY<br>PEDERSEN-27-75 |  |
| DATE<br>1/1/70                                                             |  | DRAWN BY<br>E 62983           |  | PART NUMBER<br>570937        |  |
| BY<br>N.F. PEDERSEN-27-75                                                  |  | DATE<br>1/1/70                |  | SHEET 1 OF 1                 |  |

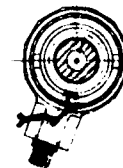
8828-28100



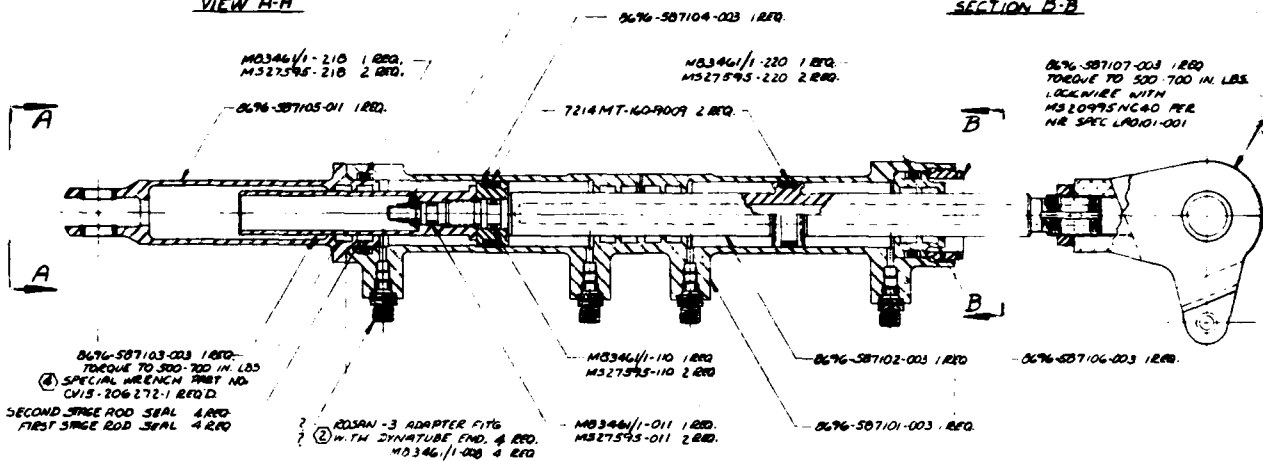
VIEW A-A

NAS624HA 4 REQ.  
MS20002C4 4 REQ.  
TORQUE TO 60-80 IN LBS  
LOCKWIRE WITH MS20995NC20  
WIRE PER NR SPEC LAD101-001

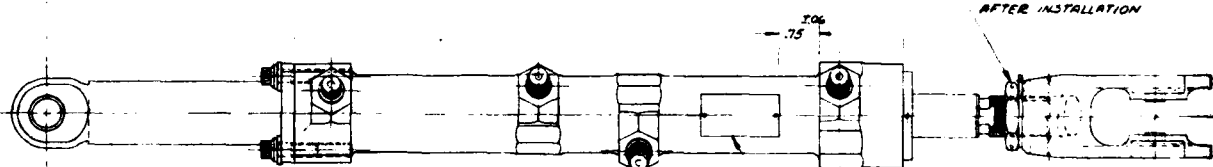
MS114-0046-0004 1 REQ. ①  
MS20002-4 1 REQ.  
TORQUE TO 30-70 IN LBS



SECTION B-B



SECTION C-C



ENGINEERING INFORMATION (REF)

MEAN LENGTH 20.770  
EXTD. LENGTH 22.370  
COMP. LENGTH 19.170  
(STROKE = 3.1600)

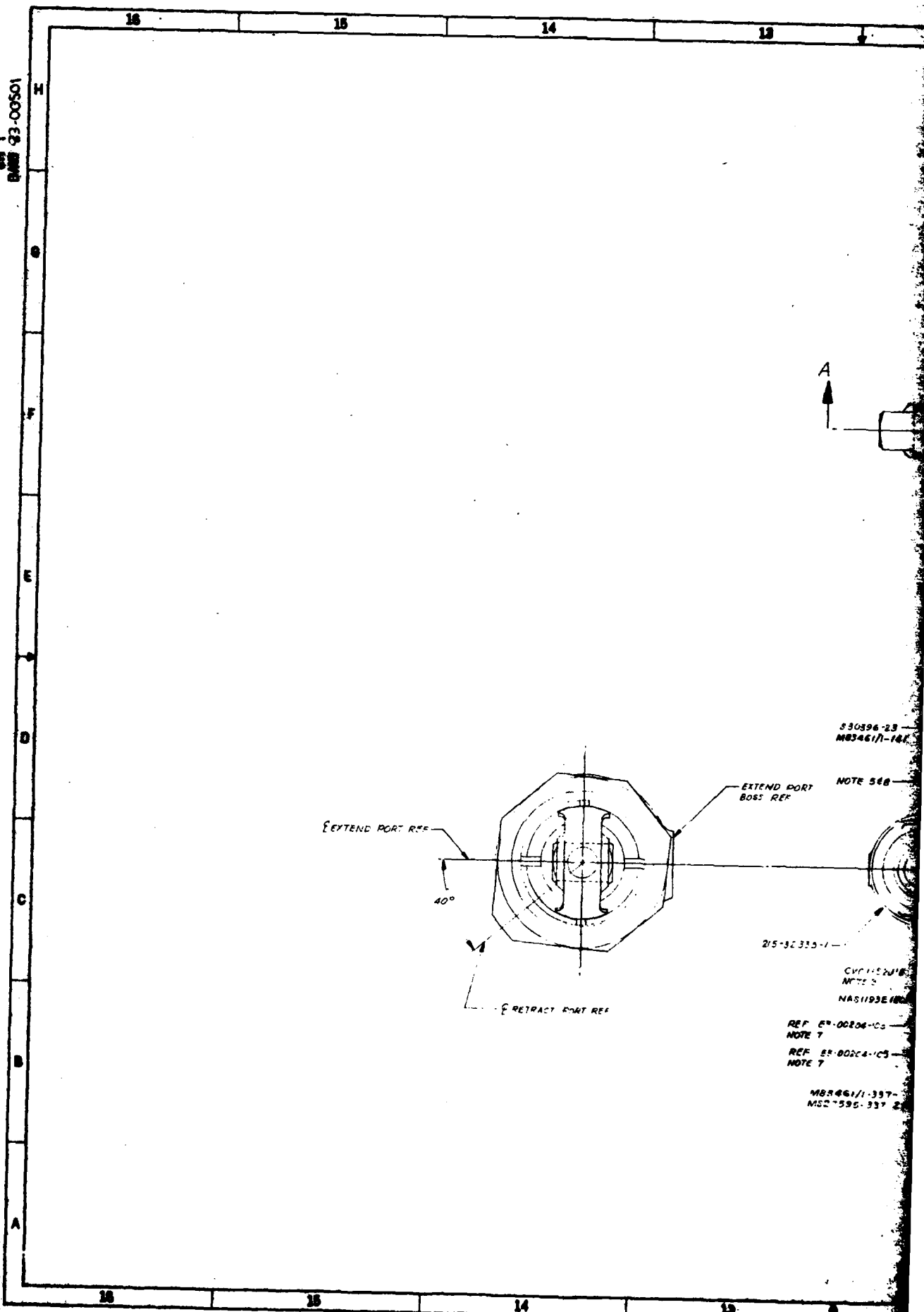
SP33 REQ.  
FORM TO MATCH CYL DIA AND  
BOND PER NR SPEC LAD106-033  
USING EC137 OR RESISTANT ADHESIVE  
BEFORE BONDING TO CYL METAL  
STAMP NAMEPLATE AS FOLLOWS:  
RATING - 8000 PSI  
PART NO - 0676-587100-001  
SERIAL NO -  
ORDER NO -

- 7 ASSEMBLE AND TEST PER NR SPEC NYA-2
  - 6 RATED PRESSURE 8000 PSI
  - ④ ③ 5 TO BE OBTAINED FROM:  
VORWIT CORPORATION, DALLAS, TEXAS 75222
  - ② 4. INSTALL PER NR SPEC LAD106-033.
  3. IDENTIFY PER NR SPEC LAD106-033.
  - ① 2. VERIFY ITEM - SEE SPEC CONTROL DRAWING.
  1. INSTALL THREADED ADAPTERS PER NR SPEC LAD101-001.
- NOTES: UNLESS OTHERWISE NOTED

|          |     |
|----------|-----|
| QTY      | 1   |
| ITEM     | 001 |
| REQ PER  | 100 |
| END ITEM |     |



10500-03-00501  
10500-03-00501  
10500-03-00501



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CVC1399-76A  
NOTE 12 LOCATE  
APPROX AS SHOWN

-101

A

30.64 RETRACTED  
50.58 EXTENDED  
19.94 STROKE

M83461/1-115  
MS27595-115 2 REQD  
M83461/1-218  
MS28774-2W 2 REQD

85-00262-101

85-00203-101

330396-23  
M83461/1-141

EXTEND PORT  
Boss REF

NOTE 568

215-32335-1

CVC1152018  
NOTE 5  
NAS1193E/RCP

REF 85-00204-105  
NOTE 7

REF 85-00264-105  
NOTE 7

M83461/1-337-  
MS27595-337 2 REQD

215-32443-1

NAS 1012-A7

215-32430-4

85-00204-111

SECTION A-A 661

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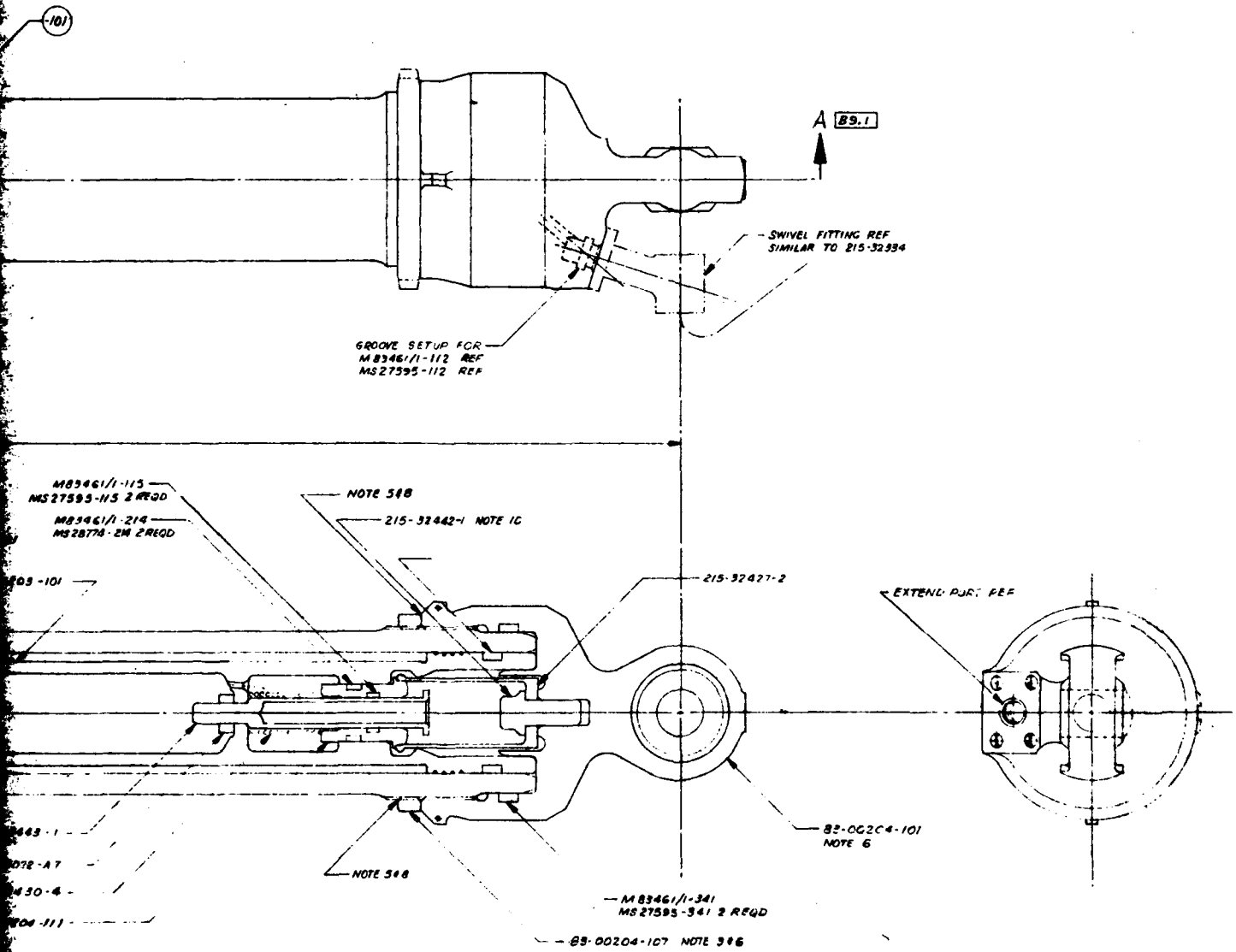
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FIGURE 8

NOTES

1. THIS UNIT TO OPERATE WITH HYDRAULIC FLUID IN ACCORDANCE WITH SPEC MIL-H-5606 OR MIL-H-83282
2. OPERATING PRESSURE 8000 PSI (5500)
3. LOCKWIRE PER SPEC CVA 13-180
4. ASSEMBLE ACTUATOR IN ACCORDANCE WITH SPEC CVA 12-170
5. FILLET SEAL PER CVA 17712
6. TORQUE 83-00204-101 NUT TO 300 ± 25 FT LBS WITH NO LOAD ON ACTUATOR. ASSURE PROPER PORT ALIGNMENT AFTER TORQUING. CAP MAY BE BACKED OFF UP TO 389° FROM BOTTOMED POSITION TO ACHIEVE PORT ALIGNMENT ALICN PORTS AS SHOWN ON DRAWING.
7. INSTALL SEALS IN RETAINER AND HOUSING AND INSTALL RETAINER IN HOUSING SO THAT ALIGNMENT MARKS LINE UP. INSTALL 83-00204-103 RING AND TORQUE TO 600 ± 100 IN LB
8. SEAL NOTED AREA USING EC 1126 MINNESOTA MINING AND MFG CO., LOS ANGELES, CALIF. CODE IDENT 04633
9. ACCEPTANCE TEST ASSY PER SPEC

10. TORQUE TO 800 TO 1000 IN LB
11. AREAS AND VOLUMES:  
FUNCTION EFFECTIVE AREA RECD OPER  
WH/IN/IN  
EXTEND 5.38 IN<sup>2</sup> 107.34 IN<sup>3</sup>  
RETRACT 1.416 IN<sup>2</sup> 28.20 IN<sup>3</sup>
12. BOND NAMEPLATE TO ACTUATOR PER SPEC CVA 6-177 (7)
13. GENERAL PROTECTIVE SPEC CVA 208-9-220 FOR DEFINITION OF PROTECTIVE FINISH CODE NUMBERS AND APPLICABLE GOV. SPECS. SEE CVA 78-21 SEE SPEC 208-13-36 FOR APPROVED MATERIAL SUBSTITUTIONS SEE SPEC 208-13-157 FOR AUTHORIZED STD PARTS SUBSTITUTION.

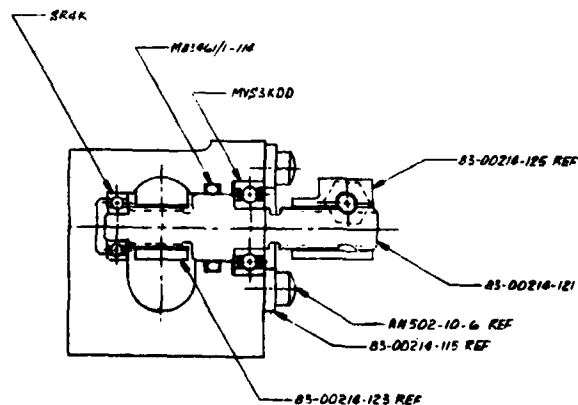
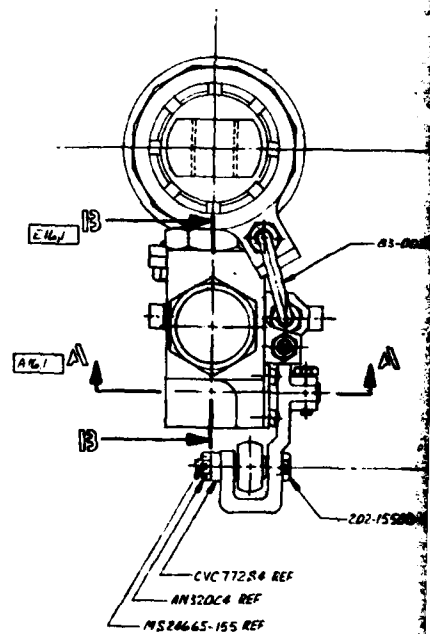
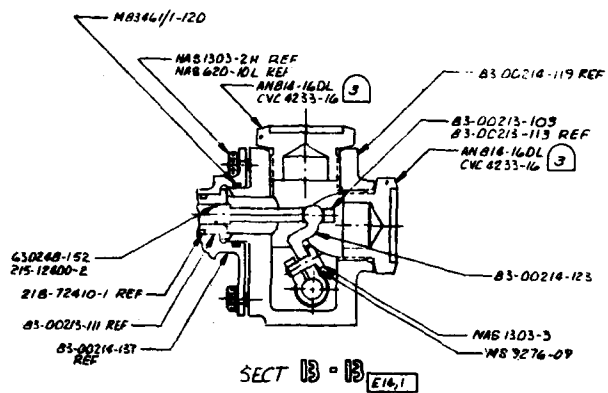
| REF      | INSERT                     |                           |
|----------|----------------------------|---------------------------|
| 1        | NAS193E10CP                | LOCKING DEVICE            |
| 1        | NAS 1072 AT                | NUT                       |
| 2        | MS28774-214                | BACKUP RING               |
| 2        | MS27595-341                | BACKUP RING               |
| 2        | MS27595-357                | BACKUP RING               |
| 2        | MS27595-115                | BACKUP RING               |
| 1        | MS24661-341                | PACKING                   |
| 1        | MS24661-357                | PACKING                   |
| 1        | MS24661-214                | PACKING                   |
| 1        | MS24661-115                | PACKING                   |
| 1        | MS24661-115                | PACKING                   |
| REF      | MS24661-115                | PACKING                   |
| 1        | CVC 393-76-A               | NAMEPLATE                 |
| 1        | CVC 1132-118               | NUT JAM                   |
| 1        | D71                        | SEAL PISTON               |
| 1        | D71                        | SEAL PISTON               |
| 1        | D72                        | SEAL MOD                  |
| 1        | D72                        | EXCLUDED                  |
| 1        | C91                        | 215-32449-1 LOCK PL       |
| 1        | 891                        | 215-31430-4 SPRING        |
| 1        | D61                        | 215-31427-2 FINGER LOCK   |
| 1        | D61                        | 215-31442-1 BOLT          |
| 1        | C81                        | 215-32335-1 RCD END ASSY  |
| 1        | 891                        | 83-00204-111 PISTON       |
| 1        | 891                        | 83-00204-107 NUT LOCK     |
| REF D121 | 83-00204-103 RETAINER SEAL |                           |
| REF D121 | 83-00204-103 RING LOCK     |                           |
| 1        | C61                        | 83-00204-101 END CAP ASSY |
| 1        | D91                        | 83-00205-101 PISTON & ROD |
| 1        | D91                        | 83-00202-101 HOUSING ASSY |
| 1        | C81                        | -101 ACTUATOR ASSY        |

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| REVISION | DESCRIPTION | DATE |
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|                                            |          |
|--------------------------------------------|----------|
| ACTUATOR ASSY-SPED<br>BRAKE<br>HYD. SYSTEM | 83-00201 |
|--------------------------------------------|----------|

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SCALE 2/1

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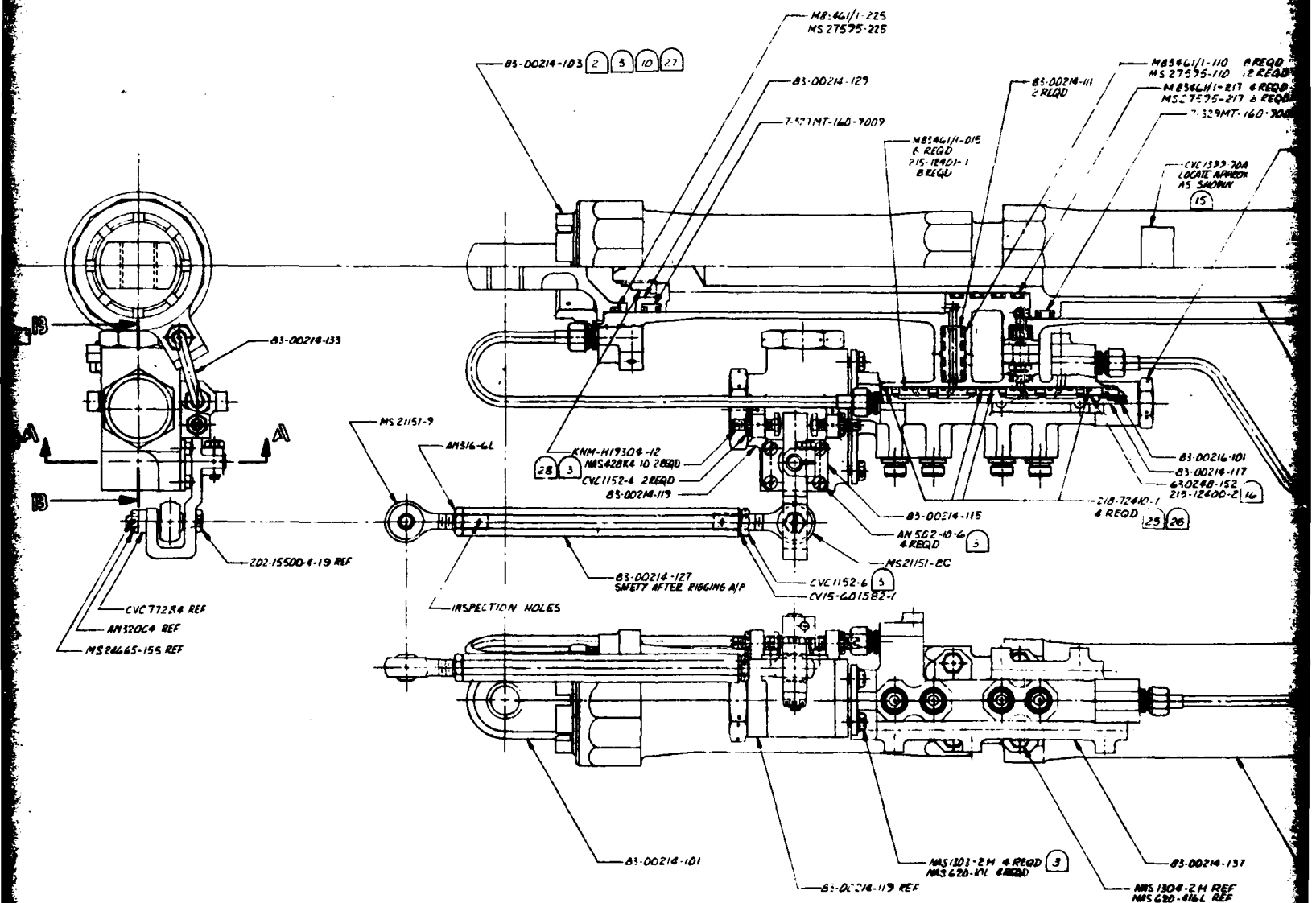
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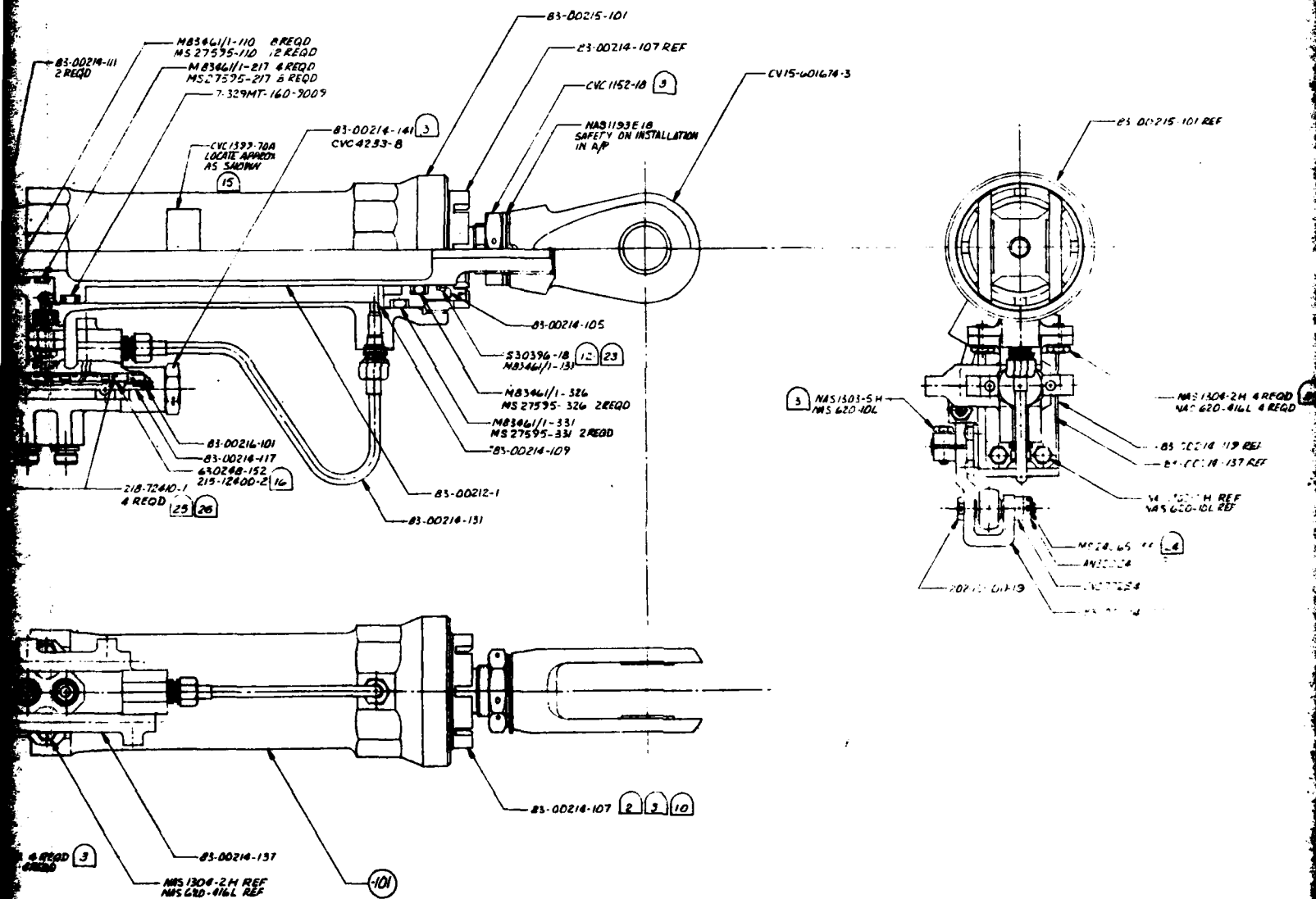
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83-00211 171

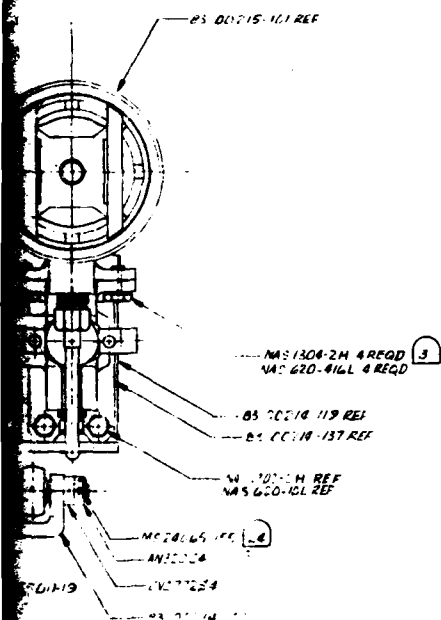
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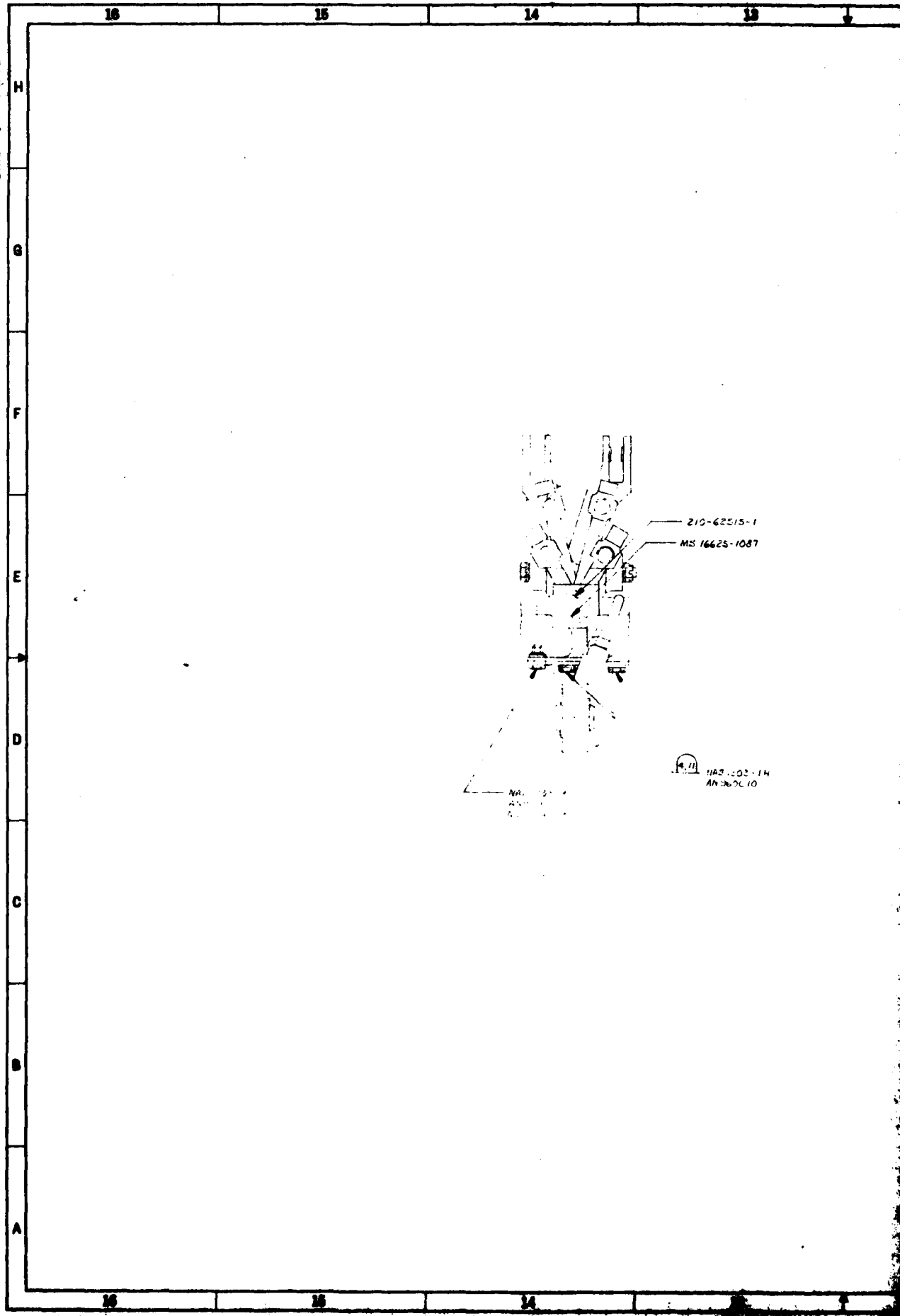
83-00211 17

FIGURE 9



| REVISIONS |  | APPROVED |  | DATE |  |
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34X60  
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03-00551



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210-62515-1  
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4.11  
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AN 167C10

4.11 83-00225-105  
83-00225-113  
M83461/1-217  
M821595-217 Z REGO  
83-00225-111  
83-00227-101

PC 2

4 PCs

8  
CVC 1395-724 ON-101  
CVC 1395-724 ON-102

83039-10  
A 146 11-17

4.11 145509-10

145 1122 A100

215 R.106

24 04 RETRACT  
29 34 EXTEND

83-00221 171

13

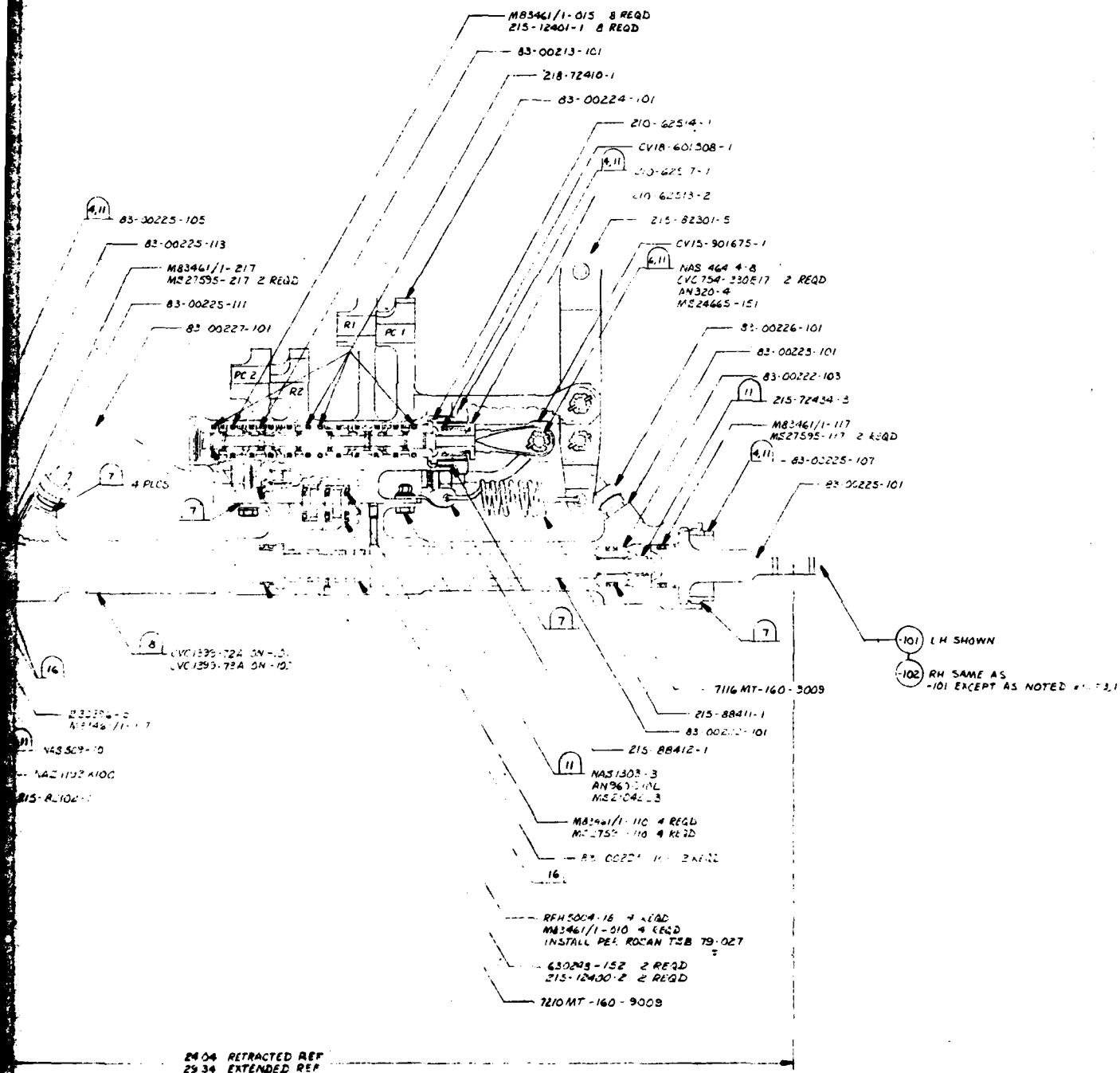
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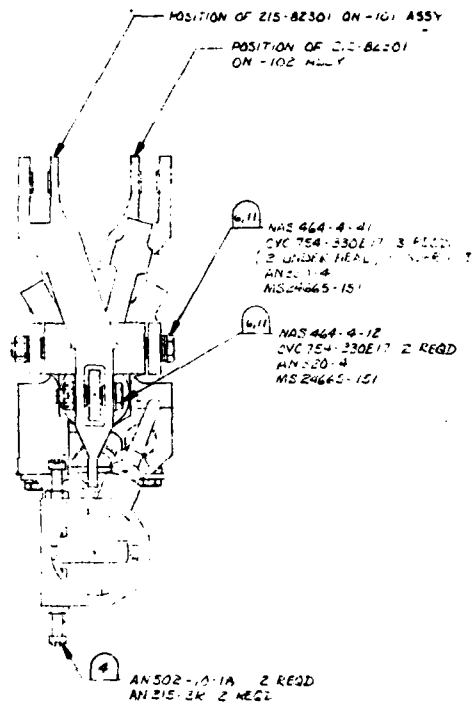


24 04 RETRACTED REF  
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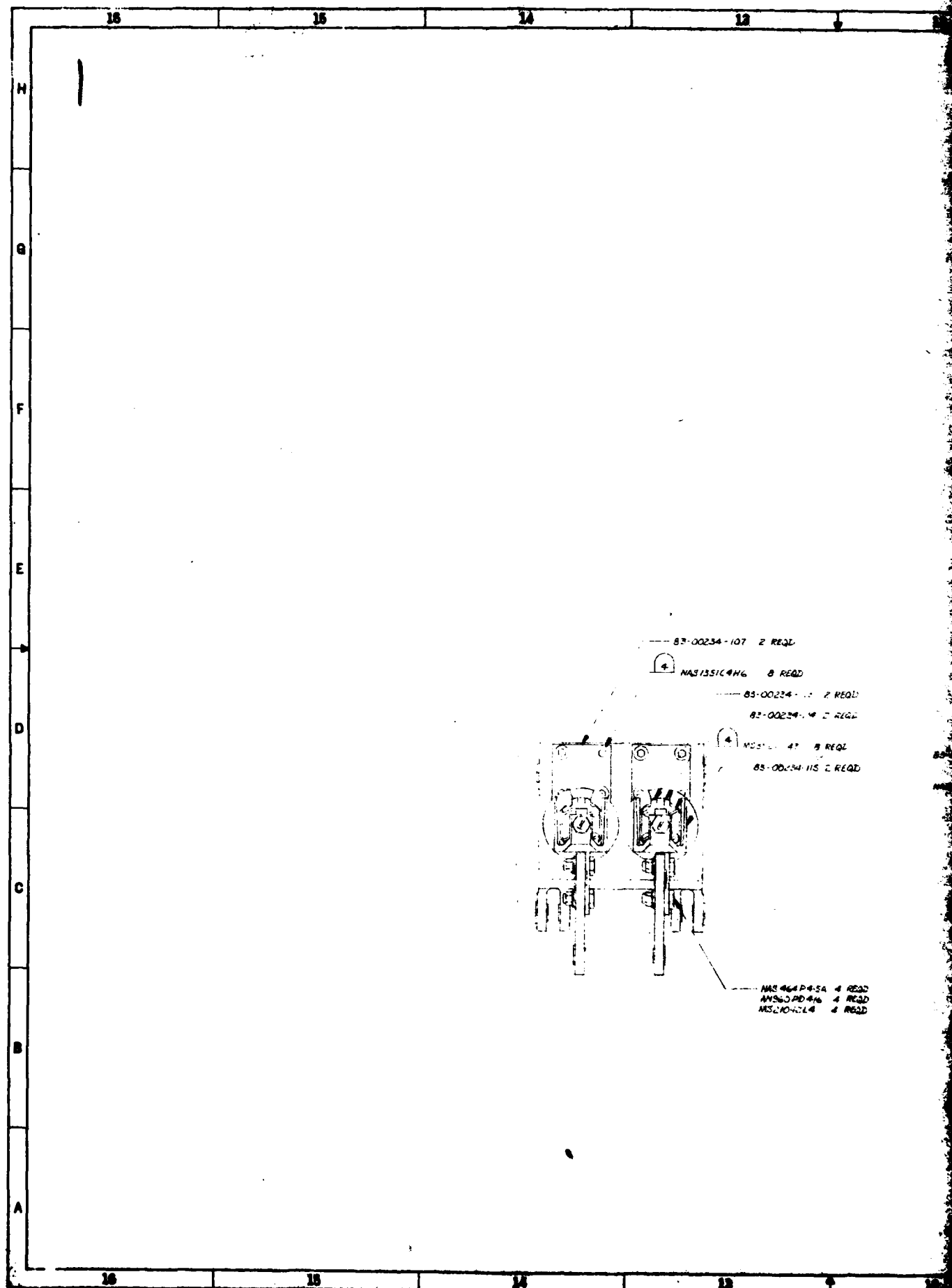
FIGURE 10



101 LH SHOWN  
102 RH SAME AS  
-101 EXCEPT AS NOTED (1, F, 3, 1)

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|                                                                                     |  |                 |
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| <p>ACTUATOR ASSY<br/>AILERON PC SERVO-<br/>LT WEIGHT HYD SYSTEM</p> <p>31-00221</p> |  | <p>31-00221</p> |
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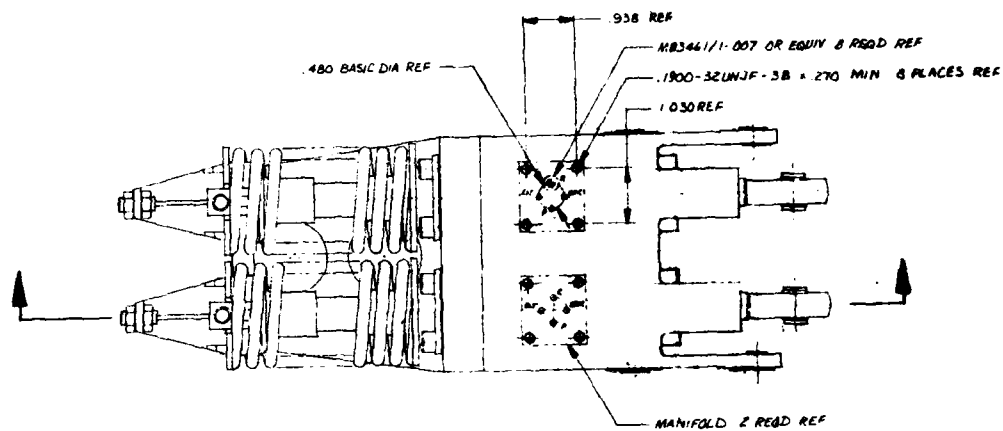
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83-00234-107 2 REQD

NAS1351C4H6 8 REQD

83-00234-111 2 REQD

83-00234-114 2 REQD

NAS1351C4H6 8 REQD

83-00234-115 2 REQD

83-00234-101 2 REQD

M83461/1-112 6 REQD

M527595-112 10 REQD

M83461/1-115 2 REQD

M527595-115 4 REQD

62-00234-101 2 REQD

83-00234-111 2 REQD

65-00234-111 2 REQD

NAS505-4 4 REQD

CV18-151528-1 2 REQD

83-00234-117 2 REQD

M83461/1-216 2 REQD

M527595-216 4 REQD

83-00234-119 2 REQD

NAC1193-BC 2 REQD

CV18-151519-1 2 REQD

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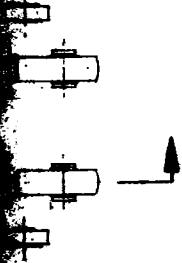
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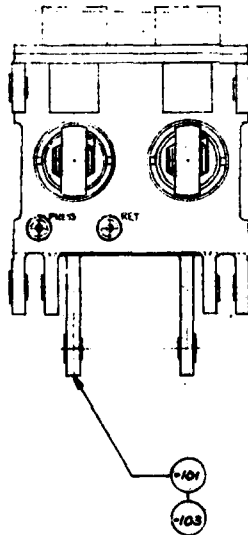
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202 OR EQUIV & READ REF  
 202F-3B = 270 MIN & PLACES REF



READ REF

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- 83-00234-117 2 REQD
- M83461/1-216 2 REQD
- MS 27595-216 4 REQD
- 4.7 83-00234-119 2 REQD
- 4 NAE 1193-8C 2 REQD
- 4.7 CV18-151519-1 2 REQD
- CV18-151526-3 2 REQD
- ±.50 WORKING STROKE
- ±.56 TOTAL STROKE
- 1/80-9009 2 REQD
- 74A ON-101
- 75A ON-103

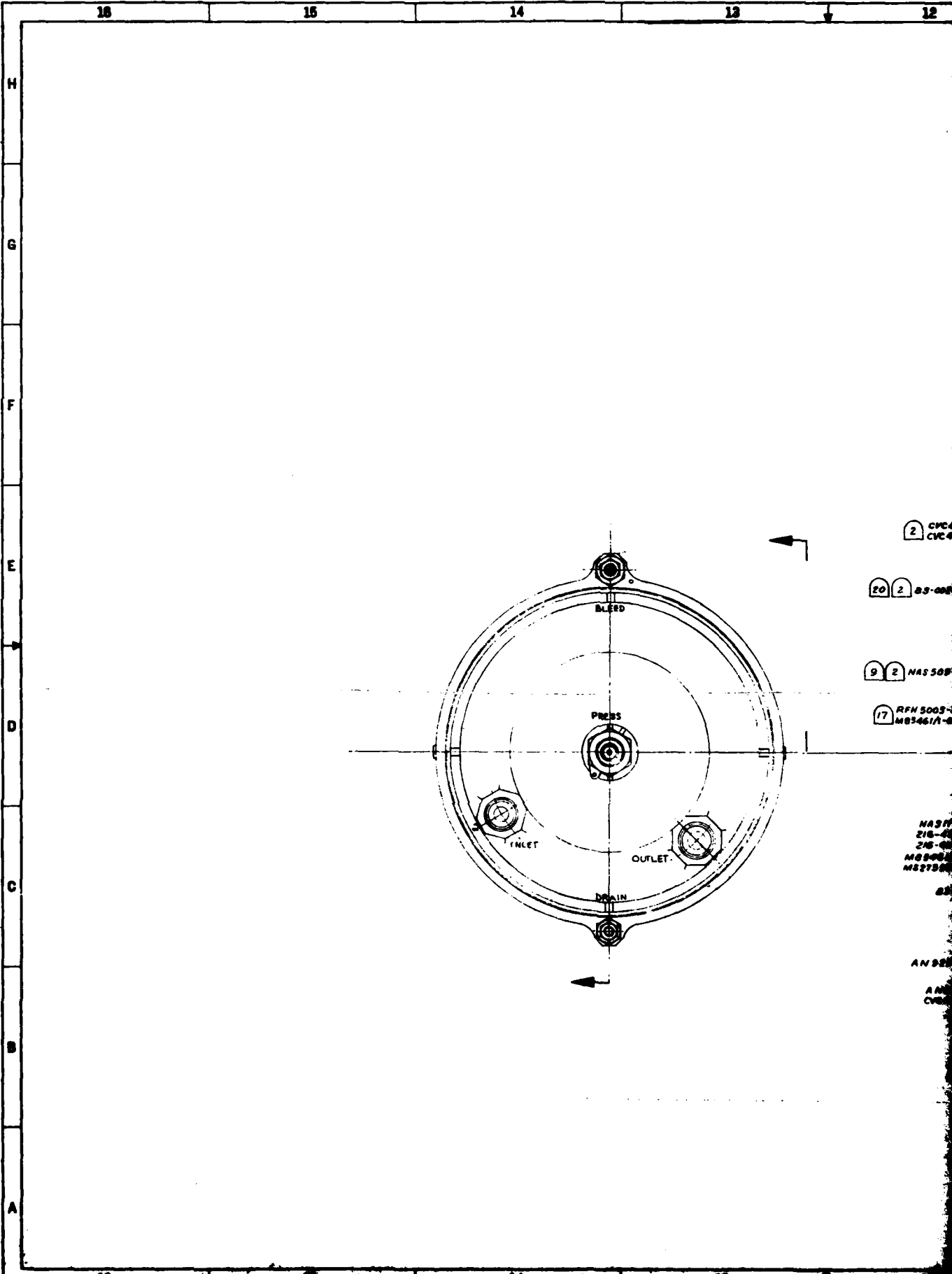


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FIGURE 11

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The image shows a technical drawing of a hydraulic system. At the top left is a grid. Below it is a schematic diagram of a hydraulic system. The diagram includes a pump, a reservoir, and various valves and actuators. The text 'HYDRAULIC SYSTEM' is written at the top. The text 'ACTUATOR, STABILIZATION LIGHTWEIGHT HYD SYSTEM' is written in the center. The text '83-00231' is written at the bottom right.



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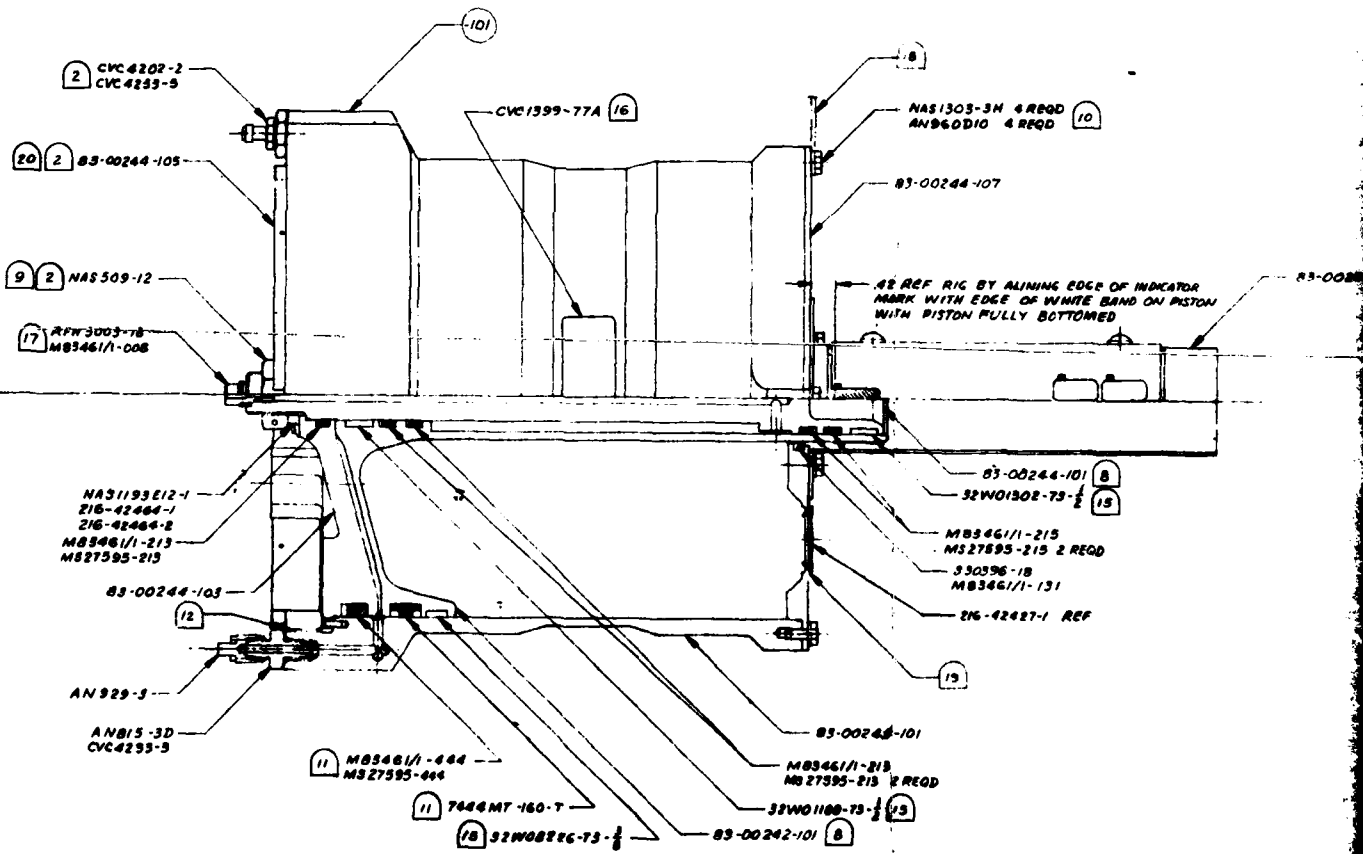
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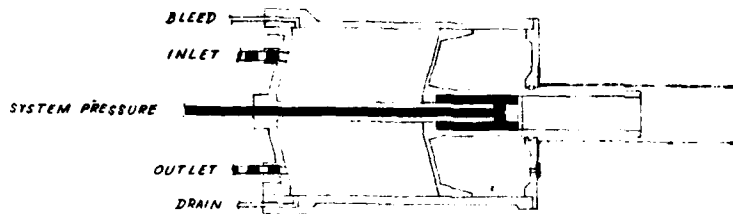


83-00241

17

3

ENGINEERING REFERENCE INFORMATION  
SCHEMATIC - HYDRAULIC  
SCALE - NONE



RESERVOIR PISTON NET AREA 52.46 IN<sup>2</sup>  
PRESSURIZATION PISTON NET AREA 64.7 IN<sup>2</sup>  
RATIO:  $\frac{52.46 \text{ IN}^2}{64.7 \text{ IN}^2} = \frac{81.08}{98.67} = \frac{800 \text{ PSI}}{98.67 \text{ PSI}}$

83-3H 4 REQD 10  
83-3H 4 REQD 10

83-407

BY ALIGNING EDGE OF INDICATOR  
EDGE OF WHITE BAND ON PISTON  
IN FULLY BOTTOMED

83-00244-103

83-00244-101 8  
83-00244-101 13

83-00244-101-215  
83-00244-101-215 2 REQD  
83-00244-101-151

83-42427-1 REF

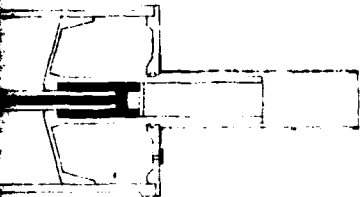
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AN-560D10 3 REQD

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21 178

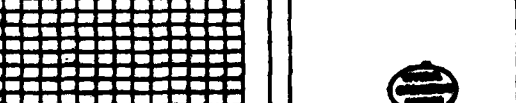
E-HYDRAULIC  
NONE



PISTON NET AREA 52.48 IN<sup>2</sup>  
 W PISTON NET AREA .647 IN<sup>2</sup>  
 $\frac{52.48 \text{ IN}^2}{.647 \text{ IN}^2} = \frac{81.08}{1} = \frac{8000 \text{ PSI}}{98.67 \text{ PSI}}$

NAS 1303-24 3 REQD 2 10  
AN 960 D10 3 REQD

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SHEET  
 11

RESEARCH AND TEST  
 CONTROL MYD SYSTEM -  
 LT. HT MYD SYSTEM  
 22-00241

NADC-77108-30

The 8000 psi actuators were designed for the same end attach points, kinematics, load, stroke, and rate requirements as the equivalent 3000 psi actuators. Conventional design techniques and fabrication procedures were employed for all the test units. Design proof and burst pressures were 12,000 and 16,000 psi, respectively. The rudder, UHT, and aileron actuator bodies are steel; the AFCS and speed brake actuator bodies are aluminum. Control valve orifices were sized for the lower flow rates which occur at 8000 psi, and were overlapped to minimize internal leakage. Pertinent information covering each actuator fabricated is summarized below:

| Actuator       | Working<br>Stroke, in. | Max. Output<br>Force, lb. (2 sys.) | No-Load<br>Stroke Time, sec. | Max. Flow,<br>gpm (1 sys.) |
|----------------|------------------------|------------------------------------|------------------------------|----------------------------|
| Rudder         | 2.9                    | 11,104                             | 0.6                          | 1.04                       |
| Speed<br>Brake | 19.9                   | 43,064                             | 7.0                          | *4.0                       |
| UHT            | 5.7                    | 54,400                             | 1.3                          | **3.9                      |
| Aileron        | 5.0                    | 9,568                              | 0.5                          | 1.6                        |
| AFCS           | 1.0                    | 2,656                              | 0.32                         | 0.86                       |

\*4 gpm restrictor limits rate in test system.

\*\*3.9 gpm needed to meet surface velocity requirements; however, control valve designed to provide 6.0 gpm to meet time constant requirements.

The rod seal configurations were selected on the basis of evaluation tests discussed in section 5.1. The primary flight control actuators (rudder, UHT, and aileron) have a two stage unvented seal as shown on Figure 13. The speed brake actuator has a single stage seal with trapezoidal shaped cross-sections, Figure 14. The AFCS actuator has a single stage cap seal, Figure 15. This configuration was used instead of the trapezoidal seal because of the need for lower rod seal friction.

Rod seal gland dimensions were per MIL-G-5514 except 1) diametral clearance was 0.001 to 0.003 inch, and 2) groove depth tolerance was 0.001 inch. These limitations reduced the extrusion gap and minimized variations in packing squeeze due to tolerance buildups.

The piston seal configuration was selected on the basis of tests reported in Reference 10. The packing has a 'T' shaped cross-section and is supported by backup rings as shown on Figure 16.

Standard MS static seals were used for boss and diametral type applications in all LHS actuators. Standard MS seals were also employed in Rosan connector installations.

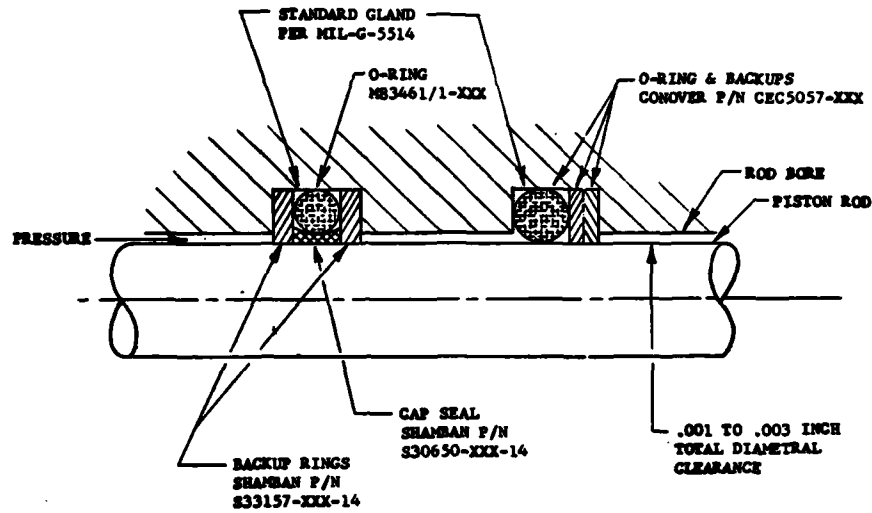


FIGURE 13. Rod seals in flight control actuators

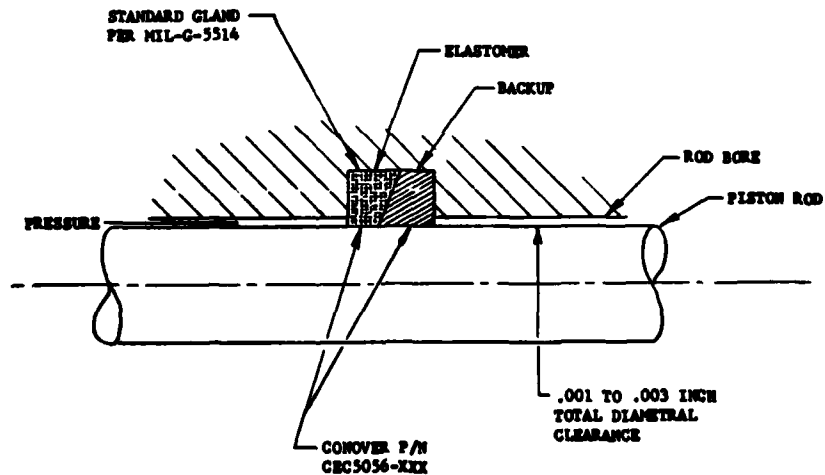


FIGURE 14. Rod seals in utility actuators

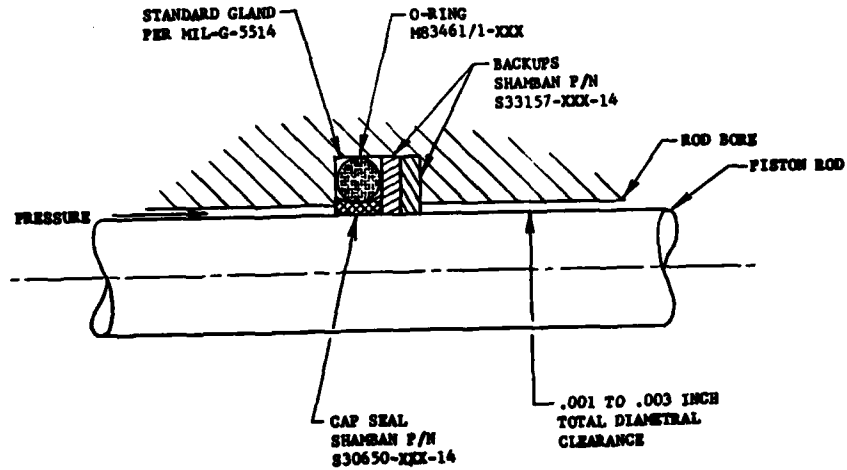


FIGURE 15. Rod seal in AFCS actuator

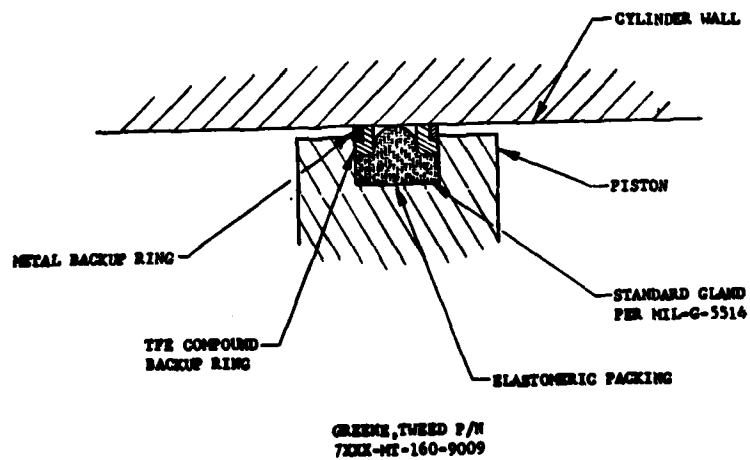


FIGURE 16. Piston seal

The AFCS actuator will have two single-stage, direct-drive electro-hydraulic control valves--one for each cylinder. Development of these valves is planned in Phase II of the LHS program. An interim direct-drive valve was used to operate the AFCS actuator in Phase I. Major components of the interim valve were:

| <u>Description</u>                                                           | <u>Remarks</u>                                                             |
|------------------------------------------------------------------------------|----------------------------------------------------------------------------|
| Force Motor<br>General Electric<br>P/N 55-666102<br>(see Figure 36)          | Developed during program reported<br>in Reference 13                       |
| Valve Assembly<br>NAAD-Columbus<br>P/N S.O. 4248-41<br>(see Figure 36)       | Designed and fabricated during program<br>reported in Reference 13         |
| Electronic Drive Unit<br>NAAD-Columbus<br>P/N 8696-546604<br>(see Figure 37) | Designed and fabricated during program<br>reported in References 14 and 15 |

### 3.1.3 Reservoir

The LHS reservoir was designed and fabricated by Vought Corporation and is identified as P/N 83-00241. The FC-1 and FC-2 reservoirs are identical, and similar in concept to the existing PC-1 and PC-3 reservoirs except for porting and capacity, Figure 12. The LHS reservoirs have a port for system return; the A-7 reservoirs do not. The FC-1 and FC-2 reservoirs each have a design capacity of 320 in<sup>3</sup>; an equivalent design reservoir for a 3000 psi system would have a capacity of 500 in<sup>3</sup>. Application of 8000 psi to the reservoir bootstrap port provides reservoir pressurization of 90 psig. The low pressure sections have design proof and burst pressures of 180 and 270 psi, respectively. The bootstrap section has proof and burst pressures of 12,000 and 16,000 psi, respectively.

### 3.2 MINOR COMPONENTS

Minor components procured for evaluation testing are listed in Table 1. Part number, manufacturer, and general design information are given for each component. Photographs of the components are presented on Figures 17 through 26. Design proof and burst pressures at +275°F were as follows:

| <u>Component</u>     | <u>Proof<br/>Pressure</u> | <u>Burst<br/>Pressure</u> |
|----------------------|---------------------------|---------------------------|
| check valve          | 12,000 psi                | 16,000 psi                |
| filter               |                           |                           |
| pressure gage        |                           |                           |
| pressure snubber     |                           |                           |
| pressure transmitter |                           |                           |
| quick disconnect     |                           |                           |
| relief valve         |                           |                           |
| restrictor           |                           |                           |
| solenoid valve       |                           |                           |
| accumulator          | 16,000 psi                | 24,000 psi                |
| fittings             |                           |                           |
| hose                 |                           |                           |
| tubing               |                           |                           |

### 3.3 SPECIFICATIONS

Under the data requirements of the contract between the Navy and Rockwell, a set of preliminary specifications were prepared and provided for use in defining system, general components, detail component, and process requirements for 8000 psi lightweight hydraulic systems. These documents were prepared and submitted to the Navy Project Office under separate cover, Reference 12. The basis under which these documents were prepared was to use the comparable 3000 psi Military Specifications, update those where required for 8000 psi, and restructure the specification formats to be consistent with MIL-STD-961, which was the specification preparation requirement of the contract.

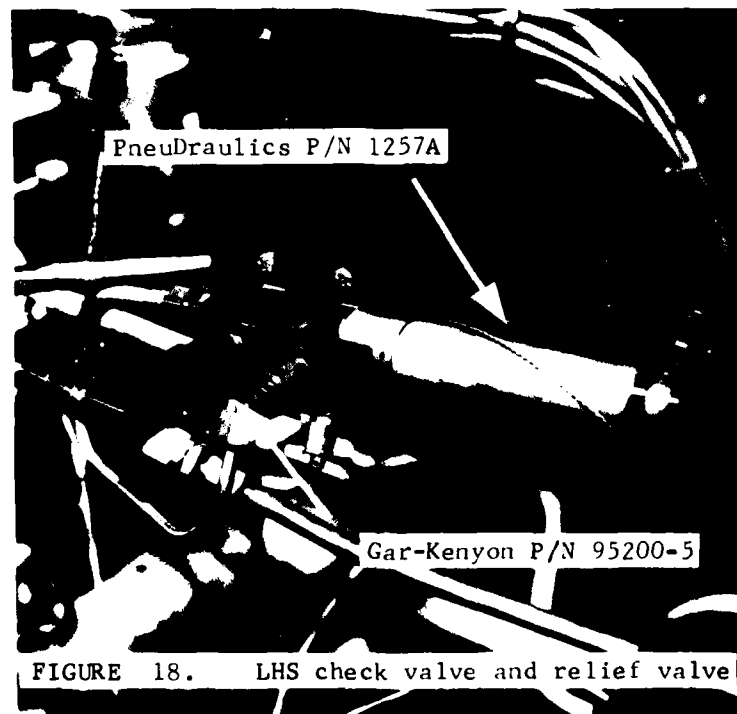
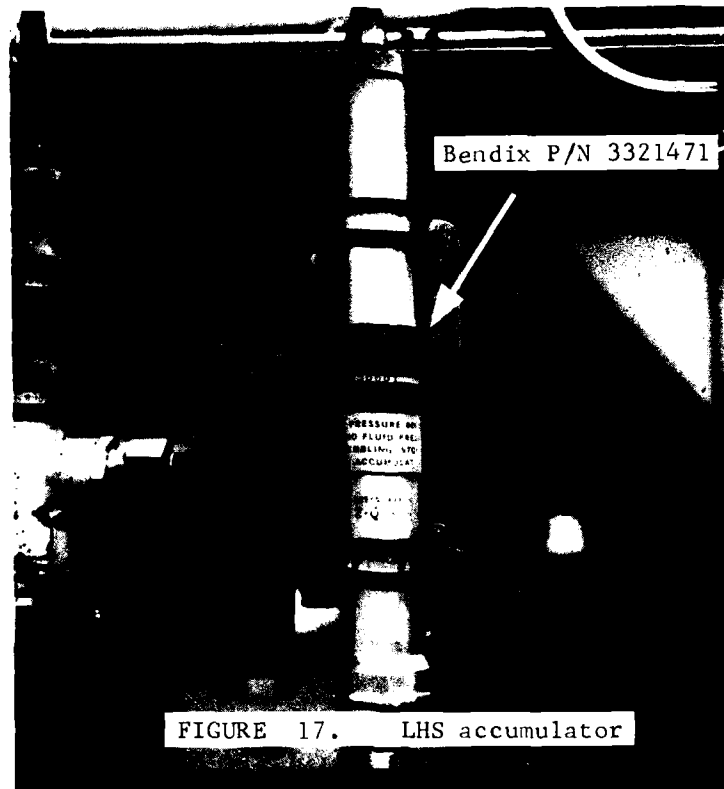
A total of 34 specifications were written. The LHS documents with the subcontractor's specifications were used for procurement of test system components fabricated in Phase I. The LHS specifications are listed in Appendix A.

TABLE 1. Minor Components

| DESCRIPTION             | PART NO.                                             | MANUFACTURER                                                          | FIGURE NUMBER | DESIGN INFORMATION                                                                                                                                                      |
|-------------------------|------------------------------------------------------|-----------------------------------------------------------------------|---------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ACCUMULATOR             | 3321471                                              | BENDIX ELECTRODYNAMICS<br>NORTH HOLLYWOOD, CA                         | 17            | 1. MIN. GAS VOL.: $2\text{in}^3$<br>MAX. OIL VOL.: $9\text{in}^3$<br>2. STEEL CONSTRUCTION<br>3. TWO-STAGE BACKUP<br>RINGS ON PISTON<br>4. ONE DIAMETRAL STATIC<br>SEAL |
| CHECK VALVE             | 98390                                                | GAR-KENYON CONTROLS<br>NEW HAVEN, CT                                  | 18            | 1. STANDARD DESIGN<br>2. STEEL CONSTRUCTION<br>3. ONE DIAMETRAL<br>STATIC SEAL                                                                                          |
| FILTER                  | AD-AM40-63Y1                                         | AIRCRAFT POROUS MEDIA<br>PINELLAS PARK, FL                            | 19            | 1. RATED FLOW: 10 gpm<br>2. FILTRATION: $5\mu\text{m}$<br>3. TITANIUM CONSTRUCTION<br>4. TWO DIAMETRAL STATIC<br>SEALS                                                  |
| FITTINGS                | SEE TABLE 2.                                         | THE DEUTSCH COMPANY<br>LOS ANGELES, CA                                | 20            | 1. EXTERNALLY SWAGED<br>FITTING<br>2. PERMANENT AND SEPARABLE<br>CONNECTIONS<br>3. LIP SEAL TYPE SEPARABLE<br>FITTINGS                                                  |
|                         |                                                      | RAYCHEM CORPORATION<br>MENLO PARK, CA                                 | 21            | 1. HEAT SHRINKABLE<br>COUPLING<br>2. PERMANENT CONNECTION<br>ONLY                                                                                                       |
|                         |                                                      | REINSTOFLEX CORPORATION<br>ROSELAND, NJ                               | 22            | 1. INTERNALLY SWAGED<br>FITTING<br>2. SEPARABLE CONNECTION<br>ONLY<br>3. LIP SEAL TYPE SEPARABLE<br>FITTINGS                                                            |
|                         |                                                      | BOGAN, INC.<br>NEWPORT BEACH, CA                                      |               | 1. TITANIUM CONSTRUCTION<br>2. O-RING SEAL                                                                                                                              |
| HOSE (EXTEND)           | F37404008-0300                                       | TITEX FLEX CORPORATION<br>SPRINGFIELD, MA                             | 23            | 1. PIPE LINER<br>2. STEEL AND NON-METALLIC<br>REINFORCEMENT BRAIDS                                                                                                      |
| PRESSURE<br>GAGE        | 1318-63-1                                            | QED/INC.<br>SANTA ANA, CA                                             | 24            | 1. MINIATURE GAGE<br>2. MULTI-TURN HELICAL<br>BOURDON TUBE                                                                                                              |
| PRESSURE<br>SHOCKER     | 98330                                                | GAR-KENYON CONTROLS<br>NEW HAVEN, CT                                  | 25            | 1. CONVENTIONAL DESIGN<br>2. STEEL CONSTRUCTION                                                                                                                         |
| PRESSURE<br>TRANSMITTER | 18-3143                                              | BENDIX CORPORATION<br>COURTIER, INC.<br>BOYNE CITY, MI                | 26            | 1. SYNCHRO TYPE<br>(SIMILAR TO MS28005-8)<br>2. MULTI-TURN HELICAL<br>BOURDON TUBE                                                                                      |
| QUICK<br>DISCONNECT     | AE80943H<br>AE80944H                                 | AEROQUIP CORPORATION<br>JACKSON, MI                                   | 27            | 1. CONVENTIONAL DESIGN<br>2. THREE DIAMETRAL<br>STATIC SEALS                                                                                                            |
| RELIEF<br>VALVE         | 1357A<br>1258                                        | PNEUDRAULICS, INC.<br>MONTCLAIR, CA                                   | 28            | 1. CONVENTIONAL DESIGN<br>2. ONE DIAMETRAL STATIC<br>SEAL                                                                                                               |
| RESTRICTOR              | REF703040236AB                                       | THE LEE COMPANY<br>WESTBROOK, CT                                      | 29            | 1. 3-WAY RESTRICTOR<br>2. MULTI-STAGE ORIFICES<br>3. RATED FLOW: 4 gpm @ 1400 psid<br>4. TITANIUM CONSTRUCTION                                                          |
| SEALS                   | SEE SECTIONS 3.1.2 AND 3.1                           |                                                                       |               |                                                                                                                                                                         |
| SOLENOID<br>VALVE       | 3321472<br>(4-WAY VALVE)<br>3321473<br>(3-WAY VALVE) | BENDIX CORPORATION<br>ELECTRODYNAMICS DIVISION<br>NORTH HOLLYWOOD, CA | 30            | 1. CONVENTIONAL DESIGN<br>2. 28 VDC, PILOT OPERATED<br>3. RATED FLOW:<br>4-WAY 4.5 gpm<br>3-WAY 1.4 gpm<br>4. STEEL HOUSING                                             |
| TUBING                  |                                                      | TRENT TUBE DIVISION<br>CAUGHLIN, INC.<br>FULLERTON, CA                |               | 1. S1 CR-4NI-3Mn CRSS<br>2. TUBE SIZES:<br>3/16 X .020 3/4 X .034<br>1/4 X .023 1/2 X .046                                                                              |

TABLE 2. LHS Fittings Tested

| Manufacturer | Description | Part No.        | Quantity Tested    |              |                |
|--------------|-------------|-----------------|--------------------|--------------|----------------|
|              |             |                 | Compatibility Test | Impulse Test | Endurance Test |
| Deutsch      | Tee         | DNRI0023-080308 | 1                  |              |                |
| Deutsch      | Tee         | DNRI0023-080803 |                    | 1            |                |
| Deutsch      | Elbow       | DNRI1009TE08    | 4                  |              |                |
| Deutsch      | Tee         | D11056AT03      | 2                  |              |                |
| Deutsch      | Tee         | DNRI1076-08     | 1                  |              |                |
| Resistoflex  | Coupling    | R44101T-03      |                    | 1            |                |
| Resistoflex  | Tee         | R44122T-080803  | 1                  |              |                |
| Resistoflex  | Elbow       | R44129-90T-03   |                    | 1            |                |
| Resistoflex  | Tee         | R44130T-08      | 1                  | 1            |                |
| Resistoflex  | Tee         | R44132T-08      | 2                  |              |                |
| Resistoflex  | Tee         | R44133T-03      |                    | 1            |                |
| Resistoflex  | Connector   | R44182T-03      | 1                  |              |                |
| Resistoflex  | Connector   | R44182T-08      | 4                  |              |                |
| Resistoflex  | Female Ftg. | R44296T-03      | 18                 | 2            | 2              |
| Resistoflex  | Male Ftg.   | R44298T-03      | 1                  |              |                |
| Resistoflex  | Elbow       | R44360T-08      |                    | 1            |                |
| Resistoflex  | Tee         | R45130-030808   | 1                  |              |                |
| Resistoflex  | Female Ftg. | R54045T-08      | 11                 | 3            | 3              |
| Resistoflex  | Female Ftg. | R54045T-03      |                    | 1            |                |
| Resistoflex  | Male Ftg.   | MR54100T-08     | 1                  | 1            |                |
| Resistoflex  | Male Ftg.   | MR54100T-03     |                    | 1            |                |
| Raychem      | Coupling    | 3P00101-3       | 19                 | 2            | 2              |
| Raychem      | Coupling    | 3P02121-8       | 2                  | 1            |                |
| Rosan        | Adapter     | RFH5003-18      | 10                 |              |                |
| Rosan        | Adapter     | RFH5005-18      | 4                  |              |                |



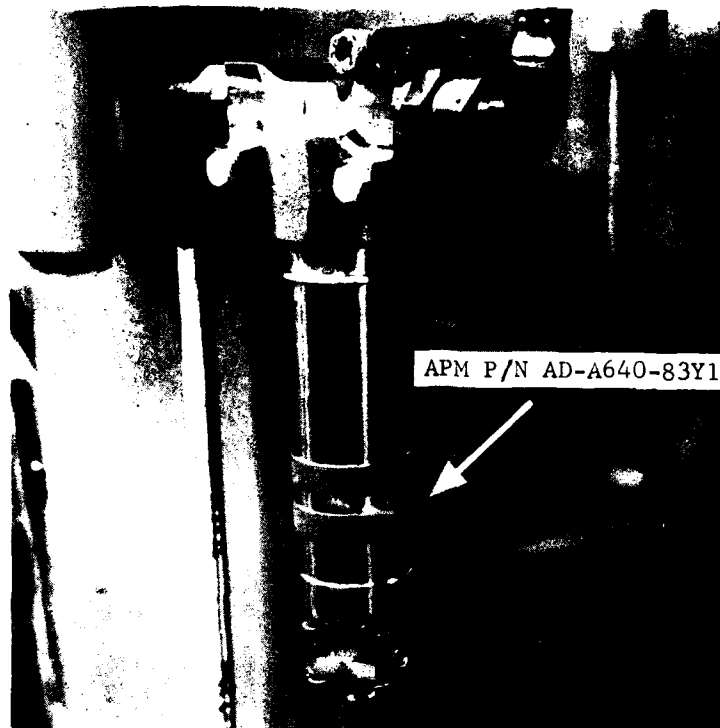


FIGURE 19. LHS filter

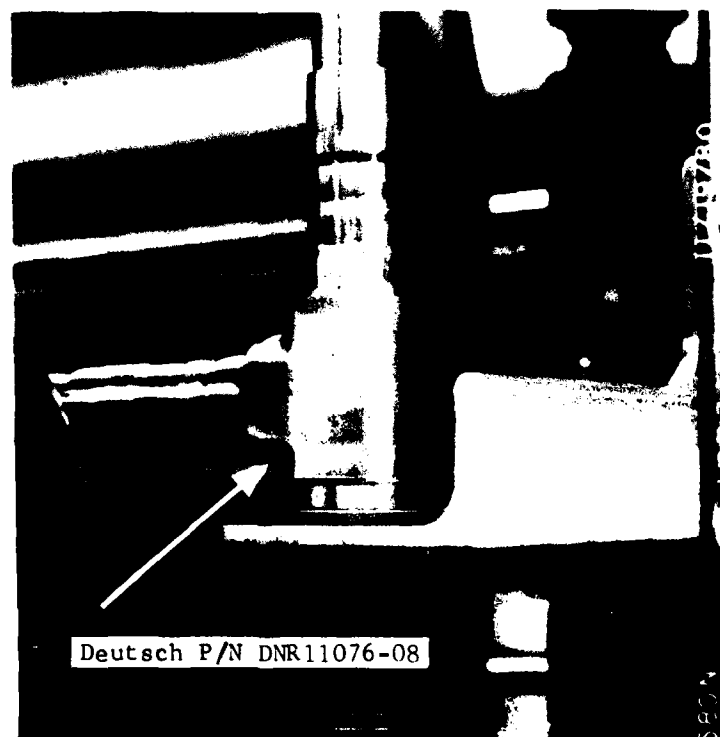


FIGURE 20. LHS fitting (externally swaged)

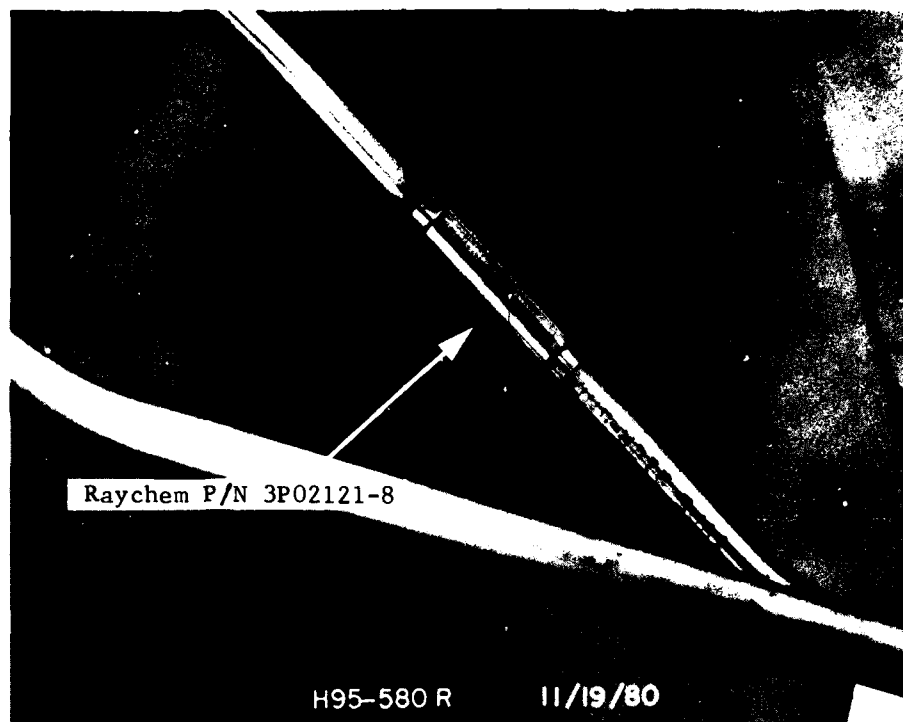


FIGURE 21. LHS fitting (shrink-fit)

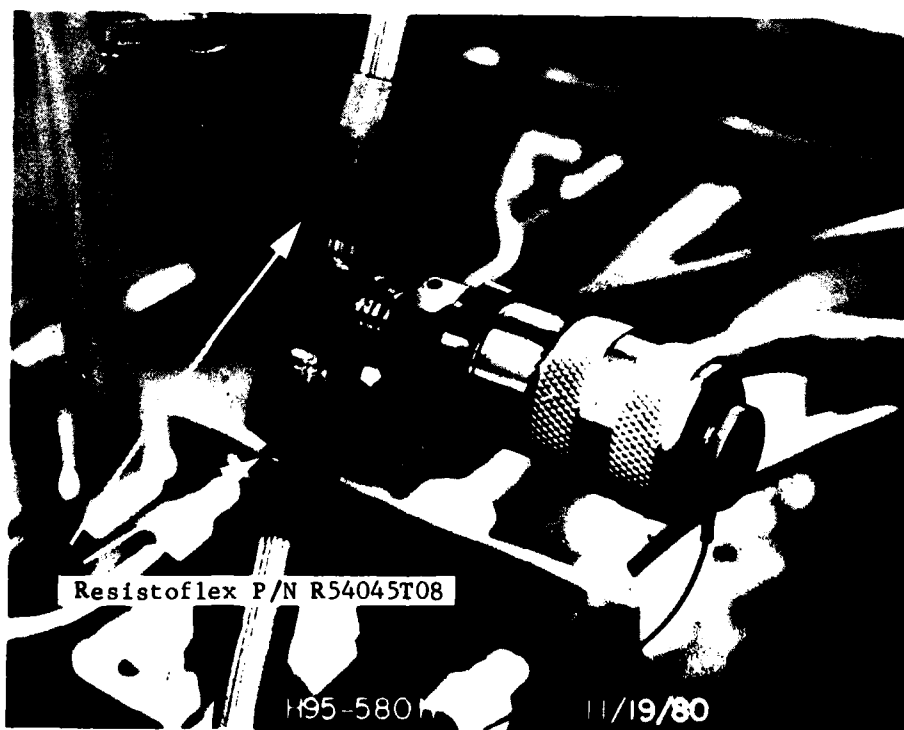


FIGURE 22. LHS fitting (internally swaged)



FIGURE 23. LHS hose and quick disconnect

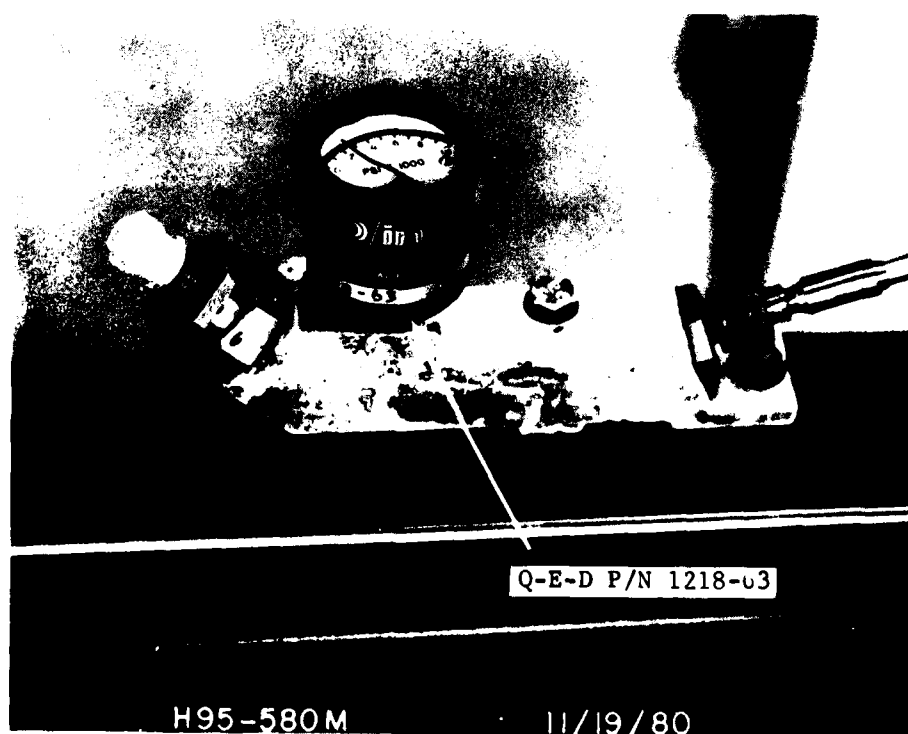


FIGURE 24. LHS pressure gage

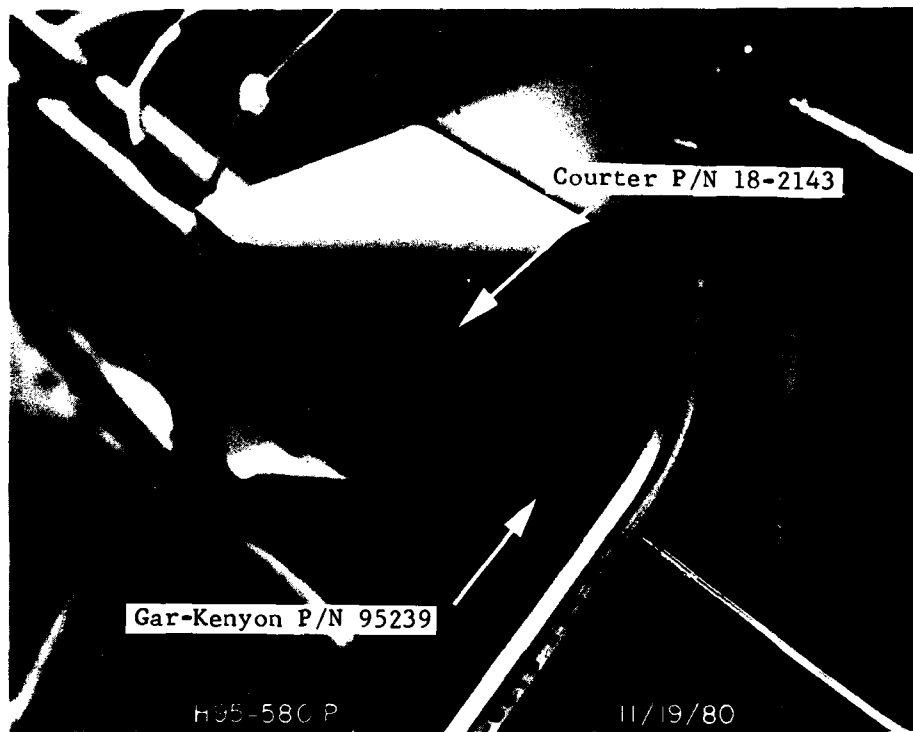


FIGURE 25. LHS pressure transmitter and snubber



FIGURE 26. LHS solenoid valve and restrictor

## 4.0 SIMULATOR DESIGN

4.1 ASSEMBLY

The simulator will be a full scale steel structure with LHS component installations and hydraulic distribution systems similar to the flight test aircraft, Figure 27. The simulator is modular in concept for cost effectiveness and program flexibility. Each module is designed to be a removable, yet integral part of the simulator. Two types of modules are employed: 1) power system modules, and 2) actuator load modules.

|                            | <u>Total Number<br/>In Test System</u> | <u>Quantity Fabricated<br/>In Phase I</u> |
|----------------------------|----------------------------------------|-------------------------------------------|
| <u>Power Modules</u>       |                                        |                                           |
| FC-1 System                | 1                                      | 1                                         |
| FC-2 System                | 1                                      | 1                                         |
| <u>Load Modules</u>        |                                        |                                           |
| Rudder Actuator            | 1                                      | 1                                         |
| Aileron Actuator           | 2                                      | 1                                         |
| Spoiler/Deflector Actuator | 2                                      | 0                                         |
| UHT Actuator               | 2                                      | 1                                         |
| Speed Brake Actuator       | 1                                      | 1                                         |
| Leading Edge Flap Actuator | 2                                      | 0                                         |

The roll feel isolation and AFCS actuators have permanent mounts in the simulator. Details of the modules fabricated in Phase I are presented in section 4.2.

4.2 MODULES4.2.1 Power Modules

The power system modules have the following components:

| <u>FC-1</u>                               | <u>FC-2</u>                  |
|-------------------------------------------|------------------------------|
| Reservoir                                 | Reservoir                    |
| Ground service disconnects                | Ground service disconnects   |
| Filters                                   | Filters                      |
| Relief valves                             | Relief valves                |
| Check valves                              | Check valves                 |
| Pressure transmitter/snubber              | Pressure transmitter/snubber |
| Speed brake solenoid valve/<br>restrictor | Shut-off valve               |
|                                           | Accumulator                  |
|                                           | Pressure gage                |

The components are mounted in the same relative locations as in the flight test aircraft. Transmission line lengths, routing, and clamping in the aircraft are duplicated as nearly as practical in the modules. Pressure and return line diameters are reduced to reflect the lower flow requirements of operating at 8000 psi. Some minor variations in plumbing were necessary to accommodate temperature, pressure, and flow instrumentation. Needle valves were installed to permit operation at low pressures. Photographs of FC-1 and FC-2 modules are presented as Figures 28 and 29.

#### 4.2.2 Load Modules

4.2.2.1 Rudder Actuator - The rudder module utilizes several A-7E components: control valve housing, valve input linkage, structural feedback linkage, and structural load forging. An input control actuator operated by an electro-hydraulic servo valve drives the aircraft linkage, Figure 30. Rudder actuator load is developed by an industrial-type hydraulic cylinder; the load-stroke curve is shown as Figure 31. Actuator swivelling is identical to the aircraft installation. Hydraulic power to the rudder actuator is supplied through 3/16 in. diameter 21-6-9 CRES tubing which flexes as the piston rod strokes.

4.2.2.2 Aileron Actuator - The aileron actuator is mounted in a linkage system identical to the aircraft installation, Figure 32. Piston rod travel and actuator body travel combine to deflect a load cylinder producing the load-stroke curve shown on Figure 33. Hoses are used to transmit hydraulic power to the actuator. The input lever on the aileron actuator is controlled by a servo actuator operating at 500 psi.

4.2.2.3 UHT Actuator - The UHT actuator mounting and swivelling are identical to the aircraft installation, Figure 34. Control of the valve input lever is through an A-7 linkage system which includes structural feedback. Actuator loading is developed when an industrial-type cylinder is moved away from a neutral position, Figure 35. Hydraulic power is supplied through 1/4 diameter 21-6-9 CRES tubing which flexes as the UHT actuator strokes.

The UHT input linkage system is operated by an AFCS pitch actuator mounted on the UHT module as shown on Figure 36. The output linkage of the AFCS actuator was modified to provide sufficient travel to drive the UHT actuator full stroke. A bungee was installed to prevent overloading the UHT actuator input linkage.

An 8000 psi direct-drive control valve operated the AFCS actuator, Figure 36. The electronic drive unit used to power the valve torque motor is shown on Figure 37. The direct-drive valve and electronic package are discussed in section 3.1.2.

16 15 14 13 12

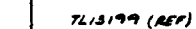
7213179 (REV)

TT-10724 (REV)

2' 6" REV

16 15 14 13 12

|   |    |    |    |   |   |
|---|----|----|----|---|---|
| 3 | 12 | 11 | 10 | 9 | 8 |
|---|----|----|----|---|---|



32' 5"

16' 2 1/2"

1-74 0252  
LEADING EDGE  
ACTUATOR



- TT-18727-301 (REF)

201 (MAY)

~~TT-10727-401-2002~~  
~~NAME SUPPORT POST~~

16'22

1-2-6-

1042



~~TL13199-1/250~~  
~~SPEED BRAKE~~  
~~TEST MODULE~~

of work

6'0"

1'0" OFF

TT-10727-30V (RPN)

1931—

~~76~~ ~~1000~~  
DEL PEE  
ISOLATION ACTIVATION

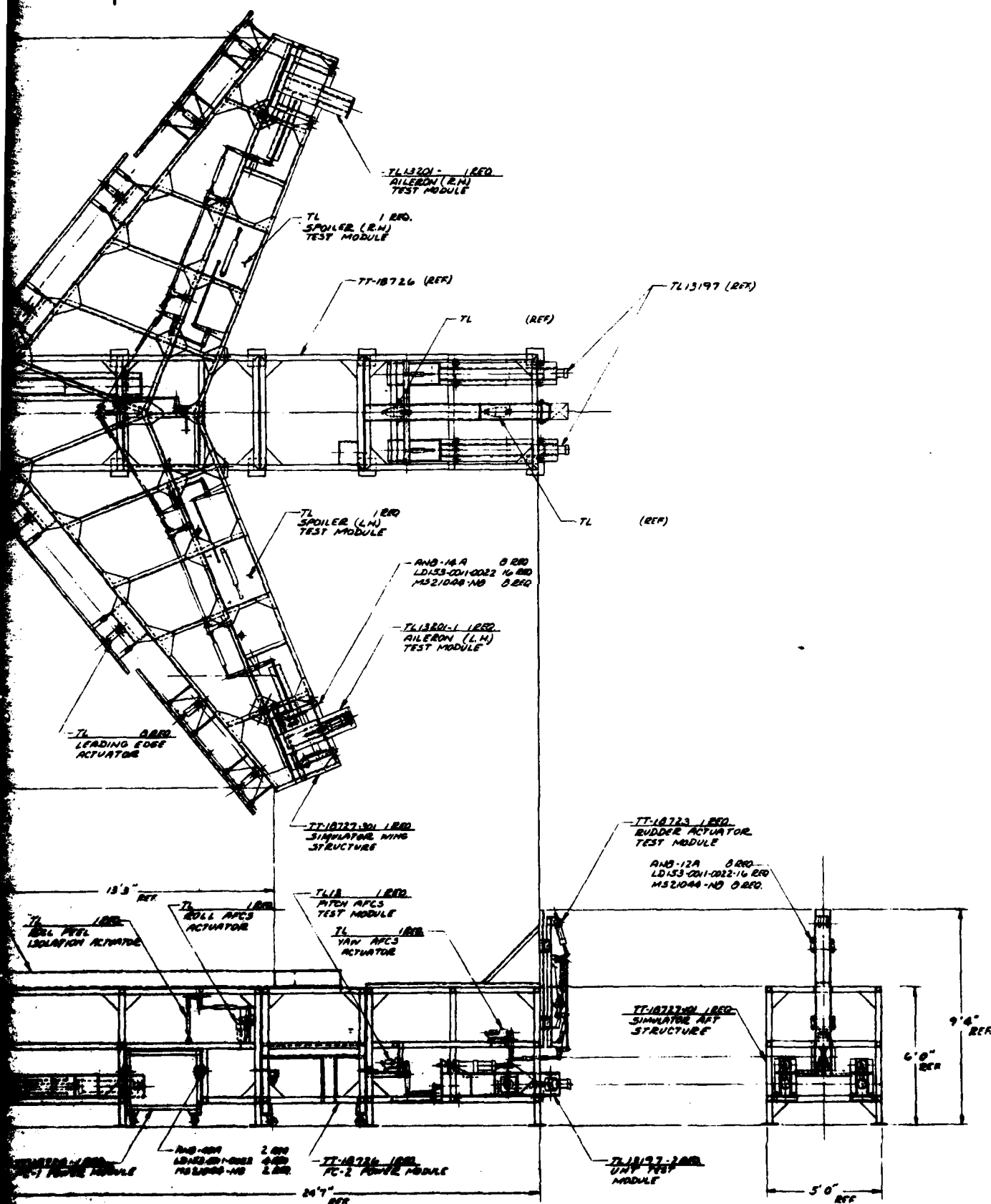
ROLL APES  
ACTIVATOR

~~TOP SECRET~~

7-10-67  
L. J. 10-10-67  
P. 10-10-67

**1 FLOREN**

|    |    |    |    |   |   |
|----|----|----|----|---|---|
| 13 | 12 | 11 | 10 | 9 | 8 |
|----|----|----|----|---|---|

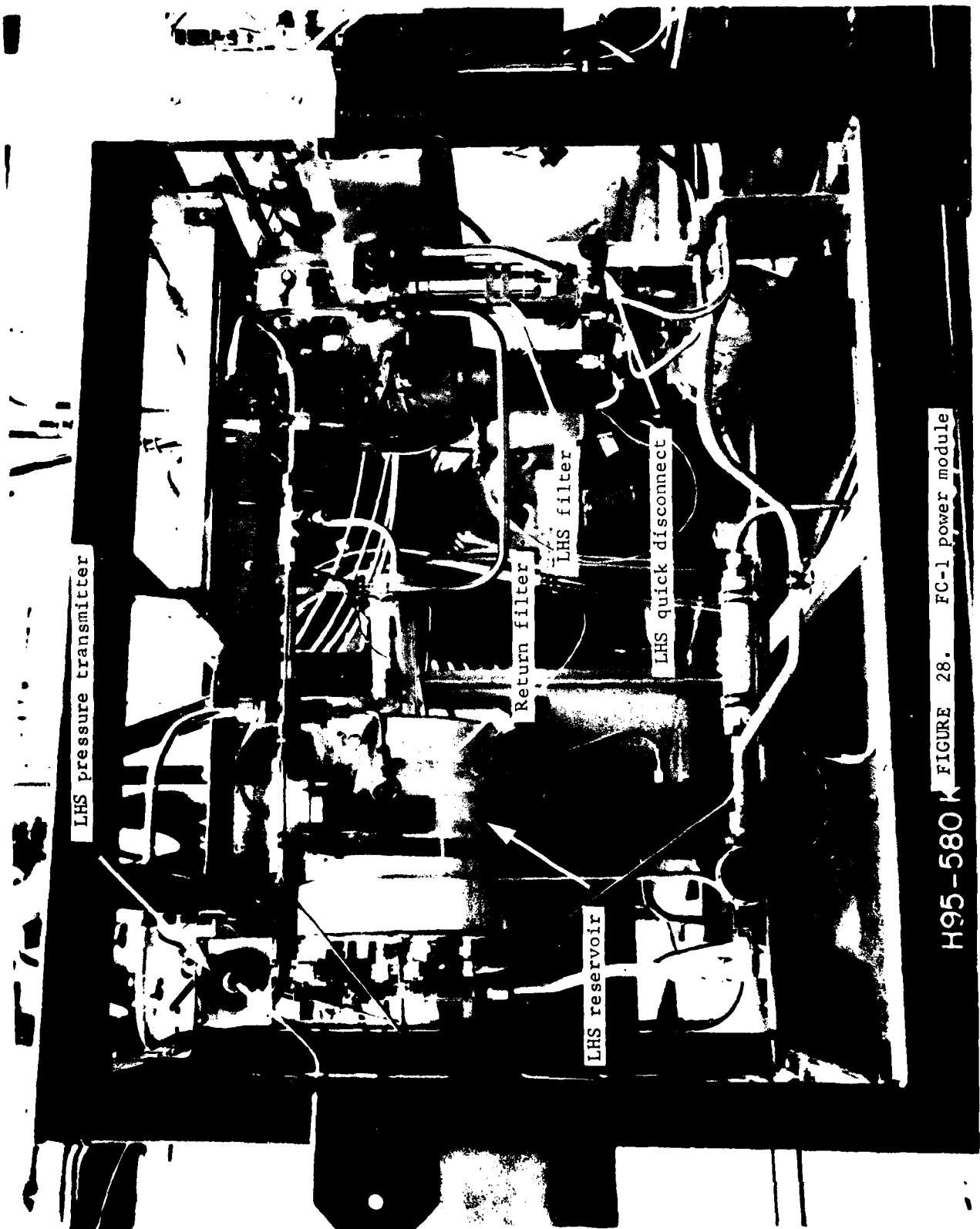


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| 0005   | 0006 | 0007 |



NADC-77108-30



H95-580 K FIGURE 28. FC-1 power module

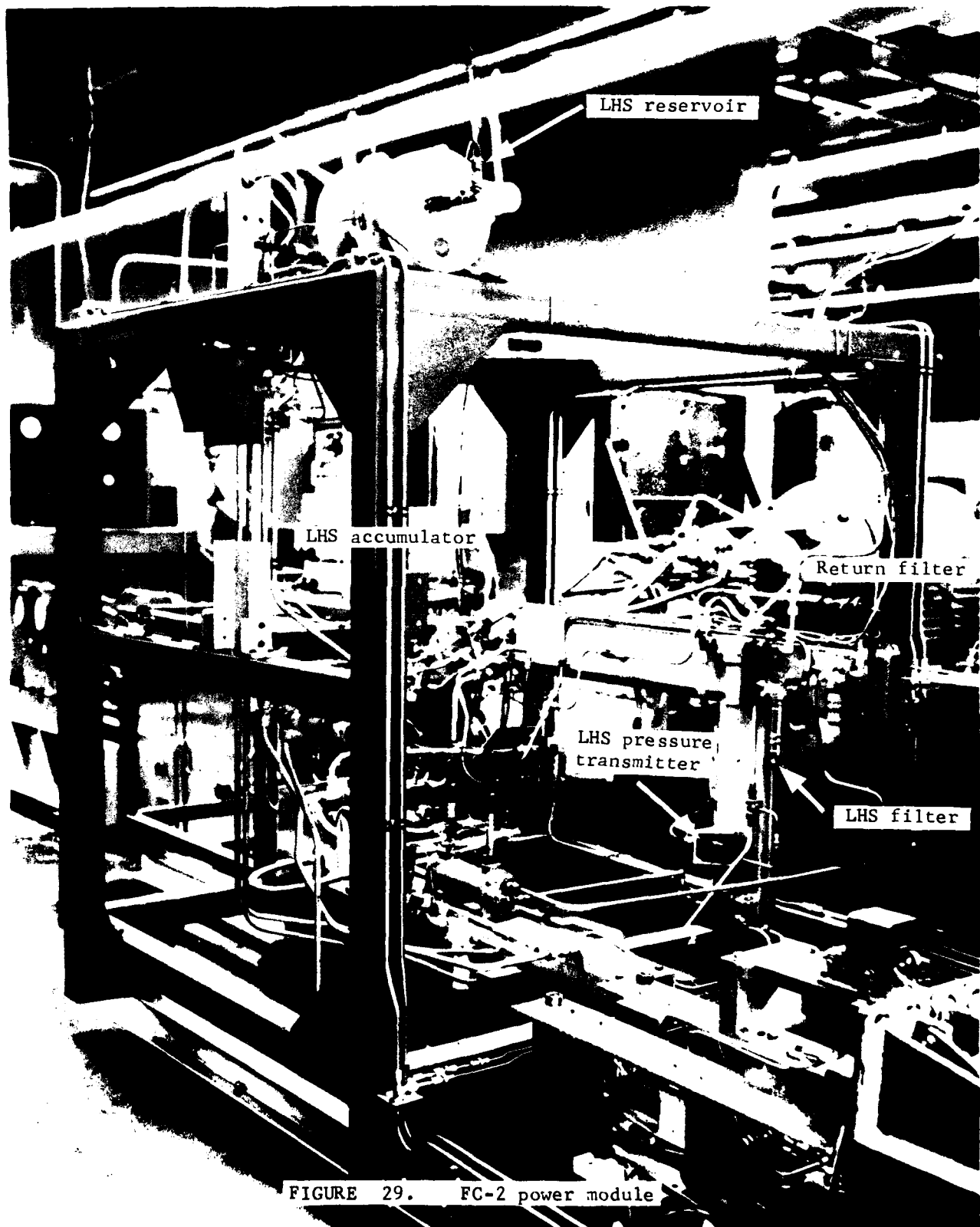


FIGURE 29. FC-2 power module

NADC-77108-30

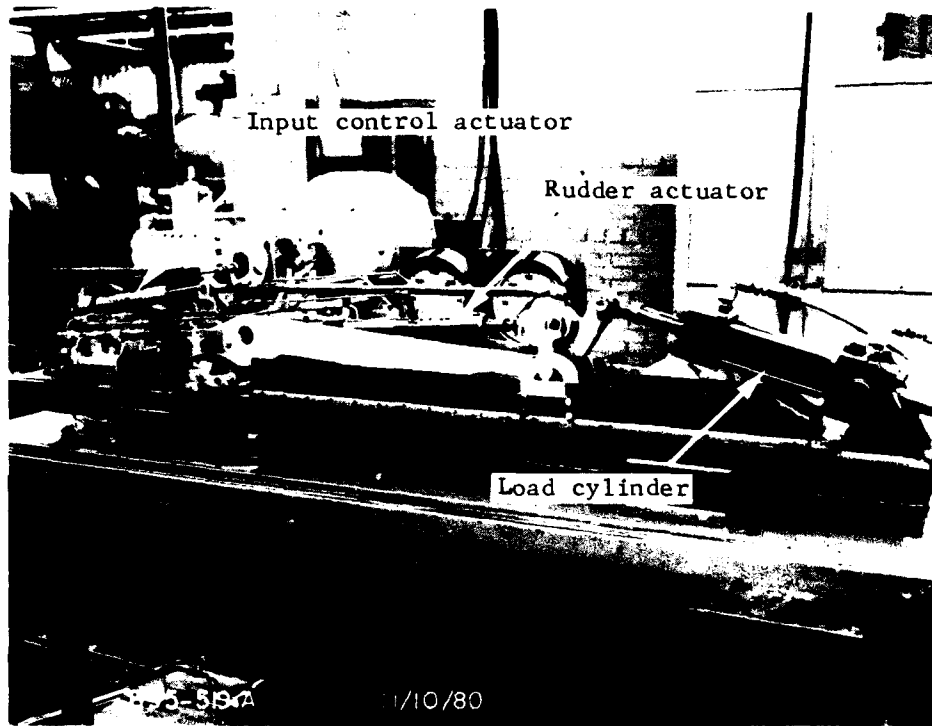


FIGURE 30. Rudder actuator module

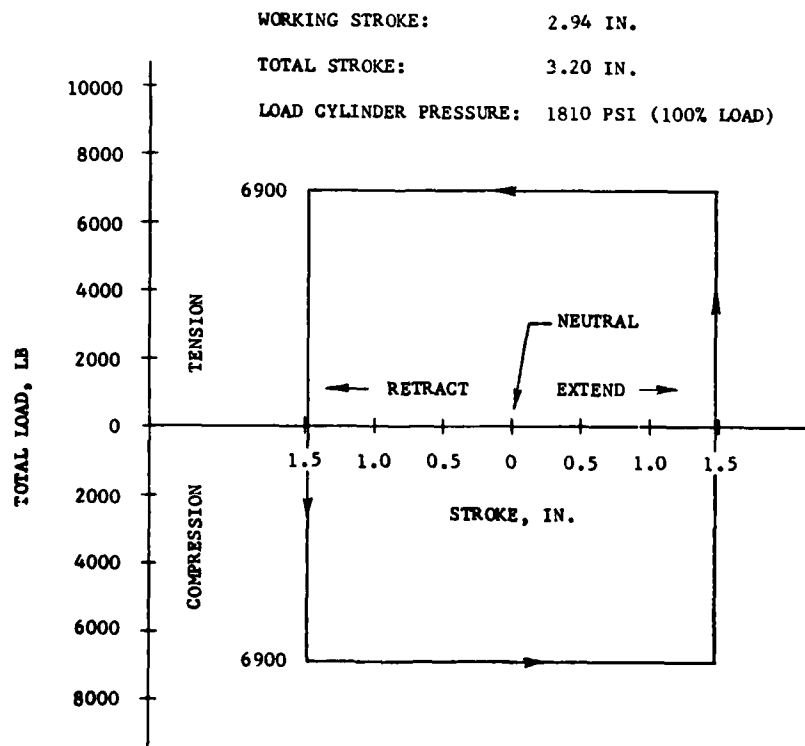


FIGURE 31. Rudder actuator load/stroke curve

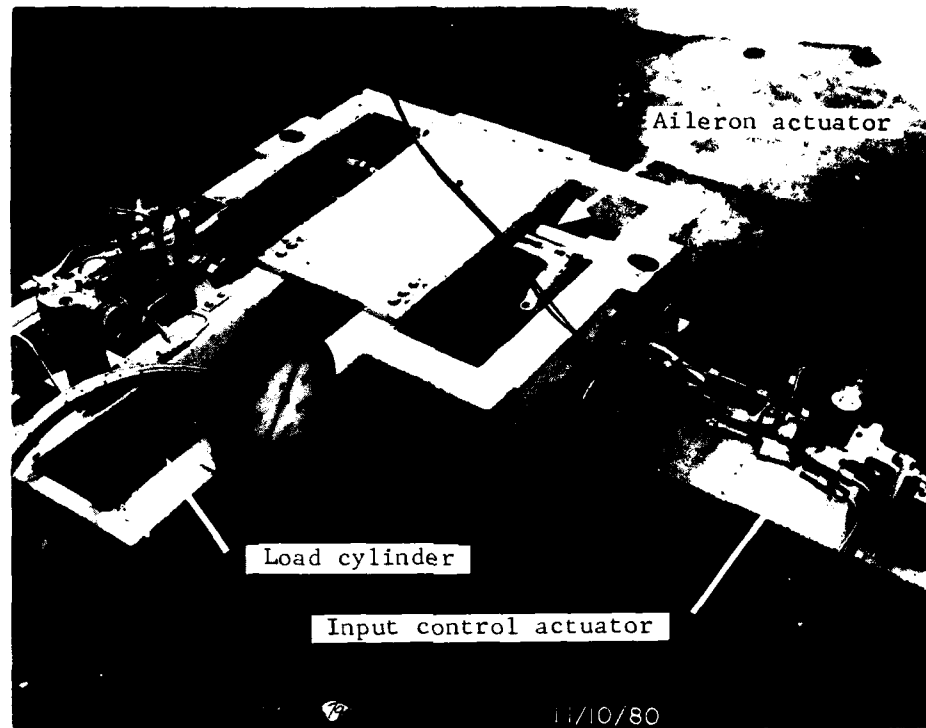


FIGURE 32. Aileron actuator module

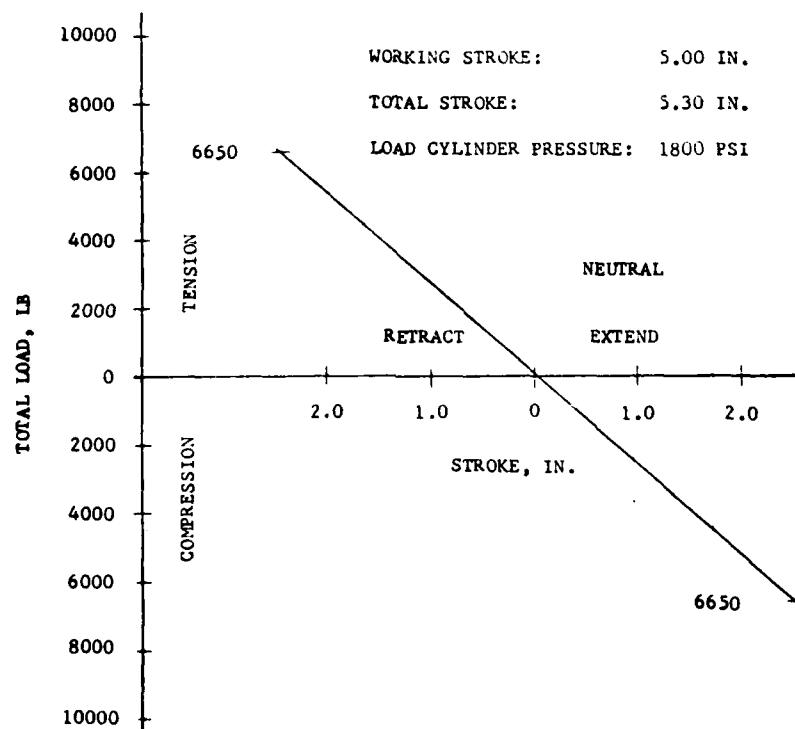


FIGURE 33. Aileron actuator load/stroke curve

AD-A097 505

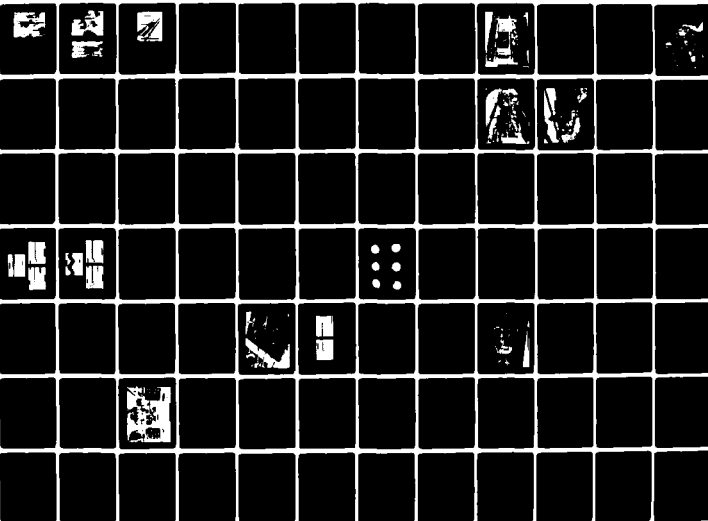
ROCKWELL INTERNATIONAL COLUMBUS OH NORTH AMERICAN AI--ETC F/6 13/7  
DESIGN, DEVELOPMENT, AND EVALUATION OF LIGHTWEIGHT HYDRAULIC SY--ETC(U)  
JAN 81 J N DEMARCHI, R K HANING N62269-78-C-0363  
NR81H-2 NADC-77108-30 NL

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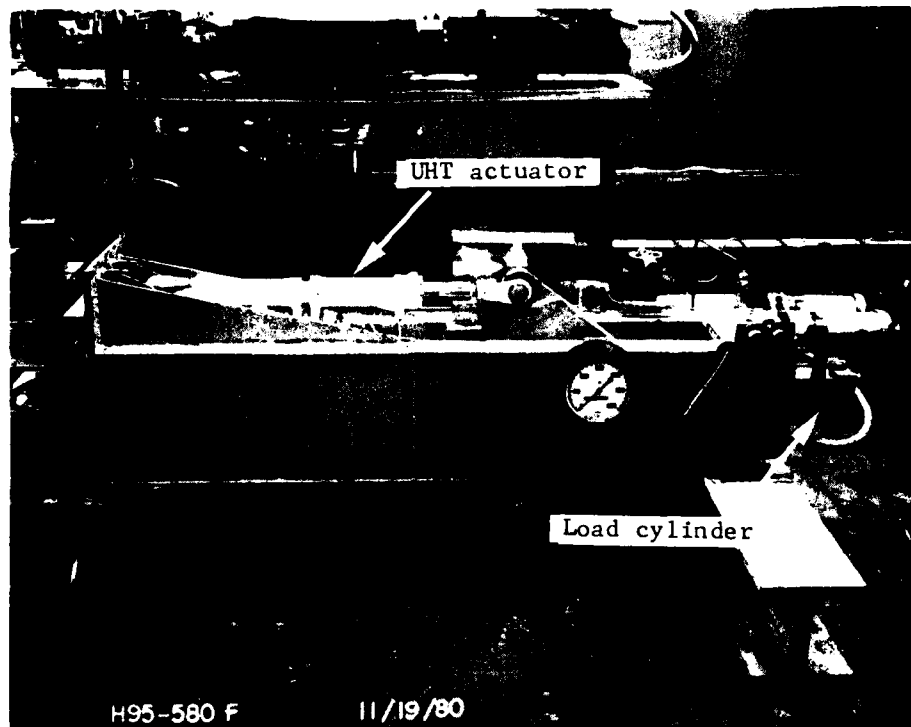


FIGURE 34. UHT actuator module

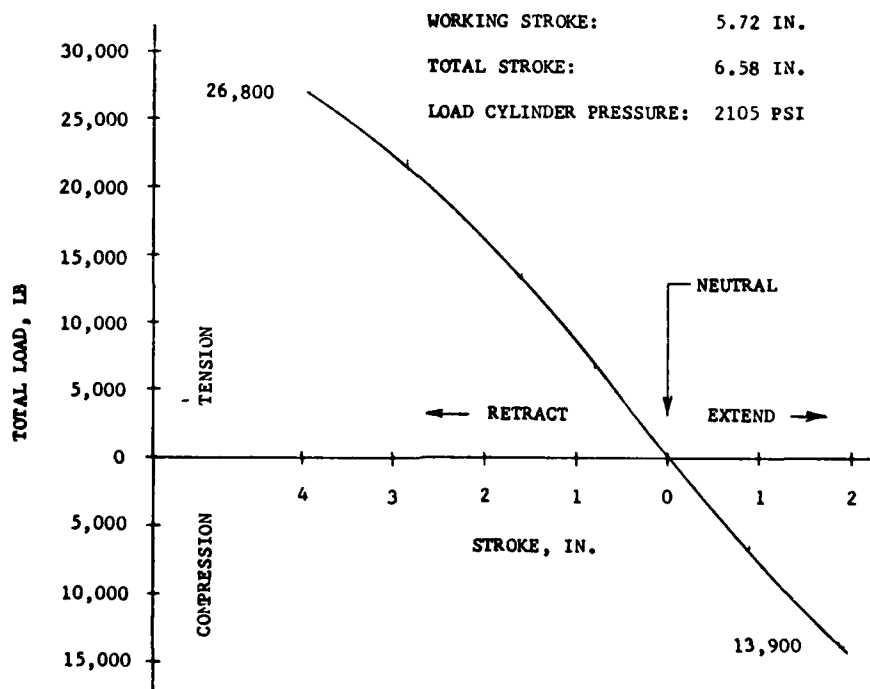


FIGURE 35. UHT actuator load/stroke curve

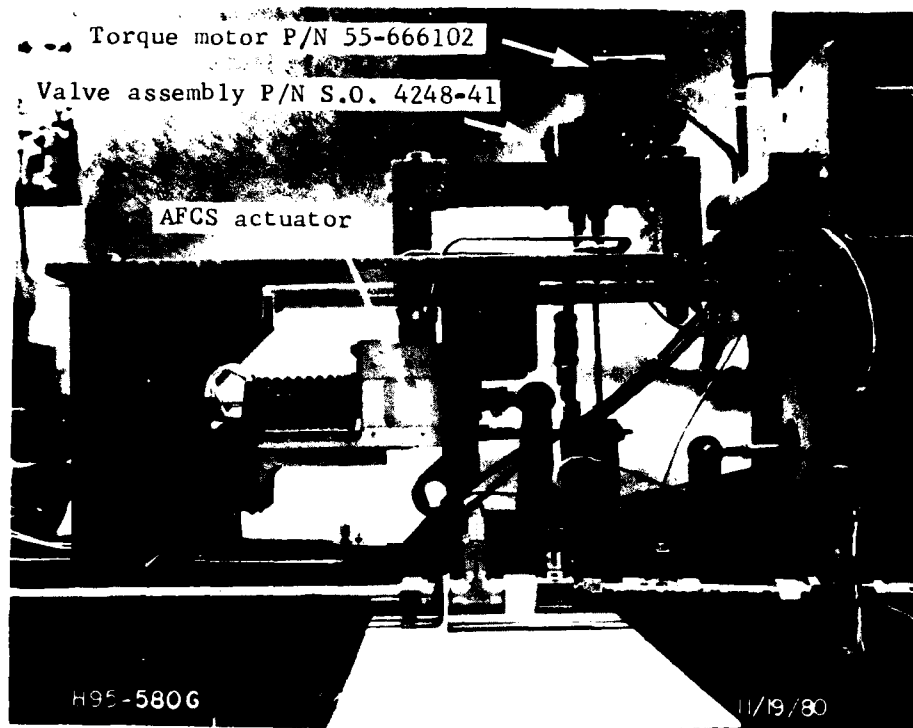


FIGURE 36. AFCS actuator

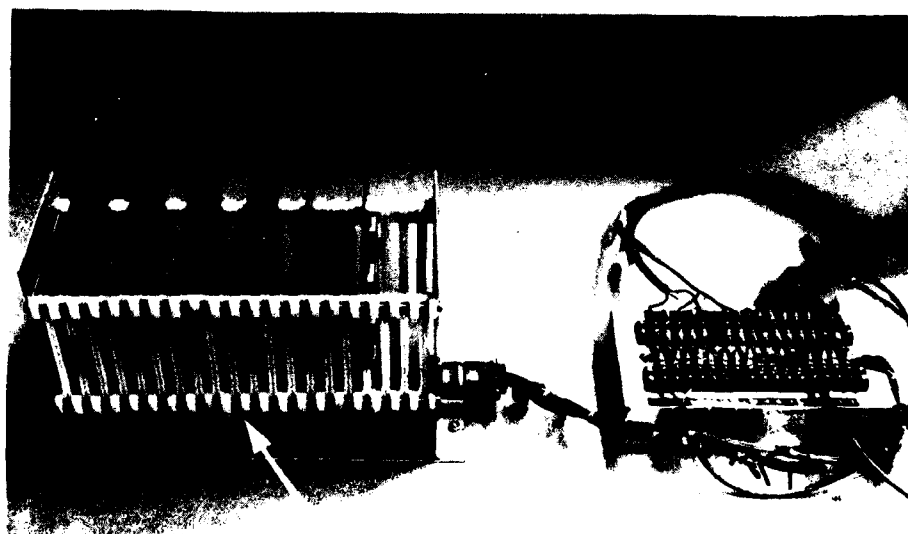
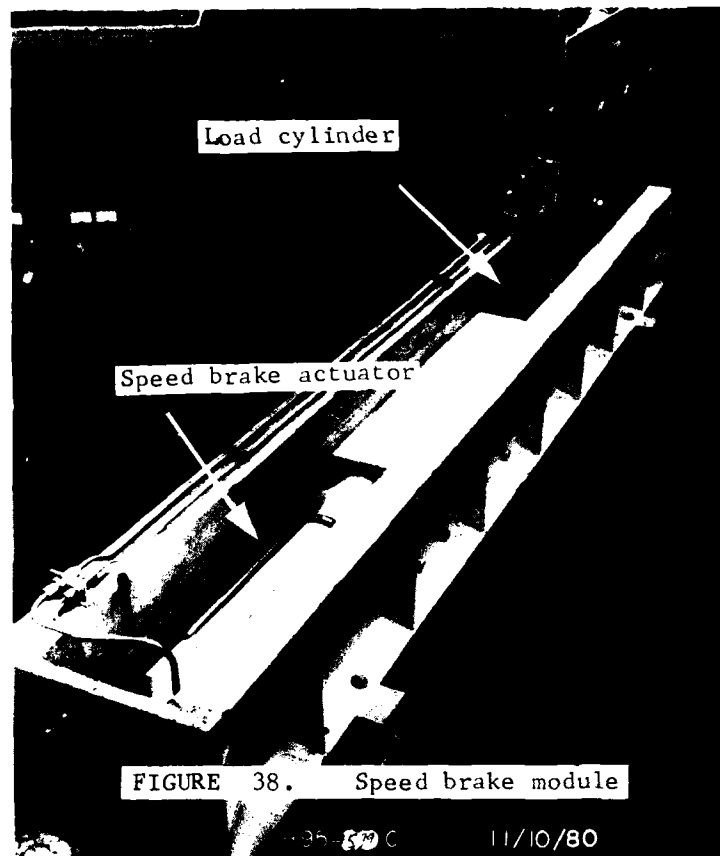


FIGURE 37. Electronic drive unit



WORKING STROKE: 19.94 IN.  
 TOTAL STROKE: 19.94 IN.  
 LOAD CYLINDER PRESSURE: 2040 PSI (100% LOAD)

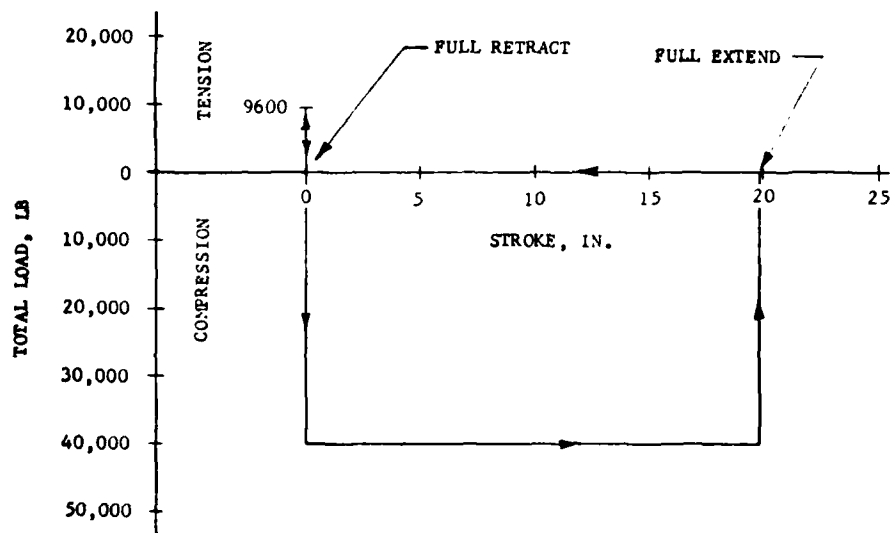


FIGURE 39. Speed brake load/stroke curve

4.2.2.4 Speed Brake Actuator - The swivelling motion of the A-7 speed brake actuator requires a minimum vertical height of 75 inches. Space constraints in the ground simulator, Figure 27, prohibited duplicating the aircraft geometry and swivelling of the speed brake actuator. Therefore, by necessity, swivelling motion in the speed brake load module was modified to eliminate ground interference.

The speed brake actuator is loaded by an industrial cylinder as shown in Figure 38, and is controlled by a 4-way solenoid valve located on the FC-1 power module. The load/stroke curve is given on Figure 39. A restrictor in the 4-way valve limits speed brake piston velocity to maintain system pressure.

## 5.0 COMPONENT TESTING

### 5.1 SEAL DEVELOPMENT

#### 5.1.1 Introduction

The selection of rod seals is recognized as critical to the successful demonstration of reliability in a lightweight hydraulic system. The rod seal in contemporary aircraft is the most likely source of external leakage. External leakage is, in turn, the most frequently cited cause of actuator removals.

A study was conducted to select candidate rod seals for use in the LHS test actuators. The investigation considered single stage seals and two stage unvented seals.

Information presented in Section 5.1 was condensed from Vought Report 2-51700-C/9R-52140, Reference 16.

#### 5.1.2 Seal Selections

A 200 hour seal test was completed by NAAD-Columbus for the LHS program shortly before the rod seal study was initiated, Reference 10. The Bal Seal, which was a part of that test, appeared to have the least wear at the conclusion of testing. Therefore, the Bal Seal was selected to be tested in both a single and a two stage seal configuration. The Bal Seal has two negative aspects which must be considered:

- (1) It is relatively inflexible and requires a split groove for installation.
- (2) It has a relatively large cross section; therefore, the groove must be deeper than that of a groove designed in accordance with MIL-G-5514.

The two seal configurations using the Bal Seal are shown in Figure 40. The seal tested by NAAD was a heavy duty unit having a cross-section height of 1/4 inch. Vought tested a medium duty seal which had a 3/16 inch cross section. Bal Seal Engineering Company recommended that a polyimide backup ring be included in the seal; this feature was not a part of the seal tested by NAAD.

Republic Aircraft Corporation performed a number of seal test programs for the USAF in the 1958 era. One of these programs evaluated seals at temperatures from +300 to +325°F where Teflon backup rings become very soft and tend to flow or creep. It was reported that two backup rings on the low pressure side of the elastomer repeatedly gave a five-fold increase in seal life as compared to a single backup ring. Seals designated "E-2", "B", and "D" in Figure 40 make use of the two backup ring concept in an attempt to close the extrusion gap. The backup rings are all uncut. Materials and seal suppliers are identified in Table 3.

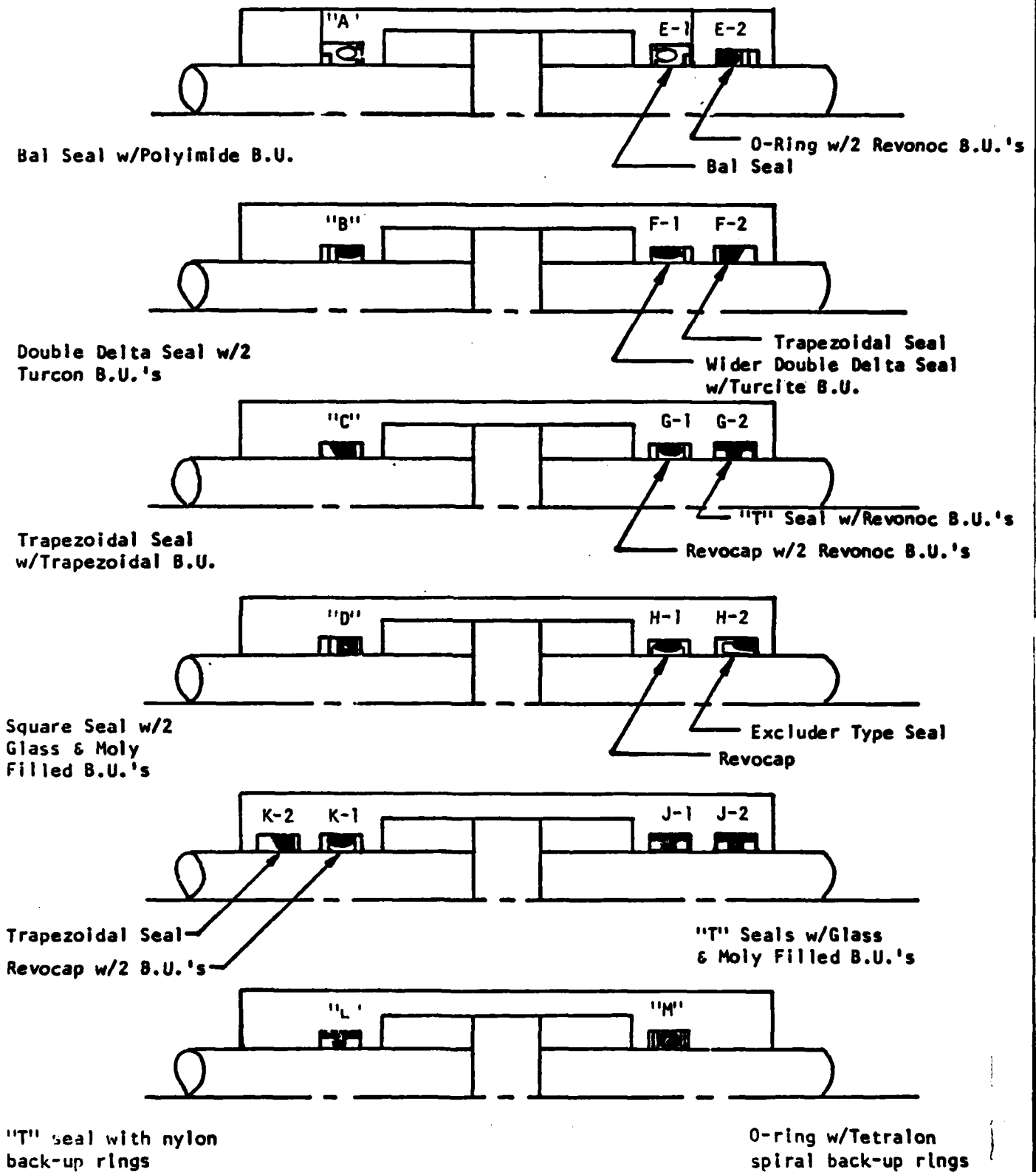


FIGURE 40. Seal configurations tested

TABLE 3. Seal Materials and Suppliers

|          | SUPPLIER                                                              | MATERIALS                                                                                |
|----------|-----------------------------------------------------------------------|------------------------------------------------------------------------------------------|
| Seal A   | Bal Seal Engineering Co.                                              | back-up ring - polyimide<br>seal - graphite filled Teflon                                |
| Seal B   | Shamban - back-up rings<br>Shamban - double delta<br>Conover - O-ring | glass/moly filled Turcon 33012<br>glass/moly filled Turcon 33012<br>MIL-P-83461 compound |
| Seal C   | Conover                                                               | back-up ring - Revonoc 18158<br>elastomer - MIL-P-83461                                  |
| Seal D   | Conover                                                               | back-up rings - Revonoc 18158<br>elastomer - MIL-P-83461                                 |
| Seal E-1 | Bal Seal Engineering Co.                                              | back-up ring - polyimide<br>seal - graphite filled Teflon                                |
| Seal E-2 | Conover                                                               | back-up rings - Revonoc 18158<br>O-ring - MIL-P-83461                                    |
| Seal F-1 | Shamban<br>Shamban                                                    | double delta - glass/moly filled<br>Turcon 33012<br>back-up ring - Turcite 79            |
| Seal F-2 | Conover                                                               | back-up ring - Revonoc 18158<br>elastomer - MIL-P-83461                                  |
| Seal G-1 | Conover                                                               | Revocap - Revonoc 6200<br>back-up rings - Revonoc 18158<br>O-ring - MIL-P-83461          |
| Seal G-2 | Conover                                                               | back-up rings - Revonoc 18158<br>elastomer - MIL-P-83461                                 |
| Seal H-1 | Conover                                                               | Revocap - bronze filled Revonoc 5300<br>O-ring - MIL-P-83461                             |
| Seal H-2 | Shamban<br>Conover                                                    | Excluder - bronze filled Turcon<br>O-ring - MIL-P-83461                                  |
| Seal K-1 | Conover                                                               | Revocap - Revonoc 6200<br>back-up rings - Revonoc 18158<br>O-ring - MIL-P-83461          |
| Seal K-2 | Conover                                                               | back-up ring - Revonoc 18158<br>elastomer - MIL-P-83461                                  |
| Seal J-1 | Greene Tweed                                                          | back-up ring - glass/moly filled<br>Teflon<br>"T" elastomer - ?                          |
| Seal J-2 | Greene Tweed                                                          | same as J-1                                                                              |
| Seal L   | Greene Tweed                                                          | back-up ring - nylon<br>"T" elastomer - ?                                                |
| Seal M   | Royal Industries<br>Conover                                           | Spiral back-up ring - Tetralon 700<br>O-ring - MIL-P-83461 compound                      |

Seal "C", "K-2", and "F-2" in Figure 40 are referred to as a trapezoidal seal. Both the backup ring and the elastomer have a trapezoidal cross-section. Under pressure, the elastomer produces a force vector which pushes the backup ring toward the extrusion gap. This Vought design is an outgrowth of a seal problem experienced on a rocket motor several years ago. The trapezoidal backup ring provides a thick cross section at the extrusion gap and has proven to be very resistant to extrusion.

The seal combination "G-1" and "G-2" shown in Figure 40 is similar to that selected by Rockwell International for the B-1 bomber except that a vent to return was provided in the B-1 seal configuration.

Seal "H-1" shown in Figure 40 was a cap strip designed for a no backup width groove. Two spacer backup rings were installed on the upstream side of the seal to prevent the cap strip/O-ring seal from being loose in the two backup width groove. The "H-2" seal is a scraper/seal which is like that used by Vought on S-3A utility actuators, except that it was made from different materials. The scraper/seal is primarily designed as a scraper. It had been determined, however, to function as a seal to at least 4500 psi if the retaining lip diameter was no more than 0.012 inch larger than the rod. A similar arrangement is used in a number of industrial cylinders. The "H-1/H-2" configuration provides a form of two stage seal in the space which would normally be needed for a single seal and scraper.

The square seal "D" shown in Figure 40 was selected because it would experience little change in shape between the pressurized and unpressurized state. This criterion of minimum change in shape came from the tear down of cylinders at the end of the NAAD tests, Reference 10. It was hypothesized that this wear might have been fretting of the rubber caused by repeatedly changing its shape when pressure was applied and relieved.

Seal "F-1" in Figure 40 is a double delta seal designed for a one backup width groove. Two seal suppliers were of the opinion that this would wear better than the cap strip designed for a no backup width groove. A Turcite backup ring was used to give greater extrusion resistance.

Seals shown as "K-1/K-2", "J-1/J-2", and "L" were not a part of the original test. These configurations received limited cycling as replacements for seals which failed.

### 5.1.3 Test Procedure

5.1.3.1 Test Actuators - Four test actuators were required for the program. The most economical way of fabricating these actuators was to use parts from industrial cylinders. The cylinders of several manufacturers were reviewed to determine which designs would most readily adapt to special end caps fabricated to house the candidate seals. An Ortman-Miller design was selected: model 3TH, mounting style DH, 1.5 in. bore, 1 in. rod, and 4 in. stroke. The four test cylinders are shown in Figure 41.

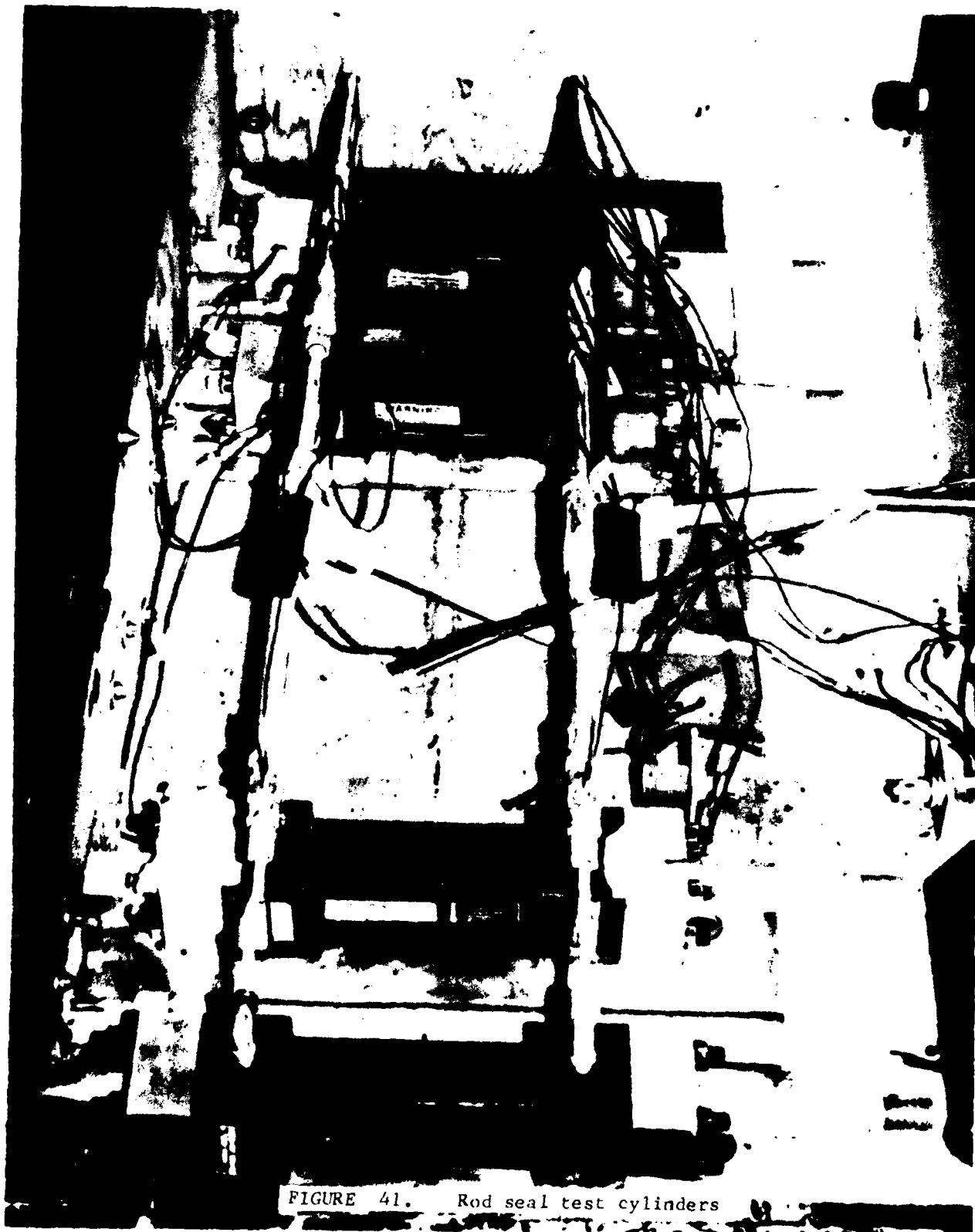


FIGURE 41. Rod seal test cylinders

5.1.3.2 Test Fixture - A fixture was designed with a large bellcrank to which each of the four test cylinders was attached. This assured that each cylinder stroked at the same velocity and displacement. A schematic of the fixture is shown on Figure 42. Figure 43 is a photograph of the test setup. Each of the test cylinders had an output force capability of 7,854 pounds at 8000 psi. The actual load selected was 80% of the maximum load. This force was reacted by one large load cylinder mounted on the centerline of the test fixture.

The control system used an electro-hydraulic actuator to stroke a mechanical input valve sinusoidally, see section 5.1.4. Flow from the mechanical input valve was directed to each of the four test cylinders simultaneously. The follow-up position of the cylinders was fed back to a summing linkage which compared the commanded input with the output positions to create an error signal. Since the actuators were plumbed in parallel, each actuator was subjected to the same differential pressure.

5.1.3.3 Test Cycling and Data - The cycling schedule was as follows:

- 8 test blocks of 50 hours each (400 hours total)
- 90% of cycling at a stroke of  $\pm 1.75$  inches
- 10% of cycling at a stroke of  $\pm 0.10$  inch
- Seal temperatures were approximately  $+250^{\circ}\text{F}$  except during warm-up periods

Specific data taken on the seals included:

- (1) Static leakage was measured at start of the test and at the end of each 50 hour test block. Leakage was measured at  $-40^{\circ}\text{F}$  and at  $250-275^{\circ}\text{F}$  with pressures of 8000, 100, and 1 psig.
- (2) Dynamic rod seal leakage was collected continuously throughout the test. This leakage was then measured and divided by the number of cycles to obtain the leakage rate.
- (3) The pressure between stages of the two stage seals was monitored until it built up to 5000 psi--the rating of the gages. At this point, the gages were shut off.
- (4) During the last 150 hours of the test, static leakage checks were made on the 1st stage of each two stage seal at one week intervals. This roughly coincided with the 50 hour test block.

The test accumulated a total of 172,618 full stroke and load cycles and 80,076 cycles of 10% stroke. While the test was far less than the number of short stroke cycles normally imposed during qualification of a flight control actuator, there were considerably more than the usual 50,000 full stroke cycles which form a part of the 2,000,000 cycle spectrum of MIL-C-5503C. Long-stroke cycling is more damaging to seals than short-stroke cycling. Furthermore, the 10% stroke cycles were run under design load conditions rather than under a 10% loading as specified by MIL-C-5503.

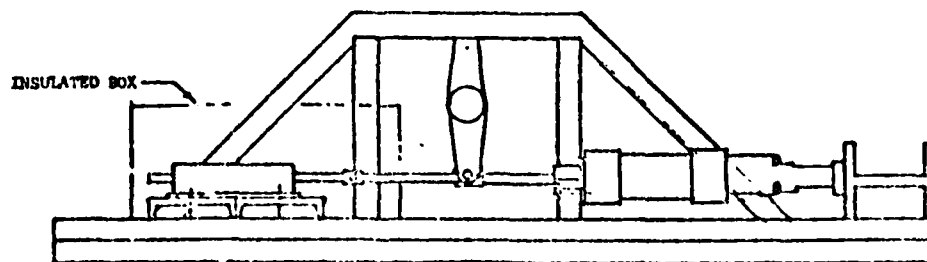
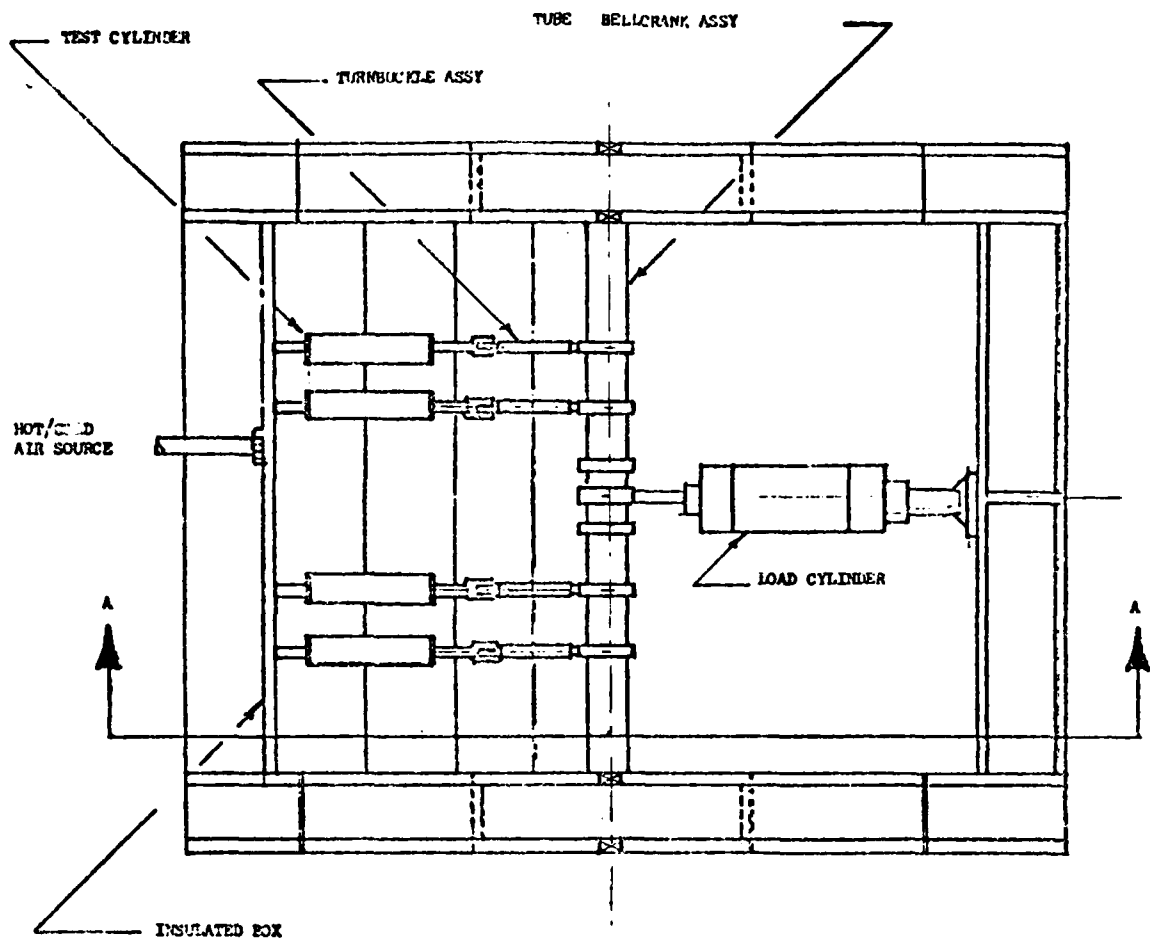


FIGURE 42. Seal test fixture schematic

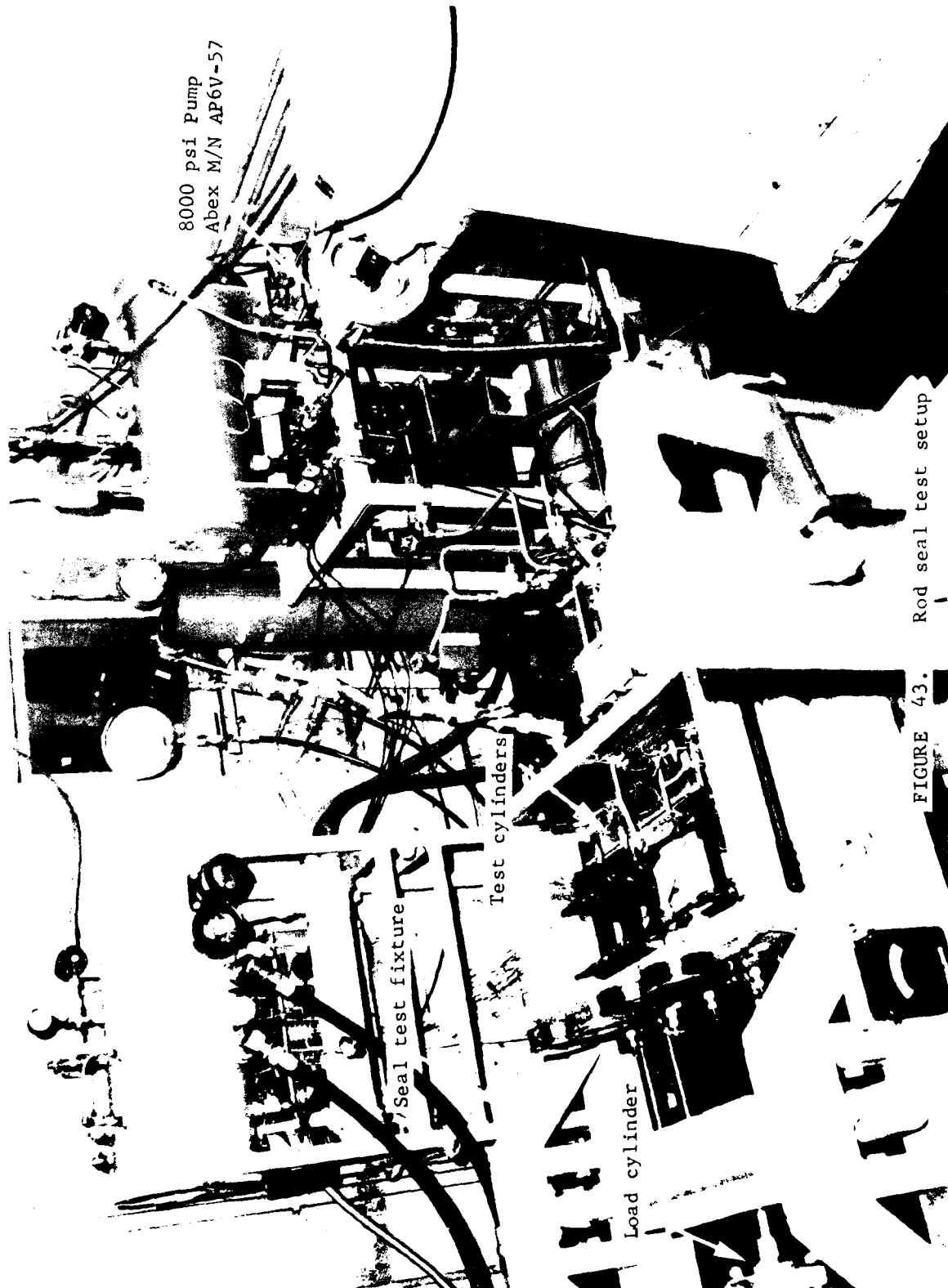


FIGURE 43.

#### 5.1.4 Test Results

The rod seal study was 410.2 hours in duration. Testing was started with eight seal configurations. Five of the eight completed the test with acceptable leakage rates using the allowable 1 drop/25 cycle criterion. Four additional seal configurations saw limited testing as replacements for failed seals. A summary of the seal test results is given on Table 4. Eight diametral type static seals were incorporated in the test actuators where the end caps mate with the cylinder barrel; all of these seals performed satisfactorily.

A detail analysis of seal failures and seal condition was made at the end of the test. The following conclusions were reached:

- (1) Reliable long life rod seals can be attained for 8000 psi systems.
- (2) Rubber against the rod wears well if protected properly. The backup ring and the extrusion gap are key elements in determining elastomer wear. The extrusion gap is one of the most powerful factors influencing seal life in a 3000 psi system and is even more important in an 8000 psi system. The range of 0.001 to 0.003 inch for diametrical clearances may be too large. The results seem to indicate that much longer life can be achieved if the extrusion gap is held to 0.002 or less.
- (3) The cap strip must be relatively thick to provide acceptable wear at 8000 psi.
- (4) TFE based seals leak more than rubber sealing elements. TFE seals may meet 25 cycles/drop requirement, but all really dry seals had rubber in contact with the rod.
- (5) Bronze filled cap strips did not wear as well as some other materials. This may have been due to insufficient thickness of the cap seal but appears to also be attributable to the material.
- (6) A two stage unvented seal can reverse pressurize the 1st stage seal; therefore, this should be considered in selecting the 1st stage configuration. Select a 1st stage with extrusion resistance in the reverse direction. A unidirectional seal for the 1st stage seal seems to add life to the second stage seal.
- (7) The no-backup width cap strip is more stable than a one backup width cap strip.
- (8) Glass/moly filled backups and cap strips did not cause rod scoring. Most of the test was long stroke which may have been a factor.

TABLE 4. Summary of Seal Test Results

| <u>Seal*</u>        | <u>Test Hours Completed</u> | <u>Configuration</u>                   | <u>Remarks</u>                                                                                 |
|---------------------|-----------------------------|----------------------------------------|------------------------------------------------------------------------------------------------|
| <u>Single Stage</u> |                             |                                        |                                                                                                |
| A                   | 410.2                       | Bal Seal                               | Negligible wear                                                                                |
| B                   | 410.2                       | Double delta,<br>2 backups             | Negligible wear, no nibbling of O-ring                                                         |
| C                   | 410.2                       | Trapezoid                              | No nibbling of elastomer, minor wear on backup                                                 |
| D                   | 253.1                       | Square seal,<br>2 backups              | Failed. Backups worn, elastomer nibbled                                                        |
| L                   | 39                          | Tee Seal                               | Failed. Elastomer nibbled badly                                                                |
| M                   | 73.3                        | O-ring,<br>2 backups                   | No leakage. Installed at 294.9 hours. Backups extruded                                         |
| <u>Two Stage</u>    |                             |                                        |                                                                                                |
| E                   | 410.2                       | 1. Bal Seal<br>2. O-ring,<br>2 backups | Negligible wear. Second stage experienced full load pressure throughout test                   |
| F                   | 263.5                       | 1. Double delta<br>2. Trapezoid        | Failed. 1st stage failed from reverse pressurization. 2nd stage failed from wear-out of backup |
| G                   | 410.2                       | 1. Revocap<br>2. Tee seal              | Revocap worn thru to O-ring. Tee seal had considerable wear                                    |
| H                   | 179.3                       | 1. Revocap<br>2. Excluder              | Failed. Cap strip wore out. Excluder then extruded                                             |
| J                   | 167.3                       | 1. Tee Seal<br>2. Tee Seal             | No leakage. Installed at 200.9 hours. Slight nibbling of 1st stage elastomer                   |
| K                   | 142.1                       | 1. Revocap<br>2. Trapezoid             | No leakage. Installed at 268.1 hours. Cap strip worn thru                                      |

\*See Figure 40 and Table 3.

- (9) On excluders, the curling up of the scraping edge is a problem which limits effectiveness.
- (10) Uncut filled backup rings can wear on the ID to a larger size and no longer be effective in eliminating nibbling if the back-up material is not somewhat compliant. A hard backup ring such as nylon against the rubber is not compliant enough to keep the extrusion gap closed. In the "T" configuration, rapid nibbling occurred.
- (11) Short duration testing of spiral backups indicated the thin member tends to extrude.
- (12) With one exception, all elastomeric seals were made from MIL-P-83461 compound. No problems occurred with this compound.
- (13) No problems occurred with the MIL-H-83282 test fluid.

Rod seal configurations recommended as candidates for LHS actuators were as follows:

| <u>Application</u>                                 | <u>Recommended Rod Seal Configuration</u>                                                                                                         | <u>Figure No.</u> | <u>Comments</u>                                                                                                                  |
|----------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|-------------------|----------------------------------------------------------------------------------------------------------------------------------|
| Primary<br>Flight<br>Control<br>Actuators          | Two stage seal:<br>-1st stage<br>Cap seal with<br>backup ring on<br>each side<br>-2nd stage<br>O-ring with two<br>backups on low<br>pressure side | 13                | -Can be installed in<br>standard unsplit<br>groove<br>-Provides dual seal<br>redundancy<br>-Rubber outer seal<br>assures dryness |
| Automatic<br>Flight<br>Control System<br>Actuators | Single stage seal:<br>Cap seal with<br>two backups on<br>low pressure side                                                                        | 15                | -Need to keep<br>friction low                                                                                                    |
| Utility<br>Actuators                               | Single stage seal:<br>Trapezoidal seal<br>with trapezoidal<br>backup                                                                              | 14                | -Utility application<br>has limited life re-<br>quirement<br>-Rubber outer seal<br>assures dryness                               |

### 5.1.5 Servo Valve Erosion Test

5.1.5.1 Test Procedure - The rod seal test was begun using a solenoid valve and limit switches to cycle the four test actuators. At 39.5 hours, a mechanical servo valve was installed to cycle the actuators. The servo valve provided smoother control and more flexibility in changing stroke lengths than the solenoid valve. It also provided an opportunity to evaluate servo valve erosion concurrently with the rod seal test and thereby minimize costs.

The servo valve assembly tested was Vought P/N 210-32263. This valve has a nominal orifice size of 0.060 in. length by 0.020 in. width. The valve was used throughout the remainder of the rod seal testing which was terminated at 410.2 hours. This provided 370.7 hours of servo valve operation at 8000 psi inlet pressure. The valve was stroked sinusoidally by an electrohydraulic actuator with position follow-up summed by a scissors linkage to null the valve. The peak flow rate was approximately 1.7 gpm during long stroke cycling of the test actuators.

The test fluid (MIL-H-83282) was filtered to 3 microns absolute by a filter in the pressure line between the pump and the servo valve. It is not known how strong a factor contaminant level is in influencing erosion. The current trend toward 5 micron absolute filtration should produce aircraft systems with a cleanliness level similar to that in the test set-up.

5.1.5.2 Test Results - The valve controller was examined under 10 power magnification for evidence of erosion on the metering lands and on the controller between lands. No sign of erosion was seen. The metering land corners were sharp. The top of the lands had a wear pattern which was apparently due to the reciprocating motion of the controller--not due to erosion. The test valve was a two system valve; however, only one side was active in the test. The land polishing was the same on the active half and the inactive half of the valve.

Three valve characteristics were measured before and after testing so that the amount of wear or degradation in performance could be determined. The measurements were made at 3000 psi since the laboratory where this work was done was not equipped for 8000 psi testing. The results are tabulated below:

| <u>Parameter</u>                         | <u>Before Test</u> | <u>After Test</u> |
|------------------------------------------|--------------------|-------------------|
| Neutral leakage, gpm                     | 0.075              | 0.095             |
| Valve underlap, in.<br>(average values)  | 0.00033            | 0.00051           |
| Flow gain, gpm/in.<br>(0.004 in. stroke) | 42.5               | 46.25             |

Comparison of the before test and after test values indicates an average increase in underlap of 0.0002 in. per land during the test. Neutral leakage increased by 0.02 gpm. The short stroke flow gain increased slightly which is the expected result of increased underlap.

From the combination of visual inspection and post test performance, it was concluded that servo valve erosion should not be a problem in 8000 psi systems. This conclusion was based upon the test of a particular valve design wherein both the sleeve and the controller were made from 440C material with a Rockwell hardness in the range of C58 to C63. It should be recognized that valves made from softer materials or other design configurations could have a wear problem. However, the test valve was considered to be a state-of-the-art unit similar to most valves commonly in use, and contained no special features to enable it to operate at 8000 psi.

The test valve was underlapped. Valves being incorporated in lightweight hydraulic systems will be overlapped to minimize power loss (and heat generation). It is expected that this will have a beneficial effect on valve wear.

## 5.2 ACCEPTANCE TESTS

### 5.2.1 Major Components

Pump acceptance testing was conducted by NAAD. Two pumps were checked (FC-1 and FC-2). Performance checks run at the beginning of the compatibility endurance test (0 hours) were considered as the acceptance tests. The results were not completely satisfactory and are discussed in section 5.3.6.1. The tests conducted were:

- Overall efficiency
- Transient response
- Heat rejection

Actuator and reservoir acceptance testing was conducted by NAAD and Vought as shown on Table 5. The tests, as applicable, were:

- Proof pressure (12,000 psi)
- Functional
  - Operation
  - Internal/External Leakage

Control valve stop adjustments were made during actuator operation checks. All actuator and reservoir acceptance tests were completed satisfactorily.

Vought conducted extreme temperature and limited endurance cycling on the UHT, aileron, speed brake, and AFCS actuators. Test details and results are documented in Vought Report No. 2-59900/9R-52172. All results were considered satisfactory.

### 5.2.2 Minor Components

Component suppliers conducted proof pressure and various individual tests necessary to assure satisfactory operation, Table 6. All acceptance test results were satisfactory.

TABLE 5. Acceptance Tests, Major Components

| <u>Component</u>            | <u>Tests Conducted</u>                             | <u>Tests Conducted By</u>           | <u>Test Results</u> | <u>Test Results Reported In</u>              |
|-----------------------------|----------------------------------------------------|-------------------------------------|---------------------|----------------------------------------------|
| LHS Pump                    | Efficiency<br>Transient Response<br>Heat Rejection | North American<br>Aircraft Division | See section 5.3.6.1 | NAAD Laboratory<br>Record Book<br>S/N N 1021 |
| LHS Rudder<br>Actuator      | Proof<br>Functional                                | North American<br>Aircraft Division | Satisfactory        | NAAD Laboratory<br>Record Book<br>S/N N 1021 |
| LHS UHT<br>Actuator         | Proof<br>Functional                                | Vought                              | Satisfactory        | Vought Report<br>2-59900/9R-52172            |
| LHS Aileron<br>Actuator     | Proof<br>Functional                                | Vought                              | Satisfactory        | Vought Report<br>2-59900/9R-52172            |
| LHS Speed<br>Brake Actuator | Proof<br>Functional                                | Vought                              | Satisfactory        | Vought Report<br>2-59900/9R-52172            |
| LHS<br>Reservoir (2)        | Proof<br>Functional                                | Vought                              | Satisfactory        | Vought Report<br>205-LHS-6                   |

TABLE 6. Acceptance Tests, Minor Components

| <u>LHS Component</u>    | <u>Tests Conducted</u>                                                                                            | <u>Tests Conducted By</u>                       | <u>Test Results</u> | <u>Test Results Reported In</u>                                     |
|-------------------------|-------------------------------------------------------------------------------------------------------------------|-------------------------------------------------|---------------------|---------------------------------------------------------------------|
| Accumulator             | Proof @ +275°F<br>Gas leakage<br>Fluid leakage                                                                    | Bendix Corporation<br>Electrodynamics Div.      | Satisfactory        | Bendix Acceptance<br>Test Report for<br>P/N 3321471                 |
| Check Valve             | Proof<br>Internal/<br>External leakage                                                                            | Gar-Kenyon Controls Div.<br>MITE Corporation    | Satisfactory        | Gar-Kenyon document<br>ATP 95200                                    |
| Filter                  | Proof<br>Bubble Point<br>Differential Pressure<br>Automatic Shut-off<br>Degree of Filtration<br>Collapse Pressure | Aircraft Porous Media, Inc.<br>Pall Corporation | Satisfactory        | APM document<br>ATP-A640-83Y1                                       |
| Hose                    | Proof                                                                                                             | Titelflex Corporation                           | Satisfactory        | Data not yet received<br>LHS hose delivered 12-8-80                 |
| Pressure Gage           | Proof<br>Scale Error                                                                                              | QED/Inc.                                        | Satisfactory        | QED/Inc. document<br>ATP 1218-63                                    |
| Pressure<br>Smubber     | Proof<br>Restricted Flow                                                                                          | Gar-Kenyon Controls Div.<br>MITE Corporation    | Satisfactory        | Gar-Kenyon document<br>ATP 95239                                    |
| Pressure<br>Transmitter | Proof<br>Case Leakage<br>Scale Error<br>Pressure Switch                                                           | Courter, Inc.<br>Bendix Corporation             | Satisfactory        | Courter P/N 18-243<br>Test Record per<br>Q.C.T.P. 525-202<br>Rev. B |
| Quick Disconnect        | Proof<br>Leakage<br>Vibration                                                                                     | Aeroquip Corporation                            | Satisfactory        | Aeroquip Report No.<br>610011-4                                     |
| Relief Valve            | Proof<br>Cracking Pressure<br>Reseat Pressure                                                                     | PneuDrualics, Inc.                              | Satisfactory        | PneuDrualics document<br>ATP 1257, ATP 1258                         |
| Restrictor              | Proof<br>Rated Flow                                                                                               | The Lee Company                                 | Satisfactory        | Lee document<br>P.S. 280                                            |
| 4-Way<br>Solenoid Valve | Proof<br>Leakage                                                                                                  | Bendix Corporation<br>Electrodynamics Div.      | Satisfactory        | Bendix letter<br>HYD-425-80                                         |
| Tubing                  | Mechanical<br>Properties<br>Chemical<br>Analysis<br>Miscellaneous<br>Inspections                                  | Trent Tube                                      | Satisfactory        | Trent Tube document<br>M.O. 1F5-20670-1                             |

### 5.3 COMPATIBILITY TEST

#### 5.3.1 Introduction

The compatibility test integrated six modules in the 8000 psi system to be assembled on the full scale simulator in Phase II. Primary purposes of this test were:

- (1) Provide a means for powering the LHS actuators
- (2) Permit preliminary evaluation of system pressure ripple and surge characteristics
- (3) Provide a means for realistically endurance testing the LHS pumps, reservoirs, actuators, valves, etc.

Secondary purposes of the test include familiarization with the newly designed system and practical experience operating the system.

#### 5.3.2 Test System

A floor layout of major sections in the system is given on Figure 44. Overall views of the laboratory setup are shown on Figures 45 and 46. The test modules were placed in locations approximating their future relative positions on the full scale simulator in Phase II. There were two independent 8000 psi hydraulic systems (FC-1 and FC-2), a 3000 psi system for loading four LHS actuators, and a 500 psi system for controlling the inputs of two LHS actuators, Figure 47. Tubing lengths used to connect LHS actuators with the power sections were based on lengths anticipated in the flight test aircraft, Figure 48. A schematic diagram of the 3000 psi load system is presented on Figure 49.

#### 5.3.3 Instrumentation

The instrumentation system had three functions: controlling, monitoring, and recording. The principal sections were (1) control panel, (2) pressure gage panel, (3) temperature recorder, and (4) oscillograph recorder, Figure 50.

##### Controls

- FC-1 and FC-2 pump on-off
- FC-1 and FC-2 pump speed
- FC-1 and FC-2 fluid temperature
- FC-1 and FC-2 automatic shut-down
  - resulting from fluid over-temp or fluid loss
- Rudder, UHT, and aileron actuator cycling
  - amplitude and frequency
- Speed brake actuator cycling

Monitoring

FC-1 and FC-2 fluid temperatures  
 FC-1 and FC-2 pump inlet, outlet, and case pressures  
 FC-1 and FC-2 pump inlet and case flows  
 Load and control system pressures  
 Pump speed  
 Running time

Recording

FC-1 and FC-2 fluid temperatures  
 FC-1 and FC-2 pressures and flows  
 Pump speed

A block diagram of the instrumentation system is presented as Figure 51. Transducer locations, operating range, accuracies, and response capabilities are given in Table 7.

5.3.4 Test Procedure

5.3.4.1 Cycling - Compatibility test cycling was performed in three blocks of 50 hours duration (150 hours total cycling time). Each 50 hour block consisted of a cycling schedule designed to subject system components to realistic operating conditions. Actuator cycling was based on the load/stroke schedule given in MIL-C-5503. Twenty percent of the endurance test cycle requirements specified in MIL-C-5503 were run.

Automatic Flight Control Actuators

|                  |   |                                                    |
|------------------|---|----------------------------------------------------|
| 10,000 cycles    |   | 100% stroke and load                               |
| 50,000 cycles    |   | 50% stroke and load                                |
| 140,000 cycles   |   | 10% stroke and load                                |
| 800,000 cycles   |   | 2% stroke and load                                 |
| 1,000,000 cycles | = | 20% of 5,000,000 cycles<br>specified in MIL-C-5503 |

Utility System Actuators

|                     |   |                                                 |
|---------------------|---|-------------------------------------------------|
| <u>4,000 cycles</u> |   | 100% stroke and load                            |
| 4,000 cycles        | = | 20% of 20,000 cycles<br>specified in MIL-C-5503 |

The cycling sequence is detailed on Table 8. Each sequence step was one hour in duration. A summary of the cycles completed in a 50 hour block is given on Table 9. Actuator strokes and loads are listed on Table 10.

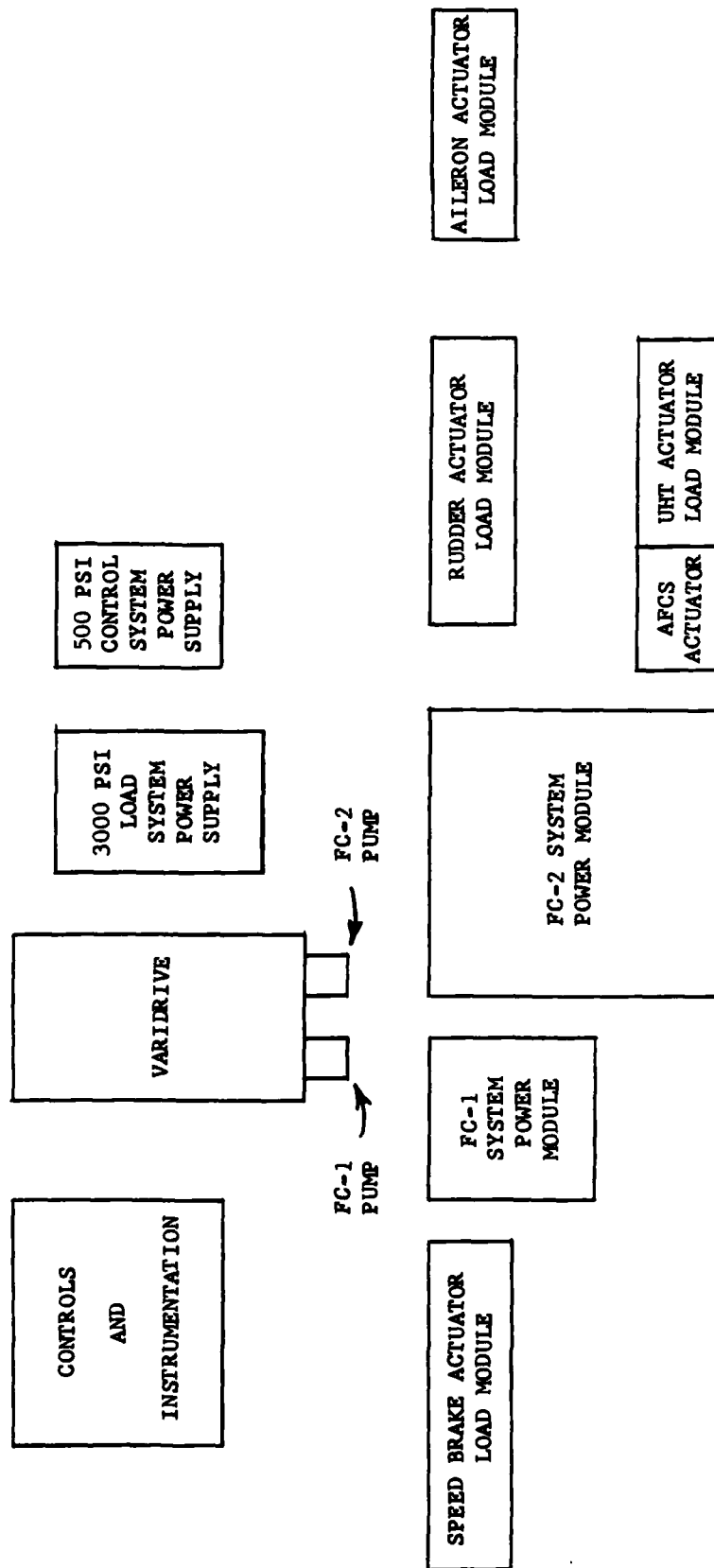


FIGURE 44. Floor layout of compatibility test system

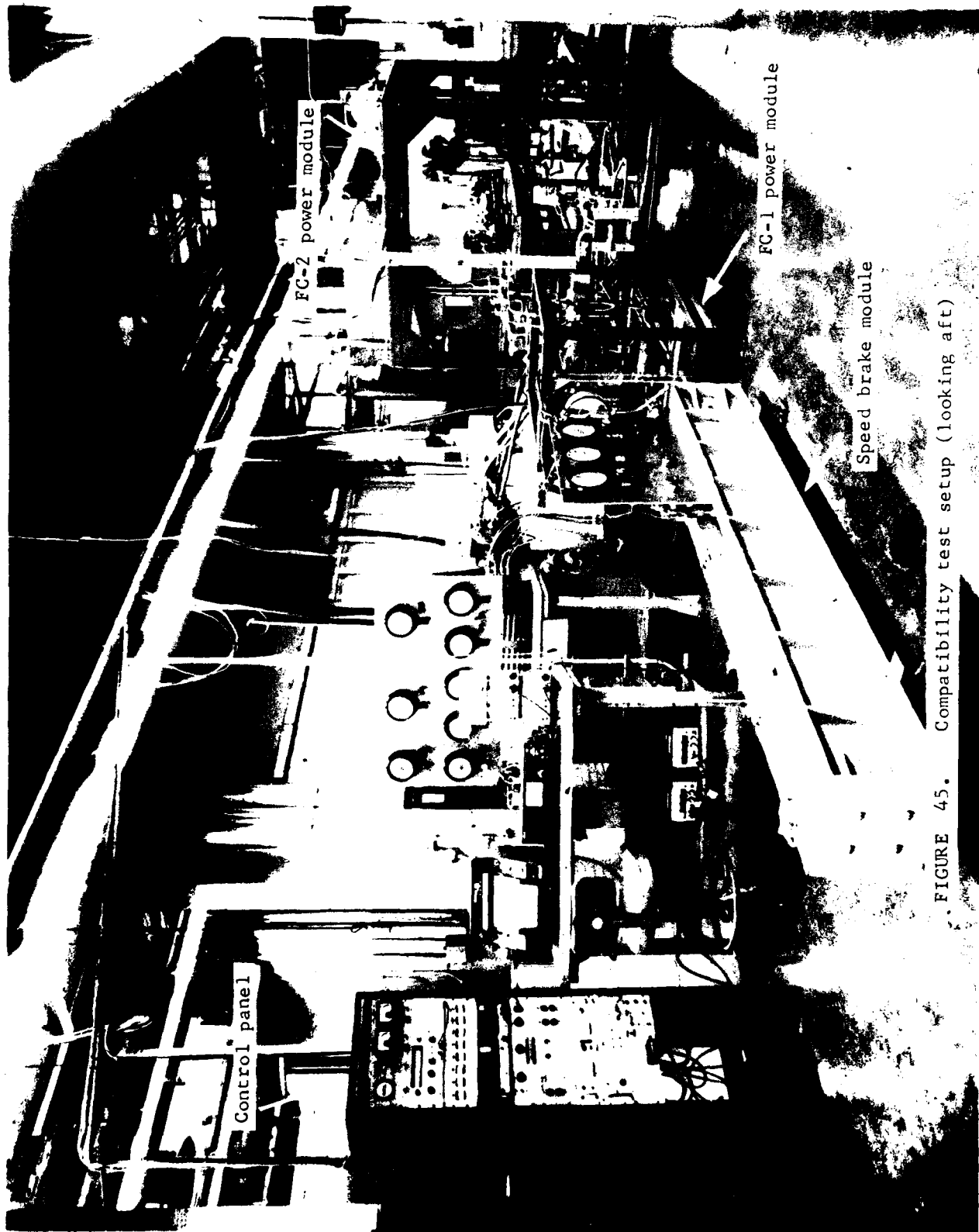


FIGURE 45. Compatibility test setup (looking aft)



FIGURE 46. Compatibility test setup (looking forward)

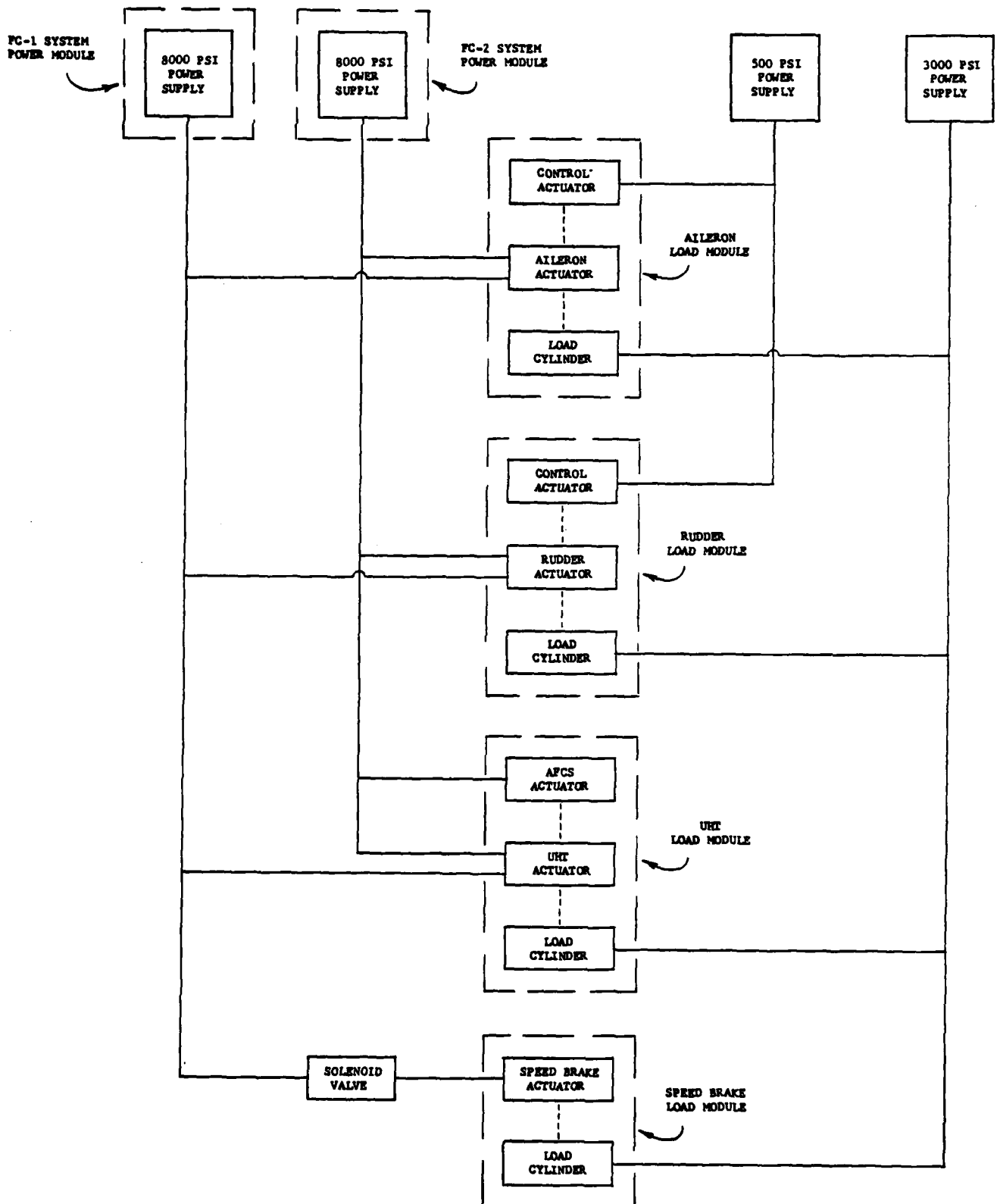
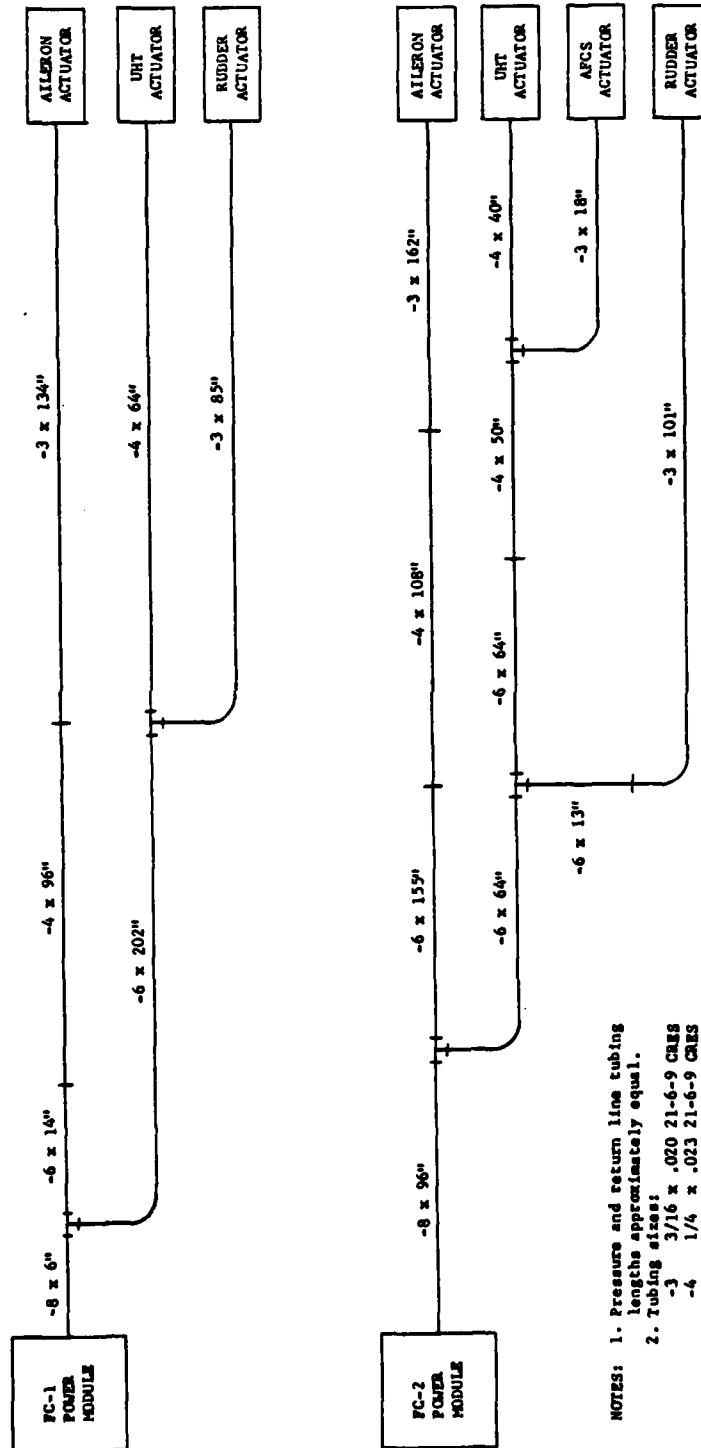


FIGURE 47. Compatibility test hydraulic systems



NOTES: 1. Pressure and return line tubing lengths approximately equal.  
 2. Tubing sizes:  
 -3 3/16 x .020 21-6-9 CRES  
 -4 1/4 x .023 21-6-9 CRES  
 -6 3/8 x .034 21-6-9 CRES  
 -8 1/2 x .046 21-6-9 CRES

FIGURE 48. Power module-to-actuator tubing lengths

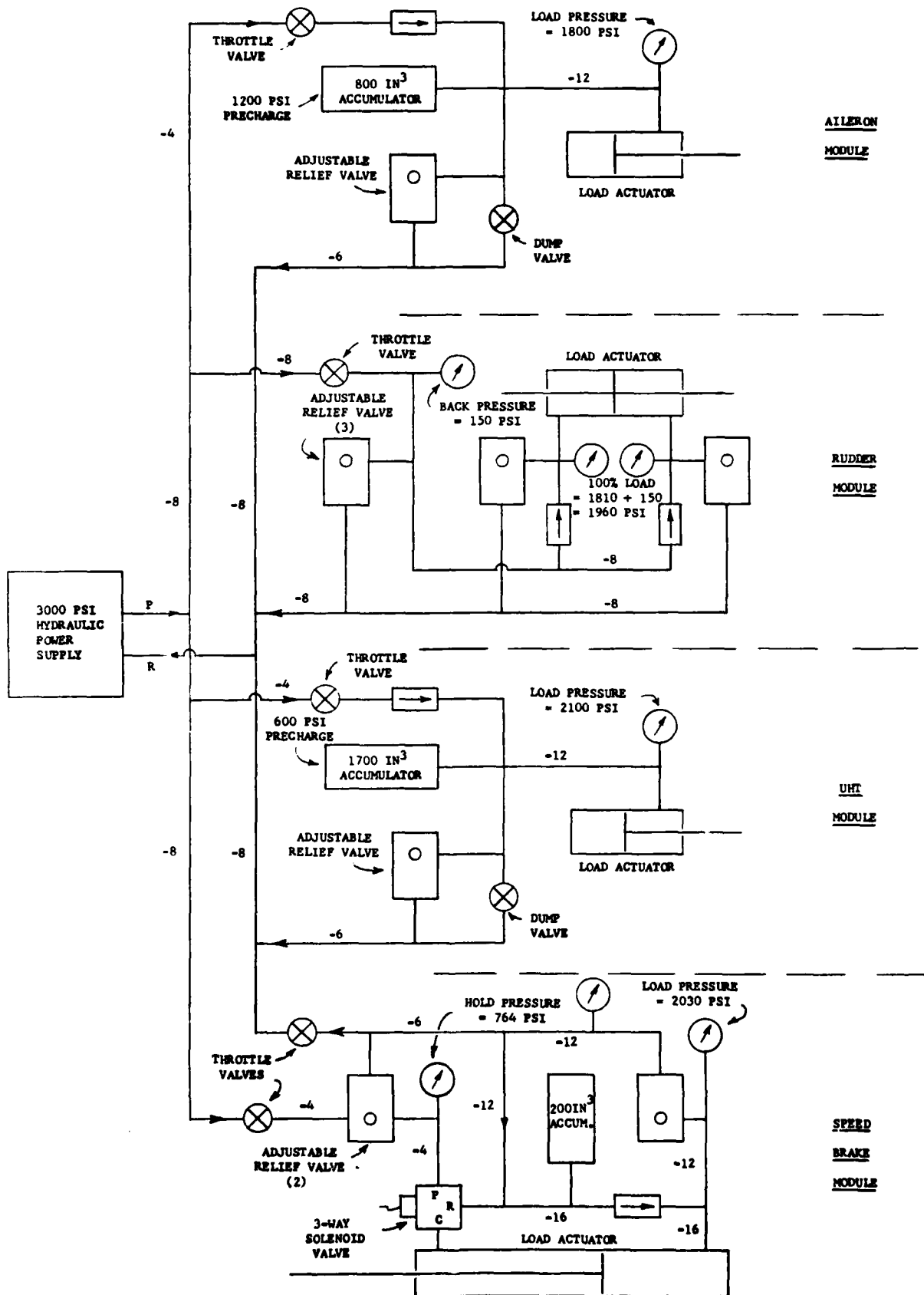


FIGURE 49. Hydraulic load system



H95-5800 FIGURE 50. Compatibility test instrumentation

TABLE 7. List of Instrumentation

| PARAMETER           | SYSTEM      | TRANSDUCER LOCATION         | TRANSDUCER TYPE              | RANGE                                                                                                                      | ACCURACY    | READOUT RESPONSE                                                     |
|---------------------|-------------|-----------------------------|------------------------------|----------------------------------------------------------------------------------------------------------------------------|-------------|----------------------------------------------------------------------|
| <u>Temperatures</u> |             |                             |                              |                                                                                                                            |             |                                                                      |
| T1                  | FC-1        | Reservoir Outlet            | Iron-Constantan thermocouple | -100 to +500°F                                                                                                             | ± 3°F       | Sixteen temperature printouts every 35 seconds (16 channel recorder) |
| T2                  | FC-1        | Pump Inlet                  |                              |                                                                                                                            |             |                                                                      |
| T3                  | FC-1        | Pump Outlet                 |                              |                                                                                                                            |             |                                                                      |
| T4                  | FC-1        | Pump Case Drain             |                              |                                                                                                                            |             |                                                                      |
| T5                  | FC-1        | Heat Exchanger Outlet       |                              |                                                                                                                            |             |                                                                      |
| T6                  | FC-2        | Reservoir Outlet            |                              |                                                                                                                            |             |                                                                      |
| T7                  | FC-2        | Pump Inlet                  |                              |                                                                                                                            |             |                                                                      |
| T8                  | FC-2        | Pump Outlet                 |                              |                                                                                                                            |             |                                                                      |
| T9                  | FC-2        | Pump Case Drain             |                              |                                                                                                                            |             |                                                                      |
| T10                 | FC-2        | Heat Exchanger Outlet       |                              |                                                                                                                            |             |                                                                      |
| T11                 | FC-2        | Rudder Actuator Return      |                              |                                                                                                                            |             |                                                                      |
| T12                 | FC-1        | UHT Actuator Return         |                              |                                                                                                                            |             |                                                                      |
| T13                 | FC-2        | AFCs Actuator Return        |                              |                                                                                                                            |             |                                                                      |
| T14                 | FC-2        | Alleron Actuator Return     |                              |                                                                                                                            |             |                                                                      |
| T15                 | FC-1        | Speed Brake Actuator Return |                              |                                                                                                                            |             |                                                                      |
| T16                 | --          | Ambient                     |                              |                                                                                                                            |             |                                                                      |
| <u>Pressures</u>    |             |                             |                              |                                                                                                                            |             |                                                                      |
| P1                  | FC-1        | Pump Inlet                  | Bonded strain gage bridge    | 0-500 psi<br>0-10,000 psi<br>0-500 psi<br>0-500 psi<br>0-10,000 psi<br>0-500 psi<br>0-2000 psi<br>0-2000 psi               | ± 2%        | 600 Hz (response limited by oscillograph galvanometers)              |
| P2                  | FC-1        | Pump Outlet                 |                              |                                                                                                                            |             |                                                                      |
| P3                  | FC-1        | Pump Case Drain             |                              |                                                                                                                            |             |                                                                      |
| P4                  | FC-2        | Pump Inlet                  |                              |                                                                                                                            |             |                                                                      |
| P5                  | FC-2        | Pump Outlet                 |                              |                                                                                                                            |             |                                                                      |
| P6                  | FC-2        | Pump Case Drain             |                              |                                                                                                                            |             |                                                                      |
| P7                  | FC-2        | Rudder Actuator Return      |                              |                                                                                                                            |             |                                                                      |
| P8                  | FC-1        | UHT Actuator Return         |                              |                                                                                                                            |             |                                                                      |
| P9                  | FC-1        | Pump Inlet                  | Dial pressure gage           | 0-200 psi<br>0-10,000 psi<br>0-600 psi<br>0-200 psi<br>0-10,000 psi<br>0-600 psi<br>0-5000 psi<br>0-2000 psi               | ± 3%        | Not applicable                                                       |
| P10                 | FC-1        | Pump Outlet                 |                              |                                                                                                                            |             |                                                                      |
| P11                 | FC-1        | Pump Case Drain             |                              |                                                                                                                            |             |                                                                      |
| P12                 | FC-2        | Pump Inlet                  |                              |                                                                                                                            |             |                                                                      |
| P13                 | FC-2        | Pump Outlet                 |                              |                                                                                                                            |             |                                                                      |
| P14                 | FC-2        | Pump Case Drain             |                              |                                                                                                                            |             |                                                                      |
| P15                 | --          | 3000 psi System Discharge   |                              |                                                                                                                            |             |                                                                      |
| P16                 | --          | 500 psi System Discharge    |                              |                                                                                                                            |             |                                                                      |
| <u>Flows</u>        |             |                             |                              |                                                                                                                            |             |                                                                      |
| F1                  | FC-1        | Pump Inlet                  | Turbine flowmeter            | 0.4 - 10 gpm<br>0.2 - 2.4 gpm<br>0.4 - 10 gpm<br>0.2 - 2.4 gpm<br>0.4 - 5 gpm<br>0.4 - 5 gpm<br>0.5 - 5 gpm<br>0.5 - 5 gpm | ± 1%        | Not applicable (readout is frequency count)                          |
| F2                  | FC-1        | Pump Case Drain             |                              |                                                                                                                            |             |                                                                      |
| F3                  | FC-2        | Pump Inlet                  |                              |                                                                                                                            |             |                                                                      |
| F4                  | FC-2        | Pump Case Drain             |                              |                                                                                                                            |             |                                                                      |
| F5                  | FC-2        | Rudder Actuator Return      |                              |                                                                                                                            |             |                                                                      |
| F6                  | FC-1        | UHT Actuator Return         |                              |                                                                                                                            |             |                                                                      |
| F7                  | FC-2        | Alleron Actuator Return     |                              |                                                                                                                            |             |                                                                      |
| F8                  | FC-1        | Speed Brake Actuator Return |                              |                                                                                                                            |             |                                                                      |
| <u>Speed</u>        |             |                             |                              |                                                                                                                            |             |                                                                      |
| S1                  | FC-1 & FC-2 | Pump Input Shaft            | Magnetic, Tachometer         | 1700 - 8000 rpm                                                                                                            | ± 3% (est.) | Not applicable                                                       |

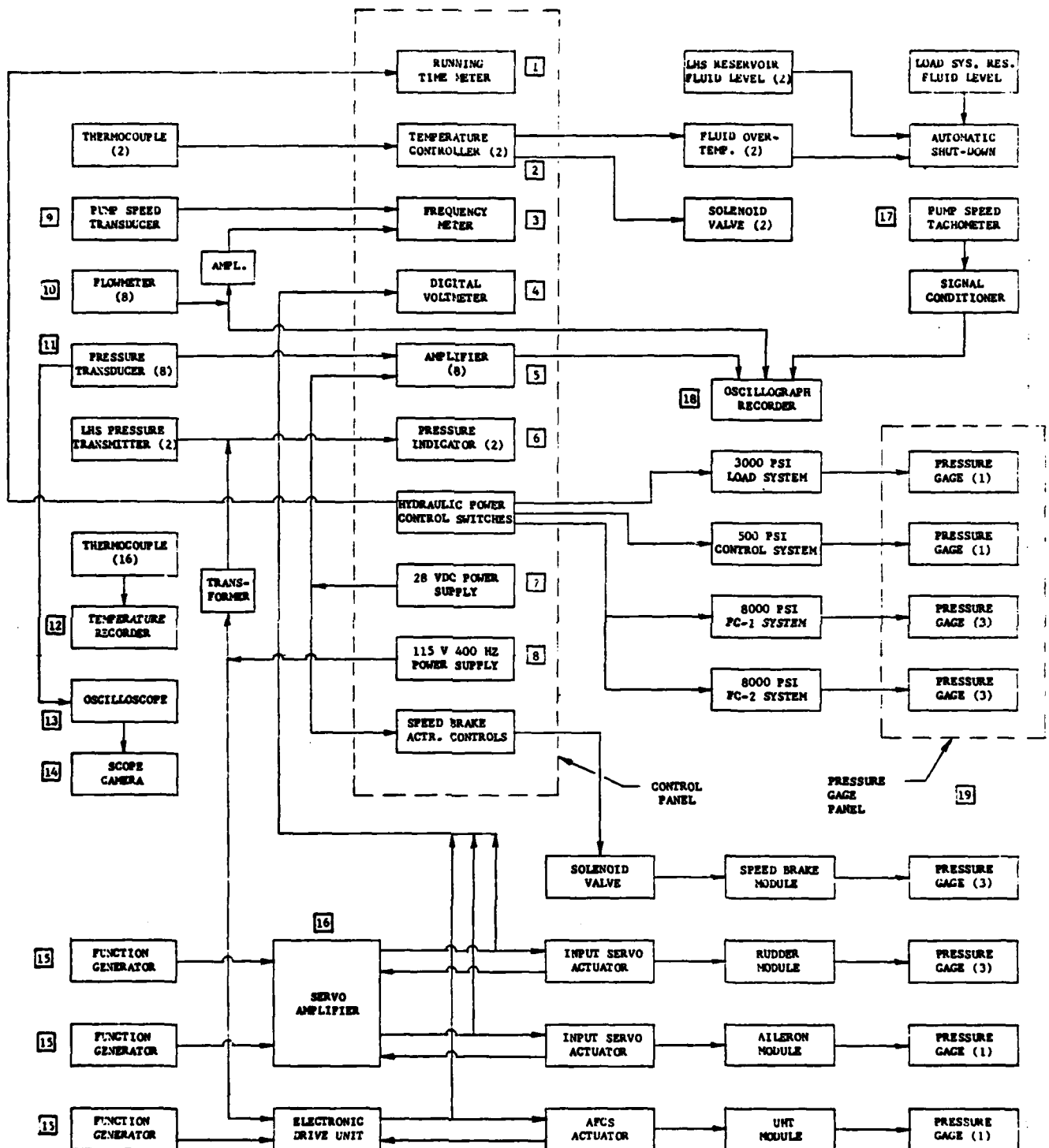


FIGURE 51. Instrumentation system

- 1 Running Time Meter, General Electric M/N 8KT 12DAB2
- 2 Temperature Controller, Love Controls M/N 56-848
- 3 Frequency Meter, Beckman M/N 6147
- 4 Digital Voltmeter, Dana M/N 5400
- 5 Amplifier, Viatran M/N 602
- 6 Pressure Indicator, MIL-I-25861, Vought P/N 218-21612
- 7 28 VDC Power Supply, Harrison Laboratories M/N 808A
- 8 115V 400 Hz Power Supply, Darcy/Behlman M/N 161A
- 9 Magnetic Pickup, Electro Products M/N 3010-AN
- 10 Turbine Flowmeter, Cox M/N 12SCRX, Waugh M/N FL-6S
- 11 Pressure Transducer, Viatran M/N 122EF76
- 12 Temperature Recorder, Brown Instruments  
M/N 153X(67)-P16H-II-III-(106)
- 13 Oscilloscope, Tektronix M/N 502A
- 14 Scope Camera, Hewlett Packard M/N 196A
- 15 Function Generator, Wavetek M/N 112
- 16 Servo Amplifier, Donner M/N 3500
- 17 Tachometer, Weston M/N 75B
- 18 Oscillograph, Minneapolis-Honeywell M/N 1108
- 19 Pressure Gages, Duragage, U.S. Gage, Ashcroft, Crosby

Figure 51. Instrumentation System (Continued)

TABLE 8. Actuator Cycling Sequences

| Sequence Step No.                             | Load/<br>Stroke                                                                                                                                                                                        | Pump<br>RPM                                                  | Pump Inlet<br>Fluid Temp. |
|-----------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|---------------------------|
| 1-1<br>-2<br>-3<br>-4<br>-5<br>-6<br>-7<br>-8 | 2%<br>2%<br>2%<br>2%<br>10%<br>2%<br>2%<br>2%                                                                                                                                                          | 3400<br>5900<br>5900<br>5900<br>5900<br>3400<br>3400<br>3400 | +180°F                    |
| 2-1<br>-2<br>-3<br>-4<br>-5<br>-6<br>-7       | 2%<br>10%<br>10%<br>10%<br>10%<br>10%<br>2%                                                                                                                                                            | 3400<br>5900<br>5900<br>5900<br>5900<br>5900<br>3400         | +200°F                    |
| 3,4,5-1<br>-2<br>-3<br>-4<br>-5<br>-6<br>-7   | 10%<br>50%<br>50%<br>50%<br>50%<br>50%<br>10%                                                                                                                                                          | 3400<br>5900<br>5900<br>5900<br>5900<br>5900<br>3400         | +200°F                    |
| 6,7-1<br>-2<br>-3<br>-4<br>-5<br>-6<br>-7     | <u>UHT</u> <u>RUD</u> <u>AIL</u><br>2%      2%      2%<br>100%      2%      2%<br>100%      2%      2%<br>2%      100%      2%<br>2%      100%      2%<br>2%      2%      100%<br>2%      2%      100% | 3400<br>5900<br>5900<br>5900<br>5900<br>5900<br>5900         | +180°F                    |

NOTE: 3400 RPM = Engine Idle  
5900 RPM = Engine Military Rated Thrust

TABLE 9. Cycling Sequence Summary

| Sequence Number                              | Duration, Hours/50 Hour Block<br>Load/Stroke Magnitude                                                                       |             |             |                |
|----------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|-------------|-------------|----------------|
|                                              | 2%                                                                                                                           | 10%         | 50%         | 100%           |
| 1-                                           | 7                                                                                                                            | 1           |             |                |
| 2-                                           | 2                                                                                                                            | 5           |             |                |
| 3-                                           |                                                                                                                              | 2           | 5           |                |
| 4-                                           |                                                                                                                              | 2           | 5           |                |
| 5-                                           |                                                                                                                              | 2           | 5           |                |
| 6-                                           | 5                                                                                                                            |             |             | 2              |
| 7-                                           | <u>5</u>                                                                                                                     | <u>    </u> | <u>    </u> | <u>2</u>       |
| TOTALS                                       | 19                                                                                                                           | + 12        | + 15        | + 4 = 50 hours |
| Cycling rate, cpm                            | 186                                                                                                                          | 56          | 15          | 11             |
| Total number of cycles in 50 hour block      | 212,000 + 40,300 + 13,500 + 2600 = 268,000 cycles/50 hr.                                                                     |             |             |                |
| Total number of cycles in compatibility test | 636,000 + 121,000 + 40,000 + 7800 = 800,000 NAAD cycles<br>+ 200,000 Vought cycles<br><hr/> 1,000,000 Total cycles completed |             |             |                |

- NOTES:
1. Load/stroke sequencing applies to UHT, rudder, and aileron actuators.
  2. Speed brake actuator cycled at 100% load and stroke at 1 cpm during third 50 hour block.  
 Total number of speed brake cycles: 3200 NAAD cycles  
 800 Vought cycles  
 4000 Total cycles completed

TABLE 10. Actuator Loads And Strokes

| Load/Stroke<br>Magnitude | Maximum Load, lb.            |          |          |                         |
|--------------------------|------------------------------|----------|----------|-------------------------|
|                          | UHT                          | Rudder   | Aileron  | Speed Brake             |
| 2%                       | 500 C (E)<br>500 T (R)       | 140 C&T  | 130 C&T  | N/A                     |
| 10%                      | 1400 C (E)<br>2700 T (R)     | 690 C&T  | 660 C&T  | N/A                     |
| 50%                      | 7,000 C (E)<br>13,400 T (R)  | 3450 C&T | 3320 C&T | N/A                     |
| 100%                     | 13,900 C (E)<br>26,800 T (R) | 6900 C&T | 6650 C&T | 40,000 C (E)<br>0 T (R) |
| <u>Total Stroke, in.</u> |                              |          |          |                         |
| 2%                       | 0.12                         | +0.03    | +0.05    | N/A                     |
| 10%                      | 0.56                         | +0.15    | +0.25    | N/A                     |
| 50%                      | 2.86                         | +0.74    | +1.25    | N/A                     |
| 100%                     | 5.72                         | +1.47    | +2.50    | 19.94                   |

NOTE: C = Compression  
T = Tension  
E = Extending  
R = Retracting  
N/A = Not Applicable

#### 5.3.4.2 Data

Laboratory notebooks were maintained to record and date all test activities including:

- Descriptions such as setup photographs, support equipment identification, test component part numbers, wiring diagrams
- Maintenance actions such as greasing bearings, tightening bolts, repairing test equipment
- Test actions such as making fluid patches, adding fluid to test system, fixing leaks, changing filter elements
- Test problems such as component malfunctions, failures, and removals
- Test results such as raw data and performance observations.

A test log sheet was used on which 13 parameters were recorded every 15 minutes of each sequence step: T2, T4, T7, T9, P10, P13, P14, F1, F2, F3, F4, and S1 (reference Table 7). Pertinent test actions were also recorded on the log sheet. Date, time of day, sequence step, and cycling time were an integral part of the record.

5.3.4.3 Startup - A detail startup plan was prepared to insure that test components were not accidentally damaged due to improper rigging, faulty hydraulic connections, fluid contamination, or incorrect operating procedure.

Actuator Rigging - The rudder and aileron input control actuators were operated and adjusted so that stroke lengths coincided with the test actuator stroke requirements. The AFCS actuator was operated, using a small portable hydraulic power supply, to check out the torque motor and electronic drive unit (reference paragraph 3.1.2). Control linkage between the AFCS and UHT actuators was then adjusted so that the electrical and mechanical nulls of the AFCS actuator coincided with the output null position of the UHT actuator. No rigging was required for the speed brake actuator.

System Fill - FC-1 and FC-2 were pressure filled with MIL-H-83282 fluid through the fill fittings and bled at numerous locations in both systems. The volume of fluid put in each system was recorded. A 3000 psi laboratory pump was installed in each system (in place of the 8000 psi test pumps). The 3000 psi pumps were run at low speeds and pressures and the two systems were checked for leaks. All test actuators were slowly cycled full stroke. Pressure was then increased to 3000 psi and the systems checked for satisfactory operation.

Proof Test - All components--filters, check valves, relief valves, quick disconnects, pressure transmitters, actuators, etc.--were removed; only tubing and fittings were proofed. Where necessary, temporary tube assemblies were installed to replace missing components. Each system (FC-1 and FC-2) was proof tested individually; all plumbing in each system was proofed simultaneously. A hand pump was used to apply pressure. For safety, an extension tube was employed to permit the hand pump to be located in an adjacent room. The proof test consisted of applying 16,000 psi for 2 minutes, releasing the pressure, and re-applying 16,000 psi for 2 minutes.

Fluid Cleanup - FC-1 and FC-2 systems were operated at 3000 psi, using the laboratory pumps, with the test actuators cycling full stroke slowly. The systems were run continuously for two hours after which fluid samples were taken for contamination checks. Fluid cleanup was completed when the contamination level was Class 8 (NAS 1638) or better.

System Stability - The system was operated at a low pressure level using the 8000 psi test pumps. This was done by opening a needle valve installed in each power module. With all actuators at null or off and the pumps running at 1800 rpm, the pressure in FC-1 was slowly increased to 8000 psi by closing the needle valve; the needle valve in FC-2 was then closed slowly. When it was clear that FC-1 and FC-2 were operating satisfactorily, pump speed was slowly increased to 5900 rpm in a preliminary search for hydraulic resonance and instabilities based on audible observations.

Temperature Control - FC-1 and FC-2 modules each had an oil-to-water heat exchanger, water solenoid valve, and automatic electrical controls to maintain desired fluid temperature levels. The operation of this equipment was checked by setting the controllers for +180°F, running FC-1 and FC-2 at 8000 psi, and observing system temperatures on the temperature recorder.

5.3.4.4 Performance Checks - Component performance checks were made at 0, 50, 100, and 150 hours.

Pump - Pump testing was conducted on a setup with instrumentation which provided the following data: (See Reference 5 for setup details.)

Steady-State Tests:

Pump speed  
Input torque  
Pressure: inlet, discharge, case  
Fluid Temp.: inlet, discharge, case  
Flow: case, discharge (measured at return pressure)

Dynamic Tests:

Pressure: peak, ripple  
Transient response time

Overall efficiency and heat rejection were determined for the following operating conditions:

|                    |          |
|--------------------|----------|
| Pump speed:        | 5900 rpm |
| Inlet fluid temp.: | +200°F   |
| Inlet pressure:    | 70 psig  |
| Case pressure:     | 120 psig |

The transient tests were run using a fast operating solenoid valve to cycle discharge flow from 5% to 90% to 5% of maximum flow. Pressure transients and pump ripple were observed on an oscilloscope and recorded photographically. Pressure system volume was approximately 125 in<sup>3</sup>.

Actuators - Aileron, rudder, and UHT actuator control valve null leakage and piston rod seal leakage were determined. Null leakage was measured at room temperature with 8000 psi applied. Leakage was collected in a graduate from open return ports (FC-1 and FC-2). Rod seal leakage was caught during endurance cycling in a small container placed under each actuator. The accumulated leakage was then measured in drops using an eye dropper.

Filters - Patch tests were run on the pressure, return, and pump case drain filters in each system (FC-1 and FC-2). The procedure consisted of: 1) flushing the outer surface of a filter element with petroleum solvent and passing the effluent through an 0.5 micron filter patch; and 2) passing the MIL-H-83282 fluid and debris in the filter bowl through the same filter patch. Each of the six patches were then examined for types and concentration of particles collected.

Fluid - Hydraulic fluid was taken from a sampling valve located in the return section of each power module. A sample consisted of approximately 200 cc of fluid collected in a specially cleaned sample jar. Care was exercised to minimize introduction of foreign contaminants when the sample was taken. The sealed jars were then allowed to set for a minimum of 24 hours to allow dissolved air to escape. Particulate contamination was then determined using a Hiac automatic particle counter M/N PC204. Fluid from each contamination check was saved and used for determination of kinematic viscosity. This was done at +100°F using a standard viscometer.

Relief Valve - Relief valve cracking pressure, reseal pressure, and internal leakage were determined. The valve was installed in a setup powered by Abex pump M/N AP6V-57. This pump has a pressure compensator with an adjustment range up to 9200 psi. A flowmeter was placed in the relief valve return line. With the pump compensator adjusted to its maximum setting and the pump operating, pressure on the relief valve was slowly increased above 8000 psi by closing a system needle valve. Cracking pressure was recorded when flow was sensed by the flowmeter. Pressure was increased until the relief valve was full open, then decreased until return flow was zero and reseal pressure was recorded. This procedure was repeated several

times to obtain average values for cracking and reseal pressure. Internal leakage was determined at room temperature with 8000 psi on the valve and the return port open. Leakage was measured after waiting 3 minutes for the rate to stabilize.

Restrictor - Flow was determined with a differential pressure of 7800 psi applied across the restrictor. Flow at return pressure was measured for both flow directions. Compressed flow at 7800 psi was calculated using inlet and outlet fluid temperatures and pressures and fluid density curves, Reference 17.

### 5.3.5 Test Notes

The compatibility test was originally scheduled to begin in March 1980 following completion of the LHS component endurance and pressure impulse tests. Delivery of several important LHS components were delayed because of development and manufacturing problems. These delays affected the LHS test schedule and test procedures. The following sections present information relative to these delays and the changes in test procedure necessitated by the delays. Compatibility test cycling was begun 27 August 1980 and completed 10 November 1980. Pressure impulse and component endurance testing was begun 26 November 1980 and completed 16 January 1981.

5.3.5.1 LHS Pump - Minor difficulties usually accompany the first-time fabrication of any new pump design. Tolerances, materials processing, quality control, etc., can cause problems; design modifications often cause delays. Development of the LHS pump was typical of conventional designs; the units functioned well, but there were several performance areas which could be improved with design changes. To avoid undue delays in the LHS program schedule, the compatibility test was begun using "interim pumps". These units had higher than desired heat rejection and excessive pressure droop. The LHS pumps to be used on the ground simulator in Phase II are expected to meet all performance requirements.

The compatibility test was stopped 3 times because of "interim pump" problems. In order to avoid further delays in the LHS program, a decision was made at the 102.7 hour point to complete the compatibility test using two backup pumps. These units, built by Abex Corporation, were evaluated in the LHS Exploratory Development Program reported in References 1 through 7. The Abex pump is shown on Figure 23.

5.3.5.2 LHS Actuator - The AFCS actuator has two parallel cylinders with pistons moving in opposite directions. Each piston has an LVDT feedback pot. Since there was only one control valve, reference section 3.1.2, only one feedback loop could be used. In order to provide smooth operation, #2 cylinder in the AFCS actuator was employed to drive the UHT actuator input linkage; #1 cylinder was pressurized but was not cycled during the compatibility test.

5.3.5.3 LHS Hose - Fabrication of the LHS hose was delayed because of manufacturing problems. Titeflex Corporation therefore provided "interim hoses" for use at the pumps in the compatibility test. These units were satisfactory strength-wise but were heavier than the anticipated weight of the LHS hose. The LHS hoses, -8 size x 30 in. long, were delivered in December 1980.

5.3.5.4 LHS 4-Way Solenoid Valve - This valve is used to control the speed brake actuator. Delivery was delayed because of manufacturing problems, and the compatibility test was begun without it. The required 3200 speed brake cycles were to be run later using an accelerated cycling schedule. The valve was received 20 October 1980, and installed on FC-1 power module just prior to the start of the third 50 hour test block. The valve operated the speed brake satisfactorily for 1049 cycles at which time it ceased to function. The unit was returned to the supplier for failure analysis. To avoid further delays and to complete the cycling requirements of the speed brake actuator, two 3-way valves were installed on FC-1 power module to replace the 4-way valve. The 3-way valves, manufactured by Sterer Engineering and Manufacturing Company, were evaluated in the LHS Exploratory Development Program reported in References 1 through 7.

5.3.5.5 LHS Fittings - Permanent type fittings used were manufactured by Deutsch and Raychem; separable fittings were Dynatube (Resistoflex) and Permaswage (Deutsch). Tooling is required to swage the Dynatube and Deutsch fittings onto tubing. Fitting sizes to be swaged were -3 (3/16 in. tube O.D.) and -8 (1/2 in. tube O.D.). No -4, -5, or -6 size tubing are used in the pressure systems on FC-1 and FC-2 power modules. All -4 and -6 size tubing used to connect the power modules with the load modules were fabricated with MS flareless type fittings. No -5 size tubing was procured.

Tooling for -3 size Dynatube fittings was not available when the compatibility test setup was fabricated because of development problems. To avoid delays, Raychem shrink-fit couplings (P/N 3P00101-3) were used to attach specially machined Dynatube fittings (P/N R44296T-03) to the -3 size tubing. This approach permitted evaluation of an excellent alternative should -3 size Dynatube tooling prove to be impractical. Tooling for -3 size Dynatube fittings was delivered 30 September 1980. Evaluation of this tooling will be made in Phase II.

The rudder module has -3 size plumbing. Since the rudder actuator was tested before the -3 tooling problem was resolved, a different style -3 Dynatube fitting was employed--butt-welded fittings used in the LHS Exploratory Development Program, Reference 6. Four of these fittings were employed on the rudder module.

5.3.5.6 LHS Fluid - The shear stability of MIL-H-83282 was planned to be evaluated during the compatibility test. As testing progressed, it became apparent the evaluation would not be completely valid because of the quantities of fluid which were periodically removed from FC-1 and FC-2 for filter patches, fluid contamination checks, component removals, etc.

| <u>Description</u>                        | <u>Total Fluid Removed During<br/>Compatibility Test, cc</u> |
|-------------------------------------------|--------------------------------------------------------------|
| Filter patch tests                        | 2600                                                         |
| Fluid contamination/<br>viscosity samples | 3200                                                         |
| Pump changes                              | 2000                                                         |
| FC-2 weekend leak                         | 1800                                                         |
| Component installations/<br>removals      | 10,000+                                                      |

System fluid levels were replenished with new MIL-H-83282. Since both systems were periodically diluted with new fluid to maintain proper reservoir fill levels, fluid circulation cycles were reduced significantly from what would have occurred if the original fluid volume could have been maintained.

#### 5.3.6 Test Results

5.3.6.1 LHS Pump - Interim pump performance at the beginning of the compatibility test is shown on Figure 52. Discharge flow was satisfactory except that flow cut-off was too gradual (excessive pressure droop). Flow cut-off from 10 gpm to 0.5 gpm is required to occur between 7700 and 8000 psi discharge pressure (300 psi droop). FC-1 pump droop was 700 psi; FC-2 was 550 psi. Revised pump timing and increased yoke moment should reduce the droop.

Maximum heat rejection of FC-1 pump was 390 BTU/min.; FC-2 pump had 615 BTU/min. The design goal was 300 BTU/min. maximum. Principal causes of the high heat rejection were distortion in the aluminum valve block and excessive piston-to-bore clearance. These are both correctable conditions.

Maximum overall efficiency of FC-1 and FC-2 pumps was approximately 85% and 80%, respectively. The design goal was 85% minimum. Improved heat rejection should increase overall efficiency to more acceptable levels.

Pump ripple and transient response are shown on Figure 53; both were satisfactory. FC-1 pump ripple was  $\pm 160$  psi; FC-2 was  $\pm 204$  psi. The design goal was  $\pm 200$  psi maximum. Transient response times were:

| <u>Pump</u> | <u>Condition</u> | <u>Observed Time, sec.</u> |       | <u>Max. Allowable Time, sec.</u> |
|-------------|------------------|----------------------------|-------|----------------------------------|
| FC-1        | 90% to 5% flow   | T <sub>1</sub>             | 0.022 | 0.050                            |
|             | 5% to 90% flow   | T <sub>2</sub>             | 0.030 | 0.050                            |
|             | Stability        | T <sub>S</sub>             | 0.207 | 1.00                             |
| FC-2        | 90% to 5% flow   | T <sub>1</sub>             | 0.020 | 0.050                            |
|             | 5% to 90% flow   | T <sub>2</sub>             | 0.027 | 0.050                            |
|             | Stability        | T <sub>S</sub>             | 0.237 | 1.00                             |

Pump performance data at 50 hours are listed on Table 11; data at 0 hours are shown for comparison. During transient response testing at 50 hours, FC-1 pump case flow suddenly increased to more than 3 gpm. The pump was returned to Sperry-Vickers for disassembly and examination. Part of one piston shoe was found to be missing. The cause was determined to be brazing voids—a quality control problem. (The possibility existed that this condition was also present to some degree in FC-2 pump.) Wear on parts in the FC-1 unit was observed during the tear-down. Maximum wear normally occurs on the porting plate interface, piston/bore interfaces, and piston shoes. No unusual wear was observed in any of these areas.

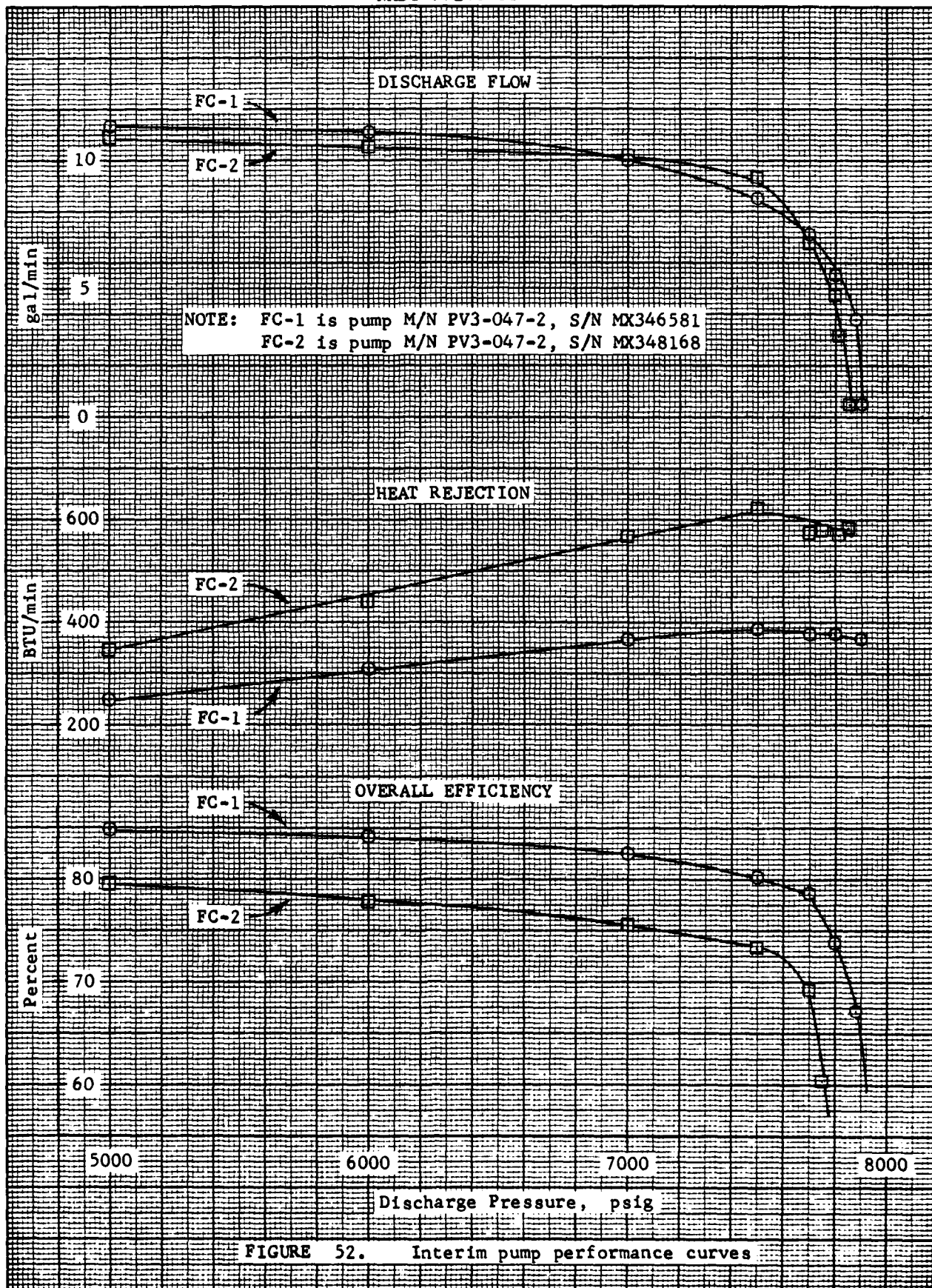
FC-1 pump was repaired and returned to NAAD-Columbus, and the second 50 hour block of hours was begun. A pin hole leak developed in the aluminum valve block of FC-1 pump at 56.2 hours, and the unit was again returned to Sperry-Vickers for disassembly and repair. Steel valve blocks were planned to be used on the LHS pumps but were not yet available for installation, so the "interim pump" was reassembled using an aluminum valve block from a development pump.

Pump performance data were not taken at the 100 hour check point since pump modifications were planned. At 102.7 hours, FC-2 pump developed an external leak in the control pressure porting section of the aluminum valve block. Erosion pitting occurred in a static seal gland bore surface, causing the seal to fail. FC-1 and FC-2 pumps were both returned to the supplier for examination and modification. The 150 hour compatibility test was completed using two backup pumps, Abex M/N AP6V-57, developed for the LHS Exploratory Development Program, Reference 2. No performance data was taken on the Abex units.

5.3.6.2 LHS Actuators - Actuator control valve null leakage and rod seal leakage are given on Table 12. Null leakage of all actuators was less than the maximum allowable 120 cc/min. (0.15 hp loss). Rod seal leakage of all actuators was less than the maximum allowable 1 drop/25 cycles (MIL-C-5503 requirement).

A significant quantity of black colored wear debris accumulated on the UHT actuator piston rod and at the mid-actuator vent hole during the course of the 150 hour test. The debris was believed to be the result of wear on the second stage backup rings; no excessive leakage was observed at any time. No unusual quantities of wear debris were observed on the rudder or aileron piston rods. The source of the black wear debris will be determined when the UHT actuator is disassembled.

The rudder actuator did not perform satisfactorily when first received for acceptance testing. The control valve tended to stick when allowed to remain at one position for a short time; null leakage was nearly zero with 8000 psi applied. The sticking was eliminated by honing the inside diameter of the control valve sleeve. The UHT actuator control valve also tended to stick, but not as severely as the rudder valve. The UHT control valve was not reworked prior to the compatibility test. Valve sticking generally occurred during startups and null leakage measurements, but was not a problem during test cycling. Sticking was not observed in the aileron control valve.



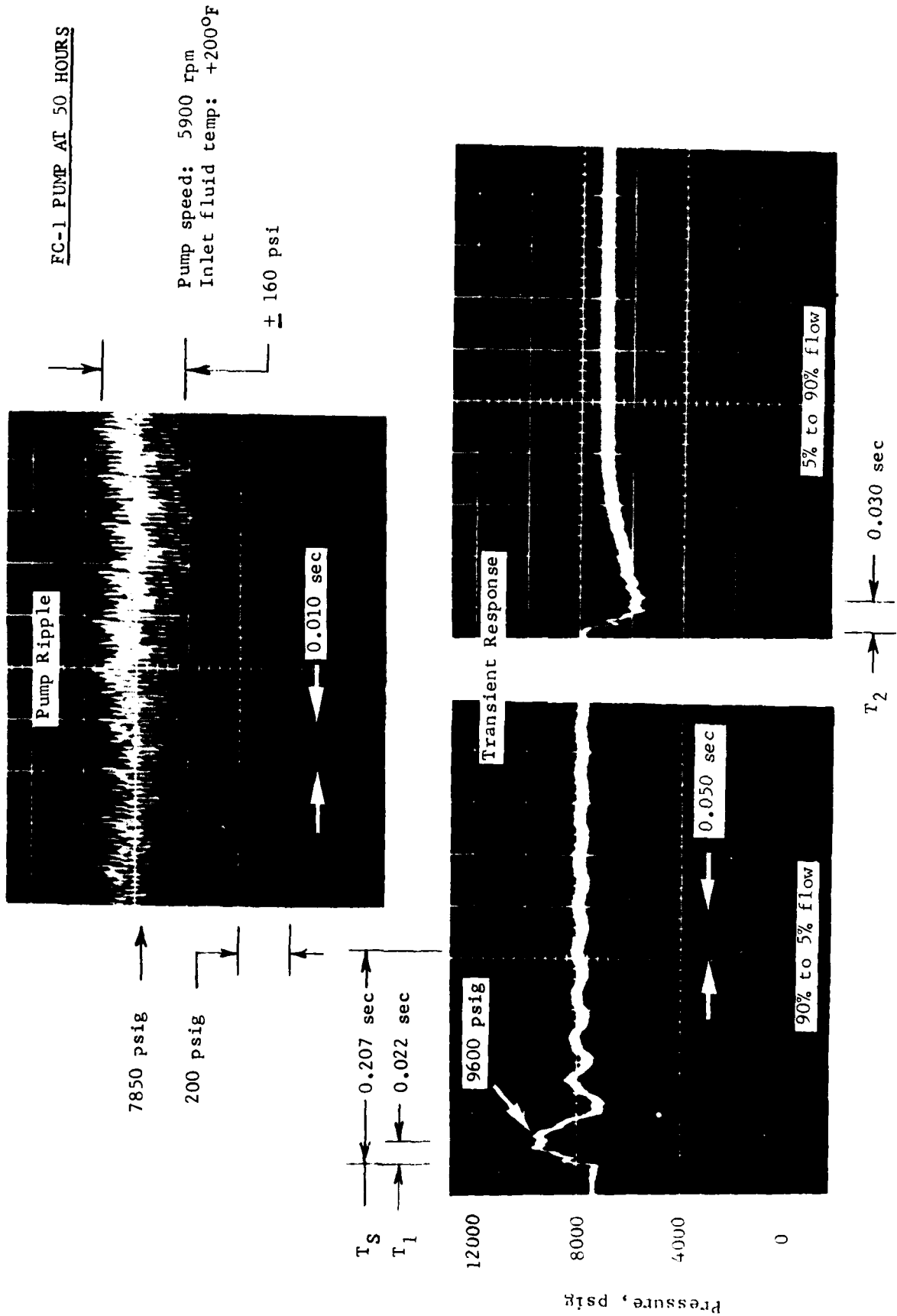


FIGURE 53. Interim pump ripple and transient response

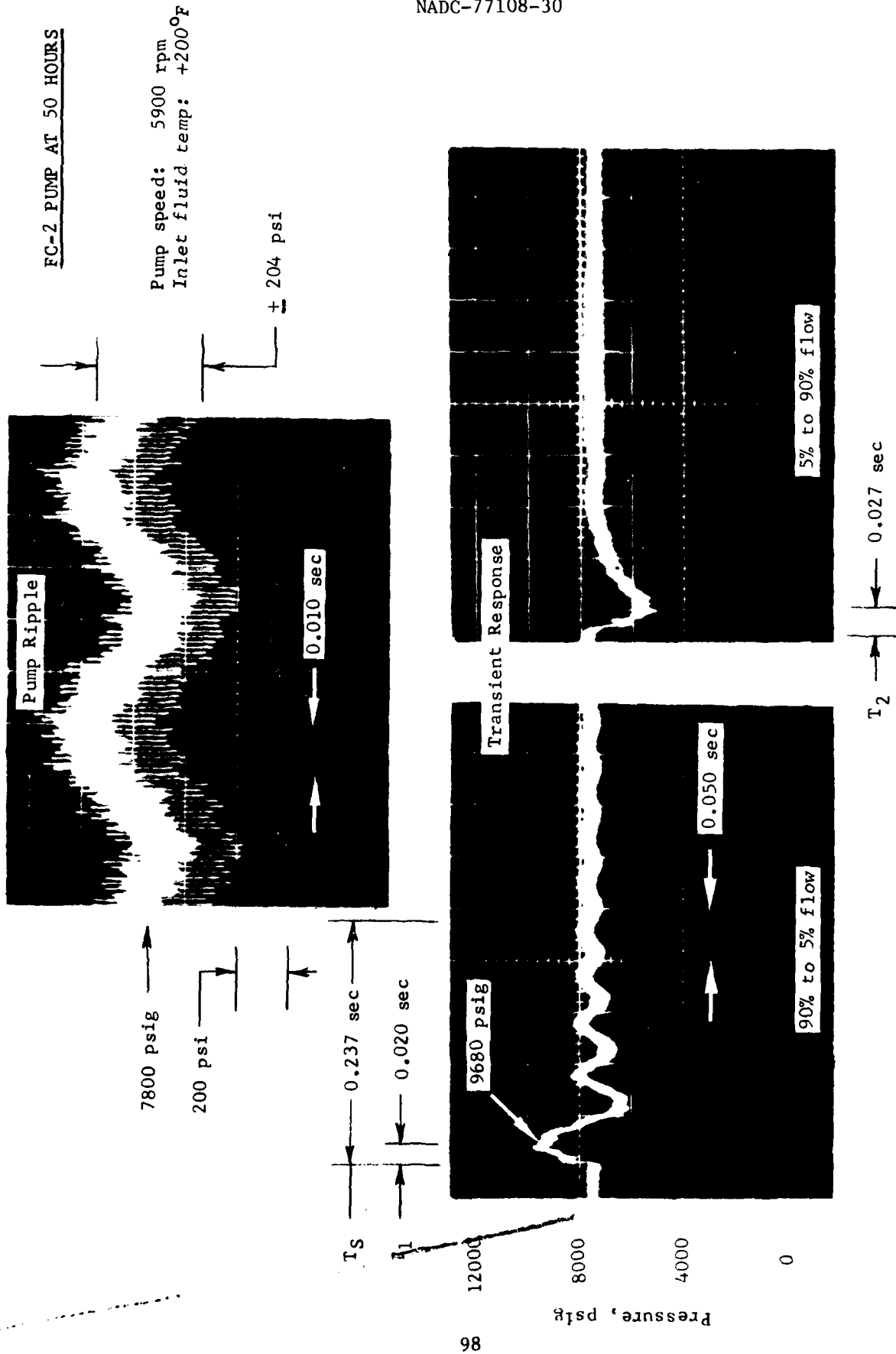


FIGURE 53. (Continued)

TABLE 11. Pump Performance Comparisons

| Pump                  | Pump Speed, RPM | Inlet Press., PSIG | Case Press., PSIG | Inlet Temp., °F | Disch. Press., PSI | Case Drain Temp., °F |        | Case Drain Flow, GPM |        | Disch. Flow, GPM |        | Input Torque, Lb-In |        | Heat Rej. BTU/Min. |        | Overall Efficiency, % |        |
|-----------------------|-----------------|--------------------|-------------------|-----------------|--------------------|----------------------|--------|----------------------|--------|------------------|--------|---------------------|--------|--------------------|--------|-----------------------|--------|
|                       |                 |                    |                   |                 |                    | 0 Hr.                | 50 Hr. | 0 Hr.                | 50 Hr. | 0 Hr.            | 50 Hr. | 0 Hr.               | 50 Hr. | 0 Hr.              | 50 Hr. | 0 Hr.                 | 50 Hr. |
| FC-1<br>S/N<br>346381 | 5900            | 70                 | 120               | +200            | 4000               | 248                  | 248    | .06                  | .77    | 11.59            | 11.13  | 339                 | 335    | 199                | 248    | 85.2                  | 81.3   |
|                       |                 |                    |                   |                 | 5000               | 250                  | 247    | .21                  | 1.08   | 11.37            | 10.71  | 417                 | 409    | 249                | 318    | 84.9                  | 80.4   |
|                       |                 |                    |                   |                 | 6000               | 254                  | 251    | .36                  | 1.39   | 11.11            | 10.14  | 493                 | 486    | 309                | 442    | 84.2                  | 77.1   |
|                       |                 |                    |                   |                 | 7000               | 258                  | 255    | .51                  | 1.64   | 9.99             | 9.32   | 528                 | 536    | 367                | 531    | 82.5                  | 75.1   |
|                       |                 |                    |                   |                 | 7500               | 260                  | 258    | .64                  | 1.82   | 8.51             | 8.79   | 495                 | 553    | 387                | 580    | 80.3                  | 73.6   |
|                       |                 |                    |                   |                 | 7700               | 259                  | 259    | .72                  | 1.86   | 7.21             | 8.54   | 440                 | 562    | 374                | 619    | 78.6                  | 72.2   |
|                       |                 |                    |                   |                 | 7800               | 259                  | 259    | .78                  | 1.94   | 5.49             | 7.90   | 362                 | 537    | 378                | 622    | 73.7                  | 70.8   |
|                       |                 |                    |                   |                 | 7850               | 259                  | 260    | .80                  | 1.99   | 3.80             | 7.33   | 278                 | 511    | 363                | 619    | 67.1                  | 69.5   |
|                       |                 |                    |                   |                 | 7880               | 259                  | 260    | .89                  | 2.06   | .46              | 6.46   | 115                 | 470    | 367                | 614    | 67.1                  | 67.1   |
|                       |                 |                    |                   |                 | 7900               | 273                  | 261    |                      | 2.20   | .47              |        |                     | 165    |                    | 563    | 19.7                  | 14.0   |
| FC-2<br>S/N<br>348168 | 5900            | 70                 | 120               | +200            | 4000               | 243                  | 243    | .37                  | .69    | 11.34            | 10.98  | 348                 | 344    | 279                | 298    | 79.8                  | 78.2   |
|                       |                 |                    |                   |                 | 5000               | 253                  | 251    | .56                  | .90    | 10.90            | 10.61  | 421                 | 419    | 343                | 370    | 79.5                  | 77.8   |
|                       |                 |                    |                   |                 | 6000               | 260                  | 254    | .78                  | 1.15   | 10.53            | 10.24  | 500                 | 497    | 440                | 471    | 77.8                  | 76.1   |
|                       |                 |                    |                   |                 | 7000               | 264                  | 257    | 1.02                 | 1.45   | 10.18            | 9.82   | 582                 | 576    | 566                | 604    | 75.5                  | 73.6   |
|                       |                 |                    |                   |                 | 7500               | 268                  | 260    | 1.17                 | 1.61   | 9.29             | 9.37   | 587                 | 602    | 623                | 668    | 73.2                  | 72.0   |
|                       |                 |                    |                   |                 | 7700               | 268                  | 265    | 1.38                 | 1.83   | 6.76             | 6.10   | 465                 | 450    | 571                | 636    | 69.1                  | 64.4   |
|                       |                 |                    |                   |                 | 7750               | 271                  | 265    | 1.50                 | 1.93   | 4.70             | 4.30   | 373                 | 370    | 588                | 652    | 60.3                  | 55.6   |
|                       |                 |                    |                   |                 | 7800               | 273                  | 267    | 2.04                 | 2.04   | 3.16             | 2.02   | 296                 | 258    | 570                | 638    | 51.5                  | 37.7   |
|                       |                 |                    |                   |                 | 7810               | 273                  | 271    | 1.60                 | 2.16   | .41              | .47    | 167                 | 177    | 584                | 613    | 51.5                  | 12.8   |
|                       |                 |                    |                   |                 | 7820               | 277                  |        | 1.75                 |        |                  |        |                     |        |                    |        | 11.9                  |        |
|                       |                 |                    |                   |                 | 7850               |                      |        |                      |        |                  |        |                     |        |                    |        |                       |        |

Table 12. Actuator Performance Summary

| <u>*Control Valve Null Leakage, cc/min.</u> |             |             |               |             |                |             |
|---------------------------------------------|-------------|-------------|---------------|-------------|----------------|-------------|
| <u>Test Hours</u>                           | <u>UHT</u>  |             | <u>Rudder</u> |             | <u>Aileron</u> |             |
|                                             | <u>FC-1</u> | <u>FC-2</u> | <u>FC-1</u>   | <u>FC-2</u> | <u>FC-1</u>    | <u>FC-2</u> |
| 0                                           | 16          | 30          | 21.5          | 35.5        | 4.6            | 9.2         |
| 50                                          | 4.1         | 17          | 15.5          | 33          | 4.9            | 47          |
| 100                                         | 8.5         | 17.2        | 9.6           | 32          | 2.5            | 19          |
| 150                                         | 9.2         | 10.8        | 3.8           | 25.2        | 11.0           | 53          |

| <u>**Rod Seal Leakage, cycles/drop</u> |            |               |                |
|----------------------------------------|------------|---------------|----------------|
| <u>Test Hours</u>                      | <u>UHT</u> | <u>Rudder</u> | <u>Aileron</u> |
| 0                                      | -          | -             | -              |
| 50                                     | 786        | 17,867        | 2602           |
| 100                                    | 1418       | 6700          | 3229           |
| 150                                    | 2414       | 44,667        | 2436           |

\*Leakage measured at room temperature with 8000 psi applied pressure. Maximum allowable leakage = 120 cc/min.

\*\*Leakage collected in small container under actuator and measured with eye dropper. Maximum allowable leakage = one drop/25 cycles.

The AFCS actuator developed rough operation at 128 hours (676,200 cycles). Since only cylinder #2 was being used, it was disconnected and cylinder #1 was plumbed to the control valve (see section 5.3.5.2). This permitted UHT actuator cycling to continue without serious delay. The cause of the rough operation will be determined when the AFCS actuator is disassembled.

#### 5.3.6.3 LHS Filters - Six filters were evaluated:

|               |                                 |
|---------------|---------------------------------|
| FC-1 and FC-2 | System Pressure (LHS filters)   |
| FC-1 and FC-2 | System Return (Std. A/C design) |
| FC-1 and FC-2 | Pump Case Drain (A-7E filters)  |

All elements had 5 micron absolute filtration ratings. The system pressure and pump case drain housings had  $\Delta P$  buttons to indicate filter element condition. As shown on Table 13, the filters maintained system cleanliness at a Class 8 (NAS 1638) level or better. Relatively few circulating particles were larger than 15 microns in size. Filter patches taken at the 150 hour point are shown on Figure 54. These are typical of other patches taken periodically throughout the test. Large quantities of extremely small black particles were present on all patches. In addition, the pressure filter patches usually had a small number of tiny metallic particles; the return filter patches had normal quantities of seal wear debris and miscellaneous metallic particles; and the case drain filter patches had typical pump wear particles.

The small black particles loaded the pump case drain filter elements such that it was necessary to change these elements four times during the test as shown on Table 14. The pressure and return filter elements had a larger contaminant holding capacity than the case drain filters and were not changed. The black particles are discussed in section 5.3.6.5.

#### 5.3.6.4 LHS Fittings

Proof Test - A swaged joint on a permanent tee, Deutsch P/N DNR 10023-080308, failed at 15,500 psi during the proof pressure test on FC-1 system. The cause was attributed to the 155,000 psi tensile strength of the 21-6-9 CRES tubing. Normally one swaging operation is sufficient to attach Deutsch fittings. Because of the tubing hardness, the supplier subsequently recommended 3 swages--120° apart. All Deutsch fittings in FC-1 and FC-2 were swaged 3 times and the proof test was completed satisfactorily.

Compatibility Test - No leakage was observed at any time during the 150 hour test at the following locations:

- All internally swaged joints (Resistoflex)
- All externally swaged joints (Deutsch)
- All heat shrink joints (Raychem)
- All broached/elastomer joints (Rosan)

Table 13. Fluid Contamination Checks

| System      | Test Hours | Micron Size Range |       |       |        |      |                 |
|-------------|------------|-------------------|-------|-------|--------|------|-----------------|
|             |            | 5-15              | 15-25 | 25-50 | 50-100 | 100+ |                 |
| <u>FC-1</u> |            |                   |       |       |        |      | System Clean-up |
| *           |            | 4829              | 162   | 15    | 0      | 0    |                 |
| *           | 0          | 10153             | 269   | 41    | 6      | 1    |                 |
| *           | 50         | 4979              | 152   | 46    | 3      | 0    |                 |
| *           | 100        | 10547             | 435   | 82    | 2      | 0    |                 |
| *           | 150        | 3284              | 118   | 17    | 2      | 1    |                 |
| <u>FC-2</u> |            |                   |       |       |        |      | System Clean-up |
| **          |            | 1651              | 113   | 60    | 17     | 1    |                 |
| **          | 0          | 1558              | 47    | 6     | 0      | 0    |                 |
| **          | 50         | 903               | 16    | 4     | 0      | 0    |                 |
| *           | 100        | 6353              | 1204  | 150   | 5      | 2    |                 |
| *           | 150        | 53728             | 597   | 30    | 2      | 1    |                 |

\*Fluid sample taken upstream of return filter.

\*\*Fluid sample taken downstream of return filter.

Reference Standard

NAS 1638      Class 8    64,000    11,400    2025    360    64

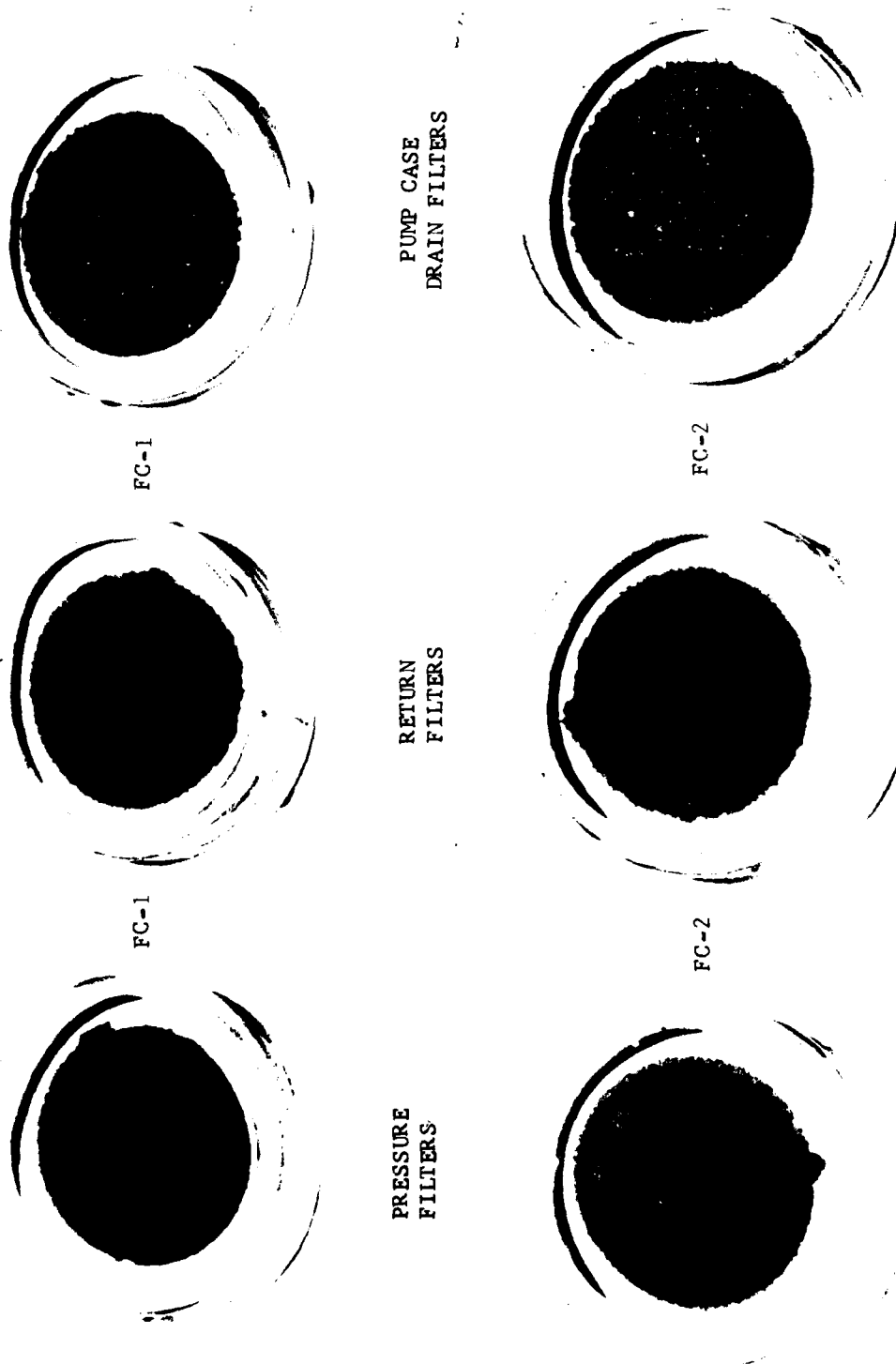


FIGURE 54. Filter patches at 150 hours

Table 14. Pump Case Drain Filter Element Changes

| <u>Compatibility<br/>Test Time, Hr.</u> | <u>Total Operating<br/>Time on Element, Hr.</u> | <u>Element*<br/>Changed</u> |
|-----------------------------------------|-------------------------------------------------|-----------------------------|
| 45.7 **                                 | 73.1 ****<br>65.3                               | FC-1<br>FC-2                |
| 70.0                                    | 24.3<br>24.3                                    | FC-1<br>FC-2                |
| 102.5 ***                               | 32.5<br>32.5                                    | FC-1<br>FC-2                |
| 129.7                                   | 27.2<br>27.2                                    | FC-1<br>FC-2                |

\*All elements were APM P/N AC-7031F-697Y6 (M8815/18-1) with a 5 micron absolute filtration rating.

\*\*Filter  $\Delta P$  indicators up; case drain pressure allowed to increase to 220 psig. All subsequent element changes made when filter  $\Delta P$  indicator operated.

\*\*\*LHS "interim pumps" replaced with backup pumps.

\*\*\*\*FC-1 system, only, used during math model tests.  
See section 6.0.

A slight seepage occurred at approximately 30% of the separable lip-seal type joints (both Resistoflex and Deutsch). The leakage rate was estimated to average about 1 drop/10 hours of test cycling. The cause was probably due to minute imperfections or scratches in the sealing surfaces.

5.3.6.5 LHS Fluid - Viscosity checks were made to provide an indication of the shear stability of MIL-H-83282 fluid. As shown on Table 16, no significant change was observed. The data has limited validity, however, because of the periodic additions of new fluid to FC-1 and FC-2 as discussed in paragraph 5.3.5.6.

The black particles observed on the filter patches (noted in section 5.3.6.3) were believed to be associated with the hydraulic fluid. A sample of black particles analyzed by the Rockwell International Science Center and reported in Reference 10 was found to be 99% carbon. Black particles were not observed during the 400 hour, 8000 psi seal test conducted by Vought, section 5.1. Formulation differences between the NAAD and Vought fluids is the most likely cause for the disparity in performance, although differences in operating conditions is a possible cause. Further investigation in this area is warranted.

5.3.6.6 LHS Relief Valves - FC-1 and FC-2 each had a relief valve to safeguard against system over-pressurization. Cracking pressure, reseal pressure, and internal leakage measured at the test check points are shown on Table 15. Valve performance was satisfactory.

5.3.6.7 LHS Restrictor - All flow cycling was performed during the third block of 50 hours (see section 5.3.5.3). A total of 3200 flow cycles were passed through the restrictor in each direction. Flow data are given on Table 17. Restrictor performance was satisfactory.

5.3.6.8 LHS 4-Way Solenoid Valve - Evaluation testing of the 4-way valve was not completed because of a failure. Test cycling was begun at the start of the third 50 hour block. The valve operated the speed brake for 1043 cycles at which time the valve ceased to function. The unit was returned to the supplier for failure analysis. A pin used to operate the pilot valve was found to be damaged; the cause was improper heat treatment of the pin. Compatibility test cycling was continued during this period using two 3-way solenoid valves to operate the speed brake actuator (see section 5.3.5.3). A total of 1682 cycles were run using the 3-way valves when the repaired 4-way valve was returned. The 4-way valve was then used to finish the required 3200 cycles on the speed brake actuator. A total of 1518 cycles were thus conducted on the 4-way valve.

Internal leakage was measured following completion of the compatibility test. With 8000 psi applied at port P, ports C1 and C2 blocked, room temperature leakage from port R was:

| <u>Operating Mode</u>   | <u>Leakage, cc/min.</u> |
|-------------------------|-------------------------|
| Solenoids #1 and #2 off | 54.2                    |
| Solenoid #1 on          | 30                      |
| Solenoid #2 on          | 11.5                    |

TABLE 15. Relief Valve Performance Summary

| Valve Location     | Test Hours | Cracking Press., psi |          | Reseat Press., psi |          | *Internal Leakage |          |
|--------------------|------------|----------------------|----------|--------------------|----------|-------------------|----------|
|                    |            | Actual               | Required | Actual             | Required | Actual            | Required |
| FC-1<br>(M/N 1257) | 0          | 8500                 | 8500±100 | 8350               | 8300±100 | 1 drop/min.       |          |
|                    | 50         | 8750                 |          | 8700               |          | **trace           |          |
|                    | ***100     | --                   |          | --                 |          |                   |          |
|                    | 150        | 8900                 |          | 8850               |          | 2 drops/min.      |          |
| FC-2<br>(M/N 1258) | 0          | 8400                 |          | 8300               |          | 4 drops/min.      |          |
|                    | 50         | 8350                 |          | 8300               |          | 9 drops/min.      |          |
|                    | 100        | --                   |          | --                 |          | --                |          |
|                    | 150        | 8500                 |          | 8450               |          | **trace           |          |

\*Room temperature leakage with 8000 psi applied to inlet port

\*\*Leakage insufficient to form a drop

\*\*\*100 hour performance check not conducted

\* TABLE 16.

## Fluid Viscosity Summary

| Test Hours | **Fluid Viscosity, cs |       |
|------------|-----------------------|-------|
|            | FC-1                  | FC-2  |
| 0          | 15.49                 | 15.35 |
| 50         | 15.35                 | 15.35 |
| ***100     | -                     | -     |
| 150        | 15.02                 | 15.27 |

\*See section 5.3.5.6 for discussion of make-up fluid

\*\*Viscosity at atmospheric pressure and +100°F

\*\*\*Viscosity check not made at 100 hours

TABLE 17. Restrictor Performance Summary

| Test Hours | Flow Direction | **Flow, gpm |           |
|------------|----------------|-------------|-----------|
|            |                | Actual      | Required  |
| 0          | *Retract       | 3.80        | 4.0 ± 0.2 |
|            | *Extend        | 3.94        | 4.0 ± 0.2 |
| 50         | -              | -           | -         |
|            | -              | -           | -         |
| ***100     | -              | -           | -         |
|            | -              | -           | -         |
| 150        | Retract        | 3.88        | 4.0 ± 0.2 |
|            | Extend         | 3.75        | 4.0 ± 0.2 |

\*Retract speed brake  
Extend speed brake

\*\*Compressed flow at 7850 psi

\*\*\*Restrictor not used during first 100 hours (see section 5.3.5.3)

Maximum allowable internal leakage is 20 cc/min. Internal leakage can be reduced to acceptable levels by minor rework.

5.3.6.9 Miscellaneous Components - Performance observations were used to evaluate LHS components on which performance tests were not run.

LHS Accumulator - The accumulator was charged with 2300 psi of nitrogen prior to compatibility test cycling. Pressure in the accumulator after completion of the compatibility test was 2300 psi (total elapsed time: 80 days). Performance was satisfactory.

LHS Check Valves - Four -8 size and two -3 size check valves were utilized in the test systems. Performance of all units was satisfactory.

LHS Pressure Gage - The gage was used to measure accumulator gas pressure and indicated 8250 psi when system pressure was 8000 psi. At 91.5 hours, the dial face and cover glass were observed to be loose. Performance was satisfactory, otherwise.

LHS Pressure Transmitters - FC-1 and FC-2 power modules each had a pressure transmitter. Readout was on a standard cockpit indicator with a dial remarked for 10,000 psi full scale, Figure 51. Indicated pressure averaged 7800 psi when system pressure was 8000 psi. Transmitter performance was satisfactory throughout the compatibility test.

LHS Pressure Snubber - A snubber was used to protect the pressure transmitters. Performance was satisfactory.

LHS Quick Disconnects - A coupled disconnect was on the discharge port of each pump; a bulkhead half disconnect with a dust cover was installed in each power module as a ground service connection. Performance of all disconnects was satisfactory.

LHS Tubing - 21-6-9 CRES tubing sizes utilized in the test systems were: 3/16 x .020, 1/4 x .023, 3/8 x .034, and 1/2 x .046. Tubing performance was satisfactory.

#### 5.3.6.10 System Performance

Temperatures - Sixteen temperatures were monitored: 15 fluid temperatures and ambient, reference Table 7. Room temperature was generally in the range of +80 to 90°F. System fluid temperatures varied with the cycling schedule; typical values are listed on Table 18. Pump inlet fluid temperature was controlled at +180°F and +200°F during the first 50 hour block, reference Table 8. Pump inlet temperatures were maintained at +180°F continuously beginning at 50 hours because of the "interim pump" difficulties which occurred. Pump case drain temperatures were not allowed to exceed +275°F.

TABLE 18. Typical Temperature Data

|                                        |      | <u>ACTUATOR LOAD/STROKE MAGNITUDE</u> |            |            |             |
|----------------------------------------|------|---------------------------------------|------------|------------|-------------|
|                                        |      | <u>2%</u>                             | <u>10%</u> | <u>50%</u> | <u>100%</u> |
| SEQUENCE STEP NO. (SEE TABLES 8 AND 9) |      | 2-7                                   | 2-6        | 4-5        | 6-3         |
| T1                                     | FC-1 | 198                                   | 202        | 200        | 206         |
| T2                                     | FC-1 | 198                                   | 202        | 200        | 206         |
| T3                                     | FC-1 | 98                                    | 96         | 92         | 82          |
| T4                                     | FC-1 | 248                                   | 268        | 270        | 275         |
| T5                                     | FC-1 | 169                                   | 180        | 160        | 143         |
| T6                                     | FC-2 | 196                                   | 197        | 194        | 193         |
| T7                                     | FC-2 | 200                                   | 200        | 199        | 199         |
| T8                                     | FC-2 | 196                                   | 202        | 202        | 199         |
| T9                                     | FC-2 | 265                                   | 274        | 274        | 276         |
| T10                                    | FC-2 | 204                                   | 191        | 185        | 178         |
| T11                                    | FC-2 | 183                                   | 129        | 173        | 159         |
| T12                                    | FC-1 | 168                                   | 172        | 180        | 183         |
| T13                                    | FC-2 | 228                                   | 228        | 229        | 225         |
| T14                                    | FC-2 | 193                                   | 158        | 188        | 190         |
| T15                                    | FC-1 | -                                     | -          | -          | -           |
| T16                                    | -    | 91                                    | 90         | 86         | 82          |

NOTE: DATA TAKEN DURING FIRST BLOCK OF 50 HRS.

Pressures - Dynamics in FC-1 and FC-2 pressure systems were sensed by a transducer located immediately downstream of the pump and by a transducer located just upstream of the UHT actuator. Pressure ripple was generally less than the maximum allowable +200 psi near the pumps and much less near the UHT actuator, Figure 55. This data was corroborated by the Air Force Flight Dynamics Laboratory, (see section 6.4). No serious hydraulic resonance was observed in FC-1 or FC-2 over a pump speed range of 2000 to 6000 rpm.

#### 5.3.7 Test Summary

The 150 hour, 800,000 cycle compatibility test was completed satisfactorily, except for a number of minor problems. The test systems were stable, actuator operation was satisfactory, and pressure fluctuations were low. The results provide convincing evidence that the Phase II simulator should function as designed.

A summary of the malfunctions which occurred in FC-1 and FC-2 pressure systems during the compatibility test is presented on Table 19. All of the malfunctions were considered to be the result of normal development problems. Although additional minor problems may surface as the LHS program progresses, no major state-of-the-art development problems are anticipated.

#### 5.4 PRESSURE IMPULSE TEST

##### 5.4.1 Test Procedure

A setup was built utilizing the following LHS components (see Figure 56):

- 3-way solenoid valve, Bendix P/N 3321473
- Quick disconnect, Aeroquip P/N AE80943H with dust cover
- Hose, Titeflex P/N 78570
- Tubing, 21-6-9 CRES, -3 and -8 sizes
- Fittings: Deutsch, Raychem, Resistoflex (see Table 20).

Pressure impulses were generated by suddenly porting fluid at 8000 psi into a closed system containing fluid at return pressure. A 125 in<sup>3</sup> fluid volume teed into the pressure system was used as an accumulator to assist in providing high instantaneous fluid velocities. The surge was sensed by a pressure transducer and recorded photographically on an oscilloscope. The test consisted of applying 40,000 pressure impulses (20% of qualification test requirements) peaking at 10,800 psi (135% of system pressure) at the rate of 60 cpm. Cycling was conducted with a fluid temperature of +110°F.

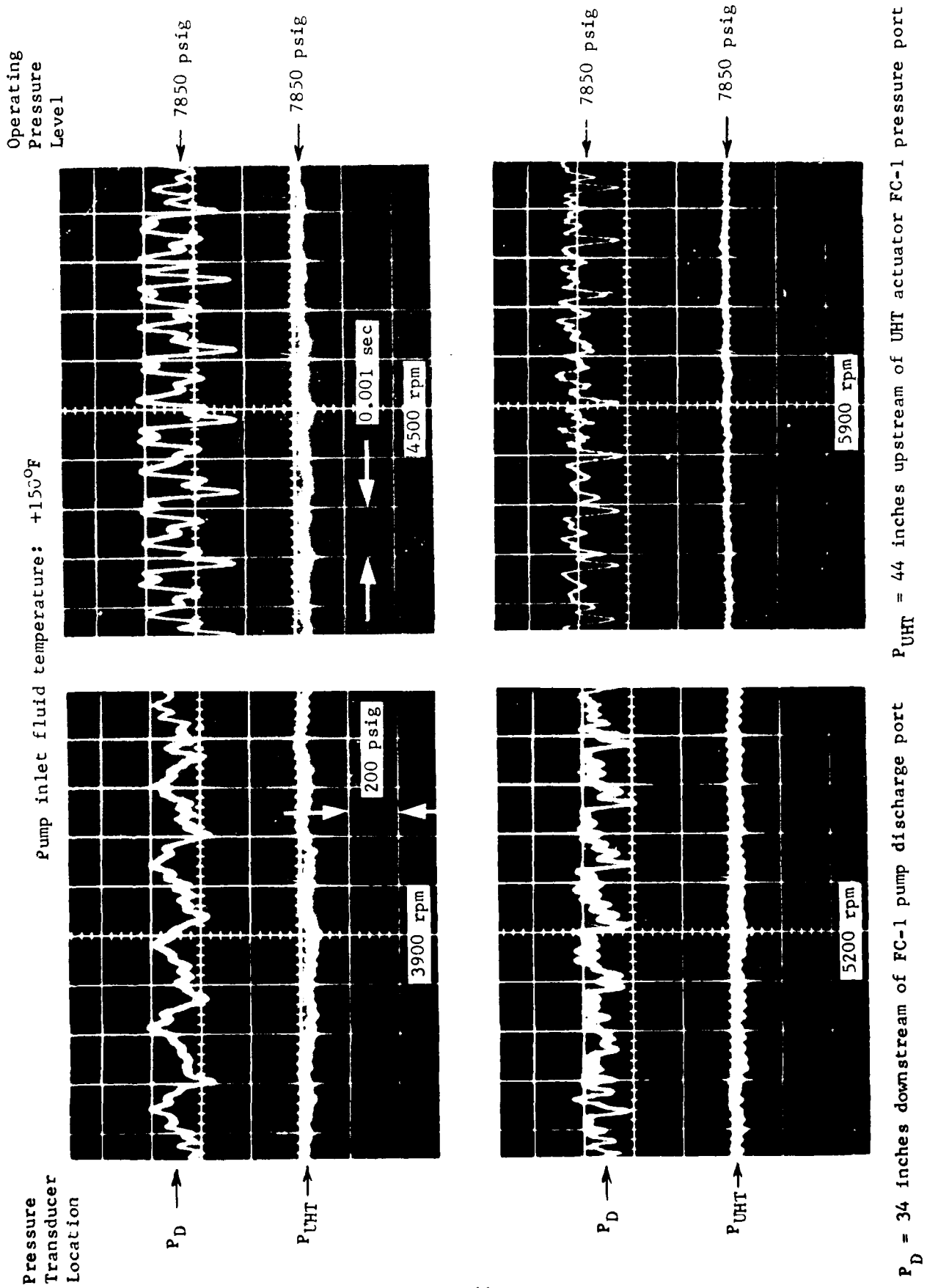


FIGURE 55. System pressure ripple

Table 19. Summary of LHS Malfunctions and Failures

| <u>Test Hours Completed</u> | <u>Component</u>                                                      | <u>Remarks</u>                                                                                                                                                 |
|-----------------------------|-----------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 39.3                        | Static O-ring on FC-1 8000 psi filter inlet port                      | Dynatube adapter fitting had rough surface where O-ring sealed.                                                                                                |
| 45.7                        | Static O-ring on FC-2 MS bulkhead fitting near P5 pressure transducer | Low pressure leak occurred over week-end. Reservoir bootstrap pressure caused fluid loss. O-ring had permanent set.                                            |
| 50                          | FC-1 pump                                                             | Excessive case flow developed during 50 hr. performance check. Part of one piston shoe was missing due to brazing voids.                                       |
| 56.2                        | FC-1 pump                                                             | Pin hole leak developed in aluminum valve block.                                                                                                               |
| 102.6                       | FC-2 pump                                                             | External leak developed in joint between valve block and housing due to erosion pitting of O-ring gland in aluminum valve block.                               |
| 119.0<br>19 hrs on valve    | 4-way solenoid valve                                                  | Valve stopped operating at 1043 cycles due to damaged pin in pilot valve. Pin not heat treated properly.                                                       |
| 128.9                       | AFCS actuator                                                         | Cylinder #2 piston operation became rough. Internal binding suspected. Cause to be determined when actuator is disassembled. Test continued using Cylinder #1. |

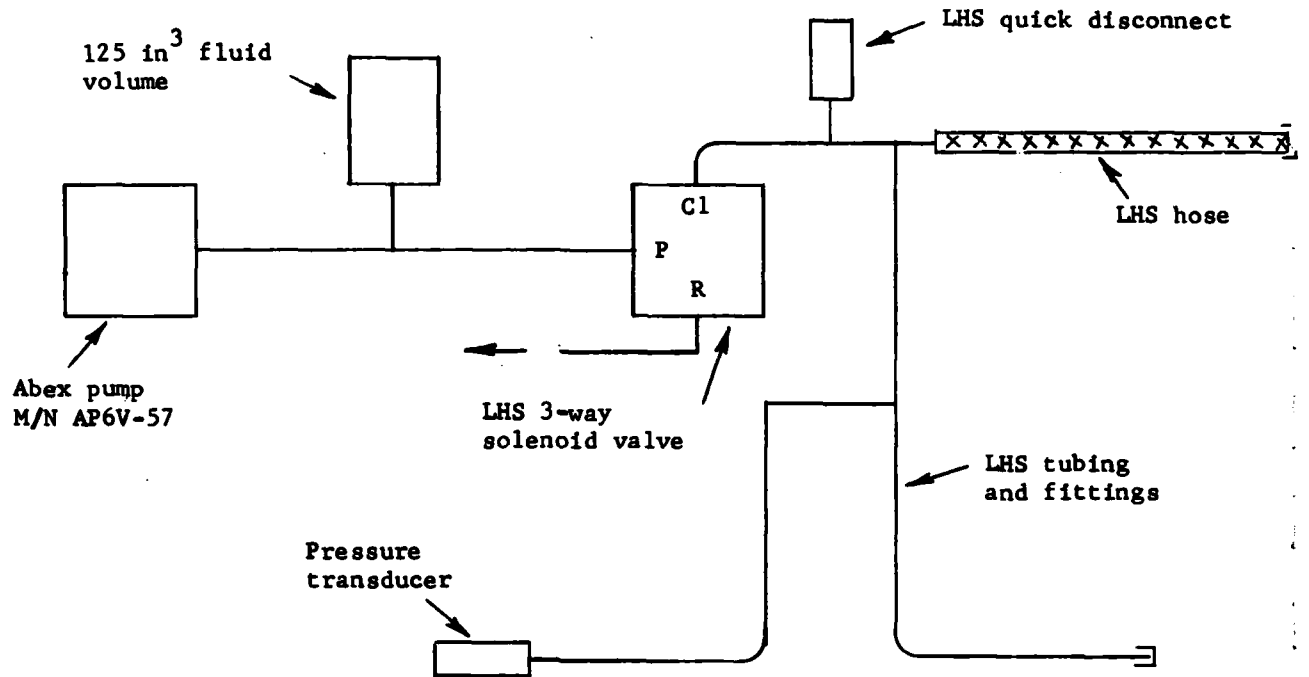


FIGURE 56. Pressure impulse test, original configuration

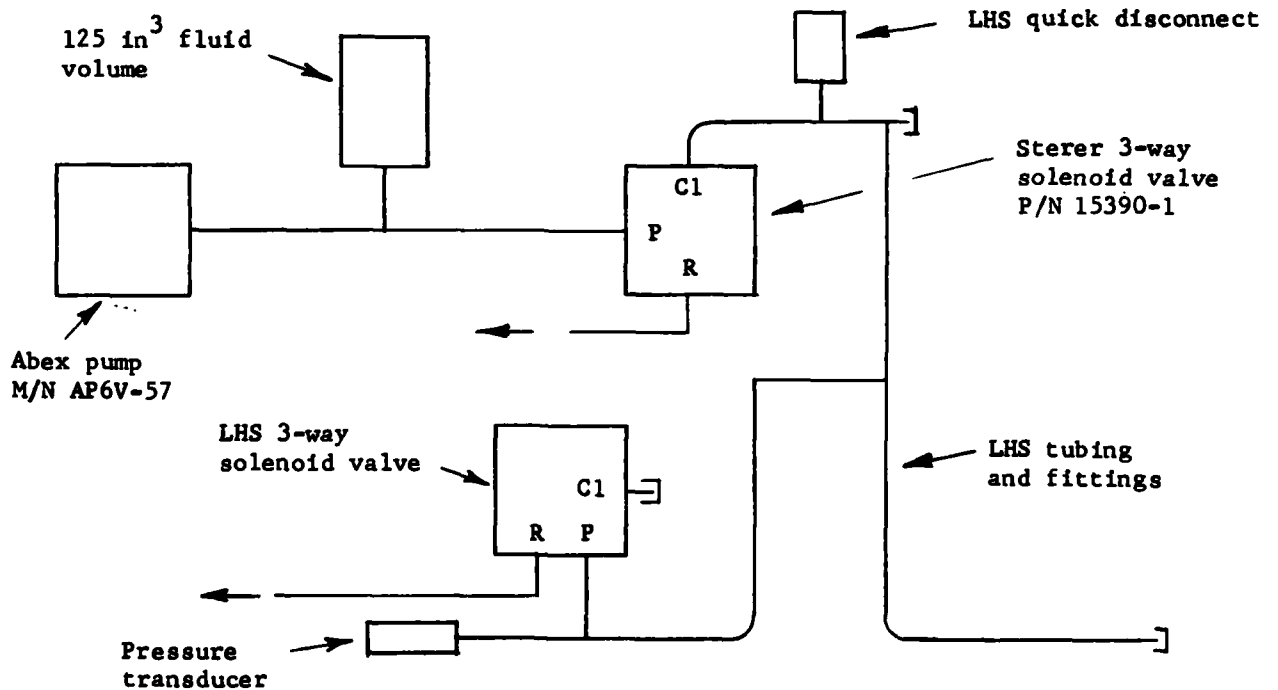


FIGURE 57. Pressure impulse test, final configuration

Table 20. Fittings Pressure Impulse Tested

| <u>Manufacturer</u> | <u>Description</u> | <u>Part Number</u> | <u>Quantity</u> |
|---------------------|--------------------|--------------------|-----------------|
| Deutsch             | Tee                | DNR10023-080803    | 1               |
| Resistoflex         | Coupling           | R44101T-03         | 1               |
| Resistoflex         | Elbow              | R44129-90T-03      | 1               |
| Resistoflex         | Tee                | R44130T-08         | 1               |
| Resistoflex         | Tee                | R44133T-03         | 1               |
| Resistoflex         | Connector, Female  | R44296T-03         | 2               |
| Resistoflex         | Elbow              | R44360T-08         | 1               |
| Resistoflex         | Connector, Male    | R54100T-03         | 1               |
| Resistoflex         | Connector, Male    | R54100T-08         | 1               |
| Resistoflex         | Connector, Female  | R54045T-03         | 1               |
| Resistoflex         | Connector, Female  | R54045T-08         | 3               |
| Raychem             | Coupling           | 3P00101-2          | 2               |
| Raychem             | Coupling           | 3P02121-8          | 1               |

The required pressure impulse of 10,800 psi could not be attained with the test setup shown on Figure 56; the surges were too small. Several configuration changes were made in an attempt to increase the surge.

| <u>Configuration</u>                                                                                                                               | <u>Maximum Impulse Pressure Attained</u> |
|----------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------|
| 1. Original setup                                                                                                                                  | 8400 psi                                 |
| 2. LHS hose removed from setup                                                                                                                     | 9600 psi                                 |
| 3. LHS 3-way solenoid valve replaced with LHS 4-way valve (4-way valve has larger internal porting than 3-way)                                     | 9800 psi                                 |
| 4. LHS 4-way solenoid valve replaced with Sterer 3-way valve, see section 5.3.5.4. (Sterer valve has larger internal porting than LHS 4-way valve) | 10,600 psi                               |

The configuration used for the pressure impulse test is shown on Figure 57. Deviations from the planned test are summarized below:

- The LHS hose was not used in the test system because of its surge damping characteristics.
- The LHS 3-way valve contained restrictions which limited surge development when it was cycled. The valve was therefore plumbed into the system so that its pressure port was subjected to the test surge. The valve was de-energized throughout the impulse test.
- A 3-way solenoid valve, Sterer P/N 15390-1, was used to port pressure into and out of the test setup. The Sterer valve had larger internal porting than the LHS 3-way valve, permitting the passage of higher fluid velocities.

Photographs of the test setup and pressure impulse wave form are shown on Figures 58 and 59.

#### 5.4.2 Test Results

The 40,000 cycle test was completed uneventfully. All fittings performed satisfactorily except for a slight seepage observed at several separable fitting lip seal joints, see compatibility test, section 5.3.6.4. No external leakage was observed at the LHS 3-way valve or quick disconnect. Two failures were found, however, during component checkouts following completion of the impulse test. These are discussed in the next sections.



FIGURE 58. Pressure impulse test setup

H-95-581B 12-17-80

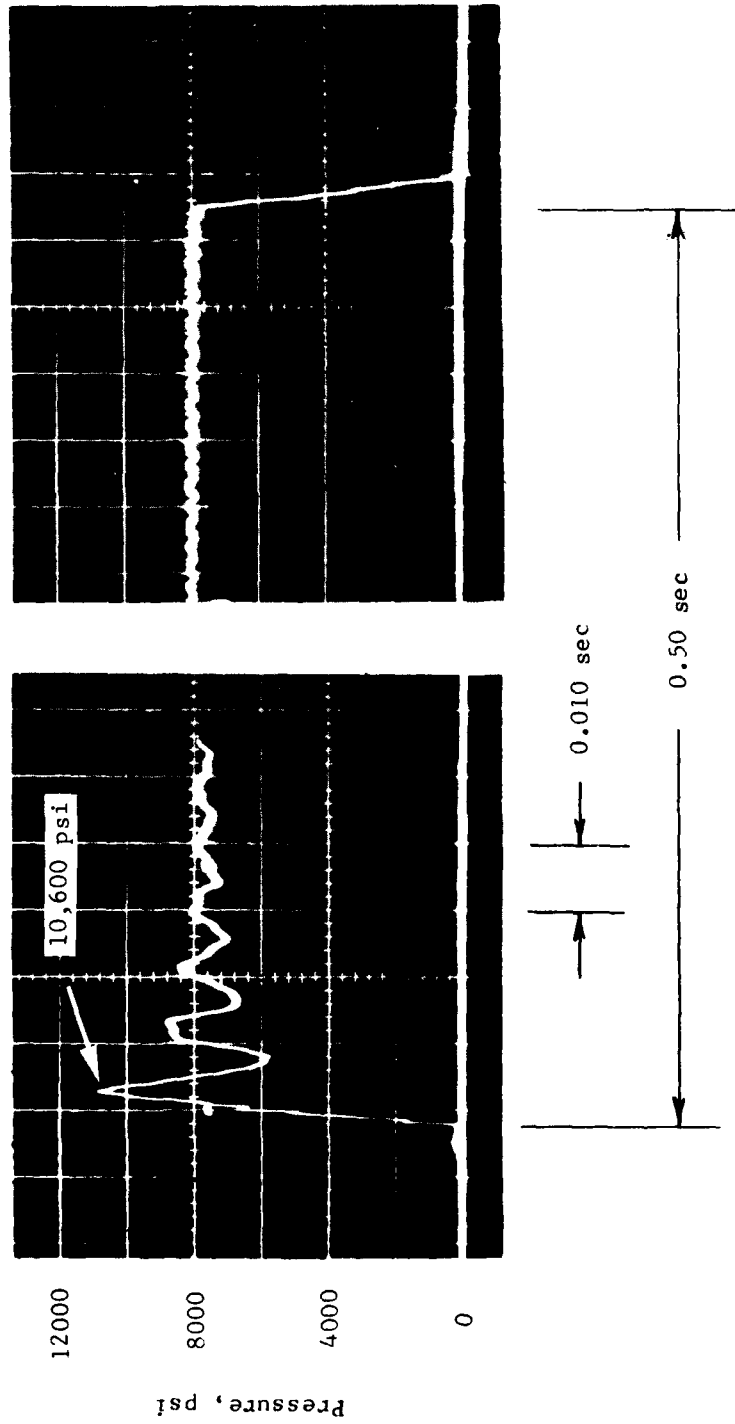


FIGURE 59. Pressure impulse wave form

LHS 3-Way Solenoid Valve - The valve functioned satisfactorily before the impulse test, but was inoperative following the test. Internal leakage measured before the impulse test was 9.6 cc/min.; after the test it was 1.5 cc/min. The valve was returned to the supplier for disassembly and failure analysis. The failure was caused by lack of heat treatment of the pilot pin.

LHS Quick Disconnect - When the protective dust cover was removed for examination of the disconnect, the porting valve was found to have failed. The time of failure was not known since there was no external evidence of a problem. The failure occurred in the web areas between the four porting holes in the steel valve.

The LHS quick disconnect specification, LHS-8828, was examined, and it was found that only coupled disconnects have pressure impulse test requirements; aircraft-half ground service disconnects (with dust covers) have no impulse test requirements. This omission was also present in the 3000 psi quick disconnect specification, MIL-C-25427. Performance requirements for aircraft-half ground service disconnects should be addressed in both specifications. The LHS disconnect specification will be updated in Phase II.

## 5.5 COMPONENT ENDURANCE TEST

### 5.5.1 Test Procedure

The test setup contained the following LHS components (see Figure 60):

\*Accumulator, Bendix P/N 3321471

Check Valves, \*Gar-Kenyon P/N 95202-1

\*Gar-Kenyon P/N 95202-5

\*\*Circle-Seal P/N P2-858

Hose, Titeflex P/N 78570

\*Manifold, CAAD P/N 8696-581201

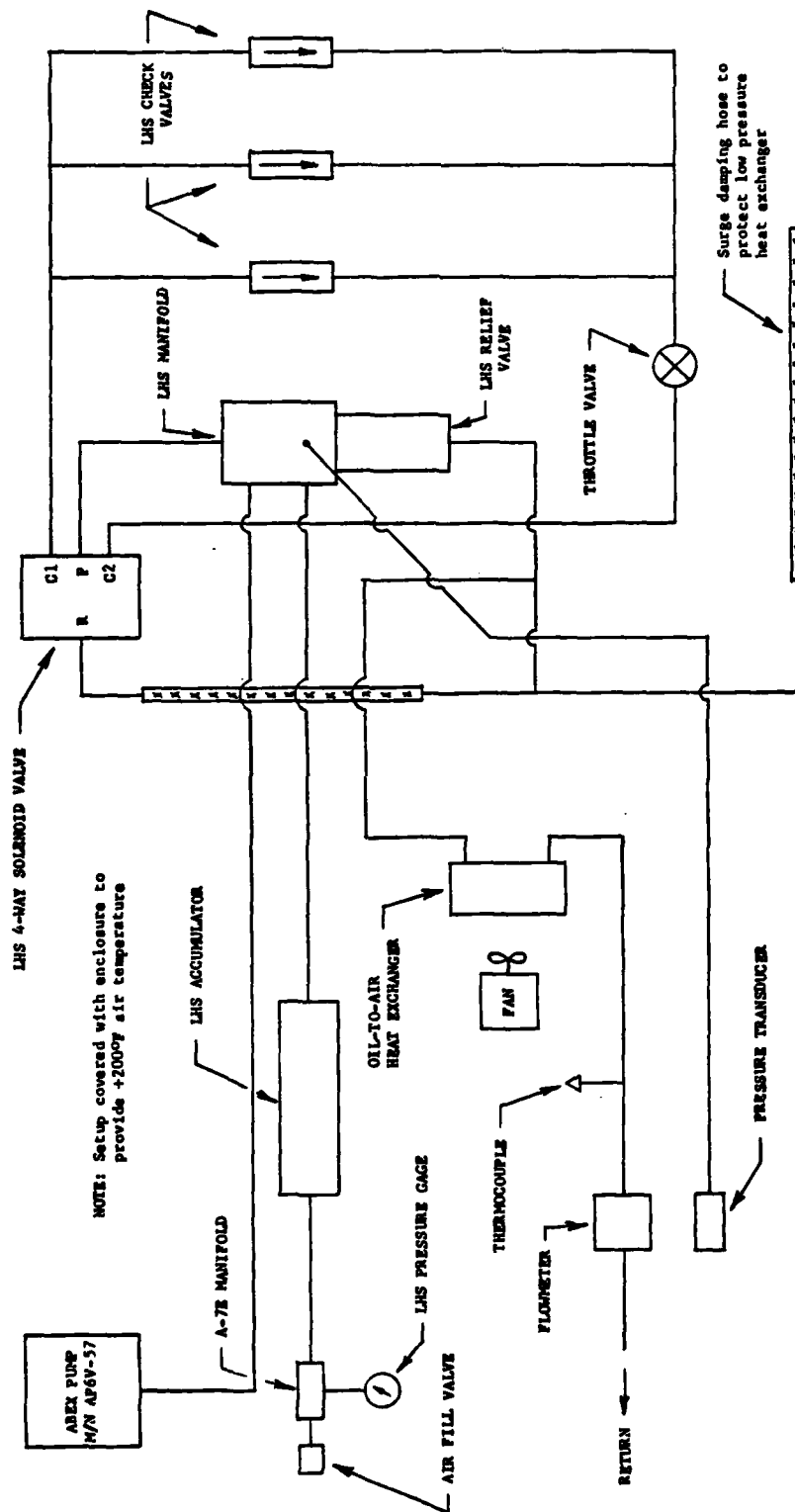
\*Pressure gage, Q-E-D P/N 1218-63-1

\*Relief Valve, PneuDraulics P/N 1257

\*4-Way Solenoid Valve, Bendix P/N 3321472

\*Component previously used in compatibility test setup, section 5.3.

\*\*Circle-Seal Controls, Anaheim, CA, provided this unit for evaluation testing.



NOTE: Setup covered with enclosure to provide +200°F air temperature

FIGURE 60. Component endurance test, original configuration

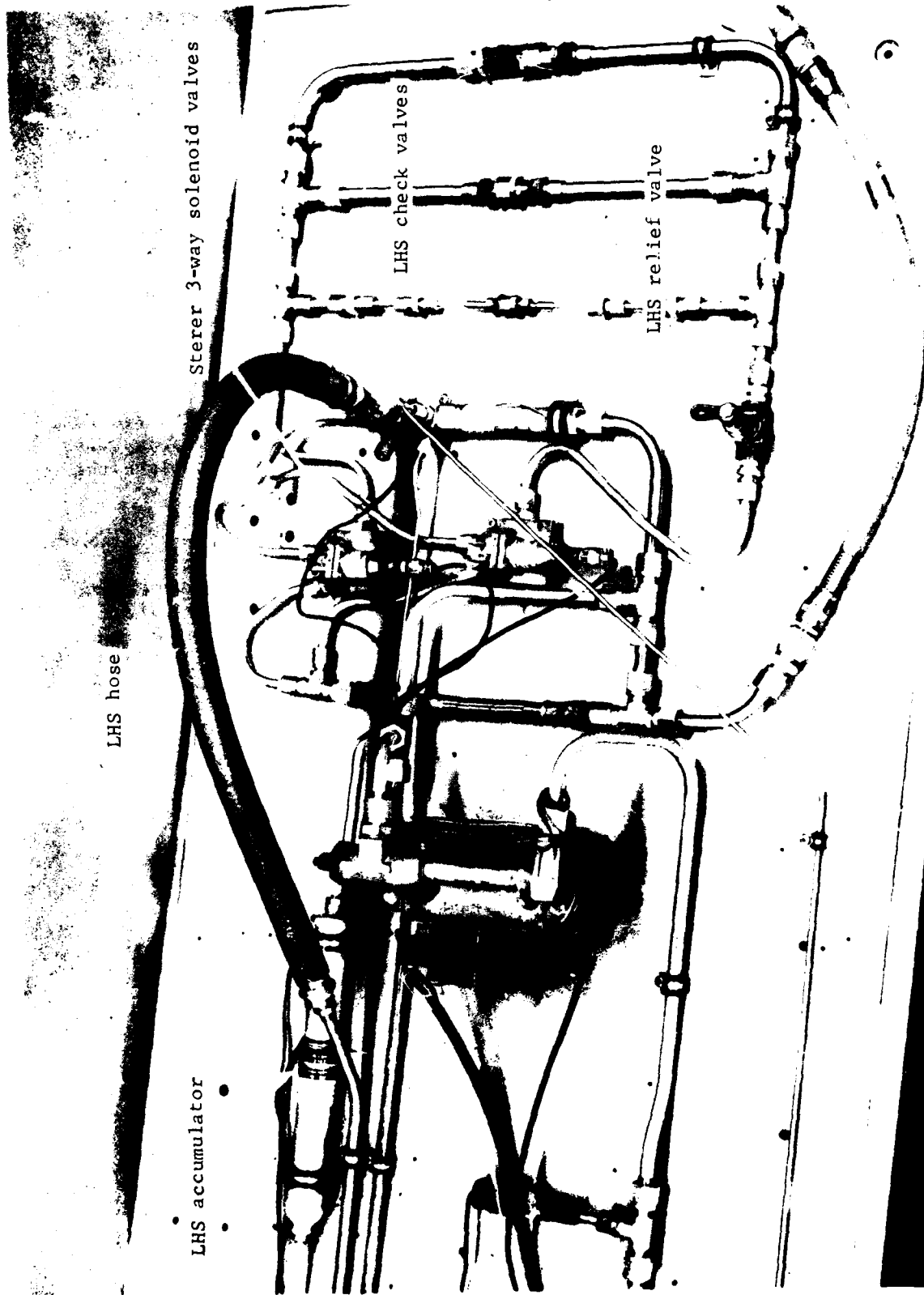


FIGURE 61. Component endurance test setup

System pressure was cycled from 7000 psi to 9000 psi using the 4-way solenoid valve, a throttle valve set for 7000 psi, and the pump compensator set at 9000 psi. Pressure was 7000 psi in the free-flow direction through the check valves, and 9000 psi in the checked direction. The 9000 psi level opened the relief valve, and the 7000/9000 psi levels cycled the accumulator piston and pressure gage. Total flow was 4 gpm through the check valves and 2 gpm through the relief valve. The test consisted of applying 10,000 pressure cycles (20% of qualification test requirements) at the rate of 2 seconds at 7000 psi and 2 seconds at 9000 psi. Cycling was conducted with fluid and air temperatures of +200°F following a warm-up period.

A static seal in check valve P/N 95202-5 failed at 826 cycles. This valve (item 49 on Figure 5) was replaced with check valve P/N 95201-5 (item 52 on Figure 5) to complete the endurance test.

The 4-way solenoid valve stopped operating at 3000 cycles and was returned to the supplier for disassembly and failure analysis (see section 5.3.6.8). The test was completed using two 3-way valves, Sterer P/N 15390-1, to replace the 4-way valve. This final configuration is shown in Figure 61.

#### 5.5.2 Test Results

LHS component performance is summarized on Table 21. The test was interrupted three times during the 10,000 cycles; two seals failed and the 4-way valve malfunctioned. As noted on Table 21, the failures were the result of design deficiencies and can be corrected.

TABLE 21. LHS Component Endurance Test Summary

| Component                     | Cycles Completed | Remarks                                                                                                                                                                      |
|-------------------------------|------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Accumulator                   | 10,000           | 1. Satisfactory performance<br>2. 2200 psi nitrogen precharge held without leakage                                                                                           |
| Check Valves<br>P/N 95202-1   | 10,000           | 1. Satisfactory performance<br>2. Internal leakage after test: None                                                                                                          |
| P/N 95202-5                   | 826              | 1. Diametral seal extruded out<br>2. Recommended design changes:<br>-Increase overlap at seal diametral clearance<br>-Increase assembly torque<br>-Install lockwire on valve |
| *P/N 95201-5                  | 9174             | 1. Poppet failed<br>2. Recommended design change:<br>-Increase web areas between porting holes                                                                               |
| P/N P2-858                    | 10,000           | 1. Satisfactory performance<br>2. Internal leakage after test: None                                                                                                          |
| Hose                          | 7,000            | 1. Satisfactory performance<br>2. Installed at 3000 cycles                                                                                                                   |
| Manifold                      | 10,000           | 1. Satisfactory performance                                                                                                                                                  |
| Pressure gage                 | 10,000           | 1. Satisfactory performance                                                                                                                                                  |
| Relief Valve                  | 10,000           | 1. Satisfactory performance<br>2. After test data:<br>Cracking pressure: 8575 psi<br>Reseat pressure: 8400 psi<br>Internal leakage: 1 drop/min                               |
| 4-Way Solenoid Valve          | 3,000            | 1. Stopped operating<br>2. Recommended design change:<br>-Relocate cross-drilled flow passage in pilot valve                                                                 |
| **Air Fill Valve,<br>MS 28889 | 800              | 1. Face seal extruded out, valve not tight in boss<br>2. New seal installed, valve tightened, and 9200 cycles completed satisfactorily                                       |

\*Used to replace P/N 95202-5.

\*\*Valve designed for 5000 psi service. An LHS fill valve was not used. The LHS valve (when procured) is recommended to have a boss type seal instead of a face seal.

## 6.0 MATH MODEL

### 6.1 INTRODUCTION

The analytical approach used to model the test system was based upon application of computer programs developed for the Air Force, Reference 18. These programs evolved from a major contracted study by McDonnell Aircraft Company and are considered the best validated methods developed to date for dynamic modeling of complex hydraulic systems. The Air Force has made this information available to industry. Three computer programs are involved:

1. Hydraulic System Frequency Response (HSFR) - This program predicts resonant frequencies, locations, and amplitudes of standing wave oscillatory flows and pressures resulting from the operation of aircraft piston-type pumps.
2. Hydraulic Transient Analysis (HYTRAN) - This program simulates the dynamic response of a hydraulic system to sudden changes in load flow demand, and predicts the pressure and flow disturbances which propagate through the system.
3. Hydraulic Transient Thermal Analysis (HYTTA) - This program predicts the effects of heat generation, dissipation, and temperatures on a hydraulic system.

References 18 through 21 contain background and user information necessary to implement the above programs.

The laboratory test system--consisting of power generation, power transmission, and actuation systems--was modeled for the HSFR computer program. Analytical data obtained from the program were compared with test data to verify the predictive capabilities of the program and to determine the most suitable test procedures.

### 6.2 FREQUENCY RESPONSE ANALYSIS VERIFICATION

#### 6.2.1 Background

Aircraft piston-type pumps cause pressure and flow oscillations (commonly known as pump ripple or pulsations) to be imposed upon the pressurized hydraulic fluid. Since the pulsations are in the audio frequency range, they are termed acoustic noise. This pump induced acoustic noise can generate standing waves of pressure and flow throughout the pressure system in a manner similar to those observed in organ pipes and electrical transmission lines. When the pulsation frequency coincides with natural frequencies in the system, hydraulic resonance occurs. This creates large pressure peaks and destructive vibratory conditions can result.

The HSFR program computes pump speeds for which hydraulic resonances occur at element locations in the system. Component modifications can be rapidly evaluated to correct unacceptable resonant conditions. Potential problems resulting from pump acoustical noise can therefore be minimized in the design stage.

#### 6.2.2 Test System

The system evaluated was FC-1, Figure 5. A schematic diagram of the math model verification system is shown on Figure 62. Components are arranged and numbered according to the format described in Reference 18. There are 44 circuit/elements. Details of the pump, actuators, and other components are given in section 3.0.

Computer input data used to model the system is tabulated in Table 22; the format is given in Reference 18. The program permits the user to input physical properties of the hydraulic fluid, operating pressure, and fluid temperature. Bulk modulus values used for MIL-H-83282 at 8000 psi were 190,000 psi @ +200°F and 210,000 psi @ +145°F. A complete pump model was utilized (N-TYPE 9, K-TYPE 21). The pressure side of the reservoir was included as a loss-less volume. A block diagram of the math model test instrumentation is shown on Figure 63. System pressures were sensed by two strain gage type transducers teed into the hydraulic system; one located near the pump outlet port, the other just upstream of the UHT actuator. The transducer had a bandwidth of 20,000 Hz; the transducer amplifier had a bandwidth of 4000 Hz. System flow pulsations were not measured because flow sensors having the required performance characteristics--8000 psi operating pressure and 3000 Hz bandwidth--are not available.

Pressure pulsation harmonic frequencies were detected with a Federal Scientific M/N VA-500 Spectrum Analyzer, Figure 64. Signal input to the analyzer (from the pressure transducer amplifier) was observed on a monitor scope. Using a marker generator in the analyzer, first and second harmonic amplitudes were read on a display scope. Pump speed was indicated on a frequency counter in the control console, Figure 51. Harmonic determinations were made every 100 rpm over a pump speed range of 1700 to 6200 rpm.

Temperatures were measured with probe-type thermocouples teed into FC-1 plumbing. Fluid temperature was sensed at a location near the pump inlet, outlet, and case drain ports. Fluid temperature was maintained by automatic controls.

#### 6.2.3 Test Results

Pressure and flow plots as a function of pump rpm were generated from the computer program. Figure 65 gives predicted peak pressure oscillations (single amplitude) at circuit element No. 8 (pressure transducer near pump). Figure 66 is a corresponding flow plot at element No. 8. A pressure plot at element No. 42 (pressure transducer near UHT actuator) is shown on Figure 67. The test conditions for these plots were:

|                     |                                   |
|---------------------|-----------------------------------|
| Operating Pressure: | 8000 psi                          |
| Flow:               | 0.2 gpm (actuator valves at null) |
| Fluid Temperature:  | +145°F (pump outlet)              |

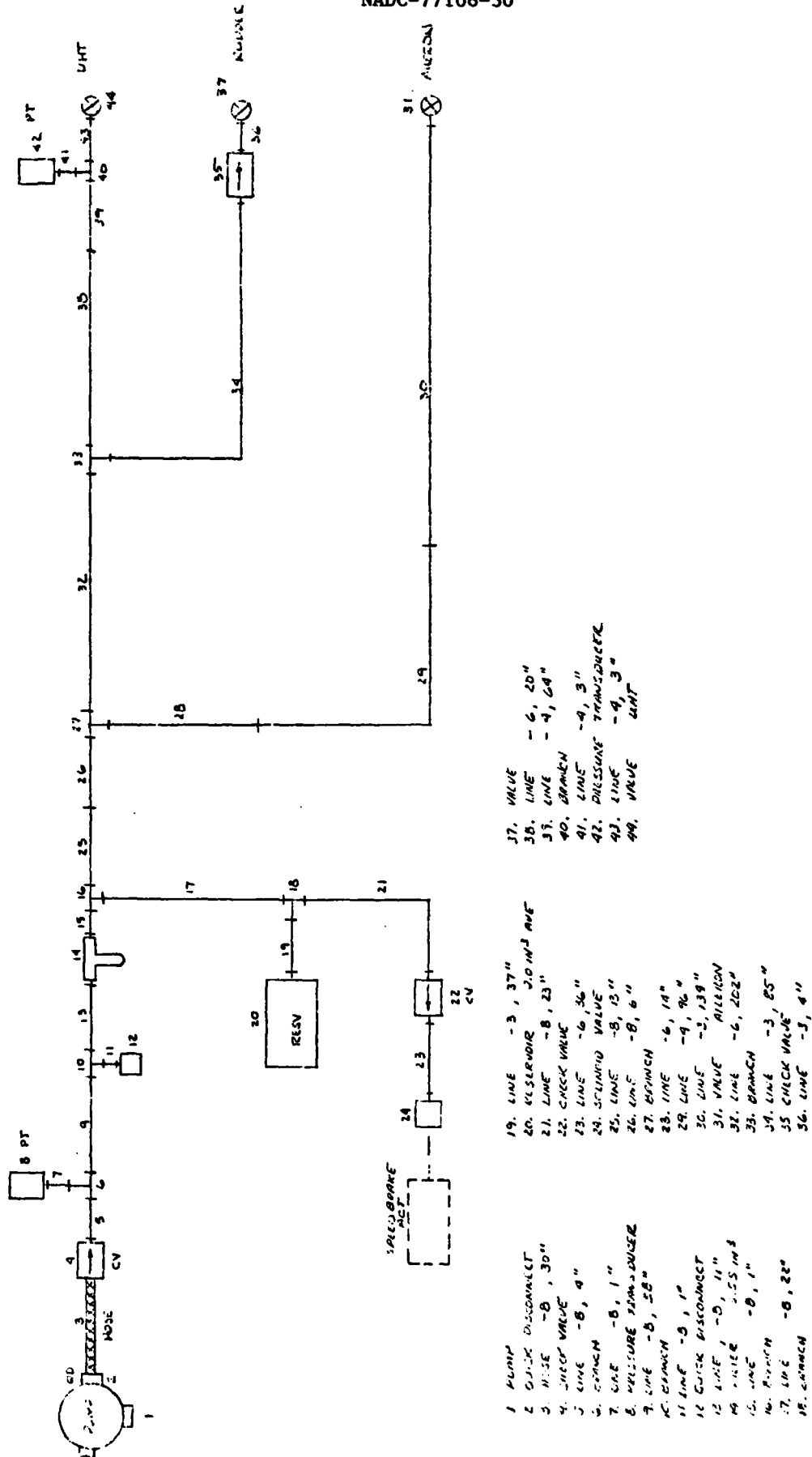


FIGURE 62. Math model verification system

TABLE 22. Computer Input Data

## HYDRAULIC SYSTEM FREQUENCY RESPONSE PROGRAM

A7/LUG POWER SYSTEM COMPONENT EVALUATION USER RUN-1

RESPONSE IS CALCULATED FROM 100.00 TO 6000.00 R.P.M. IN INCREMENTS OF 100.00 R.P.M.

RESPONSE IS PLOTTED FOR THE -FIRST- HARMONIC FREQUENCY

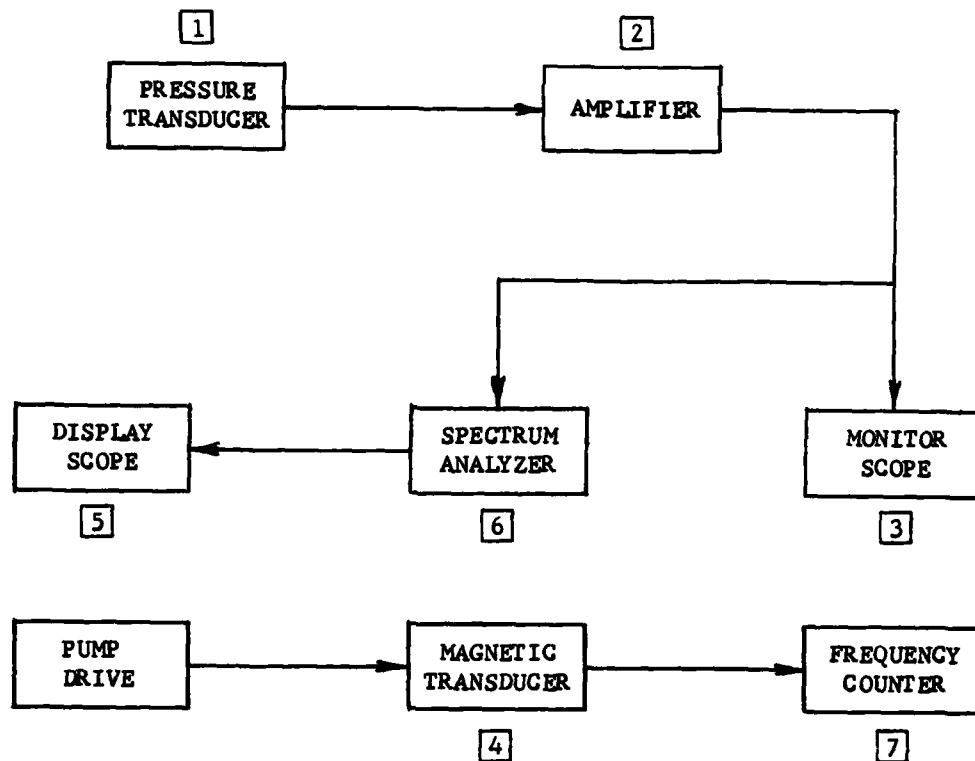
NUMBER OF PUMPING ELEMENTS= 9.

FLUID DATA FOR MIL-M-832R2/CAD 8000.0 PSIG AND 200.0 DEG F

VISCOSITY - .113E-01 IN\*\*2/SEC  
 DENSITY - .775E-04 (LB-SEC\*\*2)/IN\*\*4  
 BULK MODULUS - .190E+06 PSI

ELEMENT \*\*\*\*\*SYSTEM ELEMENT INPUT DATA\*\*\*\*\*  
NUMBER

| N    |      | R  |          | .....PHYSICAL DATA..... |         |              |          |          |          |          |
|------|------|----|----------|-------------------------|---------|--------------|----------|----------|----------|----------|
| TYPE | TYPE |    |          |                         |         |              |          |          |          |          |
| 1    | 9    | 21 | .090     | .443                    | .207    | .850         | .429     | .062     | .090     |          |
|      |      |    | .09030   | 12.00000                | 4.20000 | 3.25000      | 28.00000 | 30.20000 | 25.00000 | 22.00000 |
|      |      |    | 85.00000 | .06000                  | .30820  | 1.45000      | .00021   | 30.00000 | 60.00000 | .30600   |
| 2    | 7    | 0  | 0.000    | 0.000                   | 0.000   | 0.000        | 0.000    | 0.000    | 0.000    |          |
| 3    | 1    | 1  | 30.000   | .454                    | 0.000   | 140000.000   | 0.000    | 0.000    | 0.000    |          |
| 4    | 4    | 0  | .038     | 0.000                   | 0.000   | 0.000        | 0.000    | 0.000    | 0.000    |          |
| 5    | 1    | 0  | 4.000    | .500                    | .046    | 28000000.000 | 0.000    | 0.000    | 0.000    |          |
| 6    | 6    | 2  | 0.000    | 0.000                   | 0.000   | 0.000        | 0.000    | 0.000    | 0.000    |          |
| 7    | 1    | 0  | 1.000    | .500                    | .046    |              |          |          |          |          |
| 7    | 1    | 0  | 1.000    | .500                    | .046    | 28000000.000 | 0.000    | 0.000    | 0.000    |          |
| 8    | 13   | 0  | .010     | 0.000                   | 0.000   | 0.000        | 0.000    | 0.000    | 0.000    |          |
| 9    | 1    | 0  | 58.000   | .500                    | .046    | 28000000.000 | 0.000    | 0.000    | 0.000    |          |
| 10   | 6    | 2  | 0.000    | 0.000                   | 0.000   | 0.000        | 0.000    | 0.000    | 0.000    |          |
| 11   | 1    | 0  | 1.000    | .500                    | .046    | 28000000.000 | 0.000    | 0.000    | 0.000    |          |
| 12   | 13   | 0  | .010     | 0.000                   | 0.000   | 0.000        | 0.000    | 0.000    | 0.000    |          |
| 13   | 1    | 0  | 11.000   | .500                    | .046    | 28000000.000 | 0.000    | 0.000    | 0.000    |          |
| 14   | 3    | 0  | 5.550    | 0.000                   | 0.000   | 0.000        | 0.000    | 0.000    | 0.000    |          |
| 15   | 1    | 0  | 1.000    | .500                    | .046    | 28000000.000 | 0.000    | 0.000    | 0.000    |          |
| 16   | 6    | 8  | 0.000    | 0.000                   | 0.000   | 0.000        | 0.000    | 0.000    | 0.000    |          |
| 17   | 1    | 0  | 22.000   | .500                    | .046    | 28000000.000 | 0.000    | 0.000    | 0.000    |          |
| 18   | 6    | 2  | 0.000    | 0.000                   | 0.000   | 0.000        | 0.000    | 0.000    | 0.000    |          |
| 19   | 1    | 0  | 37.000   | .189                    | .020    | 28000000.000 | 0.000    | 0.000    | 0.000    |          |
| 20   | 13   | 0  | 2.000    | 0.000                   | 0.000   | 0.000        | 0.000    | 0.000    | 0.000    |          |
| 21   | 1    | 0  | 23.000   | .500                    | .046    | 28000000.000 | 0.000    | 0.000    | 0.000    |          |
| 22   | 3    | 0  | .010     | 0.000                   | 0.000   | 0.000        | 0.000    | 0.000    | 0.000    |          |
| 23   | 1    | 0  | 36.000   | .375                    | .034    | 28000000.000 | 0.000    | 0.000    | 0.000    |          |
| 24   | 13   | 0  | .001     | 0.000                   | 0.000   | 0.000        | 0.000    | 0.000    | 0.000    |          |
| 25   | 1    | 0  | 13.000   | .500                    | .046    | 28000000.000 | 0.000    | 0.000    | 0.000    |          |
| 26   | 1    | 0  | 6.000    | .500                    | .046    | 28000000.000 | 0.000    | 0.000    | 0.000    |          |



- [1] Pressure transducer, Viatran M/N 122EF76
- [2] Amplifier, Viatran M/N 602
- [3] Oscilloscope, Tektronix Type 545A
- [4] Magnetic transducer, Electro Products M/N 3010-AN
- [5] Oscilloscope, Tektronix Type 502A
- [6] Spectrum analyzer, Federal Scientific M/N VA-500
- [7] EPUT and timer, Beckman M/N 6147

FIGURE 63. Math model test instrumentation

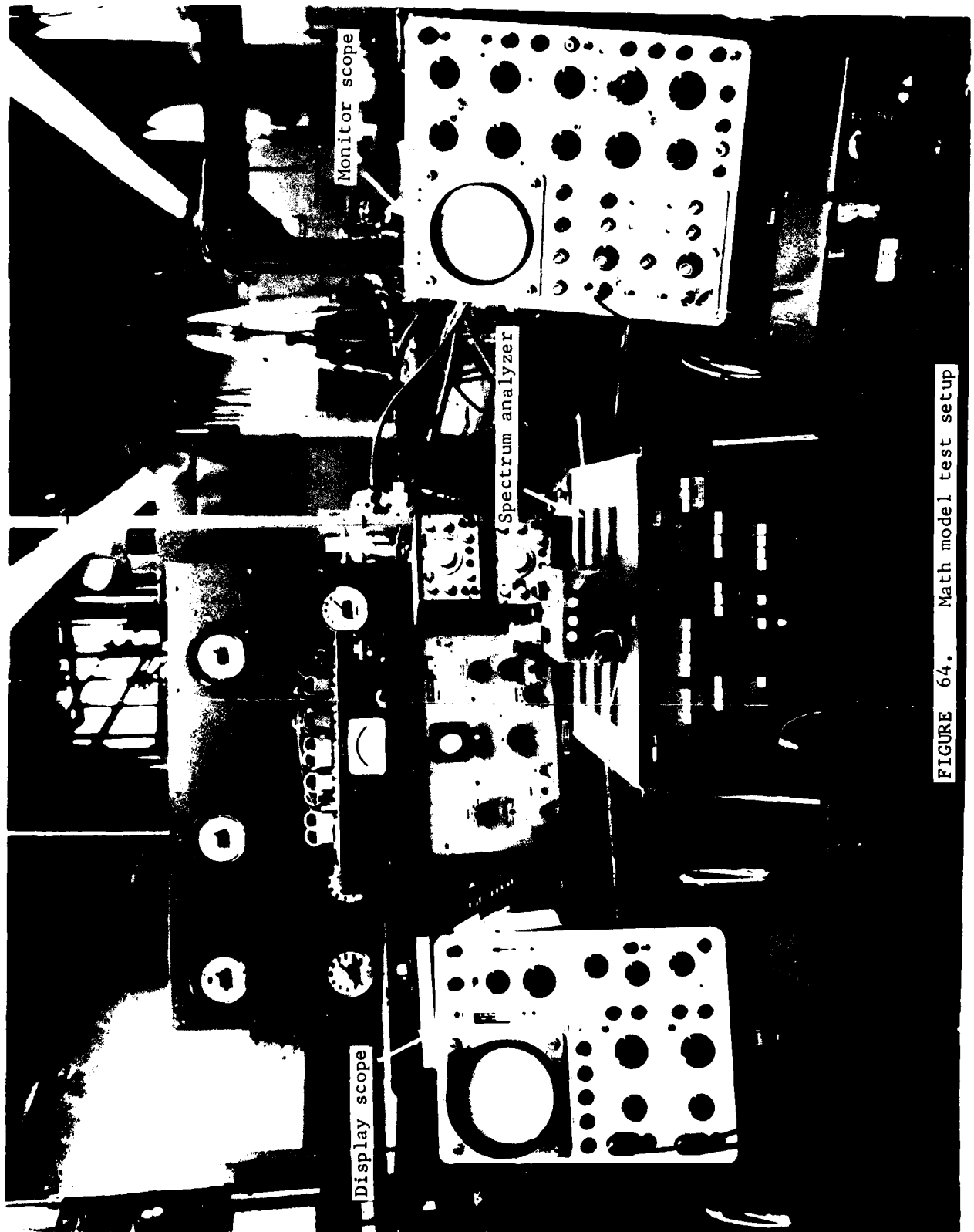


FIGURE 64. Math model test setup

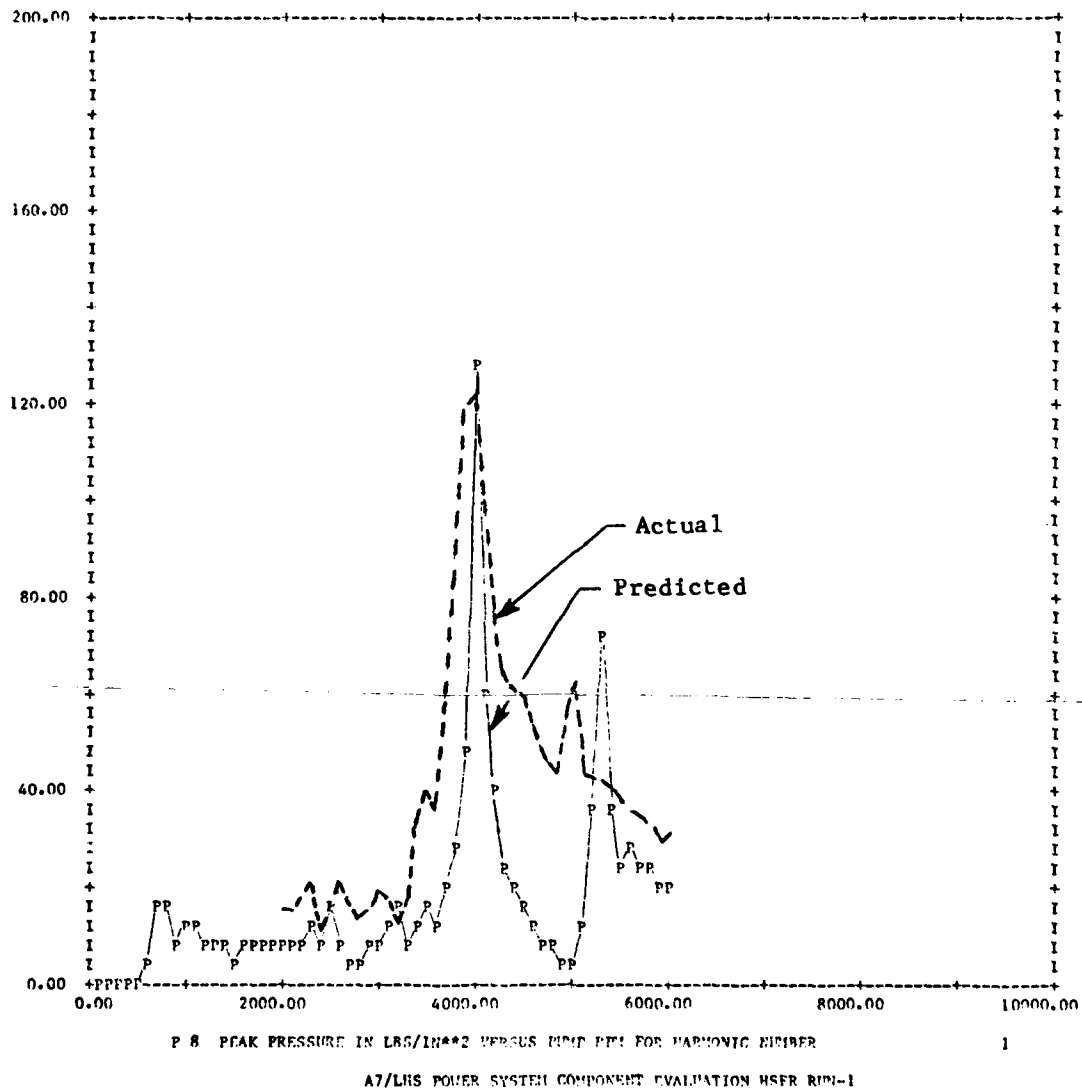
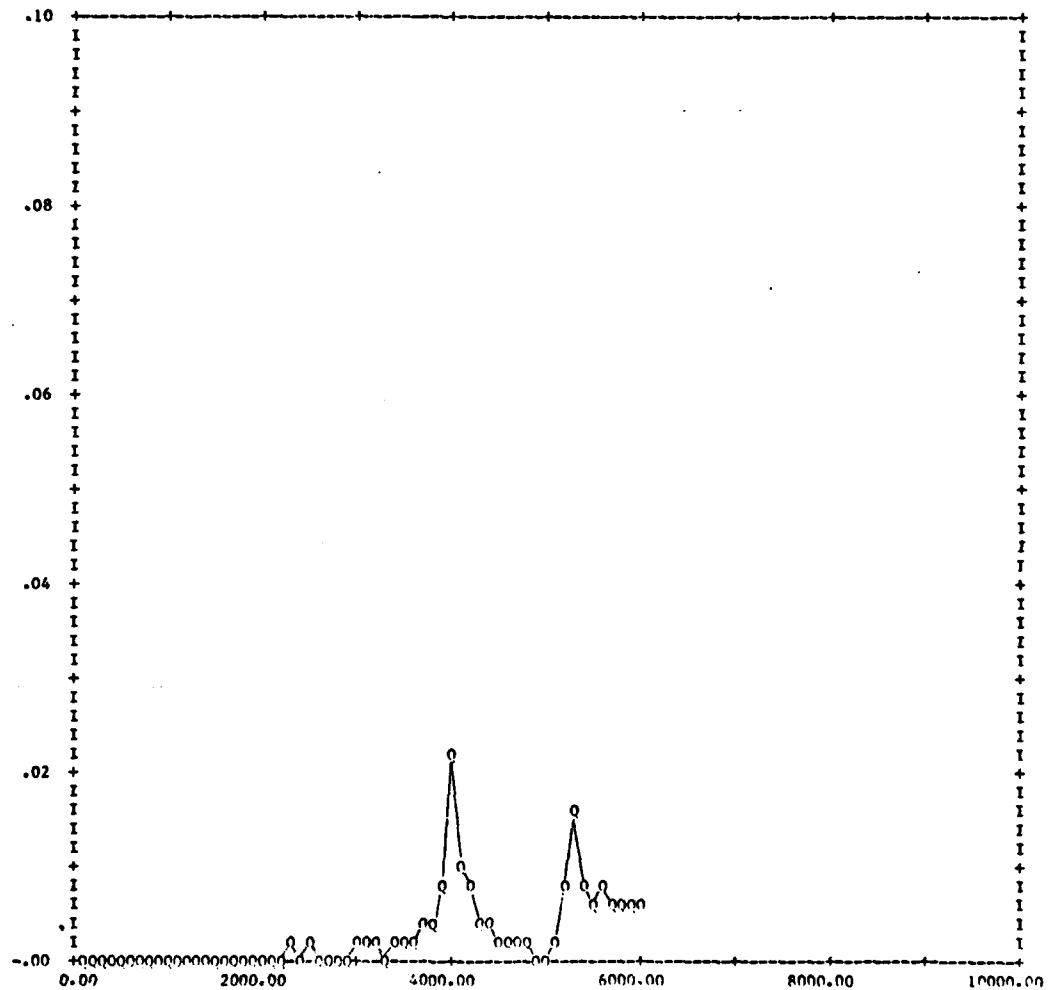


FIGURE 65. Peak pressure at P8, 1st harmonic



Q 8 PEAK FLOW IN CUBIC INCHES/SEC VERSUS PUMP RPM FOR HARMONIC NUMBER

A7/LHS POWER SYSTEM COMPONENT EVALUATION USER RUN-1

FIGURE 66. Peak flow at Q8

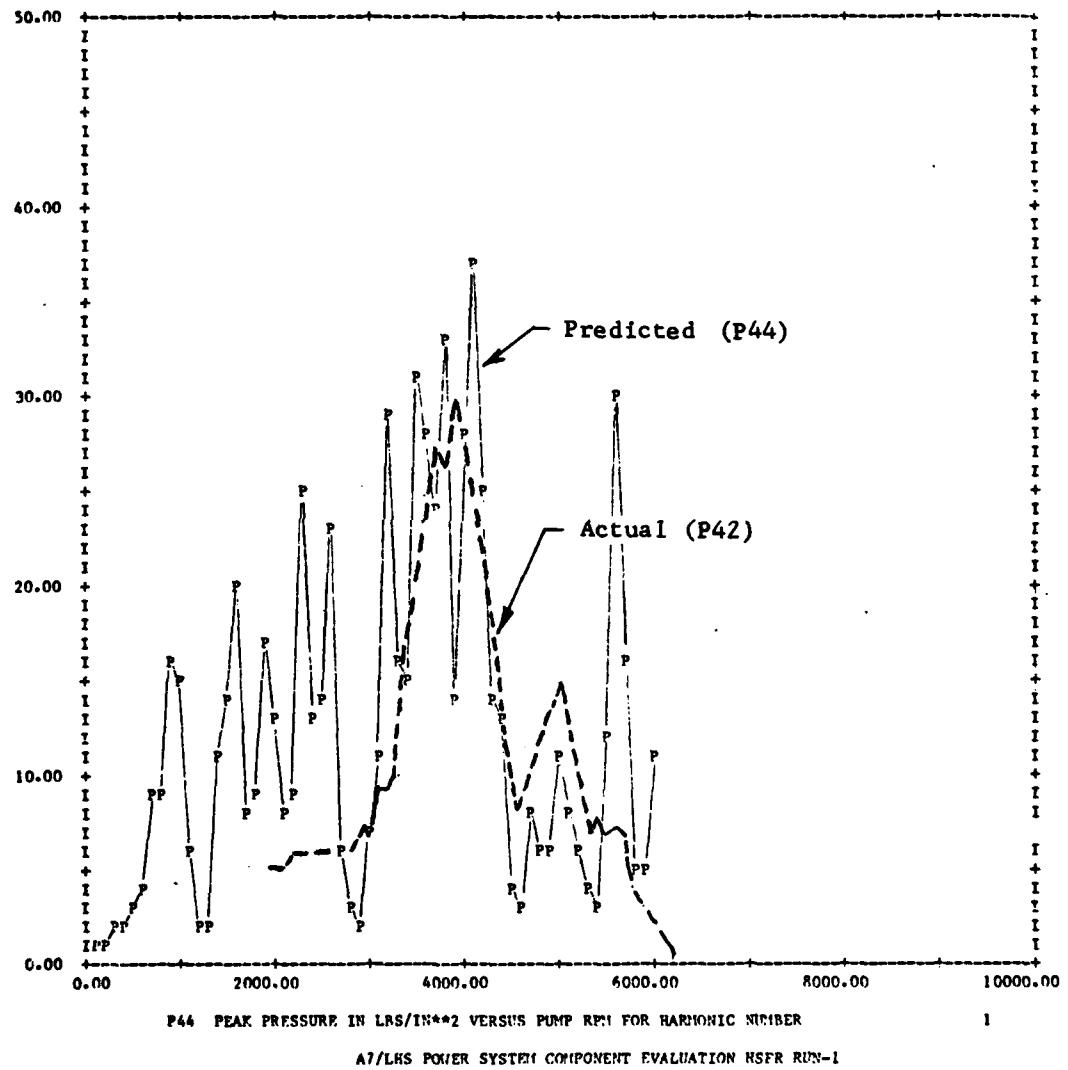


FIGURE 67. Peak pressure at P42 and P44, 1st harmonic

Spectrum analyzer data covering the first harmonic are shown on Figures 65 and 67. The measured data correlates well with the calculated data at element No. 8. Less correlation occurred at element No. 42. This was attributed to differences in fluid temperature due to the low flow rate and to marginal signal-to-noise ratios produced by the very small pressure pulsations occurring at element No. 42.

Comparison of measured and calculated second harmonic data at element No. 8 is given on Figure 68. The resonant speed conditions were predicted well, but the calculated amplitudes were much higher than the observed amplitudes.

The foregoing tests were repeated except the pump outlet temperature was increased to +200°F. First harmonic data correlated well with the predicted at 3900 rpm, but there was significant separation at higher speeds, Figure 69. Correlation of second harmonic frequencies was good, but calculated amplitudes were much higher than observed amplitudes, Figure 70.

### 6.3 DISCUSSION

The verification tests show that the HSFR modeling program produces viable, satisfactory predictions of hydraulic resonances for 8000 psi systems. The first harmonic test data showed good correlation with the predicted resonant frequencies and peak pressures. No major resonant conditions were predicted or measured especially at the pump operating speed of 5900 RPM. While the second harmonic resonant frequency predictions correlated well with the measured data, the measured amplitudes were considerably less than the peak amplitudes predicted by the model. The analytical model was reviewed to determine an explanation; however, nothing specific was uncovered and the problem was not pursued. Since the higher harmonic resonant amplitudes in general fall off well below those of the fundamental frequencies, and since the model predictions are conservatively high, the problem of amplitude matching at the higher harmonics is considered to be of minor significance.

The testing disclosed that the system resonances are sensitive to fluid temperature. The experimenter must be careful to insure that the fluid at the test locations being investigated is at the precise temperature initialized in the analytical model. Under low flow conditions, a significant temperature differential can exist between the pump outlet and an actuator located at the extreme end of the system. Therefore, the actuators should be exercised until a uniform fluid temperature is obtained which should provide better correlation between the calculated and measured data.

The verification tests show that the HSFR program is a sufficiently reliable analytical tool to permit its application on the full scale LHS simulator in Phase II. While no problem resonant conditions were evident during the verification tests, the predictive capabilities of the program can be used with confidence to avoid and/or correct potential problem areas related to pump induced resonances on the full scale simulator.

The HSFR program in conjunction with the HYTRAN transient analysis and the HYTTA thermal analysis programs will be evaluated on the LHS simulator during Phase II. The objectives of this effort will be to (1) evaluate the predictive capabilities of the three programs under controlled laboratory conditions, and (2) to identify and correct, within the scope of the program, problem areas in the analytical programs uncovered during testing.

#### 6.4 AIR FORCE DATA

A group of engineers from the Air Force Propulsion Laboratory at Wright Patterson Air Force base, Dayton, Ohio, visited NAAD in October 1980. The purpose of the visit was to observe the compatibility test setup in operation and to take spectrum analysis data using their test equipment. The group was headed by Mr. E. Binns, Systems Chief, and Mr. P. Linquist, Project Engineer. Equipment brought to NAAD were:

- Spectrum Analyzer
- X-Y Plotter
- Piezo-Electric Clamp-On Pressure Transducer

Spectrum scans were run with the transducer clamped at several locations in FC-1 and FC-2. The scans covered increasing pump speeds from 2000 to 6000 rpm, and decreasing speeds from 6000 to 2000 rpm. The data were stored in the spectrum analyzer during the scans, then retrieved and displayed by the X-Y plotter after system shut-down. Three data plots are presented in Appendix C. The data confirmed that the LHS pressure ripple spectrum was relatively quiet. Peak pressures were less than the maximum allowable 200 psi (single amplitude). No major hydraulic resonance was observed over a pump speed range of 2000 to 6000 rpm.

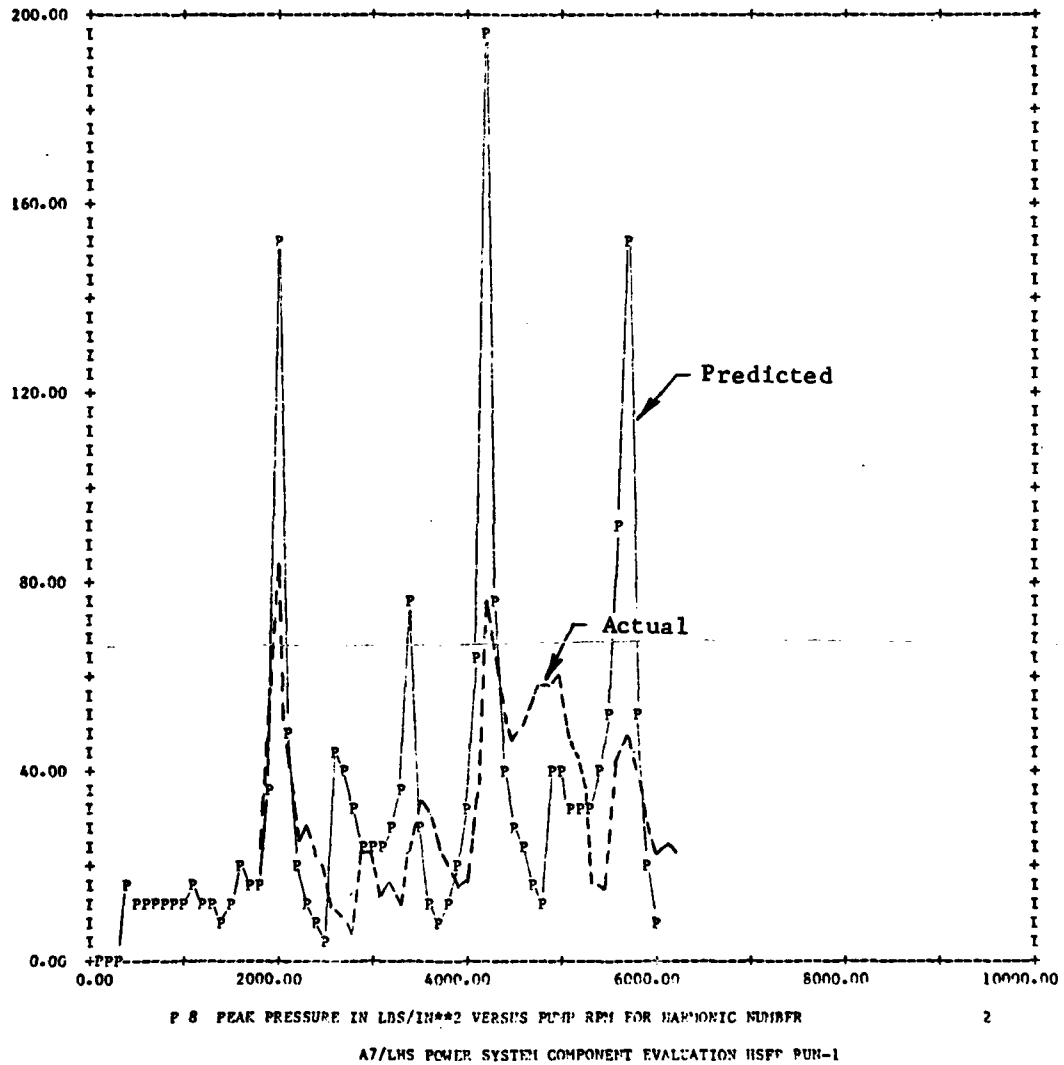
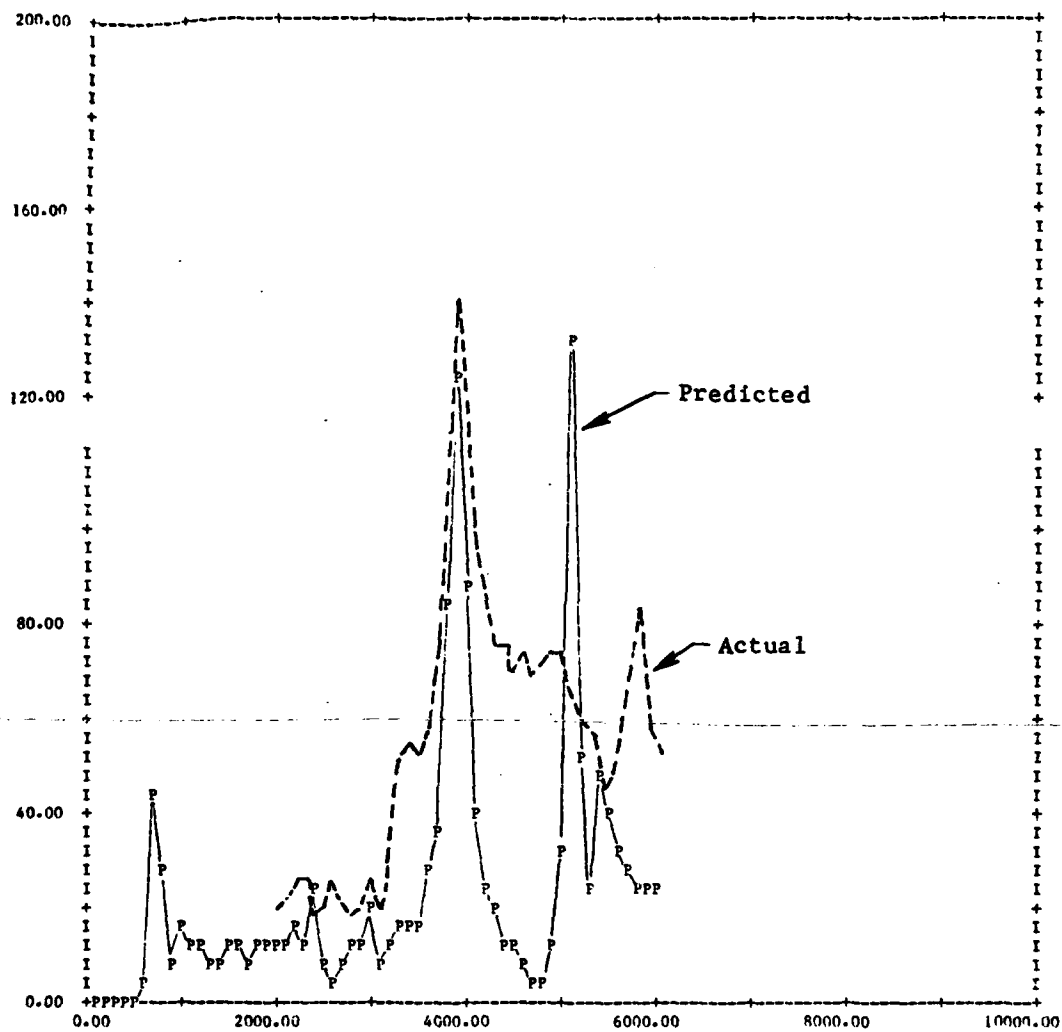


FIGURE 68. Peak pressure at P8, 2nd harmonic



P 8 PEAK PRESSURE IN LBS/IN\*\*2 VERSUS PUMP RPM FOR HARMONIC NUMBER

1

A7/LRS POWER SYSTEM COMPONENT EVALUATION HSER RUN-1

FIGURE 69. Peak pressure at P8, 1st harmonic, +200°F

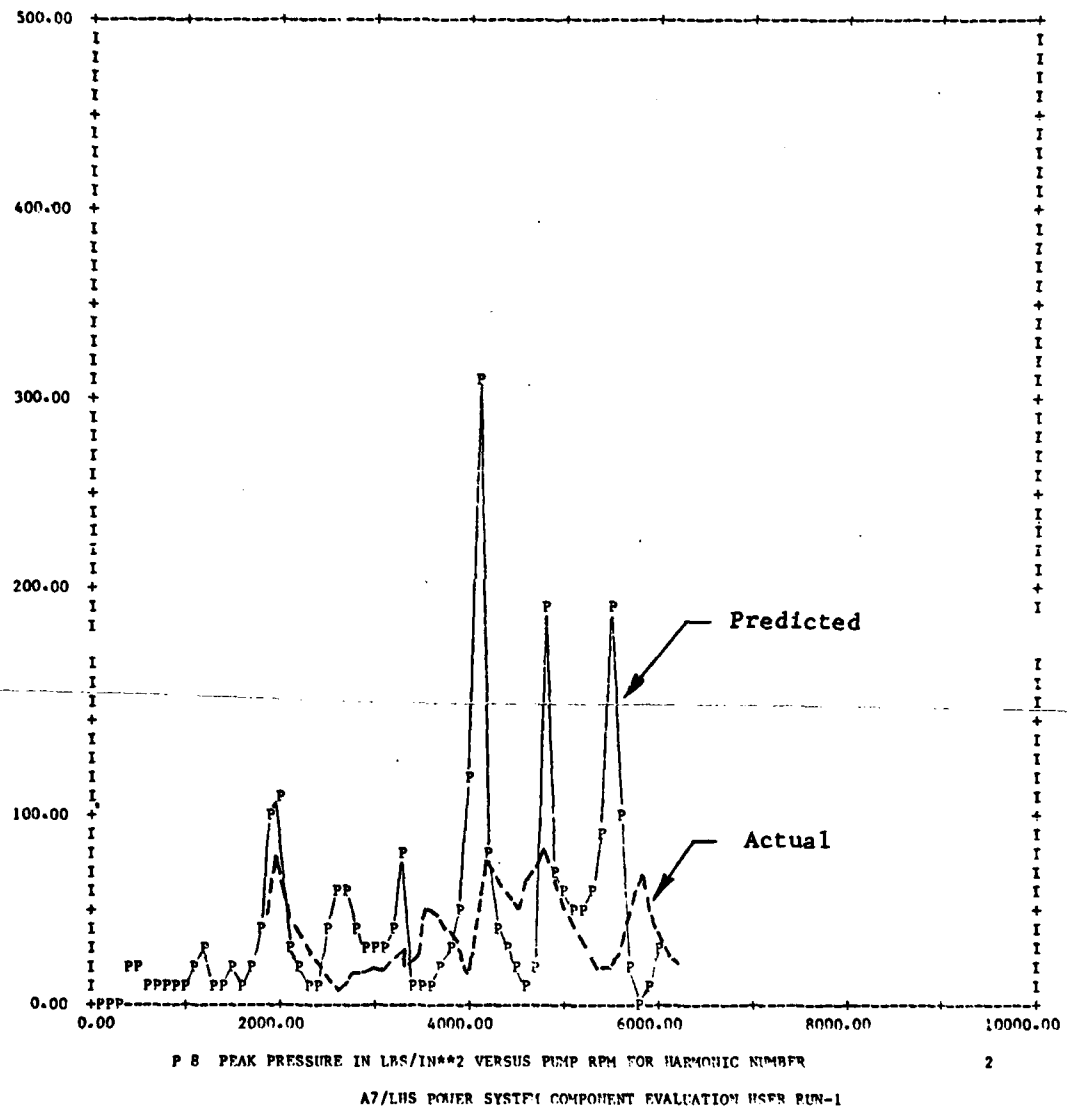


FIGURE 70. Peak pressure at P8, 2nd harmonic, +200°F

## 7.0 WEIGHT AND SPACE ANALYSIS

7.1 INTRODUCTION

The basic purpose of LHS technology is to reduce the weight of the installed hydraulic system. In addition, reduction in space occupied by smaller LHS components permits more compact installations, and in some cases, makes possible design approaches not practical with larger, lower pressure components. A major objective of the LHS program is to verify the projected 30% weight and 40% space savings achieved by progressing to an 8000 psi operating pressure level.

7.2 APPROACH7.2.1 General Guidelines

Since the A-7E 8000 psi system configuration differs somewhat from the existing A-7E 3000 psi system arrangement, the A-7E data were modified to reflect the same configuration as the LHS system. A discussion of the A-7E 3000 psi and A-7E LHS configurations is given in section 2.0. The emergency power package (ram air turbine) was not included in the analysis since it operated at 3000 psi in FC-2 and its configuration was unchanged.

The following terminology will be used to clarify identification of the systems involved:

|                               |                                                                                                                            |
|-------------------------------|----------------------------------------------------------------------------------------------------------------------------|
| EXISTING system               | The existing system or portion of a system configured in A-7E Aircraft BuNo 156801 and subsequents (A/C No. 157 and subs). |
| LHS system                    | The 8000 psi system or a portion of the system as depicted in Figure 3.                                                    |
| EQUIVALENT<br>3000 psi system | The existing system with changes incorporated to make it functionally identical to the LHS system.                         |

The analysis compares the weight and space values of the LHS system with the EQUIVALENT 3000 psi system. The data were tabulated in two forms. One was a listing by subsystem: power generation, distribution, and actuation. The second was a tabulation by major elements: tubing, actuators, fluid, pumps, reservoirs, etc.

The analysis involved assessment of each component and line on a part-for-part basis using actual weights and calculated volumes for both the 3000 psi and 8000 psi components. Line lengths were obtained from existing production drawings. Average fitting weights per line were established for each type fitting, line size, and material. Actual 3000 psi actuator weights were used where applicable. When actuators with steel barrels were required, the weight and volume of an equivalent 3000 psi steel barrel actuator was used.

Guidelines followed in the analysis are summarized below:

- The system arrangement for both the LHS and EQUIVALENT 3000 psi systems is depicted in Figure 3.
- Any changes in capacity resulting from the addition/deletion of a subsystem during the rearrangement of the existing system was accounted for in line/component size.
- Where feasible, existing line routing was followed. When not feasible, the new routing used by the LHS and EQUIVALENT 3000 psi systems were assumed to be identical. The 3000 psi system tubing material and fitting style were assumed to be the same as that used in the old routing.
- Design approaches made possible by utilizing LHS were incorporated, where applicable, such as replacing line extension units and swivels with small coiled tubing.
- The LHS pressure and return lines were 3 Al-2.5V cold worked, stress relieved titanium tubing with the following design criteria:

Pressure lines            24,000 psi burst pressure @ +275°F

Return lines            12,000 psi burst pressure @ +275°F

- Line weights were categorized as follows:

A line carrying fluid to or from more than one subsystem was considered to be in the "Distribution System".

Lines carrying fluid to or from only one subsystem were assigned to that subsystem.

#### 7.2.2 Tubing and Fittings

EQUIVALENT 3000 psi System - Each line assembly drawing in the 3000 psi FC-1 and FC-2 systems was reviewed to determine line size, material, and length, and fitting style and material. The line length thus determined was used in the 8000 psi analysis. Each 3000 psi line was tabulated and adjusted in size, if necessary, due to changes in flow resulting from systems rearrangement. Average fitting weights were determined for each style (MS or Aeroquip Braze), material (aluminum or steel), and size.

LHS System - The weight of each line was determined using actual line lengths or estimated line lengths where new routings were made. Average fitting weight per line was calculated using weights of the Deutsch Permaswage permanent fittings and Deutsch and Resistoflex "Dynatube" separable fittings.

### 7.2.3 Configuration Adjustments

Additional weight savings were achieved by incorporating the following adjustments:

- Use castings/forgings instead of "hog-outs"
- Use shrink-fit control valves on actuators instead of LHS valves made to fit standard size A-7 valve housings
- Run LHS pump at higher operating speed than is possible with existing A-7 gear box.
- Use LHS reservoir with more efficient design
- Use UHT actuator with the barrel diameter reduced one O-ring size

The above adjustments were included in both the EQUIVALENT 3000 psi and LHS system weight calculations. The adjustments were not included in the volume calculations because of their small effect. The reservoir, UHT actuator, and control valve changes are planned to be incorporated in the LHS aircraft system; the use of castings/forgings and change in pump speed are not planned for obvious economic and scheduling reasons.

### 7.3 RESULTS

Detail weight and space determinations are presented in Appendix C. Weight and space savings summaries are given on Tables 23 and 24. Weight savings achieved were:

|                                               |                 |
|-----------------------------------------------|-----------------|
| Total weight of<br>EQUIVALENT 3000 psi system | 644.4 lb        |
| Total weight of LHS system                    | <u>449.7 lb</u> |
| Weight reduction                              | 194.7 lb        |
| Weight savings                                | 30.2%           |

Space savings achieved were:

|                                               |                            |
|-----------------------------------------------|----------------------------|
| Total volume of<br>EQUIVALENT 3000 psi system | 8173 in <sup>3</sup>       |
| Total volume of LHS system                    | <u>5207 in<sup>3</sup></u> |
| Volume reduction                              | 2966 in <sup>3</sup>       |
| Space savings                                 | 36.3%                      |

Table 23. Weight Savings Summary

|            | <u>EQUIVALENT<br/>3000 psi<br/>System</u> | <u>Percent<br/>of Sys.<br/>Weight</u> | <u>LHS<br/>System</u> | <u>Percent<br/>Red. in<br/>Comp.Wt.</u> | <u>Percent<br/>Red. in<br/>Sys.Wt.</u> |
|------------|-------------------------------------------|---------------------------------------|-----------------------|-----------------------------------------|----------------------------------------|
| Actuators  | 303.9                                     | 47.2                                  | 257.6                 | -15.2                                   | -7.2                                   |
| Pumps      | 26.2                                      | 4.1                                   | 22.8                  | -13.0                                   | -0.6                                   |
| Reservoirs | 43.3                                      | 6.7                                   | 36.9                  | -14.8                                   | -1.0                                   |
| Tubing     | 75.9                                      | 11.8                                  | 31.4                  | -58.6                                   | -6.9                                   |
| Fittings   | 36.9                                      | 5.7                                   | 11.2                  | -69.6                                   | -4.0                                   |
| Fluid      | 76.0                                      | 11.8                                  | 38.9                  | -48.8                                   | -5.7                                   |
| Misc.      | <u>82.2</u>                               | <u>12.7</u>                           | <u>50.9</u>           | -38.1                                   | <u>-4.8</u>                            |
|            | 644.4 lb                                  | 100%                                  | 449.7 lb              |                                         | -30.2%                                 |

Table 24. Space Savings Summary

|            | <u>EQUIVALENT<br/>3000 psi<br/>System</u> | <u>Percent<br/>of Sys.<br/>Volume</u> | <u>LHS<br/>System</u> | <u>Percent<br/>Red. in<br/>Comp.Vol.</u> | <u>Percent<br/>Red. in<br/>Sys.Vol.</u> |
|------------|-------------------------------------------|---------------------------------------|-----------------------|------------------------------------------|-----------------------------------------|
| Actuators  | 3605                                      | 44.1                                  | 2304                  | -36.1                                    | -16.1                                   |
| Pumps      | 342                                       | 4.2                                   | 236                   | -31.0                                    | -1.3                                    |
| Reservoirs | 1634                                      | 20.0                                  | 1187                  | -27.4                                    | -5.5                                    |
| Tubing     | 1243                                      | 15.2                                  | 596                   | -52.0                                    | -7.9                                    |
| Fittings   | 319                                       | 3.9                                   | 145                   | -54.5                                    | -2.1                                    |
| Misc.      | <u>1030</u>                               | <u>12.6</u>                           | <u>739</u>            | -28.2                                    | <u>-3.4</u>                             |
|            | 8173 in <sup>3</sup>                      | 100 %                                 | 5207 in <sup>3</sup>  |                                          | -36.3%                                  |

The 30% weight savings goal was reached; the 40% space savings goal was nearly reached. Weight values are easily obtained using scales. Volume determinations are more difficult, and if calculated, require many approximations. The most accurate and practical method to determine component volume is water displacement; this was not attempted. More accurate and complete volume figures would increase space savings from the reported 36.3% to a value very close to the 40% goal.

## 8.0 R&M ASSESSMENT

### 8.1 INTRODUCTION

The purpose of the LHS technology development program is to establish the practicality of using an 8000 psi operating pressure to attain smaller and lighter weight hydraulic systems for future aircraft. Reliability and Maintainability (R&M) considerations are a part of this program, the objectives of which are to assess the potential gains high pressure technology may have for R&M, and to identify and resolve (or recommend programs to resolve) R&M improvement opportunities in hydraulic systems or components.

### 8.2 R&M MODELS

The LHS as designed for this development is configured for an A-7 airplane which is to be used as a flight test vehicle for LHS in later phases of the program. The baseline for comparison of the LHS R&M has therefore been selected as the current A-7E hydraulic system. The development system will be comprised of components necessary for providing hydraulic power to the flight control system on A-7E aircraft. These components constitute those hydraulic elements of Work Unit Code (WUC) 14 and the FC-1 and FC-2 power systems of WUC 45. The Mean-Flight-Hours-Between-Failure (MFHBF) and the Maintenance-Man-Hours per Flight Hour (MMH/FH) models constructed for this program are structured from a listing of components for the LHS designed for this program. The MFHBF and the MMH/FH models are contained in Appendices D and E, respectively, of this Phase I program report.

The item numbers listed for each component identified on the model format correspond to the items as identified on the LHS schematic drawing 8696-580001, Figure 5. The format provides for listing the MFHBF/MMH/FH for both the 8000 psi components and equivalent 3000 psi components. This allows for a direct comparison of R&M between components of the current and high pressure systems. A column for Remarks/Rationale provides for a brief description of the basis upon which the 8000 psi component was predicted relative to the current experience.

### 8.3 BASELINE DATA SOURCES

The MFHBF used as a baseline for components of the 3000 psi system were established from a three year/353,446 flight hours sample of Navy 3M data for the A-7E airplane. This data was compiled, analyzed, and summarized by the Vought Corporation as a part of the A-7E program, and provided for use in the LHS program as a baseline set of typical current aircraft hydraulic reliability data. Failure criteria was established from the reported malfunction codes in the 3M data. Specific codes were judged as not being failures related to a deficiency in the given component, and were therefore excluded in calculating the MFHBF. The censorship criteria used is presented in Table 25. These same rules applied to the prediction of 8000 psi components.

Table 25. Censorship Criteria for Navy 3M Data

The following data codes were censored to obtain equipment level failures:

1. Burned out light bulbs or fuses
2. Improper handling
3. Missing parts
4. Loose or damaged bolts, nuts, or other common hardware
5. Broken, faulty, or missing safety wire or key
6. Cut
7. Deteriorated
8. On aircraft adjustment or alignment
9. Launch damage
10. Improper or faulty maintenance
11. Foreign object damage
12. Bird strike damage
13. FOD--self induced by ingestion of aircraft parts
14. Non-metallic contamination or dirty (except for hydraulic pump)
15. Lack of, or improper, lubrication
16. Nicked or chipped
17. Failed or replaced due to associated equipment
18. Air in system
19. Corroded (on aircraft maintenance only)
20. Faulty tape--program or checkout
21. Loose (on aircraft maintenance only)
22. Battle damage
23. Obsolete/surplus
24. Transportation damage
25. Weather damage
26. Burned or overheated (on hydraulic pumps only)
27. Accidental or inadvertent operation
28. Metal in oil strainer
29. Failure discovered upon removal from supply
30. System level work unit codes (zero in fifth digit; i.e., 14750)
31. Corrosion control
32. Repair and/or replacement of attaching units, seals, gaskets, packing, electrical connections, wiring, circuits, tubing, hose, connectors, fittings, etc., that are not an integral part of work unit coded items or components as purchased from the manufacturer and held in the supply system in an RFI status

The MMH/FH 3000 psi baseline data was extracted from a 132,420 flight hours sample of A-7E 3M data. This data was machine processed by the Vought Corporation, summarizing MMH/FH for each WUC.

#### 8.4 PREDICTIONS

The limited test information available during this Phase I program hindered an in-depth analysis and prediction of reliability. All major components were designed and selected components fabricated for this program phase. The pump prediction presented was projected from an estimate made by Sperry-Vickers based on a failure-modes-and-effects-analysis (FMEA). The actuators (with exception of the rudder actuator), coiled tubing, and reservoir predictions were prepared by the Vought Corporation by a direct comparison to the design of the 3000 psi components. The number of leak paths was the basis of comparison for the projections; the improved seals and smaller piston size factors were assumed to be offset by the higher pressures for this initial prediction. The predictions prepared by Vought were adjusted by Rockwell to reflect slight differences between the data bases used in order to maintain consistency.

Reliability of minor LHS components was subjectively predicted by discussions between hydraulic system/laboratory engineers and the reliability engineer. When specific reasons could not be envisioned to substantiate either an improvement or degradation in failure rate, the estimate remained unchanged from the A-7E baseline. Where known factors influence the failure rate, these factors/rationale are briefly noted in the appropriate column of the prediction format.

Maintainability predictions for the LHS were changed proportionately to the reliability estimates. A reduced failure frequency was assumed to reduce the MMH/FH by the same proportion. Most maintenance time is a result of installation factors, and this program is not intended to improve on the basic maintenance characteristics that are already inherent in the A-7 airplane. At this phase in the program, when the hardware is limited and not installed in an aircraft, the frequency of maintenance is the most influential factor defining differences between 8000 psi and 3000 psi systems. The predictions for both R&M are included in the R&M models of Appendices D and E, respectively.

#### 8.5 FAILURE REPORTS AND ANALYSIS

Laboratory logs of all operations and failures during the Phase I testing were maintained on an hourly/daily basis. A summary of the reliability and maintainability significant actions relative to the LHS components is summarized in Table 26. Also presented in the table is a brief summary of the actions/initial analysis made of the failure. Appendix F includes analyses from Vought, Sperry-Vickers, and Bendix on failures experienced with the actuators, pumps, and solenoid valves, respectively.

TABLE 26. Failure Reports And Analysis

| COMPONENT                        | PART NUMBER                           | TEST               | TIME OF FAILURE                 | FAILURE DESCRIPTION/LOCATION                                                                                                                                                           | PROBABLE CAUSE OF FAILURE                                                                                                                                                                                                                                                  | PRELIMINARY RECOMMENDATIONS                                                                                                                                                                                                                 |
|----------------------------------|---------------------------------------|--------------------|---------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| RUDDER ACTUATOR<br>CONTROL VALVE | 83-00213                              | ACCEPTANCE         | --                              | -SPOOL STICKS WHEN ALLOWED TO<br>REMAIN AT ONE POSITION FOR<br>MORE THAN APPROX. 10 SEC.                                                                                               | -INSUFFICIENT DIAMETRAL<br>CLEARANCE BETWEEN SPOOL<br>AND SLEEVE. OPERATION AT<br>8000 PSI CAUSED SLEEVE TO<br>DEFLECT INWARD AND CLAMP<br>3-LAND SPOOL. CHECKOUT<br>TESTS AT 3000 PSI DID NOT<br>DEFLECT SLEEVE SUFFICIENTLY<br>TO CLAMP SPOOL AND SHUT OFF<br>NULL FLOW. | 1. INCREASE DIAMETRAL<br>CLEARANCE BETWEEN<br>SPOOL AND SLEEVE                                                                                                                                                                              |
| URT ACTUATOR<br>CONTROL VALVE    | 83-00213-111                          |                    | SEE SECT.<br>5.3.6.2            | -NULL LEAKAGE NEAR ZERO WHEN<br>VALVE STICKS<br>-VALVE PERFORMS SATISFACTORILY<br>AS LONG AS SPOOL IS MOVING                                                                           |                                                                                                                                                                                                                                                                            |                                                                                                                                                                                                                                             |
| PUMP                             | PV3-047-2<br>S/N 346581<br>S/N 348168 | ACCEPTANCE         | --                              | 1. EXCESSIVE PRESSURE DROOP<br>2. EXCESSIVE HEAT REJECTION<br>3. COMPENSATOR SETTING<br>AFFECTED BY OPERATING<br>TEMPERATURE                                                           | 1. NORMAL DEVELOPMENT PROBLEM<br>2. DISTORTION IN VALVE BLOCK.<br>EXCESSIVE PISTON/BORE<br>CLEARANCE<br>3. NORMAL DEVELOPMENT PROBLEM                                                                                                                                      | 1. REVISE PUMP TIMING,<br>INCREASE YOKE MOMENT<br>2. REPLACE ALUMINUM VALVE<br>BLOCK WITH STEEL, RE-<br>QUIRE CLOSER CONTROL ON<br>PISTON/BORE DIMENSIONS<br>3. INCREASE CONTROL PISTON<br>DIA., PUT ORIFICE IN<br>CONTROL PRESSURE CIRCUIT |
| TEE                              | DNR10023-<br>080308                   | PROOF              | --<br><br>SEE SECT.<br>5.3.6.4  | - 8 SIZE TUBE BLEW OUT OF<br>ONE LEG OF TEE AT 15,500<br>PSI (FC-1 SYSTEM)                                                                                                             | - 21-6-9 CRES TUBING HAS<br>TENSILE STRENGTH OF<br>155,000 PSI<br>- LHS TUBING THUS HARDER<br>THAN CONVENTIONAL TUBING                                                                                                                                                     | 1. PERFORM 3 SHAGING<br>OPERATIONS 120° APART<br>INSTEAD OF ONE SWAGE<br>NORMALLY RECOMMENDED                                                                                                                                               |
| ADAPTER<br>FITTING               | R44182T-08                            | COMPATI-<br>BILITY | 39.3 HRS.<br>SEE TABLE 19       | -SPRAY LEAK FROM BOSS SEAL<br>ON INLET PORT OF FC-1<br>PRESSURE FILTER                                                                                                                 | -O-RING FAILED DUE TO ROUGH<br>SURFACE ON FITTING WHERE<br>O-RING SEALED                                                                                                                                                                                                   | 1. ASSURE QUALITY CONTROL<br>OF DRY FILM COATING ON<br>FITTING                                                                                                                                                                              |
| O-RING                           | MS28778-04                            | COMPATI-<br>BILITY | 45.7 HRS.<br><br>SEE TABLE 19   | -LOW PRESSURE LEAK OCCURRED<br>OVER WEEKEND. RESERVOIR<br>BOOTSTRAP PRESSURE CAUSED<br>FLUID LOSS<br>-LEAK OCCURRED AT MS BULK-<br>HEAD FITTING NEAR P5 PRESSURE<br>TRANSDUCER IN FC-2 | -O-RING HAD PERMANENT SET<br>-O-RING MAY HAVE HAD OUT-<br>OF-DATE CURE DATE                                                                                                                                                                                                | 1. ASSURE THAT O-RING HAS<br>PROPER CURE DATE                                                                                                                                                                                               |
| PUMP                             | PV3-047-2<br>S/N 346581               | COMPATI-<br>BILITY | 50 HRS.<br>SEE SECT.<br>5.3.6.1 | -EXCESSIVE CASE FLOW DEVELOPED<br>DURING 50 HR. PERFORMANCE<br>CHECK (FC-1 PUMP)                                                                                                       | -PART OF ONE PISTON SHOE<br>MISSING DUE TO BRAZING<br>VOIDS                                                                                                                                                                                                                | 1. ASSURE QUALITY CONTROL<br>OF BRAZING PROCESS                                                                                                                                                                                             |

TABLE 26. Failure Reports And Analysis (Continued)

| COMPONENT            | PART NUMBER             | TEST          | TIME OF FAILURE                                         | FAILURE DESCRIPTION/LOCATION                                                                                                                                                                                                                                                                                                                        | PROBABLE CAUSE OF FAILURE                                                                                                          | PRELIMINARY RECOMMENDATIONS                                                                                                                                                                                                                                                                                                                        |
|----------------------|-------------------------|---------------|---------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| PUMP                 | PV3-047-2<br>S/N 346581 | COMPATIBILITY | 56.2 HRS.<br>SEE SECT.<br>5.3.6.1                       | -PIN HOLE LEAK DEVELOPED IN VALVE BLOCK OF FC-1 PUMP                                                                                                                                                                                                                                                                                                | -FATIGUE STRENGTH OF MATERIAL TOO LOW                                                                                              | 1. REPLACE ALUMINUM VALVE BLOCK WITH STEEL VALVE BLOCK                                                                                                                                                                                                                                                                                             |
| PUMP                 | PV3-047-2<br>S/N 348168 | COMPATIBILITY | 102.6 HRS.<br>SEE SECT.<br>5.3.6.1                      | -EXTERNAL LEAK DEVELOPED IN JOINT BETWEEN VALVE BLOCK AND HOUSING OF FC-2 PUMP                                                                                                                                                                                                                                                                      | -EROSION PITTING OF O-RING GLAND IN ALUMINUM VALVE BLOCK CAUSED O-RING TO FAIL.<br>-VALVE BLOCK MATERIAL TOO SOFT.                 | 1. REPLACE ALUMINUM VALVE BLOCK WITH STEEL VALVE BLOCK                                                                                                                                                                                                                                                                                             |
| PUMP                 | PV3-047-2<br>S/N 348168 | --            | FAILURE NOTED DURING PUMP DIS-ASSEMBLY AT 102.6 HRS.    | -SPALLING ON HIGH PRESSURE PINTLE BEARING INNER RACE (FC-2 PUMP)                                                                                                                                                                                                                                                                                    | -DESIGN LOAD TOO LOW                                                                                                               | 1. USE HEAVIER DUTY BEARING                                                                                                                                                                                                                                                                                                                        |
| 4-WAY SOLENOID VALVE | 3321472                 | COMPATIBILITY | 119.0 HRS.<br>(19 HRS ON VALVE)<br>SEE SECT.<br>5.3.6.8 | -VALVE STOPPED OPERATING AT 1043 CYCLES.<br>-VALVE IN SPEED BRAKE SECTION IN FC-1 SYSTEM                                                                                                                                                                                                                                                            | -SOFT SOLENOID SPACER PIN CAUSED LOSS OF SOLENOID STROKE.<br>-DAMAGED PILOT PIN - INSUFFICIENT MATERIAL TO REACT LOAD              | 1. ASSURE PROPER HEAT TREAT OF SPACER PIN<br>2. REDESIGN PILOT PIN CONFIGURATION                                                                                                                                                                                                                                                                   |
| AFCs ACTUATOR        | 83-00231                | COMPATIBILITY | 128.9 HRS.<br>SEE SECT.<br>5.3.6.2                      | -CYLINDER #2 PISTON OPERATION BECAME ROUGH.<br>-ACTUATOR IN FC-2 SYSTEM.                                                                                                                                                                                                                                                                            | -INTERNAL BINDING SUSPECTED.<br>-CAUSE OF ROUGH OPERATION TO BE DETERMINED WHEN ACTUATOR IS DISASSEMBLED.                          |                                                                                                                                                                                                                                                                                                                                                    |
| FLUID                | MIL-H-83282             | COMPATIBILITY | --<br><br>SEE SECT.<br>5.3.6.3                          | PUMP CASE DRAIN FILTERS IN FC-1 AND FC-2 SYSTEMS BECAME LOADED WITH BLACK PARTICLES, NECESSITATING FREQUENT ELEMENT CHANGES. BLACK PARTICLES ALSO NOTED IN FC-1 AND FC-2 PRESSURE AND RETURN FILTERS, HOWEVER THESE FILTERS HAD A LARGER CAPACITY AND WERE NOT CHANGED DURING THE 150 HR. TEST. PARTICLE SIZE ESTIMATED TO BE LESS THAN ONE MICRON. | -CAUSE AND SOURCE OF THE BLACK PARTICLES NOT ESTABLISHED.<br>-PRIOR ANALYSIS DISCLOSED THE PARTICLES ARE 99% CARBON, REFERENCE 10. | 1. THE FOLLOWING OBSERVATIONS SHOULD BE NOTED:<br>-HUNDREDS OF HOURS OF TESTING HAVE BEEN ACCUMULATED AT NADC USING MIL-H-83282 AT 8000 PSI. NO BLACK PARTICLES HAVE BEEN OBSERVED.<br>-A 400 HR. SEAL TEST WAS CONDUCTED BY VOUCHT USING MIL-H-83282 AT 8000 PSI. NO BLACK PARTICLES WERE OBSERVED.<br>2. INVESTIGATION IN THIS AREA IS WARRANTED |

TABLE 26. Failure Reports And Analysis (Continued)

| COMPONENT                                     | PART NUMBER | TEST                | TIME OF FAILURE            | FAILURE DESCRIPTION/LOCATION                                                                                                                                                              | PROBABLE CAUSE OF FAILURE                                                                                              | PRELIMINARY RECOMMENDATIONS                                                                                                                                                         |
|-----------------------------------------------|-------------|---------------------|----------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 3-WAY SOLENOID VALVE                          | 3321473     | PRESSURE IMPULSE    | NOT KNOWN<br>SEE SECT. 5.4 | -VALVE INOPERATIVE<br>-FAILURE NOT DETECTED UNTIL AFTER COMPLETION OF 40,000 CYCLE TEST                                                                                                   | -SOFT SOLENOID SPACER PIN CAUSED LOSS OF SOLENOID STROKE.<br>-DAMAGED PILOT PIN - INSUFFICIENT MATERIAL TO REACT LOAD. | 1. ASSURE PROPER HEAT TREAT OF SPACER PIN<br>2. REDESIGN PILOT PIN CONFIGURATION                                                                                                    |
| QUICK DISCONNECT (UNCOUPLED, WITH DUST COVER) | AE80943H    | PRESSURE IMPULSE    | NOT KNOWN<br>SEE SECT. 5.4 | -WEB AREAS BETWEEN PORTING HOLES IN STEEL VALVE FAILED.<br>-FAILURE NOT DETECTED UNTIL AFTER COMPLETION OF 40,000 CYCLE TEST.                                                             | -INSUFFICIENT MATERIAL IN WEB AREAS BETWEEN PORTING HOLES.                                                             | 1. SPECIFICATION LHS-8828 HAS NO PRESSURE IMPULSE TEST REQUIREMENTS FOR UNCOUPLED DISCONNECTS<br>2. UPDATE LHS-8828 SPECIFICATION AND INVOKE COMPLIANCE WITH REVISED SPECIFICATION. |
| O-RING                                        | MS28775-015 | COMPONENT ENDURANCE | 800 CYCLES<br>SEE TABLE 21 | -FACE SEAL O-RING EXTRUDED OUT<br>-SEAL ON AIR FILL VALVE FOR LHS ACCUMULATOR                                                                                                             | -AIR FILL VALVE LOOSE IN BOSS PORT ON MANIFOLD                                                                         | 1. LOCKWIRE AIR FILL VALVE TO MANIFOLD<br>2. AIR FILL VALVE USED WAS MS28889 AND RATED FOR 5000 PSI SERVICE<br>3. PROCURE LHS AIR FILL VALVE WITH BOSS TYPE STATIC SEAL             |
| CHECK VALVE                                   | 95202-5     | COMPONENT ENDURANCE | 826 CYCLES<br>SEE TABLE 21 | -DIAMETRAL SEAL EXTRUDED OUT<br>-VALVE USED PREVIOUSLY IN 150 HR. COMPATIBILITY TEST IN FC-2 SYSTEM                                                                                       | -IMPROPER GLAND DESIGN<br>-VALVE HALVES WORKED LOOSE                                                                   | 1. INCREASE OVERLAP AT SEAL DIAMETRAL CLEARANCE<br>2. INCREASE ASSEMBLY TORQUE<br>3. INSTALL LOCKWIRE ON VALVE                                                                      |
| CHECK VALVE                                   | 95201-5     | COMPONENT ENDURANCE | NOT KNOWN<br>SEE TABLE 21  | -POPPET FAILED IN WEB AREAS AROUND PORTING HOLES<br>-FAILURE NOT DETECTED UNTIL AFTER COMPLETION OF ENDURANCE TEST<br>-VALVE USED PREVIOUSLY IN 150 HR. COMPATIBILITY TEST IN FC-1 SYSTEM | -INSUFFICIENT MATERIAL IN WEB AREAS AROUND PORTING HOLES                                                               | 1. INCREASE POPPET WEB AREAS                                                                                                                                                        |

TABLE 26. Failure Reports And Analysis (Continued)

| COMPONENT                           | PART NUMBER           | TEST                            | TIME OF FAILURE                        | FAILURE DESCRIPTION/LOCATION                                                                                                                                                  | PROBABLE CAUSE OF FAILURE                                                                                                                                                                            | PRELIMINARY RECOMMENDATIONS                                                                                        |
|-------------------------------------|-----------------------|---------------------------------|----------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|
| 4-WAY SOLENOID VALVE<br>(RE-WORKED) | 3321472               | COMPONENT ENDURANCE             | 3000 CYCLES<br><br>SEE SECT.<br>5.5    | -VALVE BEGAN TO MALFUNCTION AT 2530 CYCLES AND STOPPED OPERATING AT 3000 CYCLES.<br>-VALVE OPERATED PREVIOUSLY FOR 1518 CYCLES IN COMPATIBILITY TEST.                         | -RETURN BALL IN PILOT VALVE WEDGED IN CROSS DRILLED FLOW PASSAGE, AND JAMMED WHEN SOLENOID WAS ENERGIZED.<br>-HARDENED SPACER PIN AND PILOT PIN DAMAGED DUE TO ECCENTRIC LOADING ON DIS-LODGED BALL. | 1. RELOCATE CROSS DRILLED FLOW PASSAGE                                                                             |
| LIP SEAL TYPE SEPARABLE FITTING     | DEUTSCH & RESISTOFLEX | COMPATIBILITY, PRESSURE IMPULSE | --<br><br>SEE SECT.<br>5.3.6.4 & 5.4.2 | -SLIGHT SEEPAGE FROM SEPARABLE JOINTS.<br>-RATE ESTIMATED AT 1 DROP PER 10 HOURS OF TEST TIME.<br>-APPROX. 30% OF JOINTS IN A TEST SYSTEM SEEPED. REMAINING 70% DID NOT SEEP. | 1. MINUTE IMPERFECTIONS ON LIP SEAL SURFACES MADE DURING MANUFACTURE.<br>2. SMALL SCRATCHES MADE ON LIP SEAL SURFACES DURING PLUMBING FABRICATION.                                                   | 1. ASSURE CAREFUL MANUFACTURING AND HANDLING PROCEDURES.<br>2. ASSURE CAREFUL FABRICATION AND HANDLING PROCEDURES. |

The pumps have been the pacing components in the test program, and these problems have been expanded upon and briefed in the quarterly reports and coordination meetings. The resulting program stretch-out, and re-ordering of events between the Phase I and Phase II programs have established that more detailed failure analysis of the Phase I test program will be more efficiently combined with the FMEA studies of Phase II. Thus, the impact of the failures on the system R&M predictions will be assessed relative to the final FMEA. A preliminary FMEA has been completed, and review is now being initiated by Rockwell engineers in conjunction with the Phase I test results/failures just completed.

Significant to R&M concerns with the LHS is the frequency of filter element changes. Related to this is the frequent patch tests conducted during the program in which a black substance was collected from the fluid. This has been noted in previous high pressure hydraulic programs, but the cause is speculative. Although this has occurred only in the Rockwell conducted tests, it is recommended that a controlled test/study effort be directed to determine the exact cause.

#### 8.6 CONCLUSIONS/RECOMMENDATIONS

The A-7 FMEA for the hydraulics system was reviewed with the reported maintenance and failure data from A-7E operations to establish the more significant R&M factors. The failure modes and the malfunction codes from the 3M data verifies that leaking is by far the most significant factor in the cause of repair actions in hydraulic systems. An analysis of the baseline data compiled for the 3000 psi system revealed that 10 components, or component types, contribute over 75% of the total failure rate. These items and their respective contributions are listed in Table 27.

TABLE 27. Failure Rate Contributions to Current Hydraulic Systems

| <u>Item</u>          | <u>% Contribution</u> |
|----------------------|-----------------------|
| Extension Units      | 23                    |
| Disconnects          | 11.4                  |
| Filters              | 10.6                  |
| Tubing/Fittings      | 6.5                   |
| AFCS Actuators       | 6.5                   |
| Aileron Actuators    | 5.6                   |
| Swivel Joints        | 4.5                   |
| Pumps                | 4.0                   |
| Pressure Transmitter | 2.7                   |
| UHT Actuator         | 2.6                   |

The potential leaking problem with high pressures was addressed early in the program. As a part of the initial planning, a seal improvement and test program was structured to establish the optimum seals to be used in high pressure components. The improved seals resulting from these tests have been used in the design of the actuators which were built and tested during this program phase.

The extension units, recognized as the highest contributing item to system failure rate, were able to be eliminated by the use of coiled tubing. Use of the coiled tubing became possible directly as a result of the high pressure technology. This facilitated the use of smaller diameter tubing for the coils, which in turn, allowed for installation within the space restrictions in the A-7 airplane.

The recognition and actions taken during this program phase on the above potential problems have resulted in a projected 44% improvement in system MFHBF and a 16.7% improvement in system MMH/FH. These improvements are based on the actions taken for the development hardware, and which were identified in the rationale for the predictions. It is premature at this phase in the program to "identify further improvements which may be implemented for production; therefore, production improvements percentages have not been estimated at this time. The program goal of 15% improvement in system R&M for development hardware appears to have been exceeded based on the program efforts to date. The improvements achieved re-orders the failure rate contributors; the revised order being shown in Table 28.

TABLE 28. Failure Rate Contribution to 8000 psi Hydraulic System

| <u>Item</u>          | <u>% Contribution</u> |
|----------------------|-----------------------|
| Quick Disconnects    | 16.5                  |
| Filter               | 15.3                  |
| AFCS Actuators       | 6.6                   |
| Aileron Actuators    | 5.9                   |
| Pump                 | 5.3                   |
| Tubing and Fittings  | 4.7                   |
| Pressure Transmitter | 3.9                   |
| UHT Actuator         | 3.8                   |
| Swivel Joints        | 3.4                   |
| Reservoir            | 3.3                   |

Ordering the six highest maintenance rate items, Table 29, it is noted that five of the six are also among the top failure rate contributors.

TABLE 29. Maintenance Rate Contributions to 8000 psi Hydraulic System

| <u>Item</u>       | <u>% Contribution</u> |
|-------------------|-----------------------|
| UHT Actuator      | 15                    |
| Restrictors       | 12.6                  |
| AFCS Actuators    | 10.2                  |
| Filters           | 9.3                   |
| Aileron Actuators | 7.6                   |
| Pumps             | 5.8                   |

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ROCKWELL INTERNATIONAL COLUMBUS OH NORTH AMERICAN AI--ETC F/G 13/7  
DESIGN, DEVELOPMENT, AND EVALUATION OF LIGHTWEIGHT HYDRAULIC SY--ETC(U)  
JAN 81 J N DEMARCHI, R K HANING N62269-78-C-0363

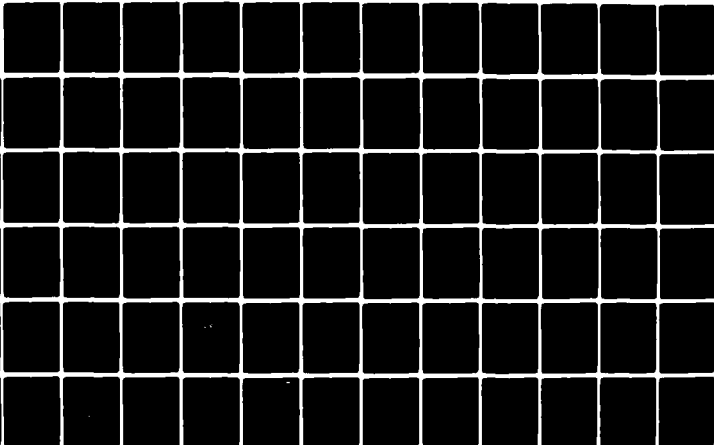
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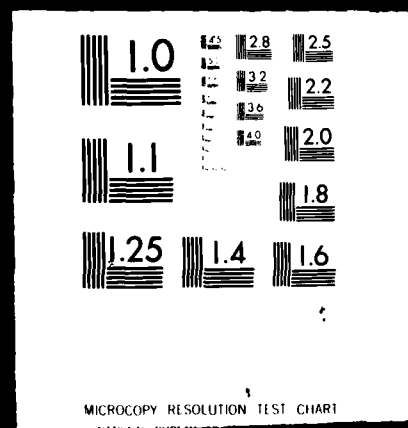
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The significance of these tables is the appearance of items which may be considered minor system components. However, the quantity of these items used in the system results in R&M influence not otherwise considered as a potential problem. Quick disconnects, ten of which are used in the system, are using the same number of seals as their 3000 psi counterparts even though "leaking" has been identified as contributing to 89% of the failure rate. Six turns are required to release these devices, which is not considered to be "quick release". Filters unfortunately appear to have a high failure rate partially because the general definition of failure includes the modes of "clogged", "Metal in filter", "No-go indication", and "low output"; all of which are evidence of its doing its job. However, 78% of the failure modes on filters were attributed to "leaking", which is an apparent undesirable failure mode requiring attention.

## 9.0 GSE INTERFACE REQUIREMENTS

An analysis of hydraulic ground support equipment (GSE) requirements for aircraft with lightweight hydraulic systems disclosed that support equipment requirements are the same as current aircraft with an operating pressure of 3000 psi. Equipment required at the Organizational Level are a portable test stand, fluid servicing equipment, and a contamination analysis kit. At the Intermediate Level, a stationary test standard and a hose burst test stand are required. The fluid servicing equipment and the contamination analysis equipment will be essentially the same current equipment. Test stands will be the same except for operating pressure level.

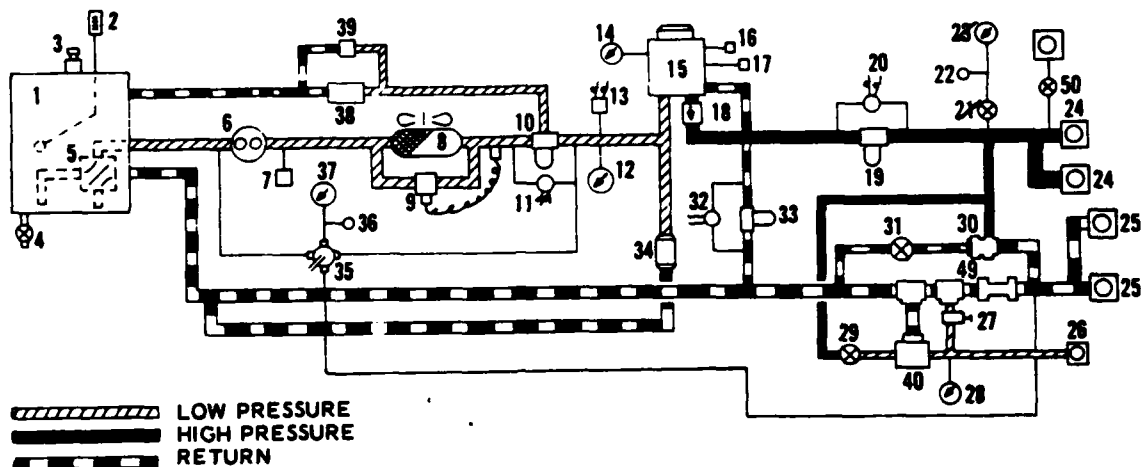
### 9.1 FOLLOW-ON PROGRAMS

For follow-on phases of the LHS advanced development program, the contractor intends to utilize existing equipment for servicing, fluid analysis, and hose burst tests. This is in accordance with a primary objective to provide the most cost effective options for the development phases of LHS. For test stands, a portable and a fixed unit are desirable for the full scale simulator test phase; however, in regards to cost effectiveness, it is possible to proceed without a fixed test stand during full scale simulator testing. A portable and a fixed unit is considered mandatory to support subsequent phases for aircraft hangar test, engine ground test, and flight test. Other GSE required to support aircraft systems other than the hydraulic system during hangar, ground, and flight test phases will be addressed under future follow-on efforts.

Cost for providing 8000 psi portable test stands for future follow-on phases can be minimized by modifying existing 3000 psi equipment such as the Models AHT-63/-64, into 8000 psi units. In these test stands, there are a total of approximately fifty (50) components. Of these, only twelve (12) are associated with the high pressure delivery subsystem of the unit. Modification of those units can be accomplished by replacing the eleven (11) 3000 psi components, as noted with asterisks on the system schematic, Figure 71, with 8000 psi components. The high pressure pump is the most complex and consequently the most expensive of the noted components.

Providing an 8000 psi pressure source can be accomplished by one of two methods; (1) utilizing an existing 8000 psi pump, development hardware, or industrial type, adapted to the test unit, or (2) using the existing 3000 psi pump to drive a 3000 psi to 8000 psi intensifier. The intensifier is essentially pump/motor technology; however, no known acceptable unit exists and therefore would require development of a new component. The intensifier approach is not considered a cost effective option and does not offer any schedule advantage, and therefore is not recommended.

It is recommended that a model AHT-63 test stand be made available for use in the LHS program.



- |                                    |                                  |
|------------------------------------|----------------------------------|
| 1. Fluid Reservoir                 | 26. Fill System Disconnect       |
| 2. Fluid Level Gage                | 27. Fill System Relief Valve     |
| 3. Reservoir Fill and Vent         | 28. Fill System Pressure Gage    |
| 4. Reservoir Drain Valve           | 29. Fill System Shutoff          |
| 5. Reservoir Selector Valve        | * 30. High Pressure Relief Valve |
| 6. Boost Pump                      | * 31. High Pressure Bypass       |
| 7. Low Boost Shutdown              | 32. Pressure Differential Switch |
| 8. Oil Cooler                      | 33. Pump Case Filter             |
| 9. Oil Temperature Controller      | 34. Pump Case Filter             |
| 10. Low Pressure Filter            | 35. Gage Selector Valve          |
| 11. Pressure Differential Switch   | 36. Gage Test Connection         |
| 12. Fluid Temperature Gage         | 37. Compound Pressure Gage       |
| 13. Thermoswitch                   | 38. Air Bleed Valve              |
| 14. Pump Volume Pointer            | 39. Thermal Relief Valve         |
| * 15. High Pressure Pump           | 40. Pressure Reducing Valve      |
| 16. Pump Volume Control            | 49. Return Back Pressure Relief  |
| 17. Pressure Compensator Control   | 50. Fluid Sampling Valve         |
| * 18. Check Valve                  | * 51. Pressure Hose, A/C to GSE  |
| * 19. High Pressure Filter         |                                  |
| * 20. Pressure Differential Switch |                                  |
| 21. Gage Shutoff Valve             |                                  |
| 22. Gage Test Connection           |                                  |
| * 23. High Pressure Gage           |                                  |
| * 24. High Pressure Disconnect     |                                  |
| 25. Return Disconnect              |                                  |

**\*Components in high pressure delivery system.**

FIGURE 71. Typical 8000 psi portable test system

9.2      PRODUCTION GSE

The support requirements for future production aircraft with LHS will be the same as 3000 psi systems except the operating pressure of the portable and fixed test stands must be increased from 3000 to 8000 psi. No unique types of equipment need be developed. An informal survey of test stand component suppliers revealed that the hydraulic pump development suitable for production requirements would have the longest lead time of all the high pressure components.

## 10.0 CONCLUSIONS

Major advances toward achieving the goals of the LHS program were made in Phase I:

- Successful testing of four 8000 psi flight control actuators and one utility actuator
- Significant progress in developing a lightweight variable delivery 8000 psi pump
- Satisfactory operation of dual 8000 psi aircraft type hydraulic systems
- Completion of 150 hours of endurance test cycling on two 8000 psi hydraulic systems
- Completion of pressure impulse and endurance cycling of 8000 psi components
- Evaluation of servo valve erosion
- Verification of the predictive capability of a math model of the test system
- Projected 30.2% weight and 36.3% volume savings for lightweight hydraulic systems
- Prediction that the R&M goal of 15% reduction in MFHBF and MMH/FH for development hardware is realistic.

The principal achievement in Phase I was the successful operation of two 8000 psi hydraulic systems containing many of the components to be installed in the Phase II aircraft simulator. The integrated systems were stable, pressure fluctuations were low, and actuator operation was satisfactory. The 150 hour compatibility test provided further proof that 8000 psi hydraulic systems are practical and do not require state-of-the-art advances. Work accomplished in Phase I will provide a sound basis for successful implementation of the tasks planned in Phase II.

In view of the inability of the LHS pump to complete the 150 hour compatibility test, additional pump development effort is warranted.

## 11.0 RECOMMENDATIONS

Preparations for the construction of an A-7E full scale lightweight hydraulic system simulator were completed in Phase I. The tasks listed below are recommended to be performed in Phase II. Successful completion of these tasks will provide the knowledge and confidence necessary to assure a successful flight test program in Phase III.

Task I                    Fabricate LHS Components (see Table 30)

- Major components
- Minor components
- Special components

Task II                   Fabricate LHS Simulator

- Prepare detail drawings and fabricate mechanical control linkages and supports
- Fabricate simulator structure, Figure 27
- Fabricate load modules, Table 30
- Integrate modules into simulator and install mechanical control linkage system
- Fabricate FC-1 and FC-2 system plumbing; fabricate load and control system plumbing
- Prepare electrical control circuit drawings and install wiring
- Install simulator controls and instrumentation

Task III                  Conduct Simulator Tests

- Proof pressure
- System integration
- Steady-state baseline
- Dynamic performance
- Math model verification
- 3000 psi/8000 psi system performance comparisons
- 300 hour mission profile/endurance test

- Task IV      Component Redesign/Retest
- Make recommendations for modifications based on test experience and reliability analysis
  - Estimate level of retesting required to validate the design changes
- Task V      Math Model Development/Verification
- Hydraulic system frequency response
  - Hydraulic transients and dynamics
  - Hydraulic transient thermal analysis
- Task VI      System Weight and Space Analysis
- Update Phase I analysis
  - Include Phase II components
  - Update projected weight and space savings
- Task VII      Specification Update
- Revise LHS specifications, as necessary, based on Phases I and II test experience
- Task VIII      Reliability and Maintainability Assessment
- Conduct FMEA
  - Update MFHBF and MMH/FH
  - Make design change recommendations, as necessary
  - Prepare FMEA report
  - Prepare Phase III R&M plan
- Task IX      GSE Requirements
- Modify portable test stand M/N AHT-63 to operate at 8000 psi
  - Evaluate performance of modified test stand
- Task X      LHS Pump
- Perform additional development effort

TABLE 30. LHS Components To Be Fabricated In Phase II

| <u>Major Components</u>         | <u>Quantity</u> |
|---------------------------------|-----------------|
| Actuator, Spoiler               | 2               |
| Actuator, Aileron               | 1               |
| Actuator, Roll Feel             | 1               |
| Actuator, AFCS                  | 2               |
| Actuator, UHT                   | 1               |
| Actuator, L.E. Flap             | 8               |
| Pump                            | 1               |
| Servo Valve, AFCS               | 6               |
| Electronics, AFCS               | 3               |
| <u>Minor Components</u>         |                 |
| Check Valves                    | 13              |
| Directional Flow Control Valves |                 |
| Solenoid, 2-way                 | 1               |
| Solenoid, 3-way                 | 2               |
| Solenoid, 4-way                 | 1               |
| Fittings, Permanent             | 200             |
| Fittings, Separable             | 200             |
| Fluid                           | 100 gal.        |
| Hose, Press.                    | 4               |
| Hose, Ret.                      | 4               |
| Quick Disconnect                | 2               |
| Restrictor                      | 9               |
| Seals                           | 400             |
| *Swivel, Wing Fold              | 2               |
| Swivel, Speed Brake             | 2               |
| Tubing, Titanium                | 1200 ft.        |
| <u>Special Components</u>       |                 |
| Coiled Tubing                   | 32              |
| Manifold, Press.                | 1               |
| Manifold, Ret.                  | 1               |
| <u>Load Modules</u>             |                 |
| Spoiler                         | 2               |
| Aileron                         | 1               |
| UHT                             | 1               |
| L.E. Flap                       | 2               |

\*Requirements for a wing fold swivel are not firm at this time.

12.0 REFERENCES

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- 8 J.N. Demarchi and R.K. Haning, Design and Test of an LHS Lateral Control System for a T-2C Airplane, NR76H-14, Columbus Aircraft Division, Rockwell International Corporation, Contract N62269-75-C-0422, May 1976, Unclassified. AD A-032 677
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- 10 J.N. Demarchi and R.K. Haning, Lightweight Hydraulic System Extended Endurance Test, NR78H-92, Columbus Aircraft Division, Rockwell International Corporation, Contract N62269-78-C-0005, September 1978, Unclassified. AD A062 749
- 11 Rockwell International Corporation Letter 79CL 1235, Submittal, Engineering Drawings and Design Layouts, North American Aircraft Division to Naval Air Development Center, dated 8 November 1979
- 12 Rockwell International Corporation Letter 80CL 973, Submittal, Lightweight Hydraulic System Advanced Development Program Specifications, North American Aircraft Division to Naval Air Development Center, dated 10 October 1980
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13.0 LIST OF ABBREVIATIONS

|                 |                                    |
|-----------------|------------------------------------|
| A/C             | aircraft                           |
| AFCS            | automatic flight control system    |
| BTU/min         | British Thermal Units per minute   |
| CIPR            | cubic inches per revolution        |
| cpm             | cycles per minute                  |
| CRES            | corrosion resistant                |
| EDU             | electronic drive unit              |
| EPP             | emergency power package            |
| FC-1            | flight control #1                  |
| FMEA            | failure-modes-and-effects analysis |
| gal.            | gallon                             |
| gpm             | gallons per minute                 |
| GSE             | ground support equipment           |
| H.O.            | hog-out                            |
| Hp              | horsepower                         |
| Hr              | hour                               |
| Hz              | Hertz (cycles per second)          |
| in.             | inch                               |
| in <sup>3</sup> | cubic inches                       |
| lb              | pound                              |
| L.E.            | leading edge                       |
| LH              | left hand                          |
| LHS             | lightweight hydraulic system       |
| max.            | maximum                            |
| MFHBF           | mean flight hours between failures |

|            |                                       |
|------------|---------------------------------------|
| M/N        | model number                          |
| min        | minute (time)                         |
| MMH/FH     | maintenance man-hours per flight hour |
| NAAD       | North American Aircraft Division      |
| NADC       | Naval Air Development Center          |
| NAS        | National Aerospace Standard           |
| No.        | number                                |
| O.D.       | outside diameter                      |
| $\Delta P$ | differential pressure                 |
| PC-1       | power control #1                      |
| P/N        | part number                           |
| psi        | pounds per square inch                |
| psig       | pounds per square inch gage pressure  |
| RAT        | ram air turbine                       |
| RH         | right hand                            |
| R&M        | reliability and maintainability       |
| rpm        | revolutions per minute                |
| sec        | second (time)                         |
| S/N        | serial number                         |
| SOV        | shut-off valve                        |
| sys.       | system                                |
| T.E.       | trailing edge                         |
| UHT        | unit horizontal tail                  |
| WUC        | work unit code                        |

NADC-77108-30

APPENDIX A

LHS SPECIFICATIONS

General  
Specifications

|          |                                                                                                     |
|----------|-----------------------------------------------------------------------------------------------------|
| LHS-8800 | Hydraulic System Aircraft, 8000 PSI, Design and Installation Requirements for, dated 26 August 1980 |
| LHS-8801 | Hydraulic System Components, 8000 PSI, Aircraft, General Specification for, dated 5 August 1980     |

Component  
Specifications

|          |                                                                                                             |
|----------|-------------------------------------------------------------------------------------------------------------|
| LHS-8810 | Pumps, Hydraulic, Variable Delivery, 8000 PSI, dated 25 August 1980                                         |
| LHS-8811 | Accumulators, Hydraulic, Cylindrical, 8000 PSI, Aircraft, dated 15 June 1980                                |
| LHS-8812 | Cylinders, Hydraulic, 8000 PSI, dated 12 September 1980                                                     |
| LHS-8813 | Valves, Aircraft Power Brake, 8000 PSI, dated 15 July 1980                                                  |
| LHS-8814 | Valves, Check, Hydraulic, 8000 PSI, Aircraft, dated 15 June 1980                                            |
| LHS-8815 | Filter and Filter Elements, Fluid Pressure, Hydraulic Line, 5 Micron Absolute, 8000 PSI, dated 15 June 1980 |
| LHS-8816 | Fittings, Fluid Connection, Aircraft, 8000 PSI, dated 15 June 1980                                          |
| LHS-8817 | Valve; Aircraft Hydraulic Flow Regulator, 8000 PSI, dated 2 July 1980                                       |
| LHS-8818 | Hose Assemblies, Hydraulic, 8000 PSI, Aircraft, dated 15 June 1980                                          |
| LHS-8819 | Motors, Aircraft Hydraulic, Constant Displacement, 8000 PSI, dated 7 August 1980                            |
| LHS-8821 | Gland Design; Seals, Hydraulic, 8000 PSI, dated 28 July 1980                                                |
| LHS-8822 | Gage, Pressure, Dial Indicating, 8000 PSI, Aircraft, dated 15 June 1980                                     |
| LHS-8823 | Valve; Aircraft Hydraulic Pressure Reducer, 8000 PSI, dated 1 July 1980                                     |
| LHS-8824 | Snubber, Hydraulic Pressure, 8000 PSI, Aircraft, dated 15 June 1980                                         |
| LHS-8825 | Pressure Switch, Aircraft, Hydraulic, 8000 PSI, dated 23 July 1980                                          |

|          |                                                                                                 |
|----------|-------------------------------------------------------------------------------------------------|
| LHS-8826 | Transmitter, Pressure, Hydraulic, 8000 PSI, Aircraft, dated 24 June 1980                        |
| LHS-8827 | Valve; Aircraft Hydraulic Priority, 8000 PSI, dated 28 July 1980                                |
| LHS-8828 | Coupling, Quick Disconnect, Self-Sealing, Hydraulic, 8000 PSI, Aircraft, dated 19 June 1980     |
| LHS-8829 | Valve, Hydraulic Pressure Relief, 8000 PSI, Aircraft, dated 19 June 1980                        |
| LHS-8830 | Reservoirs; Aircraft, Hydraulic Separated Type, dated 19 June 1980                              |
| LHS-8831 | Restrictor, Hydraulic, 8000 PSI, Aircraft, dated 15 June 1980                                   |
| LHS-8833 | Valve, Bleed, Hydraulic, 8000 PSI, Aircraft, dated 18 August 1980                               |
| LHS-8834 | Valve, Direct Drive, Electro-hydraulic, Servo Control, 8000 PSI, Aircraft, dated 19 August 1980 |
| LHS-8835 | Valve, Aircraft Hydraulic Directional Control, Rotary Selector, 8000 PSI, dated 15 August 1980  |
| LHS-8836 | Valve, Shuttle, Hydraulic, 8000 PSI, Aircraft, dated 28 August 1980                             |
| LHS-8837 | Valve, Hydraulic Control, Solenoid Operated, 8000 PSI, Aircraft, dated 21 August 1980           |
| LHS-8838 | Joint, Swivel, Hydraulic, 8000 PSI, Aircraft, dated 15 June 1980                                |
| LHS-8839 | Tubing, Steel, Corrosion Resistant (21-6-9), Hydraulic, 8000 PSI, Aircraft, dated 15 June 1980  |

Process Specifications

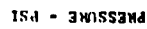
|            |                                                                                                                                 |
|------------|---------------------------------------------------------------------------------------------------------------------------------|
| HA0602-002 | Installation of Rigid and Flexible Tubing Assemblies for LHS Systems, dated 19 September 1980                                   |
| HA0602-003 | Fabrication of 3Al-2.5V Titanium Alloy Details for LHS, dated 12 September 1980                                                 |
| HA0607-005 | Swage Joining of Titanium Alloy Tubular Joints, dated 19 September 1980                                                         |
| HF0001-002 | Control of MIL-H-83282 in Test Stands, Ground Support Equipment and Aircraft Components for LHS Systems, dated 5 September 1980 |

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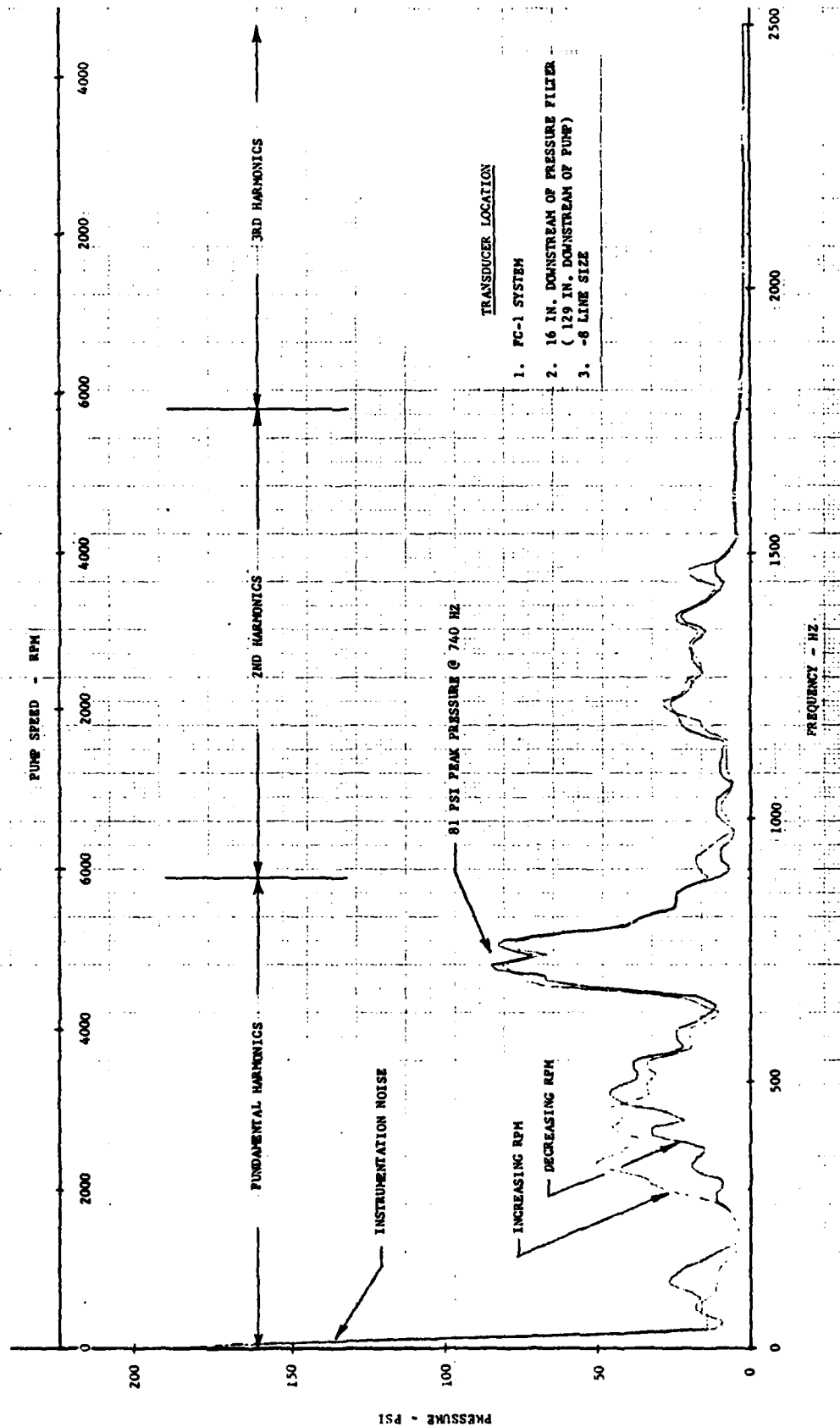
APPENDIX B

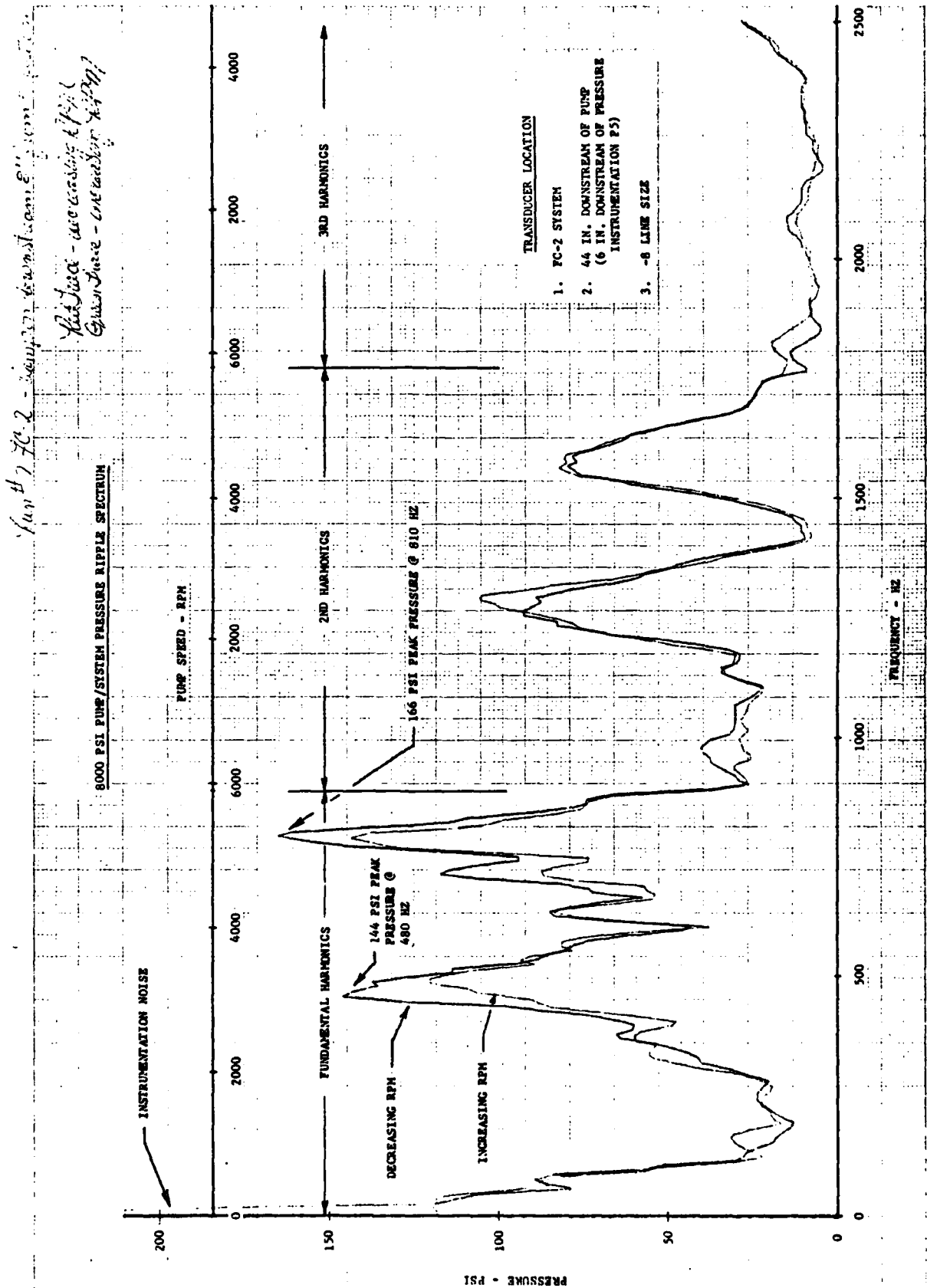
AIR FORCE DATA



Run 6 401 - Pump on at 1000 RPM  
 First three - all noise from  
 (7000 RPM - 1000 RPM)

8000 PSI PUMP/SYSTEM PRESSURE RIPPLE SPECTRUM





APPENDIX C

WEIGHT AND SPACE ANALYSIS TABULATIONS

Contents

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Table C-1. Component Weight Summary

| ITEM* | QTY/AC | DESCRIPTION                         | WEIGHT, LB                |                 |
|-------|--------|-------------------------------------|---------------------------|-----------------|
|       |        |                                     | EQUIV. 3000 PSI<br>SYSTEM | LHS<br>SYSTEM** |
| 1     | 2      | PUMP                                | 14.90                     | 16.25 (H.O.)    |
| 2/3   | 1 EA   | RESERVOIR                           | 25.28                     | 24.26           |
| 4     | 2      | RELIEF VALVE, HIGH PRESS            | .81                       | .44             |
| 5     | 2      | RELIEF VALVE, LOW PRESS             | 1.63                      | .60             |
| 6     | 2      | FILTER, PRESSURE                    | 2.75                      | 1.94 (H.O.)     |
| 7     | 2      | FILTER, RETURN                      | 2.75                      | 1.40            |
| 8     | 1      | FILTER, CASE DR                     | 1.48                      | 1.48            |
| 9     | 1      | FILTER, EMER PWR PKG                | N/A                       | N/A             |
| 10    | 2      | PRESSURE SNUBBER                    | .09                       | .07             |
| 11    | 2      | PRESSURE TRANSMITTER/SWITCH         | 1.45                      | 1.50            |
| 12    | 2      | BLEED VALVE                         | .05                       | .05             |
| 13    | 1      | ACCUMULATOR                         | 3.11                      | 1.94            |
| 14    | 1      | PRESSURE GAGE                       | .18                       | .12             |
| 15    | 1      | SOLENOID VALVE-ACCUM.ISOL.          | 1.25                      | (1.40)(H.O.)    |
| 16    | 2      | PRESS.DISC-EXTERNAL ACCESS          | .67                       | .31             |
| 17    | 2      | SUCTION DISC-EXTERNAL<br>ACCESS     | .98                       | .67             |
| 18    | 2      | PRESS. DISC-PUMP                    | 1.00                      | .60             |
| 19    | 2      | SUCTION DISC-PUMP                   | 1.00                      | .89             |
| 20    | 2      | CASE DRAIN DISC-PUMP                | .42                       | .42             |
| 21    | 1      | SELECTOR VALVE-SPEED BR             | 3.30                      | 2.21 (H.O.)     |
| 22    | -      | DELETED                             | -                         | -               |
| 23    | 1      | EMER. POWER PACKAGE                 | N/A                       | N/A             |
| 24    | 1      | FLOW SENSITIVE PRESS.REG.           | N/A                       | N/A             |
| 25    | 3      | SELECTOR VALVE-AFCS SHUTOFF         | .56                       | 1.75 (H.O.)     |
| 26    | -      | DELETED                             | -                         | -               |
| 27    | 1      | CHARGING VALVE-ACCUM.               | .11                       | .11             |
| 28    | 1      | RESTRICTOR-SPEED BRAKE              | .40                       | .04             |
| 29    | 1      | RESTRICTOR-L.E. FLAP                | .15                       | .04             |
| 30    | 4      | RESTRICTOR-L.E. FLAP<br>O.B. PANEL  | .13                       | .04             |
| 31    | 2      | RESTRICTOR-L.E. FLAP<br>INBD. PANEL | .17                       | .04             |
| 32    | 2      | RESTRICTOR-L.E. FLAP<br>INBD. PANEL | .17                       | .04             |
| 33    | 1      | SWIVEL-SPEED BRAKE EXTEND           | .69                       | .69             |
| 34    | 1      | SWIVEL-SPEED BRAKE RETRACT          | .75                       | .75             |
| 35    | 1      | SWIVEL-EMER. PWR. PKG               | N/A                       | N/A             |
| 36    | 1      | SWIVEL-EMER. PWR. PKG               | N/A                       | N/A             |
| 37    | 2      | SWIVEL-WING FOLD                    | 1.85                      | 1.75            |
| 38/43 | -      | DELETED                             | -                         | -               |

Table C-1. Component Weight Summary (Cont'd)

| ITEM* | QTY/AC | DESCRIPTION                             | WEIGHT, LB                |                 |
|-------|--------|-----------------------------------------|---------------------------|-----------------|
|       |        |                                         | EQUIV. 3000 PSI<br>SYSTEM | LHS<br>SYSTEM** |
| 44    | 4      | CHECK VALVE-RUD., SP.BR.,<br>RET., FLAP | .07                       | .07             |
| 45    | 1      | CHECK VALVE-SP.BRAKE                    | .07                       | .07             |
| 46    | 2      | CHECK VALVE-UHT PRESS<br>& RET.         | .11                       | .085            |
| 47    | 1      | CHECK VALVE-SP.BRAKE                    | .10                       | .08             |
| 48    | 4      | CHECK VALVE-RUN AROUND<br>CIRCUITS      | .18                       | .122            |
| 49    | 3      | CHECK VALVE-FILTER RUN<br>AROUND        | .18                       | .194            |
| 50    | 1      | CHECK VALVE-SP.BRAKE                    | .35                       | .209            |
| 51    | 3      | CHECK VALVE-RETURN FILTER               | .35                       | .209            |
| 52    | 2      | CHECK VALVE-PUMP PRESS                  | .36                       | .235            |
| 53    | 2      | CHECK VALVE-SYSTEM FILL                 | .07                       | .16             |
| 54    | 2      | CHECK VALVE-UHT PRESS                   | .11                       | .085            |
| 55    | 1      | CHECK VALVE-CASE DRAIN                  | .07                       | .144            |
| 56    | 1      | CHECK VALVE RAT BY-PASS                 | N/A                       | N/A             |
| 57/63 | -      | DELETED                                 | -                         | -               |
| 64    | 1      | MANIFOLD, PRESSURE                      | .58                       | .491(H.O.)      |
| 65    | 1      | MANIFOLD, RETURN                        | .55                       | .218(H.O.)      |
| 66    | 1      | MANIFOLD, RELIEF VALVE                  | .79                       | .69 (H.O.)      |
| 67    | 1      | HOSE ASSY-PUMP PRESSURE,<br>FC1         | 3.14                      | 1.41            |
| 68    | 1      | HOSE ASSY-PUMP PRESSURE,<br>FC2         | 3.14                      | 1.71            |
| 69    | 1      | HOSE ASSY-PUMP SUCTION,<br>FC1          | 2.15                      | .73             |
| 70    | 1      | HOSE ASSY-PUMP SUCTION,<br>FC2          | 2.15                      | .78             |
| 71    | 1      | HOSE ASSY-CASE DRAIN, FC1               | .63                       | .63             |
| 72    | 1      | HOSE ASSY-CASE DRAIN, FC2               | .75                       | .75             |
| 73    | 1      | CHECK VALVE-RAT SUCTION                 | N/A                       | N/A             |
| 74    | 1      | MANIFOLD-ACCUMULATOR                    | .31                       | .31             |
| 75    | 1      | CHECK VALVE-CASE DRAIN                  | .07                       | .144            |
| 76    | 1      | MANIFOLD-SUCTION DISCONNECT             |                           |                 |
| 77    | 1      | HOSE ASSY-AILERON PRESSURE              | .3                        | .336            |
| 78    | 1      | HOSE ASSY-AILERON RETURN                | .3                        | .331            |
| 79    | 1      | HOSE ASSY-AILERON RETURN                | .41                       | .589            |
| 80    | 1      | HOSE ASSY-AILERON PRESSURE              | .42                       | .509            |
| 81    | 1      | HOSE ASSY-AILERON PRESSURE              | .3                        | .331            |

Table C-1. Component Weight Summary (Cont'd)

| ITEM* | QTY/AC | DESCRIPTION                | WEIGHT, LB                |                 |
|-------|--------|----------------------------|---------------------------|-----------------|
|       |        |                            | EQUIV. 3000 PSI<br>SYSTEM | LHS<br>SYSTEM** |
| 82    | 1      | HOSE ASSY-AILERON RETURN   | .3                        | .335            |
| 83    | 1      | HOSE ASSY-AILERON RETURN   | .42                       | .578            |
| 84    | 1      | HOSE ASSY-AILERON PRESSURE | .39                       | .522            |
| 85    | 1      | SELECTOR VALVE-L.E. FLAP   | 1.16                      | (H.O.)          |
| 101   | 2      | AILERON ACTUATOR           | 16.35                     | 15.18 (H.O.)    |
| 102   | 2      | SPOILER ACTUATOR           | 16.35                     | 15.18 (H.O.)    |
| 103   | 1      | RUDDER ACTUATOR            | 8.55                      | 6.44 (H.O.)     |
| 104   | 2      | UHT ACTUATOR               | 33.80                     | 26.02 (H.O.)    |
| 105   | 1      | ROLL FEEL ACTUATOR         | 11.64                     | 10.57 (H.O.)    |
| 106   | 3      | AFCS ACTUATOR              | 15.79                     | 6.59 (H.O.)     |
| 107   | 1      | SPEED BRAKE ACTUATOR       | 46.41                     | 43.29 (H.O.)    |
| 108   | 8      | LEADING EDGE FLAP ACTUATOR | 6.73                      | 6.18 (H.O.)     |
| 109   | 1      | RUDDER SERVO VALVE         | 3.09                      | 2.86            |

\*See Figure 5

\*\*H.O. = Hog-Out

N/A = Not Applicable

Table C-2. Component Volume Summary

| ITEM* | QTY/AC | DESCRIPTION                         | VOLUME, IN <sup>3</sup>   |               |
|-------|--------|-------------------------------------|---------------------------|---------------|
|       |        |                                     | EQUIV. 3000 PSI<br>SYSTEM | LHS<br>SYSTEM |
| 1     | 2      | PUMP                                | 171                       | 118           |
| 2/3   | 1 EA   | RESERVOIR                           | 817                       | 593           |
| 4     | 2      | RELIEF VALVE, HIGH PRESS            | 7                         | 4             |
| 5     | 2      | RELIEF VALVE, LOW PRESS             | 17                        | 7             |
| 6     | 2      | FILTER, PRESSURE                    | 62                        | 24            |
| 7     | 2      | FILTER, RETURN                      | 62                        | 31            |
| 8     | 1      | FILTER, CASE DR                     | 28                        | 28            |
| 9     | 1      | FILTER, EMER PWR PKG                | N/A                       | N/A           |
| 10    | 2      | PRESSURE SNUBBER                    | < 1                       | < 1           |
| 11    | 2      | PRESSURE TRANSMITTER/SWITCH         | 22                        | 22            |
| 12    | 2      | BLEED VALVE                         | 1                         | 1             |
| 13    | 1      | ACCUMULATOR                         | 40                        | 25            |
| 14    | 1      | PRESSURE GAGE                       | 1                         | 1             |
| 15    | 1      | SOLENOID VALVE-ACCUM.ISOL.          | 15                        | 9             |
| 16    | 2      | PRESS.DISC-EXTERNAL ACCESS          | 9                         | 3             |
| 17    | 2      | SUCTION DISC-EXTERNAL<br>ACCESS     | 12                        | 7             |
| 18    | 2      | PRESS. DISC-PUMP                    | 21                        | 6             |
| 19    | 2      | SUCTION DISC-PUMP                   | 21                        | 9             |
| 20    | 2      | CASE DRAIN DISC-PUMP                | 5                         | 5             |
| 21    | 1      | SELECTOR VALVE-SPEED BR             | 50                        | 35            |
| 22    | -      | DELETED                             | -                         | -             |
| 23    | 1      | EMER. POWER PACKAGE                 | N/A                       | N/A           |
| 24    | 1      | FLOW SENSITIVE PRESS.REG.           | N/A                       | N/A           |
| 25    | 3      | SELECTOR VALVE-SAS SHUTOFF          | 10                        | 13            |
| 26    | -      | DELETED                             | -                         | -             |
| 27    | 1      | CHARGING VALVE-ACCUM.               | < 1                       | < 1           |
| 28    | 1      | RESTRICTOR-SPEED BRAKE              | 1                         | < 1           |
| 29    | 1      | RESTRICTOR-L.E. FLAP                | 2                         | < 1           |
| 30    | 4      | RESTRICTOR-L.E. FLAP<br>O.B. PANEL  | 2                         | < 1           |
| 31    | 2      | RESTRICTOR-L.E. FLAP<br>INBD. PANEL | 2                         | < 1           |
| 32    | 2      | RESTRICTOR-L.E. FLAP<br>INBD. PANEL | 2                         | < 1           |
| 33    | 1      | SWIVEL-SPEED BRAKE EXTEND           | 8                         | 10            |
| 34    | 1      | SWIVEL-SPEED BRAKE RETRACT          | 10                        | 12            |
| 35    | 1      | SWIVEL-EMER. PWR. PKG               | N/A                       | N/A           |
| 36    | 1      | SWIVEL-EMER. PWR. PKG               | N/A                       | N/A           |
| 37    | 2      | SWIVEL-WING FOLD                    | 17                        | 16            |
| 38/43 | -      | DELETED                             | -                         | -             |

Table C-2. Component Volume Summary (Cont'd)

| ITEM* | QTY/AC | DESCRIPTION                             | VOLUME, IN <sup>3</sup>   |               |
|-------|--------|-----------------------------------------|---------------------------|---------------|
|       |        |                                         | EQUIV. 3000 PSI<br>SYSTEM | LHS<br>SYSTEM |
| 44    | 4      | CHECK VALVE-RUD., SP.BR.,<br>RET., FLAP | < 1                       | < 1           |
| 45    | 1      | CHECK VALVE-SP.BRAKE                    | < 1                       | < 1           |
| 46    | 2      | CHECK VALVE-UHT PRESS<br>& RET.         | 1                         | < 1           |
| 47    | 1      | CHECK VALVE-SP.BRAKE                    | < 1                       | < 1           |
| 48    | 4      | CHECK VALVE-RUN AROUND<br>CIRCUITS      | 1                         | < 1           |
| 49    | 3      | CHECK VALVE-FILTER RUN<br>AROUND        | 1                         | < 1           |
| 50    | 1      | CHECK VALVE-SP.BRAKE                    | 1                         | < 1           |
| 51    | 3      | CHECK VALVE-RETURN FILTER               | 1                         | < 1           |
| 52    | 2      | CHECK VALVE-PUMP PRESS                  | 1                         | < 1           |
| 53    | 2      | CHECK VALVE-SYSTEM FILL                 | < 1                       | < 1           |
| 54    | 2      | CHECK VALVE-UHT PRESS                   | 1                         | < 1           |
| 55    | 1      | CHECK VALVE-CASE DRAIN                  | < 1                       | < 1           |
| 56    | 1      | CHECK VALVE RAT BY-PASS                 | N/A                       | N/A           |
| 57/63 | -      | DELETED                                 | -                         | -             |
| 64    | 1      | MANIFOLD, PRESSURE                      | 7                         | 2             |
| 65    | 1      | MANIFOLD, RETURN                        | 6                         | 3             |
| 66    | 1      | MANIFOLD, RELIEF VALVE                  | 8                         | 5             |
| 67    | 1      | HOSE ASSY-PUMP PRESSURE,<br>FC1         | 30                        | 19            |
| 68    | 1      | HOSE ASSY-PUMP PRESSURE,<br>FC2         | 37                        | 24            |
| 69    | 1      | HOSE ASSY-PUMP SUCTION,<br>FC1          | 27                        | 18            |
| 70    | 1      | HOSE ASSY-PUMP SUCTION,<br>FC2          | 29                        | 19            |
| 71    | 1      | HOSE ASSY-CASE DRAIN, FC1               | 14                        | 14            |
| 72    | 1      | HOSE ASSY-CASE DRAIN, FC2               | 13                        | 13            |
| 73    | 1      | CHECK VALVE-RAT SUCTION                 | N/A                       | N/A           |
| 74    | 1      | MANIFOLD-ACCUMULATOR                    | 3                         | 3             |
| 75    | 1      | CHECK VALVE-CASE DRAIN                  | < 1                       | < 1           |
| 76    | 1      | MANIFOLD-SUCTION DISCONNECT             |                           |               |
| 77    | 1      | HOSE ASSY-AILERON PRESSURE              | 3                         | 3             |
| 78    | 1      | HOSE ASSY-AILERON RETURN                | 3                         | 3             |
| 79    | 1      | HOSE ASSY-AILERON RETURN                | 5                         | 5             |
| 80    | 1      | HOSE ASSY-AILERON PRESSURE              | 5                         | 5             |
| 81    | 1      | HOSE ASSY-AILERON PRESSURE              | 3                         | 3             |

Table C-2. Component Volume Summary (Cont'd)

| ITEM* | QTY/AC | DESCRIPTION                | VOLUME, IN <sup>3</sup>   |               |
|-------|--------|----------------------------|---------------------------|---------------|
|       |        |                            | EQUIV. 3000 PSI<br>SYSTEM | LHS<br>SYSTEM |
| 82    | 1      | HOSE ASSY-AILERON RETURN   | 3                         | 3             |
| 83    | 1      | HOSE ASSY-AILERON RETURN   | 4                         | 4             |
| 84    | 1      | HOSE ASSY-AILERON PRESSURE | 5                         | 5             |
| 85    | 1      | SELECTOR VALVE-L.E. FLAP   | 23                        |               |
| 101   | 2      | AILERON ACTUATOR           | 206                       | 101           |
| 102   | 2      | SPOILER ACTUATOR           | 136                       | 106           |
| 103   | 1      | RUDDER ACTUATOR            | 106                       | 53            |
| 104   | 2      | UHT ACTUATOR               | 446                       | 286           |
| 105   | 1      | ROLL FEEL ACTUATOR         | 77                        | 24            |
| 106   | 3      | AFCS ACTUATOR              | 239                       | 195           |
| 107   | 1      | SPEED BRAKE ACTUATOR       | 658                       | 334           |
| 108   | 8      | LEADING EDGE FLAP ACTUATOR | 47                        | 26            |
| 109   | 1      | RUDDER SERVO VALVE         | 185                       | 170           |

\*See Figure 5

N/A = Not Applicable

Table C-3. 3000 PSI Plumbing Weight/Volume Breakdown

| <u>PRESSURE LINES</u>             |                  |               |                   |                     |
|-----------------------------------|------------------|---------------|-------------------|---------------------|
| SUBSYSTEM                         | TUBING WT<br>DRY | OIL<br>WEIGHT | FITTING<br>WEIGHT | LINE<br>VOLUME      |
| POWER GENERATION                  | 11.93            | 3.50          | 5.23              | 157                 |
| POWER TRANSMISSION                | 15.90            | 4.77          | 7.14              | 212                 |
| UHT                               | 3.65             | 1.02          | 1.02              | 43                  |
| RUDDER                            | 1.11             | .28           | 1.50              | 13                  |
| AILERON                           | 2.72             | .69           | .73               | 32                  |
| SPOILER                           | .75              | .19           | .64               | 9                   |
| ROLL FEEL                         | .29              | .04           | .18               | 3                   |
| YAW AFCS                          | .25              | .06           | .27               | 3                   |
| ROLL AFCS                         | .32              | .08           | .41               | 4                   |
| PITCH AFCS                        | .07              | .02           | .14               | 1                   |
| SPEED BRAKE                       | 2.82             | 1.07          | 2.24              | 45                  |
| LEADING EDGE FLAP                 | 8.58             | 2.15          | 3.67              | 100                 |
| TOTALS                            | 48.39 LB         | 13.87 LB      | 23.17 LB          | 622 IN <sup>3</sup> |
| <u>RETURN &amp; SUCTION LINES</u> |                  |               |                   |                     |
| POWER GENERATION                  | 9.90             | 6.47          | 5.02              | 262                 |
| POWER TRANSMISSION                | 10.86            | 5.80          | 4.73              | 247                 |
| UHT                               | 2.58             | 1.03          | .76               | 44                  |
| RUDDER                            | .27              | .12           | .36               | 7                   |
| AILERON                           | 2.34             | .74           | .73               | 33                  |
| SPOILER                           | .70              | .21           | .64               | 9                   |
| ROLL FEEL                         | .22              | .07           | .21               | 3                   |
| YAW AFCS                          | .09              | .03           | .15               | 2                   |
| ROLL AFCS                         | .14              | .07           | .21               | 4                   |
| PITCH AFCS                        | .04              | .02           | .11               | 1                   |
| SPEED BRAKE                       | .06              | .27           | .49               | 4                   |
| LEADING EDGE FLAP                 | .19              | .09           | .02               | 5                   |
| TOTALS                            | 27.39 LB         | 14.92 LB      | 13.43 LB          | 621 IN <sup>3</sup> |

Table C-4. 8000 PSI Plumbing Weight/Volume Breakdown

| <u>PRESSURE LINES</u>             |                  |               |                   |                     |
|-----------------------------------|------------------|---------------|-------------------|---------------------|
| SUBSYSTEM                         | TUBING WT<br>DRY | OIL<br>WEIGHT | FITTING<br>WEIGHT | LINE<br>VOLUME      |
| POWER GENERATION                  | 4.18             | 1.35          | 1.55              | 70                  |
| POWER TRANSMISSION                | 5.68             | 1.84          | 1.43              | 95                  |
| UHT                               | 1.24             | .39           | .24               | 21                  |
| RUDDER                            | .45              | .14           | .23               | 7                   |
| AILERON                           | 1.12             | .34           | .25               | 18                  |
| SPOILER                           | .83              | .15           | .30               | 49                  |
| ROLL FEEL                         | .63              | .09           | .20               | 22                  |
| YAW AFCS                          | .10              | .03           | .04               | 2                   |
| ROLL AFCS                         | .13              | .04           | .06               | 2                   |
| PITCH AFCS                        | .03              | .01           | .02               | 1                   |
| SPEED BRAKE                       | 1.06             | .34           | .38               | 17                  |
| LEADING EDGE FLAP                 | <u>3.72</u>      | <u>1.14</u>   | <u>1.46</u>       | <u>87</u>           |
| TOTALS                            | 19.17 LB         | 5.86 LB       | 6.16 LB           | 391 IN <sup>3</sup> |
| <u>RETURN &amp; SUCTION LINES</u> |                  |               |                   |                     |
| POWER GENERATION                  | 3.65             | 2.60          | 2.52              | 120                 |
| POWER TRANSMISSION                | 4.14             | 2.55          | 1.70              | 112                 |
| UHT                               | 1.01             | .42           | .24               | 20                  |
| RUDDER                            | .24              | .07           | .14               | 4                   |
| AILERON                           | 1.15             | .35           | .25               | 19                  |
| SPOILER                           | .81              | .16           | .30               | 49                  |
| ROLL FEEL                         | .71              | .11           | .20               | 22                  |
| YAW AFCS                          | .07              | .02           | .06               | 1                   |
| ROLL AFCS                         | .13              | .04           | .08               | 2                   |
| PITCH AFCS                        | .03              | .01           | .04               | 1                   |
| SPEED BRAKE                       | .09              | .05           | .05               | 2                   |
| LEADING EDGE FLAP                 | <u>.32</u>       | <u>.09</u>    | <u>.02</u>        | <u>3</u>            |
| TOTALS                            | 12.35 LB         | 6.47 LB       | 5.60 LB           | 355 IN <sup>3</sup> |

TABLE C-5. Actuator Weight Summary

| ACTUATOR         | EXISTING<br>WEIGHT<br>(REF) | EQUIVALENT<br>3000 PSI<br>SYSTEM | LHS<br>SYSTEM | WEIGHT<br>REDUCTION |
|------------------|-----------------------------|----------------------------------|---------------|---------------------|
| SPOILER (2)      | 11.48                       | 16.35 *                          | 15.18         | 1.17                |
| AILERON (2)      | 8.75                        | 16.35 *                          | 15.18         | 1.17                |
| ROLL FEEL (1)    | 6.58                        | 11.64 *                          | 10.57         | 1.07                |
| AFCS (3)         | 15.79                       | 15.79                            | 14.95         | .84                 |
| UHT (2)          | 34.78                       | 33.80 *                          | 26.02         | 7.78                |
| RUDDER (1)       | 7.63                        | 8.55 *                           | 6.44          | 2.11                |
| RUDDER VALVE (1) | 1.70                        | 3.09 *                           | 2.86          | .23                 |
| SPEED BR. (1)    | 46.41                       | 46.41                            | 43.29         | 3.12                |
| L.E. FLAP (8)    | 6.73                        | <u>6.73</u>                      | <u>6.18</u>   | <u>.55</u>          |
| TOTALS           |                             | 303.90 LB                        | 270.21 LB     | 33.69 LB            |

\*STEEL BARREL OR HOUSING

TABLE C-6. Subsystem Weight/Volume Breakdown

| <u>WEIGHT SUMMARY</u> |                      |                      |                      |
|-----------------------|----------------------|----------------------|----------------------|
| SUBSYSTEM             | 3000 PSI             | 8000 PSI             | REDUCTION            |
| POWER GENERATION      | 201.34               | 149.55               | 51.79                |
| DISTRIBUTION SYSTEM   | 51.69                | 18.84                | 32.85                |
| UHT                   | 84.03                | 57.96                | 26.07                |
| RUDDER                | 15.83                | 10.90                | 4.93                 |
| AILERON               | 47.15                | 40.12                | 7.03                 |
| SPOILER               | 42.08                | 33.25                | 8.83                 |
| ROLL FEEL             | 15.58                | 11.79                | 3.79                 |
| YAW AFCS              | 17.44                | 17.10                | .34                  |
| ROLL AFCS             | 17.79                | 17.26                | .53                  |
| PITCH AFCS            | 16.95                | 16.92                | .03                  |
| SPEED BRAKE           | 65.85                | 52.25                | 13.60                |
| LEADING EDGE          | 79.59                | 60.77                | 18.82                |
| TOTALS                | 655.32 LB            | 486.71 LB            | 168.61 LB            |
| <u>VOLUME SUMMARY</u> |                      |                      |                      |
| POWER GENERATION      | 3237                 | 2081                 | 1156                 |
| DISTRIBUTION SYSTEM   | 582                  | 263                  | 319                  |
| UHT                   | 989                  | 619                  | 370                  |
| RUDDER                | 323                  | 238                  | 85                   |
| AILERON               | 440                  | 284                  | 156                  |
| SPOILER               | 364                  | 314                  | 50                   |
| ROLL FEEL             | 106                  | 70                   | 36                   |
| YAW AFCS              | 257                  | 212                  | 45                   |
| ROLL AFCS             | 261                  | 214                  | 47                   |
| PITCH AFCS            | 253                  | 210                  | 43                   |
| SPEED BRAKE           | 803                  | 420                  | 377                  |
| LEADING EDGE          | 558                  | 282                  | 276                  |
| TOTALS                | 8173 IN <sup>3</sup> | 5207 IN <sup>3</sup> | 2960 IN <sup>3</sup> |

TABLE C-7. Major Elements Weight Summary

| ITEM        | EQUIVALENT<br>3000 PSI<br>SYSTEM | PERCENT<br>OF<br>SYS.WT. | LHS<br>SYSTEM | PERCENT<br>RED. IN<br>COMP.WT. |
|-------------|----------------------------------|--------------------------|---------------|--------------------------------|
| PUMP        | 29.80                            | 4.5                      | 32.50         | + 9.1                          |
| RESERVOIR   | 50.56                            | 8.2                      | 48.52         | - 4.0                          |
| ACTUATORS   | 303.90                           | 46.2                     | 270.21        | -11.1                          |
| TUBING      | 75.90                            | 11.6                     | 31.37         | -58.7                          |
| OIL         | 76.04                            | 11.6                     | 38.91         | -48.8                          |
| FITTINGS    | 36.89                            | 5.6                      | 11.21         | -69.6                          |
| MISC. COMP. | 82.23                            | 12.3                     | 53.99         | -34.3                          |
| TOTALS      | 655.32 LB                        | 100%                     | 486.71 LB     |                                |

TABLE C-8. Configuration Adjustments Weight Summary

|                                  | EQUIVALENT<br>3000 PSI<br>SYSTEM | LHS<br>SYSTEM |
|----------------------------------|----------------------------------|---------------|
| BASIC SYSTEM                     | 655.3 LB                         | 486.7 LB      |
| <u>CONFIGURATION ADJUSTMENTS</u> |                                  |               |
| RESERVOIR                        | - 7.3                            | -11.6         |
| UHT ACTUATOR                     | 0                                | - 2.0         |
| CASTINGS/FORGINGS                | 0                                | - 6.3         |
| SHRINK-FIT VALVES                | 0                                | - 7.4         |
| INCREASED PUMP SPEED             | - 3.6                            | - 9.7         |
| TOTALS                           | - 10.9 LB                        | -37.0 LB      |
| ADJUSTED SYSTEM WT.              | 644.4 LB                         | 449.7 LB      |

NADC-77108-30

APPENDIX D

LHS RELIABILITY PREDICTIONS

## LHS RELIABILITY

| ITEM NO. | COMPONENT                                | QUANT PER SYS | 8000 PSI SYS |       |      |                            | 3000 PSI SYS |            |     | 7 MFHBF CHANGE 3000 VS 8000 |                                                                                                                         | REMARKS/RATIONALE |
|----------|------------------------------------------|---------------|--------------|-------|------|----------------------------|--------------|------------|-----|-----------------------------|-------------------------------------------------------------------------------------------------------------------------|-------------------|
|          |                                          |               | P/N          | MFHBF |      | WUC (P/N)                  | MFHBF        | PER SYSTEM |     | DEV                         | PROD                                                                                                                    |                   |
|          |                                          |               |              | DEV   | PROD |                            |              |            |     |                             |                                                                                                                         |                   |
| 1        | PUMP, FC-1 & FC-2 SYS                    | 2             | PV3-047-1    | 1220  | -    | 45116 (215-22119)          | 1155         |            | 5.5 | -                           | VICKERS FMEA REV. SEPT. 18, 1979                                                                                        |                   |
| 2        | RESERVOIR, FC-1                          | 1             | 83-00241-    | 3976  | 4360 | 45113 (215-32108-3)        | 3800         |            | 4.6 | 14.7                        | DEV. RESVR. SAME SIZE AS 3000 PSI. PROD. WILL REDUCE SIZE, RESULTING IN A CORRESPONDING DECREASE IN SCORING/SCRATCHING. |                   |
| 3        | RESERVOIR, FC-2                          | 1             | 83-00241-    | 3976  | 4360 | 45113 (215-32108-3)        | 3800         |            | 4.6 | 14.7                        |                                                                                                                         |                   |
| 4        | RELIEF VALVE, FC-1 & FC-2 SYS            | 2             | 1257<br>1258 | 4909  | -    | 4521A (215-32345)          | 4909         |            | 0   | -                           |                                                                                                                         |                   |
| 5        | RELIEF VALVE, RESERVOIR, FC-1 & FC-2 SYS | 2             |              | 12623 | -    | 45112 (215-32359)          | 12623        |            | 0   | -                           |                                                                                                                         |                   |
| 6        | FILTER, PRESS FC-1 & FC-2 SYS            | 2             | AD-A640-8341 | 793   | -    | 45118 (215-32306)          | 793          |            | 0   | -                           |                                                                                                                         |                   |
| 7        | FILTER, RETURN, FC-1 & FC-2 SYS          | 2             | M8815/4A-8   | 1390  | -    | 4511E<br>4521F (210-82500) | 1390         |            | 0   | -                           |                                                                                                                         |                   |
| 8        | FILTER, PUMP BYPASS, FC-2 SYS            | 1             | M8815/4A-6   | 2780  | -    | 4511E<br>4521F (210-82500) | 2780         |            | 0   | -                           |                                                                                                                         |                   |

## LHS RELIABILITY

| ITEM NO. | COMPONENT                                             | QUANT PER SYS | 8000 PSI SYS |       |      | 3000 PSI SYS                |       |            | % MFHBF CHANGE 3000 VS 8000 |                                                                                  | REMARKS/RATIONALE |
|----------|-------------------------------------------------------|---------------|--------------|-------|------|-----------------------------|-------|------------|-----------------------------|----------------------------------------------------------------------------------|-------------------|
|          |                                                       |               | P/N          | MFHBF |      | WUC (P/N)                   | MFHBF | PER SYSTEM | DEV                         | PROD                                                                             |                   |
|          |                                                       |               |              | DEV   | PROD |                             |       |            |                             |                                                                                  |                   |
| 9        | FILTR, ENRG P.R. INCKAGE, FC-2 SYS                    | 1             | AD3258-8HV   | N/A   | N/A  | 91134/49A27 (215-32484-1)   | N/A   | N/A        | N/A                         | EXISTING A-7 3000 PSI SYS NOT PART OF BASELINE. LISTED FOR REF ONLY.             |                   |
| 10       | PRESSURE SNUBBER, FC-1 & FC-2 SYS                     | 2             | 95239        | 88362 | -    | 45133 (S-1442)              | 88362 | 0          | -                           |                                                                                  |                   |
| 11       | PRESSURE XNTR & SWITCH, FC-1 & FC-2 SYS               | 2             | 18-2143      | 1691  | -    | 45131/231 (216-32499)       | 1691  | 0          | -                           |                                                                                  |                   |
| 12       | BLEED VALVE, FC-1 & FC-2 SYS                          | 2             | 40121        | 74403 | -    | 14759 (CVC-4202)            | 74403 | 0          | -                           |                                                                                  |                   |
| 13       | ACCUMULATOR, FC-2 SYS                                 | 1             | 3321471      | 12000 | -    | 4511B (215-32523-4)         | 16066 | -25.0      | -                           | POSSIBLE SEAL PROBLEMS ON PISTON WHICH WOULD CAUSE AERATING OF FLUID.            |                   |
| 14       | PRESSURE GAGE, FC-2 SYS                               | 1             | 1218-63-1    | 26955 | -    | 45411.1 (6901-18-1)         | 26955 | 0          | -                           |                                                                                  |                   |
| 15       | SHUT-OFF VALVE, SOL OPERATED, FC-2, PRESS PUMP        | 1             |              | 70689 | -    | 453111 (707394) (215-22308) | 70689 | 0          | -                           |                                                                                  |                   |
| 16       | CHUCK DISC, PRESS, GR. CC-FLING HALF, FC-1 & FC-2 SYS | 2             | AE80942H     | 5122  | -    | 4511C 4521C (215-32587)     | 5122  | 0          | -                           | 8000 PSI VERSION REQUIRES SIX TURNS TO COUPLE. SEAL PROVISIONS SAME AS 3000 PSI. |                   |

## LHS RELIABILITY

| ITEM NO. | COMPONENT                                               | QUANT PER SYS | 8000 PSI SYS                |       |      | 3000 PSI SYS                  |            |  | % MFHBF CHANGE 3000 VS 8000 |      | REMARKS/RATIONALE                                                    |
|----------|---------------------------------------------------------|---------------|-----------------------------|-------|------|-------------------------------|------------|--|-----------------------------|------|----------------------------------------------------------------------|
|          |                                                         |               | P/N                         | MFHBF |      | WUC (P/N)                     | MFHBF      |  | DEV                         | PROD |                                                                      |
|          |                                                         |               |                             | DEV   | PROD |                               | PER SYSTEM |  |                             |      |                                                                      |
| 17       | QUICK DISC, SECTION CR. COUPLING HALF, FC-1 & FC-2 SYS  | 2             | 3018-54-12D<br>01553-57-120 | 7362  | -    | 4511D<br>4521D<br>(215-32351) | 7362       |  | 0                           | -    | SEE ITEM 16                                                          |
| 18       | QUICK DISC, PUMP PRESS. HOSE & BLKHD HALF, FC-1 & FC-2  | 2             | AE80943H<br>AE80944H        | 1370  | -    | 45114<br>45214<br>(210-82234) | 1370       |  | 0                           | -    | SEE ITEM 16                                                          |
| 19       | QUICK DISC, PUMP SUCTION HOSE & BLKHD HALF, FC-1 & FC-2 | 2             | AE94951J<br>AE94952J        | 1370  | -    | 45114<br>45214<br>(210-82234) | 1370       |  | 0                           | -    | SEE ITEM 16                                                          |
| 20       | QUICK DISC, PUMP C. PR., HOSE & BLKHD HALF, FC-1 & FC-2 | 2             | AE94951G<br>AE94952G        | 1370  | -    | 45114<br>45214<br>(210-82234) | 1370       |  | 0                           | -    | SEE ITEM 16                                                          |
| 21       | SELECTOR VALVE, SOL OPERATED, FC-1, STD BRAKE           | 1             | 3321472                     | 1851  | -    | 14621<br>(215-32106)          | 1851       |  | 0                           | -    |                                                                      |
| 22       | VALVE, UNLOADING, MAN OPERATED, FC-1, STD BRAKE         | 1             |                             | 3021  | -    | 14626<br>(707074)             | 3021       |  | 0                           | -    |                                                                      |
| 23       | ENERG POWER PACKAGE, FC-2 SYS                           | 1             | 953812-4-1                  | N/A   | N/A  | 91131<br>(954034)             | N/A        |  | N/A                         | N/A  | EXISTING A-7 3000 PSI SYS NOT PART OF BASELINE. LISTED FOR REF ONLY. |
| 24       | PRESS. REGULATOR, ENERG. PWR. PACKAGE, FC-2 SYS         | 1             | EA50002-24                  | N/A   | N/A  | 91133<br>(215-22131)          | N/A        |  | N/A                         | N/A  | EXISTING A-7 3000 PSI SYS NOT PART OF BASELINE. LISTED FOR REF ONLY. |

## LHS RELIABILITY

| ITEM NO. | COMPONENT                                               | QUANT PER SYS | 8000 PSI SYS  |        |      | 3000 PSI SYS                           |        |            | % MFHBF CHANGE 3000 VS 8000 |      | REMARKS/RATIONALE                  |
|----------|---------------------------------------------------------|---------------|---------------|--------|------|----------------------------------------|--------|------------|-----------------------------|------|------------------------------------|
|          |                                                         |               | P/N           | MFHBF  |      | WUC (P/N)                              | MFHBF  | PER SYSTEM | DEV                         | PROD |                                    |
|          |                                                         |               |               | DEV    | PROD |                                        |        |            |                             |      |                                    |
| 25       | SELECTOR VALVE, SOL OPERATED, SAS, FC-1 & FC-2 SYS      | 3             | 3321473       | 22090  | -    | 57588<br>57581<br>5758D<br>(215-32331) | 22090  |            | 0                           | -    |                                    |
| 26       | SELECTOR VALVE, MAN OPERATED, L.E. FLAP, FC-2 SYS       | 1             |               | 3184   | -    | 14751<br>(HP943100)                    | 3184   |            | 0                           | -    |                                    |
| 27       | CHARGING VALVE, PNEUMATIC, FC-2 ACCUM                   | 1             |               | 144594 | -    | 45411.3<br>(216-32509)                 | 144594 |            |                             | -    | LAB DEVEL. USING A 5000 PSI DESIGN |
| 28       | RESTRICTOR, TWO WAY, SED VALVE, FC-1 SYS                | 1             | REFX0380-250A | 28860  | -    | 1475E<br>(215-32320)                   | 28860  |            | 0                           | -    |                                    |
| 29       | RESTRICTOR, ONE WAY, L.E. FLAP, FC-2 SYS                | 1             |               | 28860  | -    | 1475E<br>(215-32320)                   | 28860  |            | 0                           | -    |                                    |
| 30       | RESTRICTOR, ONE WAY, L.E. FLAP OUTB'D, FC-2 SYS         | 4             |               | 7215   | -    | 1475E<br>(215-32320)                   | 7215   |            | 0                           | -    |                                    |
| 31       | RESTRICTOR, ONE WAY, L.E. FLAP INB'D, FC-2 SYS          | 2             |               | 14430  | -    | 1475E<br>(215-32320)                   | 14430  |            | 0                           | -    |                                    |
| 32       | RESTRICTOR, ONE WAY, L.E. FLAP INB'D, EXTEN'D, FC-2 SYS | 2             |               | 14430  | -    | 1475E<br>(215-32320)                   | 14430  |            | 0                           | -    |                                    |

## LHS RELIABILITY

| ITEM NO. | COMPONENT                                              | QUANT PER SYS | 8000 PSI SYS |       |      | 3000 PSI SYS      |       |            | % MFHBF CHANGE 3000 VS 8000 |      | REMARKS/RATIONALE                                                                    |
|----------|--------------------------------------------------------|---------------|--------------|-------|------|-------------------|-------|------------|-----------------------------|------|--------------------------------------------------------------------------------------|
|          |                                                        |               | P/N          | MFHBF |      | WUC (P/N)         | MFHBF | PER SYSTEM | DEV                         | PROD |                                                                                      |
|          |                                                        |               |              | DEV   | PROD |                   |       |            |                             |      |                                                                                      |
| 33       | SWIVEL JOINT, STD BRAKE, EXTEND, FC-1 SYS              | 1             |              | 6730  | -    | 14625 (215-32334) | 6730  | 6730       | 0                           | -    | SWIVEL JOINTS NOT DEVELOPED IN PHASE I. SEALS NOT DECIDED "O" RINGED NOT ACCEPTABLE. |
| 34       | SWIVEL JOINT, STD BRAKE, RETRACT, FC-1 SYS             | 1             |              | 6730  | -    | 14625 (215-32334) | 6730  | 6730       | 0                           | -    | SEE ITEM 33                                                                          |
| 35       | SWIVEL JOINT, EXEC FOR PACK, (EAT) FC-2 SYS            | 1             |              | N/A   | N/A  | 91132 (215-23307) | N/A   | N/A        | N/A                         | N/A  | EXISTING A-7 3000 PSI SYS NOT PART OF BASELINE. LISTED FOR REF ONLY.                 |
| 36       | SWIVEL JOINT, EXEC FOR PACK, (EAT) FC-2 SYS            | 1             |              | N/A   | N/A  | 91132 (215-23307) | N/A   | N/A        | N/A                         | N/A  | EXISTING A-7 3000 PSI SYS NOT PART OF BASELINE. LISTED FOR REF ONLY.                 |
| 37       | SWIVEL JOINT, WING FOLD, FC-1 & FC-2 SYS               | 2             |              | 10395 | -    | 14237 (215-72042) | 10395 | 10395      | 0                           | -    | SEE ITEM 33                                                                          |
| 38       | SWIVEL JOINT, WING FOLD, FC-2                          | 2             |              | 24772 | -    | 1475A (216-32201) | 24772 | 24772      | 0                           | -    | SEE ITEM 33                                                                          |
| 39       | SWIVEL JOINT, L.E. FLAP JING CONNECT, FC-2 (JCS SIDE)  | 2             |              | 24772 | -    | 1475A (216-32201) | 24772 | 24772      | 0                           | -    | SEE ITEM 33                                                                          |
| 40       | SWIVEL JOINT, L.E. FLAP JING CONNECT, FC-2 (WING SIDE) | 2             |              | 24772 | -    | 1475A (216-32201) | 24772 | 24772      | 0                           | -    | SEE ITEM 33                                                                          |

## LHS RELIABILITY

| ITEM NO. | COMPONENT                                                   | QUANT PER SYS | 8000 PSI SYS |        |      | 3000 PSI SYS                                       |            |  | 7 MFHBF CHANGE 3000 VS 8000 |      | REMARKS/RATIONALE                  |
|----------|-------------------------------------------------------------|---------------|--------------|--------|------|----------------------------------------------------|------------|--|-----------------------------|------|------------------------------------|
|          |                                                             |               | P/N          | MFHBF  |      | WUC (P/N)                                          | MFHBF      |  | DEV                         | PROD |                                    |
|          |                                                             |               |              | DEV    | PROD |                                                    | PER SYSTEM |  |                             |      |                                    |
| 41       | SKIVEL JOINT, L.E.<br>FLAP ACIR, OUTRD,<br>FC-2 (RING SIDE) | 8             |              | 11,364 | -    | 1475A<br>(215-82306)<br>(215-72310)<br>(216-32201) | 6193       |  | 83.5                        | -    | TO BE REPLACED BY<br>COILED TUBING |
| 42       | SKIVEL JOINT, L.E.<br>FLAP ACIR, OUTRD,<br>FC-2 (ACIR SIDE) | 8             |              | 11,364 | -    | 1475A<br>(215-82306)<br>(215-72310)<br>(216-32201) | 6193       |  | 83.5                        | -    | SEE ITEM 41                        |
| 43       | SKIVEL JOINT, L.E.<br>FLAP ACIR, INRD,<br>FC-2 (RING SIDE)  | 8             |              | 11,364 | -    | 1475A<br>(215-82306)<br>(215-72310)<br>(216-32201) | 6193       |  | 83.5                        | -    | SEE ITEM 41                        |
| 44       | CHEK VALVE, PRESS<br>(TYPE IIB - 3 SIZE)<br>SEP FLARE       | 3             | 95202-1      | 49605  | -    | 14759<br>(CVC-4120)                                | 49605      |  | 0                           | -    |                                    |
| 45       | CHEK VALVE, PRESS<br>(TYPE IIB - 3 SIZE)<br>SEP FLARE       | 2             | 95200-1      | 74408  | -    | 14759<br>(CVC-4120)                                | 74408      |  | 0                           | -    |                                    |
| 46       | CHEK VALVE, PRESS<br>(TYPE IIB - 4 SIZE)<br>SEP FLARE       | 4             | 95202-2      | 37204  | -    | 14759<br>(CVC-4120)                                | 37204      |  | 0                           | -    |                                    |
| 47       | CHEK VALVE, PRESS<br>(TYPE IIB - 4 SIZE)<br>SEP FLARE       | 1             | 95200-2      | 148816 | -    | 14759<br>(CVC-4120)                                | 148816     |  | 0                           | -    |                                    |
| 48       | CHEK VALVE, PRESS<br>(TYPE I - 6 SIZE)                      | 4             | 95202-4      | 37204  | -    | 14759<br>(CVC-4120)                                | 37204      |  | 0                           | -    |                                    |

## LHS RELIABILITY

| ITEM NO. | COMPONENT                                            | QUANT PER SYS | 8000 PSI SYS |        |      | 3000 PSI SYS     |        |     | % MFHBF CHANGE 3000 VS 8000 |          | REMARKS/RATIONALE |
|----------|------------------------------------------------------|---------------|--------------|--------|------|------------------|--------|-----|-----------------------------|----------|-------------------|
|          |                                                      |               | P/N          | MFHBF  |      | WUC (P/N)        | MFHBF  | DEV | PROD                        |          |                   |
|          |                                                      |               |              | DEV    | PROD |                  |        |     |                             |          |                   |
| 49       | CHECK VALVE, PRESS (TYPE I - 8 SIZE) ADJUST ISOL     | 1             | 95202-5      | 148816 | -    | 14759 (CVC-4120) | 148816 | 0   | -                           |          |                   |
| 50       | CHECK VALVE, PRESS (TYPE IIB - 8 SIZE) STD PLATE     | 1             | 95200-5      | 148816 | -    | 14759 (CVC-4120) | 148816 | 0   | -                           |          |                   |
| 51       | CHECK VALVE, PRESS (TYPE IA - 3 SIZE) PAT 8 G OUTLET | 1             | 952XX-5      | 148816 | -    | 14759 (CVC-4120) | 148816 | 0   | -                           |          |                   |
| 52       | CHECK VALVE, PRESS (TYPE IIB - 8 SIZE) FRT SUSS      | 2             | 95201-5      | 74408  | -    | 14759 (CVC-4120) | 74408  | 0   | -                           |          |                   |
| 53       | CHECK VALVE, RETURN - 3 SIZE FILL & I.E. LAP         | 3             |              | 49605  | -    | 14759 (CVC-4120) | 49605  | 0   | -                           |          |                   |
| 54       |                                                      |               |              |        |      |                  |        |     |                             | NOT USED |                   |
| 55       | CHECK VALVE, RETURN - 6 SIZE CASE TRAIN              | 2             |              | 74408  | -    | 14759 (CVC-4120) | 74408  | 0   | -                           |          |                   |
| 56       | CHECK VALVE, RETURN - 8 SIZE                         | 5             |              | 29763  | -    | 14759 (CVC-4120) | 29763  | 0   | -                           |          |                   |

## LIHS RELIABILITY

| ITEM NO. | COMPONENT                                              | QUANT PER SYS | 8000 PSI SYS |       |      | 3000 PSI SYS                  |       |            | % MFIBF CHANGE 3000 VS 8000 |      | REMARKS/RATIONALE               |
|----------|--------------------------------------------------------|---------------|--------------|-------|------|-------------------------------|-------|------------|-----------------------------|------|---------------------------------|
|          |                                                        |               | P/N          | MFIBF |      | WUC (P/N)                     | MFIBF | PER SYSTEM | DEV                         | PROD |                                 |
|          |                                                        |               |              | DEV   | PROD |                               |       |            |                             |      |                                 |
| 57       | EXTENSION UNIT, ROLL FEEL, FC-2 PRESS & RETURN         | 2             |              | 45455 | -    | 14234 (215-72301)             | 1498  |            | 2934                        | -    | TO BE REPLACED BY COILED TUBING |
| 58       | EXTENSION UNIT, ROLL FEEL, FC-1 FEELER                 | 1             |              | 90909 | -    | 14234 (215-32336) (215-32337) | 2996  |            | 2934                        | -    | SEE ITEM 57                     |
| 59       | EXTENSION UNIT, ROLL FEEL, FC-1 PRESS                  | 1             |              | 90909 | -    | 14234 (215-32336) (215-32337) | 2996  |            | 2934                        | -    | SEE ITEM 57                     |
| 60       | EXTENSION UNIT, SPOOLER, FC-1 PRESS & RETURN           | 4             |              | 22727 | -    | 1423C (215-72304) (215-72303) | 1602  |            | 1319                        | -    | SEE ITEM 57                     |
| 61       | EXTENSION UNIT, SPOOLER, FC-2 PRESS & RETURN           | 4             |              | 22727 | -    | 1423C (215-72304) (215-72303) | 1602  |            | 1319                        | -    | SEE ITEM 57                     |
| 62       | EXTENSION UNIT, ALLEYS, FC-1 PRESS, FC-1 & FC-2 RETURN | 6             |              | 15152 | -    | 14238 (215-82302) (215-82303) | 556   |            | 2625                        | -    | SEE ITEM 57                     |
| 63       | EXTENSION UNIT, ALLEYS, FC-2 PRESS                     | 2             |              | 45455 | -    | 14238 (215-82302) (215-82308) | 1668  |            | 2625                        | -    | SEE ITEM 57                     |
| 64       | MANIFOLD, FC-1 PRESS                                   | 1             |              | -     | -    | 45119                         | -     |            | -                           | -    |                                 |

## LHS RELIABILITY

| ITEM NO. | COMPONENT                        | QUANT PER SYS | 8000 PSI SYS |       |      |                   | 3000 PSI SYS |            |   | % MFHBF CHANGE 3000 VS 8000 |      |  | REMARKS/RATIONALE |
|----------|----------------------------------|---------------|--------------|-------|------|-------------------|--------------|------------|---|-----------------------------|------|--|-------------------|
|          |                                  |               | P/N          | MFHBF |      | WUC (P/N)         | MFHBF        | PER SYSTEM |   | DEV                         | PROD |  |                   |
|          |                                  |               |              | DEV   | PROD |                   |              |            |   |                             |      |  |                   |
| 65       | MANIFOLD, FC-1 RETURN            | 1             |              | -     | -    | 45119             | -            | -          | - | -                           | -    |  |                   |
| 66       | MANIFOLD, FC-1 RELIEF VALVE      | 1             | 8696-581201  | -     |      | 45119             | -            | -          | - | -                           | -    |  |                   |
| 67       | HOSE ASSY, PUMP PRESS FC-1       | 1             |              | 17672 | -    | 4511X             | 17672        |            | 0 | -                           | -    |  |                   |
| 68       | HOSE ASSY, PUMP PRESS, FC-2      | 1             |              | 13594 | -    | 4521R (218-42502) | 13594        |            | 0 | -                           | -    |  |                   |
| 69       | HOSE ASSY, PUMP SUCTION, FC-1    | 1             |              | 25246 | -    | 4511Y (218-42501) | 25246        |            | 0 | -                           | -    |  |                   |
| 70       | HOSE ASSY, PUMP SUCTION, FC-2    | 1             |              | 9063  | -    | 4521Q (218-42501) | 9063         |            | 0 | -                           | -    |  |                   |
| 71       | HOSE ASSY, PUMP CASE DRAIN, FC-1 | 1             |              | 23563 | -    | 4511Z (218-42502) | 23563        |            | 0 | -                           | -    |  |                   |
| 72       | HOSE ASSY, PUMP CASE DRAIN, FC-2 | 1             |              | 13594 | -    | 4521R (218-42502) | 13594        |            | 0 | -                           | -    |  |                   |

[illegible]

## LHS RELIABILITY

| ITEM NO. | COMPONENT                                       | QUANT PER SYS | 8000 PSI SYS |       |      |                                              | 3000 PSI SYS |            |      | % MFHBP CHANGE 3000 VS 8000 |      | REMARKS/RATIONALE |
|----------|-------------------------------------------------|---------------|--------------|-------|------|----------------------------------------------|--------------|------------|------|-----------------------------|------|-------------------|
|          |                                                 |               | P/N          | MFHBP |      | MUC (P/N)                                    | MFHBP        | PER SYSTEM |      | DEV                         | PROD |                   |
|          |                                                 |               |              | DEV   | PROD |                                              |              |            |      |                             |      |                   |
| 101      | AILERON ACTUATOR                                | 2             | 83-00221     | 1101  |      | 14233 (215-82031)                            | 807          |            | 36.5 |                             |      |                   |
| 102      | SPOILER ACTUATOR                                | 2             | 83-00271     | 2645  |      | 1423B (215-72031)                            | 2067         |            | 28.0 |                             |      |                   |
| 103      | RUDER ACTUATOR                                  | 1             | 8696-587100  | 3351  |      | 14431 (CV15-151039)                          | 3073         |            | 9.0  |                             |      |                   |
| 104      | UNIT HORIZONTAL TAIL ACTUATOR                   | 2             | 83-00211     | 1725  |      | 14531 (CV15-601051)                          | 1741         |            | -0.9 |                             |      |                   |
| 105      | ROLL FEEL CONTROLLING ACTUATOR                  | 1             | 83-00251     | 3324  |      | 14231 (210-32277)                            | 2761         |            | 20.4 |                             |      |                   |
| 106      | ROLL FEEL CONTROLLING ACTUATOR ROLL, YAW, PITCH | 3             | 83-00231     | 997   |      | 5758A&B<br>5758CAF<br>57582&3<br>(210-32230) | 696          |            | 43.3 |                             |      |                   |
| 107      | SPEED BRAKE ACTUATOR                            | 1             | 83-00201     | 7864  |      | 14622 (215-32031)                            | 8621         |            | -8.8 |                             |      |                   |
| 108      | LEADING EDGE FLAP ACTUATOR                      | 8             | 83-00261     | 3113  |      | 14753<br>14755<br>(215-72033)                | 2783         |            | 11.8 |                             |      |                   |

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APPENDIX E

LHS MAINTAINABILITY PREDICTIONS

## LHS MAINTAINABILITY

| ITEM NO. | COMPONENT                     | QUANT PER SYS | 8000 PSI SYS |        |       |                               | 3000 PSI SYS |            |      | 2 MMH/FH CHANGE 3000 VS 8000 |                                         | REMARKS/RATIONALE |
|----------|-------------------------------|---------------|--------------|--------|-------|-------------------------------|--------------|------------|------|------------------------------|-----------------------------------------|-------------------|
|          |                               |               | P/N          | MMH/FH |       | WUC (P/N)                     | MMH/FH       | PER SYSTEM | DEV  | PROD                         |                                         |                   |
|          |                               |               |              | DEV    | PROD  |                               |              |            |      |                              |                                         |                   |
| 1        | FUEL, FC-1 & FC-2 SYS         | 2             | PV3-047-1    | .0173  | -     | 45116<br>(215-22119)          | .018288      |            | -5.4 | -                            | Proportional to change in failure rate. |                   |
| 2        | RESERVOIR, FC-1               | 1             | 83-00241-    | .0031  | .0028 | 45113<br>(215-32108-3)        | .003215      |            | -4.4 | -12.5                        |                                         |                   |
| 3        | RESERVOIR, FC-2               | 1             | 83-00241-    | .0031  | .0028 | 45113<br>(215-32108-3)        | .003215      |            | -4.4 | -12.5                        |                                         |                   |
| 4        | FUEL VALVE, FC-1 & FC-2 SYS   | 2             | 1257<br>1258 | .0034  | -     | 4521A<br>(215-32345)          | .00342       |            | 0    | -                            |                                         |                   |
| 5        | FUEL VALVE, FC-1 & FC-2 SYS   | 2             |              | .0009  | -     | 45112<br>(215-32359)          | .000928      |            | 0    | -                            |                                         |                   |
| 6        | FUEL, PRESS FC-1 & FC-2 SYS   | 2             | AD-A640-8341 | .0093  | -     | 45118<br>(215-32306)          | .009256      |            | 0    | -                            |                                         |                   |
| 7        | FUEL, RETURN, FC-1 & FC-2 SYS | 2             | M8815/4A8    | .0125  | -     | 4511E<br>4521F<br>(210-82500) | .012545      |            | 0    | -                            |                                         |                   |
| 8        | FUEL, FUEL PUMP, FC-2 SYS     | 1             | M8815/4A-6   | .0063  | -     | 4511E<br>4521F<br>(210-82500) | .006273      |            | 0    | -                            |                                         |                   |

## LHS MAINTAINABILITY

| ITEM NO. | COMPONENT                                                   | QUANT PER SYS | 8000 PSI SYS   |        |      | 3000 PSI SYS                     |            |      | % MMH/FH CHANGE<br>3000 VS 8000 |                                                                            | REMARKS/RATIONALE |
|----------|-------------------------------------------------------------|---------------|----------------|--------|------|----------------------------------|------------|------|---------------------------------|----------------------------------------------------------------------------|-------------------|
|          |                                                             |               | P/N            | MMH/FH |      | WUC<br>(P/N)                     | MMH/FH     |      | DEV                             | PROD                                                                       |                   |
|          |                                                             |               |                | DEV    | PROD |                                  | PER SYSTEM |      |                                 |                                                                            |                   |
| 9        | FILTER, EMERG<br>PAR. PACKAGE,<br>FC-2 SYS                  | 1             | AD3258-<br>8HV | N/A    | N/A  | 91134/49A27<br>(215-32484-1)     | N/A        | N/A  | N/A                             | EXISTING A-7 3000 PSI SYS<br>NOT PART OF BASELINE.<br>LISTED FOR REF ONLY. |                   |
| 10       | PRESSURE SNUBBER,<br>FC-1 & FC-2 SYS                        | 2             | 95239          | .00002 | -    | 45133<br>(S-1442)                | .000016    | 0    | -                               | Proportional to change in<br>failure rate.                                 |                   |
| 11       | PRESSURE MTR<br>& SWITCH,<br>FC-1 & FC-2 SYS                | 2             | 18-2143        | .0062  | -    | 45131/231<br>(216-32499)         | .0062      | 0    | -                               |                                                                            |                   |
| 12       | BLEED VALVE,<br>FC-1 & FC-2 SYS                             | 2             | 40121          | .0002  | -    | 14759<br>(CVC-4202)              | .00018     | 0    | -                               |                                                                            |                   |
| 13       | ACTUATOR,<br>FC-2 S/S                                       | 1             | 331471         | .0010  | -    | 4511B<br>(215-32523-4)           | .00074     | 35.1 | -                               |                                                                            |                   |
| 14       | PRESSURE GAGE,<br>FC-2 S/S                                  | 1             | 1218-63-1      | .00006 | -    | 45411-1<br>(6901-18-1)           | .000064    | 0    | -                               |                                                                            |                   |
| 15       | SHUT-OFF VALVE,<br>S/L OPERATED,<br>FC-2, PRESS DUMP        | 1             |                | .0004  | -    | 4531H<br>(707394)<br>(215-22308) | .00036     | 0    | -                               |                                                                            |                   |
| 16       | QUICK DISC, PRESS,<br>GR. COUPLING HALF,<br>FC-1 & FC-2 SYS | 2             | AE80942H       | .0015  | -    | 4511C<br>4521C<br>(215-32587)    | .00146     | 0    | -                               | Y                                                                          |                   |

## LHS MAINTAINABILITY

| ITEM NO. | COMPONENT                                              | QUANT PER SYS | 8000 PSI SYS                |        |      | 3000 PSI SYS                  |         |     | % NMH/FH CHANGE 3000 VS 8000 |                                                                      | REMARKS/RATIONALE |
|----------|--------------------------------------------------------|---------------|-----------------------------|--------|------|-------------------------------|---------|-----|------------------------------|----------------------------------------------------------------------|-------------------|
|          |                                                        |               | P/N                         | NMH/FH |      | WUC (P/N)                     | NMH/FH  | DEV | PROD                         |                                                                      |                   |
|          |                                                        |               |                             | DEV    | PROD |                               |         |     |                              |                                                                      |                   |
| 17       | QUICK DISC, SUCTION GR. COUPLING HALF, FC-1 & FC-2 SYS | 2             | 3018-54-12D<br>01553-57-120 | .0008  | -    | 4511D<br>4521D<br>(215-32351) | .00076  | 0   | -                            |                                                                      |                   |
| 18       | QUICK DISC, PUMP FEEDS, HOSE & BLKHD PART, FC-1 & FC-2 | 2             | AE80943H<br>AE80944H        | .0017  | -    | 45114<br>45214<br>(210-82234) | .00166  | 0   | -                            |                                                                      |                   |
| 19       | QUICK DISC, PUMP FEEDS, HOSE & BLKHD PART, FC-1 & FC-2 | 2             | AE94951J<br>AE94952J        | .0017  | -    | 45114<br>45214<br>(210-82234) | .00166  | 0   | -                            |                                                                      |                   |
| 20       | QUICK DISC, PUMP FEEDS, HOSE & BLKHD PART, FC-1 & FC-2 | 2             | AE94951G<br>AE94952G        | .0017  | -    | 45114<br>45214<br>(210-82234) | .00166  | 0   | -                            |                                                                      |                   |
| 21       | PISTON VALVE, OPERATED, FC-1, 11D FRAME                | 1             | 3321472                     | .0069  | -    | 14621<br>(215-32106)          | .006859 | 0   | -                            |                                                                      |                   |
| 22       | VALVE, UNLOADING, MAN OPERATED, FC-1, SPD BRAKE        | 1             |                             | .0041  | -    | 14626<br>(707074)             | .00412  | 0   | -                            |                                                                      |                   |
| 23       | EMERG PWR PKG, FC-2 SYS                                | 1             | 953812-4-1                  | N/A    | N/A  | 91131<br>(954034)             | N/A     | N/A | N/A                          | EXISTING A-7 3000 PSI SYS NOT PART OF BASELINE. LISTED FOR REF ONLY. |                   |
| 24       | PRESS. REGULATOR, EMERG. PWR. PACKAGE, FC-2 SYS        | 1             | EA50002-24                  | N/A    | N/A  | 91133<br>(215-22131)          | N/A     | N/A | N/A                          | EXISTING A-7 3000 PSI SYS NOT PART OF BASELINE. LISTED FOR REF ONLY. |                   |

## LHS MAINTAINABILITY

| ITEM NO. | COMPONENT                                              | QUANT PER SYS | 8000 PSI SYS  |        |      | 3000 PSI SYS                           |         |     | MMH/FH CHANGE 3000 VS 8000 |   | REMARKS/RATIONALE                       |
|----------|--------------------------------------------------------|---------------|---------------|--------|------|----------------------------------------|---------|-----|----------------------------|---|-----------------------------------------|
|          |                                                        |               | P/N           | MMH/FH |      | WUC (P/N)                              | MMH/FH  | DEV | PROD                       |   |                                         |
|          |                                                        |               |               | DEV    | PROD |                                        |         |     |                            |   |                                         |
| 25       | SELECTOR VALVE, SOL OPERATED, SAS, FC-1 & FC-2 SYS     | 3             | 3321473       | .0027  | -    | 57588<br>57581<br>5758D<br>(215-32331) | .00267  |     | 0                          | - | Proportional to change in failure rate. |
| 26       | SELECTOR VALVE, MAN OPERATED, L.F. FLAP, FC-2 SYS      | 1             |               | .0047  | -    | 14751<br>(HP943100)                    | .004712 |     | 0                          | - |                                         |
| 27       | CHARGING VALVE, ELECTRIC, FC-2 ACCN                    | 1             |               | .0001  | -    | 45411.3<br>(216-32509)                 | .000106 |     | 0                          | - |                                         |
| 28       | RESTRICTOR, TWO WAY, STD LENS, FC-1 SYS                | 1             | REFX0380-250A | .0134  | -    | 14629<br>1475E<br>(215-32320)          | .001367 |     | 0                          | - |                                         |
| 29       | RESTRICTOR, ONE WAY, L.E. FLAP, FC-2 SYS               | 1             |               | .0134  | -    | 1475E<br>(215-32320)                   | .001367 |     | 0                          | - |                                         |
| 30       | RESTRICTOR, ONE WAY, L.E. FLAP CONT'D, FC-2 SYS        | 4             |               | .0055  | -    | 1475E<br>(215-32320)                   | .005468 |     | 0                          | - |                                         |
| 31       | RESTRICTOR, ONE WAY, L.E. FLAP INB'D, EXTEND, FC-2 SYS | 2             |               | .0027  | -    | 1475E<br>(215-32320)                   | .002734 |     | 0                          | - |                                         |
| 32       | RESTRICTOR, ONE WAY, L.E. FLAP INB'D, EXTEND, FC-2 SYS | 2             |               | .0027  | -    | 1475E<br>(215-32320)                   | .002734 |     | 0                          | - |                                         |

## LHS MAINTAINABILITY

| ITEM NO. | COMPONENT                                              | QUANT PER SYS | 8000 PSI SYS |        |      |                   | 3000 PSI SYS |            |     | % MMH/FH CHANGE 3000 VS 8000 |                                                                      | REMARKS/RATIONALE |
|----------|--------------------------------------------------------|---------------|--------------|--------|------|-------------------|--------------|------------|-----|------------------------------|----------------------------------------------------------------------|-------------------|
|          |                                                        |               | P/N          | MMH/FH |      | WUC (P/N)         | MMH/FH       | PER SYSTEM | DEV | PROD                         |                                                                      |                   |
|          |                                                        |               |              | DEV    | PROD |                   |              |            |     |                              |                                                                      |                   |
| 33       | SWIVEL JOINT, SPD FLAKE, EXTEND, FC-1 SYS              | 1             |              | .0030  | -    | 14625 (215-32334) | .0030165     |            | 0   | -                            |                                                                      |                   |
| 34       | SWIVEL JOINT, STD FLAKE, RETRACT, FC-1 SYS             | 1             |              | .0030  | -    | 14625 (215-32334) | .0030165     |            | 0   | -                            |                                                                      |                   |
| 35       | SWIVEL JOINT, FUSELAGE PACK, (BAT) FC-2 SYS            | 1             |              | N/A    | N/A  | 91132 (215-23307) | N/A          |            | N/A | N/A                          | EXISTING A-7 3000 PSI SYS NOT PART OF BASELINE. LISTED FOR REF ONLY. |                   |
| 36       | SWIVEL JOINT, FUSELAGE PACK, (BAT) FC-2 SYS            | 1             |              | N/A    | N/A  | 91132 (215-23307) | N/A          |            | N/A | N/A                          | EXISTING A-7 3000 PSI SYS NOT PART OF BASELINE. LISTED FOR REF ONLY. |                   |
| 37       | SWIVEL JOINT, WING FOLD, FC-1 & FC-2 SYS               | 2             |              | .0001  | -    | 14237 (215-72042) | .000141      |            | 0   | -                            | PROPORTIONAL TO CHANGE IN FAILURE RATE                               |                   |
| 38       | SWIVEL JOINT, L.E. WING CONNECT, FC-2 FUS & RETURN     | 2             |              | .0004  | -    | 1475A (216-32201) | .0003626     |            | 0   | -                            |                                                                      |                   |
| 39       | SWIVEL JOINT, L.E. FLAP WING CONNECT, FC-2 (FUS SIDE)  | 2             |              | .0004  | -    | 1475A (216-32201) | .0003626     |            | 0   | -                            |                                                                      |                   |
| 40       | SWIVEL JOINT, L.E. FLAP WING CONNECT, FC-2 (WING SIDE) | 2             |              | .0004  | -    | 1475A (216-32201) | .0003626     |            | 0   | -                            |                                                                      |                   |

## LHS MAINTAINABILITY

| ITEM NO. | COMPONENT                                                   | QUANT PER SYS | 8000 PSI SYS |        |      | 3000 PSI SYS                                       |          |            | % MMH/FH CHANGE 3000 VS 8000 |      | REMARKS/RATIONALE |
|----------|-------------------------------------------------------------|---------------|--------------|--------|------|----------------------------------------------------|----------|------------|------------------------------|------|-------------------|
|          |                                                             |               | P/N          | MMH/FH |      | WUC (P/N)                                          | MMH/FH   | PER SYSTEM | DEV                          | PROD |                   |
|          |                                                             |               |              | DEV    | PROD |                                                    |          |            |                              |      |                   |
| 41       | SWITCH JOINT, L.E.<br>FLAP ACTR, OUTSD,<br>FC-2 (WING SIDE) | 8             |              | .0008  | -    | 1475A<br>(215-82306)<br>(215-72310)<br>(216-32201) | .00145   |            | -45.5                        | -    |                   |
| 42       | SWITCH JOINT, L.E.<br>FLAP ACTR, OUTSD,<br>FC-2 (ACTR SIDE) | 8             |              | .0008  | -    | 1475A<br>(215-82306)<br>(215-72310)<br>(216-32201) | .00145   |            | -45.5                        | -    |                   |
| 43       | SWITCH JOINT, L.E.<br>FLAP ACTR, INSD,<br>FC-2 (WING SIDE)  | 8             |              | .0008  | -    | 1475A<br>(215-82306)<br>(215-72310)<br>(216-32201) | .00145   |            | -45.5                        | -    |                   |
| 44       | CHECK VALVE, PRESS<br>(TYPE 1 - 3 SIZE)<br>RUE (FD BRAKE)   | 3             | 95202-1      | .0015  | -    | 14759<br>(CVC-4120)                                | .001484  |            | 0                            | -    |                   |
| 45       | CHECK VALVE, PRESS<br>(TYPE 118 - 3 SIZE)<br>STD BRAKE      | 2             | 95200-1      | .0010  | -    | 14759<br>(CVC-4120)                                | .000989  |            | 0                            | -    |                   |
| 46       | CHECK VALVE, PRESS<br>(TYPE 118 - 4 SIZE)<br>LHT            | 4             | 95202-2      | .0020  | -    | 14759<br>(CVC-4120)                                | .001978  |            | 0                            | -    |                   |
| 47       | CHECK VALVE, PRESS<br>(TYPE 118 - 4 SIZE)<br>STD BRAKE      | 1             | 95202-2      | .0005  | -    | 14759<br>(CVC-4120)                                | .0004945 |            | 0                            | -    |                   |
| 48       | CHECK VALVE, PRESS<br>(TYPE 1 - 6 SIZE)                     | 4             | 95202-4      | .0020  | -    | 14759<br>(CVC-4120)                                | .001978  |            | 0                            | -    |                   |

## LHS MAINTAINABILITY

| ITEM NO. | COMPONENT                                            | QUANT PER SYS | 8000 PSI SYS |        |      |                  | 3000 PSI SYS |            |     | 7 MMH/FH CHANGE 3000 VS 8000 |          | REMARKS/RATIONALE |
|----------|------------------------------------------------------|---------------|--------------|--------|------|------------------|--------------|------------|-----|------------------------------|----------|-------------------|
|          |                                                      |               | P/N          | MMH/FH |      | WUC (P/N)        | MMH/FH       | PER SYSTEM | DEV | PROD                         |          |                   |
|          |                                                      |               |              | DEV    | PROD |                  |              |            |     |                              |          |                   |
| 49       | CHECK VALVE, PRESS. (TYPE I - 8 SIZE) ROOM ISOL      | 1             | 95202-5      | .0005  | -    | 14759 (CVC-4120) | .0004945     |            | 0   | -                            |          |                   |
| 50       | CHECK VALVE, PRESS (TYPE IIB - 8 SIZE) SH BAKE       | 1             | 95200-5      | .0005  | -    | 14759 (CVC-4120) | .0004945     |            | 0   | -                            |          |                   |
| 51       | CHECK VALVE, PRESS (TYPE IA - 8 SIZE) FAP REC OUTLET | 1             | 952XX-5      | .0005  | -    | 14759 (CVC-4120) | .0004945     |            | 0   | -                            |          |                   |
| 52       | CHECK VALVE, PRESS (TYPE IIB - 8 SIZE) FISH PRESS    | 2             | 95201-5      | .0010  | -    | 14759 (CVC-4120) | .000989      |            | 0   | -                            |          |                   |
| 53       | CHECK VALVE, RETURN - 3 SIZE FILL & L.E. FLAP        | 3             |              | .0015  | -    | 14759 (CVC-4120) | .001484      |            | 0   | -                            |          |                   |
| 54       |                                                      |               |              |        |      |                  |              |            |     |                              | NOT USED |                   |
| 55       | CHECK VALVE, RETURN - 6 SIZE CASE DRAIN              | 2             |              | .0010  | -    | 14759 (CVC-4120) | .000989      |            | 0   | -                            |          |                   |
| 56       | CHECK VALVE, RETURN, - 8 SIZE                        | 5             |              | .0025  | -    | 14759 (CVC-4120) | .0024725     |            | 0   | -                            |          |                   |

## LHS MAINTAINABILITY

| ITEM NO. | COMPONENT                                               | QUANT PER SYS | 8000 PSI SYS |        |      |                               | 3000 PSI SYS |  |       | % MMH/FH CHANGE 3000 VS 8000 |  | REMARKS/RATIONALE |
|----------|---------------------------------------------------------|---------------|--------------|--------|------|-------------------------------|--------------|--|-------|------------------------------|--|-------------------|
|          |                                                         |               | P/N          | MMH/FH |      | WUC (P/N)                     | MMH/FH       |  | DEV   | PROD                         |  |                   |
|          |                                                         |               |              | DEV    | PROD |                               | PER SYSTEM   |  |       |                              |  |                   |
| 57       | EXTENSION UNIT, ROLL FEEL, FC-2 PRESS & RETURN          | 2             |              | .0003  | -    | 14234 (215-72301)             | .008344      |  | -96.7 | -                            |  |                   |
| 58       | EXTENSION UNIT, ROLL FEEL, FC-1 PRESS                   | 1             |              | .0001  | -    | 14234 (215-32336) (215-32337) | .004172      |  | -96.7 | -                            |  |                   |
| 59       | EXTENSION UNIT, ROLL FEEL, FC-1 PRESS                   | 1             |              | .0001  | -    | 14234 (215-32336) (215-32337) | .004172      |  | -96.7 | -                            |  |                   |
| 60       | EXTENSION UNIT, SPOOLER, FC-1 PRESS & RETURN            | 4             |              | .0005  | -    | 1423C (215-72304) (215-72303) | .006749      |  | -93.0 | -                            |  |                   |
| 61       | EXTENSION UNIT, SPOOLER, FC-2 PRESS & RETURN            | 4             |              | .0005  | -    | 1423C (215-72304) (215-72303) | .006749      |  | -93.0 | -                            |  |                   |
| 62       | EXTENSION UNIT, AIRLIFT, FC-1 PRESS, FC-2 & FC-2 RETURN | 6             |              | .0007  | -    | 14238 (215-82302) (215-82308) | .019627      |  | -96.3 | -                            |  |                   |
| 63       | EXTENSION UNIT, AIRLIFT, FC-2 PRESS                     | 2             |              | .0002  | -    | 14238 (215-82302) (215-82308) | .006542      |  | -96.3 | -                            |  |                   |
| 64       | EXTENSION D, FC-1 PRESS                                 | 1             |              | -      | -    | 45119                         | -            |  | -     | -                            |  |                   |

## LHS MAINTAINABILITY

| ITEM NO. | COMPONENT                        | QUANT PER SYS | 8000 PSI SYS |        |      |                   | 3000 PSI SYS |            |     | % MMH/FH CHANGE 3000 VS 8000 |  | REMARKS/RATIONALE |
|----------|----------------------------------|---------------|--------------|--------|------|-------------------|--------------|------------|-----|------------------------------|--|-------------------|
|          |                                  |               | P/N          | MMH/FH |      | WUC (P/N)         | MMH/FH       | PER SYSTEM | DEV | PROD                         |  |                   |
|          |                                  |               |              | DEV    | PROD |                   |              |            |     |                              |  |                   |
| 65       | MANIFOLD, FC-1 RETURN            | 1             |              | -      | -    | 45119             | -            | -          | -   | -                            |  |                   |
| 66       | MANIFOLD, FC-1 RELIEF VALVE      | 1             | 8696-81201   | -      | -    | 45119             | -            | -          | -   | -                            |  |                   |
| 67       | HOSE ASSY, PUMP PRESS FC-1       | 1             |              | .00007 | -    | 4511X             | .0000673     | 0          | -   | -                            |  |                   |
| 68       | HOSE ASSY, PUMP PRESS, FC-2      | 1             |              | .00006 |      | 4521R (218-42502) | .0006336     | 0          | -   | -                            |  |                   |
| 69       | HOSE ASSY, PUMP SUCTON, FC-1     | 1             |              | .00005 |      | 4511Y (218-42501) | .0005423     | 0          | -   | -                            |  |                   |
| 70       | HOSE ASSY, PUMP SUCTON, FC-2     | 1             |              | .00005 |      | 4521Q (218-42501) | .000506      | 0          | -   | -                            |  |                   |
| 71       | HOSE ASSY, PUMP CASE DRAIN, FC-1 | 1             |              | .00003 |      | 4511Z (218-42502) | .0003368     | 0          | -   | -                            |  |                   |
| 72       | HOSE ASSY, PUMP CASE DRAIN, FC-2 | 1             |              | .00006 |      | 4521R (218-42502) | .0006336     | 0          | -   | -                            |  |                   |

## LHS MAINTAINABILITY

| ITEM NO. | COMPONENT                         | QUANT PER SYS | 8000 PSI SYS |        |      | 3000 PSI SYS     |          |            | % MMH/FH CHANGE 3000 VS 8000 |      | REMARKS/RATIONALE |
|----------|-----------------------------------|---------------|--------------|--------|------|------------------|----------|------------|------------------------------|------|-------------------|
|          |                                   |               | P/N          | MMH/FH |      | WUC (P/N)        | MMH/FH   | PER SYSTEM | DEV                          | PROD |                   |
|          |                                   |               |              | DEV    | PROD |                  |          |            |                              |      |                   |
| 73       | CHECK VALVE, RETURN, P.T. SECTION | 1             |              | .0005  | -    | 14759 (CVC-4120) | .0004945 | 0          | -                            |      |                   |
| 74       | MANIFOLD, FC-2 ACCUMULATOR        | 1             |              | -      | -    | 45419            | -        | -          | -                            |      |                   |
|          |                                   |               |              |        |      |                  |          |            |                              |      |                   |
|          |                                   |               |              |        |      |                  |          |            |                              |      |                   |
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|          |                                   |               | </           |        |      |                  |          |            |                              |      |                   |

## LHS MAINTAINABILITY

| ITEM NO. | COMPONENT                           | QUANT PER SYS | 8000 PSI SYS |        |      | 3000 PSI SYS                                 |            |     | 7. MMH/FH CHANGE 3000 VS 8000 |   | REMARKS/RATIONALE |
|----------|-------------------------------------|---------------|--------------|--------|------|----------------------------------------------|------------|-----|-------------------------------|---|-------------------|
|          |                                     |               | P/N          | MMH/FH |      | WUC (P/N)                                    | PER SYSTEM | DEV | PROD                          |   |                   |
|          |                                     |               |              | DEV    | PROD |                                              |            |     |                               |   |                   |
| 101      | AILERON ACTUATOR                    | 2             | 83-00221     | .0228  | -    | 14233<br>(215-82031)                         | .031142    |     | -26.7                         | - |                   |
| 102      | SPOILER ACTUATOR                    | 2             | 83-00271     | .0063  | -    | 14238<br>(215-72031)                         | .008052    |     | -21.9                         | - |                   |
| 103      | RUDDER ACTUATOR                     | 1             | 8696-587100  | .0082  |      | 14431<br>(CV15-151039)                       | .008968    |     | - 8.3                         | - |                   |
| 104      | UNIT HORIZONTAL TAIL ACTUATOR       | 2             | 83-00211     | .0451  |      | 14531<br>(CV15-601051)                       | .044672    |     | 0.9                           |   |                   |
| 105      | ROLL FEEL ISOLATING ACTUATOR        | 1             | 83-00251     | .0073  |      | 14231<br>(210-32277)                         | .008811    |     | -17.1                         |   |                   |
| 106      | AUTOPILOT ACTUATOR ROLL, YAW, PITCH | 3             | 83-00231     | .0305  |      | 5758A6B<br>5758E6F<br>5758E63<br>(210-32230) | .04367     |     | -30.2                         |   |                   |
| 107      | SPEED BRAKE ACTUATOR                | 1             | 83-00201     | .0030  |      | 14622<br>(215-32031)                         | .002743    |     | 9.6                           |   |                   |
| 108      | LEADING EDGE FLAP ACTUATOR          | 8             | 83-00261     | .0033  |      | 14753<br>14755<br>(215-72033)                | .003668    |     | -10.6                         |   |                   |

[illegible]

NADC-77108-30

## APPENDIX F

FAILURE ANALYSIS REPORTSContents

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| 03-812019             | Valve Block Control Pressure Bore Erosion (P/N 570934) | 224             |
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| HYD-36-81             | 4-Way Solenoid Valve, P/N 3321472                      | 232             |

SPERRY VICKERS

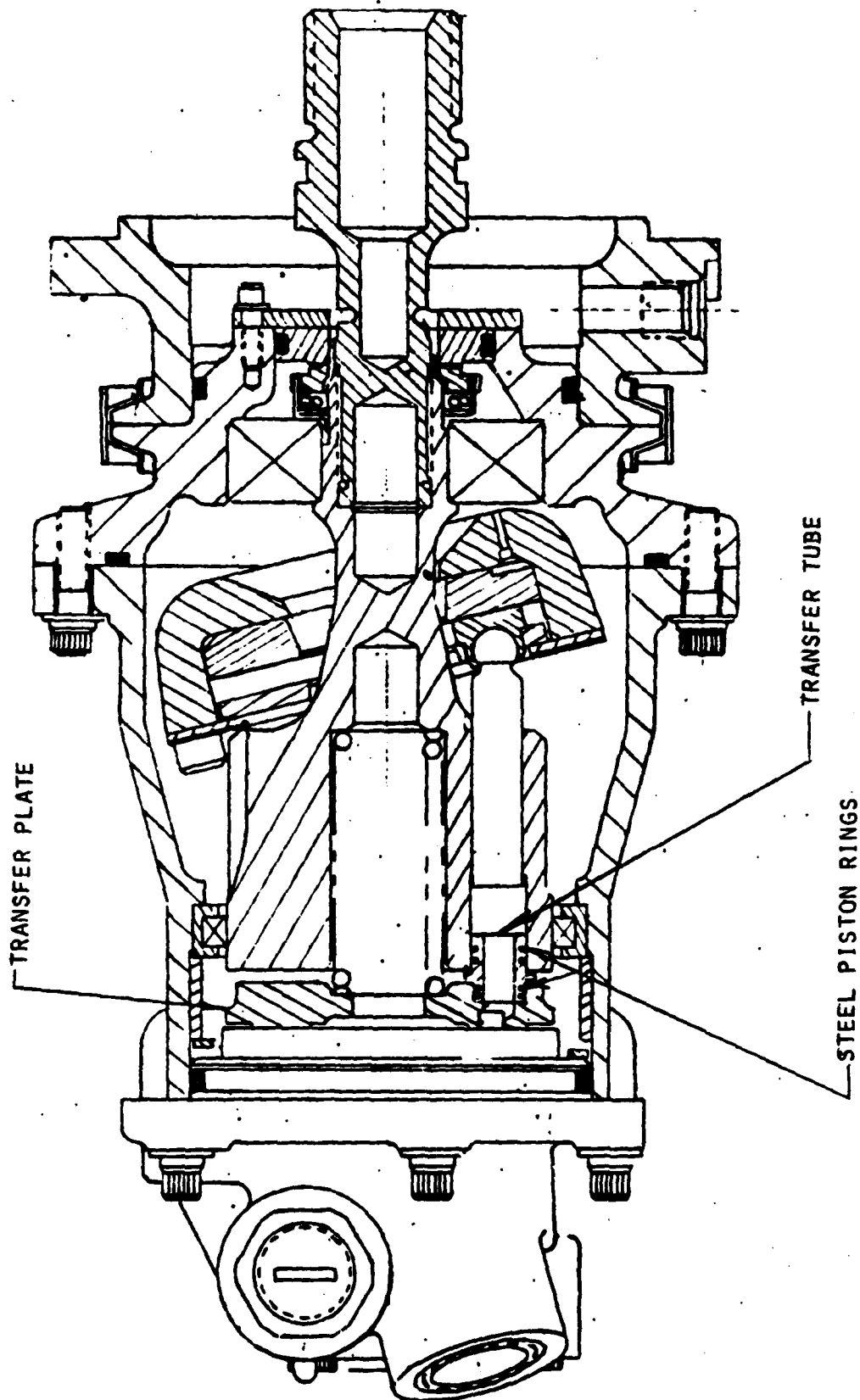
ENGINEERING  
TECHNICAL REPORT I

RELEASE DATE 19 Jan 1981

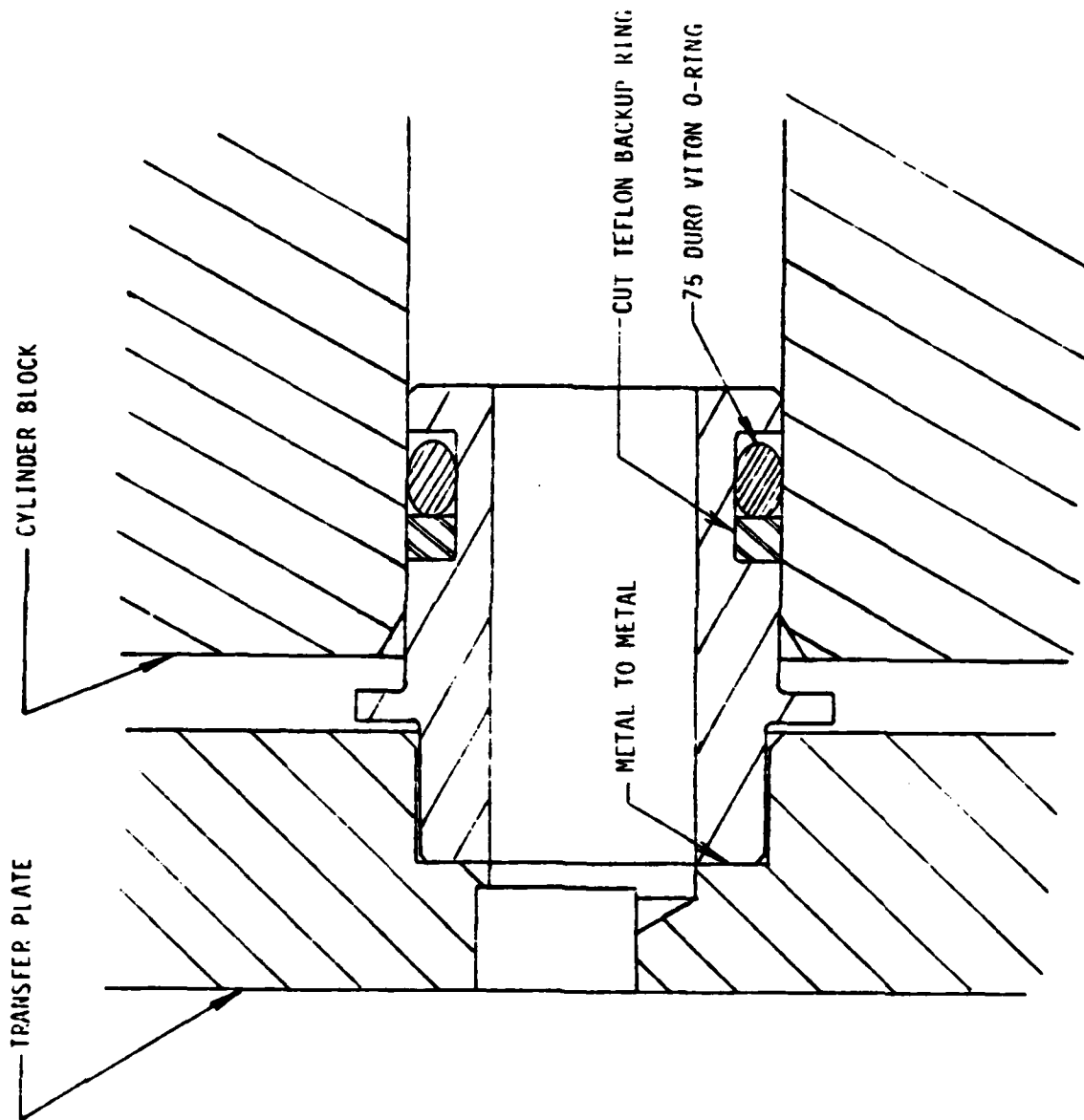
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|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------|-------------------------------|---------------|
| TITLE<br>Transfer Tube Material and Seal Changes                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                 | MODEL - PART NO.<br>PV3-047-2 |               |
| REFERENCES (INCLUDE R.E.O., SER. OR OTHERS)<br>SER AA-79-069                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | PROJECT NO.<br>8-1121-203       | NO. OF UNITS                  | OBTAINED FROM |
| INTRODUCTION<br>The PV3-047-2 hydraulic pump has a floating transfer plate whose kidney slots are connected to the cylinder block bores by transfer tubes, Figure 1. In the initial design, these tubes were made of aluminum. The transfer tube seal at the cylinder block end, Figure 2 was an elastomer O-ring with a teflon backup ring. The bore to tube diametrical clearance was 12-30% of that specified for 3000 psi systems by MIL-G-5514F. The seal at the transfer plate end was metal-to-metal, Figure 2.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                 | TYPE OF FLUID<br>MIL-H-83282  |               |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                 | FLUID TEMP.<br>Various        |               |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                 | TEST SPEC.                    |               |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                 | CIRCUIT NO.                   |               |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                 | GRAPHS                        |               |
| PURPOSE: The purpose of this report is to summarize transfer tube material and seal changes dictated by development test results.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                 | OSCILLOGRAPHS                 |               |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                 | PHOTOGRAPHS                   |               |
| CONCLUSION<br>(1) The use of aluminum as a transfer tube material gave unacceptable strength and wear properties.<br>(2) Graphitic tool steel, type 06, has been shown to be sufficiently strong and gall-resistant.<br>(3) Elastomer seals had insufficient life when used on the transfer tubes.<br>(4) Steel piston rings used as seals on both ends of the tubes, Fig. 3, reduce leakage from case to inlet and eliminate the seal life problem.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                 | DRAWINGS<br>3                 |               |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                 |                               |               |
| SUMMARY OF RESULTS<br>(1) Inspection of aluminum transfer tubes early in development testing showed cracks along the length of some tubes. Since the material was changed to tool steel, this has not been encountered.<br>(2) Tests with the elastomer seals on the cylinder block end showed that they began to leak excessively after 30 hours of operation.<br>(3) Tests showed that when pump case pressure was higher than the intake pressure, the tubes could not be prevented from having some cyclical motion as they went from the high-pressure side to the intake side and back to the high pressure side. This rendered the metal-to-metal seal on the transfer plate end ineffective, resulting in no case leakage at case pressures more than about 60 psi above inlet. This occurred because all the leakage was being forced back into the pistons on the intake side of the revolution. Addition of seals at this end of the tubes alleviated this problem. The steel piston rings have been run for 120 hours with no significant wear. |                                 |                               |               |
| COPIES TO                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                 |                               |               |
| WRITTEN BY<br><i>R.A. Bruckmiller</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | APPROVED<br><i>J. W. Perian</i> | RELEASED                      |               |
| CHECKED                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | APPROVED                        | REL. OUTSIDE DISTRIBUTION     |               |

Report No. 03-802060

FIGURE 1 PV3-047-2 CONFIGURATION



Report No. 03-802060



TRANSFER TUBE SEAL CONFIGURATION No. 1

FIGURE 2

Report No. 03-802060

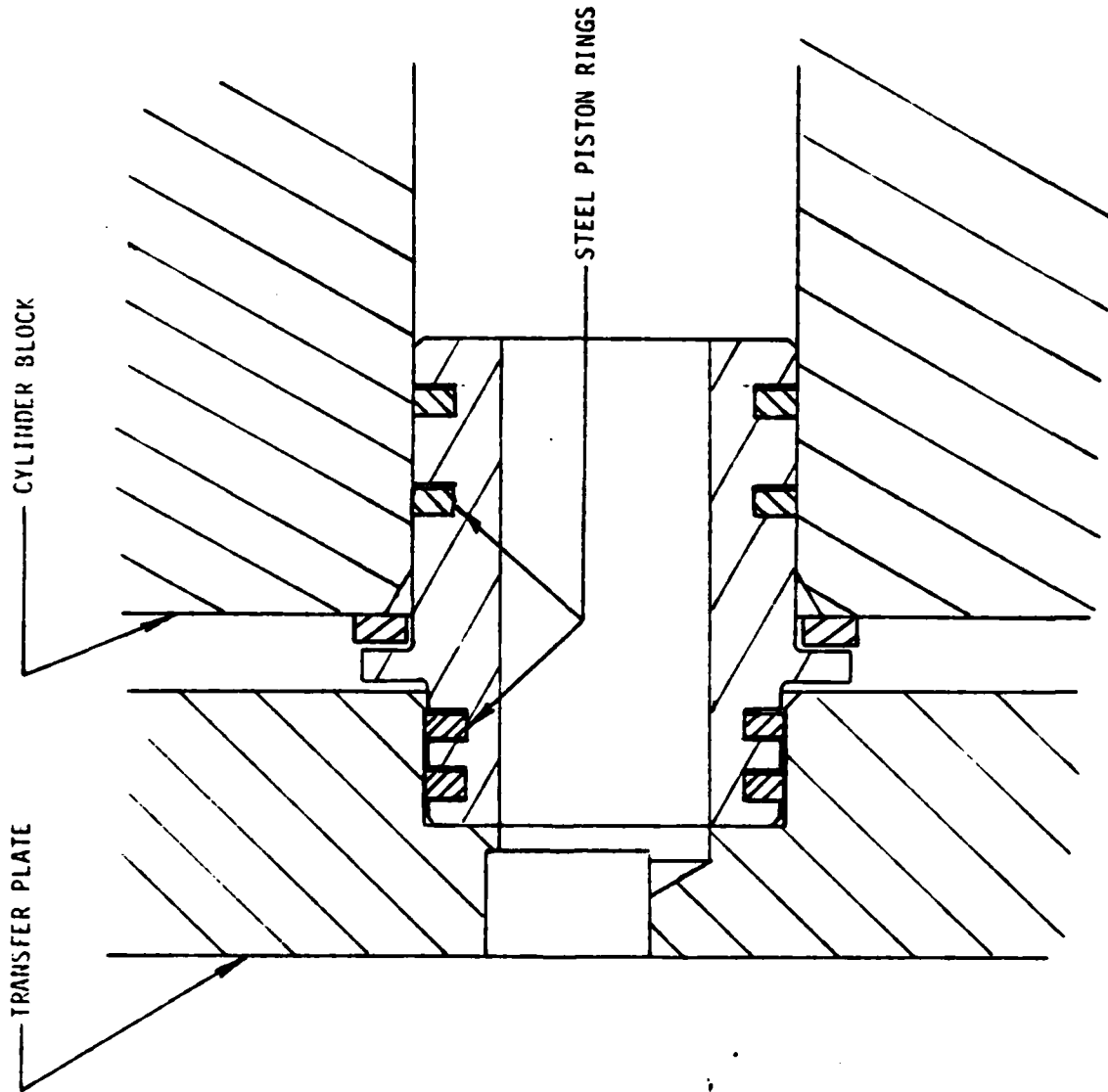


FIGURE 3 STEEL PISTON RING CONFIGURATION

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TECHNICAL REPORT (

RELEASE DATE 19 JAN 1991

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                               |                               |               |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|-------------------------------|---------------|
| TITLE<br>Pintle Bearing Brinnelling                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                               | MODEL - PART NO.<br>PV3-047-2 |               |
| REFERENCES (INCLUDE R.E.O., SER. OR OTHERS)<br>SER AA-79-069                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | PROJECT NO.<br>8-1121-203     | NO. OF UNITS                  | OBTAINED FROM |
| INTRODUCTION<br>Two interim pumps were delivered to Rockwell International to run their 150-hour system compatibility test. Both pumps exhibited increasing case leakage and bronze particles in the case drain filters. One pump was returned after 50 hours of cycling and the other after about 100 hours of cycling. Teardown inspection revealed that one shoe from each pump had a broken bronze ring (See Report No. 03-802063), and that each pump had a spalled high pressure pintle bearing inner race.                                                                                                                                                                                                                  |                               | TYPE OF FLUID<br>MIL-H-83282  |               |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                               | FLUID TEMP.<br>Various        |               |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                               | TEST SPEC.                    |               |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                               | CIRCUIT NO.                   |               |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                               | GRAPHS                        |               |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                               | OSCILLOGRAPHS                 |               |
| PURPOSE:<br>The purpose of this report is to summarize the results of the analysis of the pintle bearing race brinnelling.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                               | PHOTOGRAPHS                   |               |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                               | DRAWINGS                      |               |
| CONCLUSION<br><ol style="list-style-type: none"> <li>(1) The pintle bearings on the high-pressure side do not have sufficient load-carrying capability.</li> <li>(2) Cycling the pump contributes to the brinnelling. The pumps have been run extensively at steady-state conditions at Vickers without bearing damage.</li> <li>(3) Analytical results showed that larger bearings are required to meet the life requirements - 204 envelope size on the high pressure side and 203 on the low pressure side, both with full complement of rollers.</li> </ol>                                                                                                                                                                    |                               |                               |               |
| SUMMARY OF RESULTS<br><p>At the end of 50 hours of cycling, the high-pressure pintle bearing was brinnelled on one of the pumps. The bearing was replaced, and the pump was disassembled again after seven hours of cycling. The new bearing showed the onset of brinnelling.</p> <p>The other pump was disassembled after 100 hours of cycling, and the high-pressure pintle bearing exhibited brinnelling, but was not significantly worse than the bearing from the other after 50 hours. The pump was still operable.</p> <p>Digital computer program A0011 was used to calculate the Hertzian stresses on the rollers. These calculations verified that the allowable stress levels were exceeded on the failed bearings.</p> |                               |                               |               |
| COPIES TO                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                               |                               |               |
| WRITTEN BY<br><i>R.H. Beckwith</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | APPROVED<br><i>J.W. Perin</i> | RELEASED                      |               |
| CHECKED                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | APPROVED                      | REL. - OUTSIDE DISTRIBUTION   |               |

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| TITLE<br>Pump Leakage with Shoe Balance Plate                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                | MODEL - PART NO.<br>PV3-047-1  |               |
| REFERENCES (INCLUDE A.E.G., SER. OR OTHERS)<br>SER AA-79-069                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | PROJECT NO.<br>8-1121-203      | NO. OF UNITS                   | OBTAINED FROM |
| INTRODUCTION<br>In the original design of the 8000 psi pump, the piston shoes were encased in a riveted plate assembly consisting of a balance plate, a holddown plate, and a spacer plate, Figure 1. The entire plate assembly rotated, so that a hydrodynamic oil film was established between the balance plate and the wear plate. This accomplished the purpose of limiting the shoe motion relative to the balance plate.                                                                                                                                                                                                                                                                                                                 |                                | TYPE OF FLUID<br>MIL-H-83282   |               |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                | FLUID TEMP.<br>Various         |               |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                | TEST SPEC.                     |               |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                | CIRCUIT NO.                    |               |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                | GRAPHS                         |               |
| PURPOSE<br>The purpose of this report is to summarize the effect of shoe balance plate configuration on case leakage.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                | OSCILLOGRAPHS                  |               |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                | PHOTOGRAPHS                    |               |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                | DRAWINGS<br>2                  |               |
| CONCLUSION<br>Yoke bending with the balance plate shoe configuration induces case leakage. In order to use this configuration, the yoke must be reinforced.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                |                                |               |
| SUMMARY OF RESULTS<br>The pump was tested with the balance plate shoe configuration, and case leakage was observed much higher than that allowed to meet heat rejection requirements.<br><br>This shoe configuration was a departure from the standard configuration used in Vickers 3000 psi pumps. The leakage tests for the PV3-047-1 were repeated with this standard shoe configuration, shown in Figure 3. The results showed a case leakage reduction of about 1 gpm from the leakage observed with the plate configuration.<br><br>Yoke bending calculations indicated that the yoke may bend as much as .0008 when loaded. When the balance plate assembly was used, this deflection would open up leakage paths as shown in Figure 2. |                                |                                |               |
| COPIES TO                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                |                                |               |
| WRITTEN BY<br><i>R.A. Bruckbridge</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | APPROVED<br><i>F.W. Perian</i> | RELEASED<br><i>[Signature]</i> |               |
| CHECKED                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | APPROVED                       | REL. - OUTSIDE DISTRIBUTION    |               |

FIGURE 1 Shoe Balance Plate Design

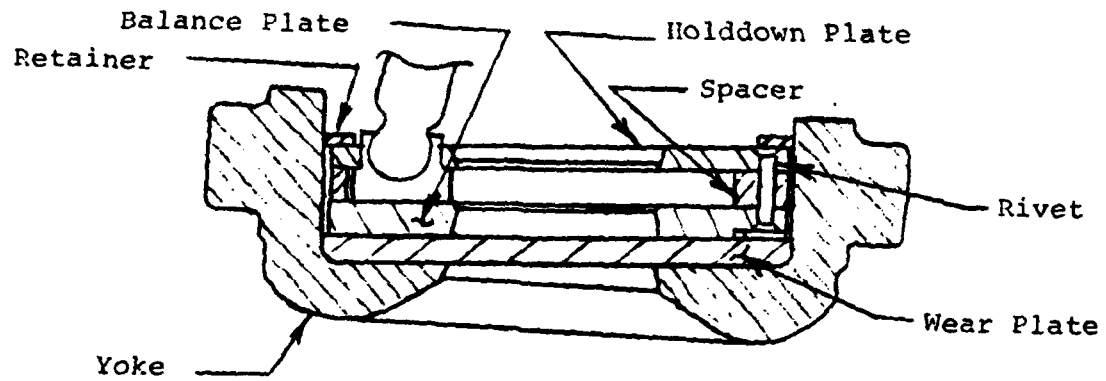


FIGURE 2 Leakage Path Opened Up By Yoke Bending

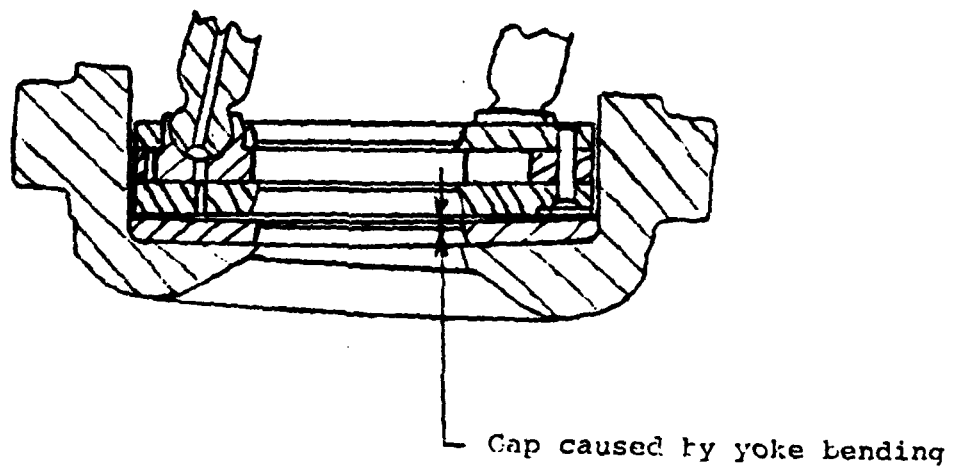
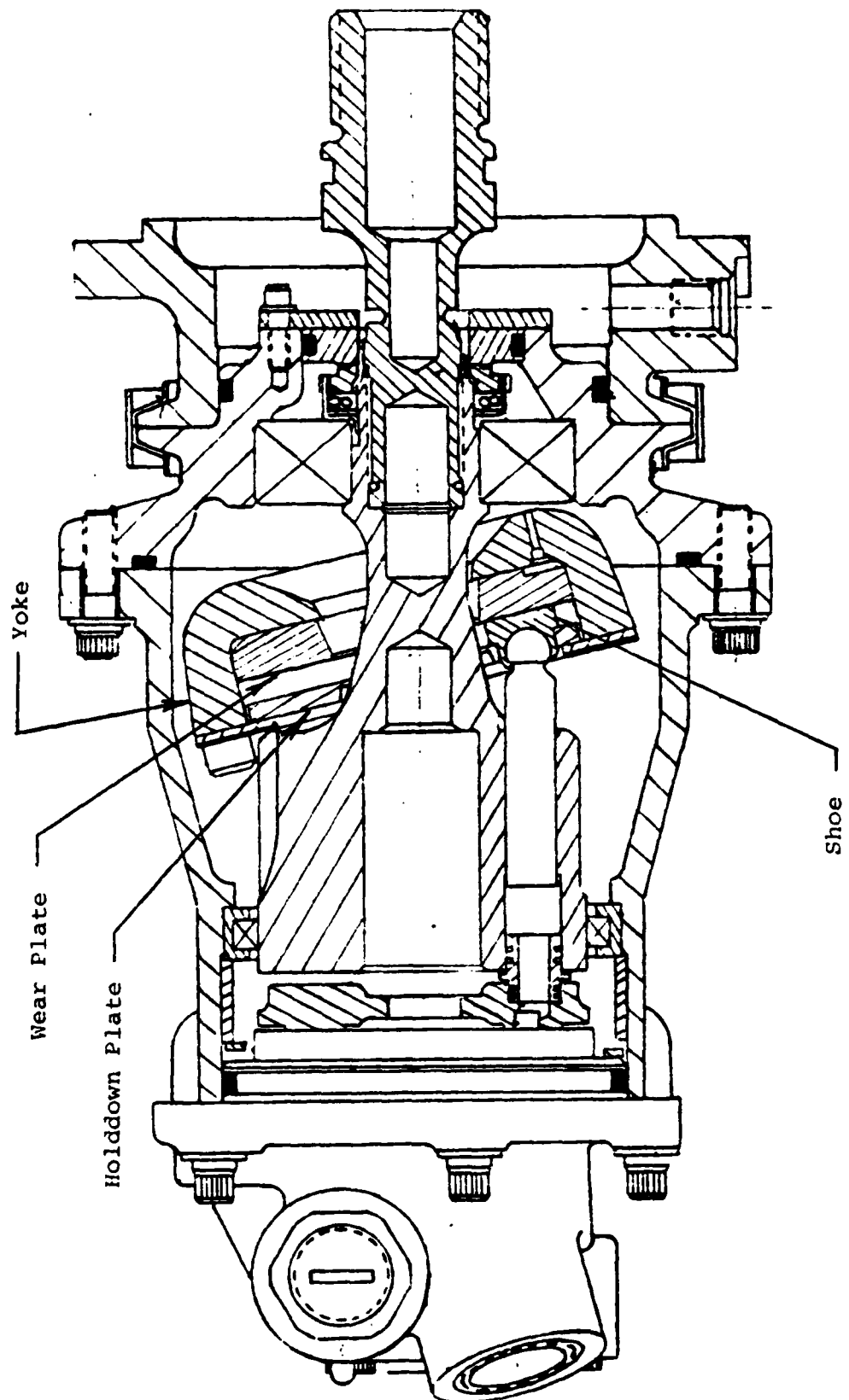


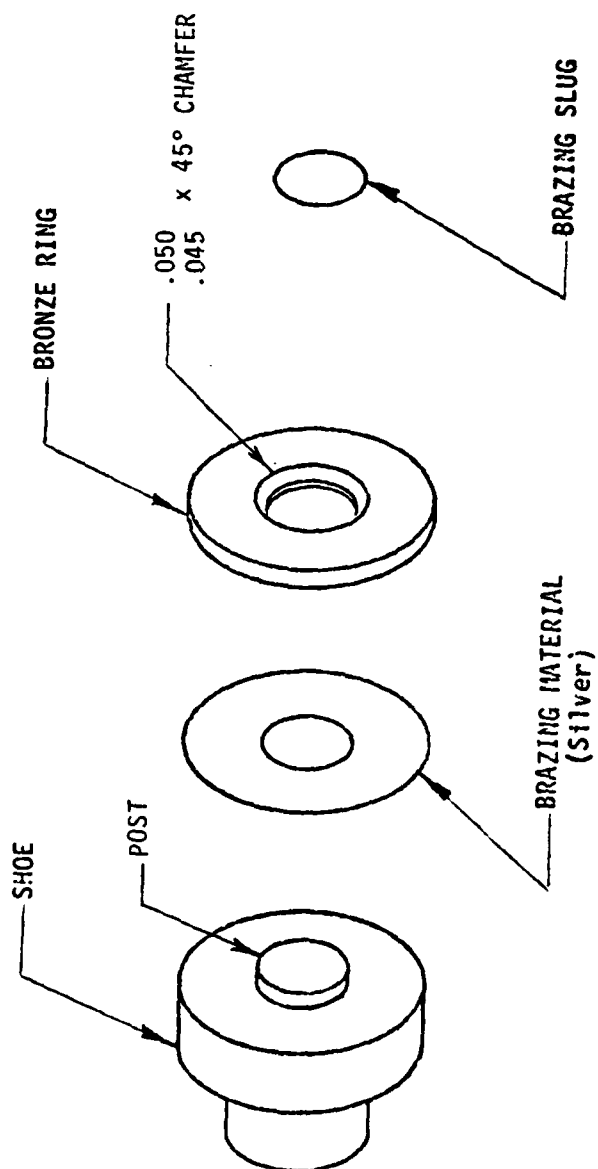
FIGURE 3 Standard Vickers Shoe Configuration



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|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                  |                                      |                                 |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------|--------------------------------------|---------------------------------|
| TITLE<br><b>Shoe Failure</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                  | MODEL - PART NO.<br><b>PV3-047-2</b> |                                 |
| REFERENCES (INCLUDE R.E.O., SER. OR OTHERS)<br><b>SER AA-79-069</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | PROJECT NO.<br><b>8-1121-203</b> | NO. OF UNITS<br><b>2</b>             | OBTAINED FROM<br><b>Jackson</b> |
| INTRODUCTION<br>Two interim pumps were delivered to Rockwell International to run their 150-hour compatibility test. Both pumps exhibited increasing case leakage and bronze particles in the case filters. Teardown inspection revealed that one shoe from each pump had a portion of the bronze ring cracked which resulted in excessive leakage and eventually the removal of a significant part of the bronze ring.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                  | TYPE OF FLUID<br><b>MIL-H-83282</b>  |                                 |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                  | FLUID TEMP.<br><b>200-220°F</b>      |                                 |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                  | TEST SPEC.                           |                                 |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                  | CIRCUIT NO.                          |                                 |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                  | GRAPHS                               |                                 |
| PURPOSE<br>The purpose of this report is to summarize the observations during disassembly of the pumps and to summarize reasons for the failures.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                  | OSCILLOGRAPHS                        |                                 |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                  | PHOTOGRAPHS                          |                                 |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                  | DRAWINGS                             |                                 |
| CONCLUSION<br>1. The shoe failures were due to voids of the braze, between the bronze ring and the steel shoe.<br>2. Improvement is required in the quality of brazing to minimize voids and assure that the braze joint between the steel shoe and bronze ring is homogeneous to prevent oil pressure getting under the bronze ring and causing cracking. Quality assurance can be verified by instituting the quality "step plan" on the process sheet.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                  |                                      |                                 |
| SUMMARY OF RESULTS<br>One of the units exhibited high leakage at the end of about 46 hours of cycling. Disassembly showed that one of the shoes had a piece missing from the bronze ring.<br><br>The other pump discharged a piece of bronze through the case drain during the first 50-hour leg of the test. It continued to run through completion of about 100 hours of cyclings after which it was disassembled. It was found that the piece of bronze had come from a shoe.<br><br>Examination of the broken shoes and sectioning of another shoe in the batch revealed a large number of voids under the bronze ring. There were large voids next to the post, Figure 1, because the bronze ring was installed inverted, so that the .050 x 45° chamfer was against the post. Other voids occurred randomly throughout the braze, and were apparently due to poorly developed brazing technique. Experimentation with the brazing parameters reduced the number of voids in subsequent shoes. |                                  |                                      |                                 |
| COPIES TO                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                  |                                      |                                 |
| WRITTEN BY <i>R. A. Breckenridge</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | APPROVED <i>J. W. Perian</i>     | RELEASED                             |                                 |
| CHECKED                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | APPROVED                         | RELEASED OUTSIDE DISTRIBUTION        |                                 |

SHOE BRAZING PROCEDURE  
FIGURE 1

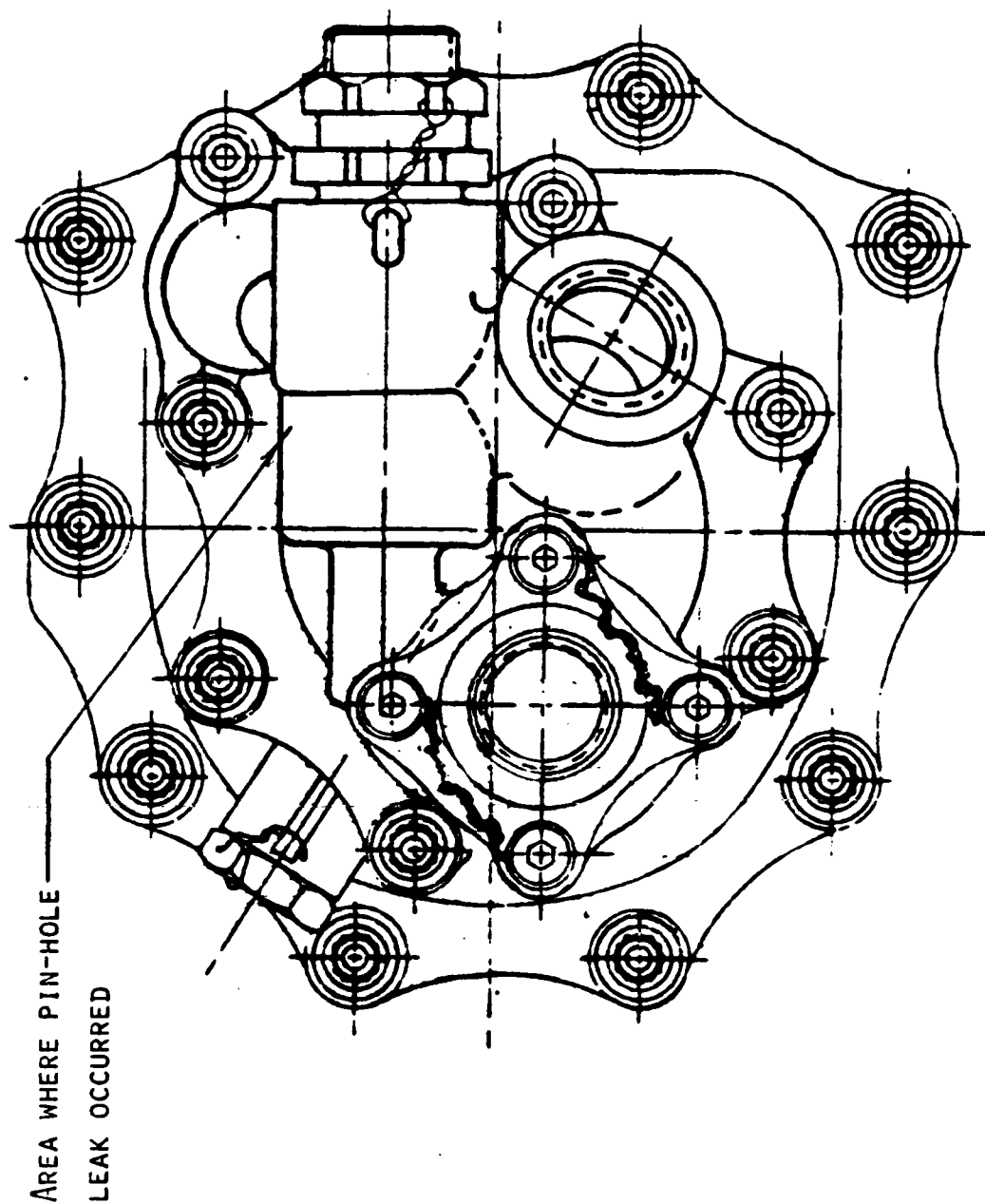


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TECHNICAL REPORT (**

RELEASE DATE \_\_\_\_\_

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                  |                                      |                      |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------|--------------------------------------|----------------------|
| <b>TITLE</b><br>Pin-Hole Leak in 7075-T6 Valve Block (PN 570934)                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                  | <b>MODEL - PART NO.</b><br>PV3-047-2 |                      |
| <b>REFERENCES (INCLUDE R.E.O., SER. OR OTHERS)</b><br>AA-79-069                                                                                                                                                                                                                                                                                                                                                                                                                                          | <b>PROJECT NO.</b><br>8-1121-203 | <b>NO. OF UNITS</b><br>1             | <b>OBTAINED FROM</b> |
| <b>INTRODUCTION</b><br><br>Hydraulic pump serial number MX-346581 was one of two pumps delivered to Rockwell International to run Lightweight Hydraulic System (LHS) compatibility tests. The valve block material was 7075-T6 aluminum. This pump was returned after about 87 hours of accumulated time at Rockwell with a pin-hole leak in the valve block.                                                                                                                                            |                                  | <b>TYPE OF FLUID</b><br>MIL-H-83282  |                      |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                  | <b>FLUID TEMP.</b><br>Various        |                      |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                  | <b>TEST SPEC.</b>                    |                      |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                  | <b>CIRCUIT NO.</b>                   |                      |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                  | <b>GRAPHS</b>                        |                      |
| <b>PURPOSE</b><br><br>The objective of this report is to present the results of investigation of the leakage.                                                                                                                                                                                                                                                                                                                                                                                            |                                  | <b>OSCILLOGRAPHS</b>                 |                      |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                  | <b>PHOTOGRAPHS</b>                   |                      |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                  | <b>DRAWINGS</b><br>1                 |                      |
| <b>CONCLUSION</b><br><br>The leak was caused by non-homogeneity in the material. The material used for future high pressure parts should be inspected for uniformity.                                                                                                                                                                                                                                                                                                                                    |                                  |                                      |                      |
| <b>SUMMARY OF RESULTS</b><br><br>The leak was through the material around the compensator annulus machined in the valve block and was not visible except under a 30-power microscope. Under microscopic examination the leak appeared as a pore. The material showed no sign of overloading or fatigue, such as deformation or cracking. This was compatible with stress calculations - maximum hoop stress was 20% of the yield strength, and alternating stress was about 30% of the fatigue strength. |                                  |                                      |                      |
| <b>COPIES TO</b><br>M. Carson                      J. Rass<br>J. D. Layton                  B. G. Stevenson<br>F. W. Perian                                                                                                                                                                                                                                                                                                                                                                              |                                  |                                      |                      |
| <b>WRITTEN BY</b> <i>R. A. Breckenridge</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                  | <b>APPROVED</b> <i>[Signature]</i>   |                      |
| <b>CHECKED</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                  | <b>RELEASED</b>                      |                      |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                  | <b>REL. OUTSIDE DISTRIBUTION</b>     |                      |

FIGURE 1 LOCATION OF PIN-HOLE LEAK

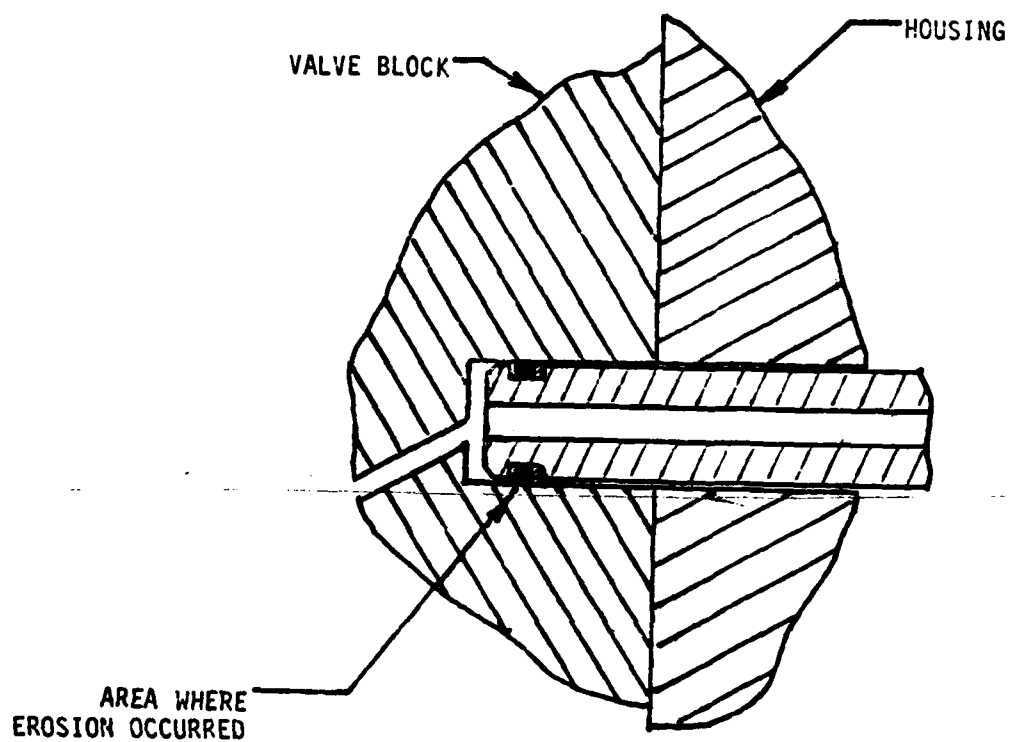


**SPERRY-VICKERS****ENGINEERING  
TECHNICAL REPORT (**

RELEASE DATE \_\_\_\_\_

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                  |                                      |                                  |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------|--------------------------------------|----------------------------------|
| <b>TITLE</b><br>Valve Block Control Pressure Bore Erosion (PN 570934)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                  | <b>MODEL - PART NO.</b><br>PV3-047-2 |                                  |
| <b>REFERENCES (INCLUDE R.E.O., SER. OR OTHERS)</b><br>AA-79-069                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | <b>PROJECT NO.</b><br>8-1121-203 | <b>NO. OF UNITS</b><br>1             | <b>OBTAINED FROM</b>             |
| <b>INTRODUCTION</b><br>Hydraulic pump serial number MX-348168 was one of two interim pumps delivered to Rockwell International to run their Lightweight Hydraulic System (LHS) compatibility tests. This pump was returned after about 120 hours with a leak between the housing and valve block. The valve block was 7075-T6 aluminum.                                                                                                                                                                                                                                                                        |                                  | <b>TYPE OF FLUID</b><br>MIL-H-83202  |                                  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                  | <b>FLUID TEMP.</b><br>Various        |                                  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                  | <b>TEST SPEC.</b>                    |                                  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                  | <b>CIRCUIT NO.</b>                   |                                  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                  | <b>GRAPHS</b>                        |                                  |
| <b>PURPOSE</b><br>The objective of this report is to present the results of investigation of the leak.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                  | <b>OSCILLOGRAPHS</b>                 |                                  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                  | <b>PHOTOGRAPHS</b>                   |                                  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                  | <b>DRAWINGS</b><br>1                 |                                  |
| <b>CONCLUSION</b><br>The leak was due to porosity or non-homogeneity of the material.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                  |                                      |                                  |
| <b>SUMMARY OF RESULTS</b><br>The control pressure in the PV3-047-2 is transmitted to the actuator piston in the housing by means of a transfer tube, as demonstrated in Figure 1. The static seals at the ends of the transfer tube are accomplished by O-rings and backup rings with bore-rod clearances about half that used in 3000 psi systems. The material in the wall of the valve block bore developed patches of erosion that opened up leakage paths around the seal. Microscopic examination revealed a large amount of porosity in this area, and this allowed leakage paths to start the erosion. |                                  |                                      |                                  |
| <b>COPIES TO</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | M. Carson                        | J. Rass                              |                                  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | J. D. Layton ✓                   | B. G. Stevenson                      |                                  |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | F. W. Perian                     |                                      |                                  |
| <b>WRITTEN BY</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | <i>R. A. Breckenridge</i>        | <b>APPROVED</b>                      | <b>RELEASED</b>                  |
| <b>CHECKED</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                  | <b>APPROVED</b>                      | <b>REL. OUTSIDE DISTRIBUTION</b> |

FIGURE 1 LOCATION OF MATERIAL EROSION



## RELIABILITY ENGINEERING FAILURE REPORT

|                                                                                                                                                       |                |                                                   |                    |                                 |          |                                   |  |
|-------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|---------------------------------------------------|--------------------|---------------------------------|----------|-----------------------------------|--|
| EQUIPMENT NAME<br><b>AFCS ACTUATOR</b><br><b>83-00231</b>                                                                                             |                | PART NO.<br><b>83-00234-107</b><br><b>END CAP</b> |                    | SERIAL NO.<br><b>—</b>          |          | PROGRAM (MODEL)<br><b>IHS</b>     |  |
| TEST CONDITIONS AT FAILURE                                                                                                                            |                |                                                   |                    | TYPE TEST                       |          | REPORT NO.                        |  |
| TEST ACTUATOR                                                                                                                                         |                | PRESSURE                                          | <b>11,200 psig</b> | SEAL EVALUATION                 |          | <b>1</b>                          |  |
|                                                                                                                                                       |                | FLUID TEMP                                        | <b>80 °F</b>       | ACCEPTANCE                      |          |                                   |  |
|                                                                                                                                                       |                | LEAKAGE                                           | <b>MASSIVE</b>     | COMPONENT                       |          | DATE OF FAILURE<br><b>3-21-80</b> |  |
|                                                                                                                                                       |                | SEAL TEMP                                         | <b>80 °F</b>       | QUALIFICATION                   |          |                                   |  |
| PRESSURE BETWEEN TWO STAGE SEALS                                                                                                                      |                | <b>N/A psig</b>                                   | BLOCK NO.          | <b>N/A</b>                      | STROKE   | <b>N/A</b>                        |  |
| LOAD CYLINDER PRESSURE                                                                                                                                |                | <b>N/A psig</b>                                   | NO. CYCLES         | <b>N/A</b>                      | LOAD (%) | <b>N/A</b>                        |  |
|                                                                                                                                                       |                |                                                   | TEST TIME          | <b>N/A</b>                      |          |                                   |  |
| FAILURE DESCRIPTION                                                                                                                                   |                |                                                   |                    |                                 |          |                                   |  |
| <b>PROOF PRESSURING OF BY-PASS VALVE WAS IN PROGRESS.</b><br><b>AT 11,200 PSI, LARGE QUANTITIES OF HYD FLUID SPENT</b><br><b>FROM THE RH END CAP.</b> |                |                                                   |                    |                                 |          |                                   |  |
|                                                                                                                                                       |                |                                                   |                    |                                 |          |                                   |  |
|                                                                                                                                                       |                |                                                   |                    |                                 |          |                                   |  |
| VOUGHT LAB FINDINGS                                                                                                                                   |                |                                                   |                    |                                 |          | DISASSEMBLY TIME                  |  |
| <b>THE END CAP HAD FLOWED UNDER PRESSURE</b><br><b>TO THE POINT AT WHICH THE HYD FLUID</b><br><b>BLEW OUT PAST THE STATIC SEAL.</b>                   |                |                                                   |                    |                                 |          |                                   |  |
|                                                                                                                                                       |                |                                                   |                    |                                 |          |                                   |  |
| CORRECTIVE ACTION                                                                                                                                     |                |                                                   |                    |                                 |          |                                   |  |
| <b>ORIGINAL PART WAS OUT OF TOLERANCE.</b><br><b>WILL MAKE NEW PARTS OUT OF STEEL.</b>                                                                |                |                                                   |                    |                                 |          |                                   |  |
|                                                                                                                                                       |                |                                                   |                    |                                 |          |                                   |  |
|                                                                                                                                                       |                |                                                   |                    |                                 |          |                                   |  |
| ORIGINATOR                                                                                                                                            | DATE           | LAB RESULTS                                       | DATE               | CORRECTIVE ACTION DOCUMENTATION |          |                                   |  |
| <b>A.M. HILL</b>                                                                                                                                      | <b>3-23-80</b> |                                                   |                    | <b>INCORPORATION</b>            |          |                                   |  |
| <b>(WDP)</b>                                                                                                                                          |                |                                                   |                    |                                 |          |                                   |  |

## RELIABILITY ENGINEERING FAILURE REPORT

|                                                                                                                                                                                                                                                                                                |            |                                       |                 |                 |          |                                 |                           |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|---------------------------------------|-----------------|-----------------|----------|---------------------------------|---------------------------|
| EQUIPMENT NAME<br>AFCS ACTUATOR<br>83-00231                                                                                                                                                                                                                                                    |            | PART NO.<br>S30650-116-14<br>ROD SEAL |                 | SERIAL NO.<br>— |          | PROGRAM (MODEL)<br>IHS          |                           |
| TEST CONDITIONS AT FAILURE                                                                                                                                                                                                                                                                     |            |                                       |                 | TYPE TEST       |          | REPORT NO.                      |                           |
| TEST ACTUATOR                                                                                                                                                                                                                                                                                  | PRESSURE   | 8000 psig                             | SEAL EVALUATION |                 |          | 2                               | DATE OF FAILURE<br>4-1-80 |
|                                                                                                                                                                                                                                                                                                | FLUID TEMP | 250 °F                                | ACCEPTANCE      |                 |          |                                 |                           |
|                                                                                                                                                                                                                                                                                                | LEAKAGE    | MODERATE                              | COMPONENT       |                 |          |                                 |                           |
|                                                                                                                                                                                                                                                                                                | SEAL TEMP  | 250 °F                                | QUALIFICATION   |                 | X        |                                 |                           |
| PRESSURE BETWEEN TWO STAGE SEALS                                                                                                                                                                                                                                                               |            | N/A psig                              | BLOCK NO.       | —               | STROKE   | 10%                             |                           |
| LOAD CYLINDER PRESSURE                                                                                                                                                                                                                                                                         |            | N/A psig                              | NO. CYCLES      | 20,000          | LOAD (%) | 10                              |                           |
|                                                                                                                                                                                                                                                                                                |            |                                       | TEST TIME       | 1600            |          |                                 |                           |
| FAILURE DESCRIPTION                                                                                                                                                                                                                                                                            |            |                                       |                 |                 |          |                                 |                           |
| WITH 5% RETURN PRESS (90 PSI) EXCESSIVE LEAKAGE (2.5 DROPS/MIN) WAS OBSERVED OUT THE LH SIDE AFT ROD SEAL (SPRING END).                                                                                                                                                                        |            |                                       |                 |                 |          |                                 |                           |
| VOUGHT LAB FINDINGS                                                                                                                                                                                                                                                                            |            |                                       |                 |                 |          |                                 |                           |
|                                                                                                                                                                                                                                                                                                |            |                                       |                 |                 |          | DISASSEMBLY TIME 4-2-80         |                           |
| APPROX 1/4 OF THE CAP STRIP ON BOTH THE ROD END AND SPRING END ROD JERL WERE MISSING. THERE WAS EVIDENCE ALSO THAT THE PISTON ROD WAS RAMPING UP DUE TO INTERFERENCE OF ITS 83-00234-121 (FLANGE) WITH THE 83-00234-115 RETAINER. THE RAMPING ACTION SEEMS TO HAVE CAUSED EXCESSIVE SEAL WEAR. |            |                                       |                 |                 |          |                                 |                           |
| CORRECTIVE ACTION REPLACED CAP STRIPS; EXTRA CLEARANCE WAS OBTAINED BY FILING THE 83-00234-115 RETAINER IN THE AREA OF INTERFERENCE.                                                                                                                                                           |            |                                       |                 |                 |          |                                 |                           |
| ORIGINATOR                                                                                                                                                                                                                                                                                     |            |                                       |                 |                 |          |                                 |                           |
| DATE                                                                                                                                                                                                                                                                                           |            | LAB RESULTS                           |                 | DATE            |          | CORRECTIVE ACTION DOCUMENTATION |                           |
| A.M. HILL                                                                                                                                                                                                                                                                                      |            | 4-2-80                                |                 |                 |          | INCORPORATION                   |                           |

**Internal  
Memorandum**

NADC-77108-30



Date 12/3/80

Letter No. HYD-506-80

North Hollywood, CA

To R. L. Vick

From J. Toon

Subject Rockwell 8000 PSI Valve, P/N 3321472

The subject valve was received into R & O on 11/10/80 after being returned from Rockwell International. The unit was returned to:

- 1) Reduce internal leakage.
- 2) Determine source of valve failure that occurred after 1043 cycles.
- 3) Reduce the pull-in and drop-out voltages.

Internal Leakage: During assembly and test prior to the initial delivery of the valve assembly to Rockwell, the valve housing and slide were subjected to numerous modifications. Resultant burrs (etc.) in the housing bore and slide O.D. were removed by lightly lapping the surfaces. As a result, the lap clearance and internal leakage became excessive. To bring the lap clearance into the .000110 - .000150 diametrical clearance range on the drawing, the slide O.D. was stripped, chrome plated IAW QQ-C-320, Class 2, and lapped to achieve the required final clearance.

Valve Failure:

1. Operate to determine failure characteristics at ambient temperature and 3000 psi --
  - S1 --Operated normally
  - S2 -- Did not operate
2. Disassemble S1 and S2 --
  - S1 --The spacer pin had an indentation from the pilot valve ball
  - S2 --The spacer pin had an indentation from the pilot valve ball and was swaged or mushroomed on that end. Hardness reading showed that these pins were not hardened IAW the print (Rc 50 min.).. In the pilot valve, there was no ball stroke. Evaluation of the valve pin (a modified drill) showed the fluted end of the drill to be battered down with a portion sheared off.
3. Rework -- Replaced the spacer pins in S1 and S2 with new pins hardened to Rc 50 minimum. Replaced the pilot valve pins with a triangular cross-section pin giving a larger surface for the pilot valve balls to push on.

Reduce Pull-in/Drop-out Voltages: The core plunger protrusion, ball stroke and spacer pin protrusion were minimized to minimize the total air gap. The pull-in/drop-out voltages were reduced to 12.0V/4.4V and 14.5V/5.0V for S1 and S2 respectively at ambient temperature and 8000 psi.

*John Toon*  
J. Toon:sah

Internal  
Memorandum

NADC-77108-30



Date Jan. 27, 1981

Letter No. HYD-35-81

North Hollywood, California

To Ralph Vick

From John Toon

Subject Rockwell 8000 psi 3-way Valve, P/N 3321473

The subject valve was received into R&O on 1/5/81 after being returned from Rockwell International. The valve was returned because it failed to operate after being subjected to 40,000 impulse cycles at 10,700 psi while in the de-energized state.

The tasks performed on the valve while in R&O were:

- 1) Determine source of valve failure and repair.
- 2) Reduce pull-in and drop-out voltages and up-grade the solenoid/pilot valve section to current design status.
- 3) Cycle:operate at 8000 psi and ambient temperature to verify unit integrity.

Conclusion

The valve failure is attributed to failure of the Solenoid spacer pin, P/N 3321871 which was not properly heat treated ( $R_c$  20 vs requirement of  $R_c$  50 min). Replacement of this pin along with reduction of the total solenoid air gap resulted in an approximate 10 volt Solenoid pull-in voltage. Integrity of the valve was verified by successful completion of 24,248 cycles at 8000 psi and ambient fluid and air temperatures.

1) Determine Source of Failure

- A. Operated to determine failure characteristics at ambient temperature and 3000 psi fluid pressure. With 24 volts applied to the solenoid there were not any changes in the valve conditions. Return was open to cylinder indicating that the slide was in the de-energized position.
- B. Measured 85.9 ohm across leads on the solenoid. There were not any shorts (lead to case).
- C. Removed slide and spring. Visual inspection showed two light scratches across two lands on the slide, but the slide moved freely in the bore.
- D. Disassembled solenoid/pilot valve section. The spacer pin was battered (mushroomed) down which eliminated all solenoid air gap. The pilot valve had .009 ball stroke. These conditions are shown in Figure 1.
- E. Other than the battered spacer pin, no other condition was found that could have caused valve failure.

The spacer pin for the subject 3-way valve was installed and delivered to Rockwell prior to discovery that the lot of spacer pins manufactured for the 3-way and 4-way valves were not properly heat treated. Measurements made on a pin removed from a failed 4-way valve showed a reading of less than  $R_c$  20. A new spacer pin was manufactured per print ( $R_c$  50 min) and installed.

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Memorandum NADC-77108-30



Date Jan. 27, 1981

Letter No. HYD-35-81

2) Reduce Pull-in and Drop-out Voltages and Upgrade Status

The core plunger protrusion, ball strike and spacer pin protrusion were minimized to minimize the total air gap. With a total air gap of .009 inch maximum, the pull-in/drop-out voltages were 10.6 volts/3.5 volts respectively. Figure 2 shows the current design configuration for the valve's air gap.

In addition to reducing the total air gap in the solenoid/pilot valve section the pin in the pilot valve was re-designed. The new pin design has a triangular cross-section with a hardness of  $R_c$  55 min. The original pin design utilized a drill modified to the required length. The intent was for the drill flutes to allow fluid passage in the pilot valve. All drills found to date had flutes approximately .25 inch long, too short for the valve. As a result the remainder of the drill rod had a flat machined on it making the part difficult to make and non symmetrical.

3) Cycle

Conditions: 8000 psi inlet at ambient fluid and air temperature.

Cycle Rate: 12 cycle/minute

Applied Voltage (to solenoid): 24 volts

Summary of Results:

| After ---- Cycles | leakage cc/min |     | Pull-in | Drop-out |
|-------------------|----------------|-----|---------|----------|
|                   | P-C            | C-R | Volts   | Volts    |
| 0 (ATP Results)   | 6.0            | 2.5 | 10.6    | 3.5      |
| 1000 Cycles       | 11.5           | 5.5 | -       | -        |
| 2081              | 15.0           | 6.3 | -       | -        |
| 5,687             | 14.5           | 6.8 | 10.1    | -        |
| 10,112            | 13.0           | 6.3 | 9.9     | -        |
| 15258             | 15             | 7.3 | 9.9     | -        |
| 20408             | 15             | 7.4 | 9.9     | -        |
| 24248 End of Test | 20.5           | 7.5 | 9.9     | -        |

After the first 5000 cycles the solenoid/valve section stabilized without any additional significant changes. Visual inspection of the spacer pin shown that the ball formed a natural coined surface on the end of the pin. The depth (.001 measured) of this natural coining should be taken into consideration in the air gap of future hardware.

*John Toon*  
John Toon

JRT:mjb

cc:

R. V. Lukas

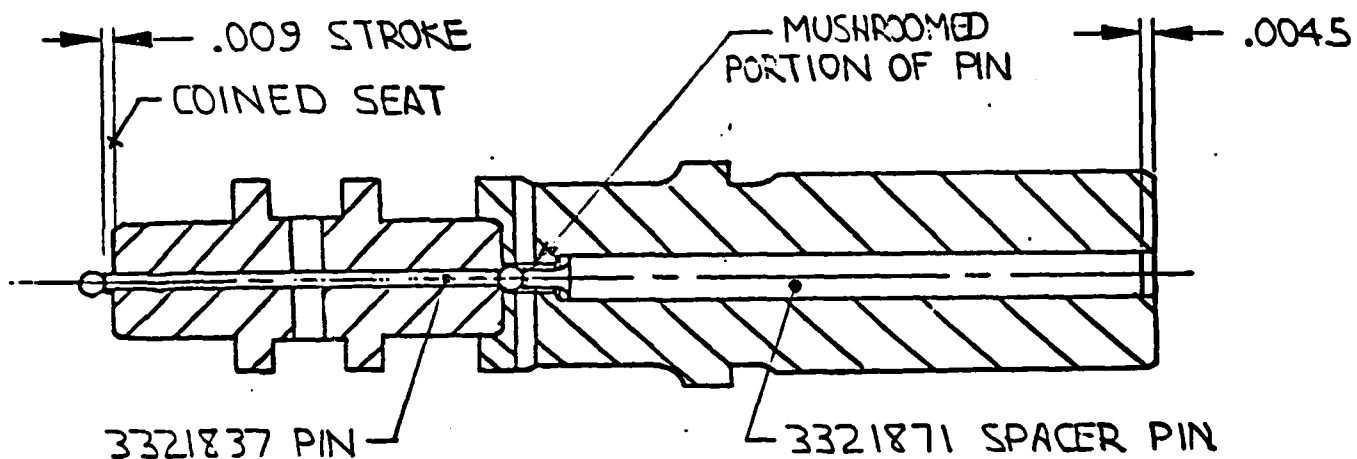


FIGURE 1  
FAILED UNIT

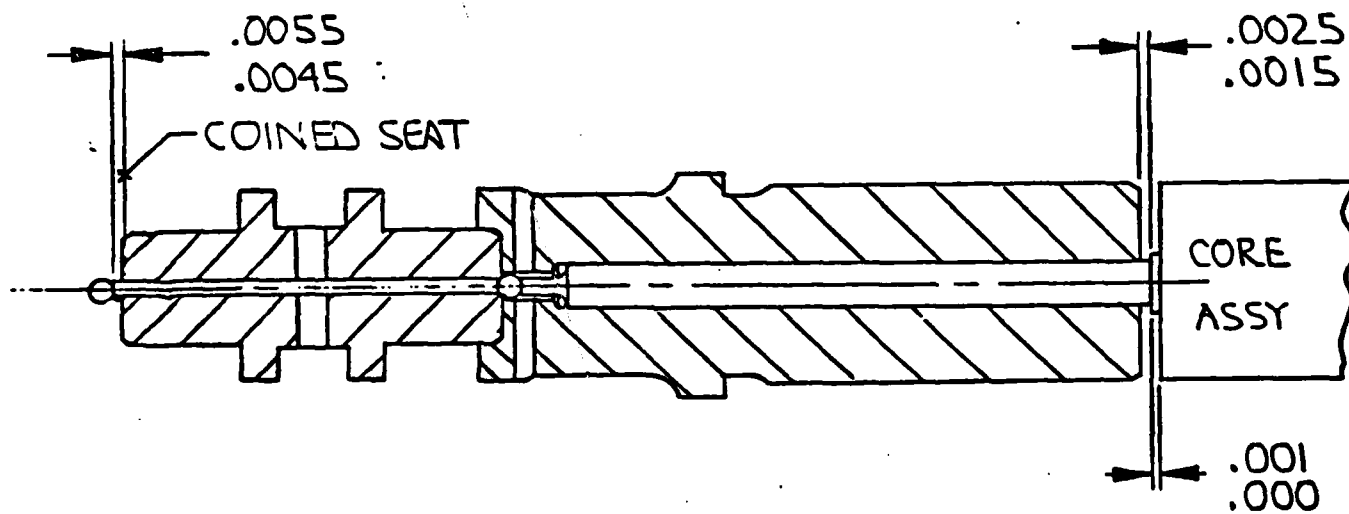


FIGURE 2  
CURRENT CONFIGURATION

Internal  
Memorandum

NADC-77108-30



Electrodynamics  
Division

Date Jan. 27, 1981

Letter No. HYD-36-81

North Hollywood, Ca. 91607

To Ralph Vick

From John Toon

Subject Rockwell 8000 psi 4-way Valve, P/N 3321472

The subject valve was received into R&O on 1/20/81 after being returned from Rockwell International (hand carried by Bernie Holland). The valve was returned because Solenoid No. 2 (S2) failed after 2900 cycles in a endurance test at 9000 psi preceded by 475 successful speed brake cycles. The source of failure and the repair method are discussed below.

Conclusion

It was found that the design of the solenoid spacer P/N 3321841 allowed the pilot valve ball to move into an off center position in the ball guide section of the spacer. The pilot (return) ball was able to move into a position which could jam the spacer pin preventing solenoid/pilot valve operation. Redesign of the spacer to prevent the pilot (return) ball from being located in this position is complete. New parts are presently in the fabrication cycle.

Following is a summary of tests performed before disassembly of the returned unit:

- 1) At 3000 psi: S1 energized twice  
S2 energized twice  
Normal operation
- 2) At 6000 psi: S2 energized twice  
Normal operation
- 3) At 8000 psi: S2 energized twice  
S1 energized 4 times  
S2 energized  
Normal operation
- 4) At 9000 psi: S2 energized twice  
Normal operation
- 5) Set up for cycling S2 at 8000 psi:
  - a) S2 cycled between 10 and 30 times and failed
  - b) S1 cycled (manually) once
  - c) S2 cycled and failed after two cycles
  - d) Repeat b)
  - e) S2 cycled and failed after five cycles
  - f) Repeat b)
  - g) S2 cycled and failed after seven cycles
  - h) S1 cycled 20 times. Normal operation
  - i) S2 failed to operate at 8000 psi, 5000 psi, 3000 psi, 3000 psi, 8000 psi (one cycle each)

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Memorandum

NADC-77108-30



Date Jan. 27, 1981 Letter No. HYD-36-81

- 6) S2 was disassembled. Figure 1 shows an exaggerated view of the condition that was found. The pilot ball was able to locate itself in a position at the fluid return hole jamming the spacer pin. A corresponding mark was found on the spacer pin showing the off center position of the ball in the spacer.

Figure 2 shows an exaggerated view of the redesigned spacer. Basically the cross drilled fluid return holes were moved further away from the pilot valve seat and the hole size was decreased (additional holes were added to prevent added pressure drop through the spacer) to prevent the ball from shifting too far to the side.

Spacers made to the new design are presently in the fabrication cycle. Upon completion they will be matched to the spacer pins (the damaged pin discussed above will be replaced) taking into consideration that the natural coining of the pilot ball into the pin will require an additional .001 inch in the initial air gap.

*John Toon*  
John Toon

JRT:mjb

NADC-77108-30

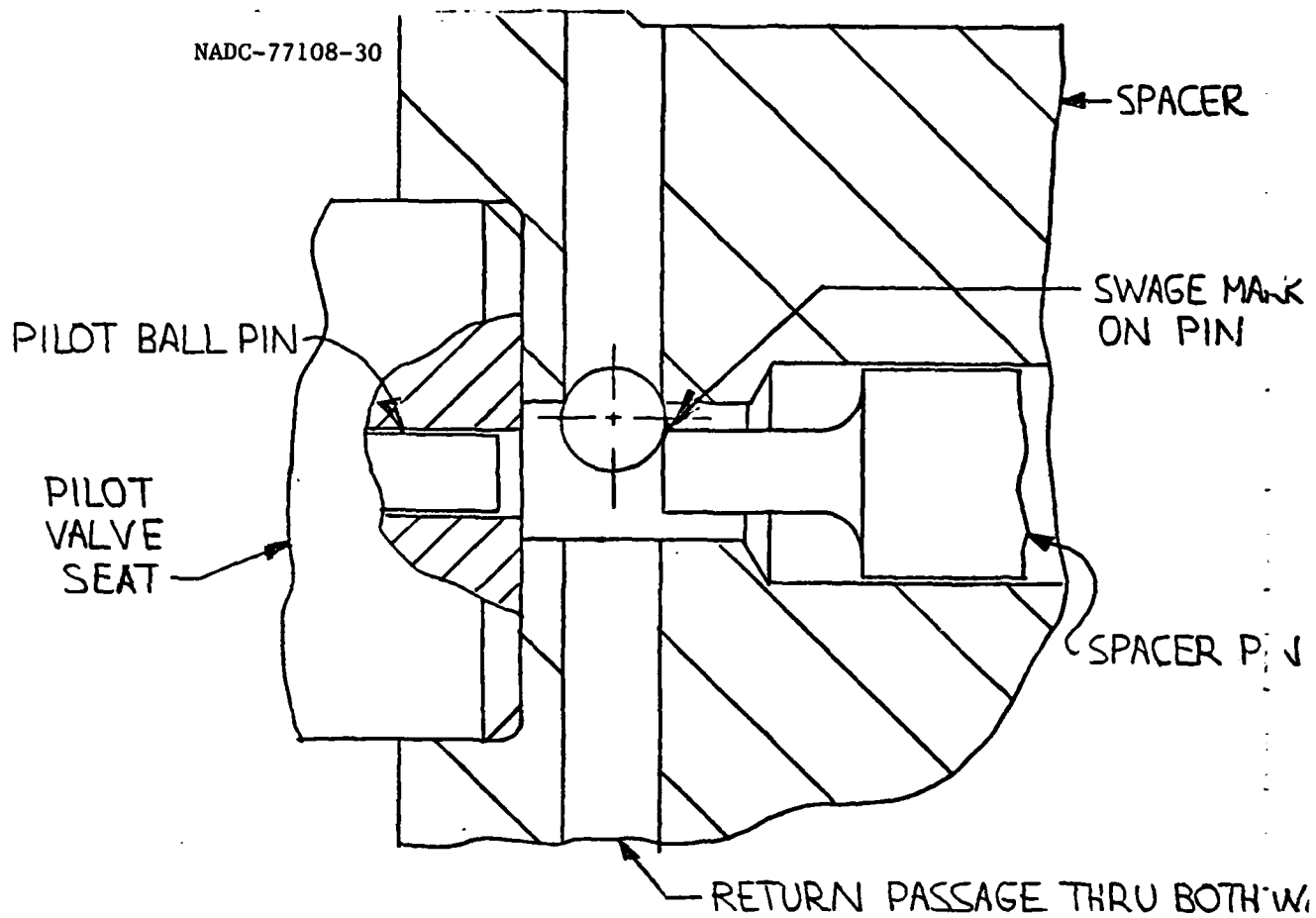


FIGURE 1

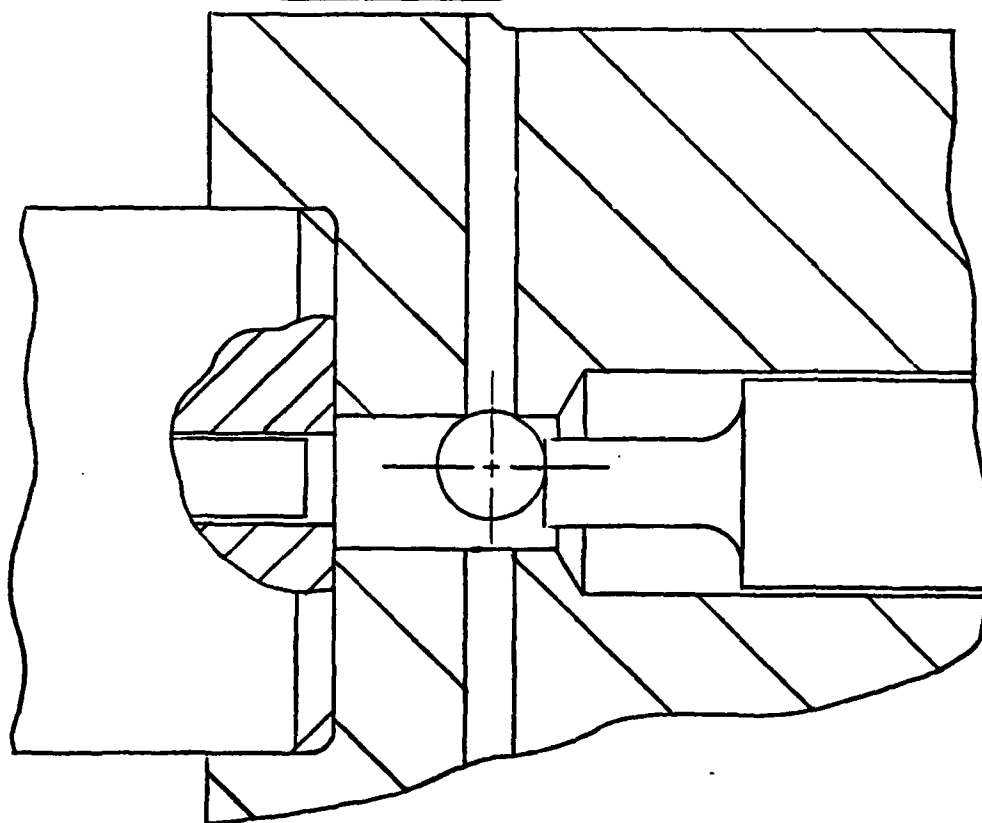


FIGURE 2

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