

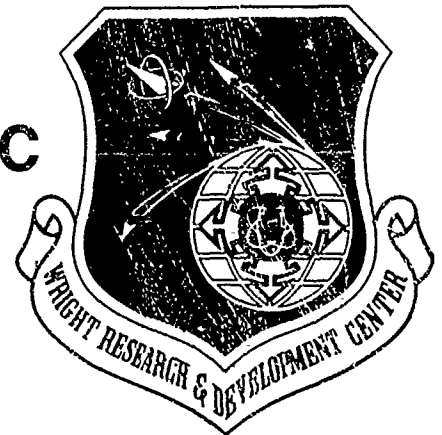
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VOLUME I

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# NONFLAMMABLE HYDRAULIC POWER SYSTEM FOR TACTICAL AIRCRAFT



## Volume I - Aircraft System Definition, Design and Analysis

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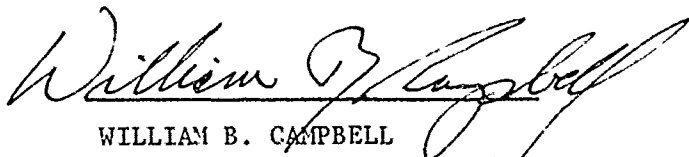
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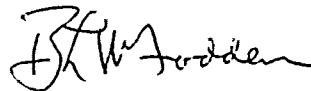
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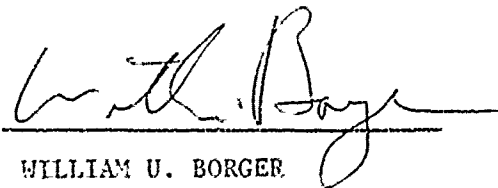


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13	07	Nonflammable hydraulic system.	
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19 ABSTRACT (Continue on reverse if necessary and identify by block number)			
<p>The Nonflammable Hydraulic Power Systems for Tactical Aircraft, program objective was to develop and demonstrate an advanced hydraulic system designed to operate at a maximum pressure of 8000 psi and use an Air Force developed, nonflammable fluid, chlorotrifluoroethylene (CTFE). It followed four previous programs directed at this technology at Boeing and MCAIR. It was further complemented by three other Air Force sponsored programs which embrace either 8000 psi, CTFE or both. These programs are being conducted at Parker Controls Systems Division of Parker Hannifin Corporation (Seal Evaluation), at Vickers Incorporated (High Pressure Pump Development) and at Rockwell International (High Pressure Distribution System Evaluation).</p> <p>(Continued)</p>			
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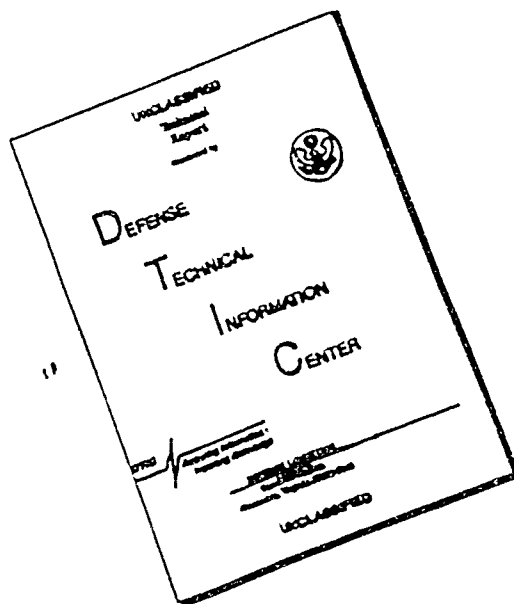
Variable Pressure.  
Nonflammable Hydraulic Fluid.  
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Flow Augmentation.  
Reservoir Level Sensing.  
Enhanced Dynamic Stiffness.  
Nonflammable Hydraulic Power System for Tactical Aircraft (NHPSTA).  
Power Efficient Technology.  
Engine Nozzle Actuation.  
Reservoir Pressurization.  
Variable Displacement Hydraulic Motor.  
Fly-by-wire.

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In order to place the technology in a low risk category which can be embraced for future programs, many complementary technologies are being addressed which greatly enhance the use of the nonflammable fluid at high operating pressures. Power efficient technologies, which have resulted from previous programs such as Low Energy Consumption Hydraulic Techniques (LECHT), were used to improve the efficiency of the system and reduce heat exchanger requirements to a minimum. Advanced construction materials were exploited to provide minimum weight and long fatigue life. Redundancy management has been addressed with proven techniques such as multiple systems, reservoir level sensing shutoff valves, pressure operated shuttle valves as well as introduction of a new device, the hydraulic integrity monitor (HIM). With expanded interest in airframe central powered engine nozzle actuators, the program included several actuators designed for high temperature operation and included several advanced fluid cooling techniques.

In Phase V of the program, a 550 hour endurance test of the Laboratory Technology Demonstrator will be performed to exercise a complete aircraft shipset of hydraulic central power equipment, about half of a complete fly-by-wire flight control set, a complement of engine nozzle actuators and several other advanced actuation devices.

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## FOREWORD

This report was prepared by the McDonnell Aircraft Company (MCAIR) for the United States Air Force under contract number F33615-86-C-2600. This contract was accomplished under Project Number 30350102. Reported herein is the period of performance from the contract award date, 31 March 1987 through 30 June 1988. This work was administered under the direction of the Aero Propulsion and Power Laboratory at the Wright Research Development Center, Air Force Systems Command, Wright-Patterson AFB, Ohio with Mr. W. B. Campbell (WRDC/POOS) as Project Manager. Technical assistance with the hydraulic fluid was provided by Mr. C. E. Snyder and Mrs. L. Gschwender of the Materials Laboratory (WRDC/MLBT).

Program functions at MCAIR were administered by Mr. J. B. Greene as Program Manager with Mr. J. A. Wieldt as Principal Investigator. Mr. N. J. Pierce served as program advisor until his retirement in August 1987. Other MCAIR hydraulic staff contributors included Mr. M. A. Clay, Mr. S. N. Lohe, Mr. M. R. Emsley, Mr. J. R. Jeffery, Mr. M. A. Orf, Mr. S. E. Pehowski, Mr. J. M. Roach, and Mr. J. J. Sheahan. Laboratory design and procurement activities were coordinated by Mr. E. A. Koertge along with the efforts of Mr. R. Lai, Mr. D. W. Bradrick, Mr. J. E. Flach and Mr. T. F. Dowdy.

This report is the first of two volumes which will fully document the technical efforts for the program. This volume describes the level of effort expended in Phases I, II, III and equipment descriptions generated from Phase IV. The second volume will report the results of the individual component tests performed in Phase IV and system level tests of a Laboratory Technology Demonstrator (LTD) in Phase V.

Phase I established a baseline aircraft hydraulic system based on the F-15 Short Takeoff and Landing (STOL) Maneuvering Technology Demonstrator (SMTD) Aircraft. The configuration of that aircraft's hydraulic power and flight control system was modified to represent a combat survivable version intended to demonstrate satisfaction of future tactical aircraft power needs using nonflammable CTFE hydraulic fluid. This phase also entailed certain secondary issues such as the establishment of equipment reliability goals and evaluation criteria for assessing design approaches which would be demonstrated. It culminated in an industry wide oral briefing at WPAFB on June 25, 1987.

Phase II consisted of a computer analysis effort of the systems required to establish line diameters, predict hydraulic pressure transients and evaluation pump performance for pressure pulsations. During this phase, the design approaches intended to enhance system performance with reduced energy consumption were trade studied. Computer analysis technology (SSFAN, HYTRAN and HSFR), developed during a previous Air Force contract performed by MCAIR, were used in the analysis effort.

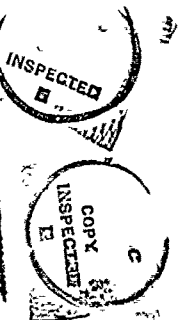
Phase III developed the design requirements for the equipment, however due to the maturity of the baseline aircraft only minor changes were required. The design of the LTD in the laboratory environment was an ongoing task assigned to this phase. Several documents such as a Preliminary Hazards

Analysis (PHA), an Operation and Support Hazard Analysis (OASHA) and a Laboratory Test Plan were also addressed in this program phase.

Phase IV was allocated to selection of equipment suppliers, placement of purchase orders and any activities involved with subcontractors to design, develop, test and deliver equipment to be demonstrated on the LTD. Because of the maturity of equipment design requirements, this phase was allowed to begin concurrently with Phase I at the onset of the program. This was necessary to meet the overall program schedule. This report describes all of the equipment needed for this demonstration program. Volume II of this report will describe the results from the supplier level testing.

Phase V activities will be reported in Volume II. This Phase is dedicated to fabrication, installation, shakedown, performance and endurance testing of the system level testing of the equipment. This Phase will culminate in an industry wide program briefing at MCAIR at or near the conclusion of the endurance test program.

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LIST OF ABBREVIATIONS AND ACRONYMS

ABDR	Aircraft Battle Damage Repair
ADP	Advanced Development Program
AMAD	Airframe Mounted Accessories Drive
CBW	Chemical Biological Warfare
cipr	cubic inches per revolution
cis	cubic inches per second
CRES	Corrosion Resistant Steel
CTFE	Chlorotrifluoroethylene
CWSR	Cold Work Stress Relieved
gpm	gallons per minute
GSE	Ground Support Equipment
HIM	Hydraulic Integrity Monitor
hp	Horsepower
HSFR	Hydraulic System Frequency Response
HYTRAN	Hydraulic Transient Analysis
HX	Heat Exchanger
IRAD	Independent Research and Development
JFS	Jet Fuel Starter
L/H	Left Hand
LCC	Life Cycle Cost
LECHT	Low Energy Consumption Hydraulic Techniques
LEF	Leading Edge Flap
LTD	Laboratory Technology Demonstrator
LVDT	Linear Variable Displacement Transducer
MCAIR	McDonnell Aircraft Company
MTBF	Mean-Time-Between-Failures
MFHBF	Mean-Flight-Hours-Between-Failure

LIST OF ABBREVIATIONS AND ACRONYMS (Continued)

MMHFH	Maintenance Man Hours per Flight Hours
NHPSTA	Nonflammable Hydraulic Power Systems for Tactical Aircraft
OASHA	Operation and Support Hazard Analysis
PC (1 or 2)	Primary Control
PDU	Power Drive Unit
PEEK	Polyetheretherketone
PHA	Preliminary Hazard Analysis
PI	Pressure Intensifier
PS	Procurement Specification
psi	pounds per square inch (lbs/in <sup>2</sup> )
psid	pounds per square inch (lbs/in <sup>2</sup> ) differential
psig	pounds per square inch (lbs/in <sup>2</sup> ) gage
QD	Quick Disconnect
R/H	Right Hand
RFP	Request for Proposal
RLS	Reservoir Level Sensing
R&M	Reliability and Maintainability
rpm	revolutions per minute
RVDT	Rotary Variable Displacement Transducer
SOW	Statement of Work
SSFAN	Steady State Flow Analysis
SMTD	STOL Manuevering Technology Demonstrator
STOL	Short Take-Off and Landing
TIG	Tungsten Inert Gas
VDHM	Variable Displacement Hydraulic Motor
WPAFB	Wright-Patterson Air Force Base
WRDC	Wright Research Development Center

## SECTION I

### INTRODUCTION

#### 1.1 PROGRAM DESCRIPTION

The Nonflammable Hydraulics Power System for Tactical Aircraft (NHPSTA), Contract No. F33615-86-C-2600, an Air Force Advanced Development Program (ADP), was awarded to McDonnell Aircraft Company (MCAIR) on 30 March 1987 and spans a forty month period. The purpose of the program was to develop and demonstrate an advanced hydraulic system designed to operate using an Air Force developed, nonflammable fluid, chlorotrifluoroethylene (CTFE), at a maximum operating pressure of 8000 psi. A total quantity of 600 gallons of CTFE base stock was manufactured for this program by Halocarbon Products and blended with a lubricity additive and a corrosion inhibitor by the Air Force Materials Laboratory. A major portion of an advanced aircraft flight control system was duplicated using lightweight, flightworthy hydraulic components developed by twenty four equipment suppliers contracted to support the program. In addition to the high pressure and new fluid, the program integrated several advanced concepts which reduce power consumption and system heat rejection. The most significant of these is variable system pressure which allows the system to remain at a lower power setting (3000 psi), until a demand occurs. The computer controlled variable pressure pumps then respond with only the amount of increased power needed. Energy savings remains a key issue with this new technology as future tactical aircraft are projected to require three times as much hydraulic power at peak periods than conventional aircraft. The increased system pressure serves to reduce component size to accommodate thinner wings and offset the increased weight of CTFE fluid.

#### 1.2 REPORT ORGANIZATION

This report is organized chronologically by the program tasks. Technical details are integrated within the applicable task. To avoid repetition where technical information is needed more than once, the principal task indicates where additional information is provided. Because this is a demonstration program and deals with many broad technical issues, no attempt has been made to include all of the technical background and detail which has evolved from previous Air Force programs and MCAIR Independent Research and Development (IRAD). Where appropriate, references to the applicable documentation has been included. This report is the first of two volumes which will fully document the technical efforts for the program. This volume describes the level of effort in Phases I, II, III and equipment descriptions generated from Phase IV. The second volume will report the results of the individual component tests performed in Phase IV and system level testing of a Laboratory Technology Demonstrator (LTD) in Phase V.

#### 1.3 PROGRAM SCHEDULE

The program master schedule, shown in Figure 1, displays that the program was organized into five phases. Phase I was dedicated to establishing the base line system which is to be simulated in the Phase V demonstration test. Phase II included all of the system computer analysis and several technical trade studies. Phase III covered the design of the Laboratory Technology

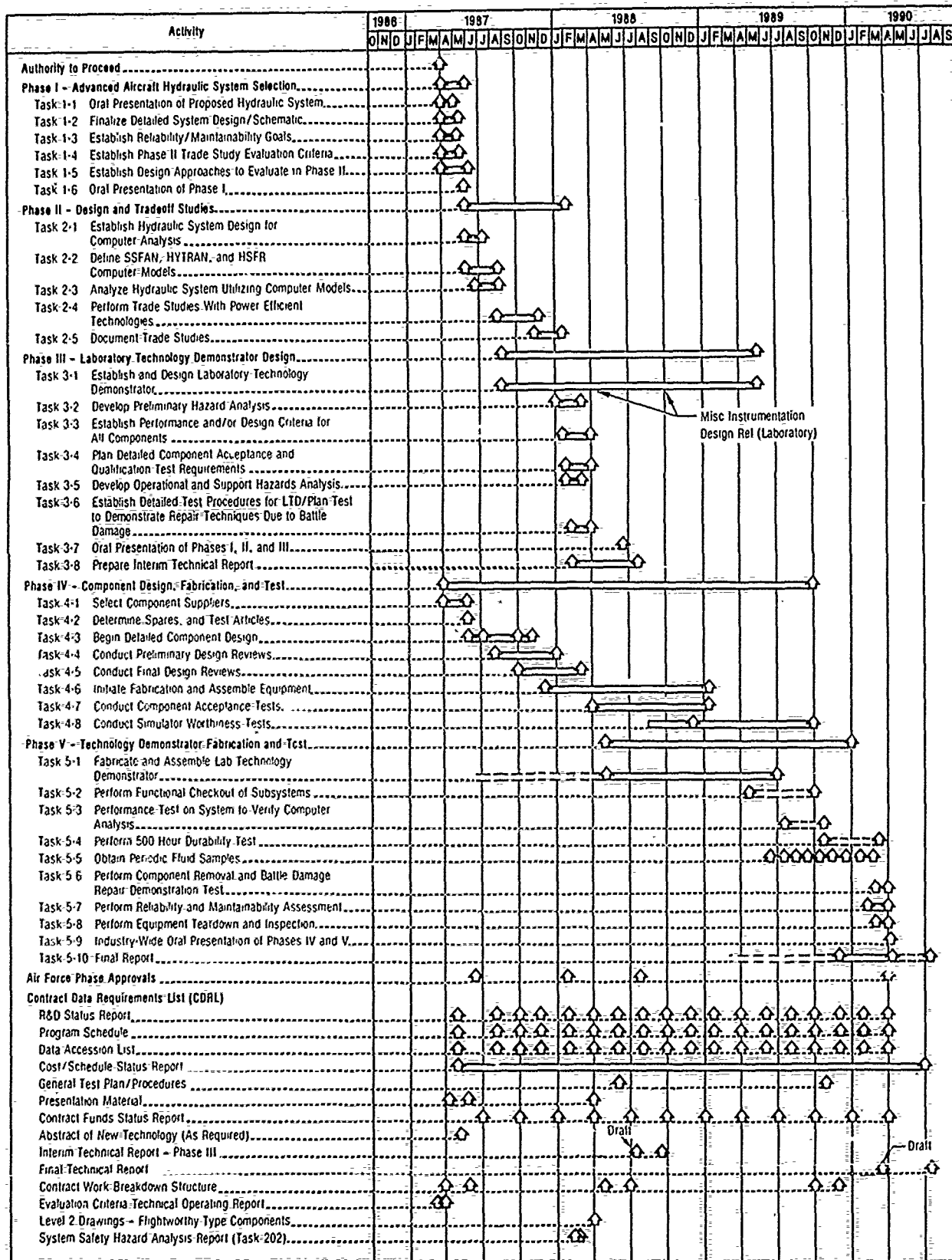


Figure 1. Program Master Schedule

Demonstrator (LTD), development of supplier equipment requirements and this technical report. Because of advanced work, equipment requirements had been established in preparation for the program technical proposal and therefore preempted Phase III activity. This allowed Phase IV design, development and test of the flightweight subcontracted equipment to begin concurrently with Phase I. This approach was absolutely essential to conduct this program in the time span required by the Air Force. Phase V includes the fabrication of the LTD and the system level testing of the subcontracted equipment.

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## SECTION II

### PHASE I - ADVANCED AIRCRAFT HYDRAULIC SYSTEM SELECTION

Phase I included several tasks that included the initial proposal and corrections/modifications to finalize a system design. Also included in this Phase were tasks to define trade study evaluation criteria and summarize any design options to be studied, develop reliability and maintainability goals, and finally to give an oral presentation to the Air Force to discuss these tasks.

#### 2.1 TASK 1-1 - ORAL PRESENTATION OF PROPOSED HYDRAULIC SYSTEM

2.1.1 Kickoff Meeting - At the kickoff meeting held at Wright-Patterson Air Force Base (WPAFB) on April 8, 1987, MCAIR presented the proposed program and the base line system which was structured from the requirements of the F-15 STOL Maneuvering Technology Demonstrator (SMTD) Aircraft.

2.1.2 Aircraft Selection - The F-15 SMTD aircraft was selected because the F-15 hydraulic system has the highest redundancy level of those aircraft in production at MCAIR. This particular experimental aircraft is statically unstable and has a power usage level that is closely matched to the capacity of the hydraulic system. The higher power level stems from the addition of maneuvering flaps, canards and airframe powered engine nozzle actuators. As such, this configuration was felt to be representative of future hydraulic power systems for unstable aircraft.

2.1.3 Aircraft Description - There were several other advantages to using the F-15 SMTD as a base line aircraft. Being statically unstable, its flight controls had to be converted to fly-by-wire and all of the flight control actuators of this aircraft were built with force motor operated direct drive servovalves. The basic F-15 has mechanical controls for the servo-actuators. As a 3000 psi system, there exists a potential to demonstrate a comparison of the weight savings possible with 8000 psi design technology. Much of the basic equipment, common to the F-15 production series, had a substantial data base for performance, cost, reliability and maintenance of the 3000 psi system.

2.1.4 Survivability Provisions - Survivability provisions were a fundamental consideration in this program. All of the survivability provisions which existed on the basic aircraft, were included as well as provisions for newer technology. The conceptual aircraft and the LTD were based on having three hydraulic systems, each system being separated into three subcircuits by valves slaved to a reservoir fluid level. Reservoir Level Sensing (RLS) was provided in both the F-15 and the F-18 series aircraft. Those aircraft have dual RLS circuits for each system; the LTD systems have three. This program also introduced the Hydraulic Integrity Monitor (HIM) which measures the difference in supply and return flow rates and isolates the function in the event of an imbalance (leak). This device was used in the stabilator and rudder circuit, replacing the switching valve.



2.1.5 Power Efficient Technology - Technology derived from previous programs was also implemented. Energy saving concepts were used wherever possible. All of the system pumps were variable pressure and computer controlled. Supply power reduction techniques were also demonstrated. Servovalves were overlapped wherever possible to reduce leakage. Flow augmentation was developed for servoactuators to reduce peak no-load central supply flow to 50 percent of the actual displacement of the cylinder. This concept was developed and demonstrated in the Low Energy Consumption Hydraulic Techniques (LECHT) Program conducted for the Air Force by MCAIR, Reference (1). A variable displacement hydraulic motor (VDHM) was also demonstrated in a leading edge flap system as a means for reducing central system flow requirements.

2.1.6 Engine Nozzle Actuation - Other significant features of this program were areas where newer system requirements, such as engine powered nozzles, introduced the need for hydraulic power consumption solely for bleed cooling of nozzle actuators. This program provisioned a means of simulating a 450°F ambient environment needed to test the complement of eight engine actuators, one engine set, and to evaluate methods of cooling other than that which was implemented on the F-15 SMTD.

## 2.2 TASK 1-2 - FINALIZE DETAILED SYSTEM DESIGN/SCHEMATIC

2.2.1 Aircraft Block Diagram - The block diagram of a combat survivable version of the F-15 SMTD is shown in Figure 2. This is a three system

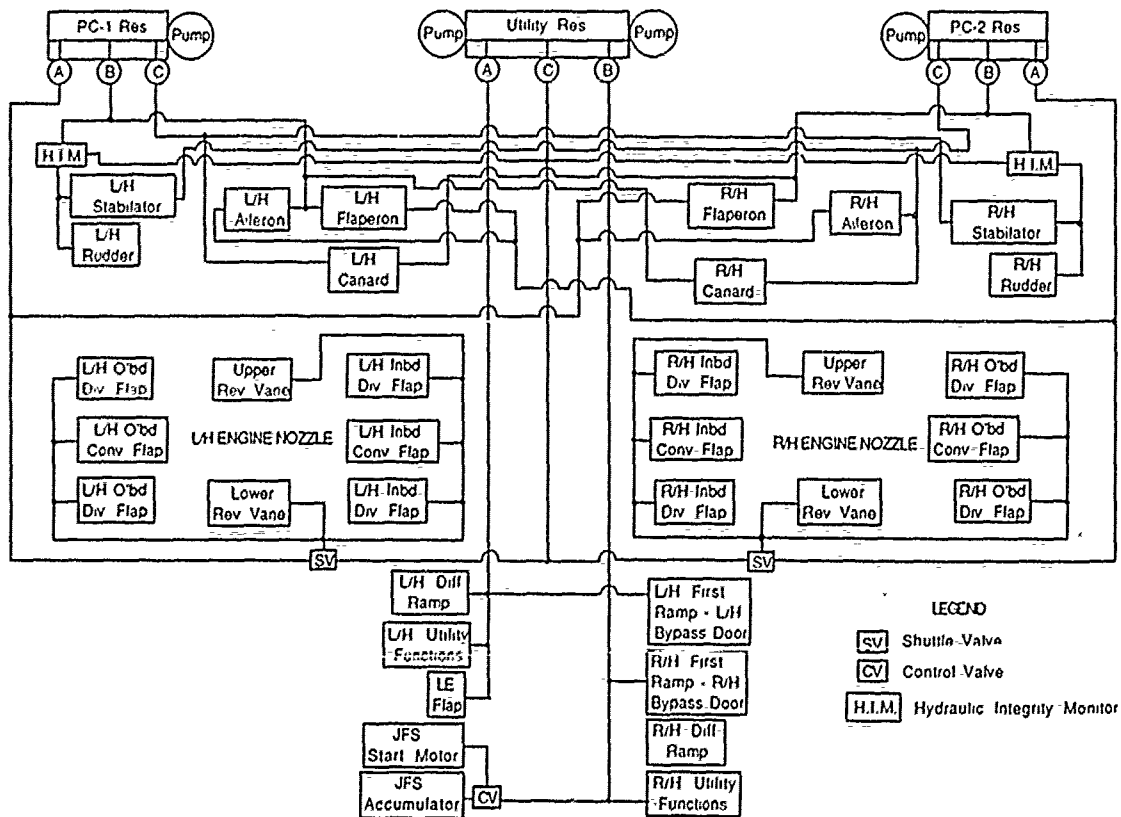


Figure 2. Block Diagram - Base line Aircraft

configuration having nine subcircuits which are subdivided by RLS shutoff valves integrated into the reservoirs. The stabilators are powered by three sources of hydraulic power, remaining operative should failure of any two of the three hydraulic systems occur. This system arrangement was selected because of the additional power load introduced by the airframe powered vectored thrust nozzles on the engines and redundancy considerations.

2.2.2 Demonstrator Block Diagram - Figure 3 shows the block diagram of the LTD system to be tested in Phase V of the program. The emphasis was on placing enough equipment into the program to give a reasonable representation of a total aircraft hydraulic system. All of the flight control actuator functions have been duplicated, including the central power generation systems and several utility functions.

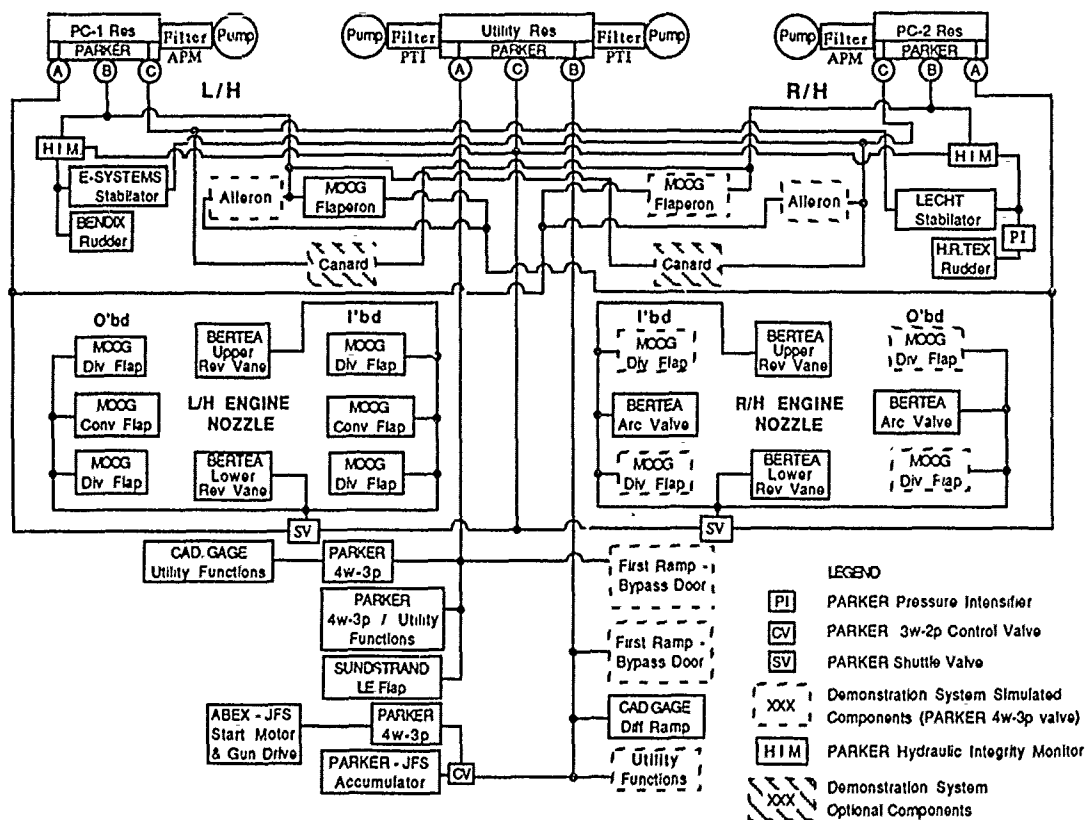


Figure 3. Block Diagram - Laboratory Technology Demonstrator

2.2.3 Detail Schematics - Appendix A contains the detail system schematics of the hydraulic systems which are to be integrated into the LTD. The schematics are organized as hydraulic systems PC-1 (Primary Control), PC-2 and Utility; Left Hand (L/H) and Right Hand (R/H) flight control systems and utility functions including engine nozzle actuation. A schematic of a smaller hydraulic power unit, used for servicing or powering the systems without the main pumps, is also shown.

### 2.3 TASK 1-3 - ESTABLISH RELIABILITY/MAINTAINABILITY GOALS

One of the program goals was to improve the reliability or the maintainability of the system three fold over current standards. This task was aided by complementary IRAD efforts at MCAIR (IRAD 7-450 Reference 2) and previous work which was required for the technical proposal.

2.3.1 Reliability Survey - The first part of this task was to survey the reliability data on the hydraulic systems of several current technology tactical aircraft to assess which had the best supportability record in the field. Figure 4 shows the comparison of four current aircraft evaluated on two levels; the first comparison being the basic aircraft, and the second comparison with their equipment reliability normalized to the equipment quantities and types used in this program. The results of this study show the F-16 as having the best overall hydraulic system reliability. The system reliability levels shown are considerably below published values for hydraulic systems.

	Aircraft Actual	Normalized to LTD Equipment
F-14	16.2	23.4
F-15	33.4	37.1
F-16	69.6	55.5
F/A-18	43.1	46.7

System Reliability Goal  $3 \times 55.5 = 167$  MTBF

**Figure 4. Hydraulic Systems Reliability Comparison**

Typical reliability data for hydraulic systems does not include flight control actuators, landing gear actuation and many utility functions. The MCAIR effort reviewed other subsystems which use hydraulic power and evaluated failure records on their hydraulic components. This extra effort truly defines "total hydraulics." The detailed analysis of the reliability data is provided in References (3) and (4).

2.3.2 Equipment Requirements - The procurement specification (PS) reliability requirements for the LTD equipment which had been established previously, matched the normalized F-16 system reliability when factored roughly by three. The conclusion was the equipment reliability goals were satisfactory as written. This was due to the following considerations; the specifications were based on F-15 procurement specification reliability requirements, and the F-16 equipment was expected to have an improvement increment since the aircraft program was newer. Figure 5 shows the reliability goals for comparison of the LTD equipment. Detail and methodology for this effort was documented in Reference (4).

Utility Actuator.....	15,000 hr	LEF System .....	3,000 hr
Charge Valve .....	7,500 hr	Pressure Switch.....	15,000 hr
Pumps .....	3,700 hr	Relief Valve.....	20,000 hr
Reservoirs .....	25,000 hr	Pressure Transmitter.....	15,000 hr
Filter Manifolds .....	15,000 hr	Hydraulic Integrity Monitor.....	27,000 hr
Servoactuators.....	9,000 hr	Accumulators.....	20,000 hr
Heat Exchangers .....	100,000 hr	Hydraulic Motor .....	9,000 hr
Pressure Intensifier.....	7,500 hr	Shuttle Valve .....	27,000 hr

Figure 5. Hydraulic Equipment Reliability Goals

2.3.3 R&M 2000 Objectives - It is an expressed Air Force R&M 2000 objective that reliability and maintainability be coequal in importance to performance, cost and schedule. Cost is assumed to be acquisition cost which is included in life cycle cost (LCC) and is in concert with performance and schedule. Since performance is related to weight, particularly when attempting to satisfy several other design requirements, improved reliability is considered relative to weight as well. Maintainability is also relative to provisions on the aircraft which may also add weight.

2.3.4 R&M/Life Cycle Cost Link - It was possible to place a dollar value on reliability and maintainability improvements which have weight impact through LCC. This relationship applies to only one subsystem at a time so the values in this instance would apply to hydraulics only. If one pound is added to the hydraulic subsystem in some manner to improve subsystem reliability, how much improvement would be required to justify the LCC associated with increasing the hydraulic subsystem weight by that amount? Similarly, if total aircraft maintenance was increased to a degree by increasing hydraulic subsystem weight by one pound, how much improvement would be required to justify that pound in LCC?

2.3.5 Life Cycle Cost Analysis - A life cycle cost model of the F-15 aircraft was used to examine the relative effect of aircraft hydraulic subsystem weight, subsystem reliability and subsystem maintenance on the total aircraft life cycle cost. Because each of these parameters can be associated directly with operating cost, they may serve as a relative comparison in trade studies where a value of merit of either adding weight, improving reliability or decreasing maintenance is needed. The analysis showed that one pound of hydraulic subsystem weight for this aircraft costs 1.881 million dollars over the life of the fleet. This includes the effect of additional weight in other subsystems, structure, engine and fuel. Similarly a change in subsystem reliability of 0.57 percent has a total life cycle cost impact of 1.881 million dollars. (For relative comparison, total hydraulic subsystem reliability is on the order of 63 hours Mean-Time-Between-Failures.) Reduced (or increased) maintenance time reaches this same dollar value at change of 1.4 percent where the average system maintenance is 0.434 MMHFH (Maintenance-Man-Hours-per-Flight-Hour). The payoff for simultaneous improvement of these three parameters is enormous and obviously the designer's goal. This measure

of relative merit for each, however, can be used in trade studies for evaluating several design approaches.

#### 2.4 TASK 1-4 - ESTABLISH PHASE II TRADE STUDY EVALUATION CRITERIA

The contract Statement of Work (SOW) required a trade study evaluation criteria (Reference 5). The trade studies performed, which are summarized herein, considered the criteria set forth in this document. An attempt was made in generating these trade studies to include all of the considerations which could apply to a large variety of hydraulic equipment and considerations which could be applied on a system level. Much of the criteria could not be applied on all studies. The criteria was most useful in those studies where hardware configurations were an issue.

#### 2.5 TASK 1-5 - ESTABLISH DESIGN APPROACHES TO EVALUATE IN PHASE II

MCAIR identified nine trade studies to be performed in Phase II of the program. These studies are outlined below and discussed in Section III.

- TS-1 - Fluid reservoir pressurization methods for variable pressure nonflammable hydraulic systems
- TS-2 - System circuit configuration for a combat survivable F-15 SMTD aircraft with a nonflammable hydraulic system
- TS-3 - Technique for cooling engine exhaust nozzle actuators
- TS-4 - Configurations for direct drive valves for flight control actuators
- TS-5 - Optimum techniques for controlling peak pressures in the system
- TS-6 - Materials for 8000 psi nonflammable hydraulic system components
- TS-7 - Use of overlapped valves to reduce total system null leakage
- TS-8 - Parallel variable pressure pump integration and control in nonflammable hydraulic systems
- TS-9 - Approaches to achieve stiffness and prevent flutter of flight controls with 8000 psi systems

#### 2.6 TASK 1-6 - ORAL PRESENTATION OF PHASE I

The Phase I Oral Presentation was held at WPAFB on June 25, 1987. The presentation was attended to room capacity by representatives from industry, the Air Force and the Navy.

2.6.1 Industry Feedback - The most significant item which arose from industry feedback was objection to the percentage of time planned for testing at the higher pressure (8000 psi) of the demonstrator with variable pressure hydraulic pumps. It was the general consensus that there would not be enough operating time at 8000 psi system pressure as originally conceived. The original plan was to operate the variable pressure pumps with higher pressure on demand. On stable aircraft such as the F-15 or F-18, this would result in

the system pressure remaining at 3000 psi over 90 percent of the time. The system is designed to be capable of continuous operation at 8000 psi. There are no design factors which are either increased or decreased as a result of variable pressure operation. The only affect on the system is increased fatigue in the central system and increased heat rejection as a function of increased operating time at 8000 psi. There are no known parameters which are enhanced by variable pressure operation other than total heat rejection. Ideally, system operating temperature is not affected because the system heat exchangers would be downsized accordingly and operated at maximum fluid temperatures. A more rigorous duty cycle was developed, however which would be more representative of advanced unstable aircraft and have more residence time at 8000 psi.

2.6.2 Operating Duty Cycle - The solution to the objections raised by the industry at the Oral Presentation was an alternate duty cycle for operation of the systems during the 550 hour endurance test. This was still consistent with a program goal to run the demonstrator mission profiles with duty cycles consistent with the objective of developing technology which could be applied to advanced aircraft. Flight control duty cycles from two aircraft configurations were analyzed. One configuration had reduced static stability; the other was highly unstable. A composite duty cycle was derived which would have surface activity which could be applied to the F-15 S/MTD's complement of flight controls. This duty cycle, described in Section III, results in the system being at 8000 psi operating pressure approximately 25 percent of the total operating time. The intensity of activity can be increased during the endurance test phase to a level which results in operation at 8000 psi approximately 50 percent of the time in order to give a measure of the reduced heat rejection.

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## SECTION III

### PHASE II - DESIGN AND TRADEOFF STUDIES

Phase II of the program included the tasks of actual system design and analysis. These tasks were accomplished utilizing computer modeling programs of SSFAN (Steady State Flow Analysis), HYTRAN (Hydraulic Transient Analysis), HSFR (Hydraulic System Frequency Response), and a Heat Transfer program. The additional task performed in this phase was the documentation of the trade studies identified in Phase I.

#### 3.1 TASK 2-1 - ESTABLISH HYDRAULIC SYSTEM DESIGN FOR COMPUTER ANALYSIS

Several computer models of subsystems or subsystem elements were developed. Some changes were incorporated into the base line system to carry out a key objective of the program, the demonstration of advanced technology. Functions which were not part of the base line aircraft were provided to fulfill this goal. The analysis work also included the LTD, which deviates from the minimum requirements for F-15 SMTD in order to comply with the contract statement of work, and to demonstrate advanced technology.

3.1.1 Leading Edge Flap Drive System - The addition of a leading edge flap (LEF) drive system powered by a variable displacement hydraulic motor, required an increase in size of hydraulic lines in the Utility system. The variable displacement motor required only one half of the hydraulic power required by fixed displacement motors. However, to effect test comparisons, it will also be operated as a fixed displacement motor with a higher flow demand.

3.1.2 Oversized Central System - The flow rate of the Utility hydraulic pumps are intended to be increased from 40 gpm to 55 or 60 gpm. Nonoptimum design conditions existed to render these changes workable. The filter manifolds used in the Utility system were also rated at 60 gpm. The F-15 SMTD would have required 8000 psi pumps rated at 25 gpm each whereas the statement of work required pumps having a capacity of 40 gpm or larger to serve the future needs of tactical aircraft.

#### 3.2 TASK 2-2 - DEFINE SSFAN, HYTRAN, AND HSFR COMPUTER MODELS

3.2.1 SSFAN Models - SSFAN (Steady State Flow Analysis) models were based on a combat survivable version of the F-15 SMTL. There were five models in all: PC-1 with L/H Flight Controls, PC-2 with R/H Flight Controls, Central Utility System, Engine Nozzle Subsystem and Utility System Functions. Line lengths between components were established for this aircraft configuration and line sizes were adjusted to match actuator no-load rates. Local velocity reduction, asymmetric line loss and flow augmentation schemes were also incorporated. The nozzle hydraulic power supply lines were shown to be the most marginal because of the extremely low loss allowed in the supply lines. Line lengths and sizes are shown in Appendix A.

3.2.2 HYTRAN Models - HYTRAN (Hydraulic Transient Analysis) models were developed for key areas of the LTD; the stabilator actuator supply and return, the canard actuator supply and return and each pump suction system. The models were created to seek pressure transients, a routine task in aircraft system development. In this program, this work overlapped with Trade Study No. TS-7, to establish the optimum methods for pressure transient control in the systems.



3.2.3 HSFR Models - An HSFR (Hydraulic System Frequency Response) model was developed to predict pump pulsations in one PC system. Pump model parameters were received from Abex and Vickers whose design approaches were compatible with the HSFR pump model. The HSFR pump model could not be used with one of the pump concepts proposed, the Lucas Aerospace Power check valve pump. It was also not feasible to model the Utility system, which used two pumps in parallel, because the HSFR computer program did not have the capability to analyze parallel pumps.

### 3.3 TASK 2-3 - ANALYZE HYDRAULIC SYSTEM UTILIZING COMPUTER MODELS

3.3.1 Actuator and Load Data - The first step in analyzing the LTD hydraulic system, was to collect the actuator data to determine system and tubing flow rates. Figure 6 summarizes each component that demands flow from the central system, outlines the geometry of the component, the rated output force and no-load velocity. Figure 6 also shows design flow rates, extending and retracting.

Component Title and Function	PS No. (71 13)	Mfg. Part No	Usage	System	Qty	Stroke (in)	Bore (in)	Rod Dia. (in)	Tail Dia. (in)	Effective Area (in <sup>2</sup> )				Diff. Vol. (in <sup>3</sup> )	Force Output (Lbs@7900 psi)		No Load Velocity (in/sec)	Flow Rate (gpm)			
										System 1		System 2			Ext	Ret		Ext	Ret	Ext	Ret
										Ext	Ret	Ext	Ret								
Aileron	6901-101	Deleted	L/H	PC-2A2																	
	LECHT Stab (FAST)	Parker Bertea 330400ADP	R/H	PC-1C1 PC-2C1 PC-1A2	1	7.77	2.369	1.022	1.242	3.196	2.341			6.64	43742	36988	8.2	3.50	2.50		
Flaperon	6935-101 -103	MCOG L-4797 Simulator	L/H	PC-2A2	1	1.42	1.76	1.249	0.749	1.992	1.208			1.11	25280	19086	3.33	1.72	1.04		
			R/H	PC-1B1 PC-2B1 PC-1A2	1								1.208	1.208					1.04	1.21	
Stabilator (FAST)	6934-101	E-Systems	L/H	PC-2C2	1	7.77	2.286	1.498	1.123	3.114	2.342			6.00	43102	37004	8.2	3.50	2.50		
			R/H	PC-1B1 PC-1C2 PC-2B1	1	7.77	2.286	1.498	1.123	3.114	2.342			2.342	2.342	6.00	43102	37004	8.2	2.50	2.50
Canard (FAST)	6902-101	HR Textron	L/H	PC-2B2	1	7.77	2.286	1.498	1.123	3.114	2.342			6.00	43102	37004	8.2	3.50	2.50		
			R/H	PC-1C1 PC-1B2 PC-2C1	1	7.77	2.286	1.498	1.123	3.114	2.342			2.342	2.342	6.00	43102	37004	8.2	2.50	2.50
Rudder	6937-101	HR Textron	L/H	PC-1B1	1	60*	2.125	1.50		1.766	1.766						105*	0.74	0.74		
	6920-101		Bendix Electro	R/H	PC-2B1	1	60*	1.594	1.00	7.25	4.232	4.232			21682	21682	105*	1.31	1.31		
Diffuser Ramp Utility Act -103	6904-101	Cadillac Gage	L/H	UT-A	1	10.18	2.08	1.434		3.40	1.783			16.45	26844	14086	10.18	0.66	0.23		
			R/H	UT-A	1	10.18	2.08	1.434		3.40	1.783			16.45	26844	14086	10.18	9.00	4.71		
Leading Edge Flap PDU -103	6940-101	Vickers Garrett	L/H	UT-A	1																
			R/H	UT-B	1																
Utility Functions 4W-3P Valve	6915-101	Parker 3860029	L/H	UT-A	1													10.7	2.70		
			R/H	UT-B	1														3.15	0.25	
JFS Motor 3W-2P Valve	6912-101	Abex	R/H	UT-B	1																
Gun Motor 4W-3P Valve	6912-101 6915-101	Abex Parker	R/H	UT-B	1													10.2	10.2		
Convergent Flap	6907-207	MCOG	L/H	UT-C3	2	10.04	2.47	1.436	1.03	3.958	3.172			15.78	31270	25059	7.2*	14.0	11.9		
Divergent Flap (PRA) -209	6907-205	MCOG	L/H	UT-C3	4	15.25	1.93	1.374	1.03	2.09	1.443			39.47	5111	11400	11.8*	7.93	17.7		
			R/H	UT-C3	1														7.93	17.7	
Reverser Vane	6938-101	Parker Bertea	L/H	UT-C3	2	2.00	1.64	1.122	0.926	1.439	1.124			1.26	11368	8879	4.00*	2.99	2.34		
			R/H	UT-C3	2	2.00	1.64	1.122	0.926	1.439	1.124			1.26	11368	8879	4.00*	2.99	2.34		
Arc Valve	6918-103	Parker Bertea	R/H	UT-C3	2	7.34	1.712	1.122	0.926	1.628	1.313			4.62	12861	10373	7.34	6.21	5.01		
TOTALS					33					40.99	30.66	12.92	12.92	127				125	111		

\* These units are in degrees or degrees/second  
^ Rate limited up to at least 2/3 stall load  
(PRA) Pressure Regenerative Actuator  
(FAST) Flow Augmented Servo Valve Technology

Figure 6. Advanced Development Program (ADP) Actuator Data

3.3.2 Flow Demand Analysis - For simultaneous operation of all components, the total LTD flow demand was 125 gpm extending and 111 gpm retracting. Standard practice at MCAIR placed pump capacity at 85 percent of maximum simultaneous demand.

a. PC-1 Pump Capacity - Figure 7 summarizes the flow demand of the PC-1 system. During normal operation, the flight controls on these circuits demand a maximum of 17.5 gpm from the central system. PC-1 also backed up the left hand engine nozzle actuators in the event of a Utility system failure. In the back up mode, the flow demand was 47.4 gpm. The 40 gpm pumps procured for the LTD, were adequately sized for this demand as 85 percent of 47.4 gpm is 40 gpm.

Component Title and Function	PS No. (71 13)	Mfg. Part No	Usage	System	Qty	Stroke (in)	Bore (in)	Rod Dia. (in)	Tail Dia. (in)	Effective Area (in <sup>2</sup> )				Diff. Vol. (in <sup>3</sup> )	Force Output (Lbs@7900 psi)		No Load Velocity (in/sec)	Flow Rate (gpm)			
										System 1		System 2			Ext	Ret		Ext	Ret	Ext	Ret
										Ext	Ret	Ext	Ret								
Aileron	6901-101	Deleted	L/H	PC-2A2																	
		LECHT Stab (FAST)	Parker Bertea 330400ADP	R/H	PC-1C1 PC-2C1 PC-1A2	1	7.77	2.369	1.622					2.341	2.341	18494	18494	8.2	2.50	2.50	
Flaperon	6935-101 -103	MCOG L-4797 Simulator	L/H	PC-2A2	1	1.42	1.76	1.249					1.208	1.208	9543	9543	3.33	1.04	1.04		
			R/H	PC-2B1 PC-1A2	1													1.21	1.21		
Stabilator (FAST)	6934-101	E-Systems	L/H	PC-2C2																	
			R/H	PC-1B1 PC-1C2 PC-2B1	1	7.77	2.286	1.498	1.123	3.114	2.342	2.342	2.342	6.00	18502 24600	18502	8.2	2.50 3.50	2.50		
Canard (FAST)	6902-101	HR Textron	L/H	PC-2B2																	
			R/H	PC-1C1 PC-1B2 PC-2C1	1	7.77	2.286	1.498	1.123	3.114	2.342	2.342	6.00	18502 24600	18502	8.2	2.50 3.50	2.50			
Rudder	6920-101 6937-101	HR Textron Bendix Electro	L/H	PC-1B1	1	6.0	2.125	1.50		1.766	1.766						105	0.74	0.74		
			R/H	PC-2B1																	
PC-1 TOTALS					8					7.994	6.45	8.233	8.233	12.00				17.5	15.5		

BACKUP SYSTEM																			
Convergent Flap	6907-207	MCOG	L/H	UT-C3	2	10.04	2.47	1.436	1.03	3.958	3.172			15.78	31270	25059	7.2 <sup>^</sup>	14.8	11.9
Divergent Flap (PRA)	6907-205 -209	MCOG	L/H	UT-C3	4	15.25	1.93	1.374	1.03	2.09	1.443			39.47	5111	11400	11.8 <sup>^</sup>	7.93	17.7
			R/H	UT-C3															
Reverser Vane	6938-101	Parker Bertea	L/H	UT-C3	2	2.00	1.64	1.122	0.926	1.439	1.124			1.26	11368	8879	4.00 <sup>^</sup>	2.99	2.34
Arc Valve	6938-103	Parker Bertea	R/H	UT-C3															
TOTALS					16					15.48	12.19	8.233	8.233	68.51				43.2	47.4

\* These units are in degrees or degrees/second  
<sup>^</sup> Rate limited up to at least 2/3 stall load  
(PRA) Pressure Regenerative Actuator  
(FAST) Flow Augmented Servo Valve Technology

Figure 7. Actuator Data  
PC-1 System

b. PC-2 Pump Capacity - Figure 8 summarizes the flow demand of the PC-2 system. During normal operation, the flight controls on these circuits demand a maximum of 19.7 gpm from the central system. PC-2 also backed up the right hand engine nozzles (simulated on LTD), in the event of a Utility system failure. In the back up mode, the flow demand was 41.1 gpm. The 40 gpm pumps being procured for the LTD were adequately sized for this demand.

c. Utility Pump Capacity - The Utility hydraulic system is summarized in Figure 9. During normal operation, the flow demand on this system is 87.3 gpm. It backs up the stabilators and rudders and also gives a back up mode maximum flow of 94.3 gpm. The two paralleled 40 gpm pumps were adequately sized for this demand.

Component Title and Function	PS No. (71 13)	Mfg. Part No	Usage	System	Qty	Stroke (in)	Bore (in)	Rod Dia (in)	Tail Dia (in)	Effective Area (in <sup>2</sup> )				Diff. Vol (in <sup>3</sup> )	Force Output (Lbs@7900 psi)		No Load Velocity (in/sec)		Flow Rate (gpm)			
										System 1		System 2			Ext	Ret	Ext	Ret	Ext	Ret	Ext	Ret
										Ext	Ret	Ext	Ret									
Aileron	6901-101 LECHT Stab (FAST)	Deleted Parker Berteau 330400ADP	L/H	PC-2A2																		
			R/H	PC-1C1	1	7.77	2.369	1.662	1.242	3.196	2.341			6.64	25248	18494	8.2	3.50	2.50			
				PC-1A2																		
Flaperon	6935-101 -103	MCOG L-4797 Simulator	L/H	PC-2A2	1	1.42	1.76	1.249	0.749	1.992	1.200			1.11	15734	9543	3.33	1.72	1.04			
			R/H	PC-1B1	1														1.21	1.21		
				PC-2B1 PC-1A2																		
Stabilator (FAST)	6934-101	E-Systems	L/H	PC-2C2	1	7.77	2.286	1.498	1.123	3.114	2.342			6.00	24600	18502	8.2	3.50	2.50			
			R/H	PC-1B1																		
				PC-1C2 PC-2B1	1	7.77	2.286	1.498					2.342	2.342		18502	18502	8.2	2.50	2.50		
Canard (FAST)	6902-101	HR Textron	L/H	PC-2B2	1	7.77	2.286	1.498	1.123	3.114	2.342			6.00	24600	18502	8.2	3.50	2.50			
			R/H	PC-1C1																		
				PC-1B2 PC-2C1	1	7.77	2.286	1.498					2.342	2.342		18502	18502	8.2	2.50	2.50		
Rudder	6920-101	HR Textron	L/H	PC-1B1																		
	6937-101	Bendix Electro	R/H	PC-2B1	1	60°	1.594	1.00	7.125	4.232	4.232					21682	21682	105°	1.31	1.31		
<b>PC-2 TOTALS</b>					<b>8</b>							<b>15.65</b>	<b>12.47</b>	<b>4.684</b>	<b>4.684</b>	<b>19.75</b>				<b>19.7</b>	<b>16.1</b>	

**BACKUP SYSTEM**

Convergent Flap	6907-207	MCOG	L/H	UT-C3																	
Divergent Flap (PRA)	6907-205-209	MCOG	L/H R/H	UT-C3 UT-C3	1															7.93	17.7
Reverser Vane	6938-101	Parker Berteau	L/H R/H	UT-C3 UT-C3	2	2.00	1.64	1.122	0.926	1.439	1.124			1.26	11368	8879	4.00*	2.99	2.34		
Arc Valve	6938-103	Parker Berteau	R/H	UT-C3	2	7.34	1.712	1.122	0.926	1.628	1.313			4.62	12861	10373	7.34	6.21	5.01		
<b>TOTALS</b>					<b>13</b>							<b>18.72</b>	<b>14.9</b>	<b>4.684</b>	<b>4.684</b>	<b>25.63</b>				<b>36.9</b>	<b>41.1</b>

\* These units are in degrees or degrees/second  
 ^ Rate limited up to at least 2/3 stall load  
 (PRA) Pressure Regenerative Actuator  
 (FAST) Flow Augmented Servovalve Technology

**Figure 8. Actuator Data  
PC-2 System**

Component Title and Function	PS No (71 13)	Mfg. Part No	Usage	System	Qty	Stroke (in)	Bore (in)	Rod Dia (in)	Tail Dia (in)	Effective Area (in <sup>2</sup> )				Diff. Vol (in <sup>3</sup> )	Force Output (Lbs@7900 psi)		No Load Velocity (in/sec)		Flow Rate (gpm)			
										System 1		System 2			Ext	Ret	Ext	Ret	Ext	Ret	Ext	Ret
										Ext	Ret	Ext	Ret									
Diffuser Ramp Utility Act.	6904-101-103	Cofifac Gage	L/H	UT-A	1	10.18	2.08	1.434														
			R/H	UT-A	1	10.18	2.08	1.434			3.40	1.783			16.45	26844	14086	10.18	9.00	4.71		
Loading Edge Flap PDU	6940-101-103	Vickers Garrett	L/H	UT-A	1																	
			R/H	UT-B	1																	
Utility Functions 4W-3P Valve	6915-101	Parker 3860029	L/H	UT-A	1															10.7	2.70	
			R/H	UT-B	1															3.15	0.25	
			R/H	UT-B	1																10.7	4.73
JFS Motor 3W-2P Valve	6912-101 6917-101	Abex Parker	R/H	UT-B	1																	
Gun Motor 4W-3P Valve	6912-101 6915-101	Abex Parker	R/H	UT-B	1																10.2	10.2
Convergent Flap	6907-207	MCOG	L/H	UT-C3	2	10.04	2.47	1.436	1.03	3.958	3.172			15.78	31270	25059	7.2^	14.8	11.9			
Divergent Flap (PRA)	6907-205-209	MCOG	L/H	UT-C3	4	15.25	1.93	1.374	1.03	2.09	1.443			39.47	5111	11400	11.8^	7.93	17.7			
			R/H	UT-C3	1															7.93	17.7	
Reverser Vane	6938-101	Parker Berteau	L/H	UT-C3	2	2.00	1.64	1.122	0.926	1.439	1.124			1.26	11368	8879	4.00*	2.99	2.34			
			R/H	UT-C3	2	2.00	1.64	1.122	0.926	1.439	1.124			1.26	11368	8879	4.00*	2.99	2.34			
Arc Valve	6938-103	Parker Berteau	R/H	UT-C3	2	7.34	1.712	1.122	0.926	1.628	1.313			4.62	12861	10373	7.34	6.21	5.01			
<b>Utility Totals</b>					<b>24</b>							<b>17.35</b>	<b>11.74</b>	<b>0</b>	<b>0</b>	<b>95.29</b>				<b>87.3</b>	<b>79.8</b>	

**BACKUP SYSTEM**

Stabilator (FAST)	6934-101	E-Systems	L/H	PC-2C2																	
			R/H	PC-1B1	1	7.77	2.286	1.498					2.342	2.342		18502	18502	8.2	2.50	2.50	
				PC-1C2																	
Rudder	6920-101	HR Textron	L/H	PC-1B1	1	60°	2.125	1.50		1.766	1.766										
	6937-101	Bendix Electro	R/H	PC-2B1	1	60°	1.594	1.00	7.125	4.232	4.232					21682	21682	105°	1.31	1.31	
<b>TOTALS</b>					<b>28</b>							<b>23.35</b>	<b>17.74</b>	<b>4.684</b>	<b>4.684</b>	<b>95.29</b>				<b>94.3</b>	<b>86.9</b>

\* These units are in degrees or degrees/second  
 ^ Rate limited up to at least 2/3 stall load  
 (PRA) Pressure Regenerative Actuator  
 (FAST) Flow Augmented Servovalve Technology

**Figure 9. Component Data  
Utility System**

3.3.3 SSFAN Analysis - All of the SSFAN models were assembled using tubing lengths measured on the F-15 SMTD aircraft as shown in Figure 10. Because this aircraft was an experimental configuration, production tubing lengths were approximated for the engine nozzle shuttle valves, the utility reservoirs and filters, and the leading edge flap drive for the LTD. After all lines were sized using the line lengths shown in Figure 10, all no-load actuator rates were within specification tolerances.

**Flight Control Subsystems**

From	To	SMTD	LTD
PC-1 Pump	PC-1 Filter	50	50
PC-1 Filter	PC-1 Reservoir	13	13
PC-1 Reservoir	L/H Stabilator	285	291
PC-1 Reservoir	L/H Canard	175	175
PC-1 Reservoir	L/H Aileron	477	478
PC-1 Reservoir	L/H Flaperon	417	417
PC-1 Reservoir	L/H Rudder	282	288
PC-1 Reservoir	L/H Nozzle Shuttle Valve	486	250
PC-1 Reservoir	R/H Stabilator	348	353
PC-1 Reservoir	R/H Canard	276	276
PC-1 Reservoir	R/H Aileron	213	254
PC-1 Reservoir	R/H Flaperon	153	194
PC-2 Pump	PC-2 Filter	50	50
PC-2 Filter	PC-2 Reservoir	13	13
PC-2 Reservoir	R/H Stabilator	298	304
PC-2 Reservoir	R/H Canard	188	188
PC-2 Reservoir	R/H Aileron	145	145
PC-2 Reservoir	R/H Flaperon	85	85
PC-2 Reservoir	R/H Rudder	295	295
PC-2 Reservoir	R/H Nozzle Shuttle Valve	153	250
PC-2 Reservoir	L/H Stabilator	353	353
PC-2 Reservoir	L/H Canard	283	283
PC-2 Reservoir	L/H Aileron	359	359
PC-2 Reservoir	L/H Flaperon	299	299
<b>Utility Subsystems</b>			
UT-1 Pump	UT-1 Filter	86	50
UT-1 Filter	UT Reservoir	29	35
UT-2 Pump	UT-2 Filter	134	50
UT-2 Filter	UT Reservoir		35
UT Reservoir	L/H Nozzle Shuttle Valve	486	250
UT Reservoir	R/H Nozzle Shuttle Valve	153	250
UT Reservoir	L/H Engine Inlet Actuators	372	372
UT Reservoir	R/H Engine Inlet Actuators	93	93
UT Reservoir	L/H Stab Switching Valve		100
UT Reservoir	R/H Stab Switching Valve		100
UT Reservoir	L/H Utility Functions	N/A	280
UT Reservoir	R/H Utility Functions	N/A	85
UT Reservoir	JFS/Gun-Drive Motor		89
UT Reservoir	R/H Leading Edge Flap	150*	115

\*F-18 leading edge flap

**Figure 10. Tubing Lengths Comparisons**

a. PC-1 Central System - The PC-1 central system SSFAN model is shown schematically in Figure 11. Leg numbers were assigned to tube branches that

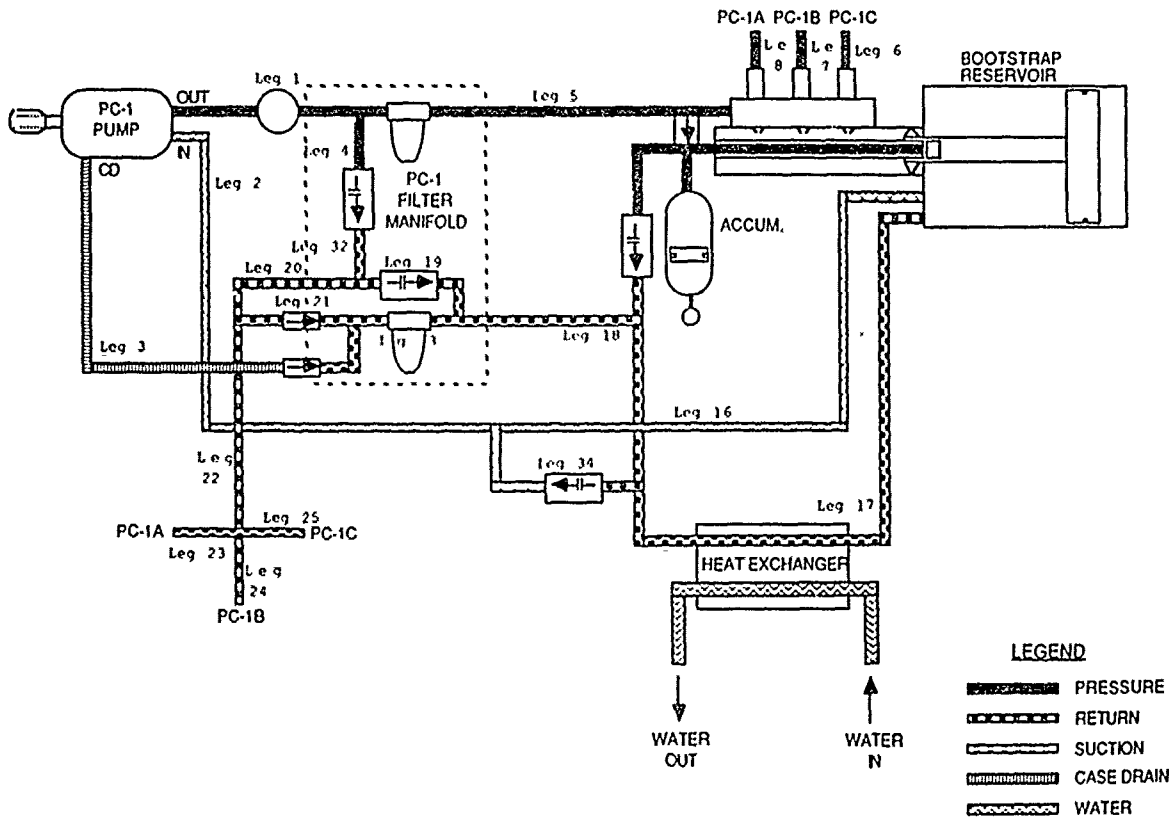


Figure 11. SSFAN Schematic  
PC-1 Central System

span between flow discontinuities. The assumptions used to size the PC-1 central system are shown in Figure 12. Line sizes were adjusted until acceptable pressure losses and flow rates were achieved. Figure 13 summarizes the tube size and length selected for each leg and identifies the corresponding flow rate and pressure loss. The same process was repeated for the rest of the subsystems.

- One 40 gpm Pump With 2.5 gpm Case Drain Flow (Pump Compensated)
- Pulsation Attenuators With 80 psi Drop at 40 gpm
- 5-Micron High Pressure Filter With 25 psi Drop at 40 gpm
- 5-Micron Return Filter With 25 psi Drop at 40 gpm
- Three Reservoir Level Sensing Circuits With 100 psi Drop at 15 gpm
- Trapped Bootstrap Reservoir With Constant Pressure of 100 psi
- Heat Exchanger Pressure Drop of 10 psi at 4.5 gpm
- Heat Exchanger Relief Valve Cracking Pressure of 15 psid

Figure 12. Sizing Assumptions  
PC-1 Central System

Leg No.	Line Size	Line Length	Flow Rate	Pressure	
				Upstream	Downstream
1	-11	46	18.95	7,879.70	7,804.91
2	-16	5	22.05	99.78	97.23
3	-6	46	3.10	150.77	132.54
4	-11	1	0.00	7,804.91	7,804.91
5	-11	14	18.95	7,804.91	7,770.39
6	-7	2	6.70	7,770.39	7,747.58
7	-7	2	8.56	7,770.39	7,733.52
8	-7	2	3.69	7,770.39	7,763.29
16	-16	15	5.28	100.00	99.78
17	-16	75	5.26	116.95	100.00
18	-16	10	22.02	117.72	116.95
19	-16	5	0.00	140.20	117.72
20	-16	6	0.00	140.21	140.20
21	-16	2	18.93	140.21	132.54
22	-16	29	18.93	141.28	140.21
23	-6	2	3.69	158.19	141.28
24	-6	2	10.22	252.25	141.28
26	-6	2	5.02	171.09	141.28
32	-16	1	0.00	140.20	140.20
33	-16	2	22.02	132.54	117.72
34	-16	4	16.77	116.95	99.78

Figure 13. Sizing Summary  
PC-1 Central System

b. Left Hand Flight Controls - The L/H flight control actuation SSFAN model is shown schematically in Figure 14, and the assumptions used to size the L/H system are shown in Figure 15. The results of optimizing the line sizes for each leg are shown in Figure 16. A summary of flow demand, pressure distribution, main ram rate, actuator interface fitting size and load for each servoactuator is presented in Figure 17.

c. PC-2 Central System - The PC-2 central system model is shown schematically in Figure 18, and the assumptions used to size the PC-2 system are shown in Figure 19. The results of optimizing the line sizes for each leg are presented in Figure 20.

d. Right Hand Flight Controls - The R/H flight control actuation system SSFAN model schematic is illustrated in Figure 21, and the assumptions used to size the system are shown in Figure 22. The line size optimization results for each leg are shown in Figure 23. The flight control actuator characteristic summary chart is presented in Figure 17.

e. Utility Central System - The utility central system model schematic is shown in Figure 24. The assumptions used to size the tubing in the Utility Central System are listed in Figure 25. The SSFAN leg description results for the Utility Central System are shown in Figure 26 for each leg number.

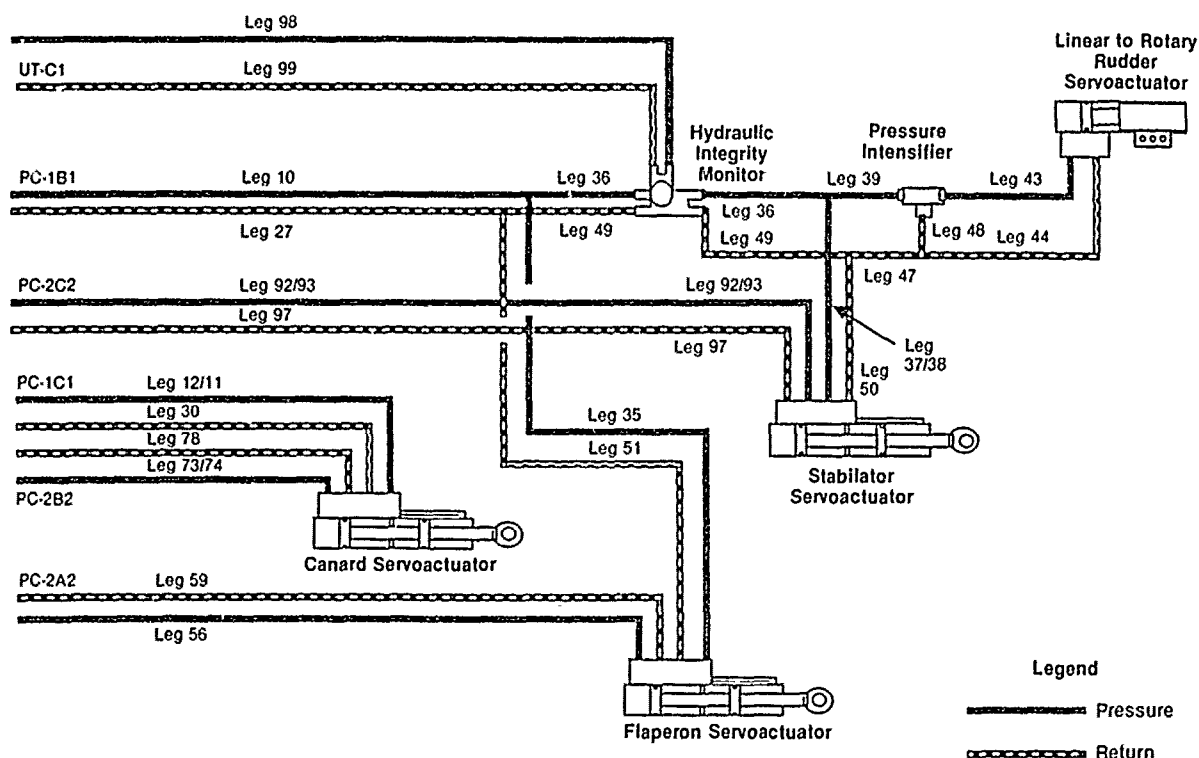


Figure 14. SSFAN Schematic  
Left Hand Flight Controls

- Moog Flaperon Servoactuator With 400 psi Drop at 1.21 gpm
- HR Textron Rudder Actuator With 400 psi Drop at 0.93 gpm
- E-Systems Stabilator Servoactuator With 400 psi Drop at 5.6 gpm
- HR Textron Canard Servoactuator With 400 psi Drop at 5.6 gpm
- Parker Hydraulic Integrity Monitor (HIM) Valve With 350 psi Drop at 10 gpm
- Canard and Stabilator Jet Pumps With Nozzle Area of 0.00132, and an Area Ratio of 0.3
- Sized for Maximum No-Load Rate:
  - Flaperon Extending - 3.33 in./sec
  - Canard Retracting - 8.2 in./sec
  - Stabilator Extending - 8.2 in./sec
  - Rudder Extending - 1.6 in./sec (105 deg/sec)

Figure 15. Sizing Assumptions  
Left Hand Flight Controls

Leg No.	Line Size	Line Length	Flow Rate	Pressure	
				Upstream	Downstream
10	-7	6	5.19	7,733.52	7,730.97
11	-5, -9	150, 25	3.51	7,747.58	7,632.00
12	-9	0.1	3.51	7,632.00	176.48*
27	-4	6	5.19	291.63	252.25
30	-6, -4	150, 25	3.51	248.19	171.09
35	-3	188	1.06	7,730.97	1,742.91
36	-5	260	4.13	7,730.97	7,416.55
37	-9	25	3.37	7,416.55	7,411.71
38	-9	0.1	3.37	7,411.71	533.99*
39	-3	2	0.77	7,416.55	4,159.43
43	-3	20	0.77	4,153.27	4,140.56
44	-4	20	0.77	3,688.64	3,686.27
47	-5	3	0.77	3,686.27	490.79
48	-4	0.1	0.00	3,686.27	3,686.27
49	-6, -4	195, 65	4.13	490.79	291.63
50	-4	25	3.37	540.93	490.79
51	-4	188	1.06	1,703.2	291.63
56	-3	299	1.76	7,740.81	2,080.20
59	-4	299	1.07	1,204.23	151.16
73	-9	25	3.34	7,562.12	803.30*
74	-7, -5	75, 183	3.34	7,697.33	7,562.12
78	-4	283	4.99	890.78	275.30
92	-9	0.1	2.88	7,520.79	2,481.89*
93	-5, -9	328, 25	2.88	7,694.28	7,520.79
97	-4	353	1.22	2,500.72	203.55
98	-5	100	0.00	7,433.32	7,433.32
99	-4, -6	65, 35	0.00	350.69	350.69

\*The jet pump contributes to this pressure drop

Figure 16. Sizing Summary  
Left Hand Flight Controls

Component	Pump Output Flow Demand (gpm)		Pressure Distribution (psi)				Rate (in./sec)	Fitting Size		Load (lb)
	Sys 1	Sys 2	P1	R1	P2	R2		Press	Return	
R/H Aileron	3.17	2.42	4,911	975	5,227	1,492	3.8 Ext	-3	-4	0
L/H Flaperon	1.76	1.06	1,464	1,363	1,963	1,479	3.4 Ext	-3	-4	0
R/H Flaperon Sim	1.22	1.27	2,580	1,765	2,791	1,910	N/A	-3	-4	N/A
L/H Rudder	0.77	—	3,931	3,913	—	—	105 deg/s	-3	-4	0
R/H Rudder	1.40	—	3,899	3,899	—	—	105 deg/s	-3	-4	0
L/H Canard	3.34	3.51	1,787	1,782	1,587	792	8.2 Ret	-9	-4	0
R/H Canard	3.36	3.45	1,800	1,714	1,604	910	8.2 Ret	-9	-4	0
L/H Stabilator	2.88	3.37	2,819	1,396	2,037	860	8.3 Ext	-9	-4	0
R/H Stabilator	3.20	3.30	1,537	674	1,965	1,011	8.4 Ext	-9	-4	0

Figure 17. Operation Summary for Flight Control Actuators



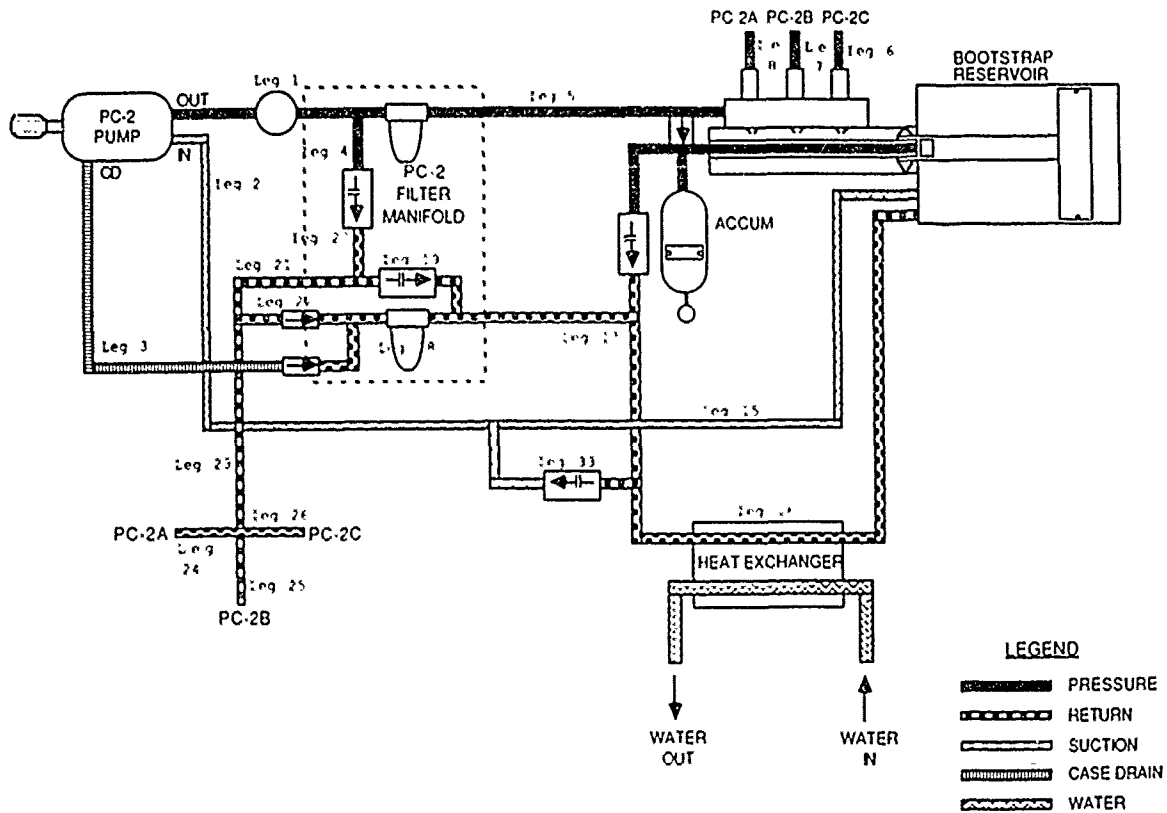


Figure 18. SSFAN Schematic  
PC-2 Central System

- One 40 gpm Pump With 2.5 gpm Case Drain Flow (Pump Compensated)
- Pulsation Attenuators With 80 psi Drop at 40 gpm
- 5-Micron High Pressure Filter With 25 psi Drop at 40 gpm
- 5-Micron Return Filter With 25 psi Drop at 40 gpm
- Three Reservoir Level Sensing Circuits With 100 psi Drop at 15 gpm
- Trapped Bootstrap Reservoir With Constant Pressure of 100 psi
- Heat Exchanger Pressure Drop of 10 psi at 4.5 gpm
- Heat Exchanger Relief Valve Cracking Pressure of 15 psid

Figure 19. Sizing Assumptions  
PC-2 Central System

Leg No.	Line Size	Line Length	Flow Rate	Pressure	
				Upstream	Downstream
1	-11	46	20.60	7,872.25	7,784.60
2	-16	5	23.58	99.71	94.46
3	-6	46	2.98	149.50	132.49
4	-11	1	0.00	7,784.60	7,784.60
5	-11	14	20.60	7,784.60	7,744.36
6	-7	2	9.50	7,744.36	7,699.11
7	-7	2	9.29	7,744.36	7,701.07
8	-7	2	1.81	7,744.36	7,742.54
15	-16	15	6.79	100.00	99.71
16	-16	75	5.24	116.88	100.00
17	-16	10	22.04	117.65	116.88
18	-16	2	22.04	132.49	117.65
19	-16	5	0.00	140.18	117.65
20	-15	1	0.00	140.18	140.18
21	-16	6	0.00	140.19	140.18
22	-16	2	19.05	140.19	132.49
23	-16	29	19.05	144.47	140.19
24	-6	2	1.12	150.30	144.47
25	-6	2	10.94	270.49	144.47
26	-6	2	6.99	199.38	144.47
33	-16	4	16.79	116.88	99.71

Figure 20. Sizing Summary  
PC-2 Central System

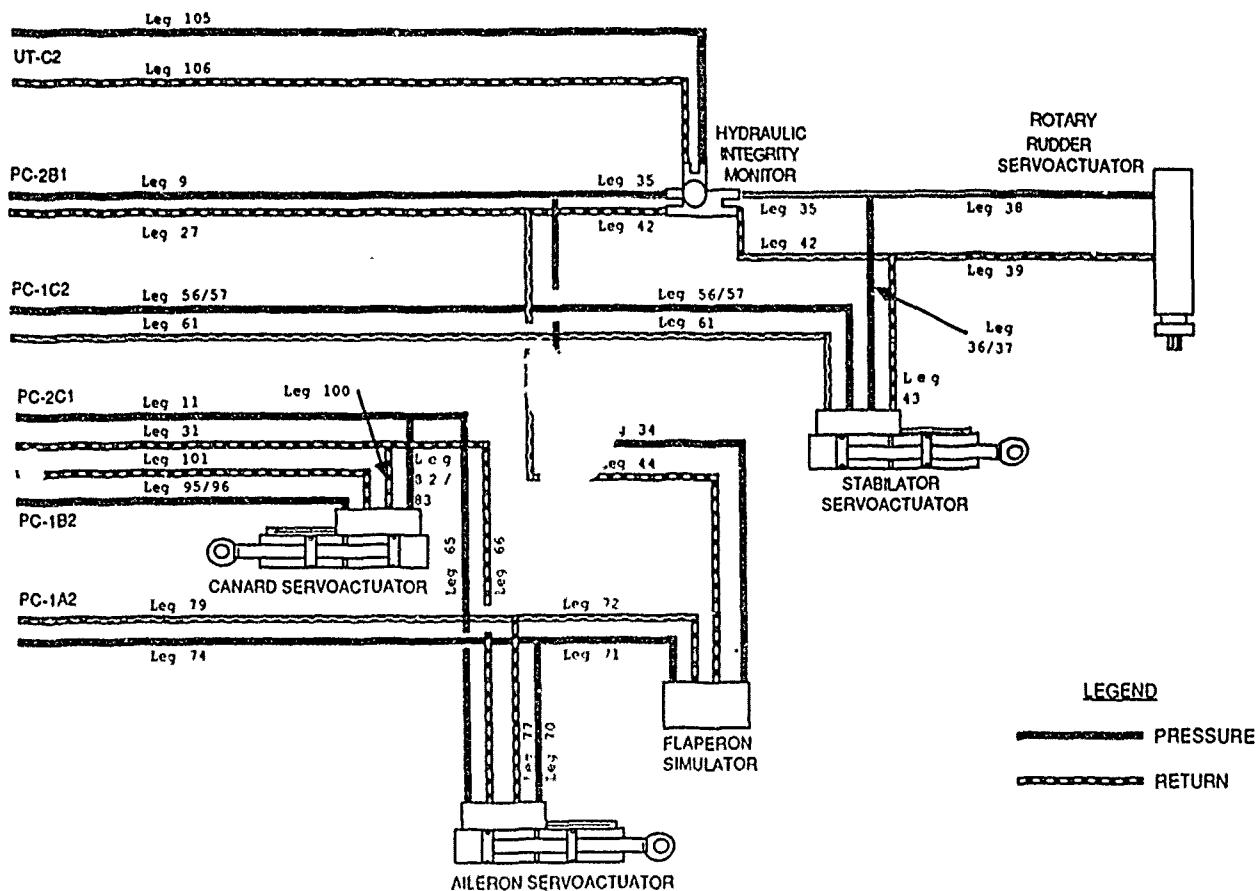


Figure 21. SSFAN Schematic  
Right Hand Flight Controls

- Moog Flaperon Servoactuator With 500 psi Drop at 1.31 gpm
- Bendix Rotary Rudder Actuator, Modelled as a Simple Linear Actuator, With 400 psi Drop at 1.54 gpm
- E-Systems Stabilator Servoactuator With 400 psi Drop at 5.6 gpm
- HR Textron Canard Servoactuator With 400 psi Drop at 5.6 gpm
- Parker Hydraulic Integrity Monitor (HIM) Valve With 350 psi Drop at 10 gpm
- Canard and Stabilator Jet Pumps With Nozzle Area of 0.00132, and an Area Ratio of 0.3
- Sized for Maximum No-Load Rate:
  - Flaperon Extending - 3.33 in./sec
  - Canard Retracting - 8.2 in./sec
  - Stabilator Extending - 8.2 in./sec
  - Rudder Extending - 1.6 in./sec (105 deg/sec)
  - Aileron Extending - 3.33 in./sec

Figure 22. Sizing Assumptions  
Right Hand Flight Controls

Leg No.	Line Size	Line Length	Flow Rate	Pressure	
				Upstream	Downstream
9	-7	6	5.96	7,701.07	7,697.04
11	-5	6	6.62	7,699.11	7,676.62
27	-4	6	5.56	321.50	270.49
31	-6	8	5.77	204.42	199.38
34	-3	79	1.27	7,697.04	2,790.74
35	-5	273	4.69	7,697.04	7,286.77
36	-9	25	3.30	7,286.77	7,282.11
37	-9	0.1	3.30	7,282.11	687.16*
38	-3	16	1.40	7,286.77	4,197.05
39	-4	16	1.40	3,609.53	576.11
42	-6	273	4.69	576.11	321.50
43	-4	25	3.30	694.41	576.11
44	-4	79	1.27	1,910.31	321.50
56	-9	0.1	3.20	7,532.91	1,316.51*
61	-4	364	1.52	1,333.43	171.91
65	-3	137	3.17	7,676.62	3,048.71
66	-4	137	2.32	3,818.13	204.42
70	-3	194	2.41	7,175.73	6,342.27
71	-3	134	1.22	7,175.73	2,579.60
72	-4	134	1.22	1,765.36	287.37
74	-3	60	3.63	7,733.59	7,175.73
77	-4	194	2.41	400.49	287.37
79	-4	60	3.63	287.37	158.57
82	-5, -9	155, 25	3.45	7,676.62	7,562.04
83	-9	0.1	3.45	7,562.04	326.41
95	-9	0.1	3.36	7,610.47	742.93*
96	-7, -5, -9	100, 151, 25	3.36	7,732.55	7,610.47*
100	-4	180	3.45	401.91	20.42
101	-4	276	5.02	826.23	254.92
105	-5	100	0.00	7,423.44	7,423.44
106	-4, -6	63, 65	0.00	350.69	350.69

\*The jet pump contributes to this pressure drop

Figure 23. Sizing Summary  
Right Hand Flight Controls

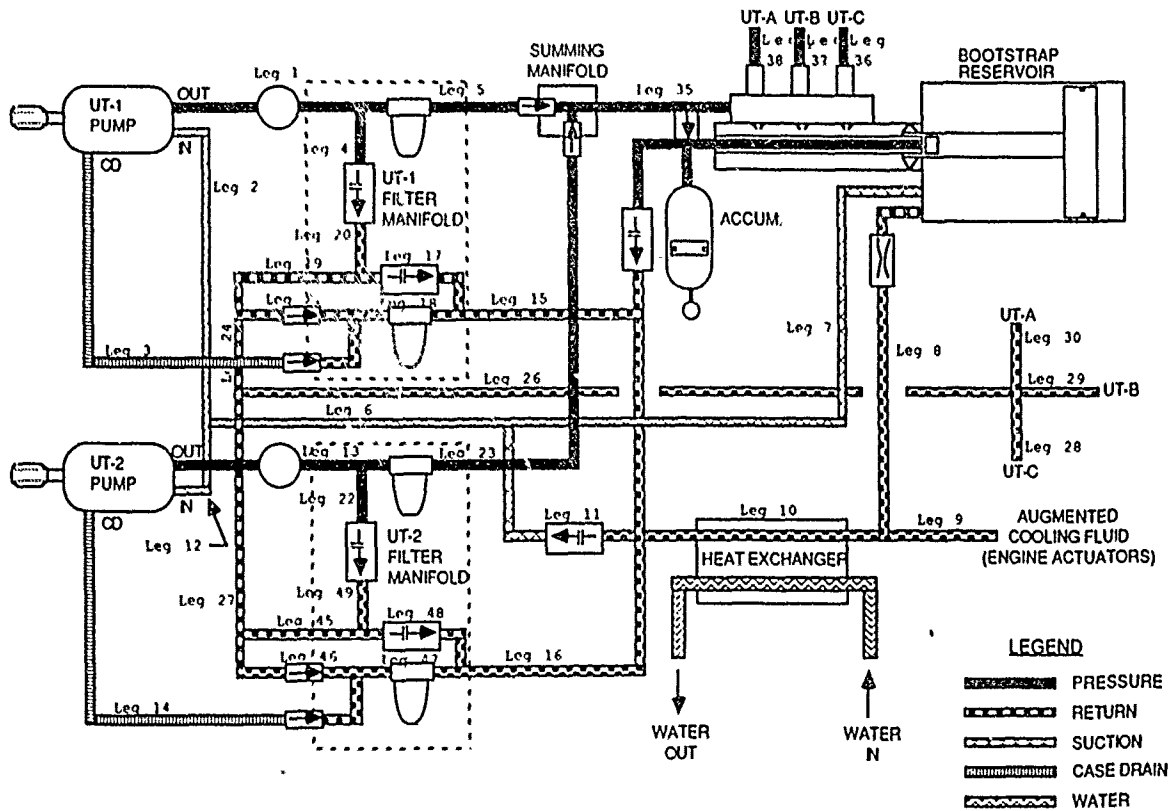


Figure 24. SSFAN Schematic  
Utility Central System

- One 40 gpm Pump With 2.0 gpm Case Drain: Flow (Pump Compensated)
- Pulsation Attenuators With 40 psi Drop at 40 gpm
- 5 Micron High Pressure Filter With 155 psi Drop at 40 gpm
- 5 Micron-Return Filter With 76 psi Drop at 40 gpm
- Two Reservoir Level Sensing Circuits With 75 psi Drop at 15 gpm and the Engine Nozzle Circuits With 200 psi at 30 gpm
- Constant Bootstrap Reservoir Pressure of 100 psi
- Heat Exchanger Pressure Drop of 10 psi at 4.5 gpm
- Constant Augmented Cooling Flow of 1.8 gpm
- Heat Exchanger Relief Valve Cracking Pressure of 100 psid
- Augmented Cooling Reservoir Restrictor With 50 psi Drop at 2 gpm
- Utility System Sized With Worst Case Engine Nozzle Actuator Flows
  - Engine Nozzle Actuators: 53.6 gpm Pressure, 49.7 gpm Return
    - All Convergent Flaps Extending - 7.2 in./sec
    - Two Divergent Flaps Extending, and Two Retracting - 11.8 in./sec
    - All Reverser Vanes Dormant
- 0.15 gpm Leakage to Utility Functions

Figure 25. Sizing Assumptions  
Utility Central System

Leg No.	Line Size	Line Length	Flow Rate	Pressure	
				Upstream	Downstream
1	-11	46	26.98	7,927.95	7,781.36
2	-16	48	30.17	92.92	86.23
3	-6	81	3.19	295.40	271.73
4	-11	1	0.00	7,781.36	7,781.36
5	-11	17	26.92	7,781.36	7,659.11
6	-6	24	20.21	99.72	92.92
7	-16	1	0.00	100.00	99.72
8	16	1	0.00	100.00	100.00
9	12	1	1.00	220.63	220.63
10	.6	80	5.00	242.51	226.49
11	.6	7	53.32	242.51	99.72
12	16	86	30.12	32.92	86.25
13	.	46	26.92	7,927.72	7,780.87
14	-6	123	3.20	295.04	271.74
15	-16	12	29.19	243.82	242.51
16	-16	12	29.19	243.82	242.51
17	-16	5	0.00	243.82	284.37
18	-16	2	29.19	271.73	243.82
19	-16	6	0.00	284.37	284.38
20	-16	1	0.00	284.37	284.37
21	-16	2	26.00	284.38	271.73
22	-11	1	0.00	7,780.87	7,780.87
23	-11	17	26.92	7,780.87	7,659.11
24	-16	10	26.00	285.38	284.38
26	-16	29	50.00	290.96	285.38
27	-16	10	26.00	285.38	284.38
28	-8	1	49.70	350.69	290.96
29	-8	1	0.15	296.06	290.96
30	-6	1	0.15	296.06	290.96
35	-11	26	53.90	7,659.11	7,610.21
36	-11	2	53.60	7,610.21	7,433.32
37	-7	1	0.15	7,610.21	7,610.08
38	-7	1	0.15	7,610.21	7,610.06
45	-16	6	0.00	284.38	284.38
46	-16	2	26.00	284.38	271.74
47	-16	2	29.19	271.74	243.82
48	-16	5	0.00	243.82	284.38
49	-16	1	0.00	284.38	284.38

Figure 26. Sizing Summary  
Utility Central System

f. Engine Nozzle Actuation - The engine nozzle actuation system schematic for the SSFAN model is shown in Figure 27. The assumptions used for sizing are illustrated in Figure 28, and the flow leg optimization data for

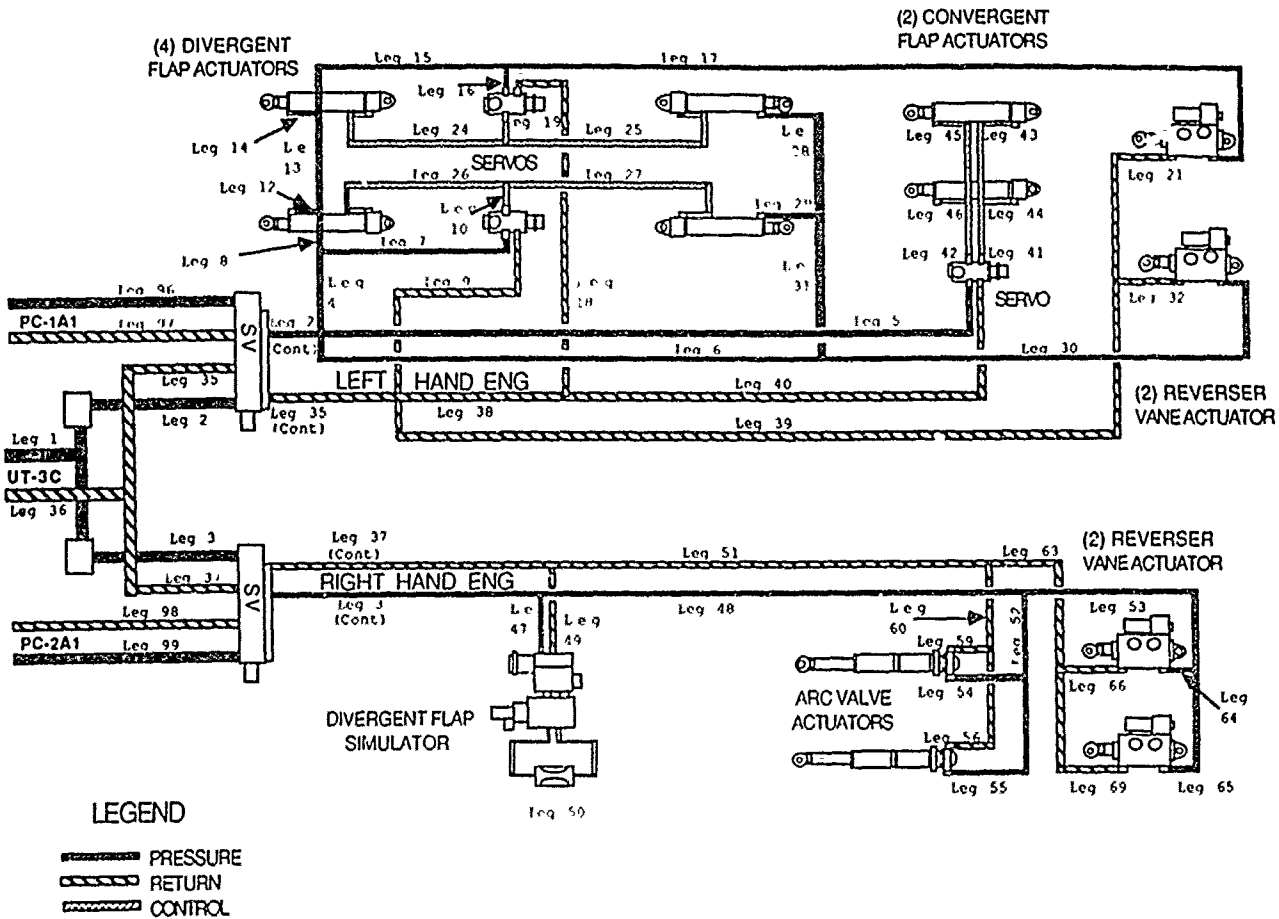


Figure 27. SSFAN Schematic Engine Nozzle System

- 7,300 psi Available From Utility Central System
- Two Moog Divergent Flap Servo Valves With 250 psi Drop at 12.8 gpm
- Convergent Flap Servo Valve(Moog) With 1,000 psi Drop at 14.8 gpm
- Shuttle Valves With 150 psi Pressure and 200 psi Return Drop at 24 gpm
- Reverser Vane Servo With 1,000 psi Drop at 3 gpm
- Arc Valve Servos With 1,000 psi Drop at 6.21 gpm
- Rate Limited Actuators Sized at 2/3 Load
- Arc Valve Actuators Sized at No-Load Rate
- Sized for Worst Case Flow Situation:
  - Two Divergent Flaps Extending -11.8in./sec
  - Two Divergent Flaps Retracting - 11.8 in./sec
  - Both Convergent Flaps Extending - 11.8 in./sec
  - Arc Valve Actuators Extending - 7.5 in./sec
  - All Reverser Vanes Dormant

Figure 28. Sizing Assumptions Engine Nozzle System

the engine nozzle actuation system is listed in Figure 29. A summary of the engine nozzle actuator operation is provided in Figure 30. The reverser vane actuator was not operating in this system because a logical evaluation of the thrust vector controls showed simultaneous operation of the convergent and divergent actuators only. The reverser vane actuator was operated independently to verify proper operation in the system.

g. Utility Functions - The left and right hand utility functions were modeled using SSFAN and are shown schematically in Figures 31 and 32 respectively. Figure 33 shows the assumptions used in building the model for both the utility functions. The L/H utility function line optimization is summarized in Figure 34 while the R/H side is described in Figure 35. A summary of the logical maximum operation of the utility functions and their effect on the system is presented in Figure 36 for both the left and right hand systems.

3.3.4 HYTRAN Analysis - Hydraulic transient analysis was performed to scrutinize the dynamic operation of the hydraulic system. Two critical areas in this system were identified and analyzed. These were the supply lines (inlet) to the stabilator and canard servoactuators, and the inlet (suction lines) to the pumps.

a. Stabilator/Canard Analysis - The stabilator and canard inlet pressures and flows were evaluated to verify that system pressure limits were not being exceeded. Figure 37 shows the HYTRAN schematic used to evaluate the water hammer transients upstream of these servoactuators. It also shows the valve and main ram positions during the one second computer simulation. It is important to note that a 0.050 second valve reversal was used to analyze the resultant water hammer transient. Without the local velocity reduction technique, the fluid velocity upstream of the stabilator/canard exceeded the maximum allowable pressure criteria of 8800 psi during no-load maximum rate conditions. (Increasing the line size upstream of the servocylinders to 9/16 in O.D. reduced the fluid velocity from 24 ft/sec to 14 ft/sec and the associated peak transient pressure from 8940 to 8340 psi.)

b. Central System Simulation Schematic - Since each pump and the associated plumbing and peripheral hardware was identical, only one installation was evaluated. The HYTRAN schematic for this pumping system is illustrated in Figure 38. The pump outlet flow travels through a series of simulated components prior to arriving at a simplex actuator which is sized to represent the worst case flow transient conditions reflected to the pump. These components are the 5-micron filter package with a check valve and two restrictors. These restrictors simulated the pressure drop between the pump and the filter package, and between the filter package and the simplex actuator through the reservoir level sensing (RLS) valving. The return flow comes from the simplex actuator through a restrictor, which represents the pressure drop between the actuator and the return central system flow, then goes through a return check valve summed to case drain flow, through another 5-micron filter and on to the heat exchanger. At this point, the flow goes through the heat exchanger (shown as a restrictor), through the reservoir, and to the pump inlet port. The heat exchanger relief valve bypasses flow around the heat exchanger and reservoir, when the pressure drop across it exceeds 15 psid.



Leg No.	Line Size	Line Length	Flow Rate	Pressure	
				Upstream	Downstream
1	-11	2	53.39	7,407.00	7,400.12
2	-11, -7	200, 10	28.88	7,400.12	6,933.97
3	-11, -7	200, 10	24.51	7,400.12	7,057.76
4	-7	9	13.05	6,933.97	6,917.13
5	-7	25	14.73	6,933.97	6,883.73
6	-5	36	1.11	6,933.97	6,930.26
7	-5	25	0.08	6,917.13	6,916.99
8	-7	6	12.96	6,917.13	6,904.89
9	-4	16	14.48	1,198.76	907.41
10	-5	0.1	14.39	1,467.61	1,454.80
12	-5	24	4.75	6,904.89	6,857.89
13	-7	17	8.21	6,904.89	6,892.10
14	-5	23	4.47	6,926.37	6,892.10
15	-7	8	12.68	6,892.10	6,877.50
16	-5	14	12.59	6,877.50	6,768.62
17	-3	14	0.09	6,877.50	6,876.14
18	-4	29	0.09	922.92	922.77
19	-5	0.1	12.51	6,575.25	6,564.27
21	-4	39	0.09	907.76	907.58
24	-5	36	6.47	6,564.27	6,456.92
25	-5	36	6.03	6,564.27	6,469.80
26	-5	42	6.88	1,576.90	1,467.61
27	-5	42	7.51	1,595.23	1,467.61
28	-7	27	4.17	6,945.03	6,929.58
29	-5	17	5.18	6,929.58	6,884.43
30	-3	32	0.09	6,930.26	6,928.64
31	-5	5	1.02	6,930.26	6,929.58
32	-4	31	0.09	907.74	907.58
35	-10, -6	200, 10	26.56	907.41	424.51
36	-10	2	49.71	424.51	349.00
37	-10, -6	200, 10	23.16	795.24	424.51
38	-6	5	11.91	922.77	907.41
39	-6	38	0.17	907.58	907.41
40	-6	12	11.82	945.86	922.77
41	-7	0.1	14.65	6,088.02	6,073.70
42	-7	0.1	11.74	1,465.90	1,456.90
43	-7	63	7.32	6,073.70	5,981.59
44	-7	55	7.33	6,073.70	5,985.47
45	-7	41	5.86	1,505.26	1,465.90
46	-7	55	5.88	1,510.11	1,465.90
47	-7	13	17.82	7,057.76	7,018.36
48	-5	10	6.69	7,057.76	7,030.62
49	-6	13	17.82	845.97	795.24
50	-5	136	17.73	6,203.39	1,660.93
51	-6	10	5.34	800.23	795.24
52	-3	27	6.51	7,030.62	1,650.65
53	-5	10	0.18	7,030.62	7,028.20
54	-3	22	3.25	1,650.65	1,480.94
55	-3	22	3.26	1,650.65	1,480.70
56	-4	32	2.58	972.74	920.10
59	-4	34	2.58	974.08	920.10
60	-4	20	5.16	920.10	800.23
63	-6	10	0.18	800.34	800.23
64	-3	23	0.09	7,028.20	7,027.78
65	-3	23	0.09	7,028.20	7,027.77
66	-3	23	0.09	800.55	800.34
69	-3	23	0.09	800.56	800.34
96	-7	250	0.00	7,763.29	7,763.19
97	-6	250	0.00	158.29	158.19
98	-6	153	0.00	150.40	150.30
99	-7	153	0.00	7,742.54	7,742.44

Figure 29. Sizing Summary  
Engine Nozzle System

Component	Pump Output Flow Demand (gpm)	Pressure Distribution		Rate (In./sec)	Fitting Size		Load (lbf)
		P1 (psi)	R1 (psi)		Press	Return	
<b>L/H Side:</b>							
Divergent Flap, Top Left	2.00	6,926	6,457	11.8 Ext	-5	-5	3,400
Divergent Flap Bottom Left	4.75	6,358	1,577	11.8 Ret	-5	-5	6,400
Divergent Flap, Top Right	1.87	6,945	6,470	11.8 Ext	-5	-5	3,400
Divergent Flap, Bottom Right	5.18	6,884	1,595	11.8 Ret	-5	-5	6,400
Convergent Flap, Left	7.32	5,982	1,505	7.2 Ext	-5	-5	18,500
Convergent Flap, Right	7.33	5,985	1,510	7.2 Ext	-5	-5	18,500
Reverser Vane, Top		Actuator Not Operating			-3	-4	0
Reverser Vane, Bottom		Actuator Not Operating			-3	-4	0
<b>R/H Side:</b>							
Divergent Flap Simulator	17.73	6,203	1,661	N/A	-5	-5	N/A
Arc Valve Actuator, Left	3.25	1,177	1,113	7.5 Ext	-3	-4	0
Arc Valve Actuator, Right	3.26	1,178	1,114	7.5 Ext	-3	-4	0
Reverser Vane, Top		Actuator Not Operating			-3	-4	0
Reverser Vane, Bottom		Actuator Not Operating			-3	-4	0

Figure 30. Operation Summary for Engine Nozzle Actuators

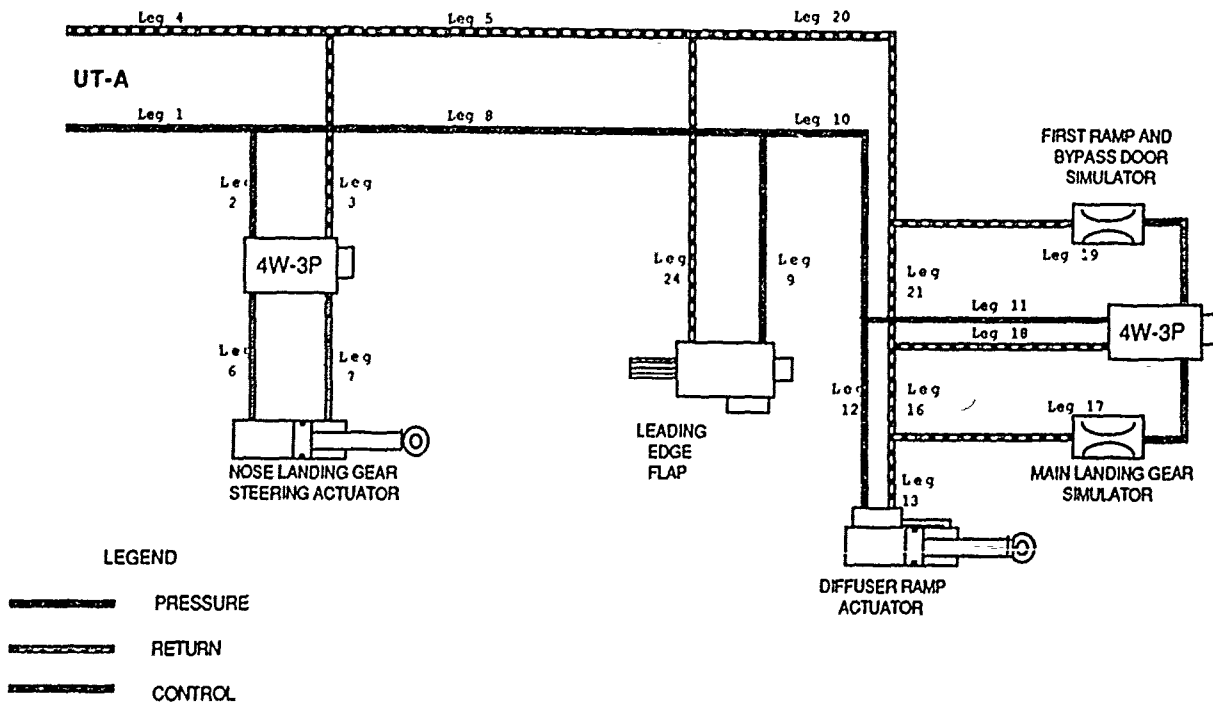


Figure 31. SSFAN Schematic Left Hand Utility Functions

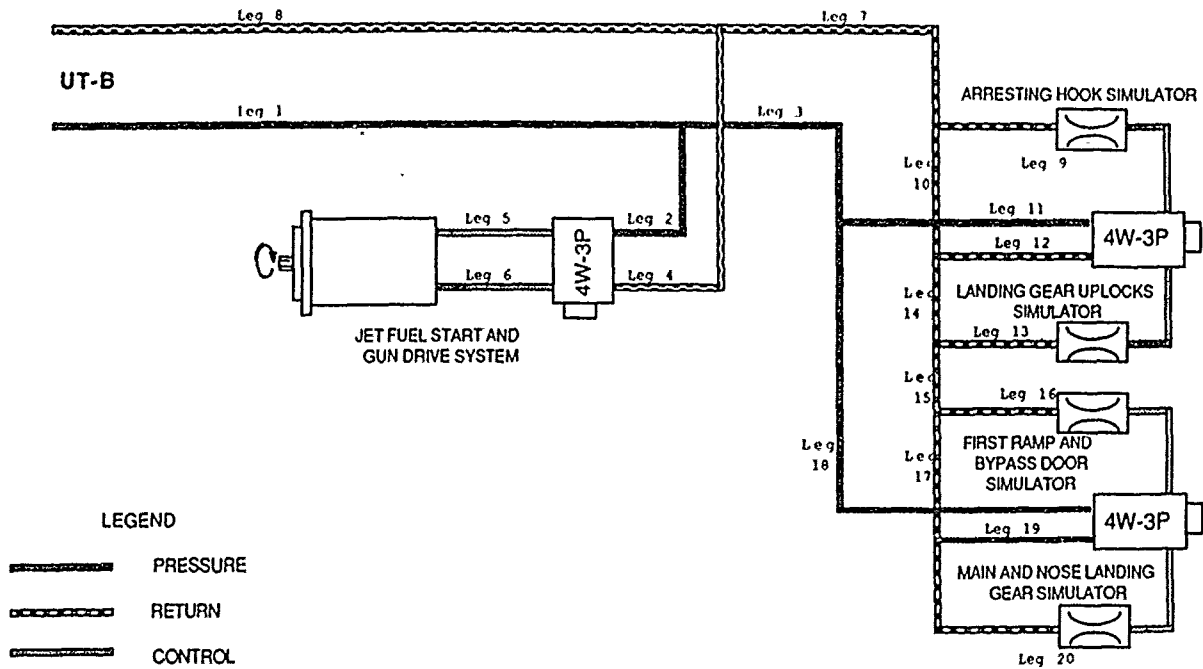


Figure 32. SSFAN Schematic  
Right Hand Utility Functions

- Diffuser Ramp Servoactuator 400 psi Drop at 0.44 gpm
- Simulator and Nose Gear Steering 4 Way Valves With 250 psi Drop at 10.0 gpm
- Gun Drive/Jet Fuel Start Motor With 3,000 psi Drop at 433 gpm
- Leading Edge Flap Actuator With 3,000 psi at 1.95 gpm
- Sized for the Following Condition:
  - Diffuser Ramp Actuator Extending at 0.5 in./s at 22,000 lb Load
  - Gun Drive/JFS Start Motor Turning at 6,600 rpm
  - L/H and R/H First Ramp and Bypass Door Simulator With 10.6 gpm
  - Engine Nozzle Actuator System Dormant With 1.0 gpm Leakage
  - All Other Simulators Inactive

Figure 33. Sizing Assumptions  
Utility Functions

Leg No.	Line Size	Line Length	Flow Rate	Pressure	
				Upstream	Downstream
1	-7	50	11.45	7,812.00	7,750.33
2	-5	230	0.10	7,750.33	7,749.62
3	-6	230	0.10	258.45	258.27
4	-8	50	11.24	258.27	243.00
5	-8	22	11.14	267.10	258.27
6	-3	4.3	0.00	7,749.61	2,754.85
7	-3	5.25	0.00	258.46	5,253.22
8	-7	22	11.34	7,750.33	7,721.62
9	-7	200	0.11	7,721.62	7,721.43
10	-7	25	11.23	7,721.62	7,689.93
11	-5	5	10.72	7,689.93	7,652.89
12	-3	300	0.52	7,689.93	7,171.08
13	-4	300	0.31	987.86	276.77
16	-8	1	0.31	276.77	276.67
17	-5, -4	4, 4	0.00	276.81	276.77
18	-6	4	0.11	276.77	276.67
19	-5, -4	4, 1	10.61	7,424.27	276.56
20	-8	25	11.03	276.56	267.10
21	-8	1	0.42	276.67	276.56
24	-8	200	0.00	4,067.14	4,067.12

Figure 34. Sizing Summary  
Left Hand Utility Functions

Leg No.	Line Size	Line Length	Flow Rate	Pressure	
				Upstream	Downstream
1	-7	25	18.68	7,812.00	7,737.37
2	-5	70	7.76	7,737.37	5,485.90
3	-7	51	10.92	7,737.37	7,678.47
4	-6	70	7.76	309.05	267.26
5	-5	2	7.68	5,485.03	5,434.39
6	-5	2	7.68	339.68	309.92
7	-8	50	10.92	282.86	267.26
8	-8	25	18.68	267.26	243.00
9	-5, -4	1, 4	0.00	282.97	282.86
10	-8	5	10.92	287.12	282.86
11	-7	10	0.11	7,678.47	7,678.37
12	-8	1	0.11	287.22	287.12
13	-5, -4	1, 4	0.00	291.29	291.29
14	-8	5	10.82	291.29	287.12
15	-8	5	10.82	295.47	291.29
16	-5, -4	4, 1	10.71	7,437.50	295.47
17	-8	1	0.11	295.57	295.47
18	-7	5	10.82	7,678.47	7,670.52
19	-6	4	0.11	295.67	295.57
20	-5, -4	4, 1	0.00	295.62	295.57

Figure 35. Sizing Summary  
Right Hand Utility Functions

Component	Pump Output Flow Demand (gpm)	Pressure Distribution		Rate (in./sec)	Fitting Size		Load (lbf)
		P1 (psi)	R1 (psi)		Press	Return	
<b>L/H Side:</b>							
Diffuser Ramp	0.5	7,031	985	0.49 Ext	-3	-4	20,000
First Ramp and Bypass Door Sim	10.6	7,424	277	N/A	-5	-4	N/A
Nose Landing Gear Steering		Actuator Not Operating			-3	-3	0
Leading Edge Flap		Actuator Not Operating			-7	-8	0
Main Landing Gear Simulator		Simulator Not Operating			-5	-4	N/A
<b>R/H Side:</b>							
Gun Drive/Jet Fuel Start Motor	7.7	5,434	340	6,600 rpm	-5	-5	N/A
First Ramp and Bypass Door Sim	10.7	7,438	295	N/A	-5	-4	N/A
Arresting Hook Simulator		Simulator Not Operating			-5	-4	N/A
Landing Gear Uplocks Simulator		Simulator Not Operating			-5	-4	N/A
Main and Nose Landing Gear Sim		Simulator Not Operating			-5	-4	N/A

Figure 36. Operation Summary for Utility Functions

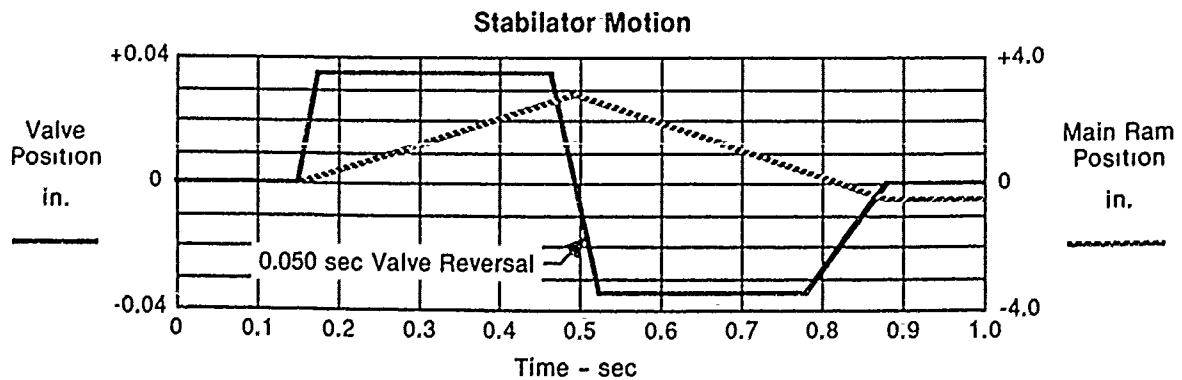
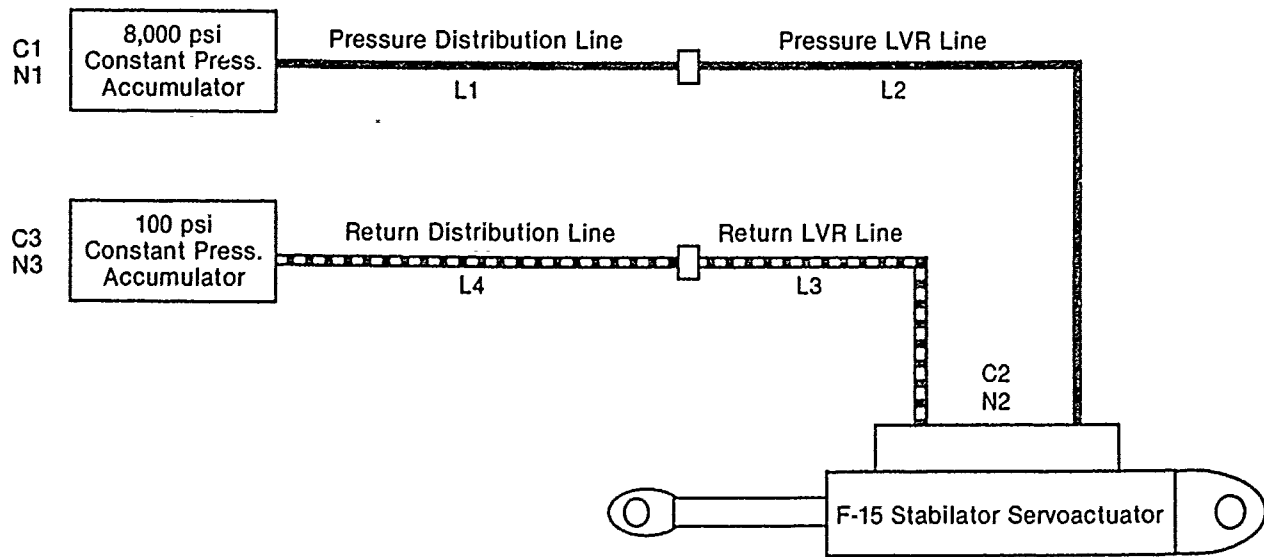


Figure 37. HYTRAN Schematic Stabilator/Canard

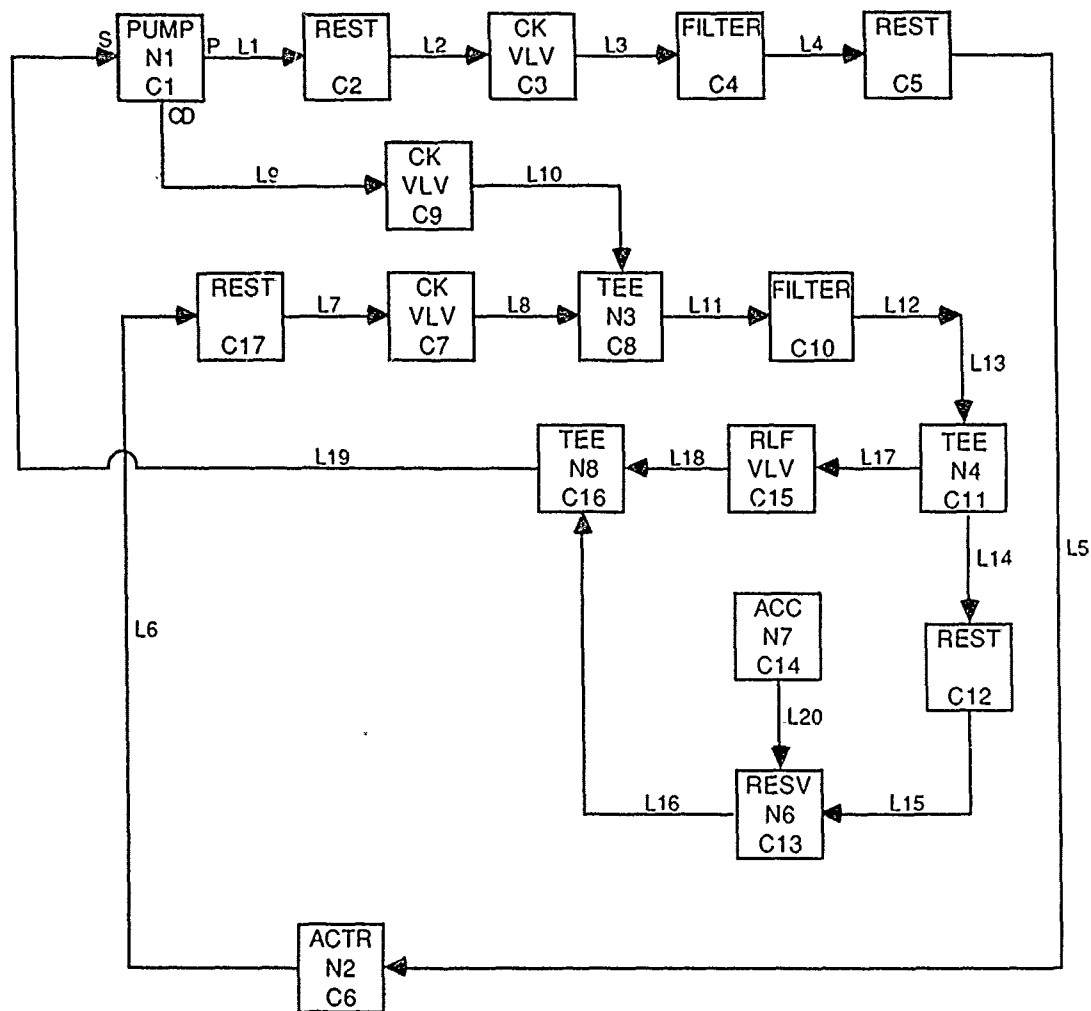


Figure 38. HYTRAN Schematic  
Central System

c. Central System Simulation Results - During the system flow demand of 20 gpm (77 cubic inches per second), the pump outlet pressure undershoots (drops) to 4400 psi (ref. Figures 39 & 40). The corresponding pressure at the actuators is transient at 2000 psi and steady state at 2800 psi during the actuator no-load rate as shown in Figure 41. The pump case drain flow is normally about 2 gpm (7.7 cis), as presented in Figure 42, but system transients cause significant flow fluctuations. Figure 43 shows the case drain pressure from these transients could be as high as 325 psi, which is still below the pump case proof pressure of 500 psi. The pump suction flow, Figure 44, was approximately 83 cis consisting of 44 cis across the relief valve through the reservoir and 39 cis through the heat exchanger as shown in Figures 45 and 46, respectively. Figure 47 illustrates that the pump suction pressure drops to 75 psi during the worst case flow transient. This pressure level is more than adequate to assure proper pump performance and ensure that pump cavitation does not occur.

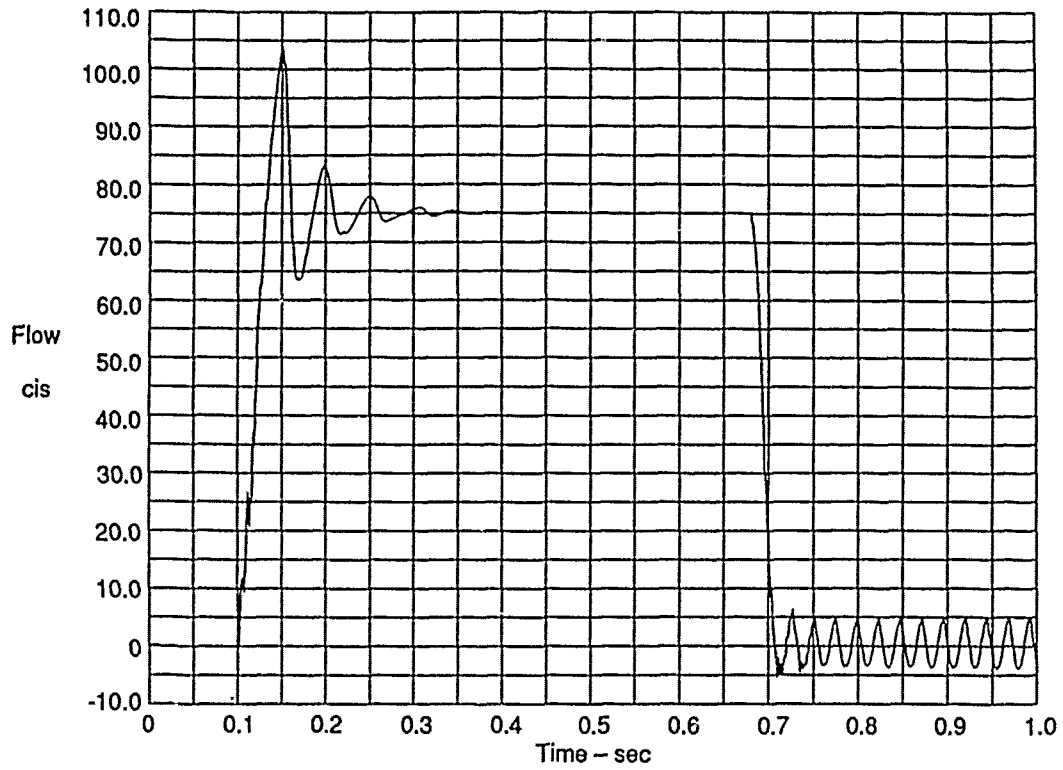


Figure 39. System Flow Demand for HYTRAN Analysis

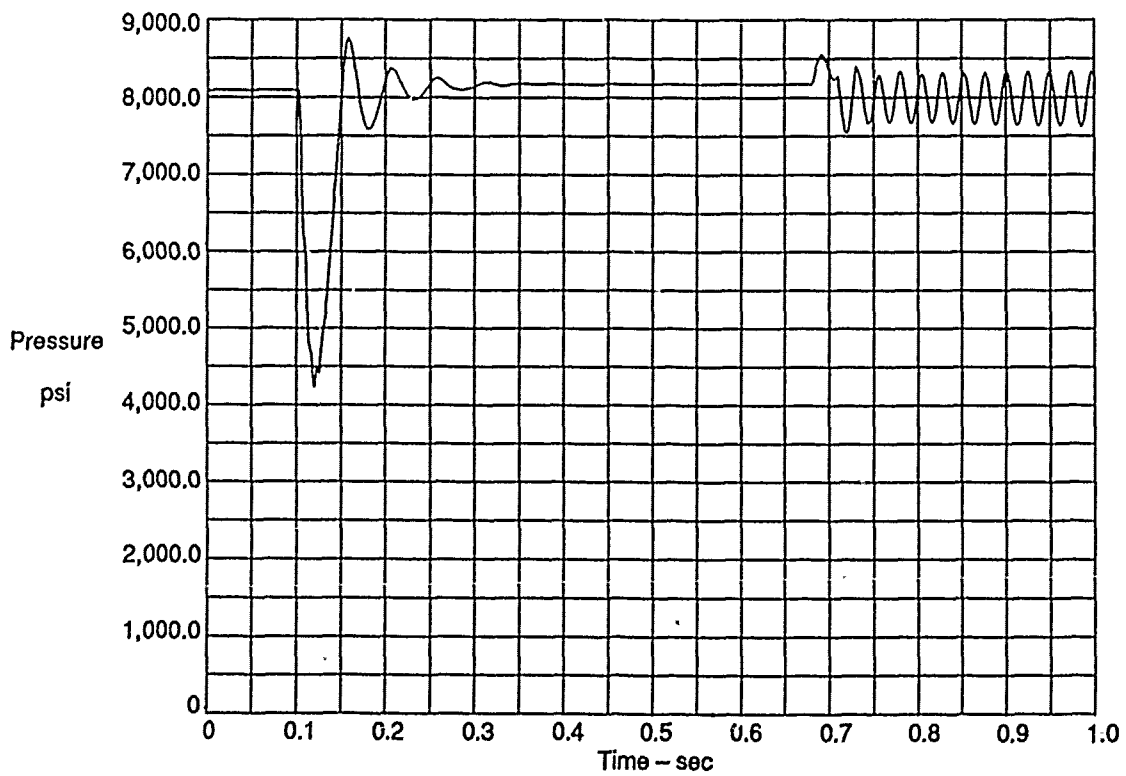


Figure 40. Pump Outlet Pressure with Flow Demand

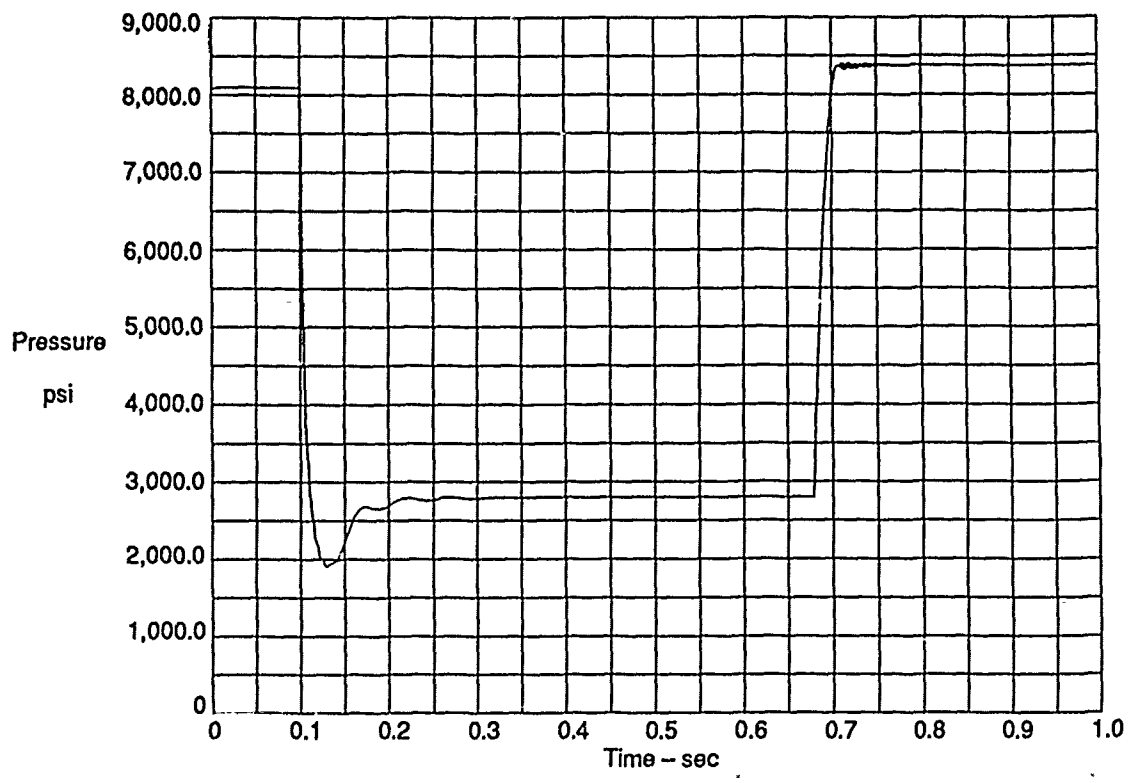


Figure 41. Servoactuator Inlet Pressure at No-Load Rate

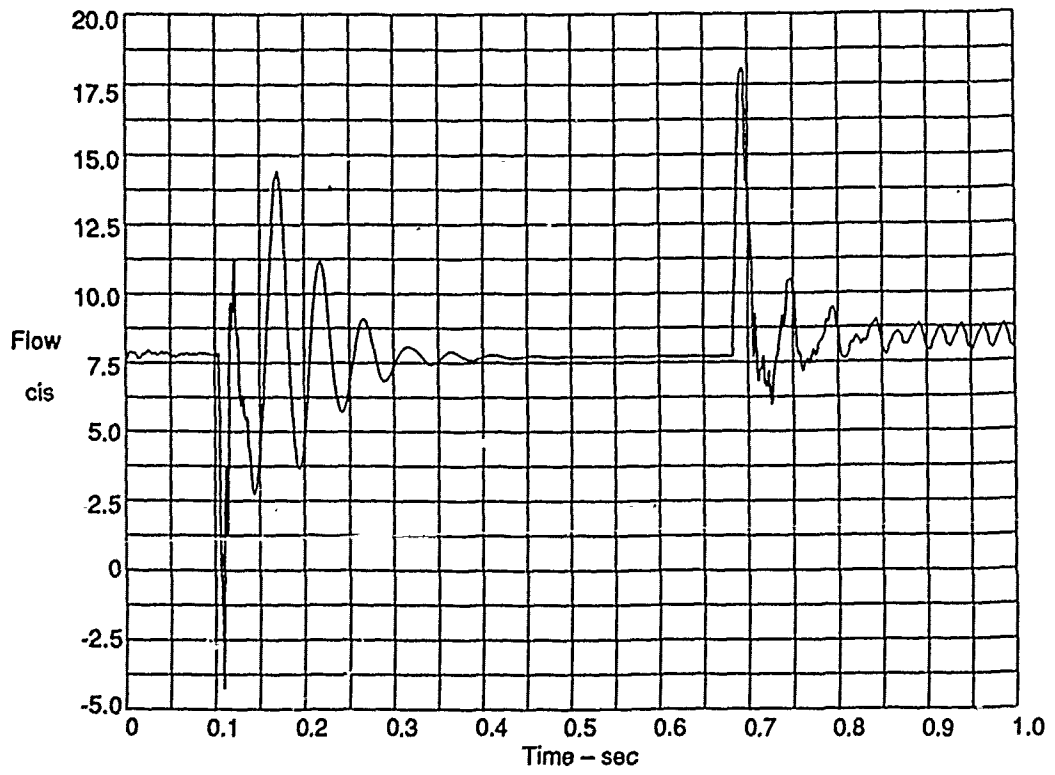
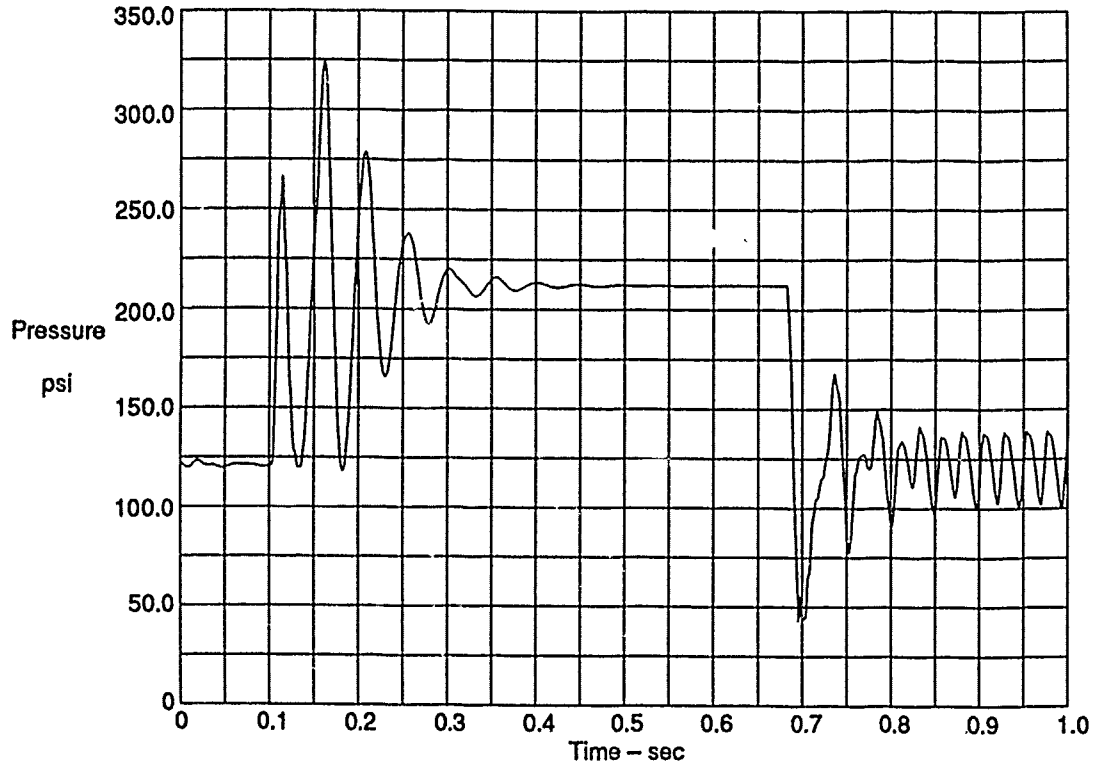
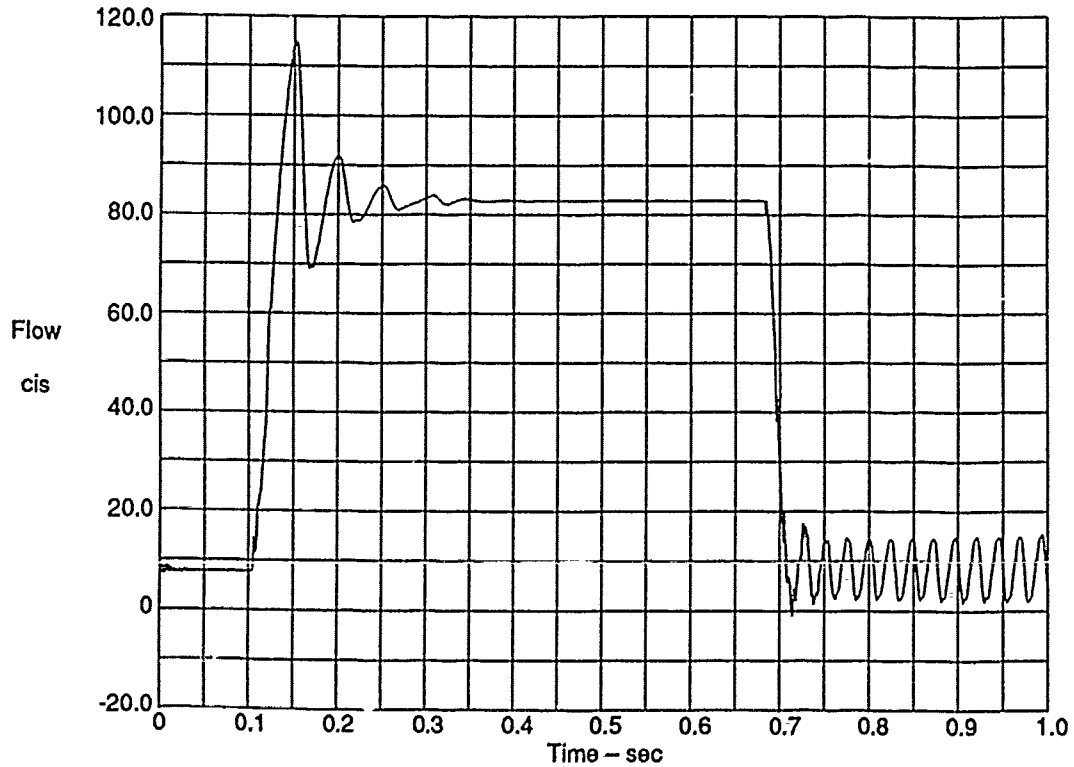


Figure 42. Flow Transients  
Pump Case Drain





**Figure 43. Pressure Transients  
Pump Case Drain**



**Figure 44. Pump Suction Flow**

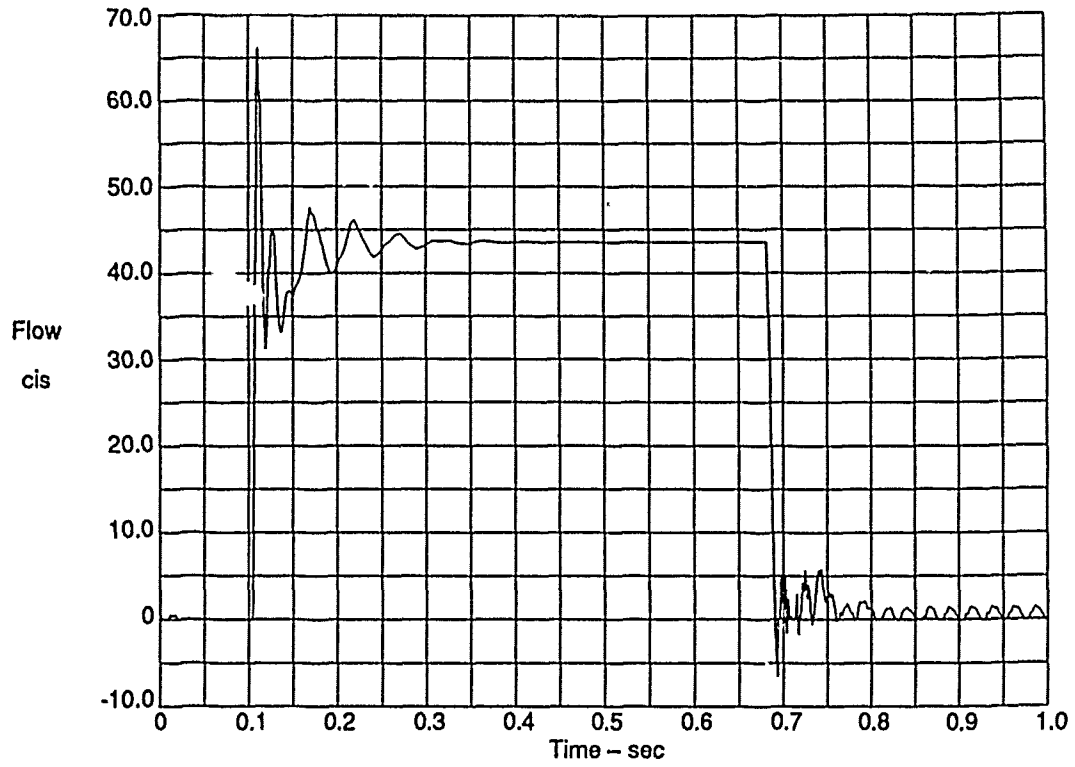


Figure 45. System Relief Valve Flow

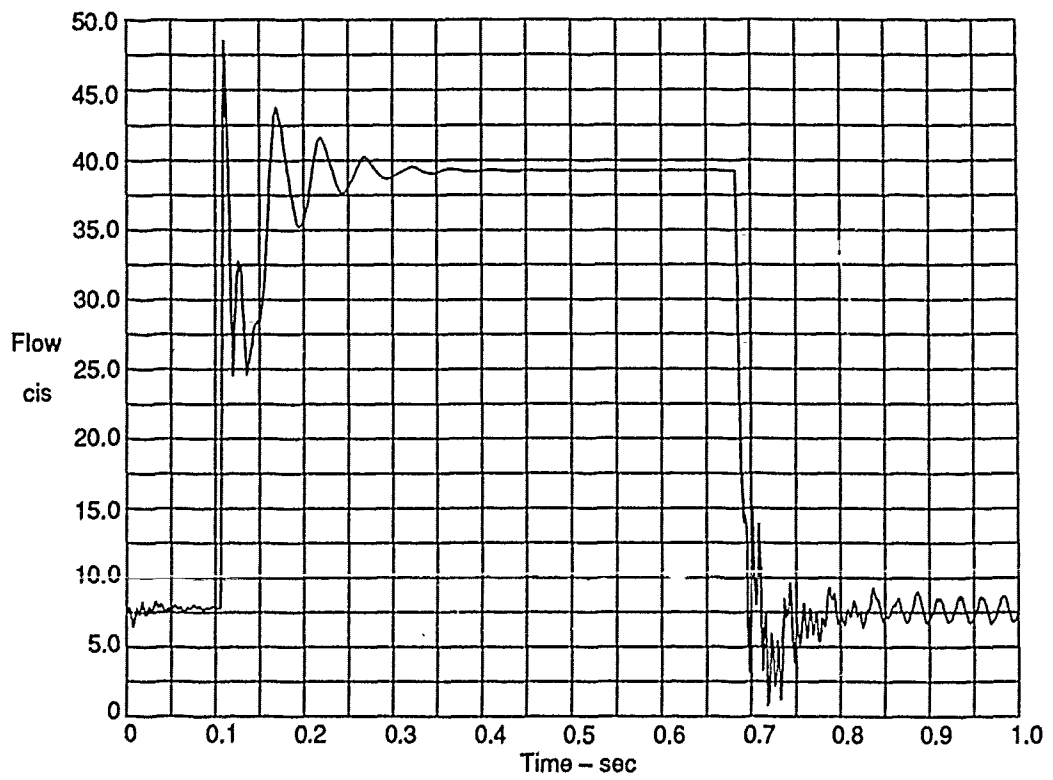


Figure 46. System Heat Exchanger Flow

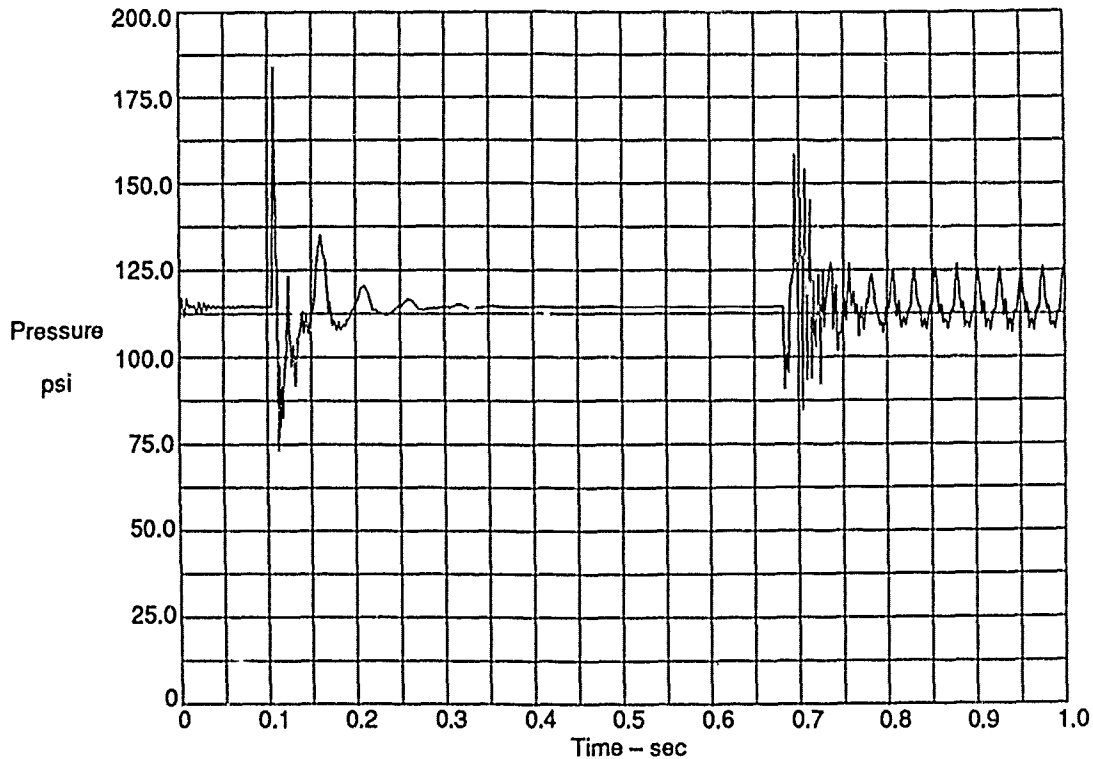


Fig. 47. Pressure Transients  
Pump Suction

3.3.5 HSFR Analysis - The HSFR computer program was used to determine the pump pulsation frequencies, and locations, in the PC-1 system. Only the PC-1 system was analyzed because the central system of the PC-2 was identical. The Utility system could not be analyzed because simulation capability for parallel pumps was not within the HSFR program.

a. HSFR Computer Model - Figure 48 shows the schematic of the PC-1 system including data on line lengths, diameters and wall thicknesses. The entire high pressure side of the PC-1 was modeled and included the effect of quiescent leakage.

b. Abex Pump Pulsations - A pulsation pressure map is shown in Figure 49 for the Abex pump as a function of line location and pump speed. This map was created to indicate where pulsation pressures occur and exceed a minimum value of excess pressure. For a selected line length of 45 inches between the pump outlet and the filter manifold, pressure spikes greater than 500 psi occurred at pump speeds of approximately 1300 and 3250 rpm. To determine the amplitude of the pressure pulsations, it was necessary to simulate a pump speed sweep up to 4500 rpm and to make plots of peak pressure at points within 45 inches of the pump outlet. Figures 50 and 51 show peak pulsation pressures during pump speed sweeps at points which were 3 inches and 30 inches downstream of the pump outlet. Peak amplitudes of 900 and 1250 psi were found respectively.

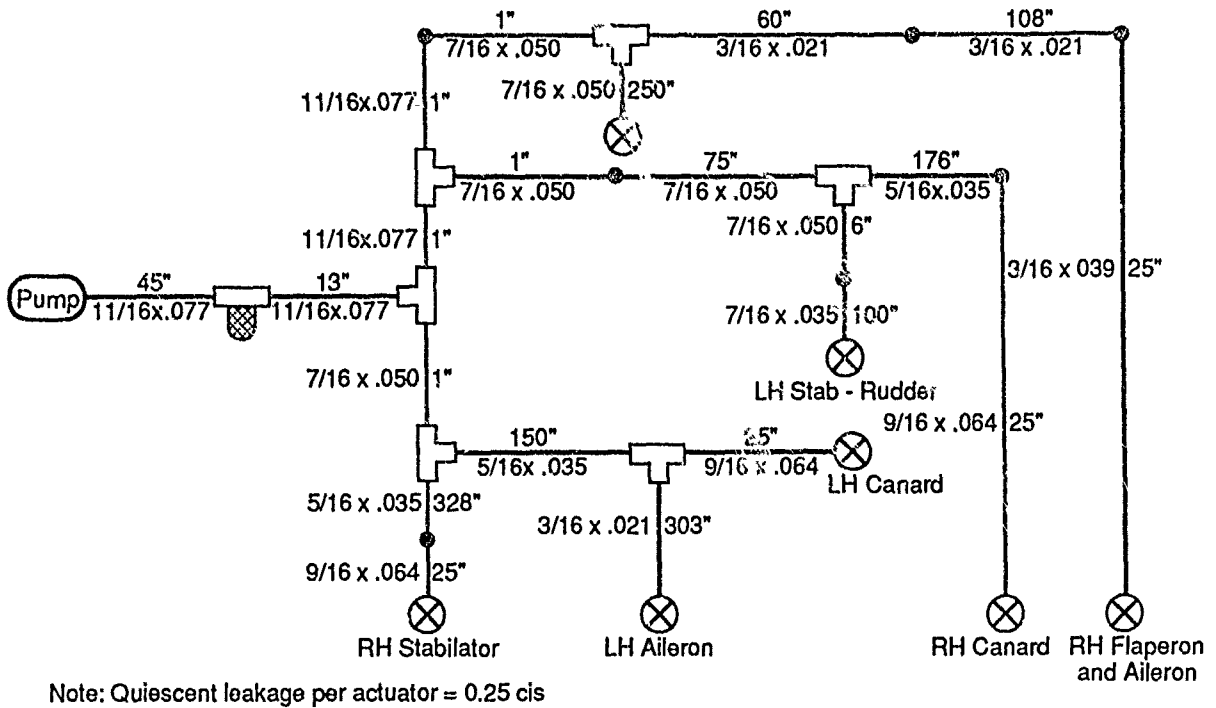


Figure 48. HSFR Schematic .  
PC-1 System

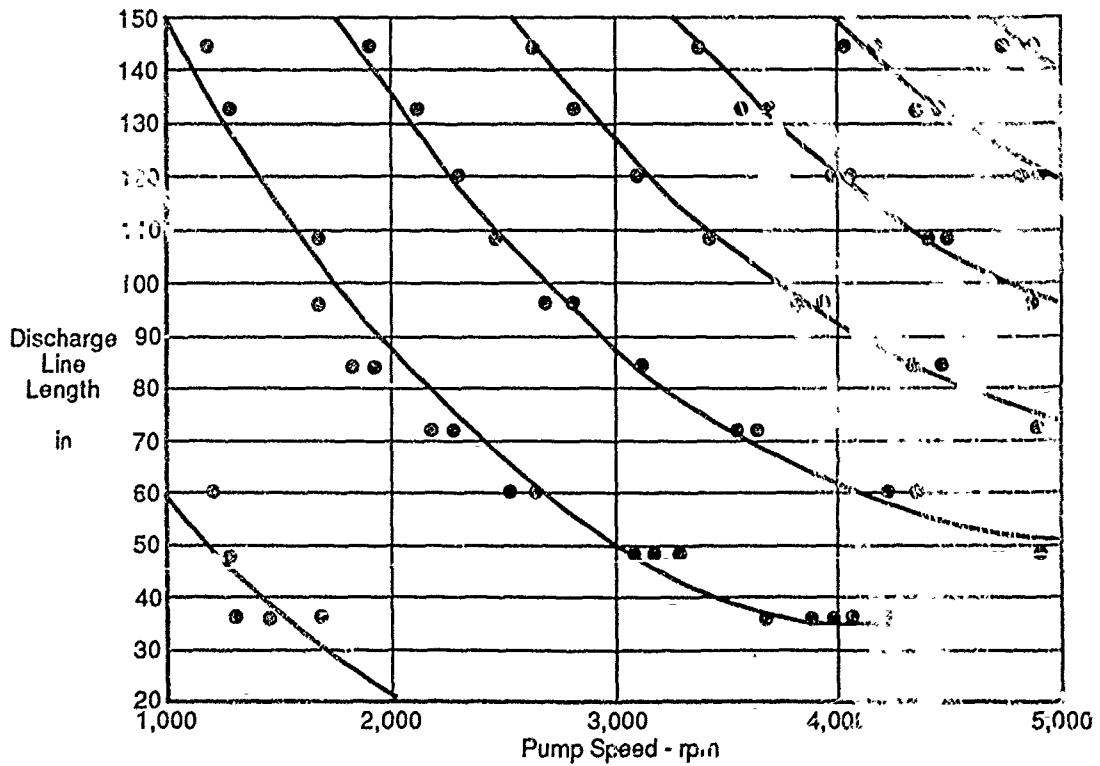


Figure 49. Peak Pulsation Pressure Map

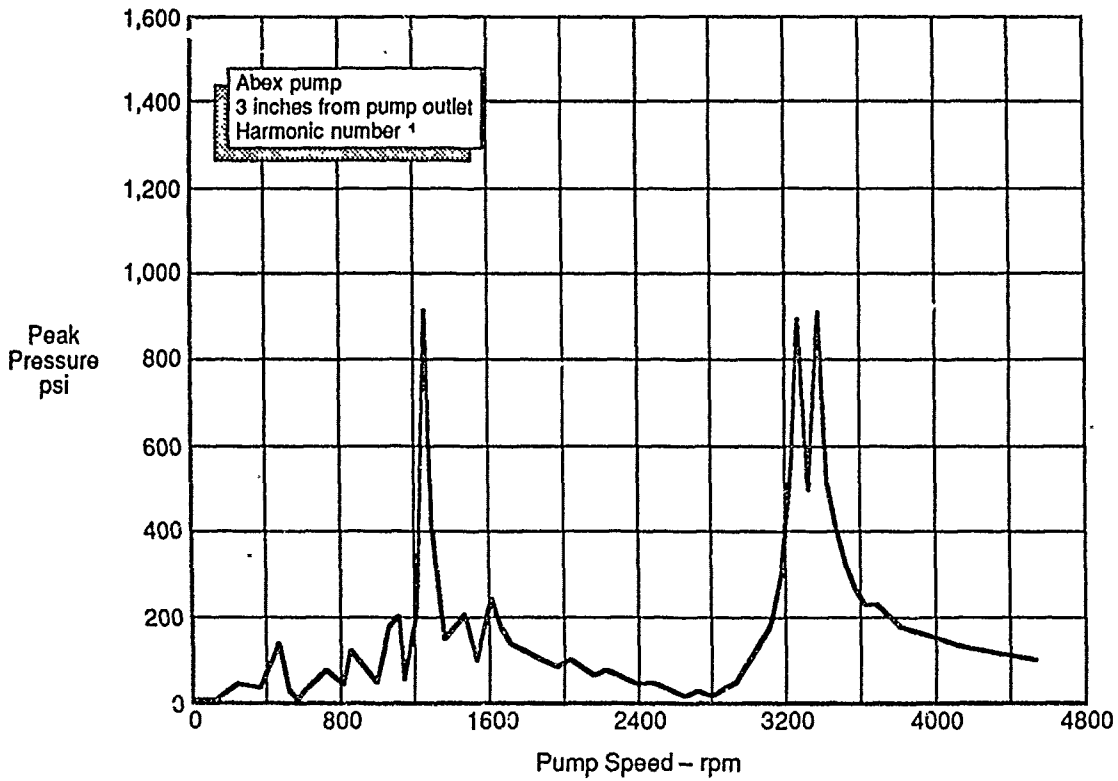


Figure 50. Abex - Pump Peak Pulsation Pressure  
3 in. from outlet

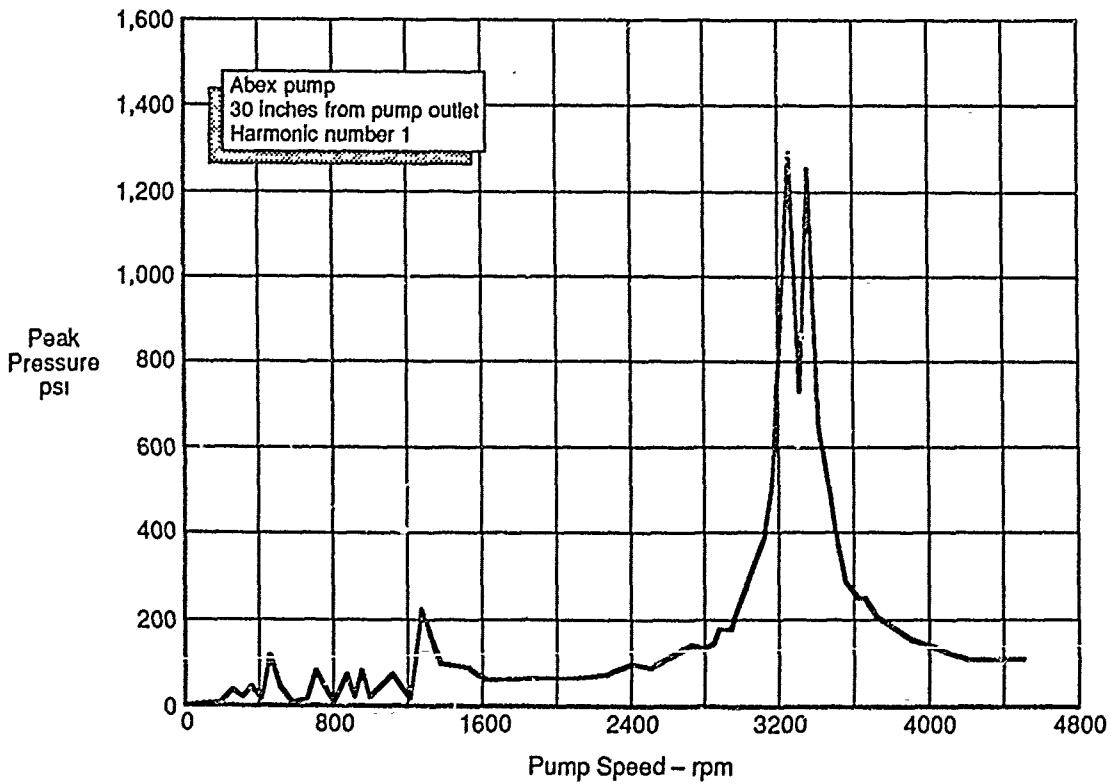


Figure 51. Abex - Pump Peak Pulsation Pressure  
30 in. from outlet

These peaks exceeded the requirement that peak pulsations must be less than five percent of system pressure or 400 psi. Figures 52-54 show the standing wave pressure plots at 1250, 3250 and 3350 rpm respectively.

c. Vickers Pump Pulsations - An analysis of the Vickers pump showed a similar pulsation problem. Figures 55 and 56 show pressure pulsation peaks occurred at approximately the same pump speed (1250 and 3400 rpm), and the pulsation pressure levels were similar but with greater amplitude (1700 and 2150 psi), at the same line points. A plot of the standing waves at 1300 and 3400 rpm are shown in Figures 57 and 58.

d. Pulsation Attenuation - This analysis supported earlier concerns regarding the need for pulsation attenuation devices downstream of the pump outlet ports. Pulsation attenuators were originally provisioned for the program and were retained as a result of this analysis.

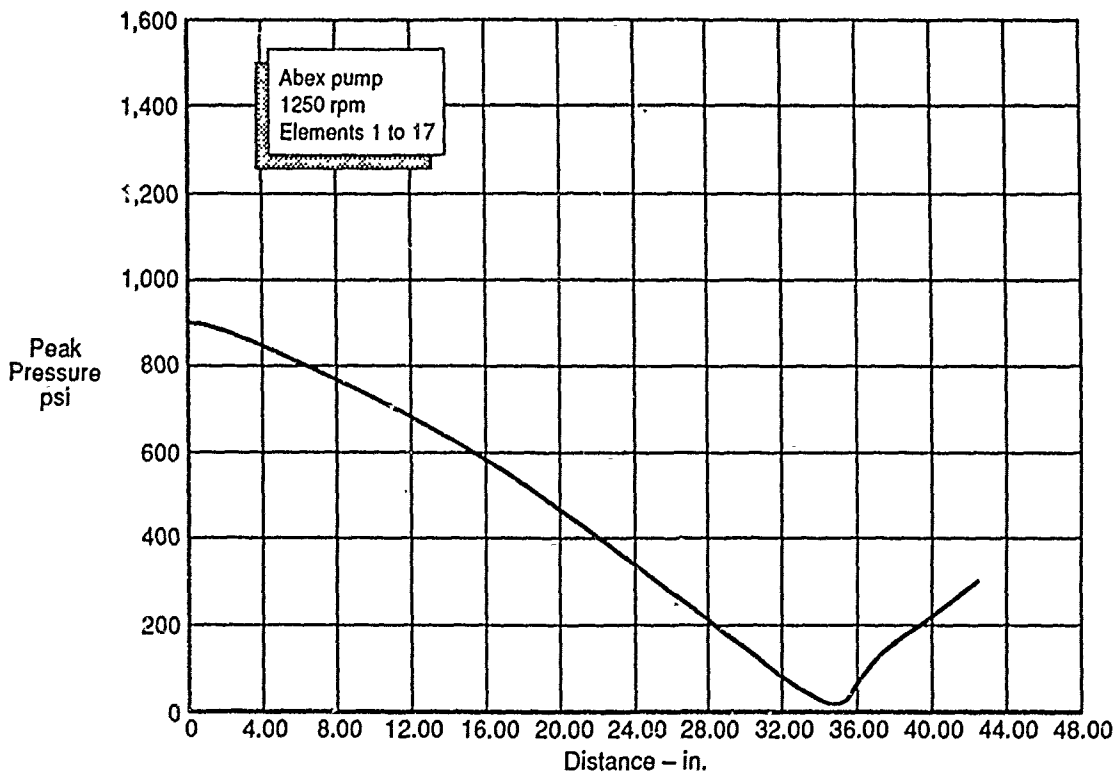


Figure 52. Abex - Pump Standing Wave Pressure Plot at 1250 rpm

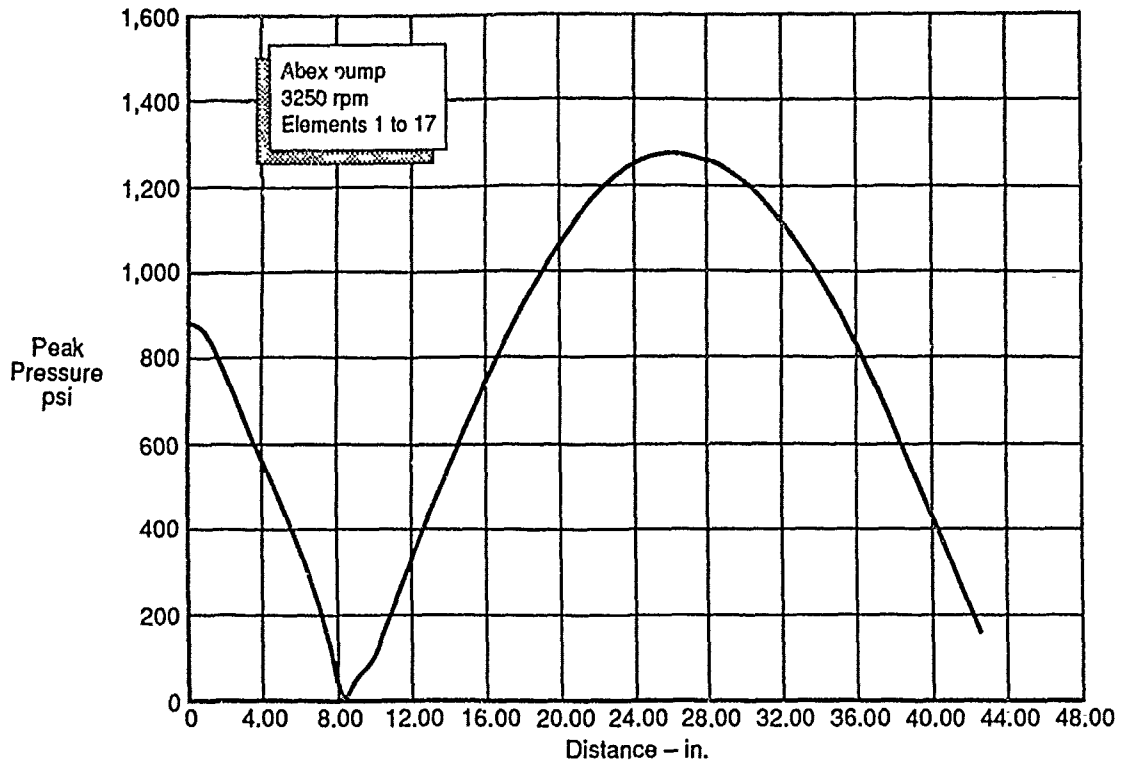


Figure 53. Abex - Pump Standing Wave Pressure  
Plot at 3250 rpm

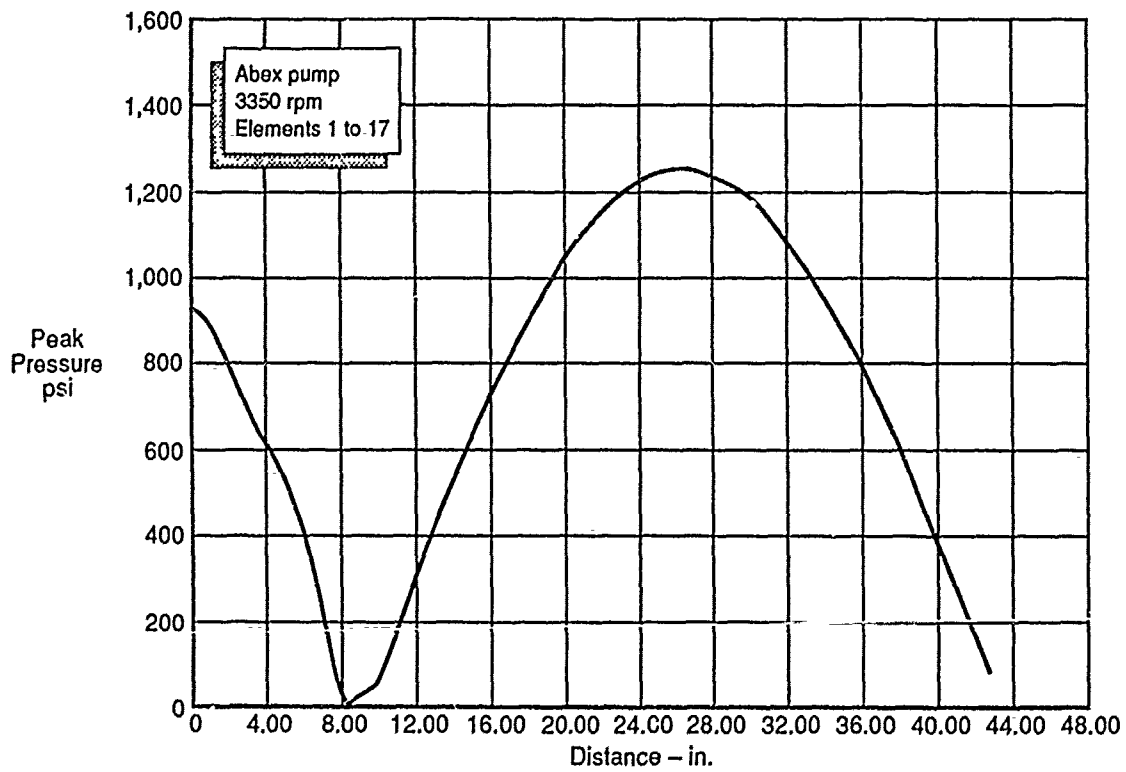


Figure 54. Abex - Pump Standing Wave Pressure  
Plot at 3350 rpm

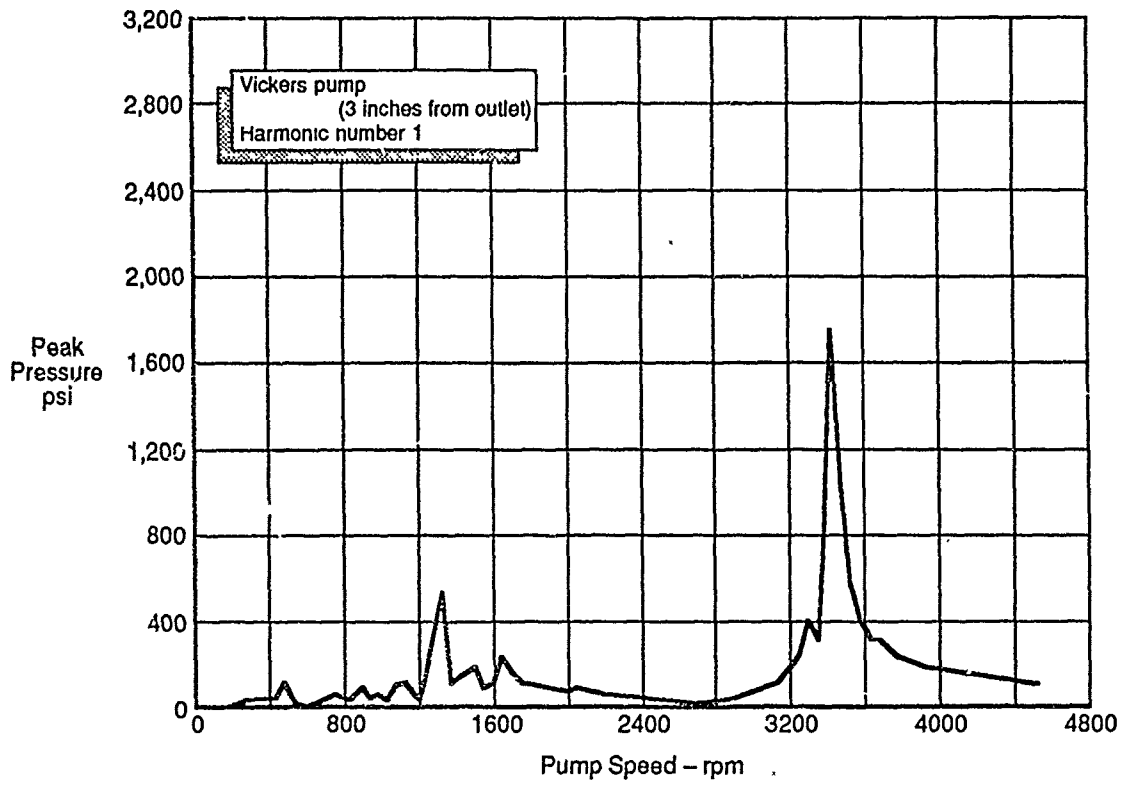


Figure 55. Vickers - Pump Peak Pulsation Pressure  
3 in. from outlet

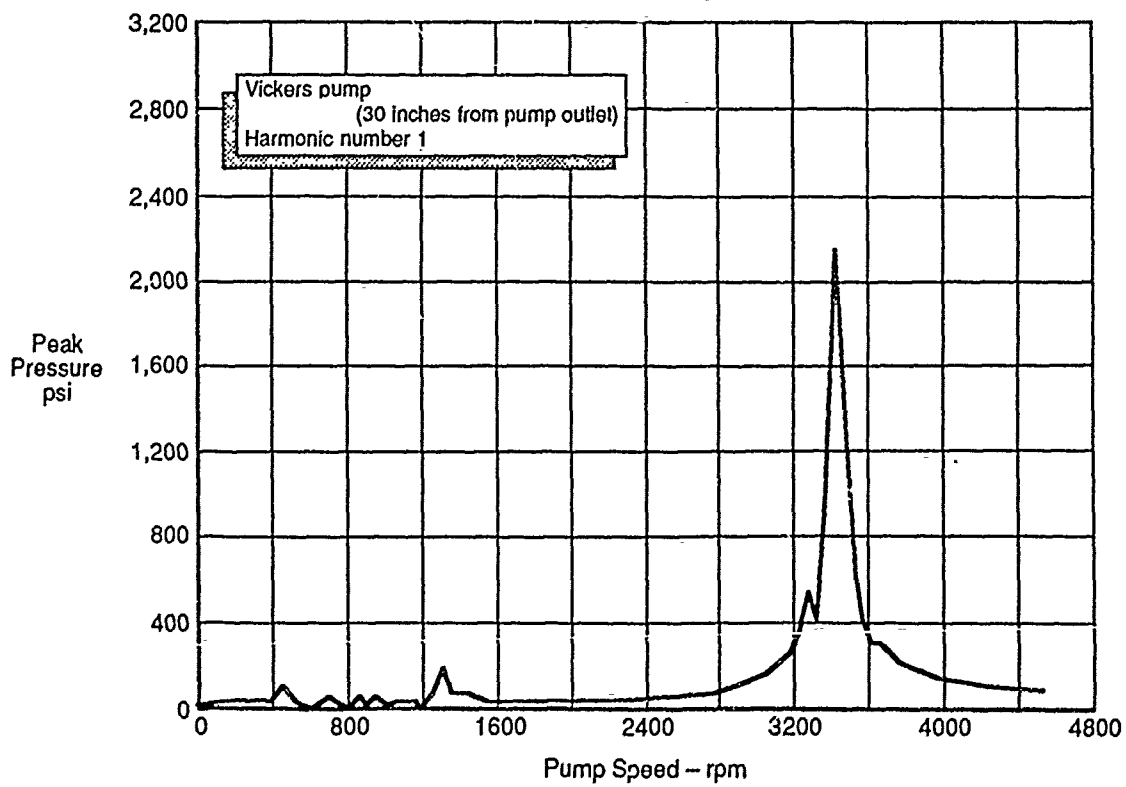


Figure 56. Vickers - Pump Peak Pulsation Pressure  
30 in. from outlet



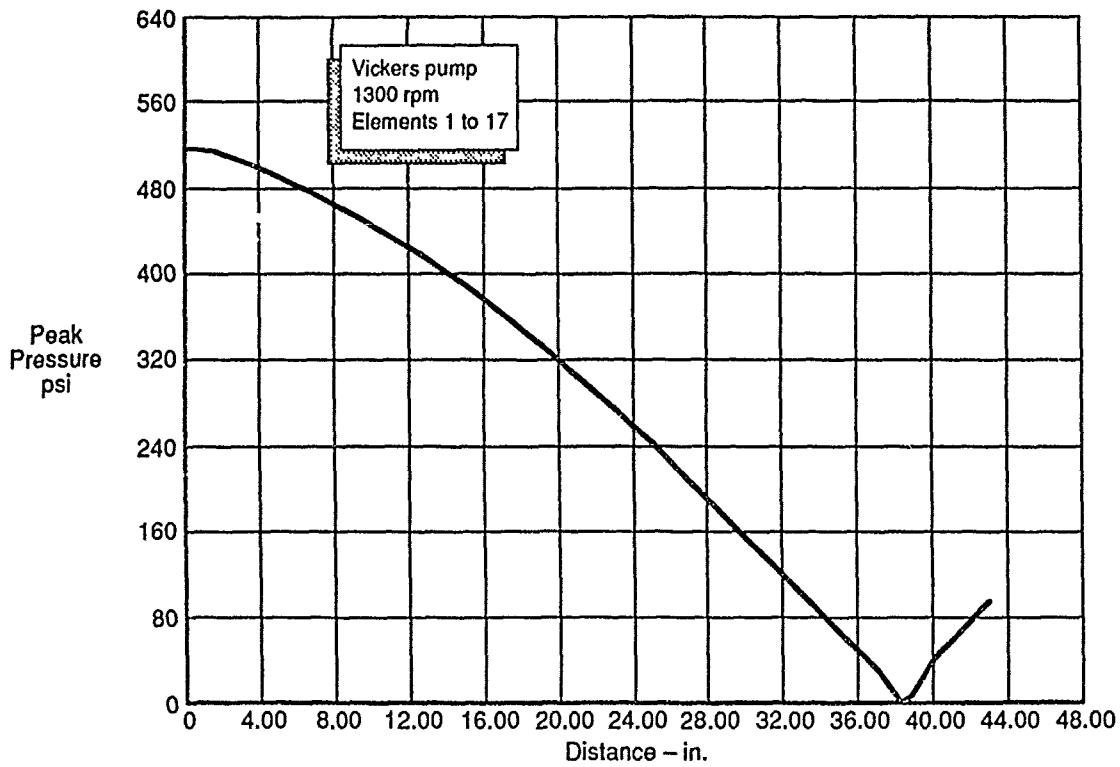


Figure 57. Vickers - Pump Standing Wave Pressure  
Plot at 1300 rpm

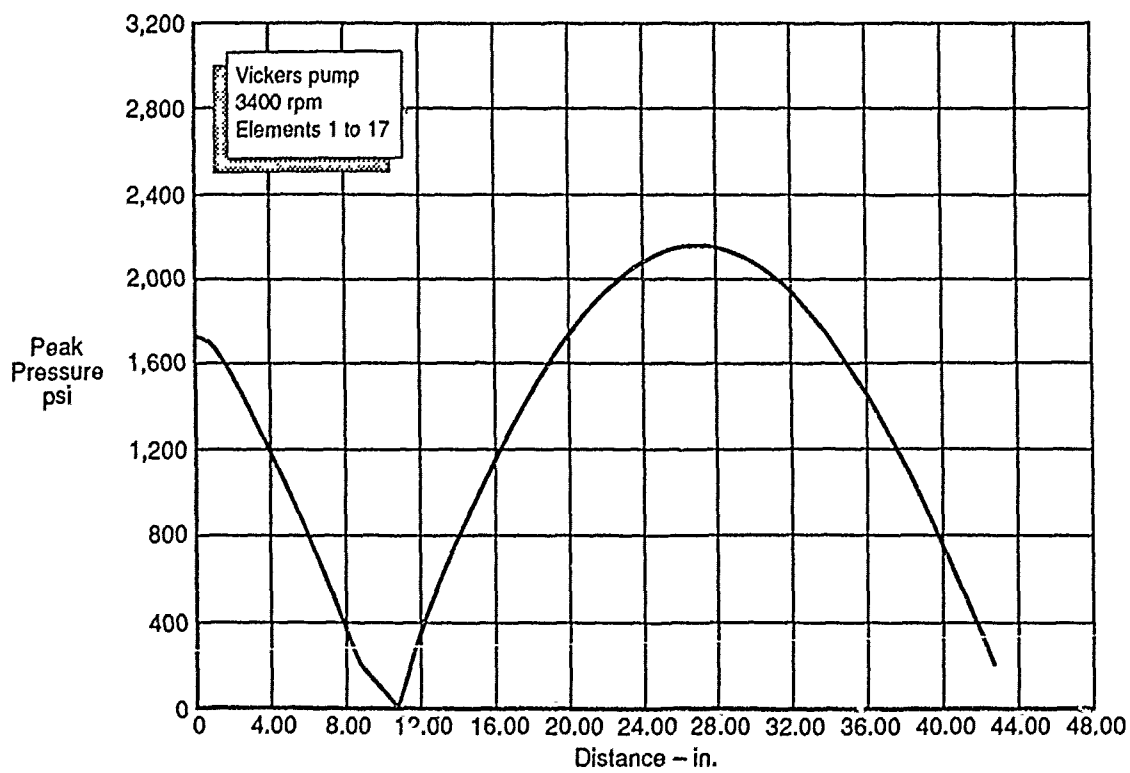


Figure 58. Vickers - Pump Standing Wave Pressure  
Plot at 3400 rpm

### 3.3.6 Thermal Analysis

a. F-15 Heat Exchangers - Three F-15E fuel/oil heat exchangers (HX) were procured for the program. These heat exchangers each have four individual core circuits. In the production arrangement, one heat exchanger is used in each of the engine fuel feed lines to the engine. The L/H unit cools PC-1 hydraulics, one half of the Utility, the L/H electrical generator and the L/H airframe mounted accessories drive (AMAD). The R/H unit cools PC-2 hydraulics, one half of the Utility, the R/H electrical generator and the R/H AMAD.

b. CTFE Thermal Characteristics - CTFE at equivalent fluid temperatures, requires twice as much HX effective surface area as MIL-H-83282 fluid for discharging equivalent heat load. This is due to the fluid having a thermal conductivity coefficient approximately half that of MIL-H-83282. Because of the density and the specific heat characteristics, CTFE has 12 percent less temperature rise in absorbing heat on a volumetric basis than MIL-H-83282. This increases the size of HXs because of the lower forcing temperature in the fluid entering the heat exchangers.

c. LTD Systems Heat Load - The F-15 aircraft has a maximum hydraulic pump power capability of 364 horsepower (hp) which represents a 100 hp reserve when all four pumps (52 gpm each at 3000 psi), are operating. The system can lose one pump and still have reserve over the maximum demand. The pumps case drain continuous heat load, however, relates more closely to maximum displacement. The LTD systems, having four pumps (40 gpm each at 8000 psi), are rated at a total power capability of 747 hp minimum, which is over twice the power of the baseline aircraft.

(1) Heat Exchanger Capacity - The increased power level placed the required heat exchange capacity at roughly four times the requirement for the production aircraft hydraulic system under the normal power load.

(2) Heat Exchanger Core Allocation - Having four cores on each heat exchanger offers alternatives as to how the system fluid return could be cooled. On an F-15 aircraft heat exchanger, the cores are allocated to one PC return, one half of the Utility return, cooling flow for one generator and cooling flow for one AMAD gearbox. When used on the LTD, with one unit used on each of the three systems, the PC and Utility cores are connected in parallel to cool the combined return flow. The two remaining cores will be unused unless additional cooling capacity becomes necessary in the course of the test program.

d. System Warm Up Time - Conventional hydraulic fluids can require active approaches to warming the hydraulic system prior to moving the aircraft when operating in an extremely cold ambient environment. This has typically been accomplished by opening a load valve providing a shunt orifice to dump pressure to return. The shunt is left open until central system fluid is warmed near operating temperature. Figure 59 shows a comparison of the viscosity values and relative comparison of MIL-H-83282 and CTFE fluids at 8,000 psi. Interpolation would show that the viscosity of CTFE at -40°F is equivalent to MIL-H-83282 at 0°F. Figure 60 shows a comparison of the thermal conductivity and specific heats for both CTFE and MIL-H-83282 fluids. Because the specific heat of CTFE fluid is approximately one half that of MIL-H-83282,

the temperature gain per pound from pressure loss is double that of MIL-H-83282. Volumetrically however, the temperature gain is 12 percent less because CTFE is 2.2 times as dense. Because the lower thermal conductivity, the capacity to transfer heat from CTFE is about half that of MIL-H-83282, which results in very rapid fluid temperature rise. A nonflammable hydraulic system does not require special provisions for pre-warmup and warmup time is of no concern. This also avoids a potential weight penalty for warming circuits.

Temperature	Viscosity (Centistokes)	
	CTFE	MIL-H-83282
- 65°F	2,239	51,689
- 40°F	716	8,091
+ 40°F	31.5	178
+ 160°F	2.9	13
+ 275°F	0.66	3.9

Figure 59. Fluid Viscosity Comparisons at 8000 psi

TEMP (deg. F)	SPECIFIC HEAT (BTU/lb/deg. F)		THERMAL CONDUCTIVITY (BTU/hr/ft <sup>2</sup> /deg. F/ft)	
	MIL-H-83282	CTFE	MIL-H-83282	CTFE
-65	.419	.194	.114	.049
-40	.431	.194	.111	.048
0	.450	.135	.107	.047
80	.489	.197	.098	.046
100	.498	.197	.096	.044
200	.546	.199	.086	.039
300	.593	.201	.076	.036

Figure 60. Fluid Comparisons at 8000 psi  
Thermal Conductivity and Specific Heat

e. Engine Nozzle Cooling - This program aggressively addressed the issues of the additional heat load introduced by engine nozzle actuators. The issues are discussed as follows.

(1) Maximum Fluid Temperature - The program contract initially stipulated that the upper temperature limit of CTFE fluid would be 350°F. Development problems with the corrosion inhibitor additive required that the fluid upper temperature limit be reduced to 275°F for the duration of the program. The upper system temperature limit for the fluid for practical purposes in this program was likely to occur in two places; the pump case drain flow and the engine nozzle actuator return. No active provisions have been added to cool the case drain flow separately, however active cooling schemes were designed to provide engine nozzle actuator temperature control in the hot nozzle environment where theoretical ambient temperatures may be as high as 450°F. There are no test provisions made to provide high ambient temperature in the LTD, however active cooling of engine nozzle actuators has been demonstrated at the component level by the supplier.

(2) Engine Nozzle Actuators - Engine nozzle actuators were designed with capabilities for enhanced cooling techniques. Two actuator configurations were approached with additional external porting to permit a dedicated supply of cooler oil to the central core of the actuators. This cooling flow entered at a slightly higher pressure than system return pressure and circulated through the core of the actuators which cooled the actuator position sensing electronic elements and the inside of the piston rod. This cooling path was extensively analyzed for effectiveness in Trade Study No. TS-3, which is discussed herein. The divergent flap actuators, which are a regenerative design, have an additional provision to be compared in the test program. These units, which have constant system pressure applied to the retract side of the system, have a bleed port in the piston head. This port was fitted with an insert which allows a small bleed flow from the high pressure (retract) side to the extend side. This served to positively replace all of the oil in the cylinder within a preset time increment. A total fluid exchange every five minutes was the design goal. This supplemented the active cooling which was implemented in the core. Two of the divergent flap actuators have the piston head bleed provision and two do not. This will give a direct comparison of cooling effectiveness in the 450°F ambient environment.

#### 3.4 TASK 2-4 - PERFORM TRADE STUDIES WITH POWER EFFICIENT TECHNOLOGIES

The trade study subjects were selected as having relevant alternatives to design approaches proposed for the demonstration system. The studies encompass a wide variety of subjects. A generic trade study evaluation criteria was developed as a Phase I task. All of the studies followed the criteria set forth as practicable. Some of the studies involved technology which was still evolving and many of the criteria could not readily be applied. A discussion of conclusions and recommendations of the individual trade studies are presented herein.

3.4.1 Fluid Reservoir Pressurization - Even though the supply pressure in the systems is variable from zero to 8000 psi on demand, it is desirable to maintain a relatively constant return system pressure. When the systems are off, it is also beneficial to maintain a static pressure in the aircraft to keep fluid seals energized. There are several methods of pressurizing reservoirs and MCAIR has traditionally favored bootstrap approaches. With variable system pressure, this approach is less advantageous without a ground rule being invoked which requires the aircraft to have autonomous operating

capability in an austere and hostile environment. Gas pressurization techniques were shown to have advantage solely on weight and reliability. Again, the results and conclusions are highly "ground rules" sensitive. A sealed trapped gas reservoir was shown to have the lowest life cycle cost. However, it made the several maintenance actions such as coupling of ground service connections and installation of filter bowls extremely difficult. Two reservoir designs were generated in the program. One was a bootstrap design with a dedicated accumulator for bootstrap pressurization and the other was a metal bellows design which could be configured to operate with any of the gas pressurized options. Only the bootstrap reservoir was manufactured for the test phase of the program.

3.4.2 System Circuit Configurations - The key issues for circuit configuration are performance, survivability (redundancy) and vulnerability. Two additional circuit configurations were evaluated and compared against the base line system which is a four pump, three system, nine RLS circuit configuration. One configuration was a four pump, two system, six RLS circuit approach and the other a two pump, two system, four RLS circuit approach. Neither compared favorably with the base line system where survivability is a prime requirement. Although both were lighter systems overall, the base line system excelled when the weight was compared on a "per circuit" basis. The primary reason that the base line system was preferred, stems mainly from the requirement to power the two engine nozzle actuation systems. Without this requirement, the four pump, two system, six RLS circuit approach would have been preferred.

3.4.3 Engine Exhaust Nozzle Cooling - This study compared an alternate approach to introducing cooling flow in the engine nozzle actuators. The F-15 SMTD uses "brute force" cooling whereby high pressure oil is throttled into the actuator core through a dropping orifice. The alternative studied was supplying jet pumped (flow augmented), cooling flow from the central system. This was found to be a very effective way to maintain resident oil temperatures below system limits for CTFE. Unfortunately, the added weight to implement this approach increased the life cycle cost. The conclusion drawn was that brute force cooling is the preferred approach to nozzle actuator cooling unless heat exchange performance within the cooled actuator is a problem, as in this case, because CTFE is half as effective as a coolant compared to conventional fluids.

3.4.4 Direct Drive Valve Configurations - The original scope of this trade study was restricted to variations which could be applied to the F-15 SMTD stabilator actuator as a dual tandem flight control actuator. As the study progressed, it was evident that a much wider range of direct drive valves should be analyzed because of the availability of many servoactuators on the program. This would seem to create an ideal environment to evaluate several direct drive concepts. However, further investigation clearly showed that an optimum selection criteria could not be established and that each direct drive valve configuration has its own unique set of design conditions dictated by overall system integration. This program has several different direct drive valve configurations. This study effort, which was approached in

a generic fashion, could not show convergence on an optimum arrangement. This result reinforced a previous MCAIR objective for direct drive valves which was the need to establish requirements for a standard, flight line replaceable direct drive valve for the technology to ultimately be successful in ongoing applications. A standardized approach to direct drive valve requirements is clearly needed to avoid a severe impact on flight control logistics.

3.4.5 Pressure Transient Control - Several techniques may be used to control pressure transients in the system which result from pump pulsation or overshoot as well as servovalve reversals. The most significant factor in hydraulic systems which effects transients from valve reversals, is fluid velocity near the valve. High performance aircraft cannot afford the weight penalty associated with maintaining low fluid velocity by using larger hydraulic line diameters. The weight penalty associated with decreasing the fluid velocity for several diameters ahead of the servovalve, is more acceptable and also serves to control peak pressures effectively. The high response relief valve is the most effective means of controlling pump overshoot. Both of these approaches will be demonstrated in this program.

3.4.6 Materials For High Pressure Components - This study assembled all of the properties of several candidate materials for use in 8000 psi hydraulic equipment with CTFE. This included titaniums, corrosion resistant steels and low carbon steels. A high premium is placed on corrosion resistance, damage tolerance and density. Previous industrial studies show that aluminum should not be considered for high pressure applications greater than 5500 psi. In general, titanium is preferred for manifolds, while high strength corrosion resistant steels are preferred for rods and cylinder barrels. Rip stop construction is not being required for this program when fracture tolerant materials are used. Titanium castings may not have the fracture tolerance required, and in this case, a rip stop construction should be considered.

3.4.7 Overlapped Valve Applications - Overlapped valves can reduce quiescent null leakage flow through a servovalve by an order of magnitude. This is accomplished with no significant cost or weight penalty and no added complexity although performance degradation potentially exists. However, the performance degradation can be compensated for by electronic control enhancements. The conclusion can be drawn that overlap should be used on any servovalve which is at null a significant amount of time and its presence does not affect performance. Very active servovalve controls on aircraft with reduced static stability, may only be at null a fractional amount of time. This study concluded that for the flight control actuators on this program, the optimum amount of overlap for leakage reduction was 10 percent of the total stroke.

3.4.8 Parallel Variable Pressure Pump Integration - The classic approach to operating two pressure compensated pumps in parallel has been to place a check valve with a cracking pressure on the the order of 250 psi in the outlet of one pump. Because the pump senses its own discharge pressure for displacement control, this has the effect of delaying operation of the check valved pump until the flow demand from the other pump drops line pressure to corresponding level. This prevents the pumps from hunting a control point at low flow since neither can control the other. The second effect is that the unvalved pump will supply most of the total power requirements of the system. This has the implication that this more active pump will expend its useful

life at a higher rate than the other. A trade study was performed in support of paralleling two variable pressure pumps. Since the pumps are electronically controlled, it becomes feasible to match the operation of the pumps such that they respond with one (the follower) lagging the other (the master) with virtually no time lag. This has the effect of forcing both pumps to expend useful life at the same rate. The predicted increased pump life was shown to be as high as 40 percent.

3.4.9 Approaches To Improve Stiffness Of 8000 psi Actuators - This study documented all of the arguments that can be presented regarding the stiffness degradation introduced from downsizing cylinders and using the lower bulk modulus CTFE fluid. The only reasonable technical solution was to improve the performance of the servovalve and its control loops. An approach that will be demonstrated in this program is Enhanced Dynamic Stiffness with Surface Acceleration Feedback. This will be integrated on the stabilator system. Stabilator position will be measured in the spindle hub with a four channel force motor. Position signal will be processed to produce the acceleration measurement for feedback.

## SECTION IV

### PHASE III - LABORATORY TECHNOLOGY DEMONSTRATOR DESIGN

This Phase introduced the task for the actual design of the LTD. The laboratory personnel are responsible for the detail design of the jigs and fixtures which are required to test the flight weight hydraulic equipment. This facility is located at MCAIR's Flight Controls Laboratory which houses the F-15 and AV-8B Iron Birds. Additional tasks in this phase included: a Preliminary Hazard Analysis (PHA), an Operation and Support Hazard Analysis (OASHA), a detailed Test Plan, the preparation of this report and the oral presentation of the first program phases which was presented at Wright-Patterson AFB Ohio.

#### 4.1 TASK 3-1 - ESTABLISH AND DESIGN LABORATORY TECHNOLOGY DEMONSTRATOR

Because all of the flight controls for the program are fly-by-wire, it was not necessary to construct the elaborate metal framework to mount the mechanical equipment, typical of iron birds that simulate aircraft with mechanical controls. This allowed the flight type equipment to be mounted in modular fixtures which could be placed for organization and convenience. The hydraulic supply lines will be as close to the length required in the base line aircraft as the facility will permit. Aircraft flight weight heat exchangers will be used for cooling the system. However, tap water will be used for the heat sink rather than jet fuel, as is the case in the aircraft. Thermal blankets are being provided for testing the engine nozzle actuation system. The pumps and drives are located in a chamber to lessen ambient noise. Figure 61 shows an artist's conception of the LTD facility.

4.1.1 Facility Control Room - The control room is enclosed and isolated from the test area to air condition the electronics and data acquisition systems and to reduce the noise level while providing an added margin of personal safety for the test conductors.

4.1.2 Central Power Generation - All four pump drives will be located in a central enclosure to improve safety and eliminate noise. The acoustic filters will also be located inside the enclosure so they can be placed as close as possible to the pump for maximum efficiency. Several test parameters will be monitored in the central system including pump speed, torque and fluid inlet, discharge and case drain conditions.

4.1.3 Distribution System - The hydraulic power distribution system follows the expressed Air Force initiative that future systems using 8000 psi operating pressure would have available a new approach to line size application. Specifically, this initiative developed "odd" sized (3/16 through 15/16), lines and fittings for use only on the high pressure side of the systems. The low pressure side continued to use "even" sizes of fittings and tubing rated for 3000 psi or less. This approach offered several advantages. It was already established that 8000 psi fittings must be more robust than 3000 or 4000 psi rated fittings that are well proliferated in size and configurations. This is particularly true in sizes greater than one half inch. Since the tubing wall thickness is greater, tooling requirements would



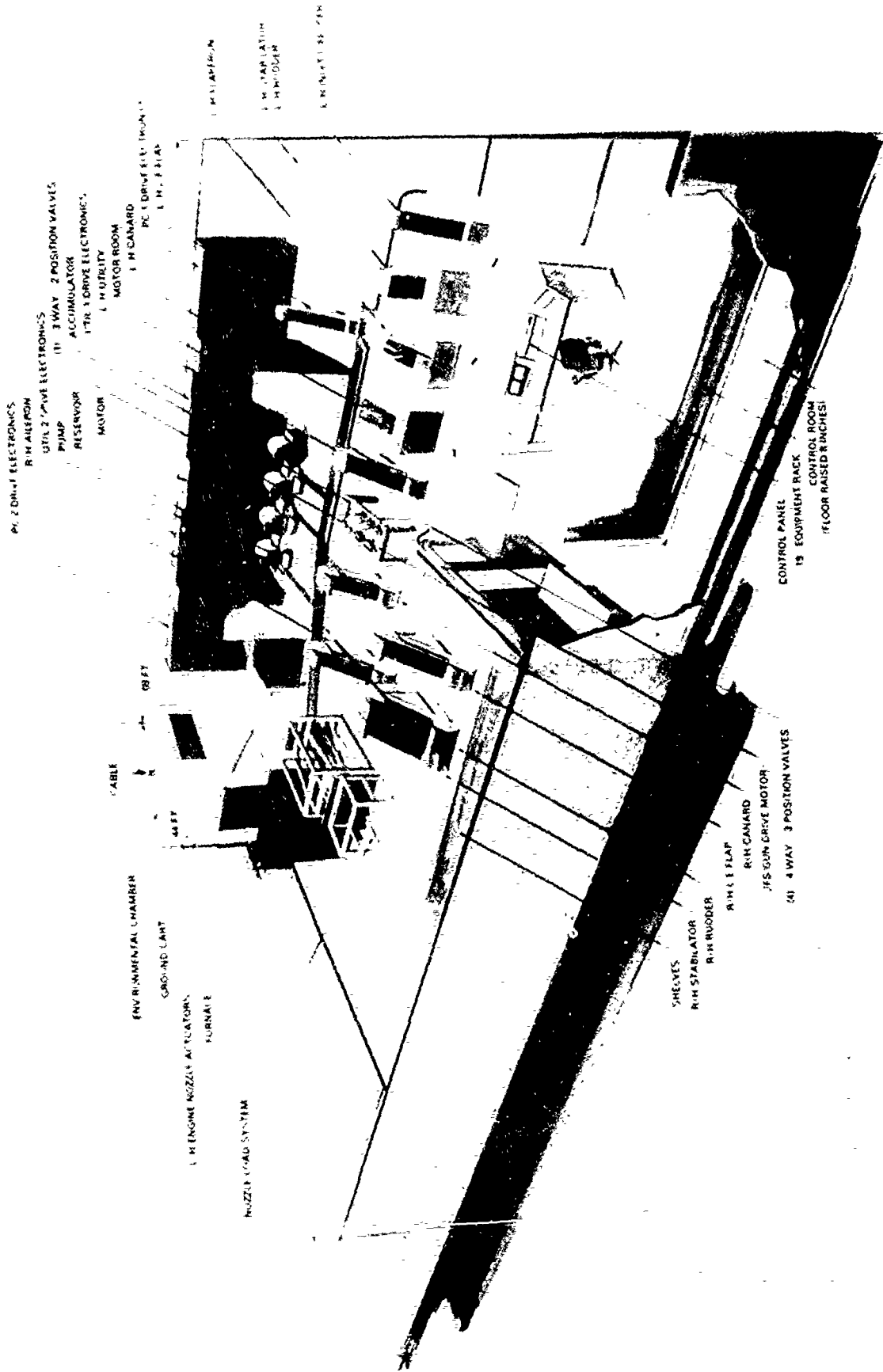


Figure 61. Layout of LTD Facility

differ if high pressure capabilities were to be developed in currently used even sizes. Development of odd sizes saves some weight and "Murphy proof" the system in the process. This program did not optimize or require fully qualified fittings. The initiatives carried in this program were to use odd sizes for high pressure and to demonstrate fittings from all of the aircraft fitting suppliers in the industry who were willing to participate in the development.

a. Tubing Standards - This program used the tubing sizes which Rockwell International selected for the 8000 psi distribution system program being sponsored by the Air Force. Tubing for this program was procured from three titanium tubing suppliers and conformed to the tube wall schedule shown in Figure 62. The tubing was 3Al-2.5V Alpha phase titanium and was cold worked and stress relieved (CWSR), to 105,000 psi yield strength. The Rockwell program is developing and testing sizes from 3/16 to 15/16 inclusive, while this program required tubing sizes from 3/16 through 11/16 only. Because this was a demonstration program, the usage of fittings from all potential suppliers was a high priority. Fittings were not required to have completed a rigorous qualification plan. Because of the heavier wall thickness, the tubing was not prestressed (autofrettaged). The benefits of the extended fatigue life provided by this practice did not warrant the cost of developing the capability to pressurize tubes to 24,000 psi or greater. The exception to the general tubing applications is the pressure intensified rudder actuation circuit, which will use 3/16 X .023 wall 15V-3Cr-3Al-3Sn (15-3) titanium tubing. This tubing was burst pressure tested to 54,000 psi, which allows for a more than adequate margin of safety.

High Pressure		Low Pressure	
SIZE	WALL THICKNESS	SIZE	WALL THICKNESS
3/16	0.021	1/4	0.016
5/16	0.025	3/8	0.019
7/16	0.050	1/2	0.026
9/16	0.064	5/8	0.032
11/16	0.077	3/4	0.039
		1	0.051

Figure 62. Titanium Tubing Wall Schedule

4.1.4 Actuation Systems - Two types of fixtures were fabricated for the program for loading the servocylinders. The principal fixture allowed full stroking of the actuator, while providing simulated surface air loads, surface inertia and mounting "springs" which duplicated the backup structural stiffness typical of the aircraft. Figure 63 shows the fixture for the stabilator actuator, which was designed to simulate air loads with inertias. Other fixtures were configured just for applying air loads. These are being used

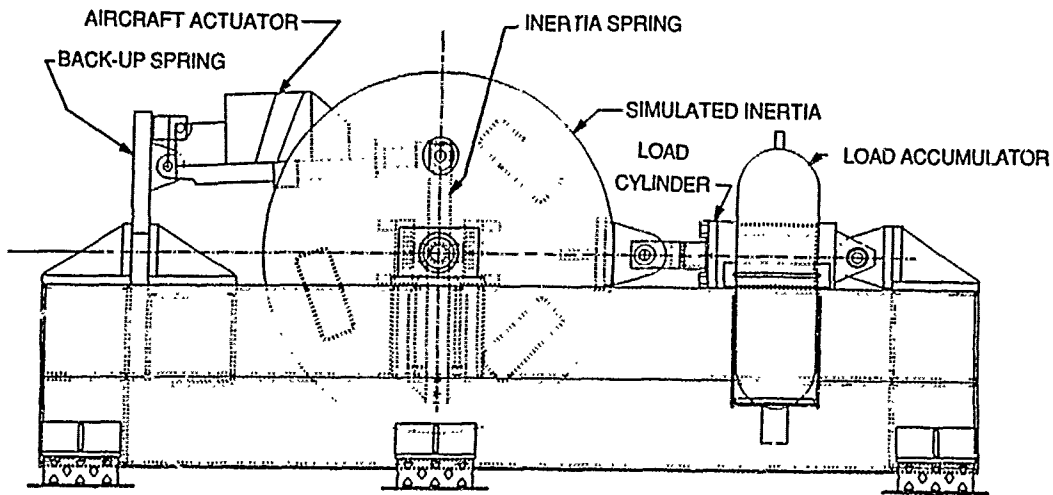


Figure 63. Stablator Actuator Load Fixture with Inertia

first in the supplier's test program and then in the system endurance test. Typical linear and rotary type fixtures are shown in Figures 64 and 65 respectively. A third fixture, which will be used in the LTD, is shown schematically in Figure 66. This is a universal fixture which can be adapted to any linear actuator and provides all of the technical amenities of the primary fixtures. This fixture is a MCAIR capital asset and was used to demonstrate IRAD work on advanced actuation electronic control techniques.

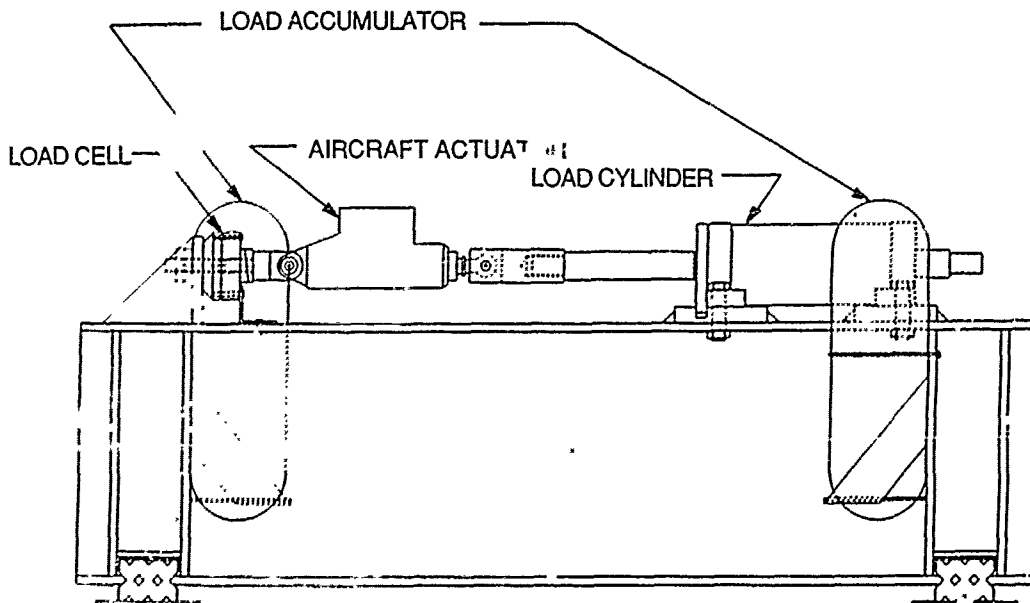


Figure 64. Linear Actuator Load Fixture

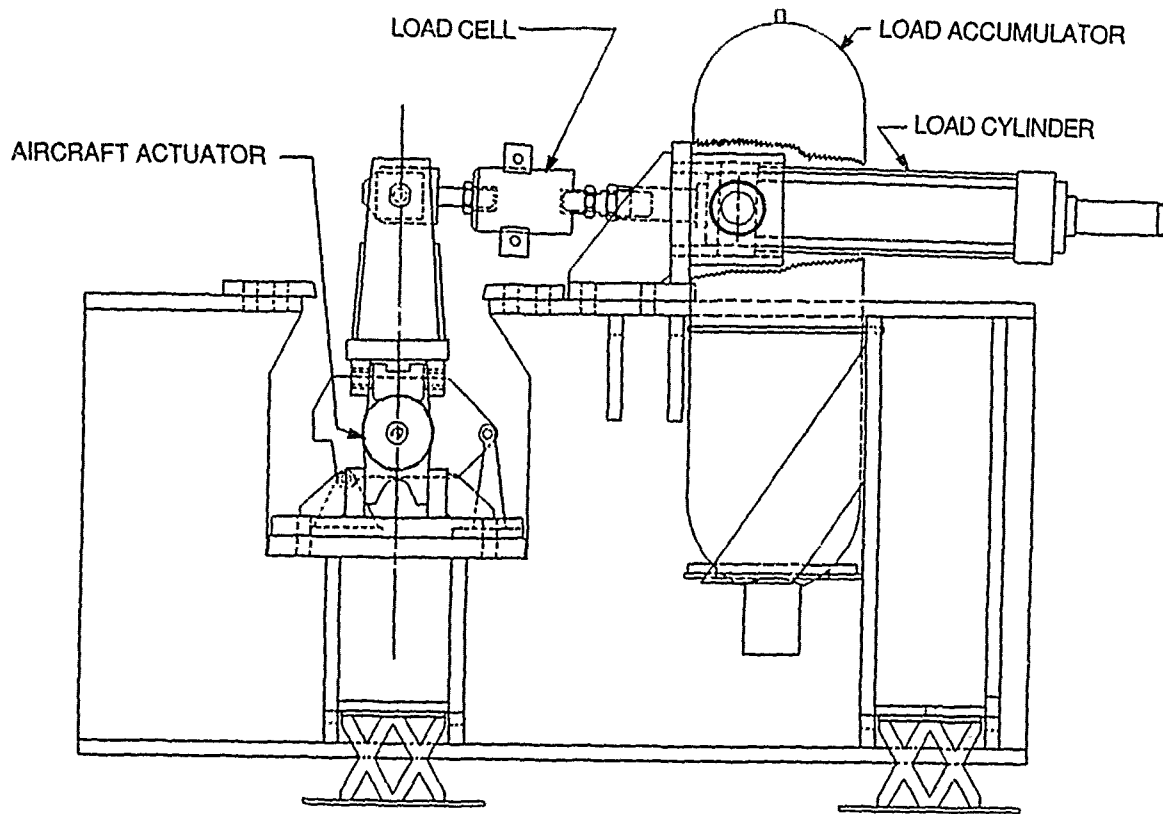


Figure 65. Rotary Actuator Load Fixture

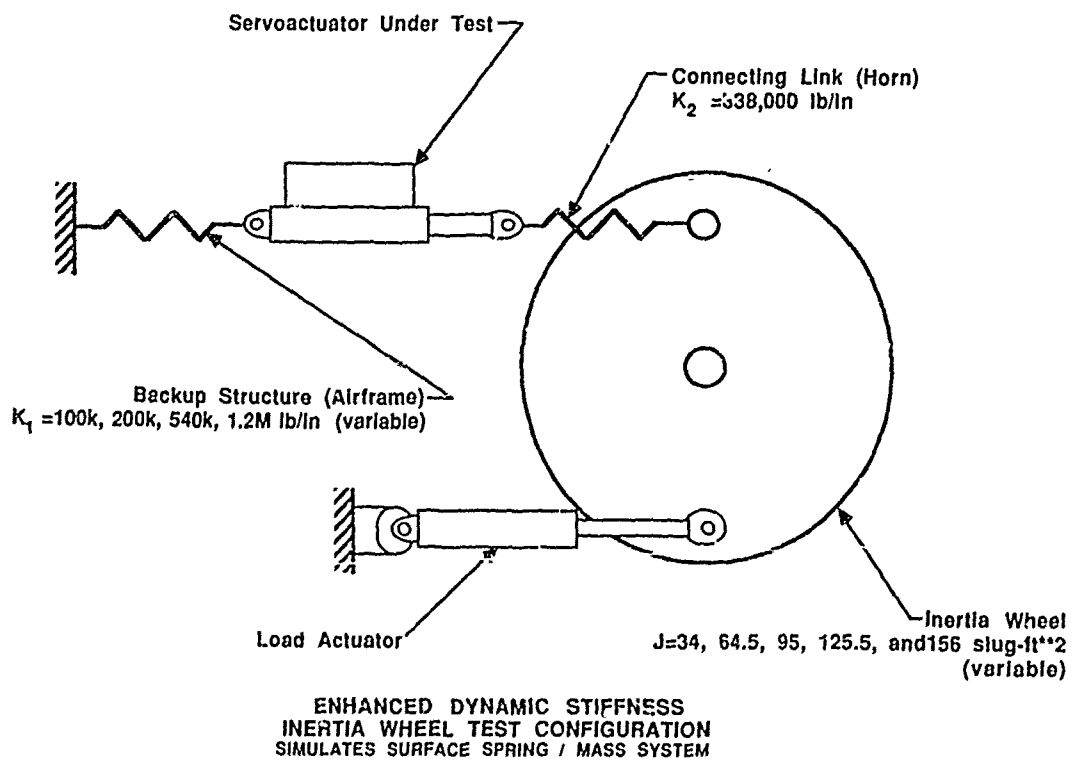


Figure 66. Universal Linear Actuator Load Fixture Schematic

4.1.5 Special Setups - One special setup will be included in the LTD to demonstrate advanced techniques for defeating the inherent loss of stiffness in 8000 psi servocylinders. This is a demonstration of an ongoing shared IRAD between MCAIR and E-Systems Montek Division. The test fixture for the aileron actuator, which was used as a stabilator actuator on the Low Energy Consumption Hydraulic Techniques program (LECHT), is a MCAIR capital asset. It is provisioned with surface inertia, which can be varied, has simulated structural backup springs and air load simulation. The axle of the inertial wheel is fitted with provisions so a four channel surface position and velocity transducer can be used to provide angular position, velocity and acceleration. These parameters were used for the LECHT program in the control loop architecture to enhance servovalve performance. The expanded feedback loop eliminates the effects of the structural springs between the hydraulic cylinders and the surface spindle.

4.1.6 Control Systems - The equipment control systems are equal in criticality to the equipment they control. Without these systems, the hydraulic equipment cannot be properly interfaced with the flight control computer. These electronic controllers are being provided by the respective suppliers of the hydraulic equipment.

a. Control Room - The control room has been designed with high priority on pump power control. The master control panel allows operation of three systems simultaneously or separately to simulate failure condition. The pump speeds can be controlled for a particular start up sequence and each pump can be operated at its rated speed. The drive capability is such that pump overspeed conditions can be achieved, enabling the pumps to be operated at a higher flow rate. Overpressure conditions can be simulated as well to verify relief valve function. The layout of the control panel is a factor in several safety features to enhance hydraulic power control. Each reservoir will be provisioned with a piston position sensor, Linear Variable Displacement Transducer (LVDT), to monitor reservoir fluid volume. In the event that a leak occurs upstream of the Reservoir Level Sensing (RLS) valving, low reservoir volume will be sensed by the LVDT and the requisite pump drive will be automatically shutdown to prevent destruction of the pump. Catastrophic pump failure normally results in the need to flush the central system of debris, and in the interest of maintaining time schedule and avoiding pump overhaul, RLS circuitry is very worthwhile. The pump drives can also be shutdown from a single switch on the panel, in the event of a major malfunction. Hydraulic power load is maintained by a central computer which is programmed for a controlled duty cycle.

b. Electronic Controllers - The electronic control boxes, which are being provided by each supplier whose equipment employs servovalves, have several functions to perform. Each unit was required to provide full scale response (stroke for actuators, pressure for pumps), when presented with an input command voltage of zero to ten volts dc. In addition, loop closure for position and stability was included as a required capability. For most of the items, it was also possible to vary loop gains. These adjustments will not be readily accessible on most of the controllers. Jacks were also provided to introduce failure modes in the redundant circuits. Typically, any given channel could be overridden as an open, a short or a hard over position command.

4.1.7 Data Systems - The LTD system will be instrumented so that all critical parameters are monitored and recorded. These parameters are outlined in the test plan and is included as Appendix B herein.

a. Test Monitoring - Instrumentation pickups will be located as near as practical to the component ports to ensure optimum readings. Pump parameters will include torque measurements using a Lebow torsional measurement system. Pump supply pressure and case drain temperature and pressures will utilize a Cyber signal conditioner to ensure accuracy. Instrumentation transducers used to monitor these and other critical parameters will have the following accuracies:

- o Pressure  $\pm 0.5\%$  full scale
- o Temperature  $\pm 2^\circ\text{F}$
- o Load Cells  $\pm 3\%$  full scale
- o LVDT  $\pm 0.5\%$  full scale
- o Flow  $\pm 1\%$  full scale (turbine flowmeter)
- o Pressure gages  $\pm 1\%$  full scale

b. Real Time Data Retrieval - Data will be recorded using a Neff differential multiplexer digital data acquisition system. Frequency response testing will be done for each pump on a component level and will utilize a Bafco recorder.

#### 4.2 TASK 3-2 - DEVELOP PRELIMINARY HAZARD ANALYSIS (PHA)

A preliminary hazard analysis was performed and has been included herein as Appendix C. This effort did not show any increase in hazard level from the increased pressure or the heavier fluid. An increased level of safety existed because of the elimination of a fire hazard from a fluid leak in any of the aircraft type circuits. There was a small residual fire hazard because flammable fluid was used in the test fixture loading systems, however, the risk was extremely small because the equipment was commercial grade and had a large margin of safety. There had been concerns over the past several years that a high pressure leak with the heavier CTFE fluid could actually cut through sheet metal. There is in fact, less kinetic energy to do damage. The high pressure dissipated through the same leak path, actually atomizes the fluid more completely and the kinetic energy is near zero. However, any fluid discharged at high pressure through a properly shaped nozzle is extremely dangerous. In this context, working with high pressure equipment in a development and test laboratory environment, continues the risk of injecting fluid into the skin if discharged through a hole that has a low discharge coefficient.

4.3 TASK 3-3 - ESTABLISH PERFORMANCE AND/OR DESIGN CRITERIA FOR ALL COMPONENTS

4.3.1 Procurement Specifications - Most of the equipment which was designed, and is being fabricated for this program, had performance requirements and design criteria defined in advance of issue of the Contract Request For Proposals (RFP). This was required to solicit bids from potential subcontractors and to establish related program costs for making a proposal. In most instances, exacting performance requirements were available in this time frame because the base line aircraft, the F-15 SMTD, was well into the design definition phase. Previous programs, related to high pressure nonflammable systems, had given a technology base for structural design requirements and other requirements related to power efficient technologies. The larger level of effort implied in this task description, was already accomplished and declared in the technical proposal. A list of Procurement Specifications written for procurement and carried into the procurement phase is shown in Figure 67.

P/N	DESCRIPTION	SUPPLIER
71-136901	Aileron Servocylinder	MOOG
71-136904	Diffuser Servocylinder	Cadillac Gage
71-136907	Nozzle Servocylinder	MOOG
71-136908	Pump	Abex
71-136909	Pump	Bendix Fluid
71-136910	Filter Manifold	APM
71-136912	Motor, Utility	Abex
71-136913	Valve, HIM	Parker Aerospace
71-136915	Valve, 4W-3P	Parker Aerospace
71-136917	Valve 3W-2P	Parker Aerospace
71-136918	Pump	Vickers
71-136919	Heat Exchanger	UAP
71-136920	Rudder Servohinge	HR Textron
71-136921	Reservoir	Metal Bellows
71-136922	Intensifier	Parker Aerospace
71-136925	Valve, Relief	Brunswick
71-136928	Valve, Shuttle	Parker Aerospace
71-136930	Switch, Pressure	ITT Neo Dyn
71-136931	Transmitter, Pressure	Consolidated
71-136932	Valve, Pneumatic	Brunswick
71-136934	Stabilator Servocylinder	E-Systems
71-136936	Accumulator	Parker Aerospace
71-136937	Rudder Servohinge	Bendix Electroynamics
71-136938	Reverser Servocylinder	Parker Berteau
71-136939	Reservoir	Parker Aerospace
71-136940	I.E. Flap System	Sundstrand
71-136941	Filter Manifold	PTI
84040102	Acoustic Filter	Pulsco

Figure 67. Procurement Specifications and Suppliers

4.3.2 Supplier Initiated Changes - The many improvement changes, detail definition of equipment characteristics and test requirements that occurred after detail work by the suppliers and internal studies at MCAIR, made it necessary to revise all of the specifications to align with the equipment as they evolved. This task was then dedicated to accomplishing those revisions and summarizing the equipment requirements.

4.3.3 Performance Parameters - The hydraulic performance parameters for the subcontracted hydraulic equipment are, in most cases, equivalent to F-15 SMTD requirements. There is however, some equipment, such as the diffuser ramp actuator, where weight optimization has been extended with the use of advanced high technology materials. These differences have not affected weight comparisons significantly.

4.3.4 Control Characteristics - Figure 68 shows the force motor characteristics for the various hydraulic items. The equipment has the same level of redundancy as the F-15 SMTD, including all of the flight control force motors which have redundant control circuits. The stabilator and canard actuators are quadruplex and the remainder are duplex. Figure 69 shows many of the characteristics of the direct drive valves for comparison.

PARAMETER	VALUE
Coil Resistance Per element	9.32 ohms
Coil Resistance Per Channel	18.64 ohms $\pm$ 0.76
Rated Current Per Channel Quad Channel Operation *	0.25 amps
Rated Power Quad Channel Operation (0.25 amp/Channel)	1.165 watts/Channel
Rated Power Dual Channel Operation (0.5 amp/Channel) **	4.66 watts/Channel
Maximum Power for Chip Shear Operation (0.75amp/Channel) *	42.0 watts Total
Maximum Continuous Current, Quad Channel Operation	0.5 amps/Channel

\* In order to minimize power for normal operating mode, the required current per channel is 0.25 amp. For this reason, the chip shear current is three times the normal operating mode, or 0.75 amp per channel, in order to produce 48 pounds at maximum travel.

\*\* Provides full performance after two electrical channel failures.

Figure 68. Force Motor Characteristics



Parameter	Units	Duplex/Single Stage			Quadruplex	
		Rotary/Rotary	Rotary/Linear	Linear/Linear	Rotary/Linear Single Stage	Linear/Linear Two Stage
Rotation	(Deg)	± 10	± 25	-	± 25	-
Eccentric Arm	(In)	.188 <sup>①</sup>	.029	-	.065	-
Valve Stroke	(In)	± .033	± .0125	± .025	± .030	± .025
Valve Force (Includes Springs- All Channels @ Max Current)	(Lbs)	86	86	80	119	1280/60 <sup>③</sup>
Rated Current	(Amps/Coll)	.89	.72	.37	.4	.37
Total Input Power	(Watts)	114	69	47	110	47
Coll Resistance @ 68 °F	(Ohms/Coll)	15	12	20	4.2	9.75
Number of Coils		4/2 <sup>②</sup>	2	2	4	4
Bandwidth @ /90 °	(Hz)	28	65	68	180	68
Power Density	(Watts/in <sup>3</sup> )	1.36	3.66	1.53	2.16	.515
Reliability	(MTBF)	43,956	37,724	27,933	52,037	29,542
Complexity/Cost		High	Moderate	High	Moderate	High
Weight	(Lbs)	5.5	2.8	8.02	9.6	15.3

1. Spool Radius
2. 4 Coils, 2 Channels
3. 2nd Stage/1st Stage

Figure 69. Direct Drive Valve Comparison

4.3.5 Structural Design Factors - Structural integrity of the component pressure vessels, required careful consideration of the design margin of safety required by the procurement specifications. Past programs clearly identified that much lower design factors for proof pressure and burst pressure can be used for 8000 psi components, ie., 16,000 psi burst pressure. Figure 70 shows the various design factors for the equipment. The selection of 17,000 psi for burst pressure had two rationale. The principal rationale was that the primary criteria for pressure vessel integrity be fatigue life. Past studies have shown that this criteria calls for a burst pressure design factor of 2.14 times system pressure regardless of the system pressure level. As a secondary consideration, the components which, for redundancy management purposes, are of a tandem arrangement (stabilator, canard and aileron), have a unique failure mode to be considered. When operating with only one system, it is possible to cavitate one cylinder, resulting in the unit having a minimum capability to react to the airload. Since the actuator is designed to react to the design load with two systems operating, the same design loads with single system operation could produce double system pressure in the active cylinder. Therefore, the higher burst factor gives an added safety margin in the event of losing a system when operating at fully loaded conditions.

	Hydraulic Equipment		Pumps	
	Pressure psi	Factor of Safety	Pressure psi	Factor of Safety
Operation	3000 - 8000	-	3000 - 8000	-
Surge	8800	-	N/A	-
Proof	10,000	1.25	10,000	1.25
Burst	17,000	2.14	12,000	1.50

Figure 70. Structural Design Factors

#### 4.4 TASK 3-4 - PLAN DETAILED COMPONENT ACCEPTANCE AND QUALIFICATION TEST REQUIREMENTS

To have a complete and comprehensive definition of test requirements so that the suppliers could provide quotations of program cost, the procurement specifications previously described in paragraph 4.3.1 identified the requirements for tests which would be required for equipment to be installed on flight vehicles. Many of these test requirements were used for design parameters. Only those test requirements which were considered directly related to 8000 psi nonflammable fluid design technology were imposed as actual tests to be performed. Typical acceptance test requirements are shown in Figure 71. Similarly, the demonstrator worthiness test requirements are shown in Figure 72. Typically, the tests that were performed were performance, proof pressure, impulse testing, endurance and a burst test, where hardware assets permitted.

4.4.1 Test Support Requirements - Test requirements, in general, had a broader implication on program cost and schedule than originally anticipated. There were several factors that required special attention and consideration.

- o 8000 psi and/or CTFE test bench capability (lack of)
- o Special test fixtures required
- o Cost of additional hardware
- o Laboratory assets to support Odd/Even line sizing
- o Impulse test capability (lack of)
- o Burn-in tests to ensure high quality

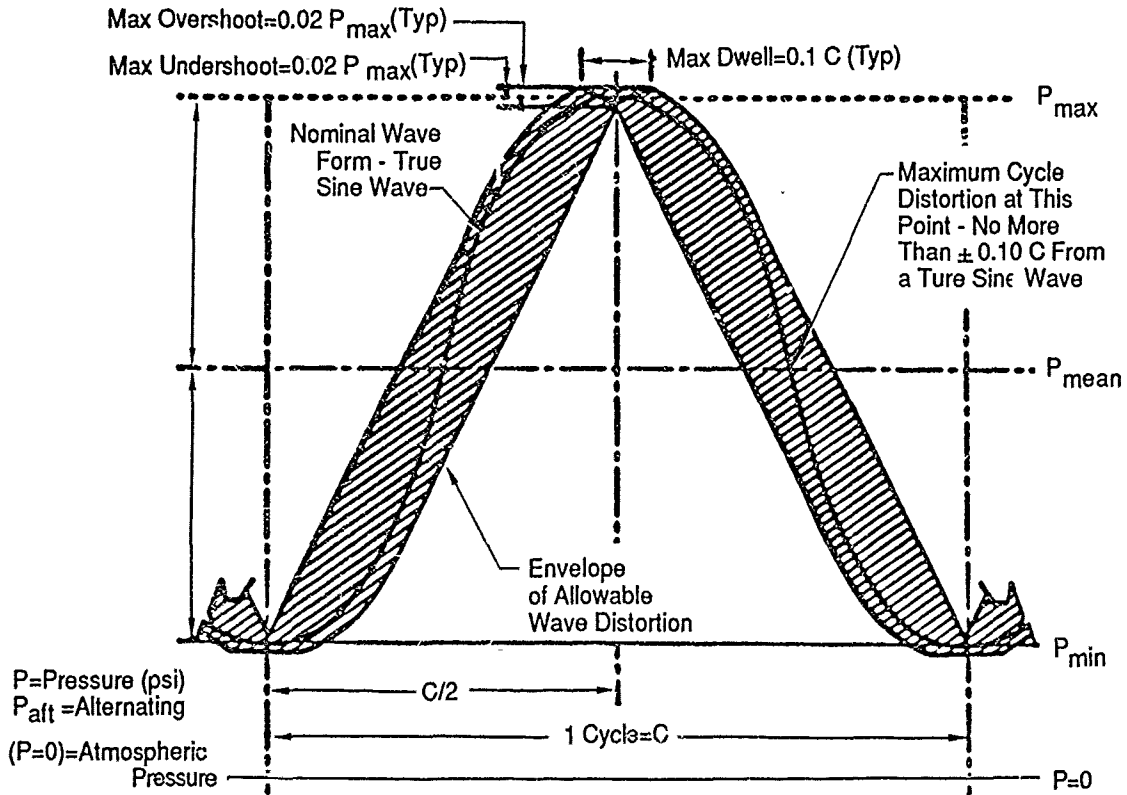
	Examination of Product	Proof Pressure	Rated Flow and Pressure Drop	Leakage	Functional/Performance	Operations/Break in	Mechanisms	Electrical	Calibration
Pumps	✓	✓		✓	✓	✓		✓	✓
Filter Manifolds	✓	✓	✓				✓		
Reservoirs	✓	✓	✓	✓		✓			✓
Servoactuators	✓	✓		✓	✓	✓	✓	✓	✓
Hydraulic Integrity Monitor	✓	✓	✓	✓		✓			
Intensifiers - Hydraulic Pressure	✓	✓		✓		✓			
Hydraulic Motor	✓	✓		✓	✓	✓		✓	
Hydraulic Valves	✓	✓	✓	✓				✓	

Figure 71. Acceptance Test Requirements

	Acceptance Test (Preliminary)	Impulse Cycling	Inspection	Endurance/Life Cycling	Performance	Calibration	Pulsation	Proof Pressure	Acceptance Test (Final)
Pumps	✓		✓	✓	✓	✓	✓	✓	
Filter Manifolds	✓	✓		✓				✓	
Reservoirs	✓	✓		✓				✓	
Servoactuators	✓	✓		✓	✓			✓	✓
Hydraulic Integrity Monitor	✓	✓	✓	✓					✓
Intensifiers - Hydraulic Pressure	✓	✓	✓	✓					✓
Hydraulic Motor	✓	✓	✓	✓	✓				✓
Hydraulic Valves	✓	✓		✓	✓			✓	✓

Figure 72. Demonstrator Worthiness Test Requirements

The equipment specifications deviated from previous efforts for impulse (fatigue) testing. Rather than having an impulse test with a specified number of shaped spike impulses, this program imposed a greater number of cycles of pure sinusoidal pressure waves having reduced and varied amplitudes as shown in Figure 73. This approach has a tighter scatter band and produces fatigue



Port Application	Impulse Pressure and Number of Cycles			
	P <sub>min</sub> to P <sub>max</sub>			
	0 to 8000	2000 to 8000	4000 to 8000	0 to 2000
Press Port	$5 \times 10^4$	-	$9.95 \times 10^6$	-
RTN Port	-	-	-	$10^7$

Figure 73. Sine Wave Impulse Test Requirements

data which can be used for analysis. The test method also differs in failure criteria. With the former approach, the success criteria was to pass the test without failure. With sinusoidal impulse, with more cycles that are less severe, the object was to test to failure. This served to identify weak points in the design and allowed evaluation of the consequences to determine if correction would be required.

#### 4.5 TASK 3-5 - DEVELOP OPERATION AND SUPPORT HAZARD ANALYSIS (OASHA)

An Operation and Support Hazard Analysis (OASHA), has been developed to ensure that the LTD operating procedures will guarantee a safe environment for the operating personnel. This document was submitted and is included as Appendix D. The conclusions of the analysis are presented herein.

4.5.1 Introduction - The 8000 psi test system program was reviewed by qualified system safety engineers to identify and assess hazards control by personnel associated with the LTD and the use of hydraulic fluid system pumps, plumbing, fluid, accumulators, actuators and environmental test chambers. The emphasis was placed on systems and procedures to prevent personnel injury during operations. The PHA, described earlier, was limited to potential hazards associated with the personnel, test equipment, test installation, operation and facility at McDonnell Douglas. Results of the PHA were used to guide the OASHA.

4.5.2 Objective and Scope - The primary concern of the analysis was to identify personnel controls and procedures to eliminate or reduce, to an acceptable risk level, any potentially hazardous problems with an 8000 psi nonflammable hydraulic power system. The OASHA was conducted to identify procedures, regulations, system operating conditions, and facility enhancements to negate potentially hazardous elements and conditions. With the hazards identified, the design and/or the safety procedures could be modified to eliminate or reduce the risks. This analysis was based on the system being used in the LTD.

4.5.3 Review Of Significant Factors - Biotechnological factors were considered for the effects of hydraulic fluid vapors, since both types of fluids, MIL-H-83282 and CTFE, will be present and small leaks will produce vapors. Since the demonstrator is located in an open hanger environment, concentration of vapor which could support a health hazard is unlikely. However, since CTFE fluid is relatively new and the effects of long term exposure have not been established, operating personnel are cautioned to avoid exposure to vapors. The fluid is a light amber color which makes small leaks difficult to detect except for wetting of surfaces. High system temperature may cause other hazardous effects, such as possible seal degradation and leakage, which could result in burns and inhalation of CTFE vapors.

The CTFE hydraulic fluid requires no special handling. Because it can evaporate at elevated temperatures (greater than 110°F), spills should be cleaned up immediately. Any contaminated fluid which is deemed unsuitable for use in the LTD or the subcontractors test facilities, will be returned to the Air Force for reclamation.

a. Pump Control Panel - Typically, tests are conducted from the hydraulic pump control panel. When seated or standing at the pump control panel, the operator has a complete view of the test area. Only one pump operator is designated per shift. Prior to starting the pumps, it is the operator's responsibility to ensure that all work personnel are clear of the test area and that the LTD is capable of being pressurized. The operator is required to perform a walk around of the facility to look for leaks, check reservoir levels, filter status, condition of test setups and remove misplaced articles. Pressure switches are installed that will not allow pumps to be started unless there is reservoir pressure. This is to ensure a measure of safety to protect the pumps from damage. Pumps are started at low speed and slowly increased until a stable operating speed is reached. Two pumps are controlled on one speed control. However, a differential control pot allows the Primary Controls pumps to operate at a reduced speed ratio to the Utility pumps. A master kill switch (button), is placed on the console which will immediately cut electrical power to all drive motors simultaneously. All personnel assigned to the control room will be aware of the master kill switch and will be authorized to engage it in the event an individual detects an apparent hazard.

b. Pump Room Noise Protection and Ventilation - The electric drives, pumps, filter manifolds and reservoirs will reside in an acoustic enclosure that will be provisioned to eliminate the extremely intense noise level of the pumps. Windows will be provided, allowing the operator to determine if the room is occupied. A room electrical capacitance system provides leak detection in the piping circuits which are not protected by the systems RLS valves. An outside ventilation system also serves the pump room.

c. Communication Techniques. It is often necessary to operate systems with personnel on the lab floor to make adjustments to instrumentation with the system pressurized. Procedures have been established wherein wireless headsets are used for two-way communication between the system operator and engineering technicians on the lab floor. In addition, the operator monitors the floor activity visually for the entire period.

d. Personnel Training - The personnel who are being assigned to the laboratory fall into three job classifications. Test engineers will have the responsibility for conducting the tests. Laboratory technicians will be assigned to assist with instrumentation work, conducting the tests and performing data retrieval. Manufacturing shop personnel are being assigned as required to remove and install equipment and plumbing. Safety training is a routine procedure. Eye wash and emergency shower facilities are located near the LTD facility. Shop personnel are experienced in the proper procedures for attaching hydraulic fittings, lines and hoses. They are also familiar with typical equipment or tubing damage which would constitute a hazard.

4.5.4 Results - No catastrophic hazards introduced by personnel or facilities were identified by this analysis. The only critical hazards identified in the PHA were associated with potential for test personnel injury from fluid spray, fragments from failed components, or contact with moving components. As identified in the PHA, injury could occur from mechanical failure of the actuators, hydraulic pumps, plumbing or fluid lines. Hydraulic

systems utilizing 8000 psi have only a slight increase in personnel injury risks over existing systems using 3000 psi. Studies indicate that a line failure, component failure, etc., causing a fluid leak at 8000 psi, is no more likely to cause injury to proximate personnel than line failures at 3000 psi.

4.5.5 Summary - The OASHA concluded that all risks identified in the PHA could be adequately controlled with the operating procedures, regulations and facilities which are currently in place. No critical single point system failures were identified in the PHA. Furthermore, no risks were identified during the PHA which were not adequately addressed for personnel interaction and procedures.

#### 4.6 TASK 3-6 - ESTABLISH DETAILED TEST PROCEDURES FOR LTD AND TEST PLAN TO DEMONSTRATE REPAIR TECHNIQUES DUE TO BATTLE DAMAGE

4.6.1 Test Equipment/Instrumentation Shakedown - The first tests performed on the LTD will ensure that the instrumentation and loading systems in the jigs and fixtures are working properly and within calibration. This is very crucial work necessary to make certain that the hydraulic equipment will not be overloaded or otherwise damaged and that the test results can be validated. It is also paramount to prevent against injuries to personnel when the equipment is first operated. During this effort, lab personnel will become thoroughly familiar with the electronic controllers which are being built for the test program by the equipment suppliers. Although the controllers are similar in form, fit and function, there are differences which must be recognized and documented with labels or special instruction sheets to ensure that program personnel operate the equipment properly.

4.6.2 Equipment/System Shakedown and Leak Check - After the instrumentation and loading systems are verified to be operating properly, the systems will be operated from the "ground" power unit. This is a precautionary measure to prevent a large oil spill in the event a joint has been left open. The system will be pressurized to a lower level, 3000 psi, and a thorough leak check of the systems will be performed. Air can be bled from the LTD by powering the systems with the ground cart operating open loop, (its reservoir vented to the atmosphere). Once the system is "hardened" up and all free air is bled from the system, the LTD will be flushed with a minimum of ten gallons of CTFE fluid. Flushed fluid from an aircraft would normally be discarded. However, fluid flushed from the LTD will be cleaned and recycled by the Air Force. The system will then be filled with fully formulated CTFE. This phase of the test effort will be culminated by powering the central system pumps and verifying stable operation at the correct operating pressure. After about an hour of operation, the system filters will be removed and inspected for debris. Filter bowls will be cleaned and reinstalled with new elements.

4.6.3 Performance Verifications - After the instrumentation, loading systems and the test systems have been verified, each piece of equipment will be tested for its particular installed performance requirements. Normally, several items could be tested simultaneously.

a. Hydraulic System Transient Test - The hydraulic system will be subjected to a transient test by operating and reversing all actuators at maximum no-load rates. This is accomplished on the longitudinal, lateral and

directional control systems to determine the transient pressures throughout the power control systems. The nozzle system inputs will be rapidly reversed to determine the utility system transients.

b. Pump Pulsation Test - Pressure transducers can be inserted in the pump-to-filter hydraulic lines and a spectrum analyzer used to ensure that pump pulsations will not cause hydraulic line fatigue and failure. This can be accomplished at all four pump areas.

c. Control System Static Gain and Hysteresis - A static gain and calibration test is performed on all aircraft actuators located in the short jigs. This includes the eight nozzle actuators, one inlet ramp actuator, and actuators for the stabilator/canard, rudder, aileron, flaperon and leading edge flap. This test will provide actuator position vs. electrical input. A hysteresis test will also be performed on the actuators located in the short jigs.

d. Control System Frequency Response - A frequency response test can be performed on the three control systems (longitudinal, lateral and directional), using a simulated stick signal and control surface position. The nozzle system frequency response tests are performed using the nozzle control system and simulated load positions. A diffuser ramp actuator frequency response test will also be performed.

e. Electrical Threshold Test - An electrical threshold test determines the lowest input required to achieve a measurable output. This will be accomplished for all three control systems, the nozzle system and the inlet system.

f. Heat Rejection Test - A heat rejection test is to be performed on a pump from each subcontractor. This involves measuring the pump input torque, speed, case drain flow and system leakage flow. All four pump installations will have provisions for measuring these required parameters.

g. Stability Test - The three control systems will be subjected to step inputs ranging from 5 percent to 75 percent of surface travel, then the systems will be instrumented to record the surface positions, and the data will be analyzed for signs of erratic motion or any instability. The nozzle and inlet systems will also be subjected to a stability test.

4.6.4 Engine Nozzle Thermal Testing - The engine nozzle test fixture has been designed to be capable of accepting thermal enclosure covers over the actuators. It had been originally planned to conduct high temperature testing on a system level, however funding constraints and certain unresolved technical questions on CTFE in the program time frame precluded the procurement of a thermal chamber or exposure of CTFE to surfaces heated above its dissociation temperature.

4.6.5 Failure Modes and Effects Test - Simulated LTD system and component failures will be initiated to analyze and record the effects on other components and portions of the system. The HIM, reservoir level sensing circuits and the shuttle valves are to be exercised sufficiently to demonstrate hydraulic circuit redundancy and aircraft survivability issues.



4.6.6 Endurance Test - The 500 hour endurance test is to demonstrate the reliability of the hydraulic equipment. Representative mission profiles of 120 minutes each, repeated successively, will be performed under a variety of simulated air loads and thermal environments. The hydraulic system will be shutdown (pump drives deactivated), the Jet Fuel Starting (JFS) accumulator and start motor exercised, and the system started up between each 90 minute mission. This shutdown and start up provides a realistic hydraulic system environment, including pressure and thermal cycling, to accurately assess supportability issues.

a. Operating Duty Cycle - A duty cycle profile has been established and is shown in Figure 74. This duty cycle was established after the Phase I Oral Presentation and was based on actual flight control duty cycles from a reduced stability aircraft and an unstable flight aircraft. Control of the variable pressure pump was a key issue for the LTD test phase.

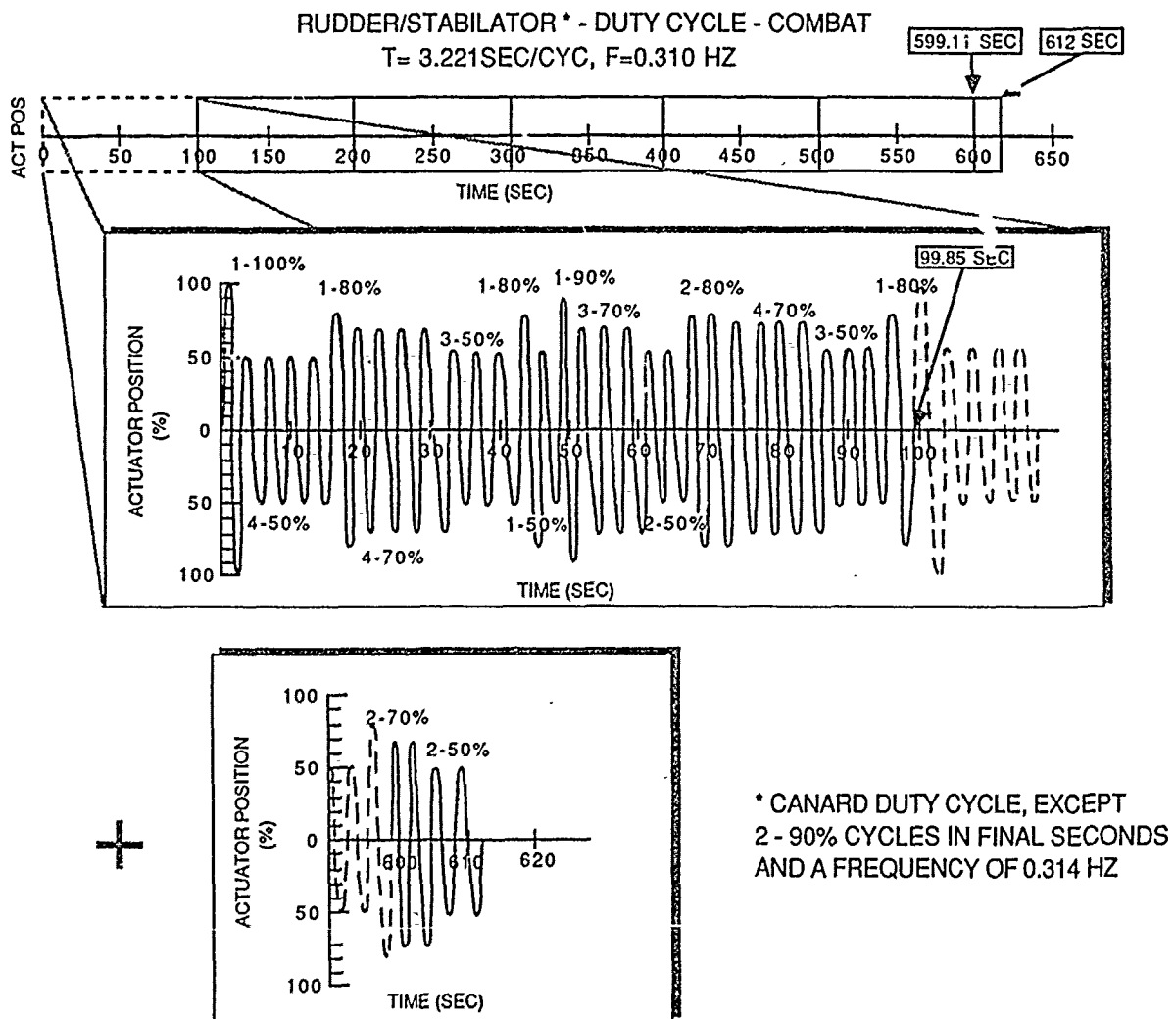


Figure 74. Duty Cycle Profile  
 100 Seconds of Combat Phase

b. Simulated Air Loads - Simulated air loads are being applied to all of the left hand flight weight servoactuators, varying from 0 percent to 100 percent of the actuator stall load. A typical loading diagram is shown in Figure 75 as applicable to the stabilator actuator. The loads are to be applied in accordance with the duty cycle shown in Figures 76 through 78.

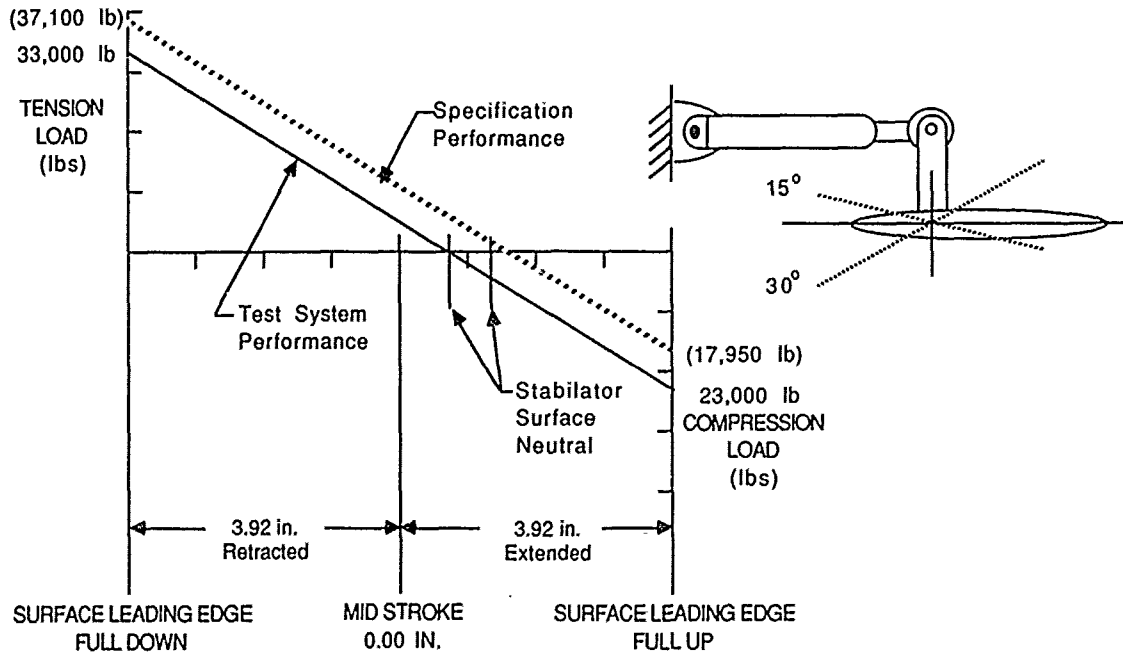


Figure 75. Typical System Loading Characteristics

Component Title and Function	PS No. (71 13)	Mfg. Part No	Usage	System	Qty	Stroke (in)	Bore (in)	Rod Dia. (in)	Tail Dia. (in)	Effective Area (in <sup>2</sup> )				Diff. Vol (in <sup>3</sup> )	Force Output (lbs @ 7900 psi)		No Load Velocity (in/sec)		Flow Rate (gpm)				
										System 1		System 2			Ext	Ret	Ext	Ret	Ext	Ret	Ext	Ret	
										Ext	Ret	Ext	Ret										
Aileron	6901-101	Deleted	L/H	PC-2A2																			
				PC-1C1																			
				PC-2C1																			
	LECHT Sab (FAST)	Parker Berteau 330400ADP	R/H	PC-1A2	1	7.77	2.369	1.622							2.341	2.341			18494	18494	8.2	2.50	2.50
Flaperon	6935-101	MOOG L-4797 -103 Simulator	L/H	PC-2A2																			
				PC-1B1																			
				PC-2B1																			
			R/H	PC-1A2	1	1.42	1.76	1.249							1.208	1.208			9543	9543	3.33	1.04	1.04
Stabilator (FAST)	6934-101	E-Systems	L/H	PC-2C2																			
				PC-1B1																			
				PC-1C2																			
			R/H	PC-2B1	1	7.77	2.286	1.498	1.123	3.114	2.342			2.342	2.342	6.00	18502	18502	8.2	2.50	2.50		
Canard (FAST)	6902-101	HR Textron	L/H	PC-2B2																			
				PC-1C1																			
				PC-1B2																			
			R/H	PC-2C1	1	7.77	2.286	1.498	1.123	3.114	2.342			2.342	2.342	6.00	18502	18502	8.2	2.50	2.50		
Rudder	6920-101	HR Textron	L/H	PC-1B1	1	60°	2.125	1.50		1.766	1.766												
	6937-101	Bendix Electro	R/H	PC-2B1																			
PC-1 TOTALS					8					7.994	6.45	8.233	8.233	12.00								17.5	15.5
BACKUP SYSTEM																							
Convergent Flap	6907-201	MOOG	L/H	UT-C3	2	10.04	2.47	1.436	1.03	3.958	3.172			15.78	31270	25059	7.2*	14.8	11.9				
Divergent Flap (PRA)	6907-205	MOOG	L/H	UT-C3	4	15.25	1.93	1.374	1.03	2.09	1.443			39.47	5111	11400	11.8*	7.93	17.7				
Reverser Vane	6938-101	Parker Berteau	L/H	UT-C3	2	2.00	1.64	1.122	0.326	1.439	1.124			1.26	11368	8879	4.00*	2.99	2.34				
Arc Valve	6938-103	Parker Berteau	R/H	UT-C3																			
TOTALS					16					15.48	12.19	8.233	8.233	68.51								43.2	47.4

Figure 76. Actuator Data  
PC-1 System Loads

\* These units are in degrees or degrees/second  
^ Rate limited up to at least 2/3 stall load  
(PRA) Pressure Regenerative Actuator  
(FAST) Flow Augmented Servovalve Technology

Component Title and Function	PS No. (71 13)	Mfg. Part No	Usage	System	Qty	Stroke (in)	Bore (in)	Rod Dia. (in)	Tail Dia. (in)	Effective Area (in <sup>2</sup> )				Diff. Vol. (in <sup>3</sup> )	Force Output (Lbs@7500 psi)		No Load Velocity (in/sec)	Flow Rate (gpm)	
										System 1		System 2			Ext	Ret		Ext	Ret
										Ext	Ret	Ext	Ret						
Aileron	6901-101	Deleted	L/H	PC-2A2															
	LECHT Stab (FAST)	Parker Berteau 330400ADP	R/H	PC-1C1 PC-2C1 PC-1A2	1	7.77	2.369	1.662	1.242	3.196	2.341			6.64	25248	18494	8.2	3.50	2.50
Flaperon	6935-101	MCOG L-4797 Simulator	L/H	PC-2A2	1	1.42	1.76	1.249	0.749	1.992	1.208			1.11	15734	9543	3.33	1.72	1.04
	-103		R/H	PC-1B1 PC-2B1 PC-1A2	1													1.21	1.21
Stabilator (FAST)	6934-101	E Systems	L/H	PC-2C2	1	7.77	2.286	1.498	1.123	3.114	2.342			6.00	24600	18502	8.2	3.50	2.50
	(FAST)		R/H	PC-1B1 PC-1C2 PC-2B1	1	7.77	2.286	1.498	1.123	3.114	2.342	2.342	2.342		18502	18502	8.2	2.50	2.50
Canard (FAST)	6902-101	HR Textron	L/H	PC-2B2	1	7.77	2.286	1.498	1.123	3.114	2.342			6.00	24600	18502	8.2	3.50	2.50
	(FAST)		R/H	PC-1C1 PC-1B2 PC-2C1	1	7.77	2.286	1.498	1.123	3.114	2.342	2.342	2.342		18502	18502	8.2	2.50	2.50
Rudder	6920-101	HR Textron	L/H	PC-1B1	1	60°	1.594	1.00	7.125	4.232	4.232								
	6937-101	Bendix Electro	R/H	PC-2B1	1	60°	1.594	1.00	7.125	4.232	4.232				21682	21682	105°	1.31	1.31
PC-2 TOTALS					8					15.65	12.47	4.684	4.684	19.75				19.7	16.1

BACKUP SYSTEM

Convergent Flap	6907-207	MCOG	L/H	UT-C3																
Divergent Flap (PRA)	6907-205 -209	MCOG	L/H	UT-C3	1														7.93	17.7
Reverser Vane	6938-101	Parker Berteau	L/H	UT-C3	2	2.00	1.64	1.122	0.926	1.439	1.124			1.26	11368	8879	4.00*	2.99	2.34	
Arc Valve	6938-103	Parker Berteau	R/H	UT-C3	2	7.34	1.712	1.122	0.926	1.628	1.313			4.62	12861	10373	7.34	6.21	5.01	
TOTALS					13					18.72	14.9	4.684	4.684	25.63				36.9	41.1	

\* These units are in degrees or degrees/second  
 ^ Rate limited up to at least 2/3 stall load  
 (PRA) Pressure Regenerative Actuator  
 (FAST) Flow Augmented Servovalve Technology

Figure 77. Actuator Data  
PC-2 System Loads

Component Title and Function	PS No. (71 13)	Mfg. Part No	Usage	System	Qty	Stroke (in)	Bore (in)	Rod Dia. (in)	Tail Dia. (in)	Effective Area (in <sup>2</sup> )				Diff. Vol. (in <sup>3</sup> )	Force Output (Lbs@7900 psi)		No Load Velocity (in/sec)	Flow Rate (gpm)	
										System 1		System 2			Ext	Ret		Ext	Ret
										Ext	Ret	Ext	Ret						
Diffuser Ramp Utility Act	6904-101	CadPac Gage	L/H	UT-A	1	10.18	2.08	1.434		3.40	1.783			16.45	26844	14086	7.5/5	0.66	0.23
	-103		L/H	UT-A	1	10.18	2.08	1.434		3.40	1.783			16.45	26844	14086	10.18	9.00	4.71
Leading Edge Flap PDU	6940-101	Vickers	L/H	UT-A	1														
	-103	Garrett	R/H	UT-B	1														
Utility Functions 4W-3P Valve	6915-101	Parker	L/H	UT-A	1													10.7	2.70
		3860029	R/H	UT-B	1													3.15	0.25
			R/H	UT-B	1													10.7	4.73
JFS Motor 3W-2P Valve	6912-101	Abex	R/H	UT-B	1														
Gun Motor 4W-3P Valve	6912-101	Abex	R/H	UT-B	1													10.2	10.2
Convergent Flap	6907-207	MCOG	L/H	UT-C3	2	10.04	2.47	1.436	1.03	3.958	3.172			15.78	31270	25059	7.2*	14.8	11.9
Divergent Flap (PRA)	6907-205	MCOG	L/H	UT-C3	4	15.25	1.93	1.374	1.03	2.09	1.443			39.47	5111	11400	11.8*	7.93	17.7
	-209		R/H	UT-C3	1													7.93	17.7
Reverser Vane	6938-101	Parker Berteau	L/H	UT-C3	2	2.00	1.64	1.122	0.926	1.439	1.124			1.26	11368	8879	4.00*	2.99	2.34
			R/H	UT-C3	2	2.00	1.64	1.122	0.926	1.439	1.124			1.26	11368	8879	4.00*	2.99	2.34
Arc valve	6938-103	Parker Berteau	R/H	UT-C3	2	7.34	1.712	1.122	0.926	1.628	1.313			4.62	12861	10373	7.34	6.21	5.01
Utility Totals					24					17.35	11.74	0	0	95.29				87.3	79.8

BACKUP SYSTEM

Stabilator (FAST)	6934-101	E-Systems	L/H	PC-2C2	1	7.77	2.286	1.498											
	(FAST)		R/H	PC-1B1 PC-1C2 PC-2B1	1	7.77	2.286	1.498				2.342	2.342		18502	18502	8.2	2.50	2.50
Rudder	6920-101	HR Textron	L/H	PC-1B1	1	60°	2.125	1.50	7.125	1.766	1.766								
	6937-101	Bendix Electro	R/H	PC-2B1	1	60°	1.594	1.00	7.125	4.232	4.232				21682	21682	105°	0.74	0.74
TOTALS					28					23.35	17.74	4.684	4.684	95.29				94.3	86.9

\* These units are in degrees or degrees/second  
 ^ Rate limited up to at least 2/3 stall load  
 (PRA) Pressure Regenerative Actuator  
 (FAST) Flow Augmented Servovalve Technology

Figure 78. Component Data  
Utility System Loads

c. Fluid Sampling - Fluid samples are to be taken at the start of the test and every 50 hours thereafter. Two samples will be obtained each time; one to be analyzed at MCAIR, and the other to be sent to WRDC/POOS for analysis by WRDC/MLBT personnel.

d. Supportability Records - Full documentation is going to be kept on maintenance and repairs with detailed failure analysis where applicable to conduct a supportability assessment. "On" time will be recorded, as well as a detailed record of all component failures.

4.6.7 Aircraft Battle Damage Repair (ABDR) - ABDR focuses on the need to repair an aircraft which is out of commission in a forward area where time and facilities do not permit a permanent repair that is factory authorized. The goal is to restore capability for completing one more mission or to be able to return the aircraft to a base where permanent repair can be made. This environment may require the wearing of Chemical Biological Warfare (CBW) outer clothing which makes handling of tools and fasteners very difficult. After completion of the 500 hour endurance test, the capability to make hydraulic line repairs and remove and install major equipment will be demonstrated.

a. Tubing Repairs - This effort will consist of at least two line repairs in extreme sizes, possibly 3/16 and one inch. The final selection will be based on repair fitting availability. Candidates for demonstration, include repair fitting designs by Aeroquip Linair, Raychem and Sierracin Harrison. Emphasis will be placed on inflicting some damage to the tubing which could not necessarily be repaired with a repair fitting alone, additional tubing will be required.

b. Equipment Installation - The second part of the demonstration is to remove and reinstall hydraulic components while wearing CBW gear. The components will be selected on the basis of requiring simple hand tools and being hampered by attached hydraulic lines.

4.6.8 Repair Integrity Test - Following completion of the ABDR demonstration, the systems will be operated for an additional 50 hours to demonstrate the integrity of the repairs. The same duty cycle used in the 500 hour endurance test will be used in the repair integrity test.

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## SECTION V

### PHASE IV - COMPONENT DESIGN, FABRICATION AND TEST

This Phase includes all of the engineering work associated with procurement of the subcontracted equipment. It entails the efforts associated with supplier coordination including selection of suppliers, design reviews, progress reporting, and test coordination.

#### 5.1 PHASE IV SCHEDULE

To produce a reasonable program schedule, it was necessary to begin Phase IV component design activities concurrently with Phase I, at the onset of the program. This was made possible by the maturity of both the test plan and the base line aircraft which was originally proposed.

#### 5.2 SELECTION OF EQUIPMENT

Equipment functions were selected from the F-15 SMTD Aircraft. To demonstrate other relevant technology and previously developed equipment, and to comply with the SOW, some other equipment has been added. Some items also have more stringent requirements than the base line aircraft would require.

#### 5.3 SELECTION OF EQUIPMENT SUPPLIERS

A host of suppliers participated in development of the program plan by providing cost quotes and design details to procurement specifications. Multiple suppliers have been selected for like equipment wherever possible for two reasons. The first reason, actually a goal in the program, was to spread the technology experience base in the industry. The second reason was to protect the program schedule.

#### 5.4 SUPPLIER LEVEL TEST PROGRAM

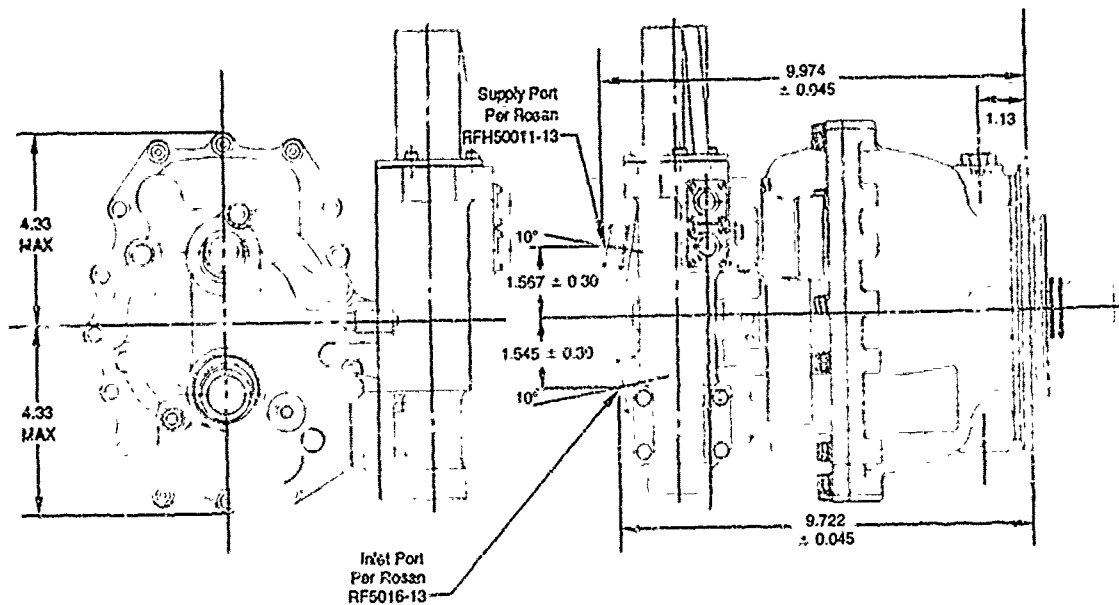
Concurrent with the development and laboratory system level testing at MCAIR, the suppliers in turn are conducting performance and endurance testing at their facilities. The tests which were required to be performed by each supplier are discussed in Section IV.

#### 5.5 DESCRIPTION OF EQUIPMENT

A detailed description of the test program at the suppliers' facilities will be provided in Volume II of this report. Also, the test results and discussion of problems encountered at both the suppliers' facilities and in the system level testing at MCAIR, will be included. A brief description is provided in this volume to provide continuity between the initial and final phases of the program. The descriptions included herein are intended to give a brief overview of the equipment designs. Volume II will have a more detailed description and will include weight and volume comparisons to similar equipment designed for 3000 psi operating pressure.

5.5.1 Variable Pressure Hydraulic Pumps - Four variable pressure pumps, with 40 gpm capacity at rated speed, are being used to evaluate different pump mechanical and control technologies. Pump suppliers are Abex, Lucas Aerospace, Garrett, and Vickers. Performance requirements for each pump are identical, and with the exception of the Allied Signal (Garrett) pump, each utilize a duplex coil force motor with a spool and sleeve valve to regulate discharge pressure. Discharge pressure is commanded via a MCAIR designed controller which monitors system demand by summing actuator control valve position errors. Pump outlet pressure is then varied between 3000 and 8000 psi based on the system demand algorithm.

a. Abex Corporation - The Abex variable pressure pump, shown in Figure 79, utilizes a NWL Control Systems direct drive valve to position a compensator set point piston. This piston acts on a spring which varies the force on the compensator spool. Pump outlet pressure acts against the spring force, controlling flow to the stroking piston which in turn controls the hanger position as shown on the pump pressure control diagram of Figure 80. In the event of a control failure, the biasing piston is fully retracted and the pump operates as a conventional 3000 psi fixed pressure variable delivery pump. Rated flow at 8000 psi is achieved at 4400 rpm. The wet weight of the



Pump Specifications

Rated Speed	4,400 rpm
Rated Delivery	40 gpm
Rated Pressure (w Zero Flow)	8,000 psi
Pressure Control Range	3,000 - 8,000 psig
Servovalve Current - Voltage	8 mA - 28 VDC
Inlet Temperature	215 deg F
Fluid	CTFE-A02
Rotation Viewing Drive End	CCW
Weight (Dry)	36.5 lb Max (Est)
Spino Per AS972 With Pitch Dia.	1.625
Ref.	

Figure 79. Abex - Pump Outline Drawing

# Abex

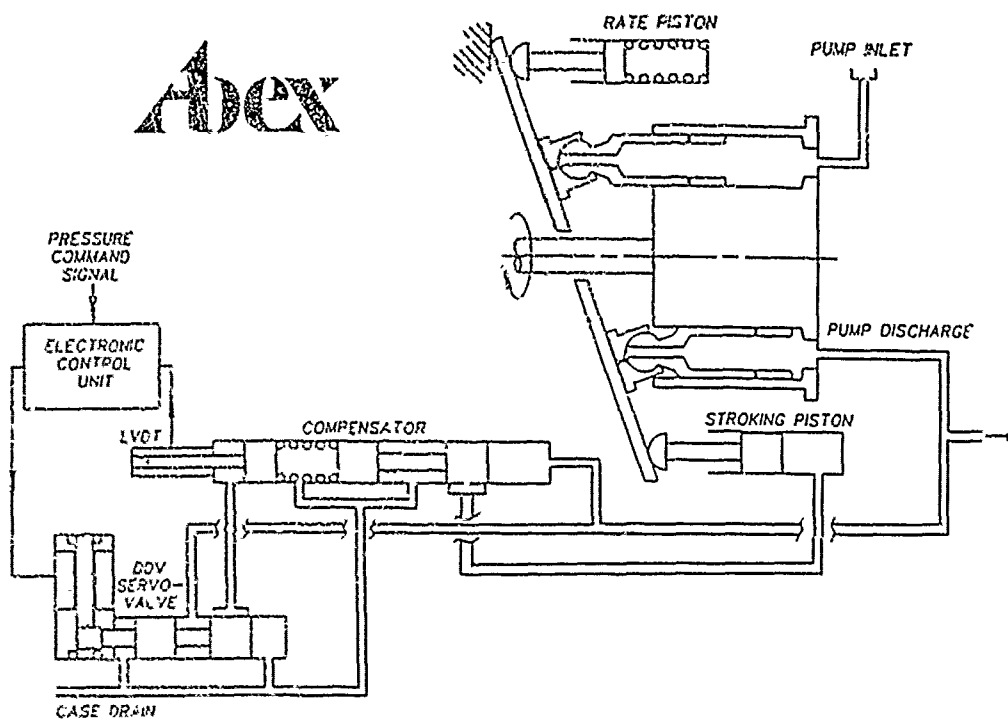


Figure 80. Abex - Pump Control Diagram

Abex pump is approximately 43 pounds. The NWL direct drive valve, as shown on Figure 81, is derived from the NWL Beta Drive System currently in production on the F-15E aircraft flight control and steering actuators.

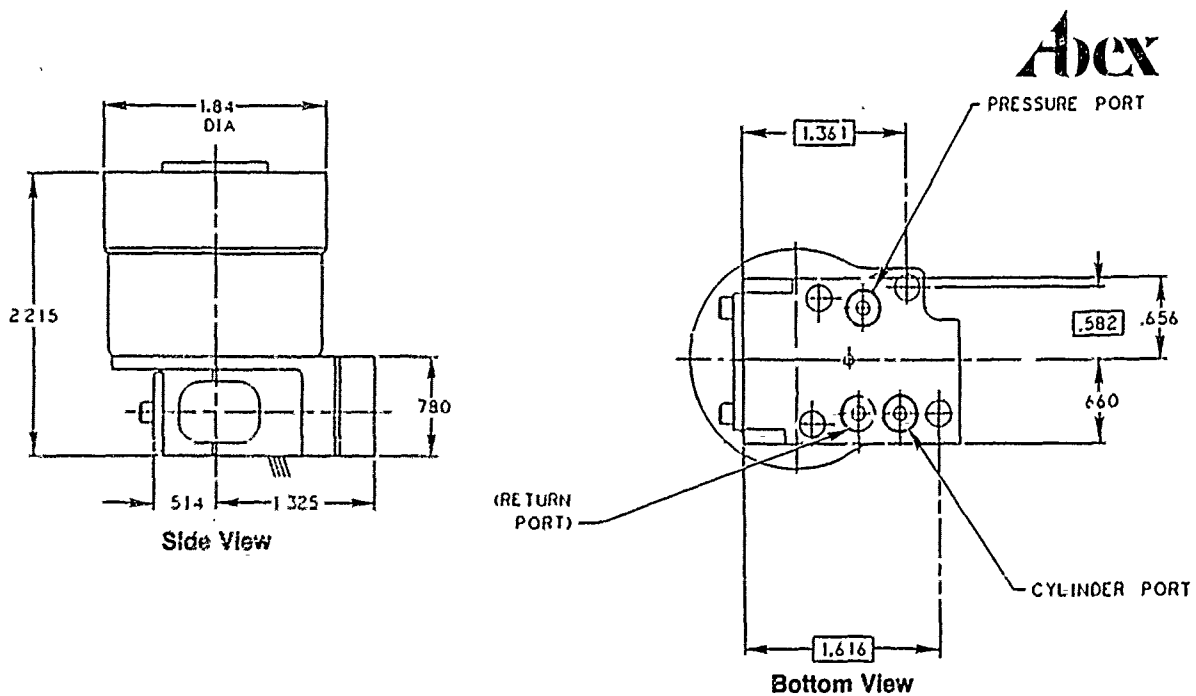


Figure 81. Abex - Pump DDV Outline Drawing (NWL)



b. Lucas Aerospace Power - Outline and cross sections of the Lucas variable pressure pump are shown in Figures 82 and 83. The unique features of

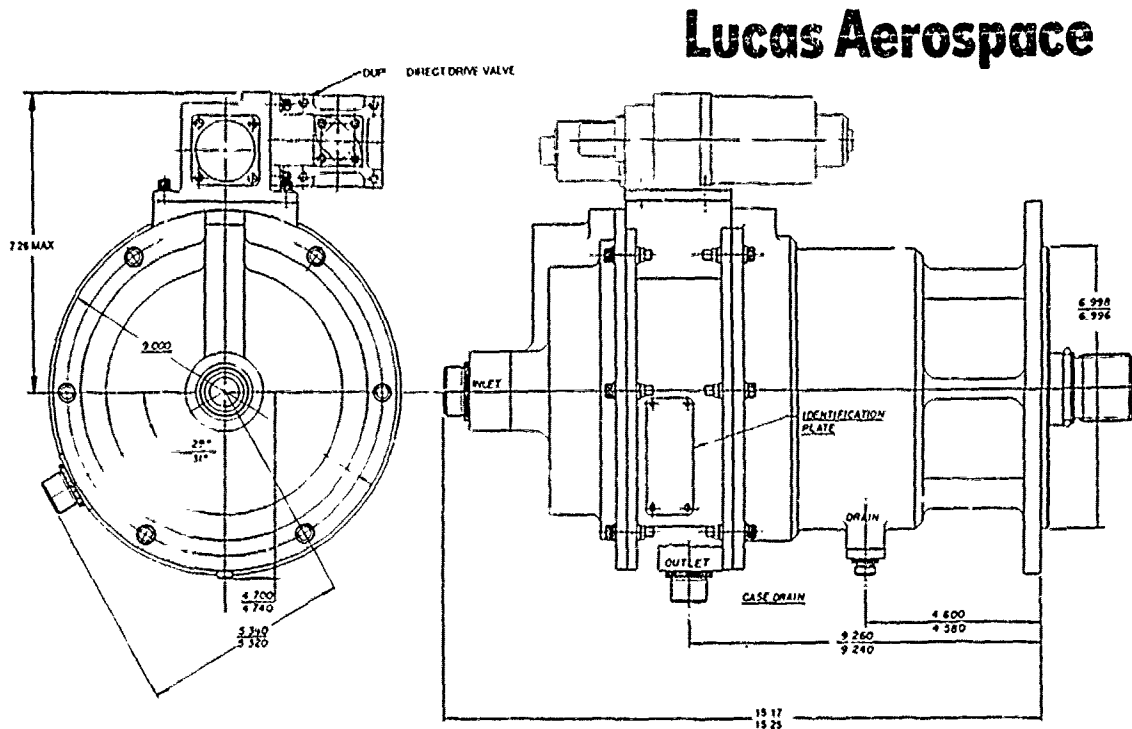


Figure 82. Lucas Aerospace - Pump Outline Drawing

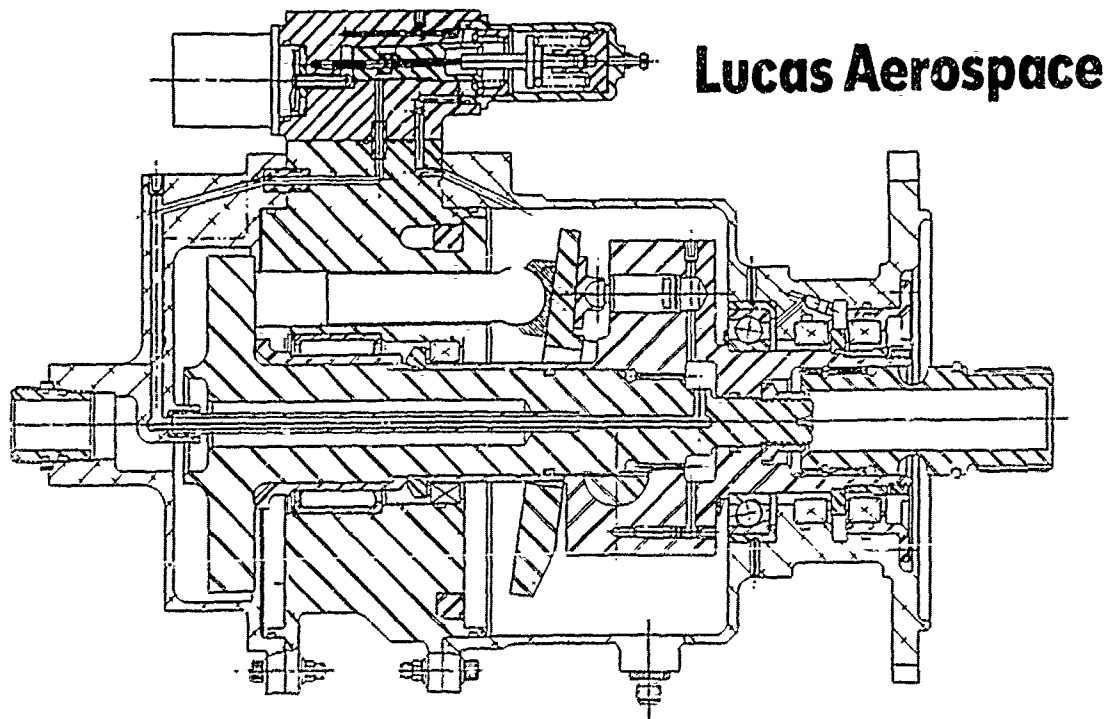


Figure 83. Lucas Aerospace - Pump Detail Drawing

this pump when compared to the Abex and Vickers models, are the balanced fixed piston/rotating tilt plate and piston outlet check valves. The balanced fixed piston/rotating tilt plate concept facilitates the check valve design and allows hydraulic loads to be contained in the rotating assembly, not in the bearings and housing. The unit will be run with a dry sump to reduce heat rejection by minimizing the windage losses due to rotating hardware. Piston outlet check valves are used to minimize system pulsations by releasing fluid to the system only when pressure in the individual cylinders equals or exceeds system pressure. Pressure control is similar to the Abex approach and is shown in Figures 84 and 85. A force motor controlled direct drive valve positions the compensator set point spool which applies a position bias in the compensator valve. This position bias sets the outlet pressure, and the compensator valve varies the pump displacement to maintain outlet pressure. The wet weight of the pump assembly is approximately 69 pounds. The force motor is supplied by Sierracin/Magnadyne.

## Lucas Aerospace

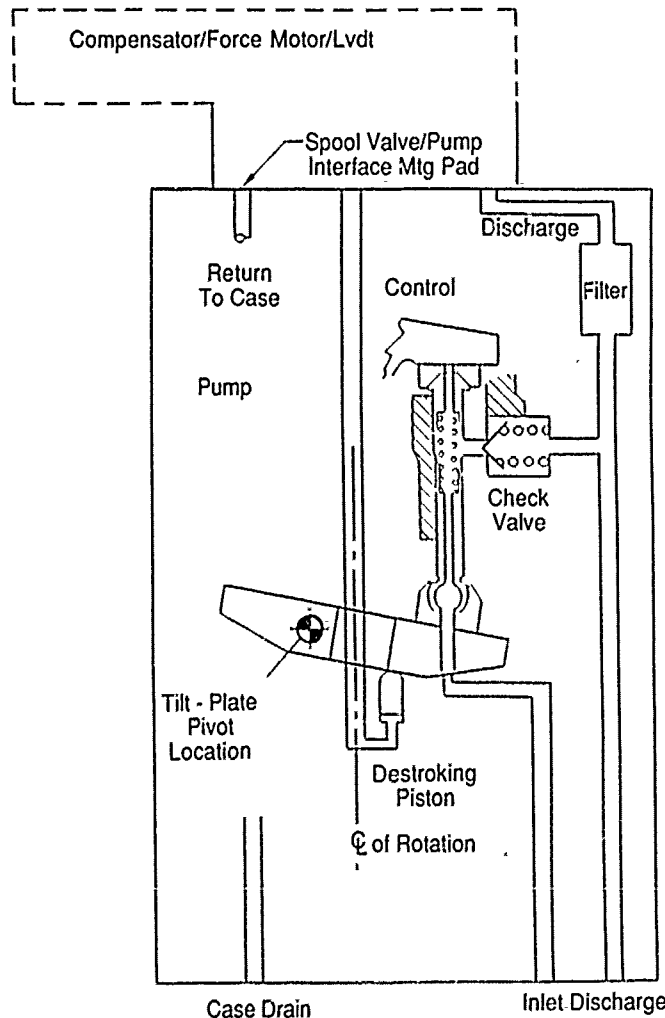


Figure 84. Lucas Aerospace - Pump Functional Schematic

# Lucas Aerospace

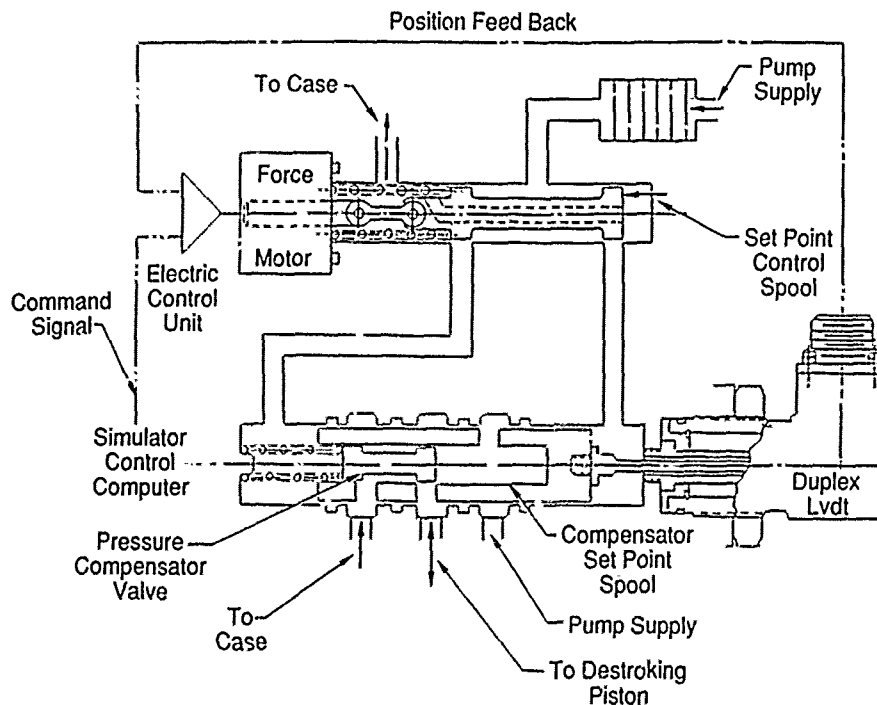


Figure 85. Lucas Aerospace - Pump DDV Functional Schematic

c. Allied Signal Aerospace Co. - The Allied Signal variable pressure pump outline is shown in Figure 86. The unique feature of this pump is the floating port plate concept, shown in Figure 87, which uses hydraulic pressure rather than spring force to seat the port plate against the piston barrel. The floating port plate allows a reduction in internal friction and higher rotational speeds, which provides for more efficient operation and lower weight through reduced parasitic losses and smaller required displacement. Pressure control is schematically shown in Figure 88 and is achieved in a manner similar to the Abex and Lucas pump designs. The Allied Signal electronic controller provides pressure commands to an E-Systems direct drive valve which modulates the pump discharge pressure setting piston which in turn acts on the compensator spring. As with the Abex and Lucas Power designs, hydraulic pressure is infinitely variable between 3000 and 8000 psi. Position feedback from the setting piston is provided to the electronic controller from an LVDT. Pump displacement at maximum hangar angle is 1.80 cubic inches per revolution. Rated flow at 8000 psi is achieved at 5703 rpm. The wet weight of the pump assembly is 40 pounds.

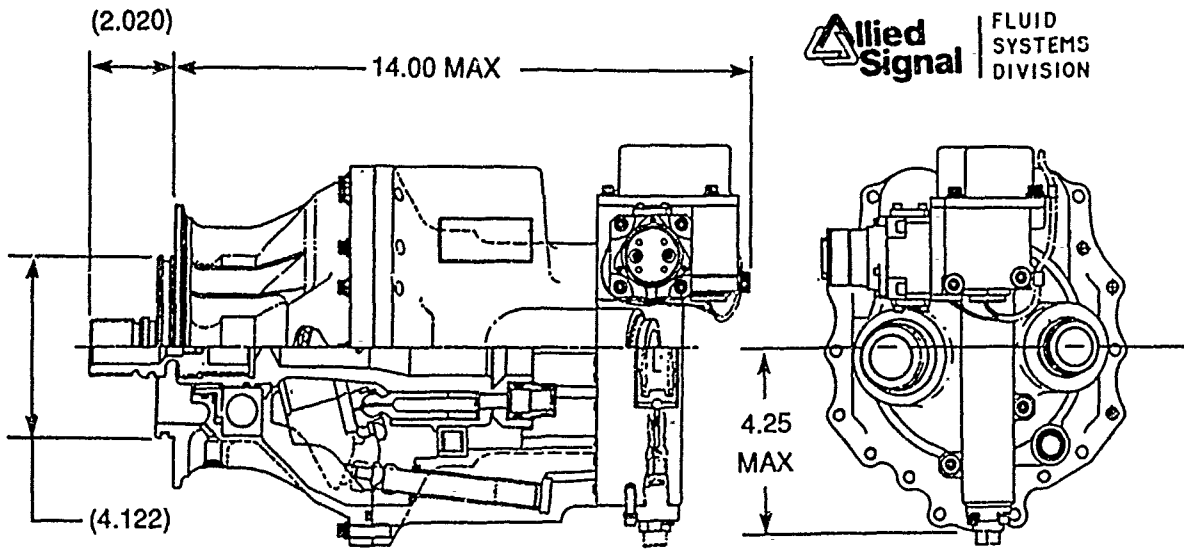


Figure 86. Allied Signal Aerospace - Pump Outline Drawing

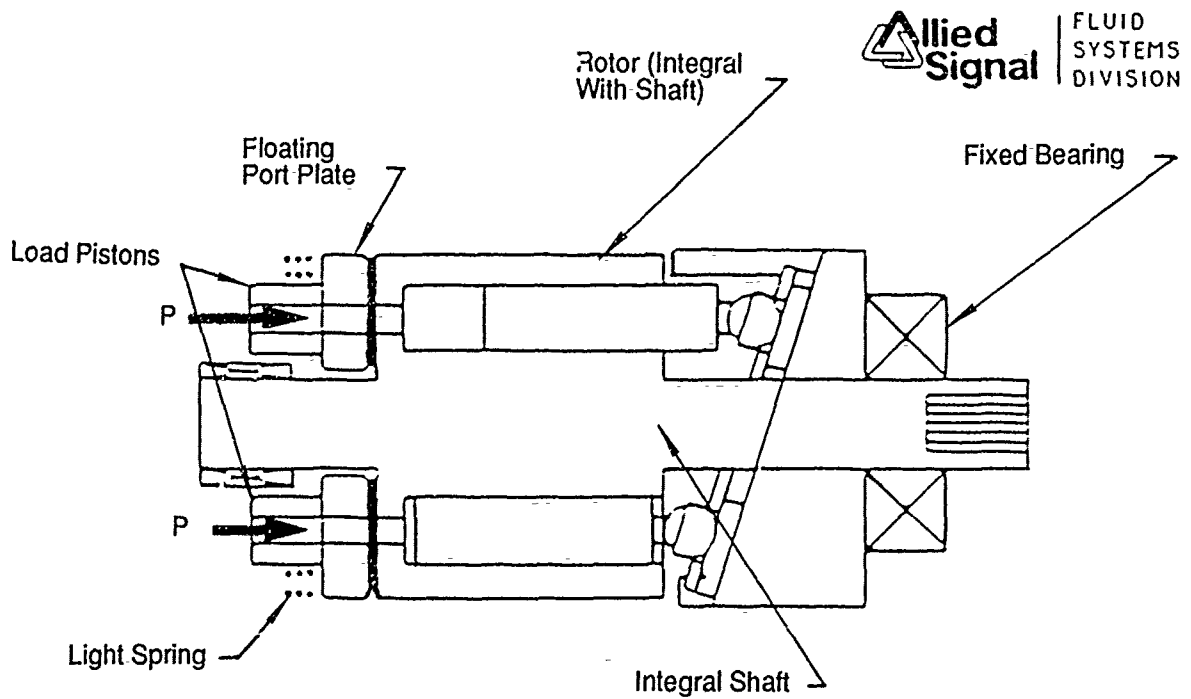


Figure 87. Allied Signal Aerospace - Pump Floating Port Plate Details

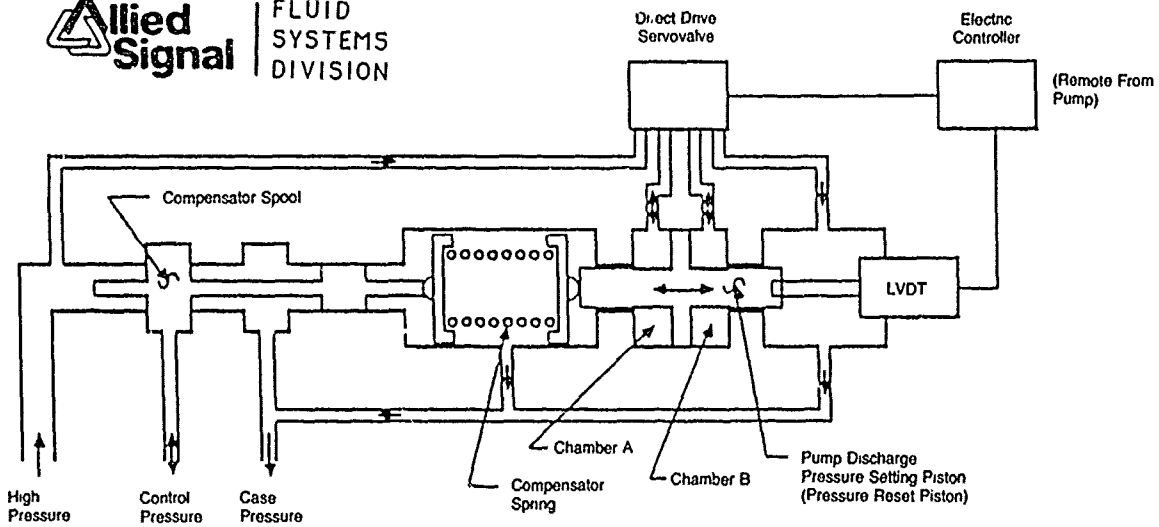
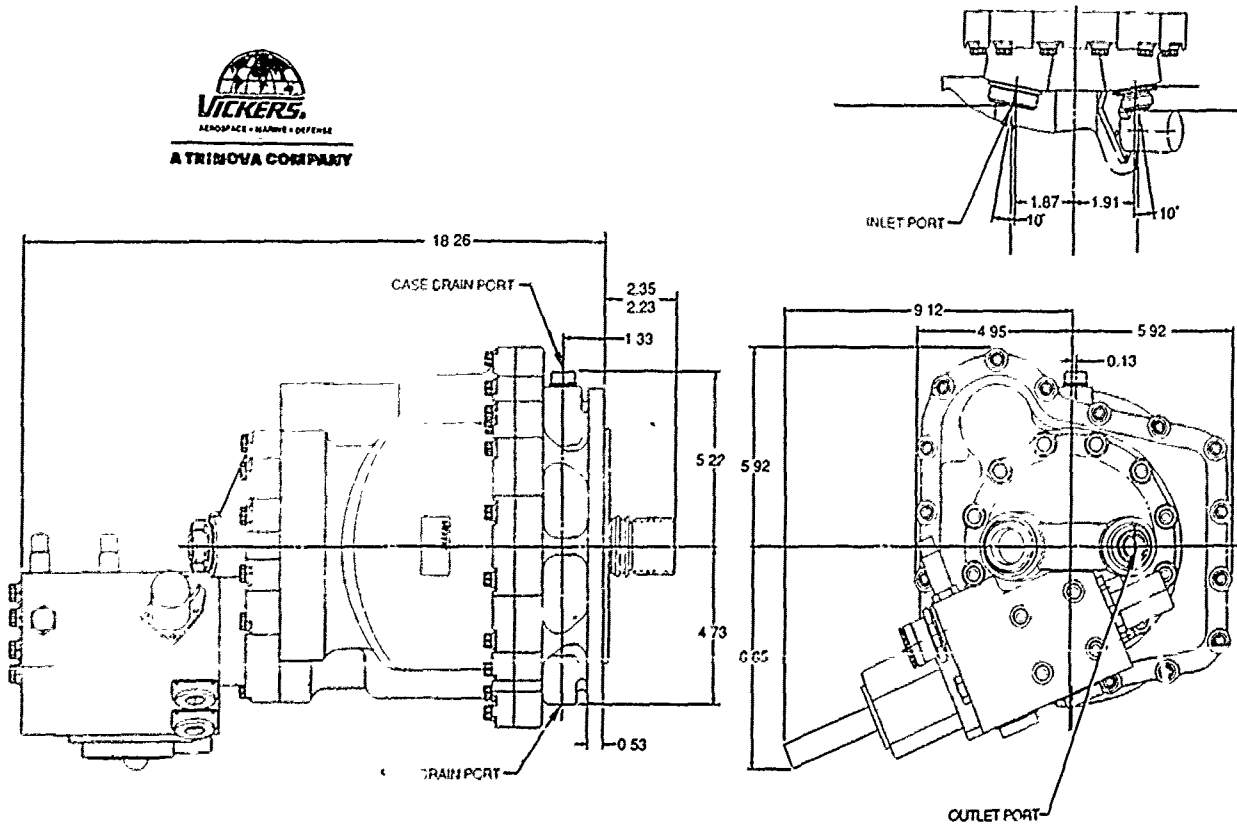


Figure 88. Allied Signal Aerospace - Pump Functional Schematic

d. Vickers Incorporated - The Vickers variable pressure pump, shown in Figure 89, differs significantly in function and control from the Abex pump. The actuator piston pressure is directly controlled by a Moog direct drive valve.



GP93-0016-246

Vickers - Pump Outline Drawing

Pressure feedback is used to close the loop as shown in the pressure control diagram of Figure 90. In the event of the loss of primary pressure control, the main solenoid valve is deenergized, which shuttles the switching valve, allowing the hydromechanical compensator to take over control of the pump. The hydromechanical compensator is adjustable to provide fixed pressure between 3000 and 8000 psi. Rated flow at 8000 psi is achieved at 3625 rpm. An outline of the Moog duplex direct drive valve selected to control the pump compensator is shown in Figure 91. The control concept chosen by Vickers has superior response characteristics when compared to the biased compensator approach of other manufacturers.

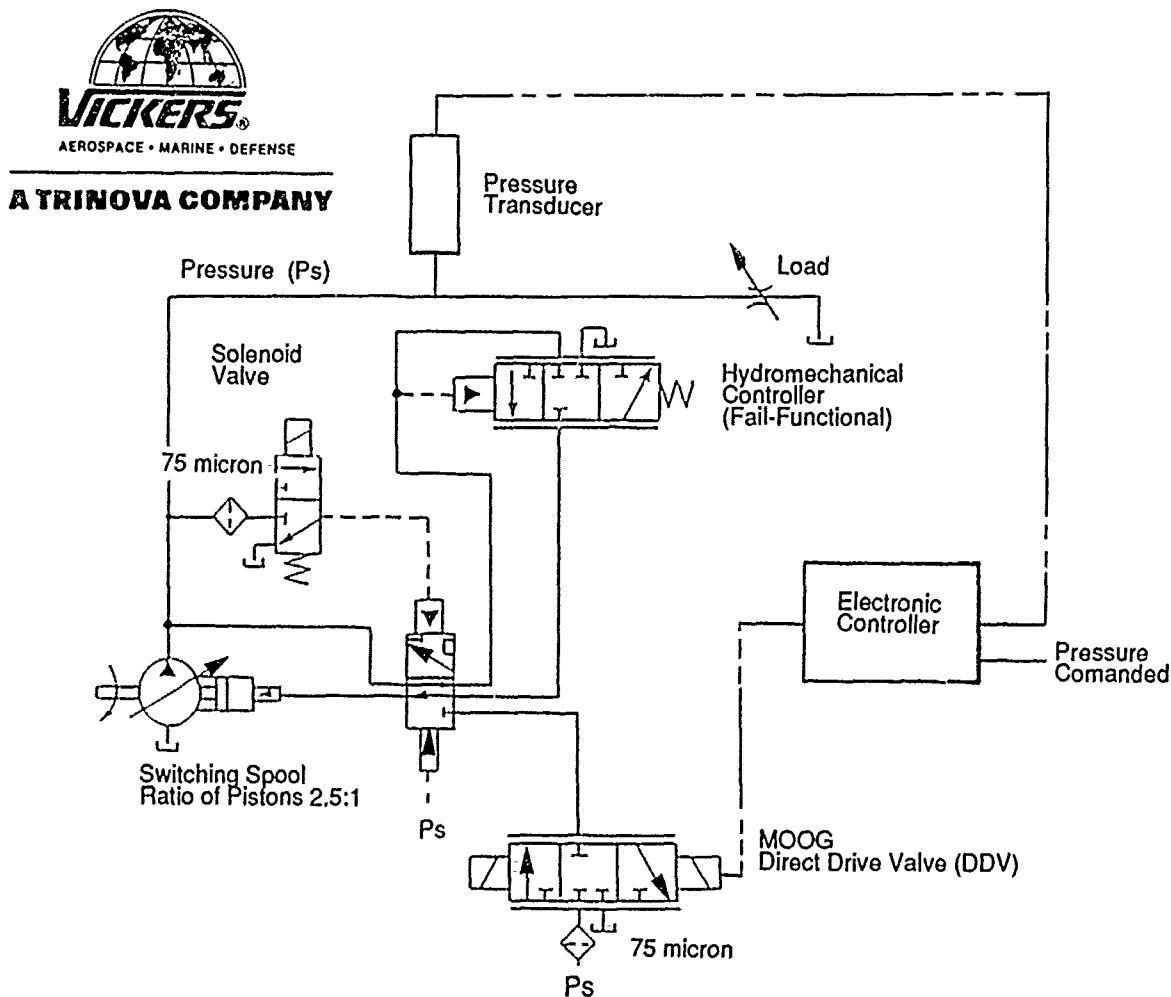


Figure 90. Vickers - Pump Functional Schematic

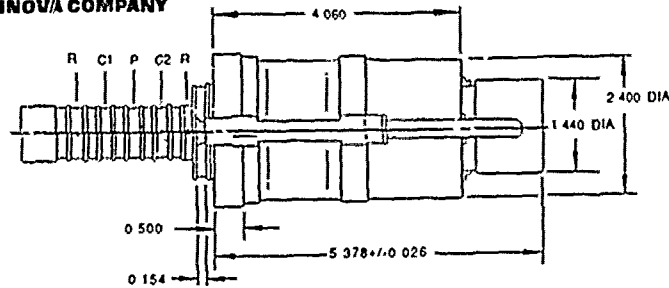


Figure 91. Vickers - Pump DDV Outline Drawing (MOOG)

e. Pulsco Pump Pulsation Attenuator - The analysis effort performed by computer simulations showed the need for active damping of the pump outlet flow on all three systems. The Pulsco unit, shown in Figure 92, is an acoustical tuning device which is installed in the pump pressure line as near as practical to the pump outlet. Ideal positioning of the attenuator is on the pump. However, this is usually not practical and placement is based on space availability with a maximum distance being based on the tuning frequency of the unit. In this program, the maximum distance of the 350 hz unit is twenty four inches. The device has multiple flow paths and tuned volumes within a pressure containment shell having a single inlet and outlet port. The tuning of the unit is calculated from the pump parameters and idle speed. A nine piston pump with 2333 rpm idle speed requires a seventy cubic inch attenuator to achieve a ninety percent attenuation of 350 hz pulsation. The attenuators have an estimated wet weight of 10.1 pounds.

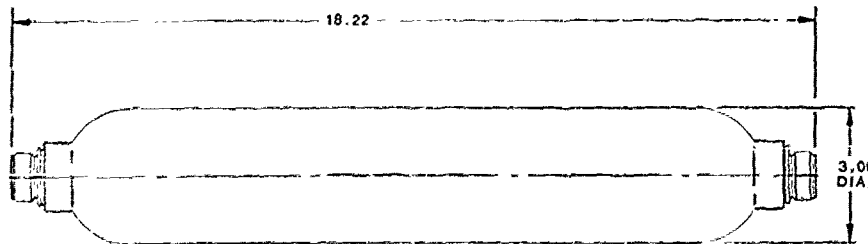


Figure 92. Pulsco - Acoustic Filter Outline Drawing

5.5.2 Hydraulic Fluid Reservoirs - Hydraulic reservoirs for the program were specified to have a three reservoir level sensing circuit isolation capability using mechanically operated shutoff valves. The original scope of work was to use reservoirs sized both for the primary control systems and for the utility system. Parker Metal Bellows, was selected to supply a bellows type reservoir which was to be gas pressurized. These were to be used in the primary systems. Parker Aerospace was selected to supply a utility reservoir which has 8000 psi bootstrap pressurization. Both types were to be supplied to the pump manufacturers for use in their pump endurance tests. Funding constraints forced cancellation of the Metal Bellows procurement and resulted in the curtailment of using program reservoirs in the suppliers' pump tests.

a. Parker Bootstrap RLS Reservoir - All three systems will use the Parker Aerospace 547 cubic inch bootstrap reservoir designed to maintain a 95 to 105 psi base system pressure with 8000 psi bootstrap pressurization. The reservoir is sized for the utility system and will function to provide fluid volume for changes in component volume, thermal expansion and system leakage. The unit's three mechanical RLS shutoff valves, shown in Figure 93, are tripped by a cam mechanism on the bootstrap piston, shown in Figure 94. The cam mechanism actuates a pilot valve that ports pressure to control the circuit shutoff valve. This in turn, shuts down flow to one of the branch hydraulic circuits and turns them back on in succession when leakage causes depletion of the reservoir capacity. The RLS circuit also includes a manual

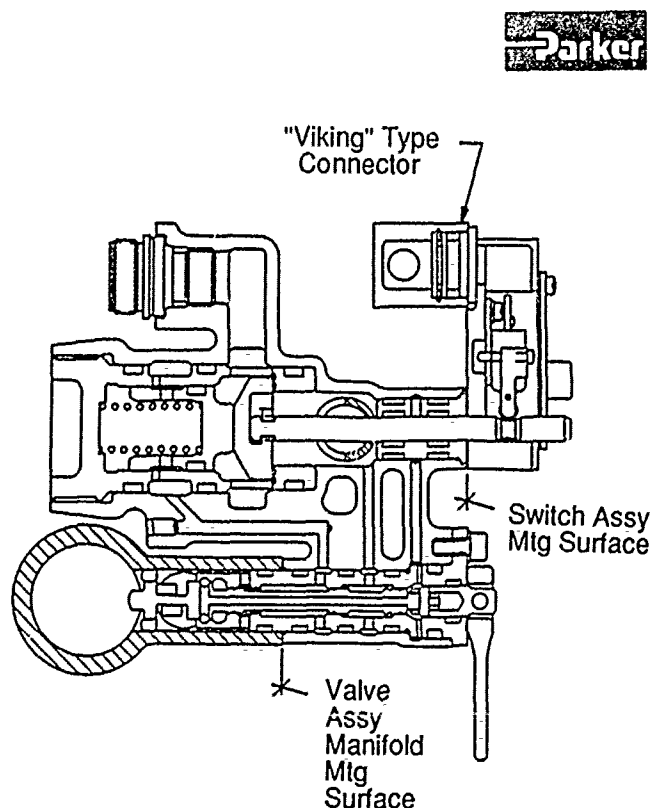


Figure 93. Parker - RLS Shutoff Valve Detail Drawing



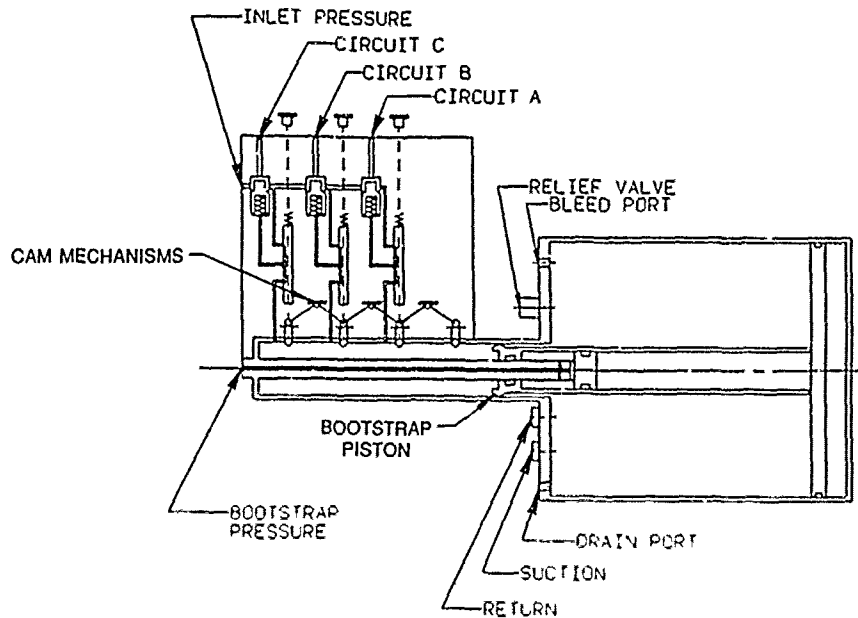


Figure 94. Parker - Bootstrap Reservoir RLS Valve

override handle for use during ground servicing. A valving manifold provides a housing for the high pressure piston and integral parts including the RLS valves and the cam following actuation mechanisms for the RLS. A pressure switch is connected to the circuit for remotely indicating the closure of applicable circuit shutoff valves. Figures 95 and 96 show the envelope and cross sectional detail of the reservoirs. The reservoir piston has a 78:1 area ratio of the bootstrap piston, which yields approximately 100 psi base pressure when the pump discharge pressure is 8000 psi. A bleed and overfill valve is incorporated to automatically bleed off excess fluid in the reservoir. It can also be manually operated to bleed air from the reservoir during servicing. The fluid level indicator can be manually adjusted to compensate for temperature variations and obtain accurate fluid level readings. A temperature sensitive tape visually indicates if the fluid temperature exceeds 275°F. The reservoir drum is 6061 aluminum anodized for corrosion resistance while the low pressure valving manifold and piston are 7075 aluminum with an anodized finish. The high pressure components of the bootstrap are comprised of Ph13-8Mo and 15-5Ph Corrosion Resistant Steel (CRES) steels. The total assembly calculated dry weight is 20.5 pounds.

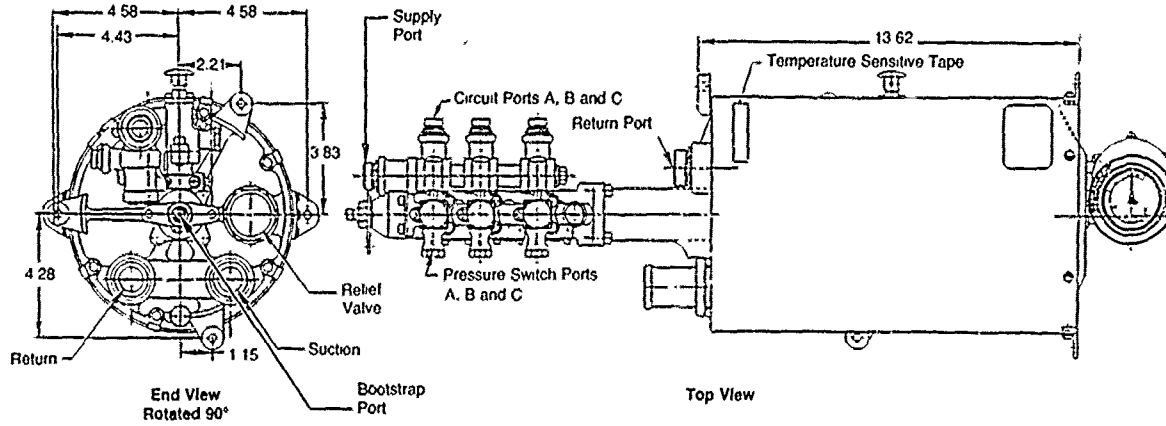


Figure 95. Parker - Bootstrap Reservoir Outline Drawing

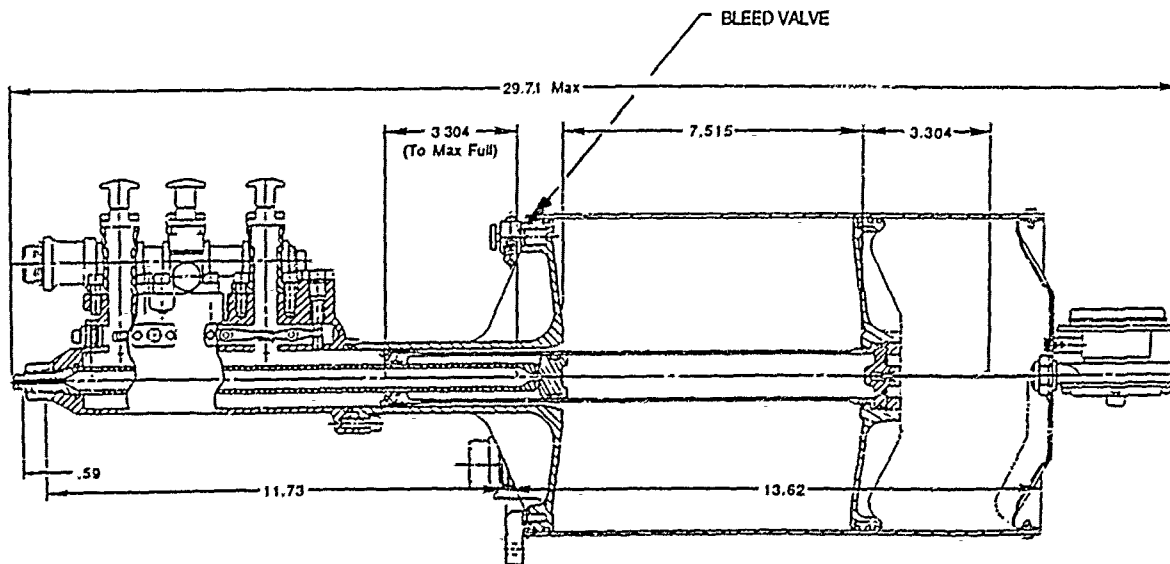


Figure 96. Parker - Bootstrap Reservoir Detail Drawing

b. Parker Metal Bellows RLS Reservoir - It was originally proposed that the primary flight control systems would use smaller metal bellows type reservoirs with gas pressurization. The procurement was terminated in order to meet program funding levels. The bootstrap reservoir described above was selected being the larger of the two and both were to use the RLS shutoff valves built by Parker Aerospace. The Metal Bellows design is shown in Figure 97.

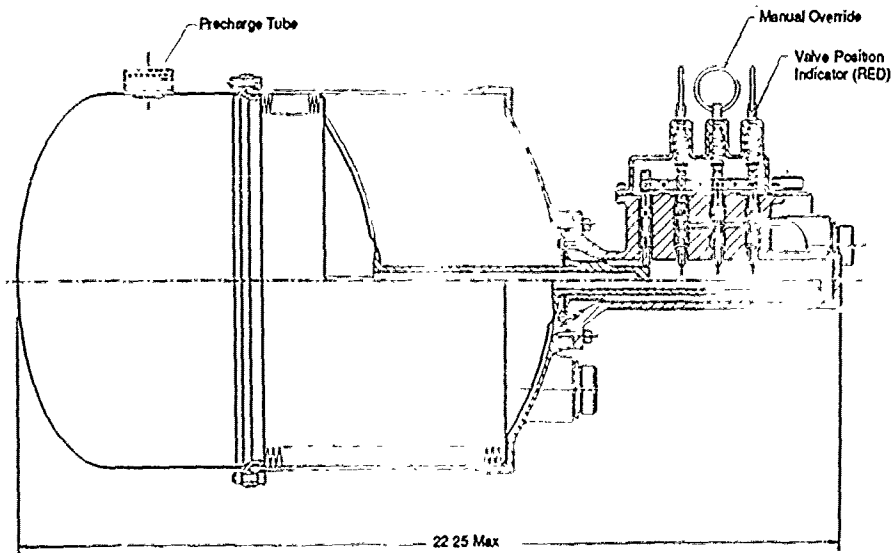
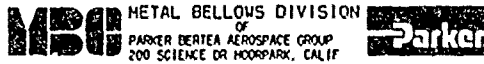


Figure 97. Parker Metal Bellows - Reservoir Detail Drawing

5.5.3 Hydraulic Filter Manifolds - This equipment is sized to accommodate the 40 gpm capacity of the pumps and will incorporate 5 micron absolute filter elements as their baseline. Finer filtration levels are expected to increase system life. This program has provisioned a small quantity of one micron absolute "ultrafine" filters which will be evaluated for reliability, filter life and any other parameters available in a system test. Figure 98 shows the hydraulic schematic of the filter packages which provide two filter bowls/elements for filtration of both the system pump high pressure and system return flow. The return filter will include case drain filtration. The filter element bowls will incorporate differential pressure indicators with thermal and time delay protection against premature actuation. In addition, a means will be provided for preventing accidental reset of the indicator and to indicate incorrect element installation.

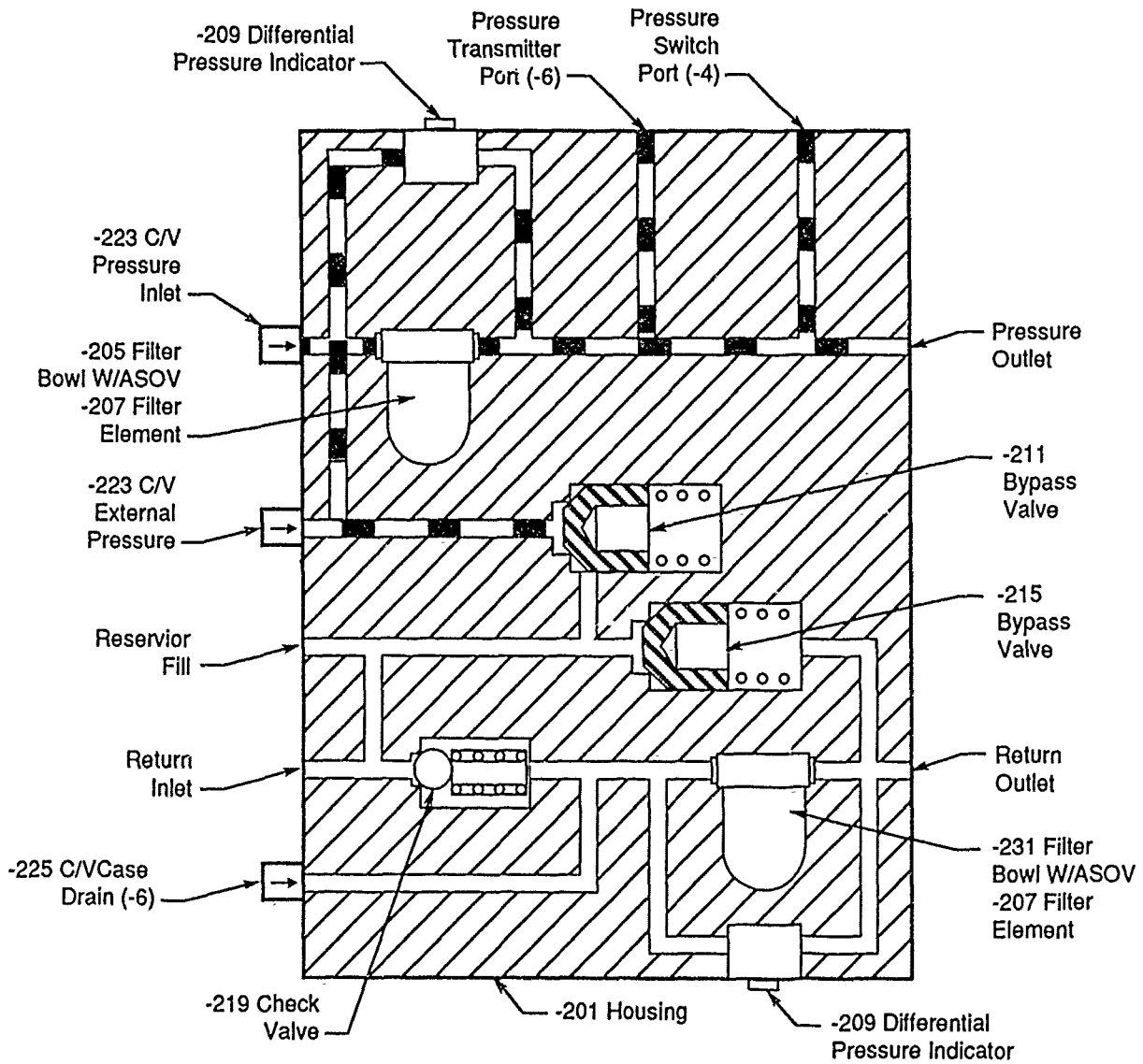
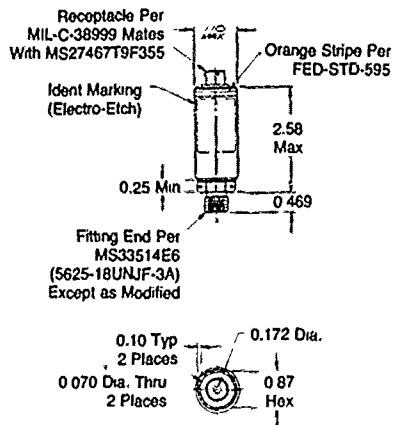


Figure 98. Filter Manifold - Hydraulic Schematic

An Eaton Consolidated Controls hydraulic pressure transducer, Figure 99, and an ITT pressure switch, Figure 100, are used to send pressure warning signals to the control room. Each manifold will also include inlet and case drain check valves, a Brunswick (Circle Seal) high pressure relief valve as shown in Figure 101, and a filter bypass valve. An automatic filter bowl shutoff is being installed to ensure minimum fluid loss during element replacement.



**EATON** Consolidated Controls  
Bethel, CT 06801-0247

**Notes:**

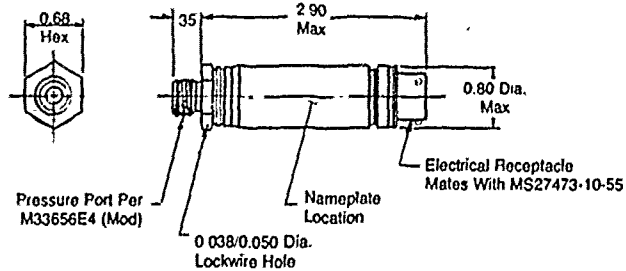
1. Pressure range: 0 - 8,000 psig
2. Proof pressure: 10,000 psig
3. Burst pressure: 17,000 psig
4. Input voltage: 16 to 30 VDC
5. Pressure media: CTFE-A02 hydraulic fluid
6. Input and output impedance: 1,000 ohms
7. All stainless steel welded construction
8. Pressure sensor is designed to meet requirements of specification PS71-136931
9. Non-operating temperature range: -80°F to +160°F
10. Operating temperature range: -40°F to +160°F
11. High temperature range: -40°F to +250°F

**Figure 99. Eaton - Hydraulic Pressure Transducer Outline Drawing**

**Specifications**

1. Actuation Points  
Increasing pressure: 1,900 psig maximum  
Decreasing pressure: at 1,500 ± 100 psig
2. Pressure Ratings  
System: 3,000 to 8,000 psig  
Proof: 10,000 psig at +275 ± 10°F  
Burst: 17,000 psig at +275 ± 10°F
3. Temperature Ratings  
Ambient: 40° to +160°F continuous  
+345°F for 10 minutes  
+420°F for 1 minute  
Media: -40° to +275°F
4. Electrical Ratings  
Switching mechanism enclosed in a chamber hermetically sealed per MIL-E-5400 para 6.3.10  
2 to 50 ma resistive at 16 to 30 VDC
5. Media  
Chlorotrifluoroethylene

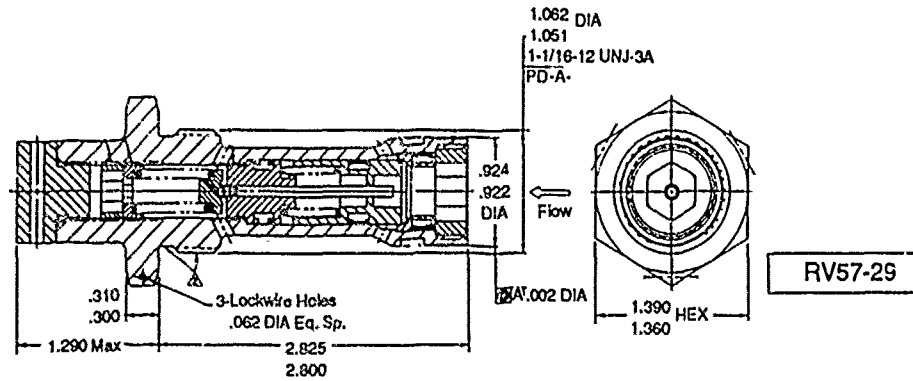
**ITT** Aerospace Controls Division  
Neo Dyn Operations



**Figure 100. ITT - Hydraulic Pressure Switch Outline Drawing**



CIRCLE SEAL CONTROLS  
ANAHEIM, CALIFORNIA 92801



**Technical Data**

Operating Pressure	0-8000 psig
Proof Pressure	10,000 psig
Burst Pressure	17,000 psig
Operating Temp.	-50°F to 325°F
Cracking Pressure	8750±50 psi
Reseat Pressure	8250 psi min.
Internal Leakage	5cc/min @8150 psi@ 90°F
External Leakage	0
Pressure Drop	9075 psid max
Flow 40 gpm	Fluid MIL-H-83282
Condition	95±25°F

Figure 101. Circle Seal - High Pressure Relief Valve Detail Drawing

a. Aircraft Porous Media - Figure 102 shows the Aircraft Porous Media (APM) filter package envelope. This unit consists of a modular housing manufactured from Ti-6Al-4V titanium alloy for the high pressure section and 2024-T851 aluminum alloy for the return section. Pressure drops across the elements are rated at 400 psid at 40 gpm across the high pressure element, 350 psid at 40 gpm across the return element, and 400 psid at 40 gpm across the return including the case drain. The wet weight has been estimated to be 26 pounds.

# AIRCRAFT POROUS MEDIA

(PALL)

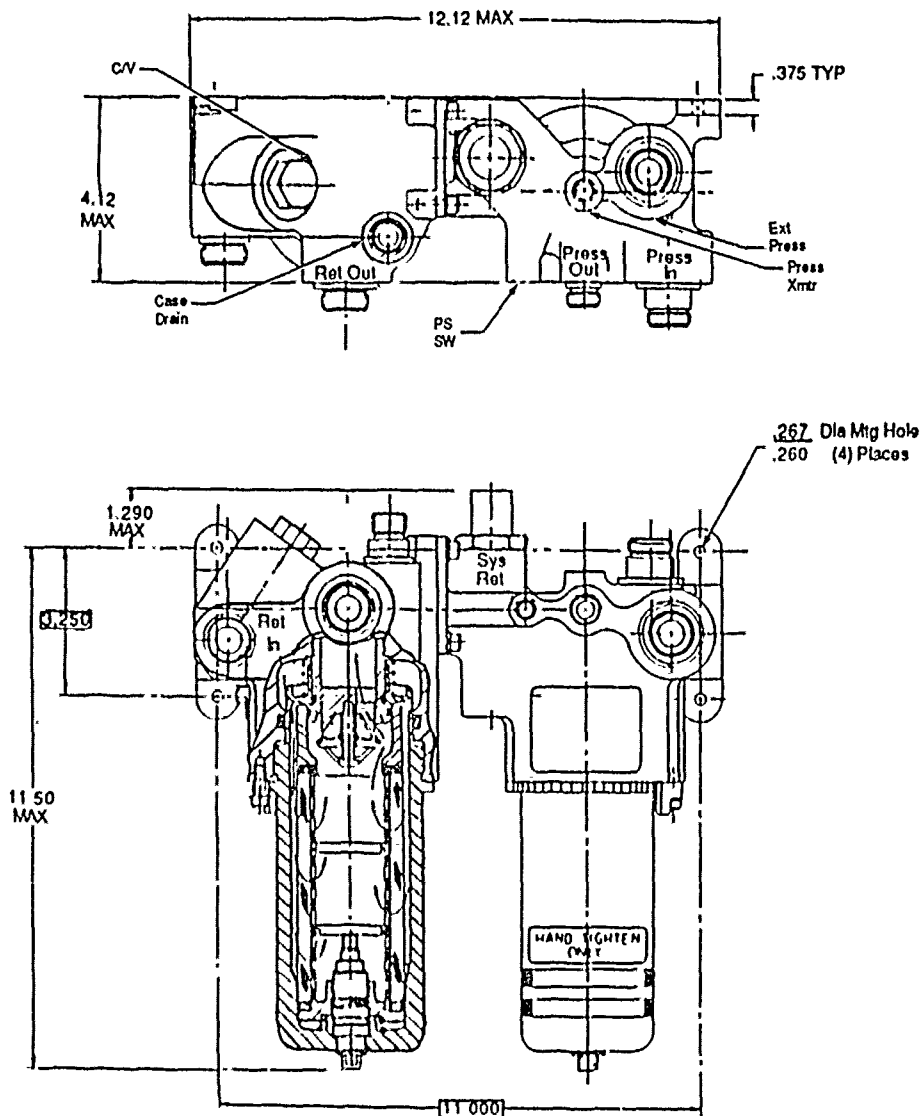


Figure 102. APM - Filter Manifold Outline Drawing

b. PTI Textron. Figure 103 is the envelope of the PTI Technologies Inc. unit. The manifold is a hot isothermal pressed titanium (6Al-4V) investment casting with 6Al-4V hand forgings being used for the filter bowls. Pressure drops across the elements are calculated at 280 psid at 40 gpm across the high pressure element, 76 psid at 40 gpm across the return element, and 108 psid at 40 gpm across the return including the case drain. The estimated wet weight is 15 pounds.

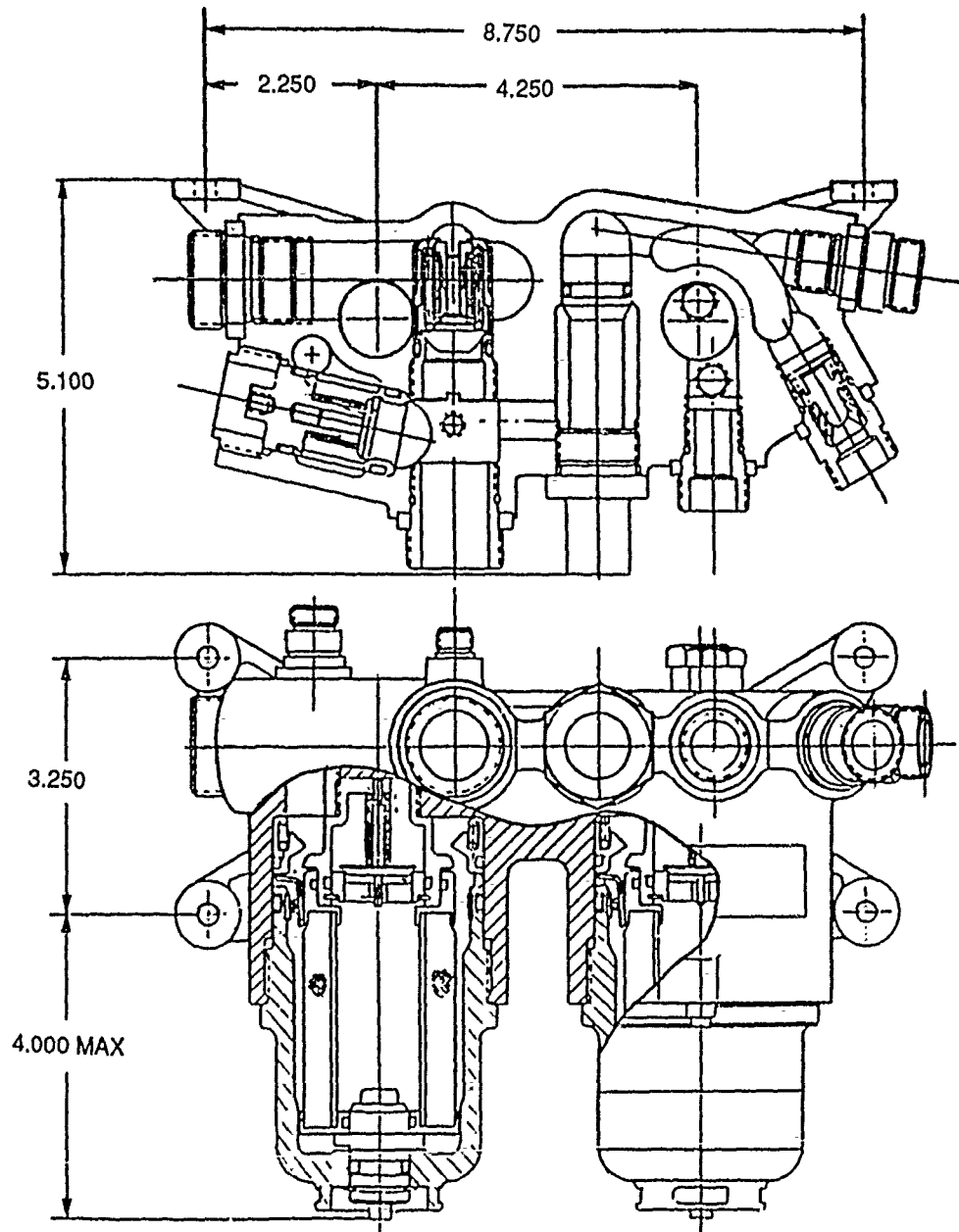


Figure 103. PTI Technologies - Filter Manifold Outline Drawing



5.5.4 Linear Flight Control Actuators. Several linear servoactuators have been developed for 8000 psi service. Performance requirements have been based on F-15 SMTD aircraft equipment characteristics and all of the actuators use direct drive valves. The flight control servoactuators on the SMTD aircraft use direct drive valves as well.

a. E-Systems Stabilator Actuator. The stabilator servocylinder was designed and built by E-Systems and incorporates a pin ended dual tandem cylinder assembly with an attached valve manifold. The servocylinder is powered by two independent hydraulic systems and four independent electrical control circuits which provide operation after two electrical and/or one hydraulic failure. A functional schematic is shown in Figure 104. An integral quadruplex LVDT provides electrical signals to a control unit proportional to the ram position. The four channel rotary force motor controls a linear single stage dual tandem main control valve. Figure 104 also shows the general arrangement of the actuator components within the manifold and cylinder assemblies. The dual tandem direct drive servovalve

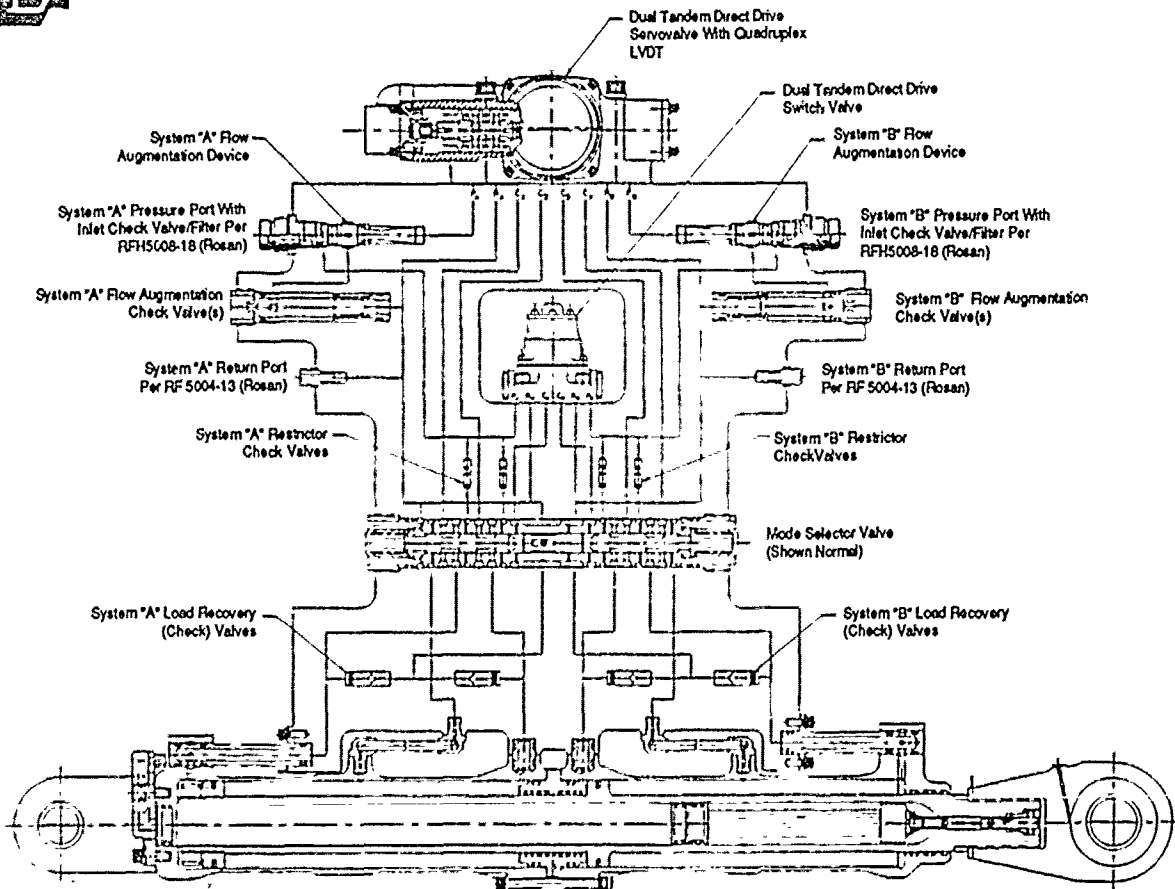
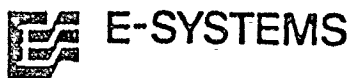


Figure 104. E-Systems - Stabilator Servoactuator Functional Schematic

employs another quadruplex LVDT for inner loop feedback and compensation control and the servovalve is a line replaceable unit. The servovalve spool and sleeve have an overlapped design which is used to reduce null leakage, to add deadband at neutral valve position and to reduce ram operation at electronic control noise levels. A unique feature of this design is the mode select pilot valve which is a quadruplex, dual tandem direct drive valve that operates the mode select valve in a "bang-bang" fashion. The pilot valve sleeve is fitted in the manifold housing and has an internal bias spring that ports pressure to the mode selector valve upon loss of all electrical power. In the event of three electrical system failures or an inoperative main control valve, the direct drive pilot moves the mode selector valve transferring control of the ram from normal force motor control to a neutral lock mode. In the electrical system failure mode, the ram is hydraulically driven to a surface neutral position. Holes are placed in the cylinder walls in the preferred failed position. In the neutral lock mode, all cylinder chambers are ported to pressure and the holes in the walls are ported to return. The ram drives toward neutral until the ram piston seals cover the holes. In the event of total hydraulic supply failure, the neutral lock mode allows the air loads to drive the surface toward, but not away from the neutral position. Four anti-cavitation valves are included and sized to allow aiding loads to pass resident cylinder fluid to the opposite cylinder chamber, preventing cavitation and reducing system flow demands. Flow augmentation is included by inducting part of the actuator's return outlet flow into the inlet flow at conditions of high flow rate and low resisting loads using an eductor (a liquid jet pump using the pressure supply fluid as the motive power). The return passages of this device are safeguarded by check valves. The two pressure port check valves isolate the aircraft hydraulic system from surges generated within the actuator. Two replaceable inlet filters purge the servocylinder of particles greater than 200 microns. Figure 105 shows the servoactuator assembly which consists of the valve manifold made of forged 6-6-2 titanium, the main control valve elements made from 440 CRES, cylinder barrels made from PH13-8Mo stainless steel, and a piston rod assembly made from 4340 steel alloy. The maximum wet weight of the complete cylinder assembly is 27.5 lbs. The complete system weight is approximately 60 pounds.

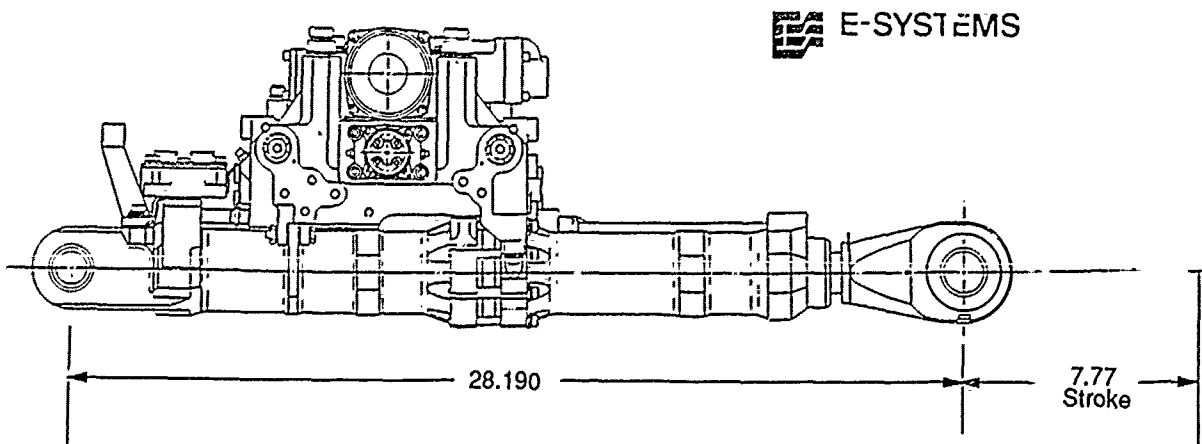


Figure 105. E-Systems - Stabilator Servoactuator Outline Drawing

b. MOOG Aileron/Flaperon Actuator - The Aileron/Flaperon servoactuator, shown in Figure 106, is supplied by MOOG Western Development Center. Two independent hydraulic systems and two independent electrical control circuits provide operation after one electrical circuit failure and/or failure of one of the hydraulic systems. After total electrical or hydraulic failure, the surface control will revert to a damped trail mode. The cylinder consists of

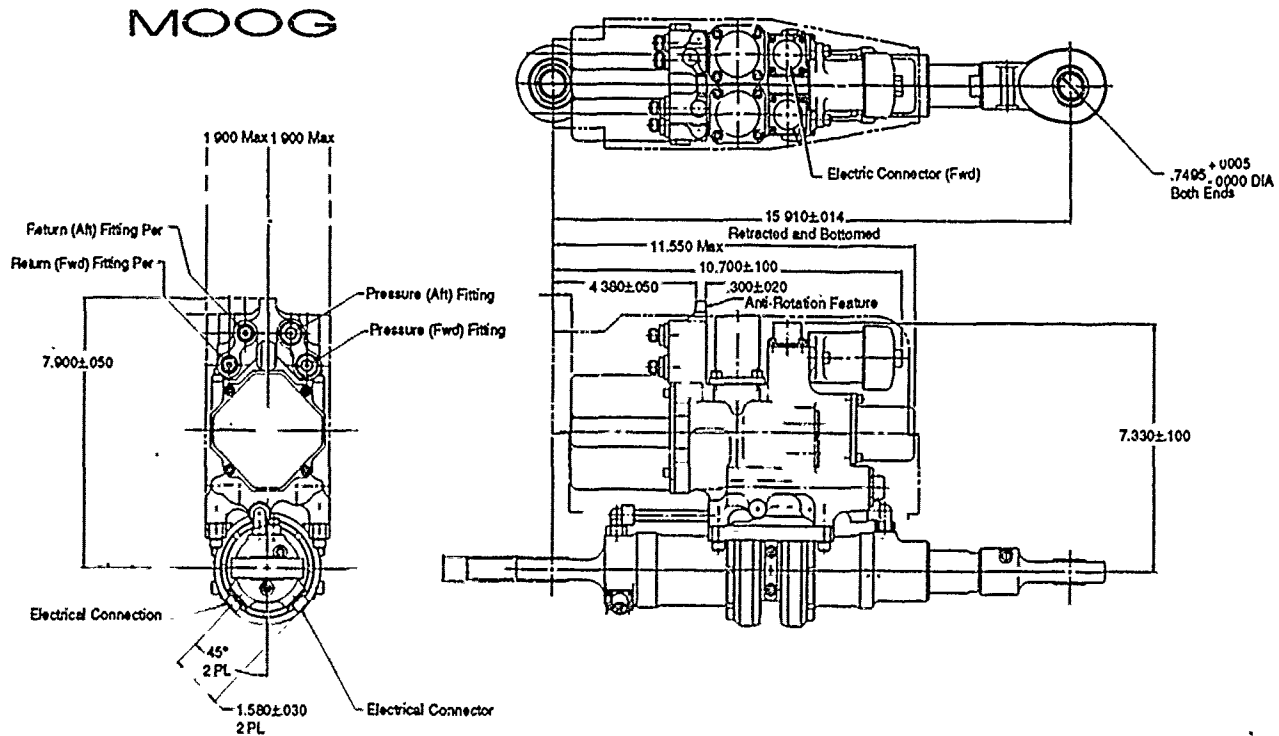
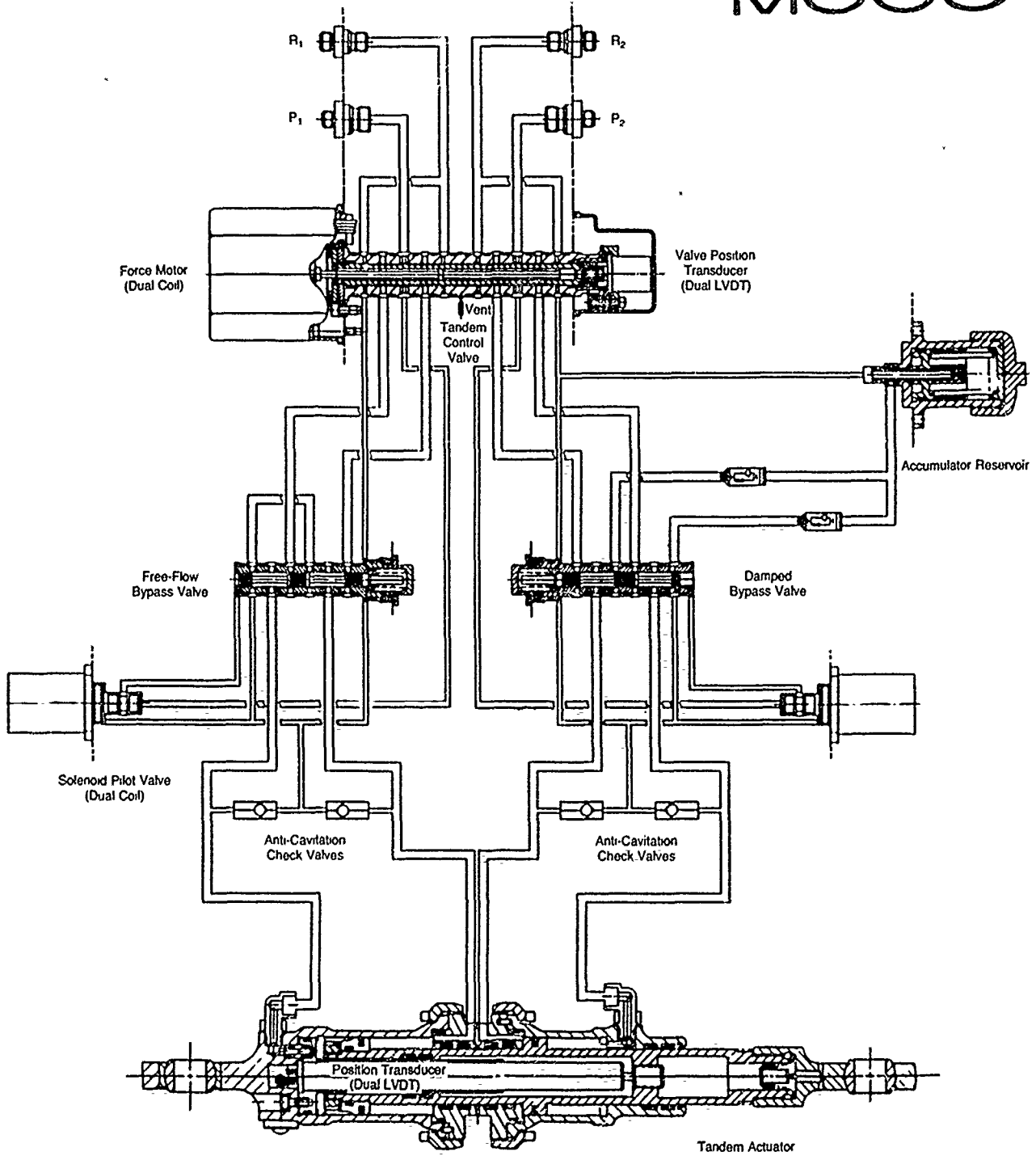


Figure 106. MOOG- Flaperon Servoactuator Outline Drawing

a dual tandem barrel and output ram assembly with an integral duplex LVDT for ram position monitoring. A direct drive valve with a dual coil force motor controls a linear single stage main control valve with a dual overlapped spool and sleeve made of 440C CRES. In addition, a position sensing LVDT is installed in a detachable valve housing. Dual duplex coil solenoid valves are used to control a mode selector valve that ensures the main ram moves to a damped surface trail position in the event of a total electrical failure, a total hydraulic failure, or a malfunction in the main control valve. Additional components included in the titanium manifold are damping orifices, an accumulator to accommodate air load damping, internal leakage and thermal contraction, four anti-cavitation check valves and two pressure port check valves with filters. Figure 107 shows the internal arrangement and interface with the ram assembly. The cylinders, piston, centerdam and lockrings are all 15-5Ph corrosion resistant steel. To prevent galling, a molydisulfide grease will be applied to the lockring threads. The wet weight of the unit is 28.77 pounds.

# MOOG



Shown in De-Pressurized Condition

Figure 107. MOOG- Flaperon Servoactuator Functional Schematic

c. Parker Berteau LECHT Actuator - Parker Berteau supplied a dual tandem actuator sized to F-15 stabilator actuator requirements for the USAF/MCAIR LECHT program, Contract No. F33657-84-C-2417. Custody of this program asset has been reassigned to this program so its usefulness can be extended. This actuator has a titanium valve manifold which has been designed to accommodate flow augmentation jet pumps in the inlets, load recovery valves, and several different combinations of main control valve options including both single and two stage direct drive valves and overlapped valve spools to reduce leakage. The actuator is shown in Figure 108. It has been further modified for this program to have provisions for hole-in-the-wall neutral centering. This provision will be used to further establish stiffness enhancement options at 8000 psi. The wet weight of the unit is 50 pounds.

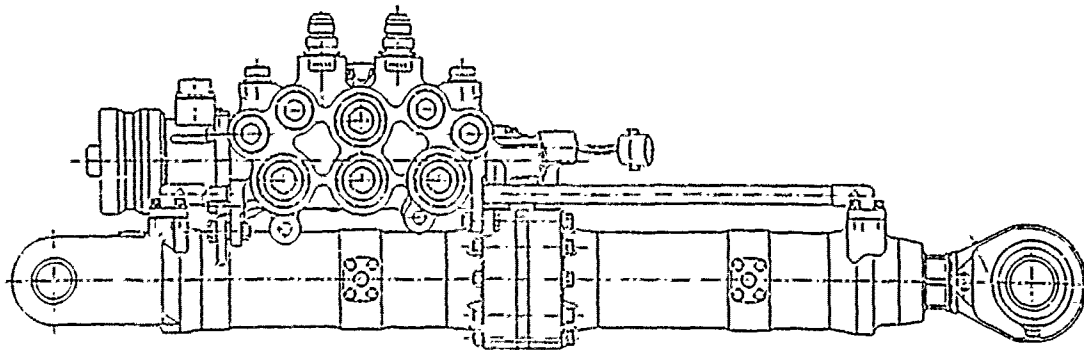


Figure 108. Parker Berteau - LECHT Actuator

d. Cadillac Gage Diffuser Ramp Actuator - An outline of the force motor controlled diffuser ramp actuator with an integral mechanical lock is shown in Figure 109. The Cadillac Gage design incorporates an HR Textron rotary force motor controlling a linear control valve. All valving shown on the hydraulic schematic in Figure 110 is contained within the aluminum matrix, silicon carbide fiber composite manifold assembly. Figure 111 depicts the integral mechanical retract lock. Main ram position feedback is to be accomplished through the use of a two wire transducer envelope and electrical interface, which performs the same function as an LVDT with less weight. Rated load is 26844 lbs. extending and 14086 lbs. retracting at 7900 psi. Maximum actuator velocity is 0.5 in/sec. The wet weight of the servocylinder is 23 pounds.

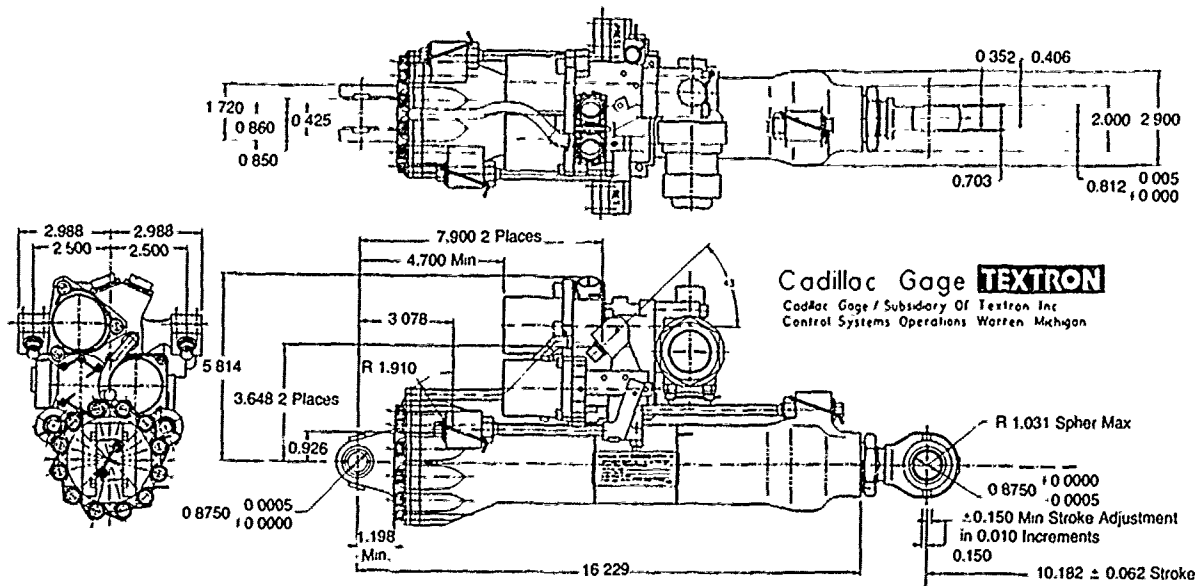


Figure 109. Cadillac Gage - Diffuser Ramp Actuator Outline Drawing

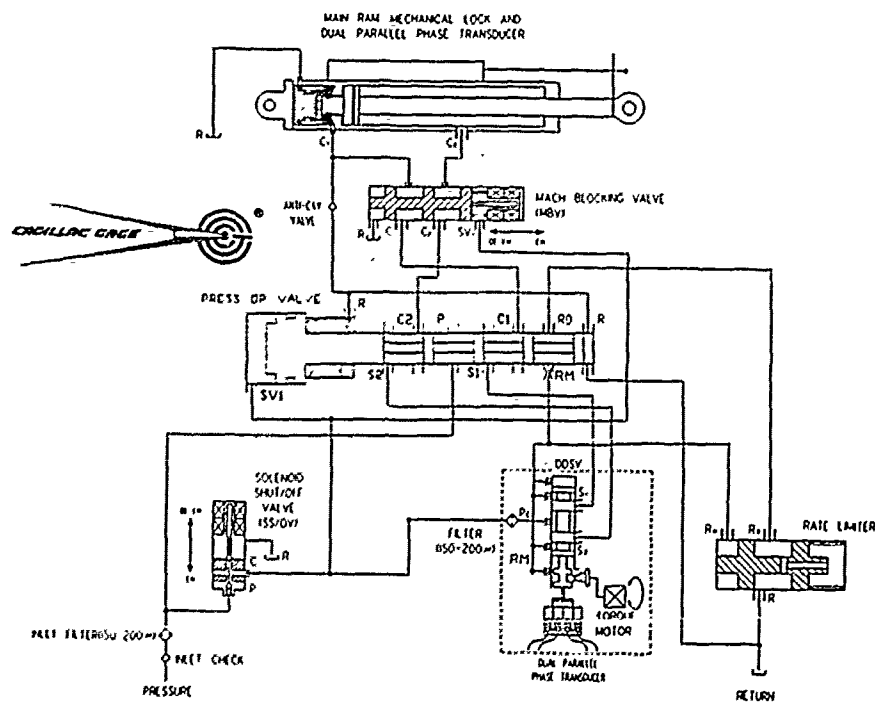


Figure 110. Cadillac Gage - Diffuser Ramp Actuator Hydraulic Schematic

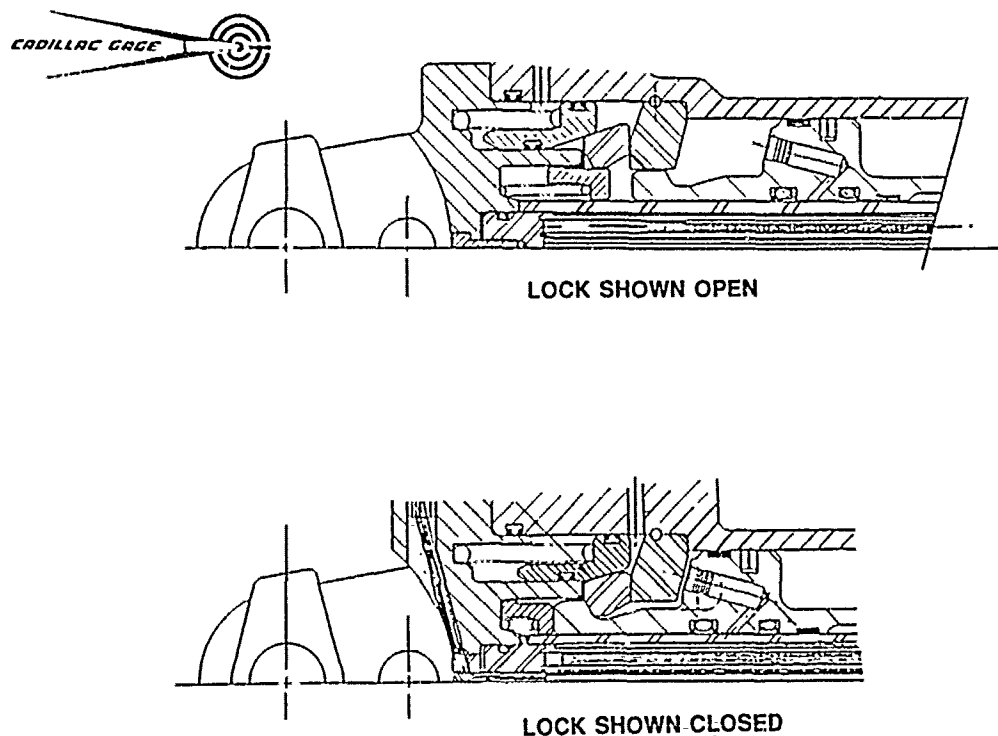


Figure 111. Cadillac Gage - Diffuser Ramp Actuator Lock Mechanism

5.5.5 Rotary Flight Control Actuators - The rudder servohinge is a hydromechanical device which converts hydraulic power to rotary motion. It is required to fit in a typical vertical tail envelope and meet the performance requirements including a torque capability of 22,000 inch-pounds (F-15 rudder ref.). The rudder is powered by one hydraulic and two electrical circuits which will provide operation after one electrical failure. After total electrical or hydraulic failure, the surface reverts to a damped trail position. Two designs are being utilized for this application: a rotary vane actuator and a linear to rotary ballscrew type that converts a linear piston motion to rotary through a reciprocating ball mechanism.

a. Bendix Rudder Actuator - The rotary vane actuator supplied by Bendix Electrodynamics is shown in Figure 112. This unit is designed for high output torque within a thin contour and provides the design hinge moment at 8000 psi

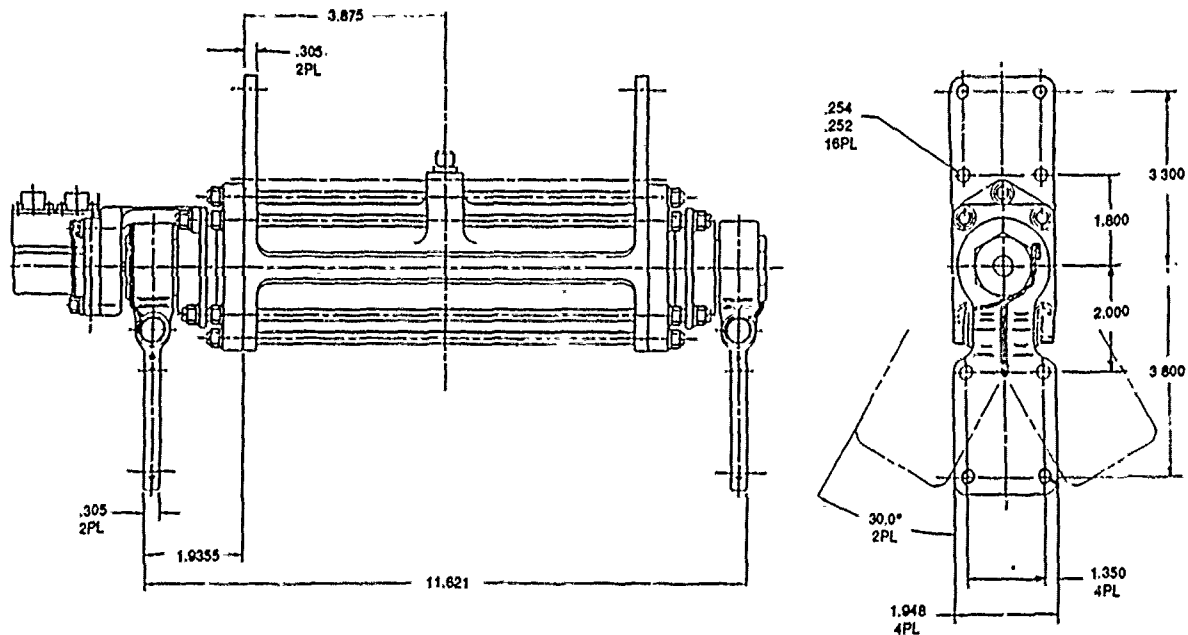


Figure 112. Bendix - Rotary Vane Actuator Outline Drawing

supply pressure. To minimize the sealing problems found in three and four vane actuators generally used for high output torques, Bendix has elected to use a dual vane actuator as illustrated by the cross section in Figure 113. The major components of the actuator include a 15-5Ph housing, a 300M vane/shaft and Arlon 1555 shaft bearings. The estimated wet weight of the rotary actuator is 11 pounds. The valve assembly is shown in Figure 114 and the hydraulic schematic in Figure 115. The control valve assembly incorporates a quadruple coil rotary torque motor which controls a rotary spool main control valve shown in detail in Figure 116. This uses a Hall effect transducer for valve positioning in lieu of an RVDT. The choice of a quadruple coil torque motor was made for availability reasons. A production motor would be a dual coil motor. To achieve the required dual channel control capability, the four coils are divided into two pairs, each pair consisting of two coils wired in parallel and controlled by one of the two electronic channels. Additional ancillary components include the bypass/damper valve, a two cubic inch accumulator (compensator) for internal leakage and fluid thermal contraction compensation in the event of hydraulic system failure, and a dual coil solenoid operated pilot valve. The two cubic inch compensator was chosen for availability and the production specification size would be one cubic inch. A dual cylinder relief valve is used as an overload device. The manifold assembly is a titanium 6Al-4V hogout with a total assembly wet weight of 13 pounds.



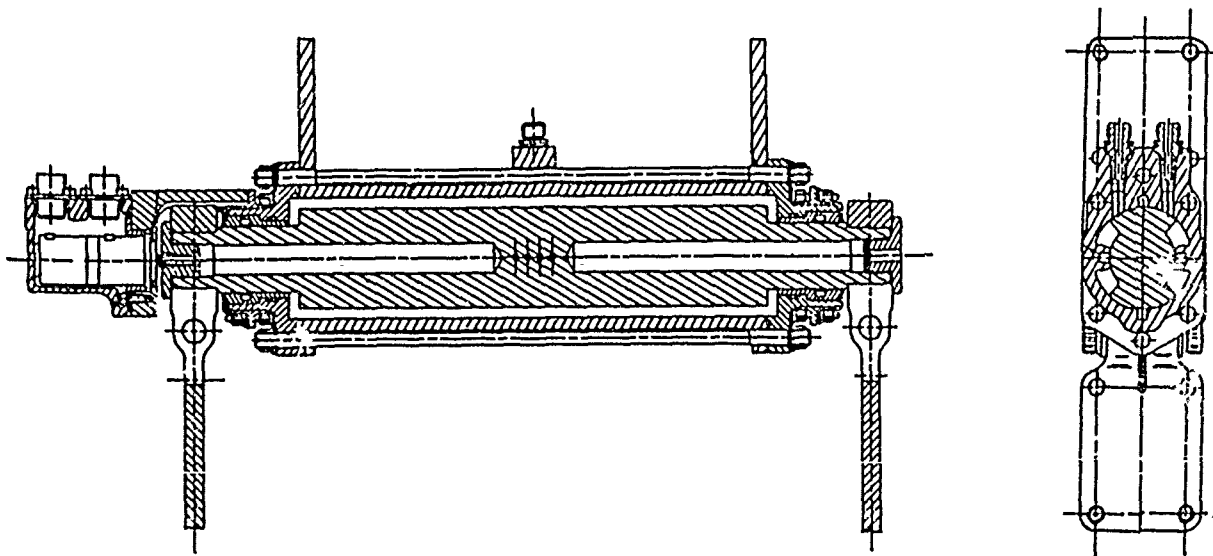


Figure 113. Bendix - Rotary Vane Actuator Detail Drawing

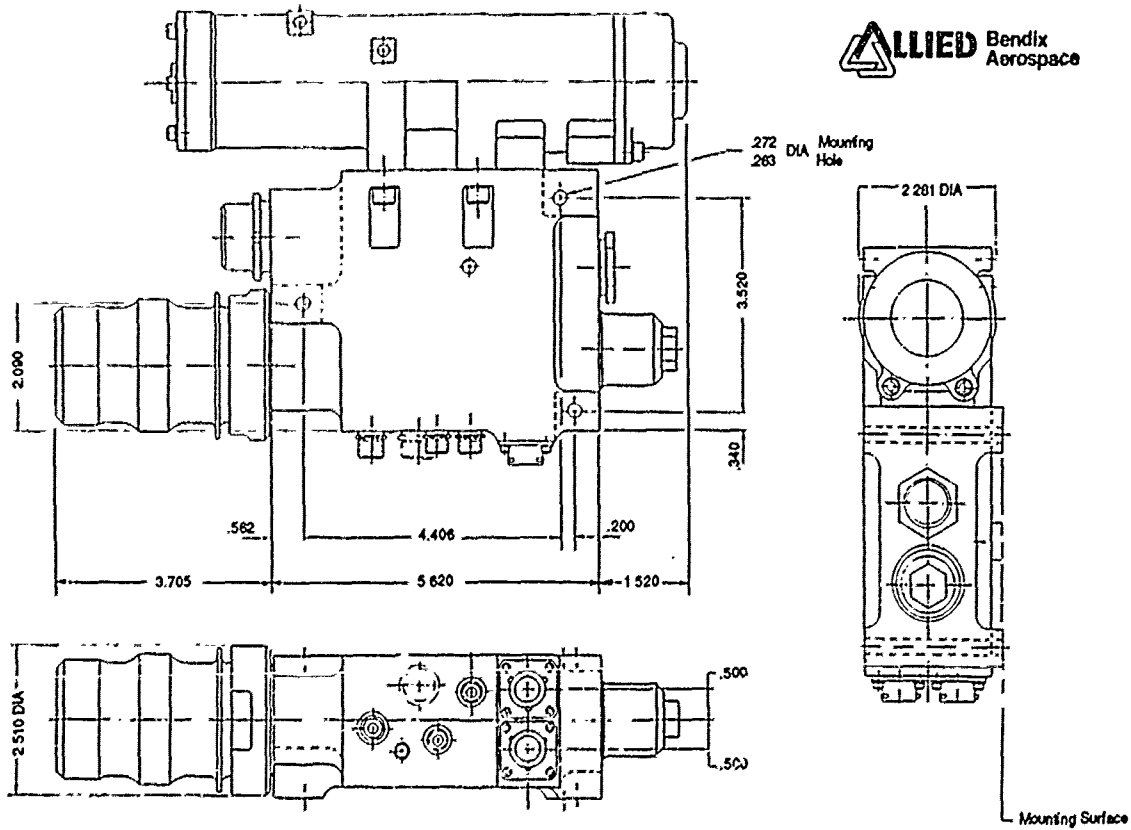


Figure 114. Bendix - Rotary Vane Actuator Control Valve Outline Drawing

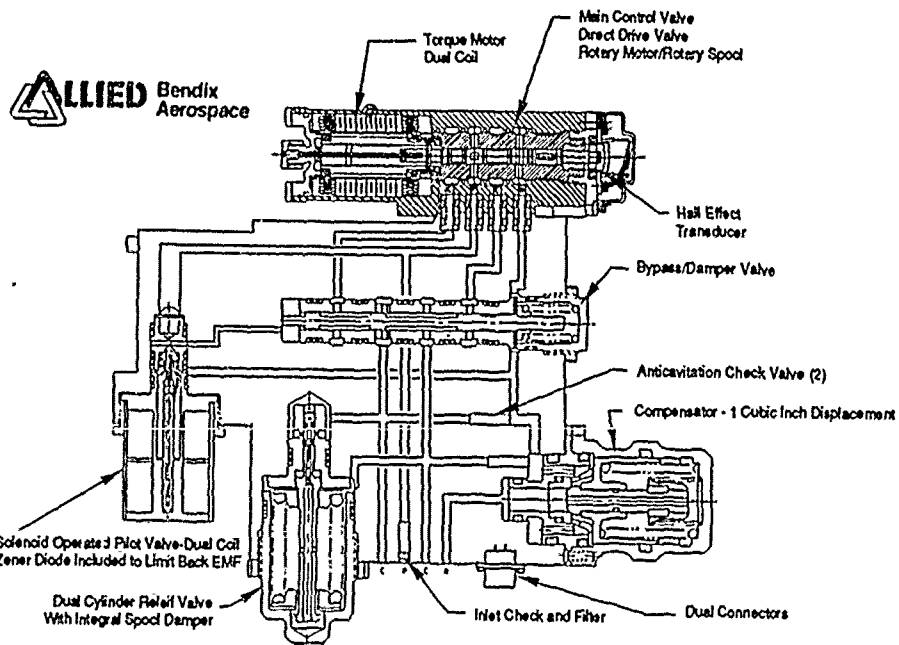


Figure 115. Bendix - Rotary Vane Actuator Functional Schematic

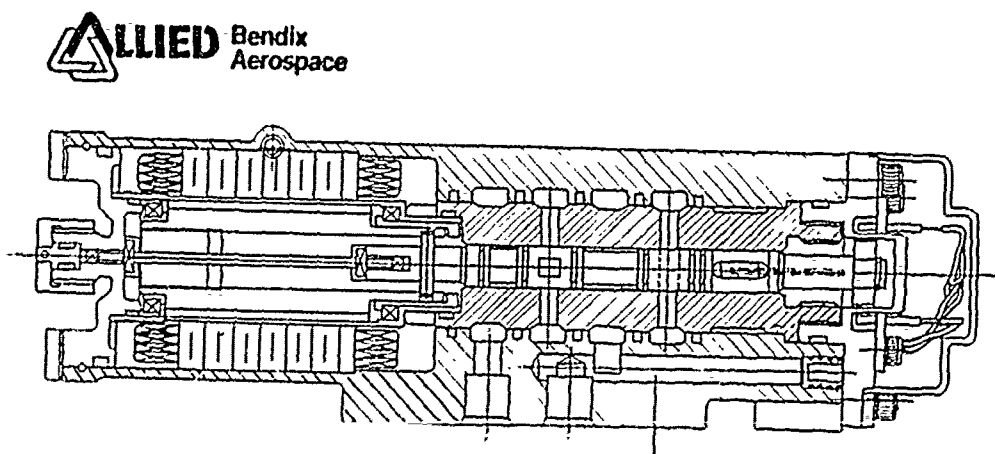


Figure 116. Bendix - Rotary DDV Detail Drawing

b. HR Textron Servohinge - HR Textron has demonstrated a second approach; that being a recirculating ballscrew type actuator developed by Ratier-Figeac in France. The operation of this design can be visualized with Figure 117. A direct drive valve assembly with a linear force motor and linear valve actuates the linear portion of the hinge assembly. The shaft is extended or retracted via a recirculating ballscrew mechanism. The unit is

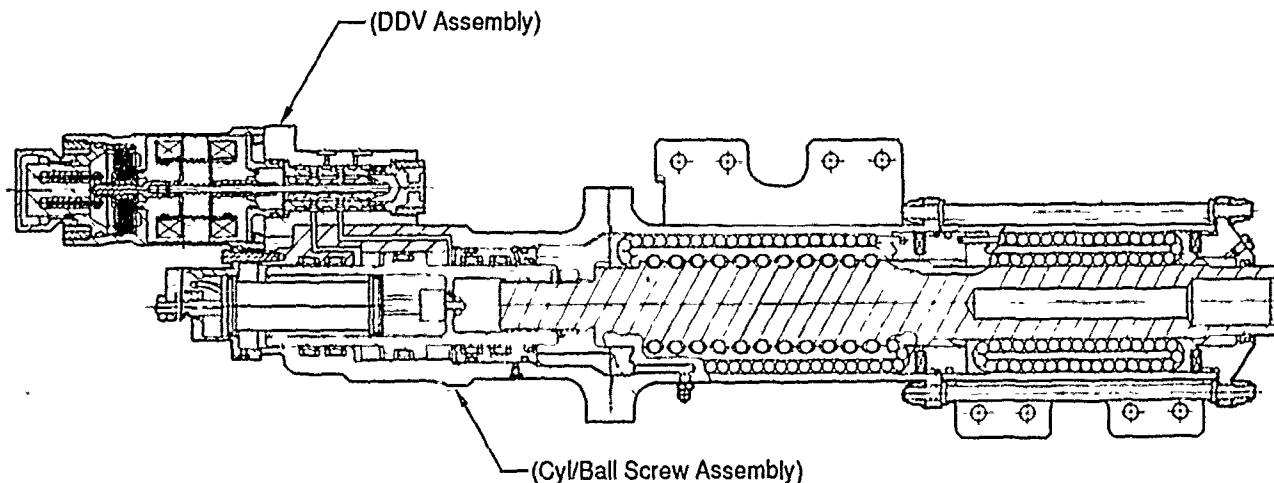
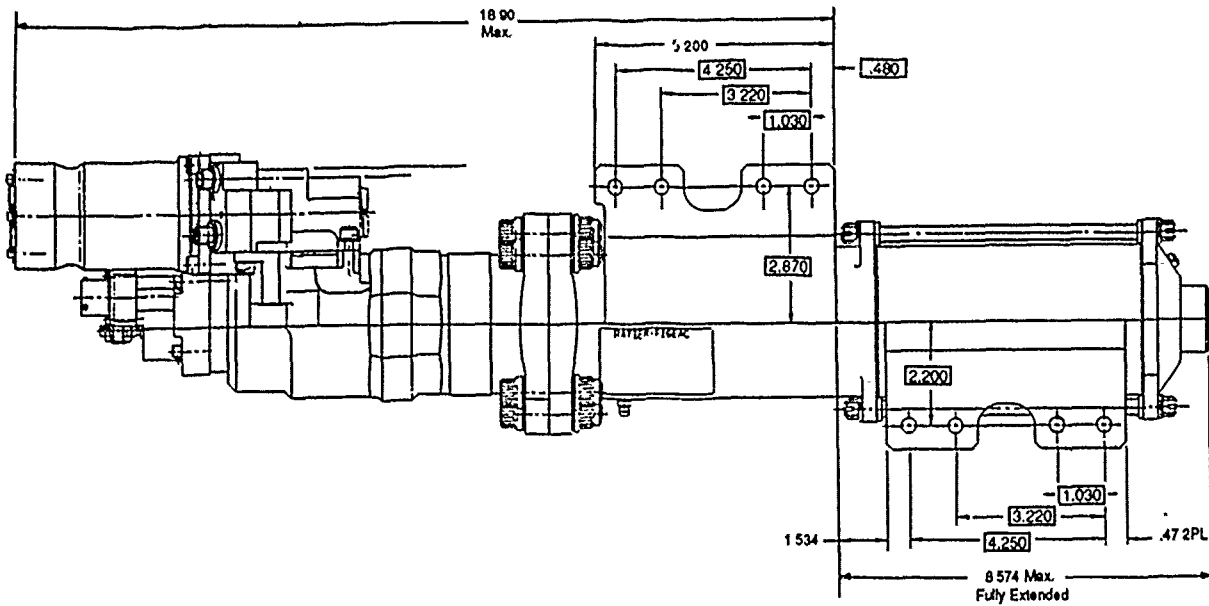


Figure 117. HR Textron - Recirculating Ball Screw Detail Drawing

designed to produce its design stall hinge moment at 16000 psi supply pressure which is produced by a pressure intensifier developed by Parker Aerospace. At no-load, the intensifier is bypassed and only half as much flow is required (compared to conventional design) to displace the actuator. Figure 118 shows the overall size of the unit. Its total weight is approximately 55 pounds which could be reduced by 20 percent by weight optimization of a production ballscrew mechanism.



**HR TEXTRON**

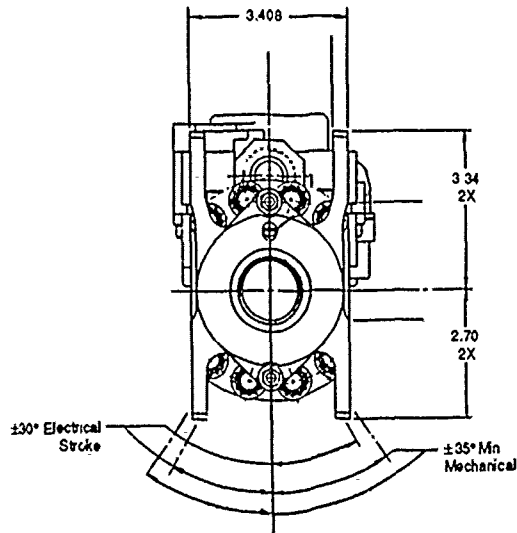


Figure 118. HR Textron - Rudder Servohinge Outline Drawing

5.5.6 Hydraulic Motor Applications - Two hydraulic motors are being utilized on the LTD. One is a fixed displacement motor and is being used to simulate a hydraulic powered gun system utility load. The fixed displacement requires a maximum of 34 hydraulic horsepower at rated speed. The other is a variable displacement motor which is being used to demonstrate a low energy leading edge flap drive system.

a. Abex Utility Function Motor - The Abex utility motor, model AM2CH-1 shown in Figure 119, is a fixed displacement, bi-directional unit. The motor is a production series unit modified to operate with CTFE at 8000 psi supply pressure. It has a stall torque of 295 in-lbs, a displacement of 0.26 cpr and a rated speed of 6600 rpm. The wet weight of the motor is 7.50 lbs.

# Abex

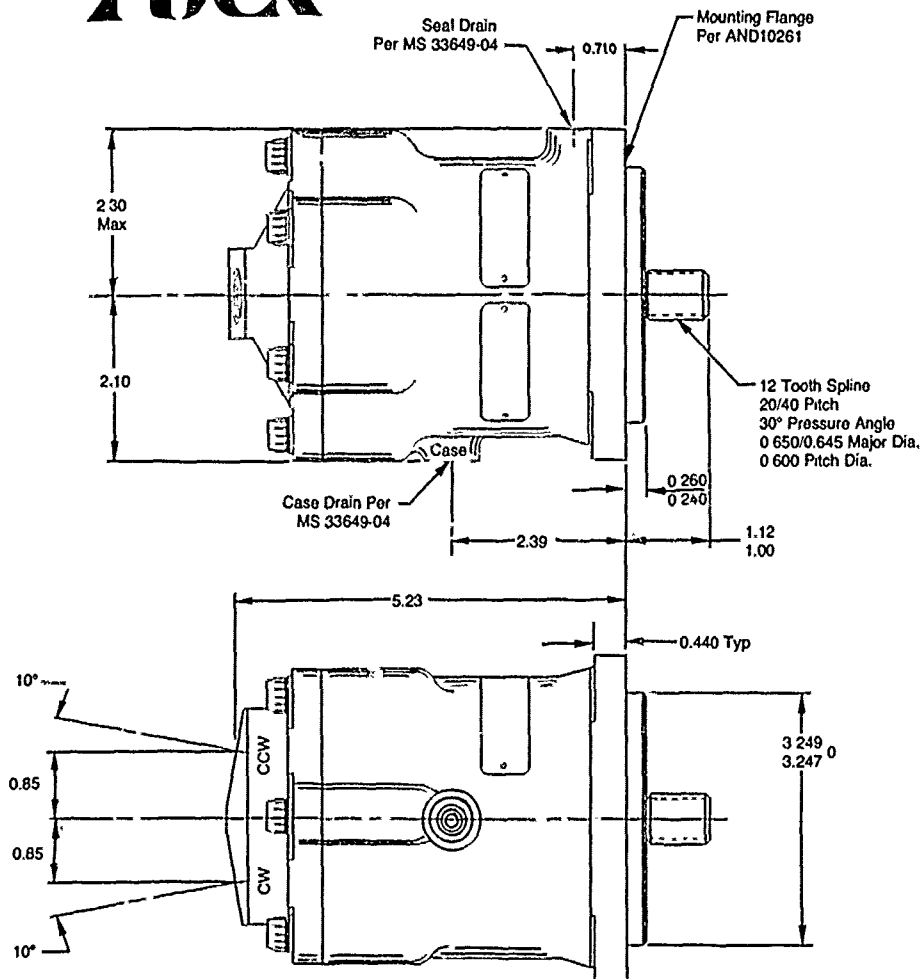


Figure 119. Abex - Utility Hydraulic Motor

b. Sundstrand Leading Edge Flap (LEF) Drive - This system consists of a variable displacement hydraulic motor operated power drive unit driving a mechanically geared rotary actuator through a torque shaft. The system is similar to the F/A-18 leading edge flap system with the exception of a change from fixed to variable displacement motor which greatly reduces flow demand during low load operation. The power drive unit consists of a direct drive

valve, displacement control pistons, variable displacement motor, and an output gearbox of 1.50:1 ratio. The motor is powered by one hydraulic system and controlled by a single channel electrical controller. The direct drive valve is a duplex coil, force motor driven, overlapped spool and sleeve servovalve. Feedback loops are closed with a motor displacement sensing resolver and gearbox mounted tachometer and resolver. The outline of the system is shown in Figure 120 with hydraulic schematic as shown in Figure 121. The direct drive valve which controls motor displacement, is supplied by E-Systems. An outline of the power drive unit (PDU) is shown in Figure 122. The geared rotary actuator is hinge line mounted with an input to output gear ratio of 293:1 and design limit load of 138,000 in-lbs. The actuator details are shown in Figure 123. Maximum no-load surface rate for the system is 116 deg/sec, and the system wet weight is 47.5 lbs. including the power drive unit, torque tube and geared rotary actuator.

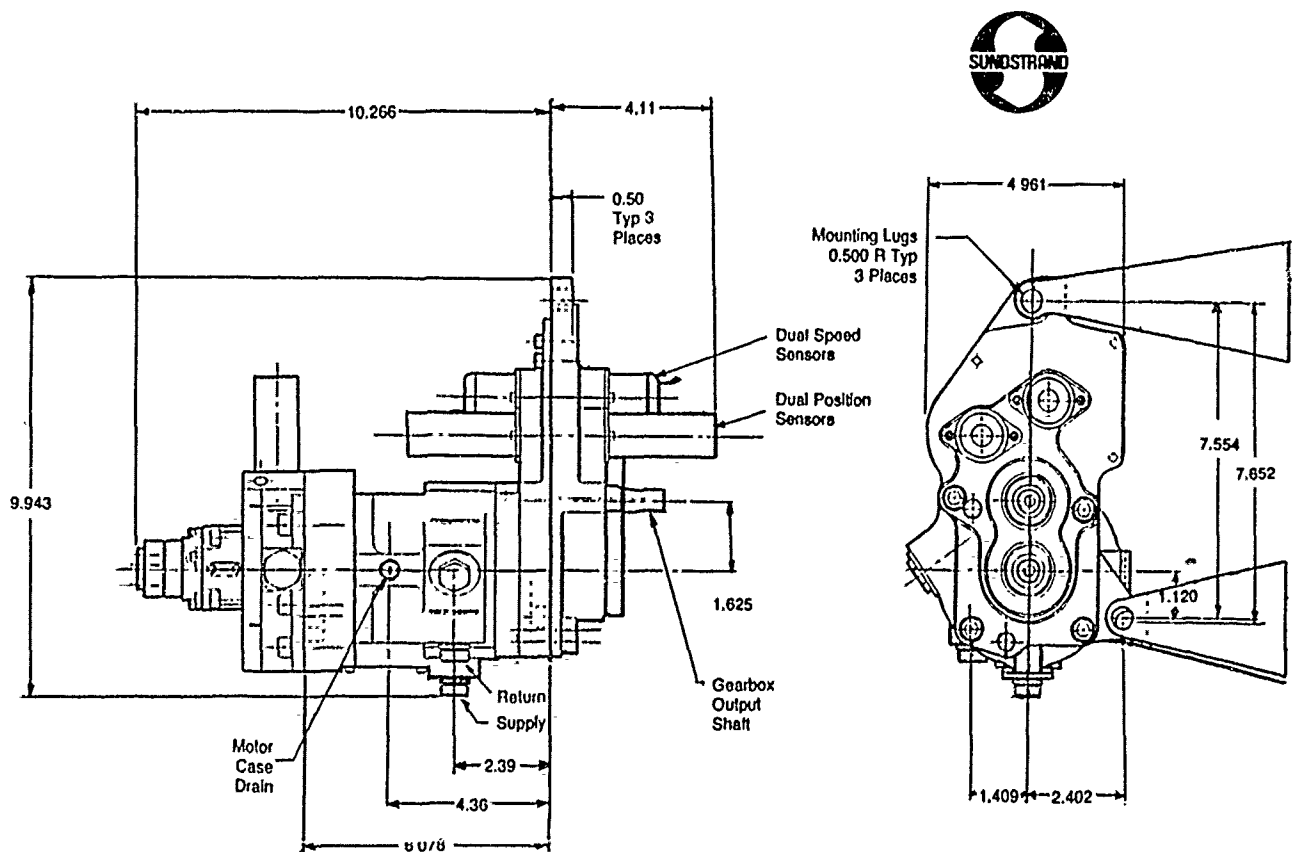


Figure 120. Sundstrand - Leading Edge Flap (LEF) Power Drive Unit Outline Drawing

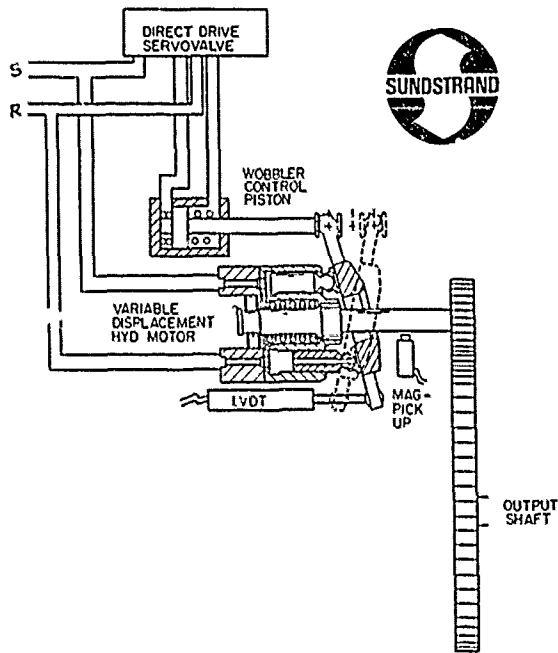


Figure 121. Sundstrand - LEF Power Drive Unit Hydraulic Schematic

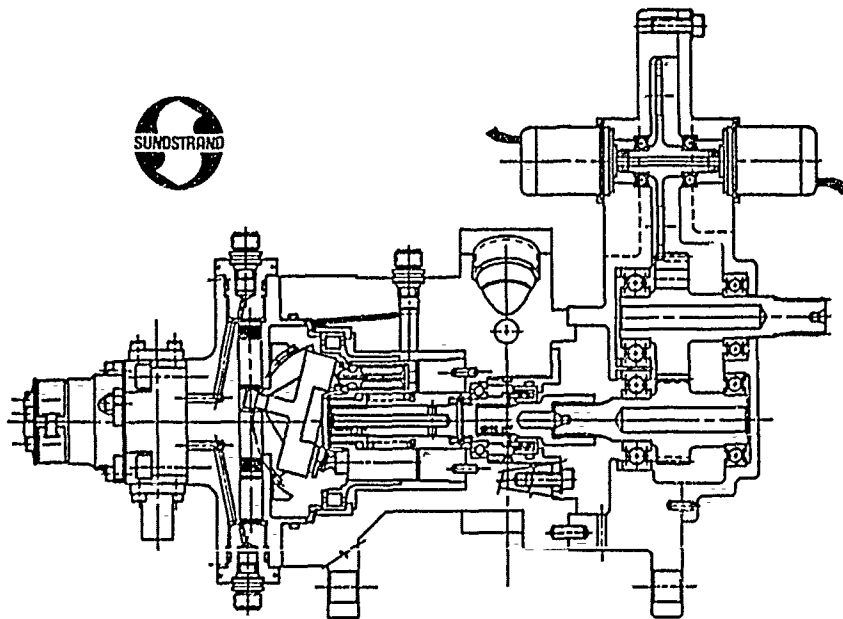
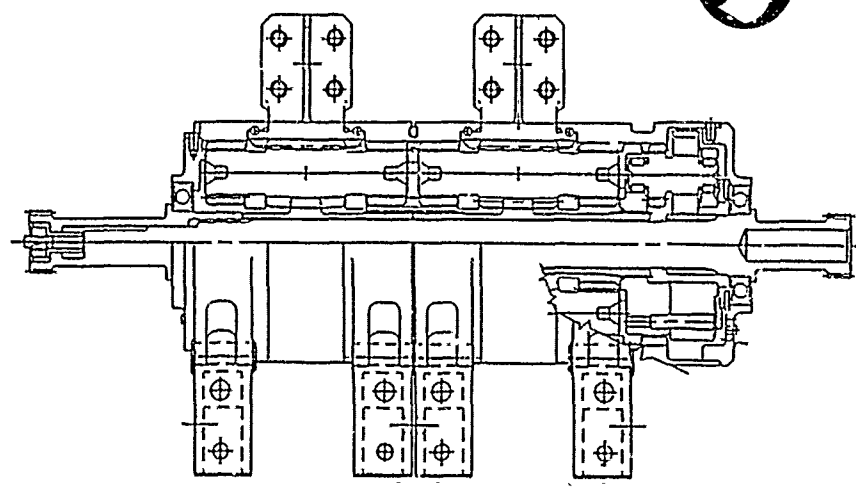


Figure 122. Sundstrand - LEF Power Drive Unit Detail Drawing



LIMIT LOAD	138000 IN-LB	GEAR RATIO	293/1
ULTIMATE LOAD	207000 IN-LB	WEIGHT	27 LBS
STIFFNESS	CALCULATED 5 IM IN-LB/ RAD	OD	3.9 IN
FREEPLAY	90 DEG. MAX @ INPUT, OUTPUT FIXED +/- 12 IN-LB INPUT TORQUE	LENGTH	13.5 IN

Figure 123. Sundstrand - LEF Actuator Detail Drawing

5.5.7 Engine Nozzle Actuation System - The engine nozzle actuation controls include a complement of eight engine mounted actuators. In order to gain the greatest experience in engine nozzle actuation in 3000 psi systems with nonflammable CTFE fluid, the program has drawn upon two sources for actuators which represent requisite technology. MOOG has provided two actuator designs based upon F-15 SMTD requirements. Both are provisioned for active internal cooling in a hostile thermal environment. The others are provided by Parker Bertea and are identical to those provided for an advanced engine program. Figure 124 shows the hydraulic arrangement of these actuators and servo control valves.



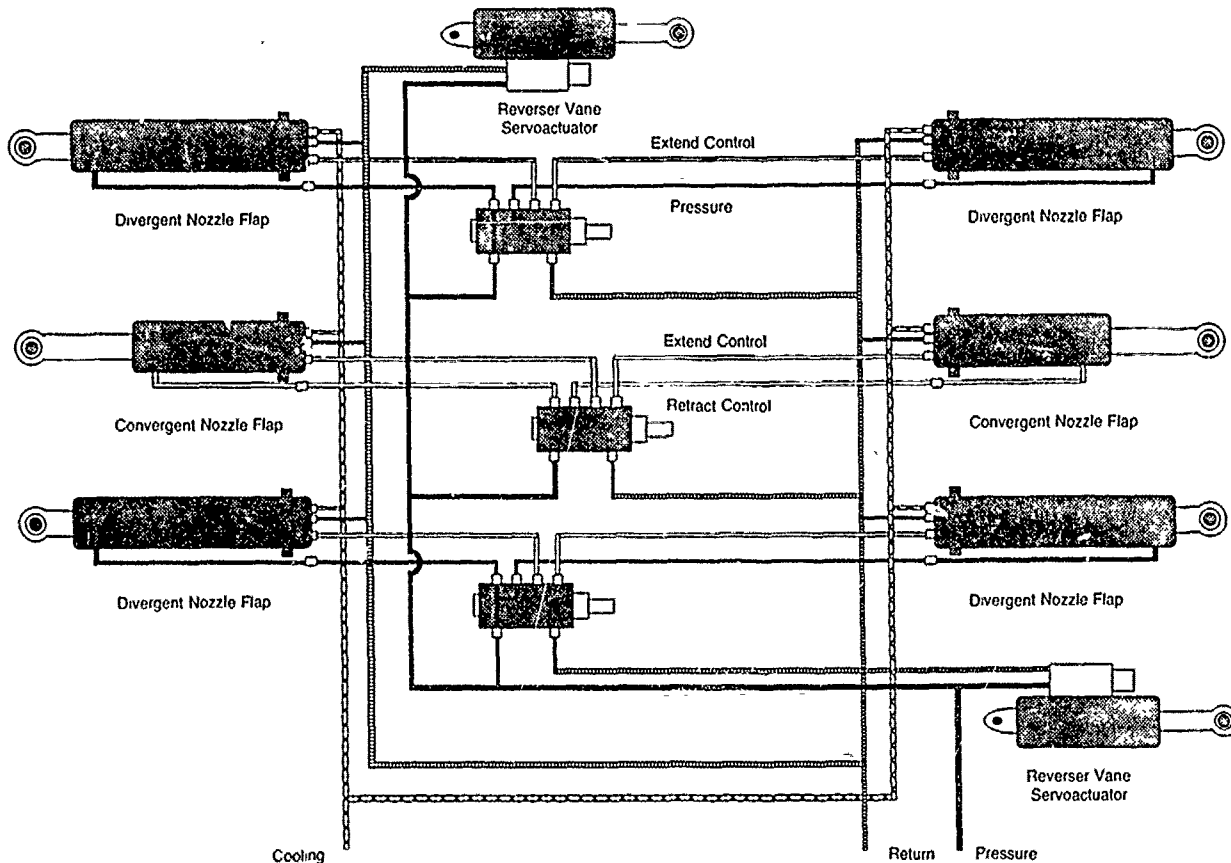


Figure 124. Engine Nozzle Actuation System - Hydraulic Schematic

a. MOOG Engine Nozzle Actuation System - The MOOG system consists of four divergent flap actuators and two convergent flap actuators controlled by remotely located servovalves. The convergent nozzle flap actuators are controlled by a four way servovalve while the divergent flap actuators are controlled by a three way valve. The engine actuators are powered by a single circuit of the utility hydraulic system with a primary control circuit as backup in case of a system failure; two independent electrical control circuits will provide operation after a single electrical failure. After total electric failure and hydraulic failure, the air loads will drive the actuators to their normal positions. Moog provided six flap actuators for this application. The servovalves are direct drive single stage force motors.

b. MOOG Convergent Nozzle Flap Actuation - The convergent flap nozzle actuation set consists of two actuators which are controlled by a single four way servovalve. Only one actuator provides electrical position at any given time. The convergent flap nozzle is the inner set of exhaust flow ramps which principally control the exhaust nozzle area ( $A_1$ ). These surfaces can be "clamshell" closed to divert exhaust flow out of the reverser vanes to produce reverse thrust.

(1) Convergent Flap Actuators - The convergent flap actuator is shown in Figure 125. Additional ports are provided for accepting cooling flow through the LVDT and inner rod area as shown in Figure 126. The actuator is trunnion mounted. In application, the actuator produces pure linear motion; i.e., no rise and fall. The actuator barrel, piston and rod are made from 15-5PH CRES steel. The convergent nozzle loads are such that this actuator could have been made regenerative except, that in this application, that approach would have created an unacceptable failure mode (nozzle closed with loss of electrical control). Duplex LVDTs provide the electrical feedback signals proportional to the ram positions. The wet weight of the actuator is 22.7 pounds.

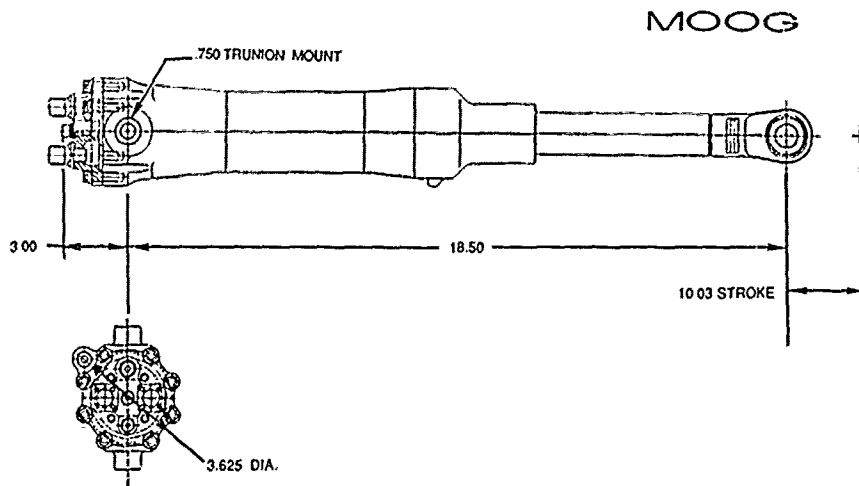


Figure 125. MOOG - Convergent Flap Actuator Outline Drawing

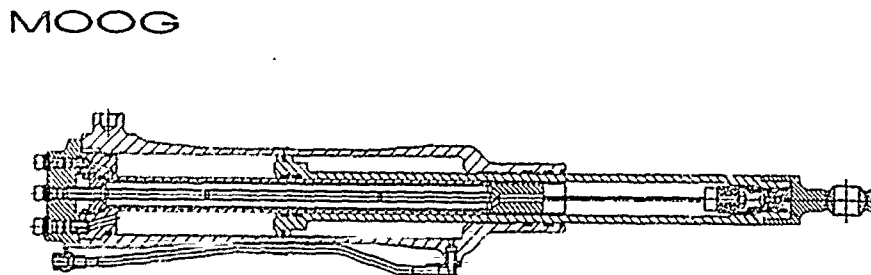


Figure 126. MOOG - Convergent Flap Actuator Detail Drawing

(2) Convergent Flap Servovalve - The direct drive servovalve used to control the convergent flap actuators is shown in Figure 127. The components in the servovalves are a spool and sleeve assembly with an in line check valve. Only one ram will provide the position feedback to the servovalve at any given moment. Actuator positioning in the case of electrical failure is provided by null bias mechanical offset of the valve spool. This requires a small amount of power to hold null, but greatly simplifies redundancy provisions. The wet weight of the servovalve is 9.7 pounds.

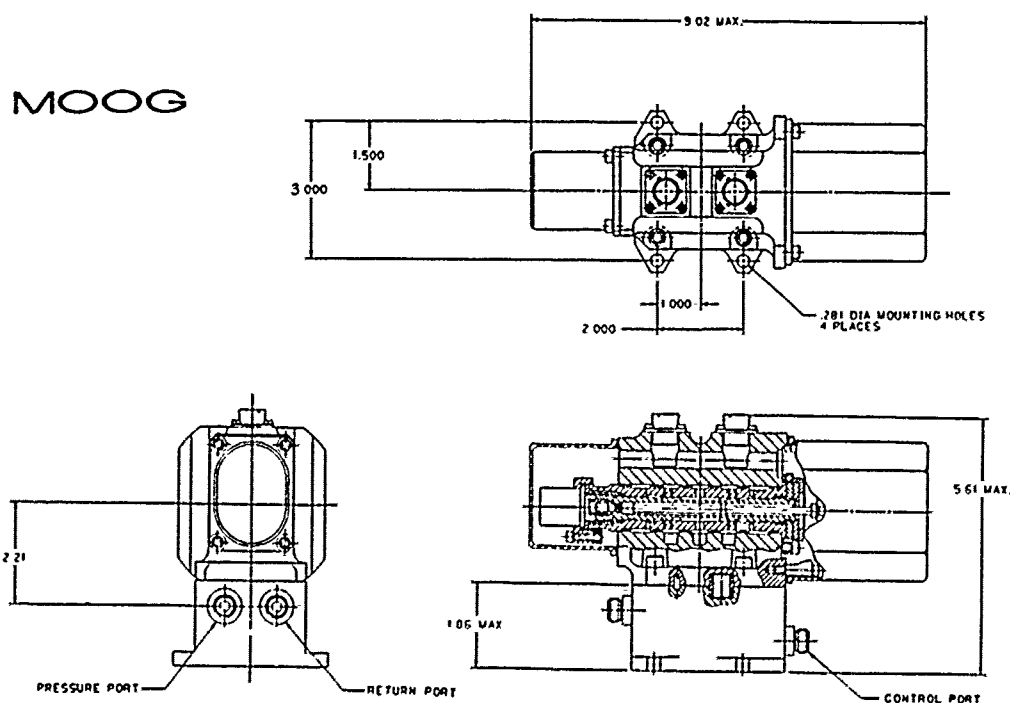


Figure 127. MOOG - Convergent Flap Servovalve Outline/Detail Drawing

c. MOOG Divergent Nozzle Flap Actuation - The divergent nozzles are the rearward most ramps in the variable geometry nozzle. These devices primarily provide the directional flow characteristics for engine thrust vectoring. The upper pair of actuators position the upper ramp and are operated in parallel from a single servovalve. The lower pair operate similarly.

(1) Divergent Flap Actuators - The divergent actuator is shown in Figure 128. These actuators have higher loads in tension than in compression and have been designed to be operated regeneratively, i.e., the rod chamber is pressurized at system pressure. This type of actuator is controlled by a three way servovalve. Additional porting has been added to the nozzle actuators to allow for an independent cooling circuit which will reduce fluid temperature and prolong actuator and seal life. The rods will be chrome plated on all actuators with the exception of one unit which will have tungsten carbide plating using a gun detonation process. Figure 129 shows the details of the divergent flap actuator. The wet weight of the actuator is 21.4 pounds.

MOOG

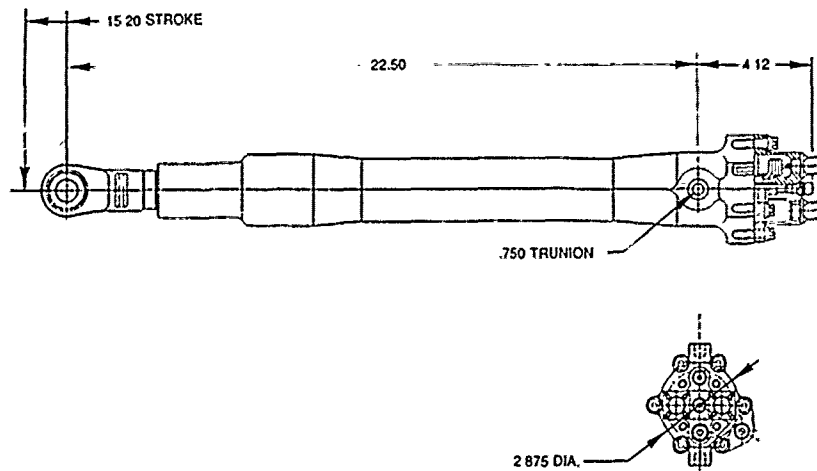


Figure 128. MOOG - Divergent Flap Actuator Outline Drawing

MOOG

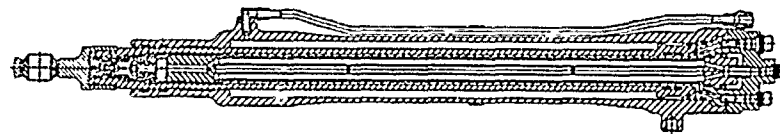


Figure 129. MOOG - Divergent Flap Actuator Detail Drawing

(2) Divergent Flap Servovalve - The direct drive servovalve used to control the divergent flap actuators is similar to the convergent nozzle actuator control valve except that it is a three way valve. No directional flow control is needed to the actuator retract port. As with the convergent set, actuator positioning in the case of electrical failure is provided by null biasing the valve spool with mechanical offset. Figure 130 shows the external arrangement and internal details of this control valve. The wet weight of the valve is 8.2 pounds.

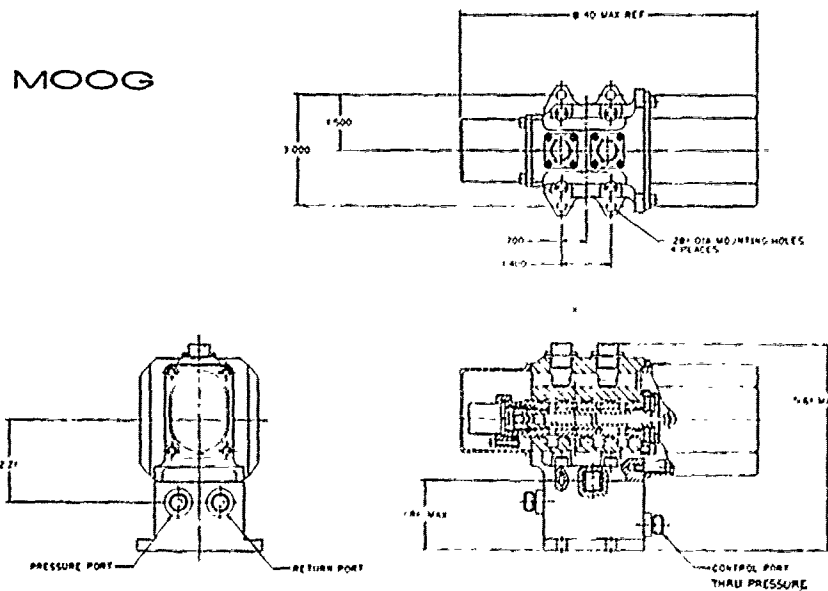


Figure 130. MOOG - Divergent Flap Servovalve Outline/Detail Drawing

d. Parker Bertea Reverser Vane Actuators - The reverser vane actuators are supplied by Bertea and are dual electrical channel, single hydraulic system operated. Cooling flow is obtained internally through an orifice, ported to supply pressure, just downstream of the inlet filter. Rated load is 11360 lbs. extending and 8887 lbs. retracting at 7900 psi. Rated velocity is 4.0 in/sec. An outline of the actuator is shown in Figure 131 and a schematic is shown in Figure 132. The wet weight of the actuator is 9.50 pounds.

Bertea



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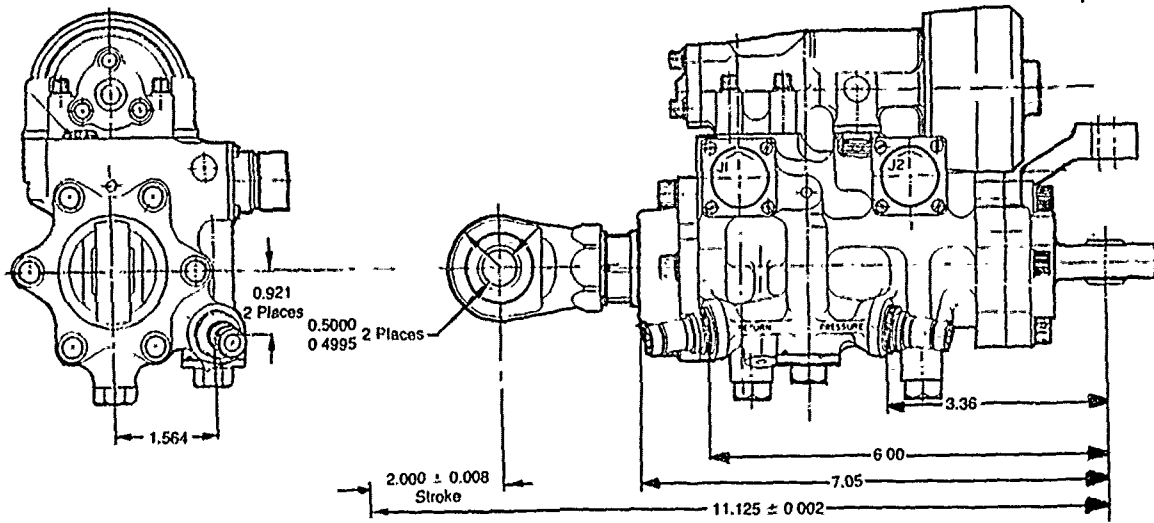


Figure 131. Parker Bertea - Reverser Vane Actuator Outline Drawing

Bertea



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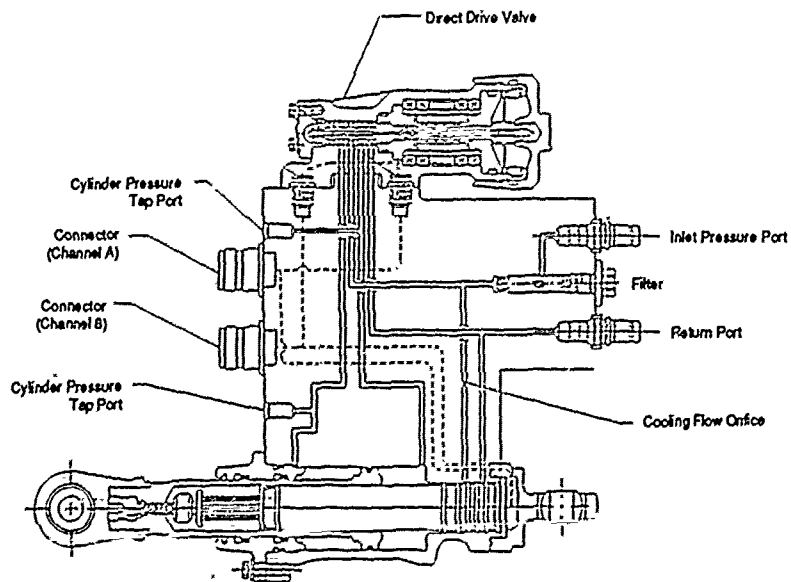


Figure 132. Parker Bertea - Reverser Vane Actuator Functional Schematic

e. Parker Berteia Arc Valve Actuators - The arc valve actuators are supplied by Berteia and are dual electrical channel, single hydraulic system operated. Cooling flow is obtained internally by porting supply pressure through a pressure dropping orifice downstream of the inlet filter. Rated load is 12861 lbs. extending and 10365 lbs. retracting at 7900 psi. Rated velocity is 7.34 in/sec. An outline of the actuator is shown in Figure 133 and a schematic is shown in Figure 134. The wet weight of the actuator is 14.40 pounds.

Berteia



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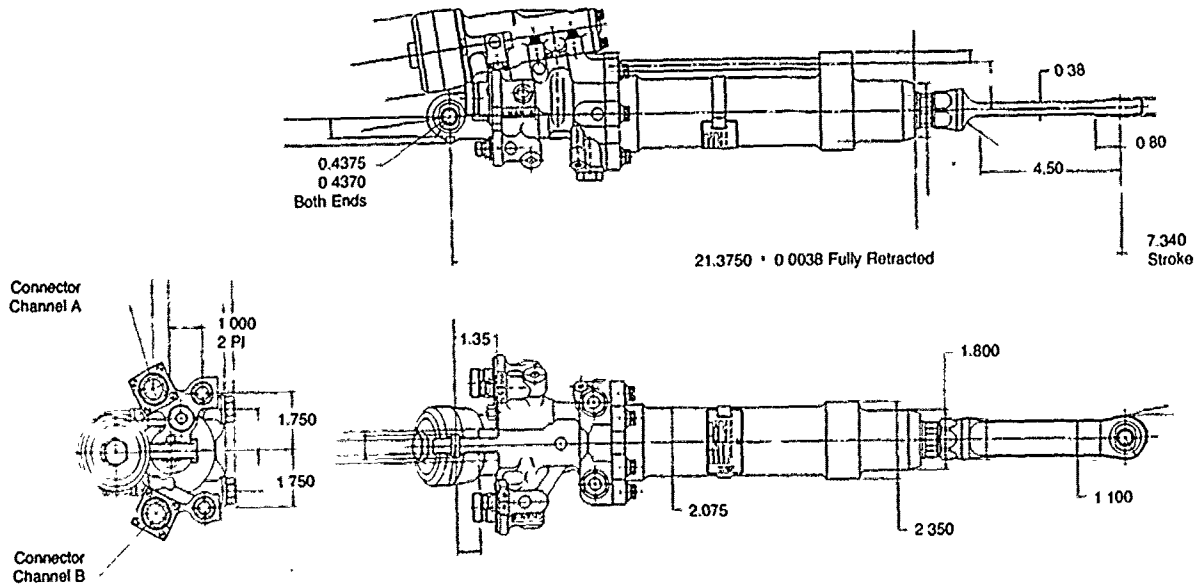


Figure 133. Parker Berteia - Arc Valve Actuator Outline Drawing

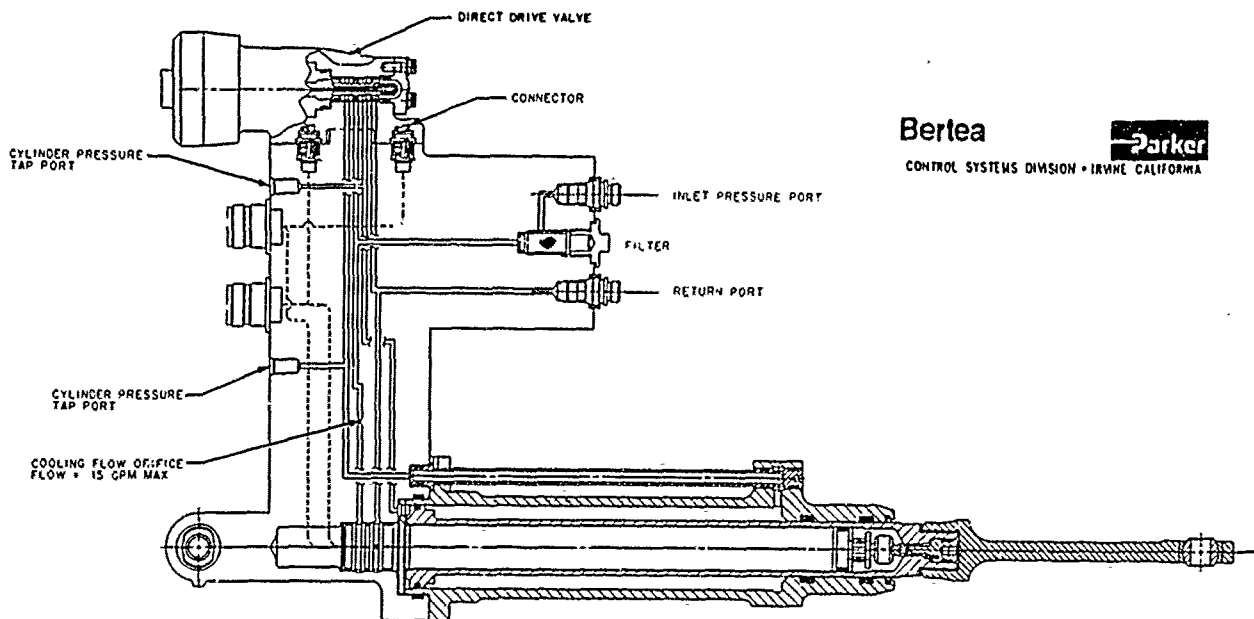


Figure 134. Parker Berteau - Arc Valve Actuator Functional Schematic

5.5.8 Utility Components - Several utility functions have been duplicated in order to demonstrate 8000 psi nonflammable design technology. These functions include nearly every generic device typically used in hydraulic systems except landing gear actuation.

a. Parker Aerospace Accumulator - An accumulator has been sized for the Jet Fuel Starter (JFS) system application. It is a gas precharged unit with 164 cubic inches total volume and 82 cubic inches oil volume at 8000 psi. The Parker designed unit is shown in Figure 135. The shell is machined from HP-9-4-30 steel and is wrapped with Kevlar to reduce weight. The cap and nut are also made from HP-9-4-30 and 15-5Ph CRES steel has been used for the piston. The piston seals are Greene-Tweed "Rotolon" spring energized lip seals facing each other but separated by a spacer. The backup rings are PEEK material. These seals are very stiff and require a two piece piston to facilitate assembly. The wet weight of the accumulator is 18.2 lbs.



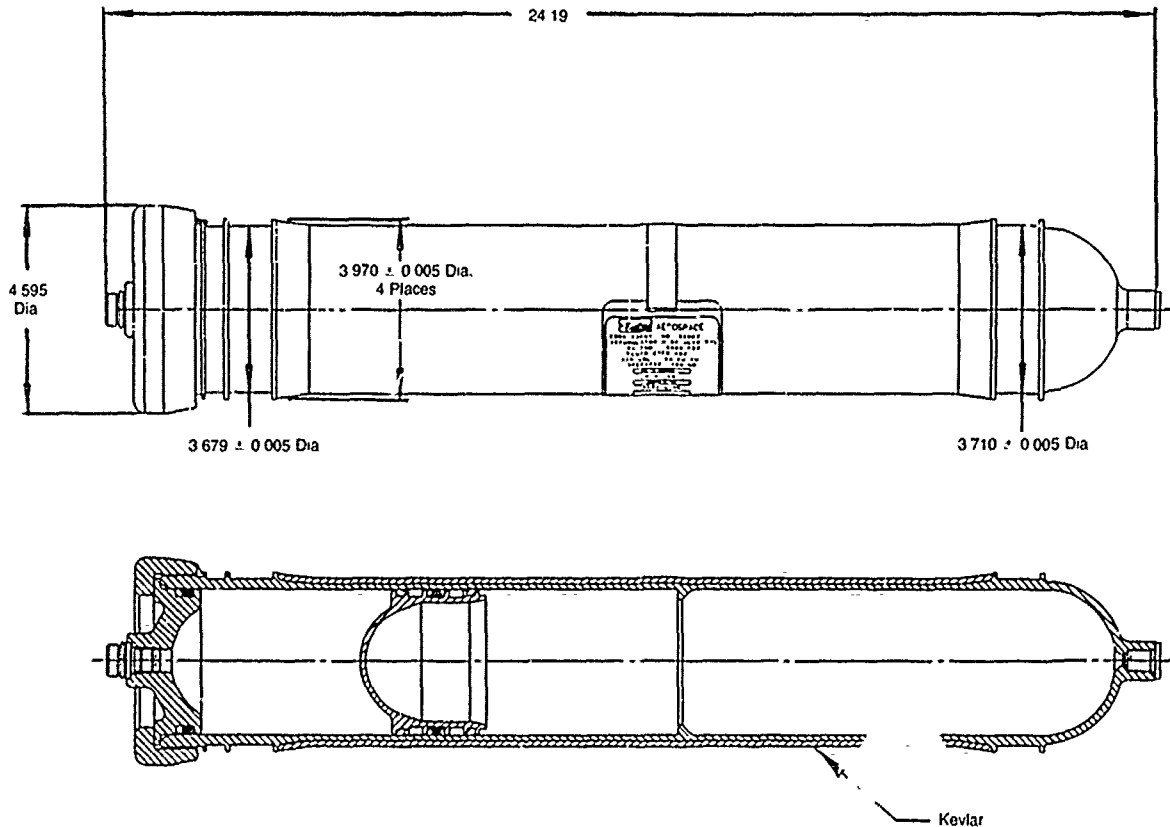


Figure 135. Parker - 8000 psi Accumulator Outline/Detail Drawing

b. Parker Aerospace 4W-3P Selector Valve - A four way, three position directional control valve has been designed by Parker Aerospace Division of the Parker Berteau Aerospace Group as shown in Figure 136. The housing is machined from a HIP 6Al-4V titanium casting and the slide and sleeve assembly is fabricated from 440C heat treated to 57 to 60 Rc. The solenoid pilot valves have a poppet configuration and are designed to be removable cartridges. Figure 137 shows the schematic of the valve. The estimated weight of the unit is 3.8 lbs dry.

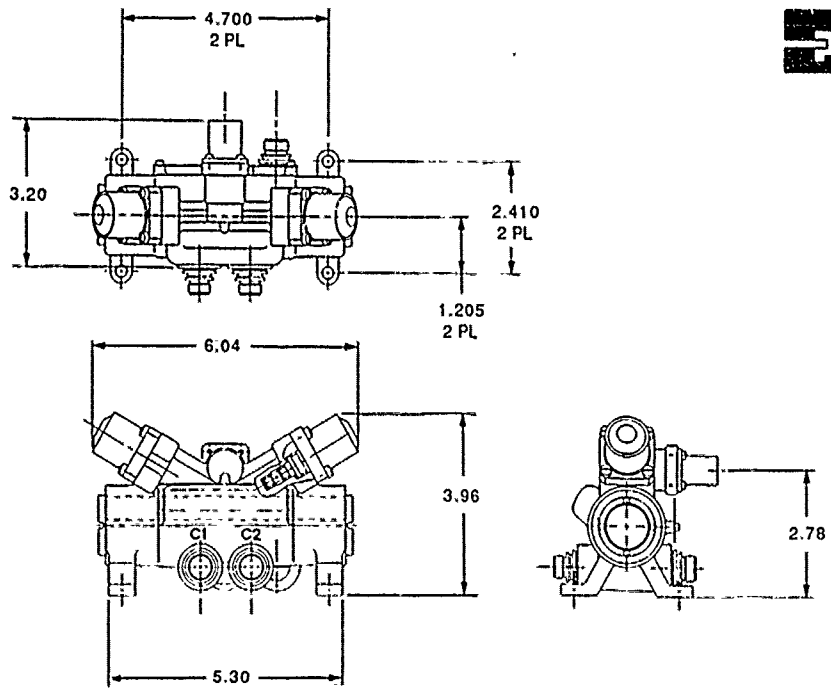


Figure 136. Parker - Selector Valve (4W-3P) Outline Drawing

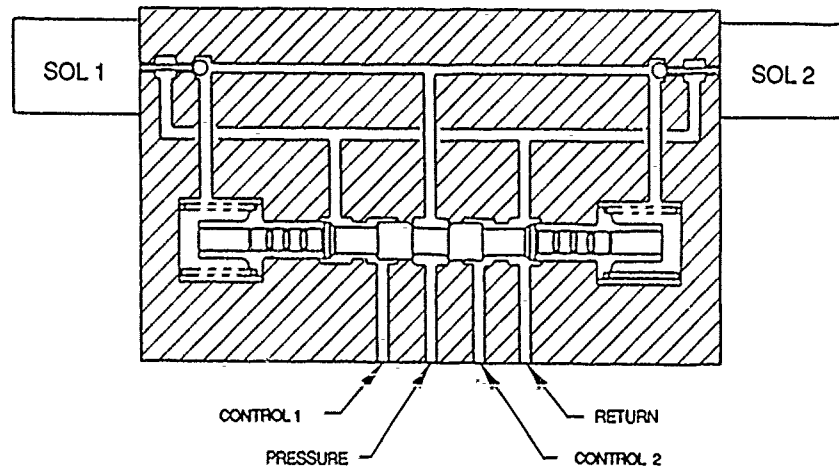


Figure 137. Parker - Selector Valve (4W-3P) Functional Schematic



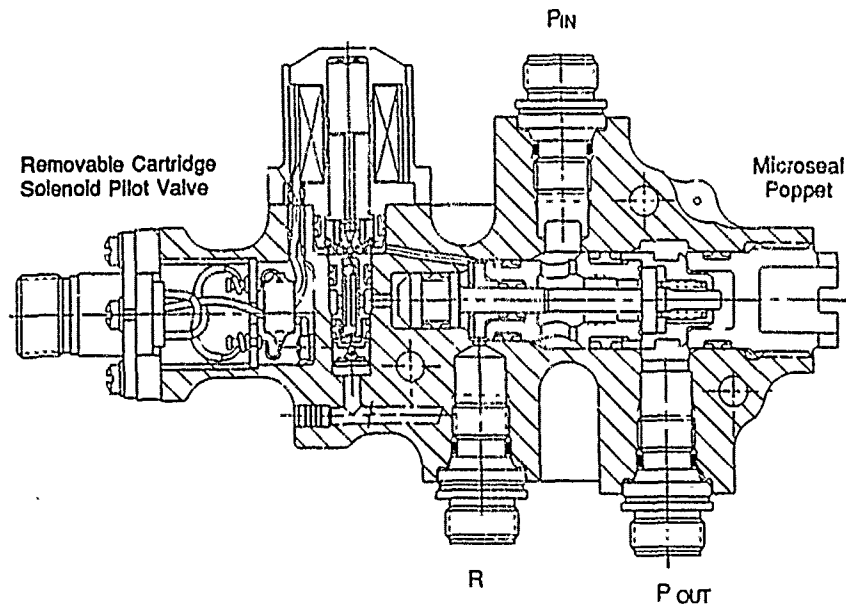


Figure 139. Parker - Selector Valve (3W-2P) Detail Drawing

d. Parker Aerospace 6W-2P Shuttle Valve - The shuttle valve is a six way, two position bi-stable switching valve which is used to provide a second source of hydraulic power to the engine nozzle actuation system. The concept is identical to the shutoff valve stage of the Hydraulic Integrity Monitor used to backup the rudder and stabilator actuators. The envelope for this unit is shown in Figure 140. The valve weight is estimated to be approximately 5.0 lbs. A cross section of the shuttle valve is shown in Figure 141 and illustrates the lap assembly and hysteresis valve with the Microseal(TM) poppet. A hydraulic schematic, Figure 142, shows the shuttle valve in the depressurized and in the pressurized positions. It should be noted that P1 and R1 are the primary supply circuit, P2 and R2 are the controlled subsystem circuit, and P3 and R3 are the backup supply system. In the depressurized position, the spool is forced to the left to shutoff the primary circuit and the backup supply system is connected to the controlled circuit. This is also the primary system failure position. With the primary system pressurized to above 1000 psi, the hysteresis valve poppet is driven off the pressure seat and onto the return seat to port pressure to the end of the shuttle valve spool. The force generated by pressure in the pilot chamber drives the spool against the spring until it stops against the cap.

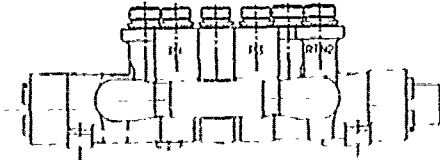
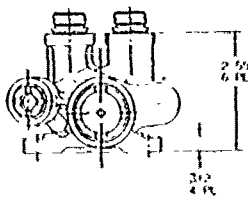
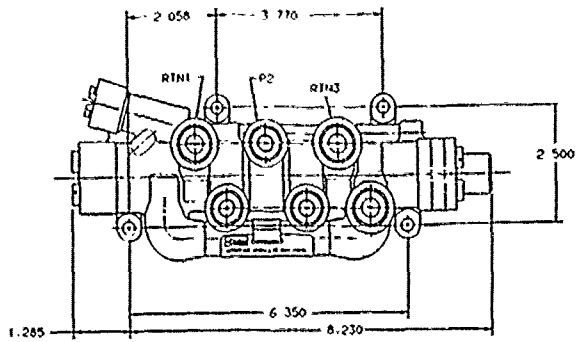


Figure 140. Parker - Switching Valve (6W-2P) Outline Drawing

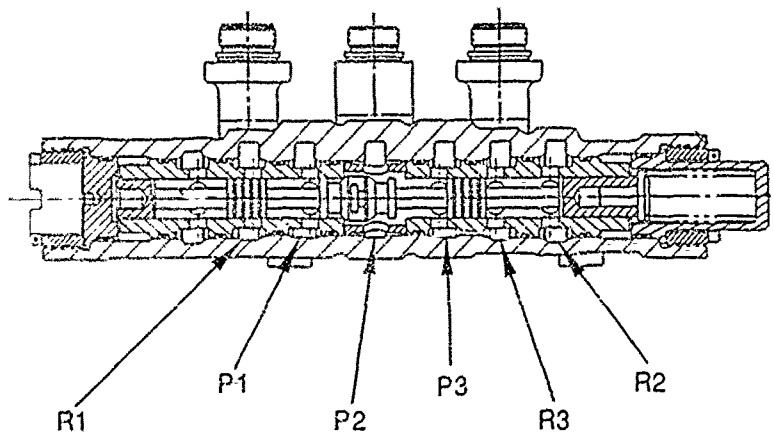
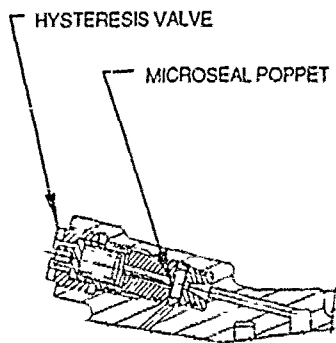
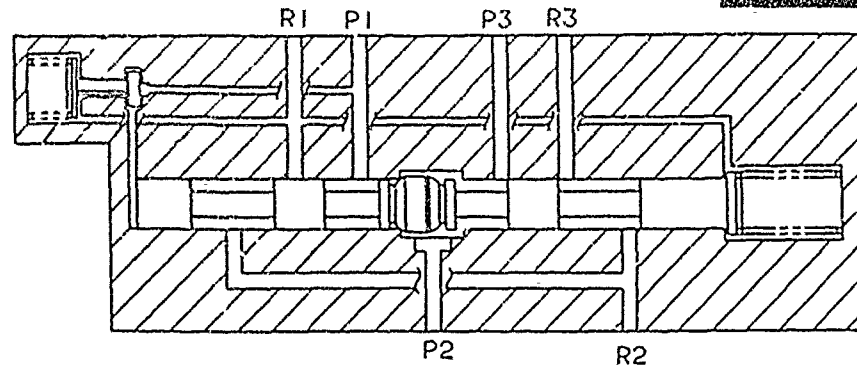
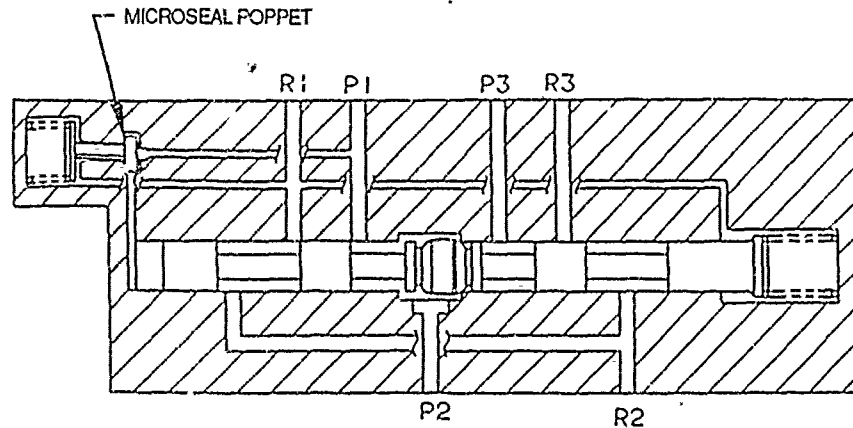


Figure 141. Parker - Switching Valve (6W-2P) Detail Drawing



DE-ENERGIZED/DE-PRESSURIZED



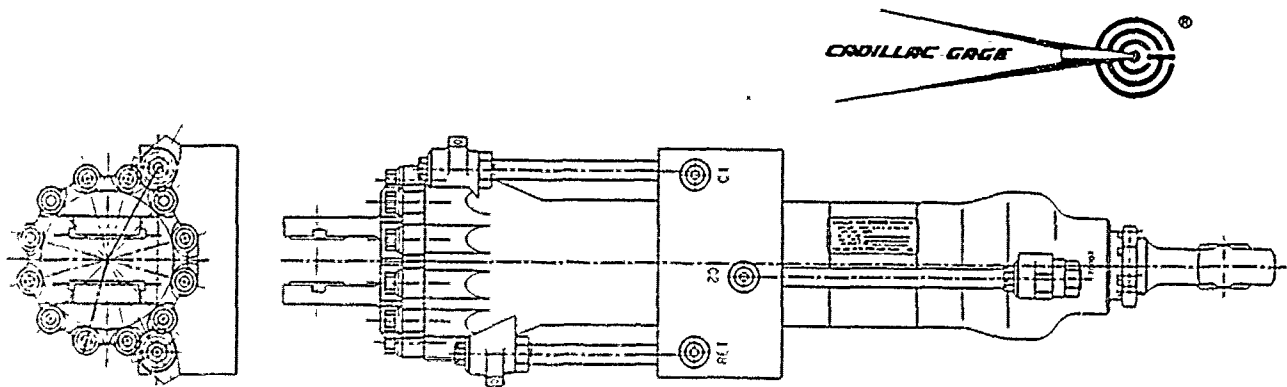
PRESSURIZED

Figure 142. Parker - Switching Valve (6W-2P) Functional Schematic

At this point, the primary system is connected to the controlled system as shown in the schematic of the unit when pressurized. When the pressure falls below 500 psi, the Microseal(TM) poppet returns to the pressure seat, porting return pressure to the pilot chamber, and allows the spring to drive the shuttle valve over to close off the primary circuit and open the backup supply to the control circuit. The valve manifold is machined from a 6Al-4V HIP casting. Having a cored internal passageway, this is a new configuration for titanium castings and was developed for this program.

e. Cadillac Gage Utility Actuator - A non-locking utility actuator, supplied by Cadillac Gage-Textron, utilizes the diffuser ramp actuator cylinder, end cap, rod end and similar piston. Special transfer tubes and a non-flightweight manifold mounted to existing lugs on the cylinder, provide the required interface to the MCAIR Iron Bird. Rated load is 26844 lbs. extending and 14086 lbs. retracting at 7900 psi. Maximum actuator velocity is 10.18 in/sec. An outline of the utility actuator is shown in Figure 143.

f. Gar-Kenyon Auxiliary RLS Valve - The flow requirements for the engine nozzle actuator sets were such that they could not be conveniently accommodated by the standard reservoir shutoff valve. The auxiliary valve is slaved to the reservoir RLS valve but is sized for minimum pressure loss at the high engine nozzle flow rates. This valve is shown in Figure 144. The valve body is machined from 15-5PH CRES steel and has been designed for 300 psi loss at a rated flow of 80 gpm.



Note: For Dimensions, See Figure 109,  
Diffuser Ramp Actuator

Figure 143. Cadillac Gage - Utility Actuator Outline Drawing

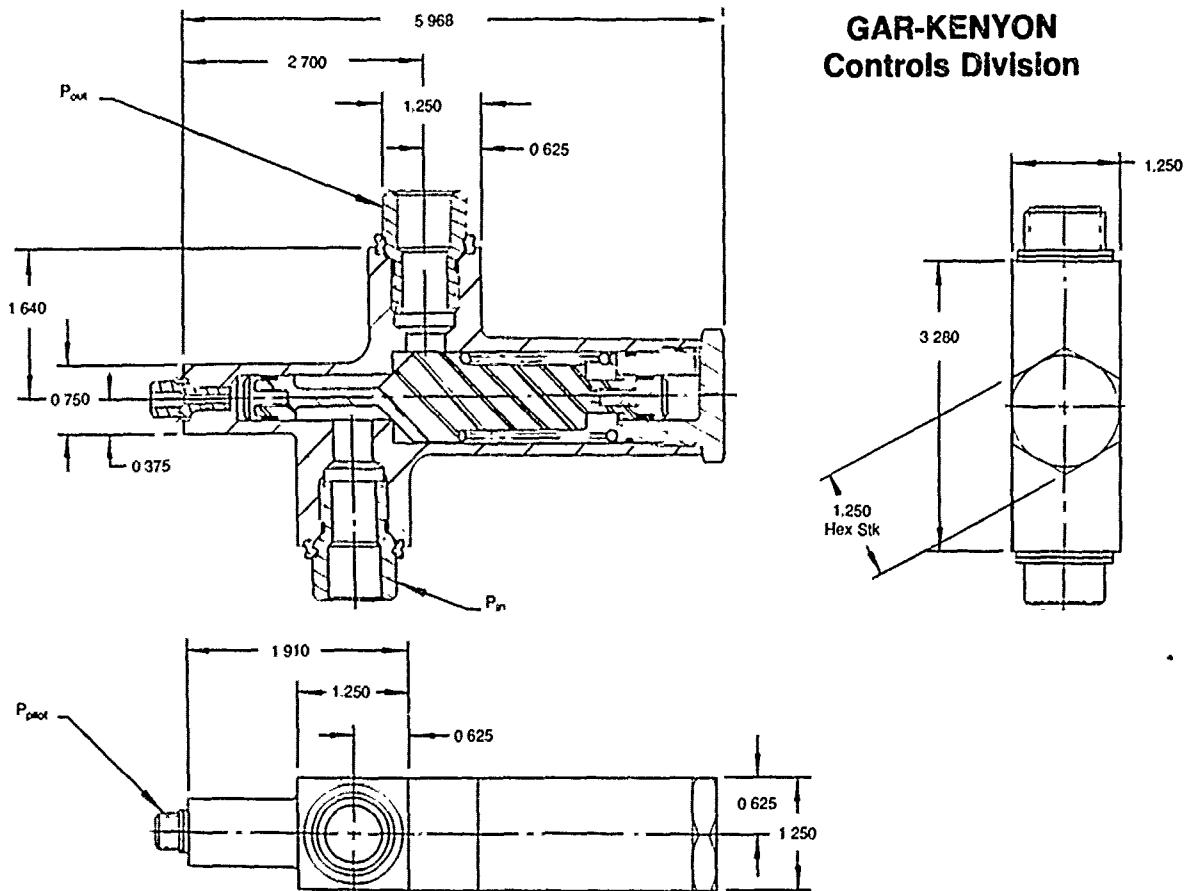


FIGURE 144. GAR-KENYON - Auxillary RLS Valve Outline/Detail Drawing

g. Circle Seal Pneumatic Fill Gage - The pneumatic fill valve and gage is manufactured by Brunswick Circle Seal Controls for use on the Parker 8000 psi accumulator. It is a combination of a Shraeder charging valve with a pressure gage mechanism for accurately charging the accumulator. Figure 145 shows the envelope and cross section of the gage.



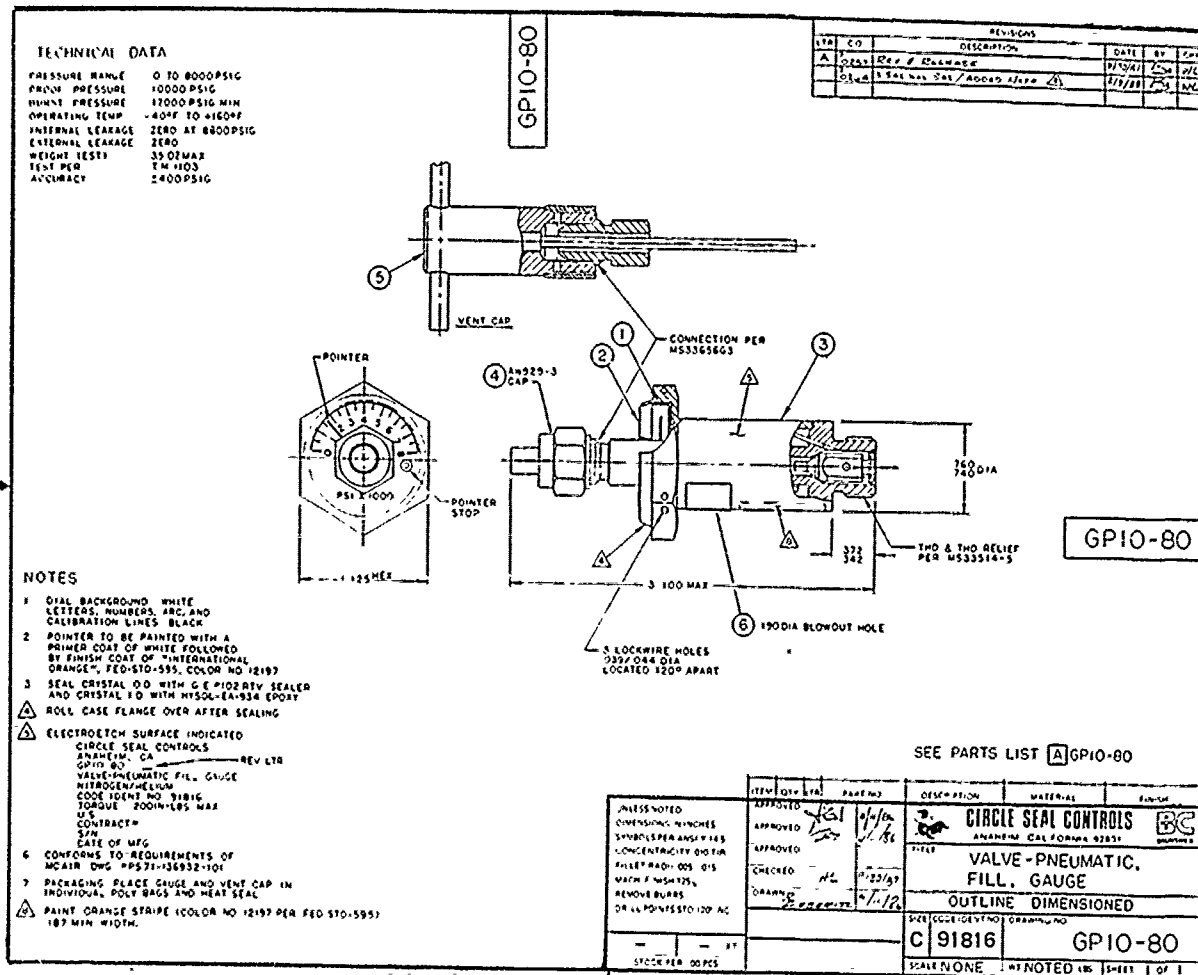


Figure 145. Circle Seal - Pneumatic Fill Gauge Outline/Detail Drawing

5.5.9 Advanced Technology Devices - This program introduced two devices which are relatively new to flight hydraulic applications. One is a hydraulic fuse device; the other a pressure intensifier. Both were developed by Parker Bertea Aerospace..

a. Parker Hydraulic Integrity Monitor (HIM) - This unique device has been designed by Parker Aerospace to supply backup hydraulic power to the stabilator and rudder servocylinders in the event of an upstream failure, and to shutdown hydraulic supply in the event of a downstream flow/pressure loss. The logic diagrams (Figure 146 and 147), illustrate the unit's operational

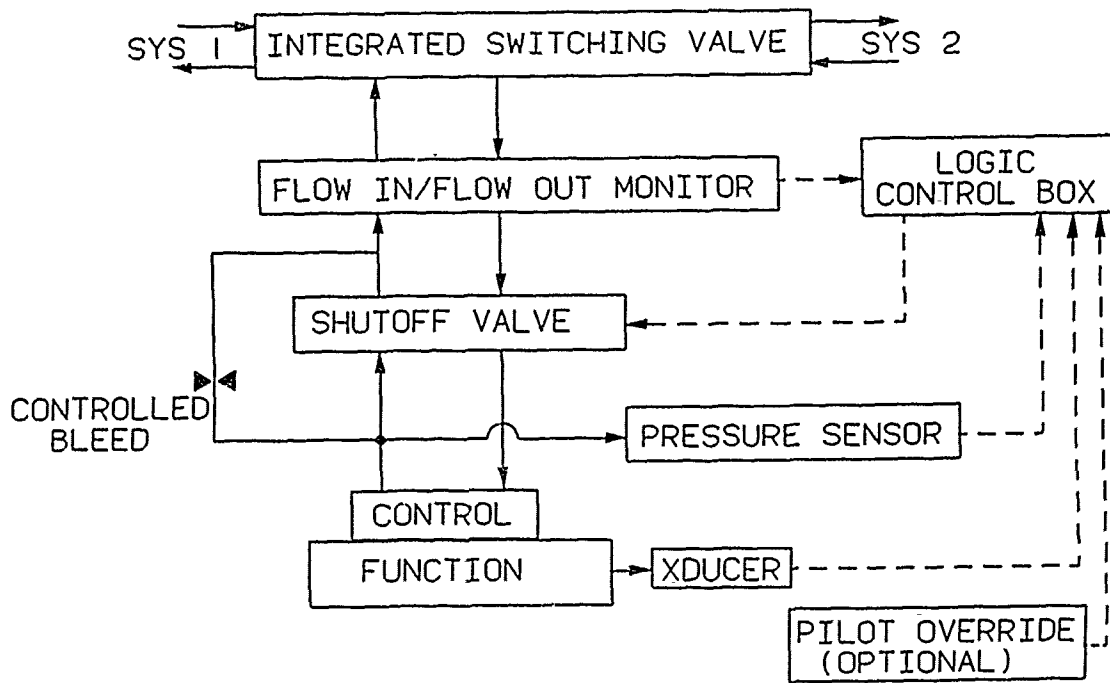


Figure 146. Parker - Hydraulic Integrity Monitor (HIM)  
Generic Logic Diagram

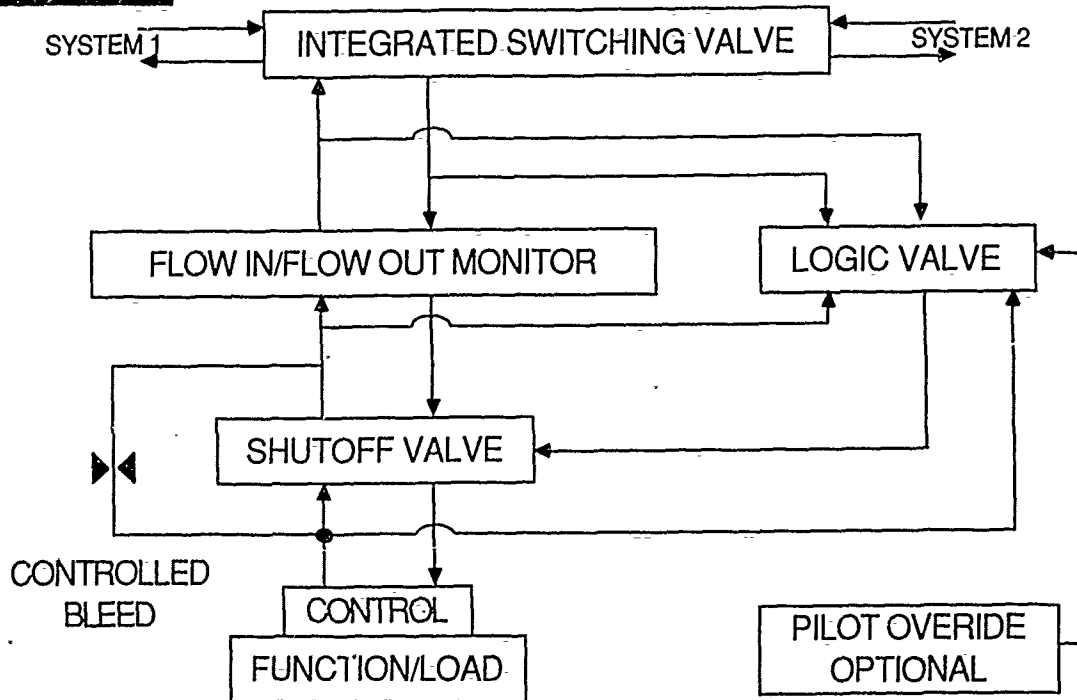


Figure 147. Parker - HIM Logic Diagram

sequence. Figure 146 is a generic diagram that can be used for unequal area actuators or for an electrohydraulic HIM. The other is a hydromechanical unit which is limited to balanced actuator applications.

The component is divided into two basic sections, a switching valve to sense supply pressure loss, and the integrity monitor to isolate the circuit when a wide disparity of inlet and outlet flow is sensed indicating a line break or leak in a component. A cross sectional detail of the internal valving is shown in Figure 148; the working elements consist of a flow comparator valve and logic valve, which compares the flow between the pressure and return legs to the load actuator and causes the shutoff valve to close the downstream circuit. A controlled bleed orifice is used to reset the valve in the event of a false shutdown. The switching valve, which is comprised of a shuttle valve and a hysteresis valve, is used to supply a hydraulic backup.

Figure 149 shows the hydraulic schematic of the HIM in its normal depressurized position. The flow comparator, logic valve and shutoff valve are in their normal or low flow positions to allow any quiescent leakage to be bypassed. At startup, pressure switches the shuttle valve and flow proceeds through the flow comparator and shutoff valve to the outlet pressure port, P2 as shown in Figure 150. As pressure is increased, the flow comparator valve compensates and moves to allow for a constant 150 psid across the pressure and return circuits. The logic valve remains in a normal position until a pressure loss is sensed which results in the shutoff valve being forced closed. In the event of a momentary shutdown or if for some reason the downstream leak discontinues, the HIM will reset itself providing the leak is smaller than the amount of flow through the restart orifice. With the HIM in the failed position, the outlet ports P2 and R2 are connected to pressure through the reset orifice. That allows for a small amount of flow into this circuit. Pressure then builds up in the load chamber and resets the logic valve for any leak smaller than the orifice flow. When the pressure is within 500 psi of the system pressure, the logic valve and the HIM will reset. If the leak is too severe, the pressure will not be able to build up and overcome the spring in the logic valve and the HIM will not reset; flow through the orifice will continue until the circuit has lost enough fluid to activate the reservoir level sensing (RLS) valves. At this point, the shuttle valve will switch circuits and bleed off that system until its RLS is activated. The estimated weight is approximately 10 pounds with a forged 6Al-4V titanium manifold and 440C spools and sleeves. The outline configuration is shown in Figure 151.

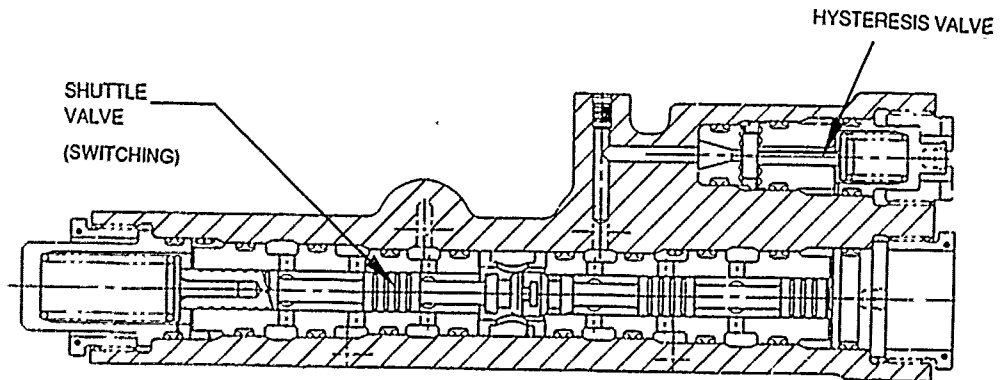
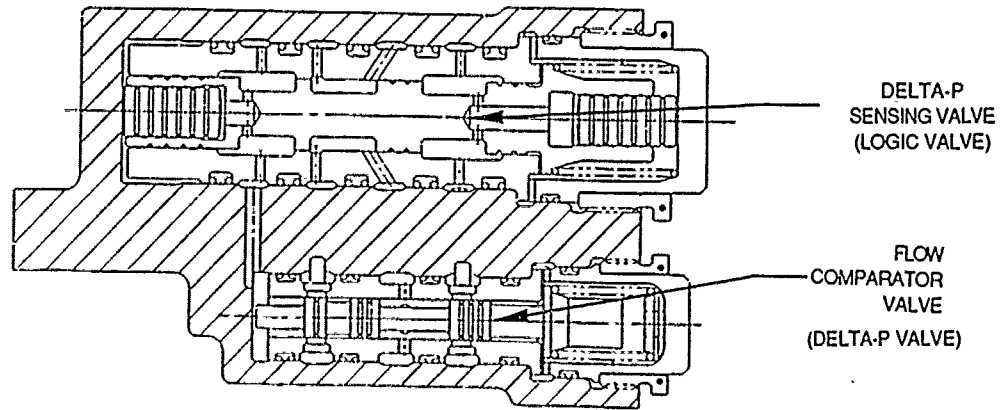
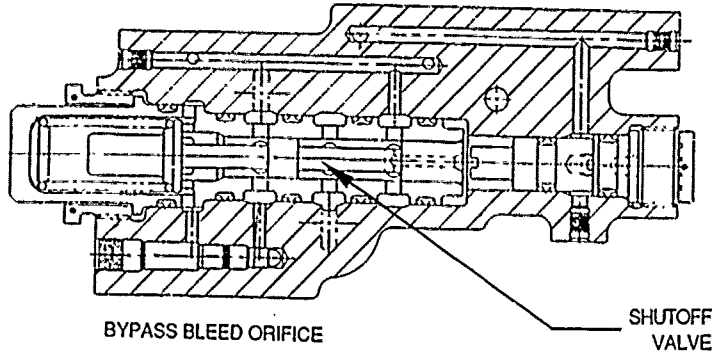


Figure 148. Parker - HIM Detail Drawing

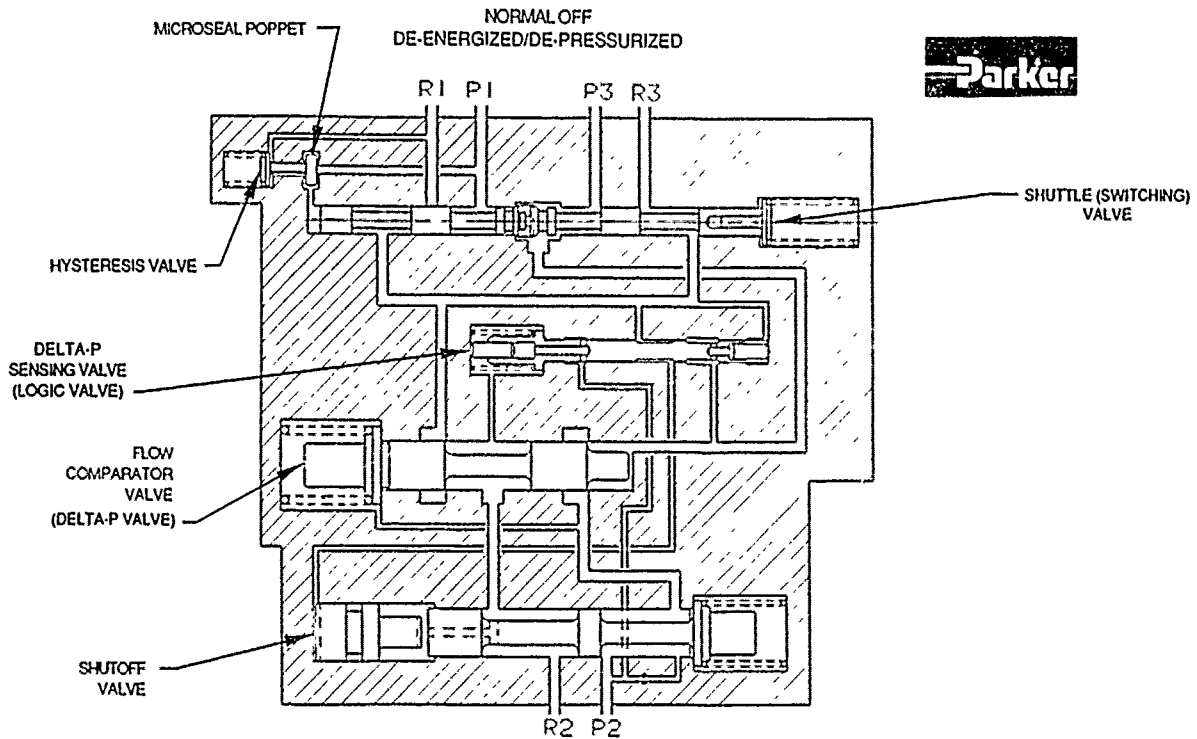


Figure 149. Parker - HIM Functional Schematic  
Normal Off Position

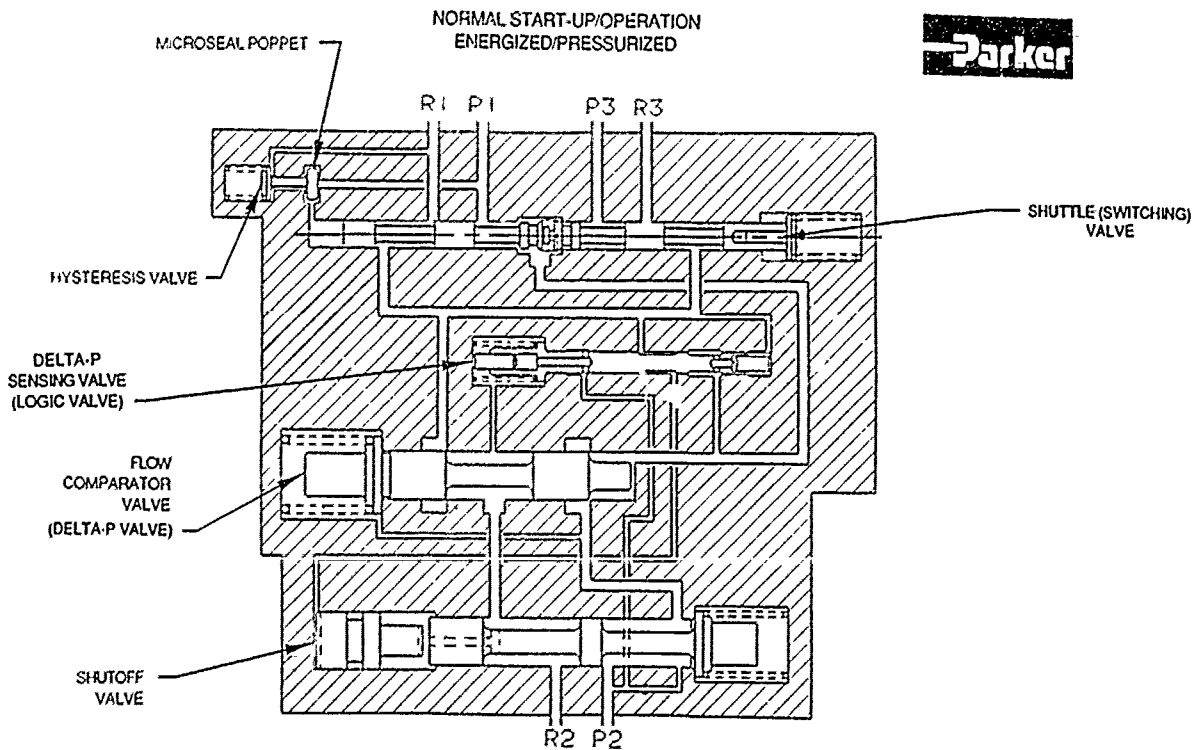


Figure 150. Parker - HIM Functional Schematic  
Startup Sequence

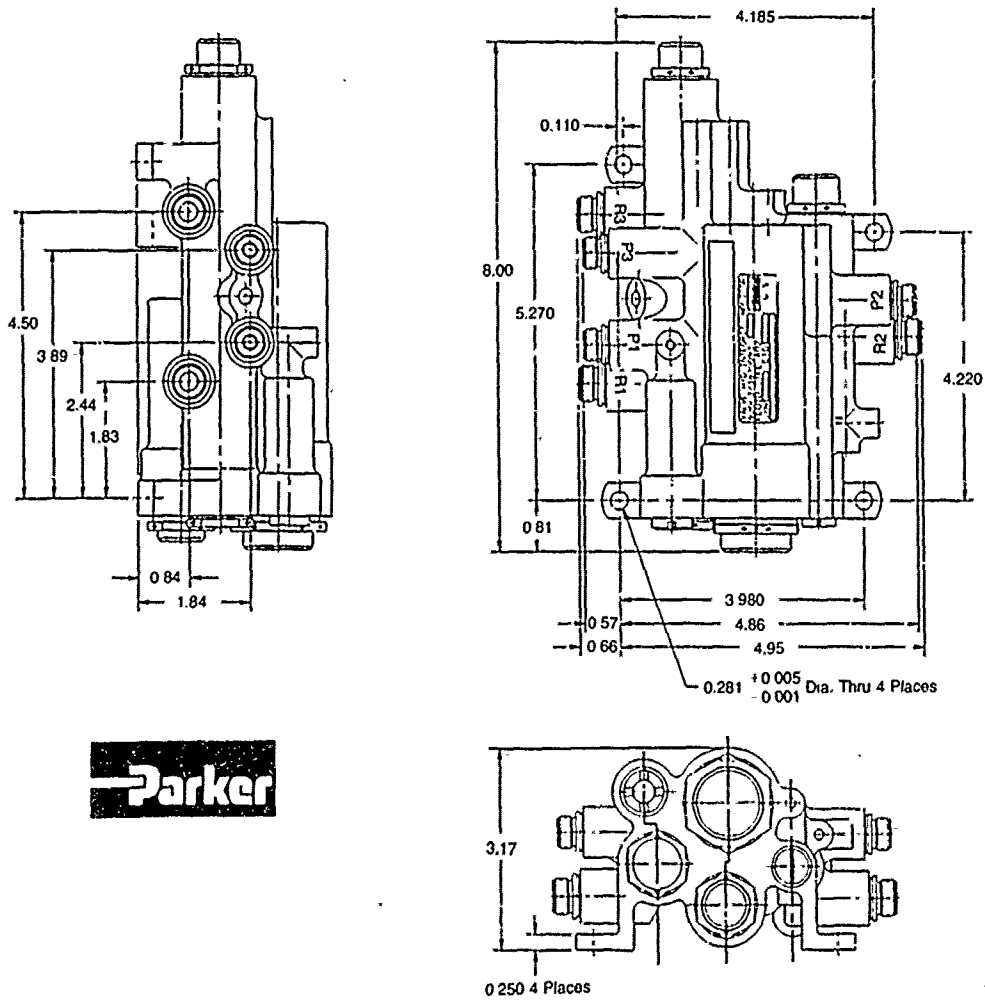


Figure 151. Parker - HIM Outline Drawing

b. Parker Aerospace Pressure Intensifier - The Pressure Intensifier (PI) developed by Parker Aerospace is a self driven reciprocating device which will deliver hydraulic fluid at a dead head pressure twice that of what is being supplied. Primary components are shown in Figure 152 and consist of a main control valve, intake and discharge check valves, opposing piston and pilot valve and the intensifier bypass check valve. Figures 153-156 illustrate the operational aspect of the component. Figure 153 can be viewed as the start up position for this discussion. With supply pressure to the inlet port and the valve in this position, supply pressure is acting on the A6 area and return pressure is acting on the A5 area causing the main valve to stay in the position shown. The opposing piston assembly is driven

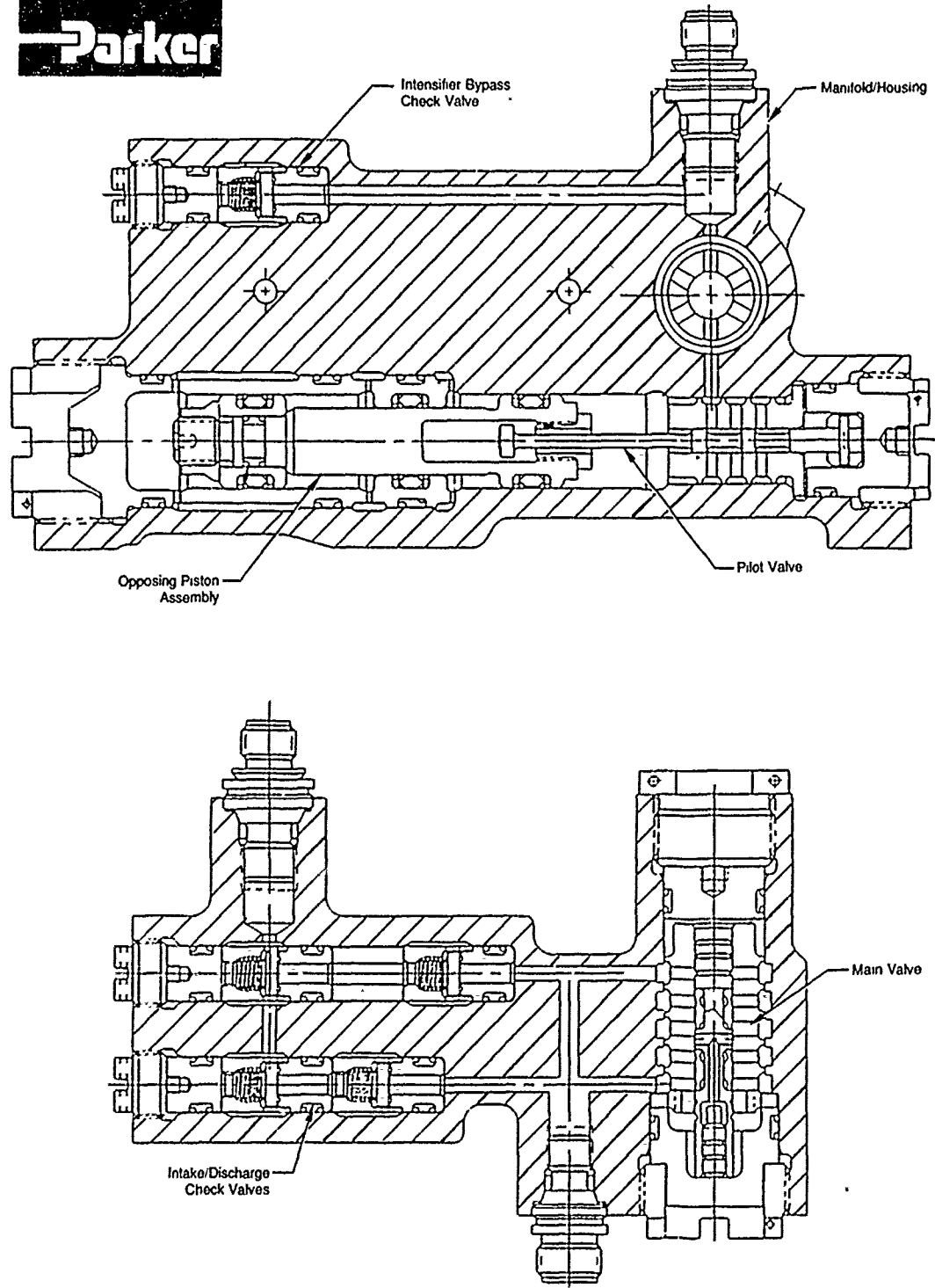


Figure 152. Parker – Pressure Intensifier (PI) Detail Drawing

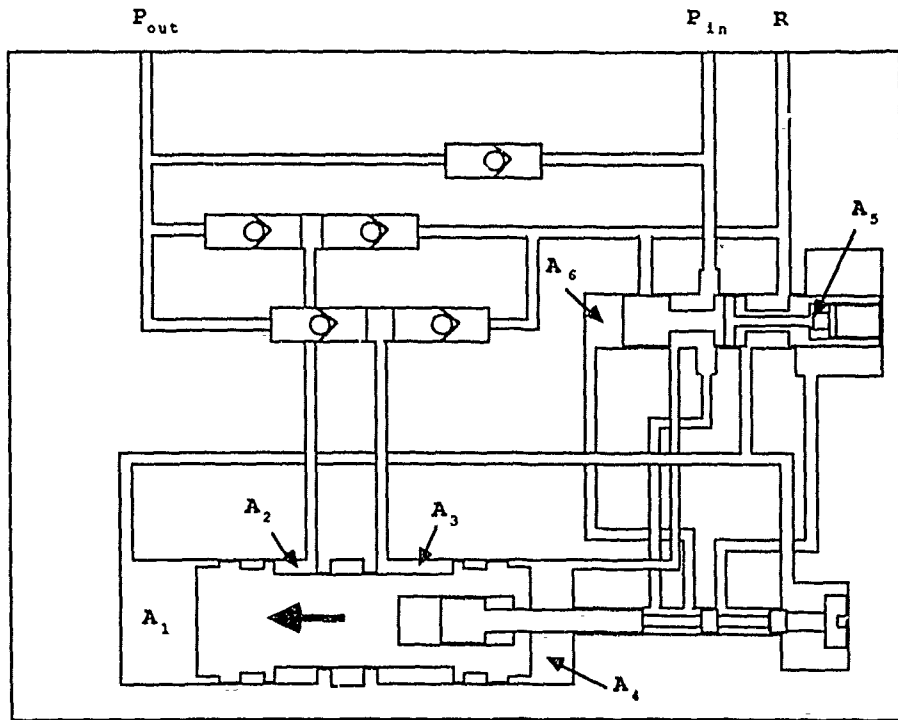


Figure 153. Parker - PI Functional Schematic  
Startup

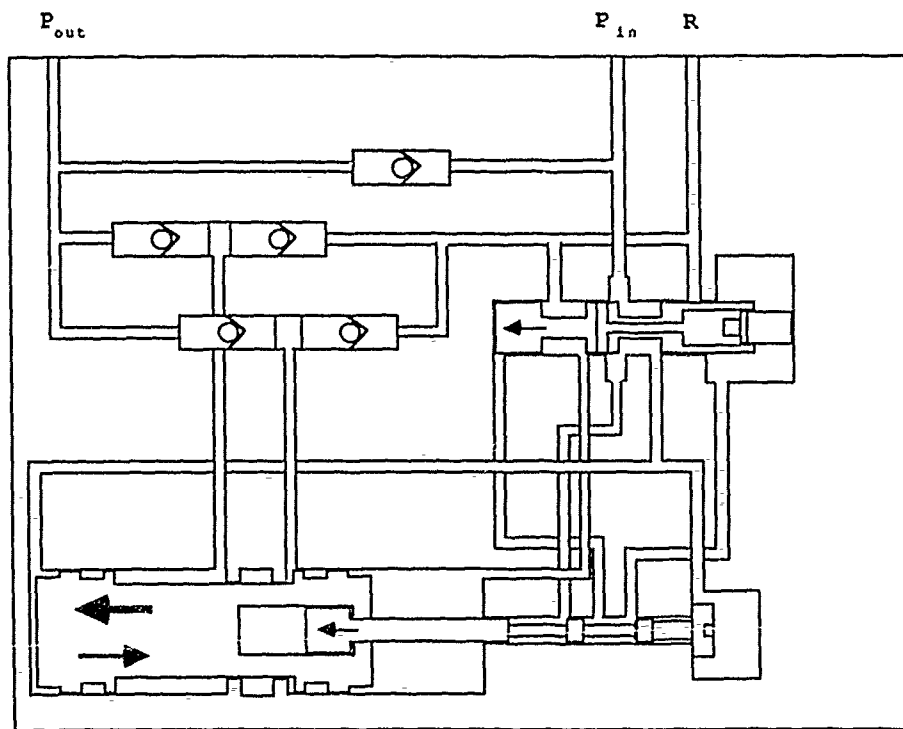


Figure 154. Parker - PI Functional Schematic  
Operational



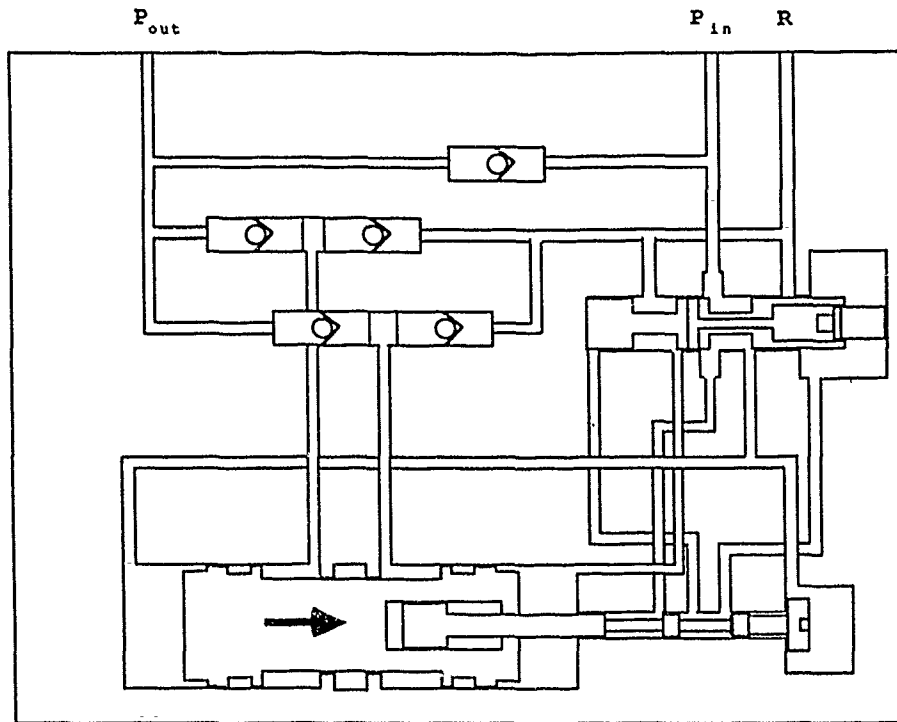


Figure 155. Parker - PI Functional Schematic  
Operational

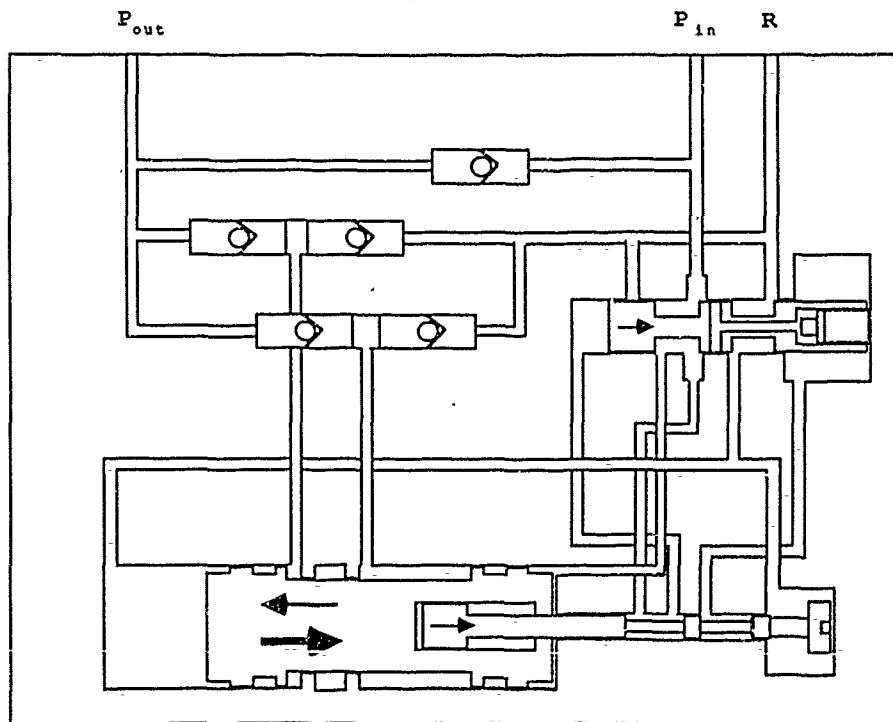


Figure 156. Parker - PI Functional Schematic  
Operational

over and displaces fluid from area A3 through the discharge check valve to the pressure outlet port, and the A1 area displaces fluid to the return port while the A2 area pulls fluid from the return. As the opposing piston nears the end of its stroke, the pilot valve is pulled over to change the pressure distribution on the main valve. This results in return pressure to the A6 side and supply pressure to the A5 side and shifts the spool. The supply pressure is then routed to the other end of the opposing piston and its direction is reversed, forcing fluid from A4 to the return and from A2 through the discharge check valve. As the opposing piston continues, the pilot valve is forced back to the startup position and the process is repeated. The area difference between A3 to A4 and A2 to A1 control the intensification ratio, in this case the ratio of A1 to A2 is 2:1. The overall size of the unit is very compact as shown in Figure 157. The total unit weight is 3.35 pounds utilizing PH13-8Mo CRES steel with 400 series steel and 15-5 CRES internal components. The unit weight could be reduced for production by using titanium castings for the housing.

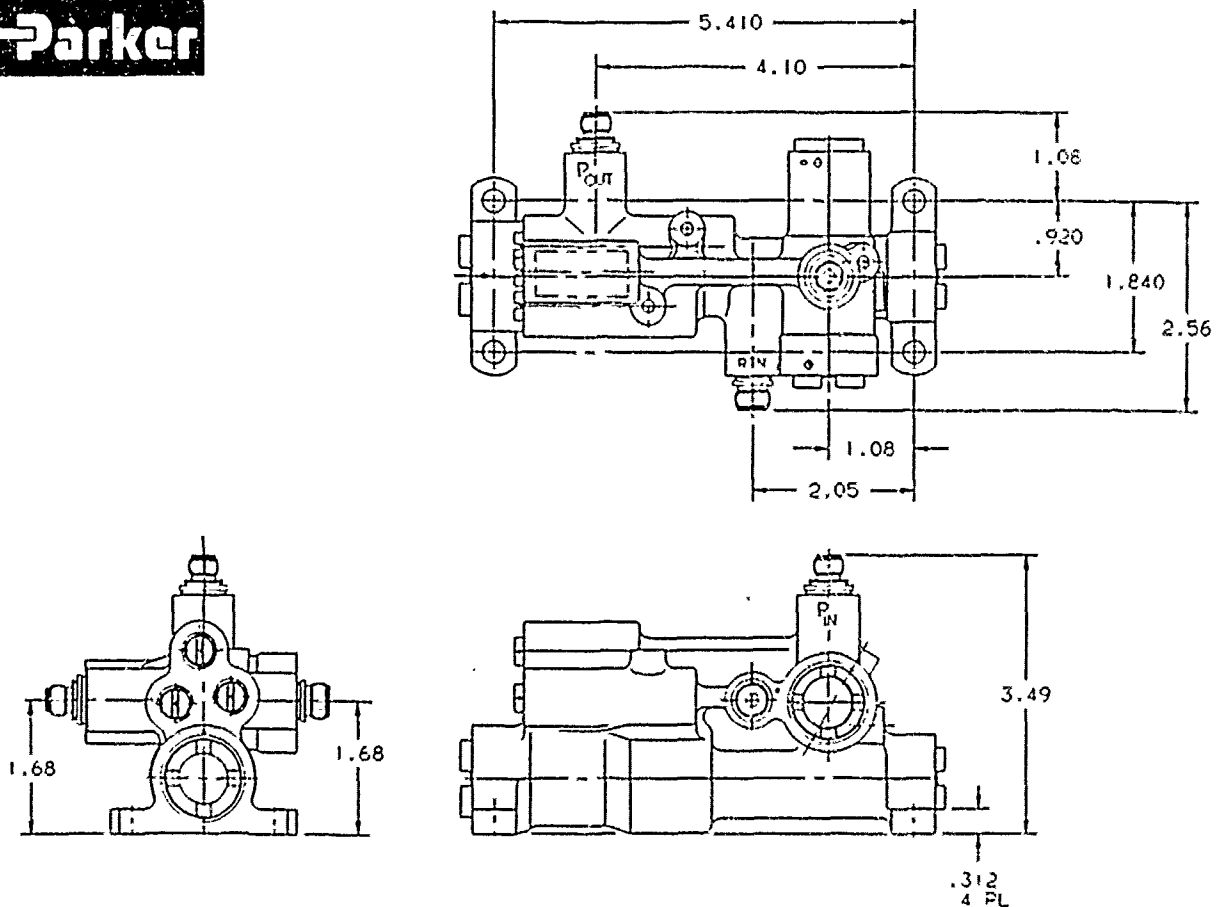


Figure 157. Parker - PI Outline Drawing

## 5.6 DISTRIBUTION SYSTEM COMPONENTS

Distribution equipment was selected based on the Air Force (WRDC/POOS) tubing and fitting program being conducted by Rockwell International. It was MCAIR's initiative to demonstrate fittings and tubing from any supplier, qualified in the aerospace industry, who were willing to participate in the development of the LTD. A host of suppliers are providing fittings and any special tooling that will be required.

5.6.1 Distribution Tubing - Three suppliers were contracted to manufacture the odd sized high pressure titanium (Ti-3Al-2.5V) tubing required for this program. Superior Tube supplied the 3/16 X .021 tubing, Nikko Wolverine supplied the 9/16 X .063 tubing and Haynes Cabot supplied the additional 5/16 X .034, 7/16 X .049 and 11/16 X .076 tubing. All odd sized tubes were manufactured with a CWSR of 105,000 psi yield. Even sized tubing for the return system will be 3000 psi rated and will all have the same CWSR rating with the exception of the 1/4 tubing which has a CWSR of 95,000 psi yield. All tubing conforms to the AMS 4944 requirements and wall sizes are shown in Figure 62.

5.6.2 Distribution Fittings - Several fittings houses were selected for the development of the LTD. Special fittings required were the odd sized 8000 psi female adapters, tube-to-tube connectors, reducers, tees and quick disconnects. In addition even sized 3000 psi fittings in the same types were required and are identical to standard production hardware. Five companies are working 8000 psi development and each will be demonstrating their own permanent attachment techniques. Following is an explanation of the various companies' participation and fittings configurations. Most of the tooling is being supplied, on a loan basis, along with all required engineering to support the assembly of the LTD; this will ensure proper installation of the fittings and rule out the possibility of failure due to improper installation.

a. Airdrome Parts Co. Dual Seal Fittings - Airdrome has manufactured the largest of the 8000 psi adapters (11/16), using their dual seal design with a welded permanent attaching technique. The welding firm they will be using is the Astro Arc company. Due to the increased wall thickness, a typical exterior orbital TIG weld was unacceptable and an interior/exterior simultaneous weld was required. This was found to be true for any titanium tubing with the wall thickness greater than .070, which includes the additional material required for a butt weld flange. Airdrome has designed their dual seal configuration to endure the 8000 psi flexure and impulse requirements currently being imposed on military aircraft fittings. Additional 8000 psi fittings being supplied include -03 tees with a permanent (welded) leg with two dual seal demateable legs and (-07 to -11) reducers. The 3000 psi rated hardware included -08, -10, -16 demateable tees.

b. Aerofit Products Inc. Adapter Fittings - Aerofit, while not manufacturing any fittings for the LTD, played a crucial role in the program by developing several adapter fittings for 8000 psi bench testing. With the odd sized fittings requirement, no test benches were capable of plumbing into

the hardware to perform the required ATP. Aeroquip has designed and manufactured an 8000 psi odd sized female lipseal to an even sized MS flareless adapter which allowed the component suppliers to attach directly to an 8000 psi tube with no additional hardware.

c. Aeroquip Corp. Aerospace Div. Fittings - The 3000 psi rated return fittings were supplied in the most part by Aeroquip Jackson. These fittings included all the required even sized adapters and several configurations of reducers. The balance of the fittings not discussed in this section were MCAIR standard parts manufactured by qualified suppliers.

d. Aeroquip Corp. Linair Div. Rynglok® Fittings - Aeroquip Linair is supplying several configurations of 8000 psi fittings for this program. They will use the standard lip seal design for sizes below -10. For sizes larger than -10 they have modified the beam seal portion of the fitting and the B nut. They are supplying -05 fittings using the standard lip seal configuration and -11 fittings using the lip seal thread configuration. The -11 fittings they will be supplied with (-07 to -11) reducers and -11 tees with all the mating female connectors. In addition, they are supplying a special reducer tee and the -05 tees.

e. Aeroquip Corp. Aerospace Div. Quick Disconnects - Several different types of quick disconnects (QD) are required to interface the ground cart and pumps to the central system. Aeroquip is supplying two different configurations of QD's. First is the standard ground support equipment (GSE) type that would be able to interface with the existing ground cart QD, but has been designed to be compatible with CTFE and 8000 psi (for the supply pressure fittings). The second style is a double thread ratchet type (1800 series) which will be used to interface the pumps with flexible hoses for vibration isolation and make the removal and replacement of the pumps faster and easier.

f. Deutsch Metal Components Permaswage Fittings - Deutsch also uses the standard dynamic beam seal except for sizes larger than -10. They are currently manufacturing several permaswage style 8000 psi fittings in the -03, -05 and -07 sizes, including -07 female adapters, -03 and -07 tees and both female and male beam seal reducers. These fittings and all the other manufacturers of beam seal fittings will not be fully qualified but will invoke a best effort design. Deutsch is currently in the process of design/redesign of three lipseals which will include several changes to the current design being used on the LTD.

g. Crane Resistoflex Dynatube Fittings - Resistoflex has elected to supply the -03 high pressure female adapters. They have developed new tooling in order to obtain a highly repeatable swage. Swage quality testing has been completed on the -03 fittings. The fittings were proof tested at 8000 psi for 5 minutes, and burst tested to 30,000 psi with no rupture or leakage. Reuseable tooling is being supplied on a loan basis.

h. Raychem Corp. Cryofit Fittings - Since these fittings are permanent fittings, Raychem will be supplying only tube-to-tube connectors in straight and 90 degree elbow configurations. The elbow fittings will include a machined elbow with two Cryofit couplings. These fittings require special handling equipment and liquid nitrogen storage.

i. Sierracin/Harrison Fittings - Sierracin will be supplying two 8000 psi fittings; the first being the -09 female coupling with an internally swaged tube end and the second being a male .03 to female -07 reducer. Sierracin/Harrison has recently developed 3000 psi lipseal fittings. New design features have been incorporated into their 8000 psi design to effect a more controlled groove fill.

5.6.3 Repair Fittings - Several fittings houses will supply repair fittings for the ABDR demonstration portion of this program. Aeroquip Linair will supply 8000 psi and 3000 psi Rynglok tube-to-tube couplings which are the standard tube union. Raychem will supply 8000 psi Cryofit fittings and 3000 psi heat-to-shrink fittings which they currently have under development. Sierracin/Harrison has an 'H' fitting for 3000 psi that requires only wrenches for assembly; they are currently looking at a lighter version with a removeable nut for the 8000 psi application.

## SECTION VI

### INTRODUCTION TO VOLUME II EQUIPMENT AND SYSTEMS - TEST AND EVALUATION

#### 6.1 TEST PROGRAM

Because of differences introduced by design approaches at the system level, namely variable system pressure, the testing to be performed by the suppliers differs in several aspects. Because of interest in the industry the test activities, which will be reported in Volume II, will be discussed separately and without reference to each other to avoid misinterpretation. The tests will be fundamentally different in terms of performance, induced wear and fatigue. The reader is cautioned against mixing the data presented. It will not be comparable in many instances. Much of the equipment will be tested under both sets of conditions and the results may appear to conflict.

#### 6.2 PHASE IV - SUPPLIER TEST PROGRAM

Part I of Volume II will show the results of the performance and endurance testing to be performed by each of the suppliers of program hydraulic equipment. All of the testing will be performed using constant 8000 psi system supply pressure. The variable pressure pumps will also be tested at constant discharge pressure.

#### 6.3 PHASE V - LABORATORY TECHNOLOGY DEMONSTRATOR TEST PROGRAM

Part II of Volume II will describe the test activities on a system level. The LTD will be operated using variable system pressure (3000 to 8000 psi). This effort will consist of performance evaluation, endurance testing, a battle damage repair demonstration, a supportability assessment, and teardown and inspection of the equipment tested.

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## SECTION VII

### CONCLUSIONS/RECOMMENDATIONS

#### 7.1 CONCLUSIONS

Significant conclusions drawn during the reported program phases are summarized herein. No single element has been found which would indicate a need for major redirection of the contract program. A primary objective of the contract is demonstration of a nonflammable hydraulic fluid (CTFE) on a system level using design approaches which would eliminate or minimize the weight penalties associated with the high density CTFE fluid. Using an upper operating pressure limit of 8000 psi in a variable pressure system which integrates energy saving enhancements is the key to accomplishing this. The primary benefit to higher operating pressure is weight and volume savings with a modest performance increase stemming from lower flow forces in servovalves. Further, the primary benefit of CTFE hydraulic fluid is the improved survivability implications of total nonflammability.

7.1.1 Phase I - Advanced Aircraft Hydraulic System Selection - Selection of the F-15 SMTD aircraft as the baseline configuration remains a sound approach for development of equipment which would be representative of advanced aircraft. Feedback from the Phase I Oral Presentation showed that the variable pressure pump duty cycle for this configuration required that the operation of the flight control actuators be intensified in activity in order to be more representative of unstable aerostructures of the future. This was easily accommodated in the design of the test control electronics for the endurance test of the Laboratory Technology Demonstrator.

7.1.2 Phase II - Design and Trade-off Studies - Design analysis of the fluid system showed that it was necessary to oversize the central system of the demonstrator in order to demonstrate 40 gpm pumps at full capacity. The weight penalty associated with doing this can be estimated and the test system has growth potential for powering more equipment than planned, which is considered an asset. Several trade studies were performed on subjects which were of concern in the initial design phase of a typical hydraulic system.

a. Reservoir Pressurization - Reservoir pressurization techniques were compared and a gas pressurized, metal bellows configuration was shown to be the optimum approach. Unfortunately, program funding precluded hardware development.

b. Circuit Redundancy - The circuit configuration originally proposed was four pumps in three systems using three circuits in each system. Two other circuit configurations were studied. One was four pumps in two systems each having three circuits and the other was two pumps in two systems each having two circuits. The hydraulic load associated with engine/airframe shared hydraulic power maintained the selection of nine circuits. Without this requirement, two systems each having three circuits would have been preferred.



c. Engine Nozzle Actuator Cooling - Two approaches to active cooling of engine nozzle actuators were studied; brute force oil bleed and flow augmented cooling. Flow augmented cooling was the better performer, but added excess weight. It will be demonstrated in this program.

d. Direct Drive Valves - An unsuccessful attempt was made to select the optimum configuration for direct drive valves. This technology is so mobile, any configuration did or could be made to best suit any particular application. All current configurations will be demonstrated.

e. Pressure Transients - Several approaches to controlling transient pressures were considered. Local velocity reduction, a passive technique, was selected for controlling transients at actuators; high response relief valves will control transient pressure in the central systems.

f. Optimum Materials - Materials which are typically used in the construction of hydraulic components and several which have similar interest in the aerospace industry were reviewed for suitability for use in 8000 psi CTFE fluid systems. Several stainless steel alloys and titanium alloys were seen to have more attributes for future applications. A general conclusion was that carbon steels, bronze and aluminum are to be avoided. Difficulties arise because of critical applications in hydraulic pumps which require carbon steel and bronze alloys.

g. Overlap Valves - Valves whose metering lands the flow slots in the sleeves by a few thousandths of an inch can have an order of magnitude less leakage. The compromise in performance varies with the appreciation. The conclusion is that the designer should plan to use overlap up to about 5% of valve stroke. The overlap is reduced during development only as much as required to meet performance requirements.

h. Parallel Variable Pressure Pumps - A brief study of control techniques for variable pressure pumps operated in parallel in the same system showed that supportability would be improved if the pumps were operated at nearly the same requirements rather than forcing one pump to provide all the low flow demand by shielding the other with a high cracking pressure check valve.

i. Dynamic Stiffness - Several techniques for increasing actuator stiffness and techniques for offsetting penalties with certain approaches were reviewed. Electronic enhancement of servovalve performance remains the most weight effective means of providing dynamic stiffness in actuators.

7.1.3 Phase III - Laboratory Technology Demonstrator Design - Design of the laboratory system followed design approaches which had been recommended from past programs or the earlier program phases. Since the flight control actuators are fly-by-wire, they could be located on the basis of efficient floor arrangement and distribution line length rather than matched to the true geometry of the baseline aircraft. All of the other components are electrically operated as well; there are no items which are mechanically operated except Reservoir Level Sensing (RLS) in the reservoirs. This subsystem survivability feature is self contained and self actuated and is an adequate design approach for the purpose of this program.

7.1.4 Phase IV - Component Design, Fabrication and Test - A secondary goal of the program was to develop a supplier experience base with CTFE fluid and 8000 psi to increase the possibility for transition to higher operating pressures in the future. Many detail conclusions have been drawn from the initial development of the subcontracted equipment at participating suppliers. Some of the general conclusions are summarized as follows.

a. Aluminum Alloy Applications - Aluminum alloys are unsatisfactory for 8000 psi operating pressures combined with typical stress concentrating features. Studies showed than pressure vessels simply cannot be made "beefy" enough to not exceed material strength limits on the inner surfaces. The upper pressure level for the efficient use of aluminum alloys is on the order of 5500 psi using conservative design factors. Impulse fatigue requirements may drive this threshold to a pressure well below 5500 psi. Aluminum alloys are compatible with CTFE and may be used for pressure vessels, seeing only return pressure, or as nonstructural piece parts in high pressure components.

b. Titanium Alloy Applications - Titanium alloys are satisfactory for CTFE and 8000 psi operating pressure. Their fracture toughness and corrosion resistance allow design approaches which produce additional weight savings over that offered by its low density and high strength. Fracture toughness allows the design of single piece valve manifolds for dual system components which typically have required "ripstop" two piece construction in aluminum. Its corrosion resistance to typical environments does not require primer or paint which saves weight and cost, and eliminates a significant source of internal contamination.

c. Carbon Steel and Bronze Application - Carbon steel and bronze have been used in hydraulic pumps and some of the actuator servovalves. CTFE offers no "oily" surface film protection for these materials and corrosion and discoloration may still occur in the presence of water or the atmosphere when the material does not remain immersed in the fluid which has a corrosion inhibitor. Suppliers have been asked to use corrosion resistant steels, however, many applications require extremely hard bearing surfaces and corrosion resistant steels inherently lack the hardness needed. A preliminary conclusion has been drawn, pending completion of endurance life tests, that the discoloration of non corrosion resistant materials is a harmless effect.

d. Hydraulic Seal Applications - Hydraulic seal development over the past several years both for high pressure (8000 psi) and CTFE has produced a mature technology for up to 275°F fluid temperature, and no longer requires reduced running clearances and modified seal gland dimensions. High operating pressure does require a minor compromise in actuator piston seals. Use of standard and catalog seal sizes produces excess output force, higher weight and supply flow penalties. Nonstandard piston and bore diameters are used to avoid these penalties. The standard piston seal sizes could be subdivided to lower fractions to reduce these penalties. If the test phase being entered had a requirement for 350°F operation, a question would arise as to the suitability of the seals.

e. CTFE Fluid Challenges - The most critical component in any hydraulic power system is the pump and CTFE presents a design challenge because its fluid properties are very different from conventional fluids which have been the standard for pump design for several decades. The suitability of many current hydraulic pump design approaches is viewed as a significant technical risk. Hydraulic pumps are the least reliable component in our aerospace hydraulic systems and based on progress to date it is unlikely that pumps for CTFE will be on a par with those for conventional fluids without additional research and development on the part of the pump suppliers.

f. Direct Drive Servovalve Enhancement - Direct drive servovalves enhance 8000 psi design even though they stand on their own merit at lower pressures very well. All new equipment developed for this program use direct drive valves and any 8000 psi system which is fly-by-wire should use direct drive valves.

g. "Lee Plug" Development - Specialty items have been developed to restore desired safety margins to pressure vessels such as a new "Lee Plug" designed to require a pressure greater than 60,000 psi for expulsion, above burst pressure capability of the equipment.

h. Energy Savings Techniques - Energy savings techniques will be demonstrated in the program and several of these which have been successfully incorporated in the equipment. These include variable pressure pumps to reduce system power extraction, overlapped valves to reduce quiescent leakage, flow augmentation to reduce central system flow and load recovery valves to increase rates and reduce central system flow demand.

7.1.5 Other Technical Issues - The conclusions below relate to the technologies which are not specifically related to the configuration of the demonstrator and are of generic interest to hydraulic system design.

a. CTFE Hydraulic Fluid - During the course of these phases, it was determined that a fluid formulation which was capable of an upper operating temperature limit of 350°F would not be developed in time for system level testing in Phase V of the program. The contract was modified to state an upper operating temperature of 275°F. Ongoing studies by the Air Force on the toxicity of CTFE produced concerns about test operations in a closed laboratory. These developments along with a need to reduce expenditures in FY 88 made it necessary to downscope the program technical efforts which involved higher temperature testing. The original goal of demonstrating a system with a higher operating temperature than current conventional systems (275°F) will not be met in the duration of the program.

There have been instances of the rust inhibitor presently used in the CTFE fluid formulation causing a precipitation in the fluid which in turn can cause sticky valve operation and clogging of filters. The phenomenon is not fully understood or controlled at this point but is believed to be associated with excess dissolved water and/or high metallic content, possibly iron, nickel and chromium. A preliminary conclusion has been drawn that no problem will occur if the water content of the fluid is held below 250 parts per million.

b. Variable 8000 Psi Operating Pressure - Variable pressure operation will not degrade the fatigue life of a central distribution systems when using design approaches typically seen in the aircraft industry. The central system in a constant pressure system typically sees nearly constant high pressure with small transients (+10%, -25%). With variable pressure, the central system is at low pressure most of the time with excursions up to 8000 psi depending on demand in outlying circuits. Low line pressure and low to high pressure spikes from water hammer require high design margins to guarantee infinite fatigue life in the environment of fluctuating pressure. In order to provide commonality of design, and since the central system uses the same standards, they are somewhat "overdesigned" with very little sacrifice in weight. Variable pressure operation then uses the fatigue life which is conveniently there. Pressure cycling in the outlying circuits is similar for both approaches. The payoff for variable pressure operation is a significant reduction in engine power extraction and hydraulic system heat rejection which saves weight in heat exchangers. To gain the full benefit of variable pressure (and the upper limit of 8000 psi for that matter) close attention is required to design approaches. Severe weight penalties can result otherwise and each aircraft flight controls configuration must be studied independently when sizing actuators and the distribution system. Again, there is little advantage to higher pressure except the potential to save system weight and volume.

c. Stiffness of Flight Control Actuators - The most significant factor in design with higher operating pressure is the reduction of stiffness in an actuator from reduced piston area. A small reduction in stiffness is due to the lower bulk modulus occurs at higher pressure. If stiffness critical actuators require significantly more piston area to meet stiffness requirements than stall loads, the benefits of high pressure are degraded. If many of the actuators are stiffness critical, there may be no weight savings unless stiffness can be met with electronic enhancement of control valve performance or oversized actuators can be flow augmented. Each configuration must be judged on its own merit. One actuator (the stabilator/canard application) in this program is stiffness critical. It is flow augmented and will be controlled with electronic enhancements.

## 7.2 RECOMMENDATIONS

Several recommendations are offered for continued support of the conclusions which have been observed thus far. These are offered constructively to those individuals responsible for continuing IRAD activities at the many aerospace hydraulic companies as well as those who interests are in the government funding of research activities.

7.2.1 CTFE Hydraulic Fluid - Effort should be expended to develop an additive package which will not precipitate and will be capable of long term operation at 350°F. An alternative to this is to develop system and component design approaches which will not require a corrosion inhibitor additive. However, pump technology suggests this alternative may not be practical in the near term. Flight formulations of conventional hydraulic fluid have no corrosion inhibitors and the inhibited versions used in ground benches and as a preservative for storage are limited to a lower operating temperature than the flight fluid. Any 350°F formulation should be tested a minimum of 500 hours in the laboratory test demonstrator.

7.2.2 CTFE Hydraulic Pumps - Further effort must be performed to develop design approaches which allow the use of complementary materials which will provide reliable pump operation with CTFE fluid.

7.2.3 Flight Control Actuator Characteristics - The performance requirements of flight control actuators for advanced, classified configurations are not readily available to independent advanced development programs such as this one. Future efforts should attempt to reconcile weight savings potential with actuator stiffness requirements.

7.2.4 Integration of Electronic Monitoring - Anyone currently working on new aircraft hydraulic systems should make every effort to take advantage of the flexibility offered by electronic control and diagnostic techniques and the capabilities of digital, electronic vehicle management systems.

## SECTION VIII

### REFERENCES

1. Report, AFWAL-TR-88-2062, "Low Energy Consumption Hydraulic Techniques," August 1988, under Air Force Contract F33615-84-C-2417
2. MDC-IR-7-450, "Reliability Attainment," January 1980 to present, Mr. David Yates
3. MDC-IR-0420, "Reliability Comparisons of Tactical Aircraft Hydraulic Systems," June 1987
4. MDC-IR-0421, "Reliability Comparisons of Tactical Aircraft Hydraulic Systems for the Nonflammable Hydraulic Power Systems for Tactical Aircraft (NHPSTA) 8000 psi Laboratory Technology Demonstrator (LTD)," June 1987, under Air Force Contract F33657-86-C-2600
5. Contract (SOW), Air Force Contract F33615-86-C-2600, Section C, paragraph 4.6, Phase II, Design and Tradeoff Studies, February 1986

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APPENDICES



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APPENDIX A  
SYSTEM DETAIL SCHEMATICS

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HYDRAULIC  
SYSTEM SCHEMATICS

FOR

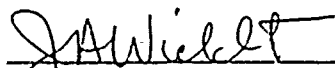
NONFLAMMABLE HYDRAULIC POWER  
SYSTEMS FOR TACTICAL AIRCRAFT  
(8000 PSI. - CTFE)

PREPARED BY



J. J. Sheahan  
Senior Engineer - Design

APPROVED



J. A. Wieldt  
Design Specialist

<b>MCDONNELL AIRCRAFT COMPANY</b> SAINT LOUIS, MISSOURI <b>MCDONNELL DOUGLAS CORPORATION</b>	SIZE	FSCM NO.	DWG NO.
	A	76301	71J136949
	SCALE:	REV C 7/15/88	SHEET

# INDEX

SHEET NO.	SYSTEM DESCRIPTION	REV LTR	SHEET NO.	SYSTEM DESCRIPTION	REV LTR
1	INDEX	C			
2	NOTES	A			
3	POWER CONTROL SYSTEM NO. 1	C			
4	LEFT HAND SIDE FLIGHT CONTROLS	C			
5	POWER CONTROL SYSTEM NO. 2	C			
6	RIGHT HAND SIDE FLIGHT CONTROLS	C			
7	UTILITY CENTRAL SYSTEM	C			
8	ENGINE NOZZLES INTERCONNECT	C			
9	ENGINE NOZZLES ACTUATION	C			
10	UTILITY SYSTEM FUNCTIONS	C			
11	GROUND SERVICE UNIT	C			

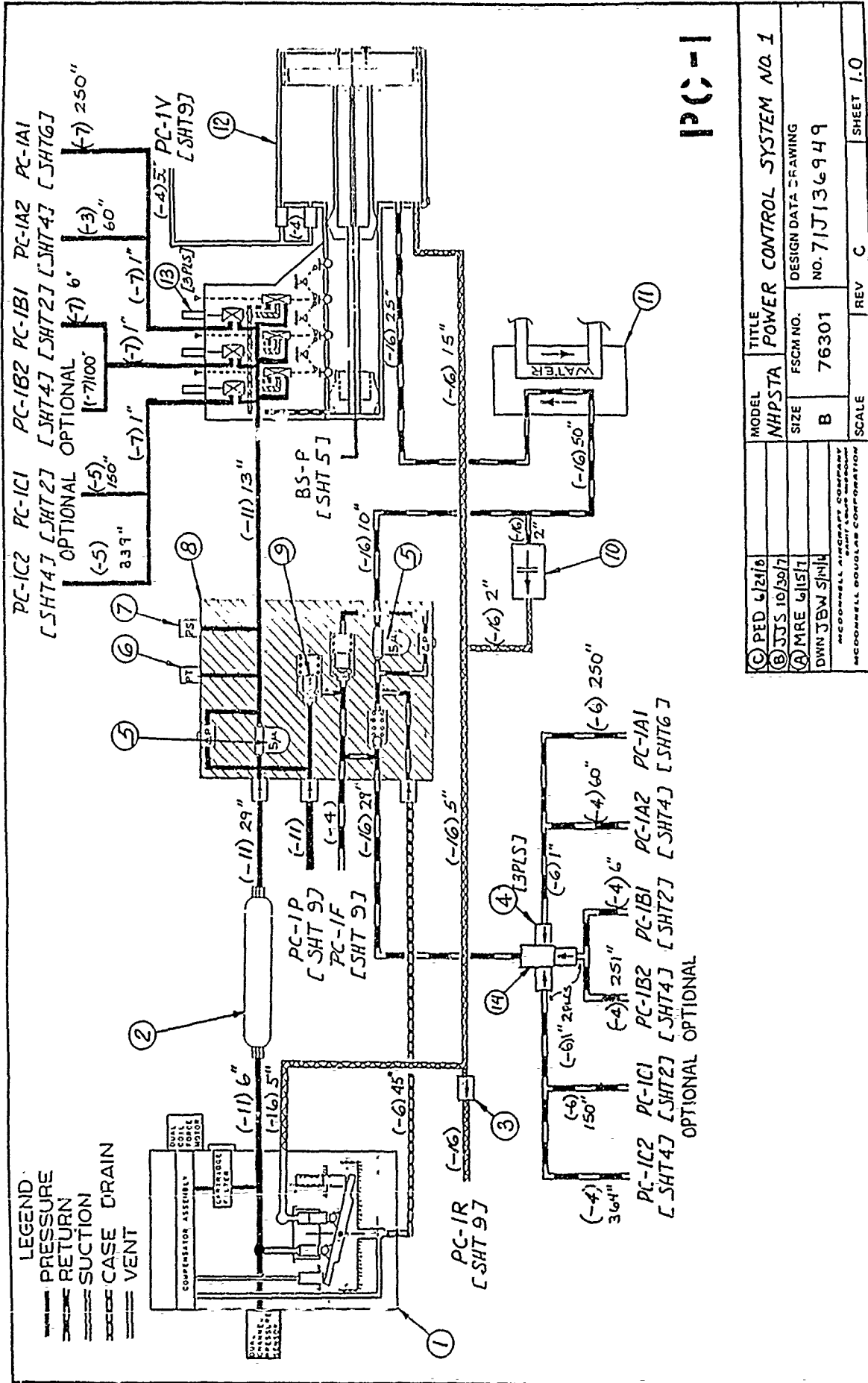
(C) PED 7/15/7 (B) JJS 10/30/7 (A) MRE 6/15/7 DWN J BW 5/14/6	MODEL MHPSTA	TITLE INDEX	FSCM NO. 76301	DESIGN DATA DRAWING NO. 71J136949	SCALE REV C	SHEET 1
MCCONNELL MACHINERY COMPANY MCCONNELL DOUGLAS CORPORATION						

# NOTES

- ① RESTRICTOR FLOW RATE AT 100 PSI  $\Delta P$  AT 90° ± 30°F FLUID TEMPERATURE.
- ② RESTRICTOR FLOW RATE AT 1100 PSI  $\Delta P$  AT 90° ± 30°F FLUID TEMPERATURE.

MODEL MHPSTA	TITLE NOTES
SIZE B	FSCM NO. 76301
DESIGN DATA DRAWING NO. 71J136949	
SCALE REV A	
SHEET 11	

① MRE 6/15/14  
DWINJBN SM/14  
MICRONNELL AIRPAC  
MICRONNELL DOUGLASS C



LEGEND  
 PRESSURE  
 RETURN  
 SUCTION  
 CASE DRAIN  
 VENT

PC-1

MODEL	NHPSTA	TITLE	POWER CONTROL SYSTEM NO. 1
SIZE	B	DESIGN NO.	NO. 71J136949
SCALE	REV C	SHEET	I.0
MCDONNELL AIRCRAFT COMPANY MCDONNELL DOUGLAS CORPORATION			

- ① PUMP - HYDRAULIC, VARIABLE PRESSURE AND DELIVERY  
P/N 71-136908-101, ABEX P/N APLVHP-2
- ② ACOUSTIC FILTER, PULSCO P/N 840 40111
- ③ VALVE - HYDRAULIC, CHECK (LOW PRESSURE)  
ST7M262-16
- ④ VALVE - HYDRAULIC, CHECK (LOW PRESSURE)  
ST7M261-6
- ⑤ FILTER ELEMENT, 5 MICRON ABSOLUTE  
P/N 71-136910-209, APM P/N AC-B655 F-12
- ⑥ TRANSMITTER - HYDRAULIC, PRESSURE  
P/N 71-136931-101, CONDEC P/N 415G252
- ⑦ SWITCH - HYDRAULIC, PRESSURE  
P/N 71-136930-101, ITT NEO-DYN P/N 1203P0018
- ⑧ MANIFOLD - HYDRAULIC, FILTER, 5 MICRON ABSOLUTE  
P/N 71-136910-101, APM P/N AE-B655-12
- ⑨ VALVE - HYDRAULIC, PRESSURE RELIEF  
P/N 71-136925-101, CIRCLE SEAL P/N RY57-29
- ⑩ VALVE - HYDRAULIC, PRESSURE RELIEF  
CIRCLE SEAL, PIN S132T-16TB-15
- ⑪ HEAT EXCHANGER - HYDRAULIC, CTFE/WATER  
UAAP P/N UA538795-3
- ⑫ RESERVOIR - HYDRAULIC, PRECHARGE  
P/N 71-136939-101, PARKER P/N 3850080

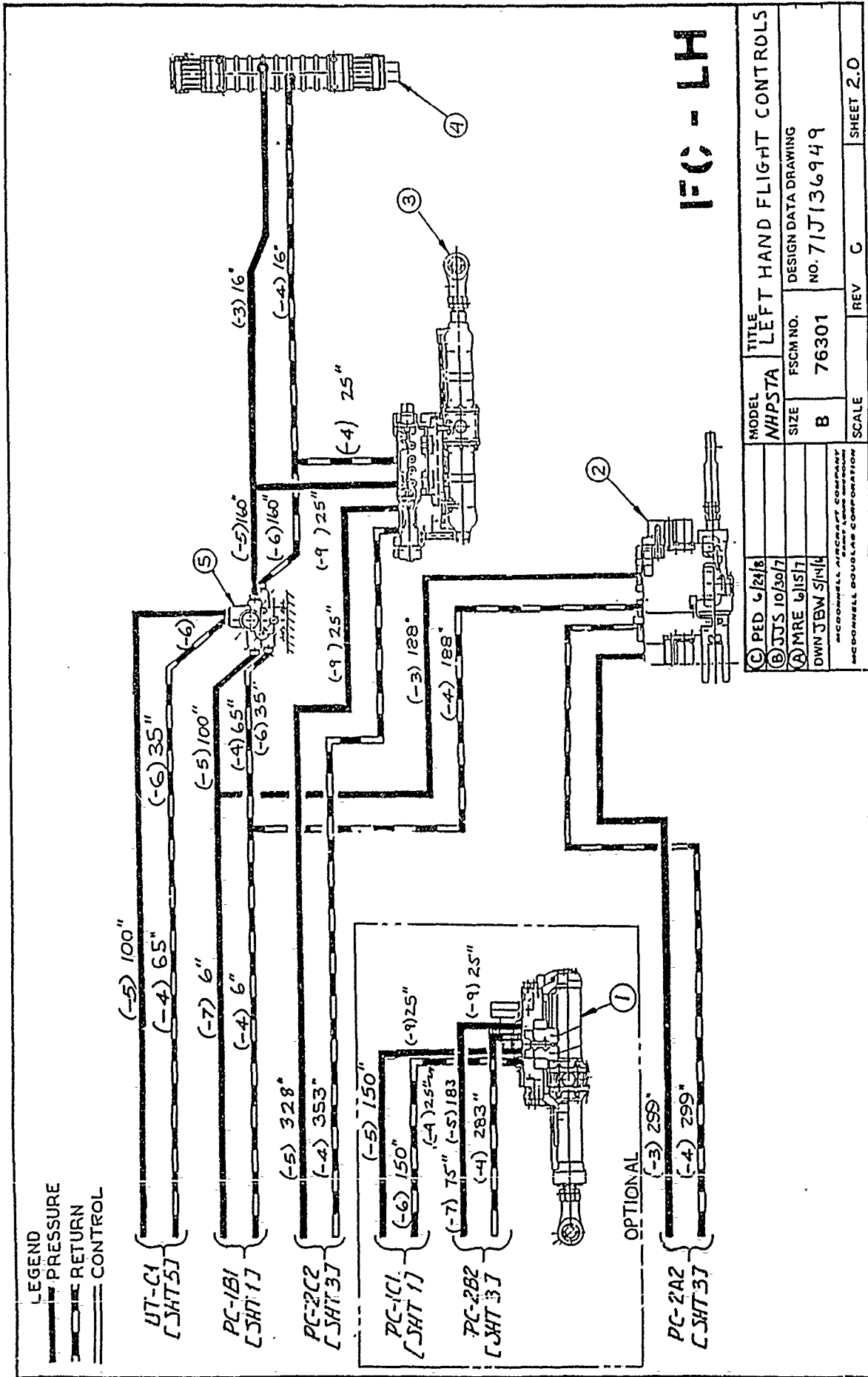
⑬ SWITCH - HYDRAULIC, PRESSURE  
P/N 71-136930-103, ITT NEO-DYN P/N 1203P0023

⑭ MANIFOLD ASSEMBLY, RETURN  
MCAIR P/N ADP-M2

136-1

MODEL NHPSTA	TITLE POWER CONTROL SYSTEM No. 1
SIZE B	FSCM NO. 76301
DESIGN DATA DRAWING NO. 71J136949	
SCALE	REV C
SHEET 1.1	



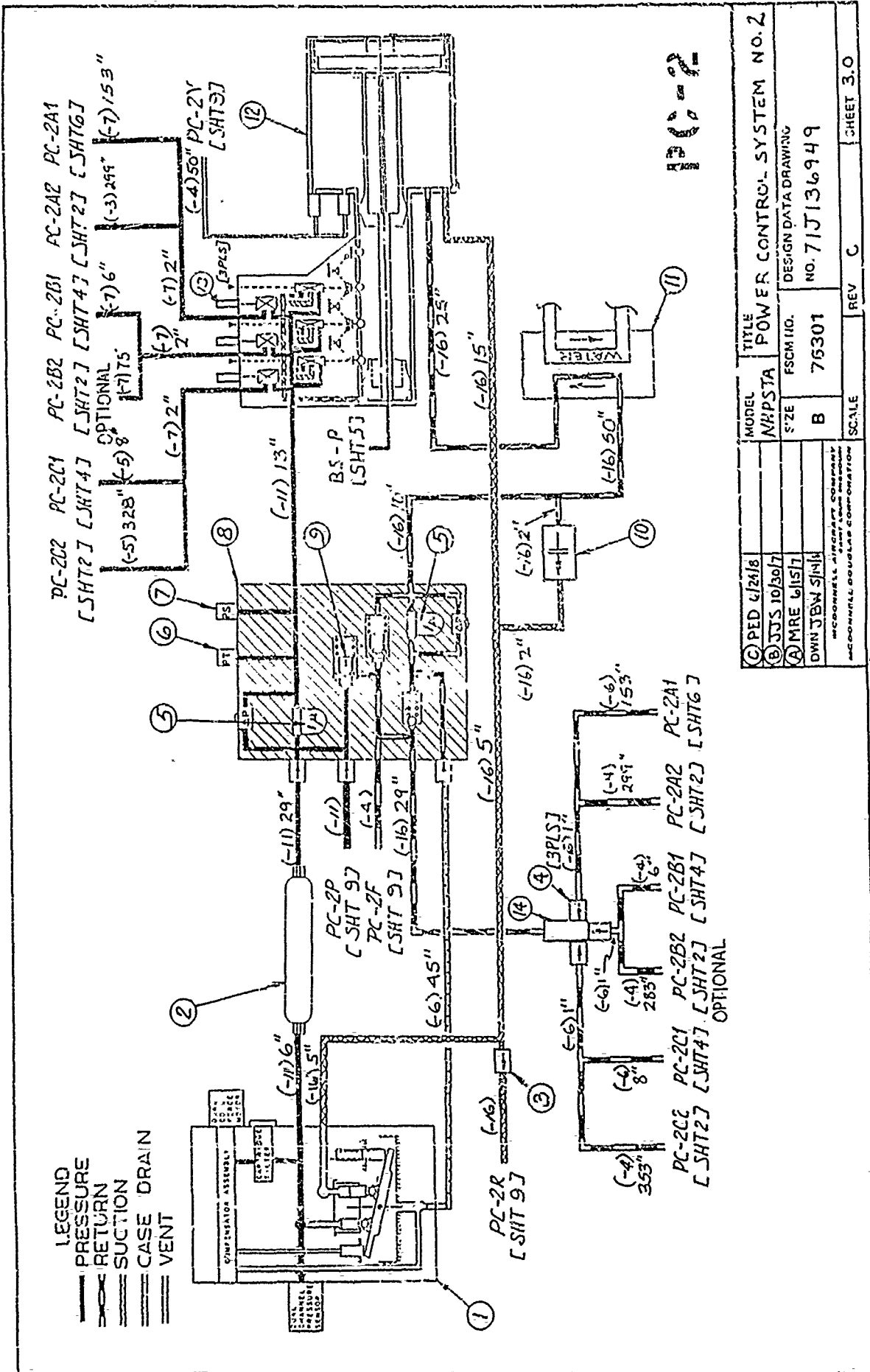


MODEL	TITLE	SCALE	REV	C	SHEET	2.0
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SIZE	FSCM NO.					
B	76301					
DESIGN DATA DRAWING						
NO. 71J136949						
MCDONNELL-DOUGLAS CORPORATION						
MCDONNELL AIRCRAFT CORPORATION						
MCDONNELL AIRCRAFT CORPORATION						

- ① SERVOCYLINDER - HYDRAULIC, CANARD  
P/N 71-136902 -101, OPTIONAL
- ② SERVOCYLINDER - HYDRAULIC, FLAPERON  
P/N 71-136901 -101, MOOG P/N L4797
- ③ SERVOCYLINDER - HYDRAULIC, STABILATOR  
P/N 71-136934 -101, E-SYSTEMS P/N
- ④ HINGE - HYDRAULIC, RUDDER  
P/N 71-136937-101 BENDIX P/N 3337026
- ⑤ VALVE - HYDRAULIC, INTEGRITY MONITOR  
P/N 71-136913 -101, PARKER P/N 3860028

# FC-LH

③ JJS 10/30/7	MODEL	TITLE	REV	SHEET
④ MRE 6/15/7	MHPSTA	LEFT HAND FLIGHT CONTROLS	B	2.1
DWN JBW 5/14/4	SIZE	FSCM NO.	DESIGN DATA DRAWING	
	B	76301	NO 71J136949	
<small>         MCCONNELL AIRCRAFT COMPANY          2501 LOUISIANA          MCCONNELL DIVISION OF CORPORATION       </small>				

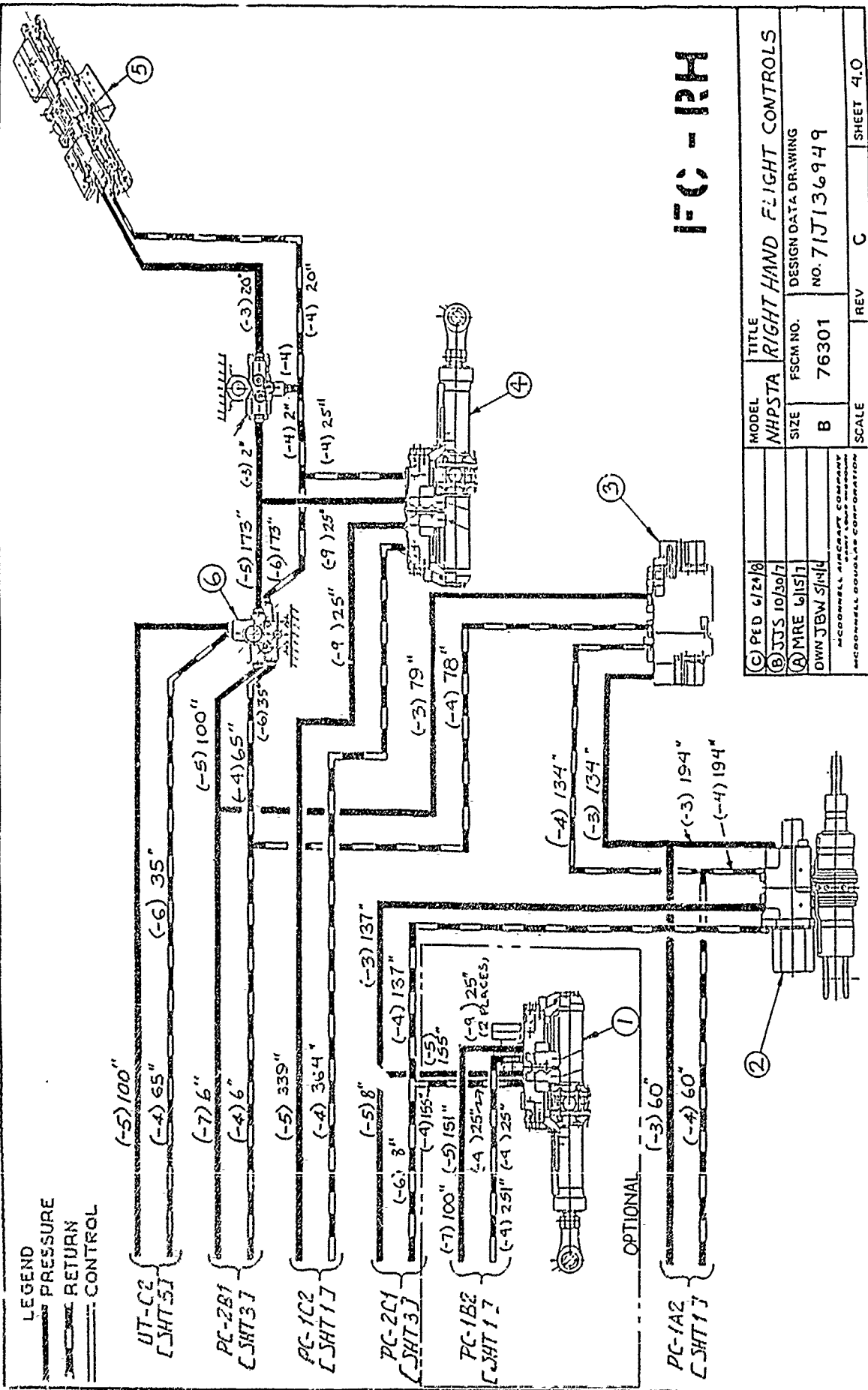


- ① PUMP - HYDRAULIC, VARIABLE PRESSURE AND DELIVERY  
P/N 71-136909-101, BENDIX P/N 34E159-1A
- ② ACOUSTIC FILTER, PULSCO P/N 840 40111  
OPTIONAL: MAY BE REPLACED WITH 18" of (-11) TUBE.
- ③ VALVE - HYDRAULIC, CHECK (LOW PRESSURE)  
P/N ST7M262-16
- ④ VALVE - HYDRAULIC, CHECK (LOW PRESSURE)  
P/N ST7M261-6
- ⑤ FILTER ELEMENT, 5 MICRON ABSOLUTE  
P/N 71-136910-209, APM P/N AC-B655.F-12
- ⑥ TRANSMITTER - HYDRAULIC, PRESSURE  
P/N 71-136931-101, CONDEC P/N 41SG252
- ⑦ SWITCH - HYDRAULIC, PRESSURE  
P/N 71-136930-101, ITT NEO-DYN P/N 1203P0018
- ⑧ MANIFOLD - HYDRAULIC, FILTER, 5 MICRON ABSOLUTE  
P/N 71-136910-101, APM P/N AE-B655-12
- ⑨ VALVE - HYDRAULIC, PRESSURE RELIEF  
CIRCLE SEAL P/N RV 57-29
- ⑩ VALVE - HYDRAULIC, PRESSURE RELIEF  
CIRCLE SEAL P/N 5132T-16TB-15
- ⑪ HEAT EXCHANGER - HYDRAULIC, CTFE/WATER  
P/N 71-136919-101,
- ⑫ RESERVOIR - HYDRAULIC, PRECHARGE  
P/N 71-136939-101, PARKER P/N 3850080

- ⑬ SWITCH - HYDRAULIC, PRESSURE  
P/N 71-136930-103, ITT NEO DYN P/N 1203P0023
- ⑭ MANIFOLD ASSEMBLY, RETURN  
MCAIR P/N ADP-M2

PC-2

① PED 6/24/8	MODEL	TITLE
② JJS 10/30/7	MHPSTA	POWER CONTROL SYSTEM NO. 2
③ MRE 6/15/7	SIZE	FSCM NO.
④ WJTBW 5/14	B	76301
DESIGN DATA DRAWING NO 71J136949		
<small>         MC DONNELL AIRCRAFT COMPANY          MC DONNELL DOUGLAS CORPORATION       </small>		
SCALE	REV	C
		SHEET 11



LEGEND  
 PRESSURE  
 RETURN  
 CONTROL

# FC - 12H

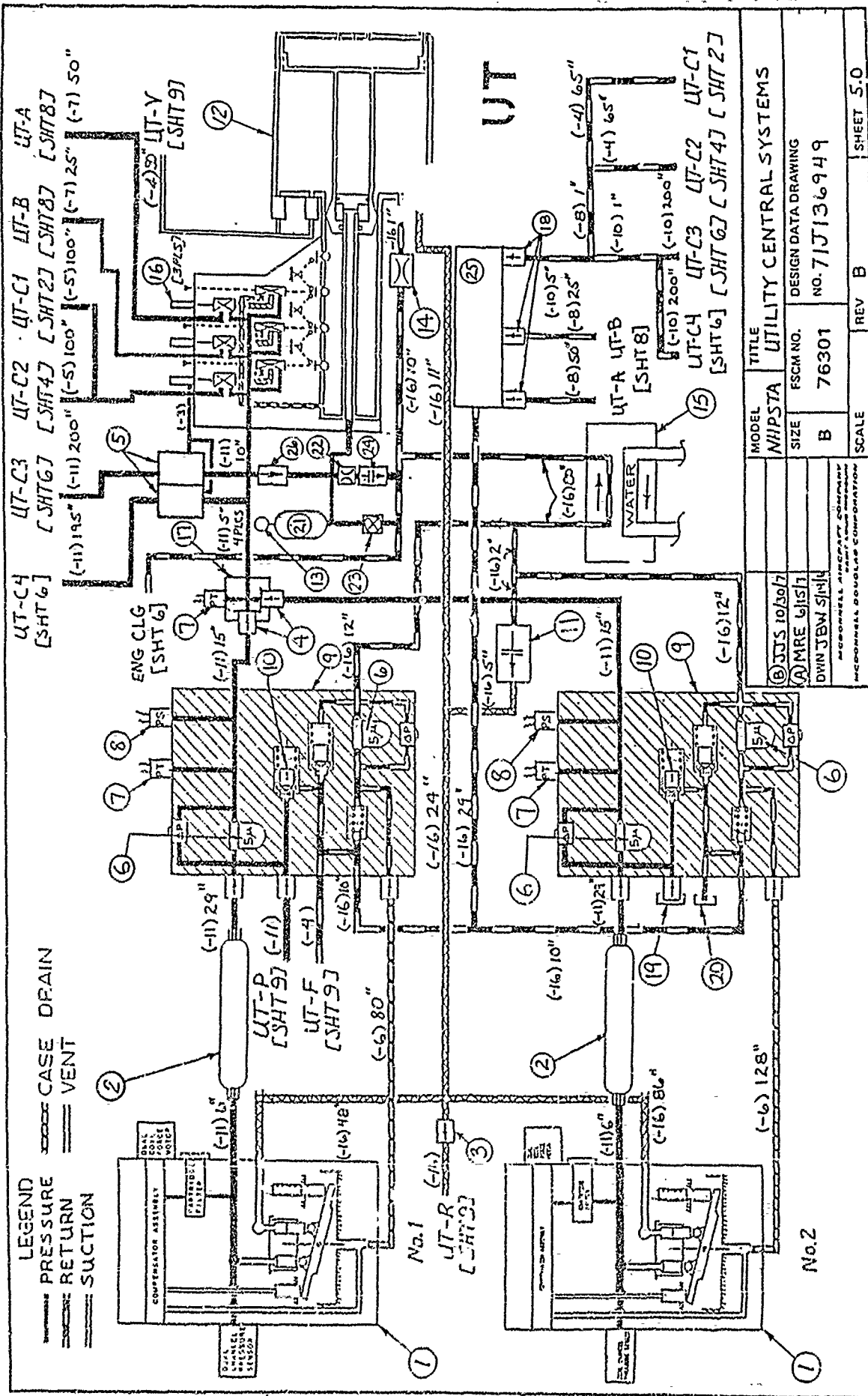
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MHPSTA	RIGHT HAND FLIGHT CONTROLS		
SIZE	FSCM NO.	DESIGN DATA DRAWING	
B	76301	NO. 71J136949	
SCALE			
REV			C
SHEET			4.0

(C) PED 6/24/0  
 (B) JJS 10/30/7  
 (A) MRE 6/15/7  
 DWN JBM SJW  
 MCDONNELL AIRCRAFT COMPANY  
 MCDONNELL DOUGLAS CORPORATION

- ① SERVOCYLINDER - HYDRAULIC, CANARD  
P/N 71-136902 -101, HR TEXTRON P/N 41008130
- ② SERVOCYLINDER - HYDRAULIC, AILERON  
BERTEA P/N 330400ADP
- ③ SERVOCYLINDER - HYDRAULIC, FLAPERON SIMULATOR  
P/N 71-136901 -103, MOOG P/N A14628
- ④ SERVOCYLINDER - HYDRAULIC STABILATOR  
P/N 71-136934 -101, E-SYSTEMS P/N
- ⑤ HINGE - HYDRAULIC, RUDDER  
P/N 71-136937-101, HR TEXTRON P/N 41007097
- ⑥ VALVE - HYDRAULIC, INTEGRITY MONITOR  
P/N 71-136913-101, PARKER P/N 3860028
- ⑦ INTENSIFIER - HYDRAULIC, PRESSURE  
P/N 71-136922-101, PARKER P/N 3850126

FC-12H

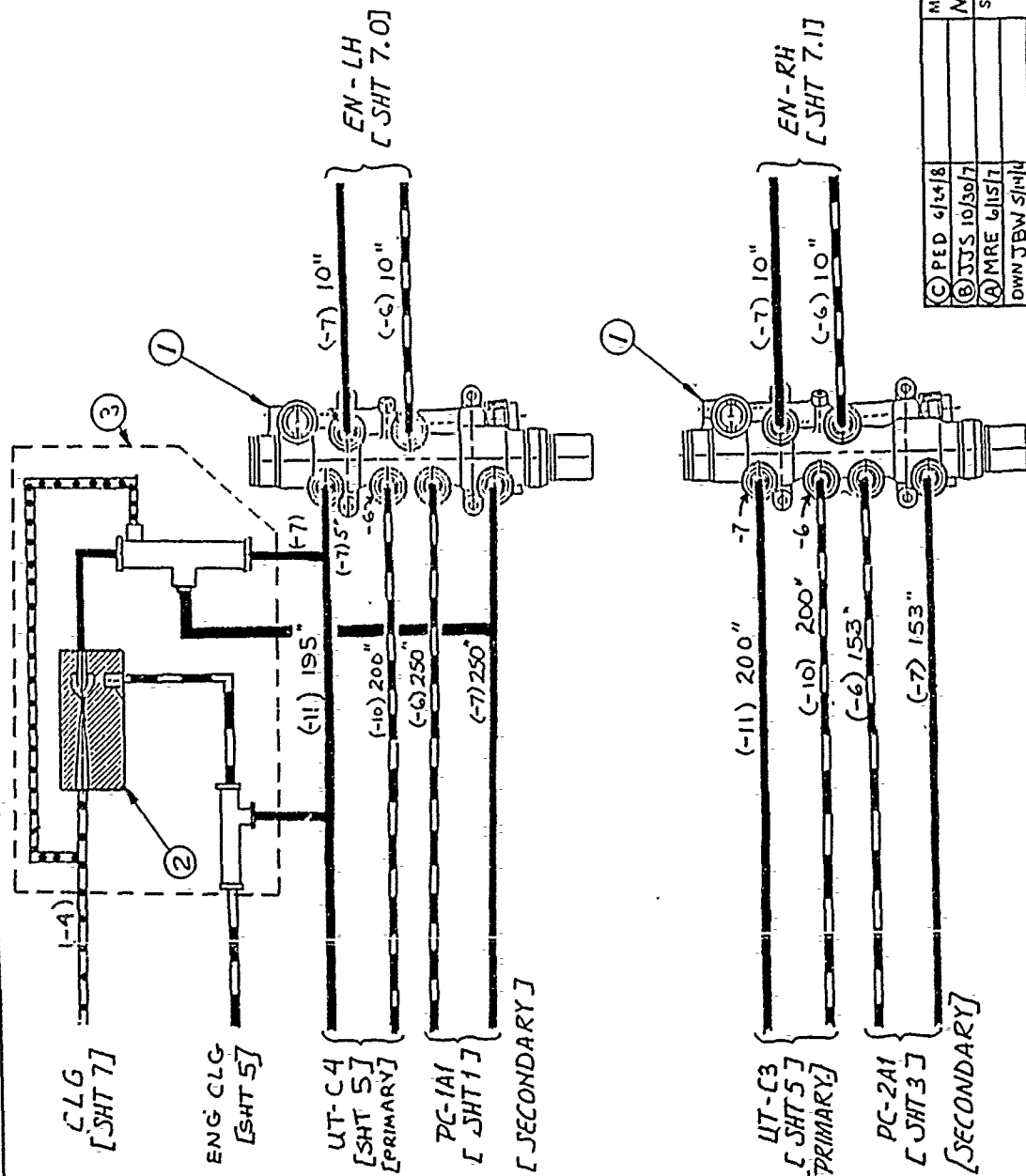
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② MRE 6/15/7	MHPSTA						
DYN JEW 5/14	SIZE	FSCM NO.	DESIGN DATA DRAWING				
	B	76301	NO. 71J136949				
<small>         MCCONNELL AIRCRAFT COMPANY          10000 WILSON AVENUE          MCKEAN, ILLINOIS 60451          MCCONNELL DOUGLAS CORPORATION       </small>						SCALE	
						REV	C
						SHEET	4.1



①	PUMP - HYDRAULIC. VARIABLE PRESSURE AND DELIVERY P/N 71-136918-101 VICKERS P/N DPV3-305-1	⑬	VALVE - PNEUMATIC, FILL, GAUGE CIRCLE SEAL P/N GP10-80																								
②	ACOUSTIC FILTER, PULSCO P/N 840 4011	⑭	RESTRICTOR - FLUID FLOW (TBD GPM $\Delta$ )																								
③	VALVE - HYDRAULIC, CHECK (LOW PRESSURE) ST7M 262-16	⑮	HEAT EXCHANGER - HYDRAULIC, CTFE/WATER																								
④	VALVE - HYDRAULIC, CHECK (HIGH PRESSURE) CRISSAIR P/N 4CH634	⑯	SWITCH - HYDRAULIC, PRESSURE P/N 71-136930-103, ITT NEO DYN P/N 1203P0023																								
⑤	RLS AUXILIARY VALVE GAR-KENYON P/N 95754	⑰	MANIFOLD - HYDRAULIC (HIGH PRESSURE) GAR-KENYON P/N																								
⑥	FILTER ELEMENT, 5 MICRON ABSOLUTE P/N 71-136941-209, PUROLATOR P/N 7590139-102	⑱	VALVE - HYDRAULIC, CHECK (LOW PRESSURE) ST7M 261-8																								
⑦	TRANSMITTER - HYDRAULIC, PRESSURE P/N 71-136931-101, CONDEC P/N 45G252	⑲	CAP, ST7M 235T4																								
⑧	SWITCH - HYDRAULIC, PRESSURE P/N 71-136930-101, ITT NEO-DYN P/N 1203P0018	⑳	CAP, ST7M 235T16																								
⑨	MANIFOLD - HYDRAULIC. FILTER. 5 MICRON ABSOLUTE P/N 71-136941-101, PUROLATOR P/N 7590095-101	㉑	ACCUMULATOR - HYD, CYL, 8000 PSI P/N 71-136936-101 PARKER P/N 3860012																								
⑩	VALVE - HYDRAULIC, PRESSURE RELIEF P/N 71-136925-101, CIRCLE SEAL P/N 2V57-29	㉒	RESTRICTOR - FLUID FLOW (TED GPM)																								
⑪	VALVE - HYDRAULIC, PRESSURE RELIEF CIRCLE SEAL P/N 5132T-16TB-100	㉓	MANUAL DUMP VALVE																								
⑫	RESERVOIR - HYDRAULIC, BOOST STRAP P/N 71-136939-101, PARKER P/N 3850080	㉔	VALVE - HYDRAULIC, PRESSURE RELIEF																								
		㉕	MANIFOLD ASSY, RETURN																								
		㉖	VALVE, HYDRAULIC CHECK (HIGH PRESSURE) <b>UT</b> GAR KENYON P/N 95753																								
		<table border="1"> <thead> <tr> <th>① PED</th> <th>6/24/8</th> <th>MODEL</th> <th>TITLE</th> </tr> </thead> <tbody> <tr> <td>② JTS</td> <td>10/30/7</td> <td>MHPSTA</td> <td>UTILITY CENTRAL SYSTEMS</td> </tr> <tr> <td>③ MRE</td> <td>6/15/7</td> <td>SIZE</td> <td>FSCM NO.</td> </tr> <tr> <td>DWN</td> <td>JBN</td> <td>B</td> <td>76301</td> </tr> <tr> <td colspan="2"> <small>REGORRELL AIRCRAFT COMPANY INCORPORATED</small> </td> <td>SCALE</td> <td>REV C</td> </tr> <tr> <td colspan="2"></td> <td></td> <td>SHEET 5.1</td> </tr> </tbody> </table>		① PED	6/24/8	MODEL	TITLE	② JTS	10/30/7	MHPSTA	UTILITY CENTRAL SYSTEMS	③ MRE	6/15/7	SIZE	FSCM NO.	DWN	JBN	B	76301	<small>REGORRELL AIRCRAFT COMPANY INCORPORATED</small>		SCALE	REV C				SHEET 5.1
① PED	6/24/8	MODEL	TITLE																								
② JTS	10/30/7	MHPSTA	UTILITY CENTRAL SYSTEMS																								
③ MRE	6/15/7	SIZE	FSCM NO.																								
DWN	JBN	B	76301																								
<small>REGORRELL AIRCRAFT COMPANY INCORPORATED</small>		SCALE	REV C																								
			SHEET 5.1																								
		<p><math>\Delta</math> SEE NOTES PAGE 11</p>																									



LEGEND  
 ——— PRESSURE  
 - - - RETURN  
 - - - COOLING



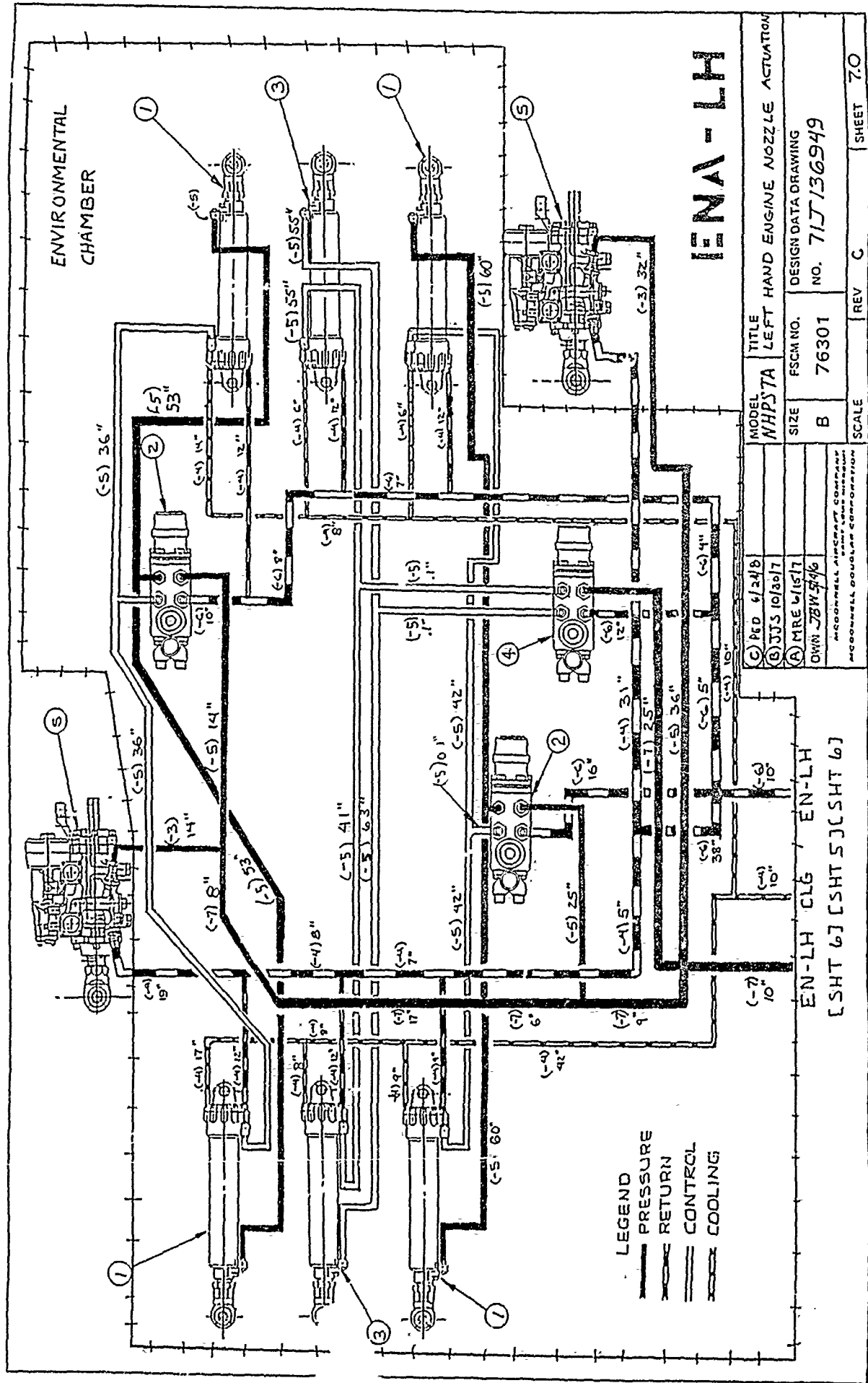
ENI

MODEL	TITLE	SCALE	REV	C	SHEET	6.0
NHPSTA	ENGINE NOZZLES INTERCONNECT					
SIZE	FSCM NO.					
B	76301					
	DESIGN DATA DRAWING					
	NO. 71J136949					
<small>ROCKWELL INTERNATIONAL CORPORATION        ROCKWELL DOUGLASS CORPORATION</small>						

- ① VALVE - HYDRAULIC, SHUTTLE  
P/N 71-136928 -101, PARKER P/N 3860017
- ② EDUCATOR - HYDRAULIC  
MCAIR P/N ADP-07
- ③ AUGMENTED COOLING VALVE  
GAR-KENYON P/N

ENI

① RED 6/24/8	MODEL	TITLE	ENGINE	NOZZLES	INTERCONNECT
② JJS 10/30/7	NHPSTA	ENGINE	NOZZLES	INTERCONNECT	
③ MRE 6/15/7	SIZE	FSCM NO.	DESIGN DATA	DRAWING	
DWN JBM 5/14/4	B	76301	NO. 71J136949		
MCCONNELL AIRCRAFT COMPANY 2000 W. 10TH AVENUE DENVER, COLORADO 80202			SCALE	REV	C
MCCONNELL DOUGLASS CORPORATION					SHEET 6.1



# ENA-LH

MODEL	WHPSTA	TITLE	LEFT HAND ENGINE NOZZLE ACTUATION
SIZE	B	FSCM NO.	76301
DESIGN DATA DRAWING		NO.	71J136949
SCALE		REV	C
SHEET		70	

(C) PED 4/24/8  
 (B) JJS 10/20/7  
 (A) MRE 6/15/7  
 DWN 28W546  
 MCDONNELL AIRCRAFT COMPANY  
 WHEAT RICH AIRCRAFT DIVISION  
 MCDONNELL DOUGLAS CORPORATION

EN-LH CLG EN-LH  
 [SHT 6] [SHT 5] [SHT 6]

**LEGEND**  
 ——— PRESSURE  
 - - - RETURN  
 = = = CONTROL  
 ~ ~ ~ COOLING

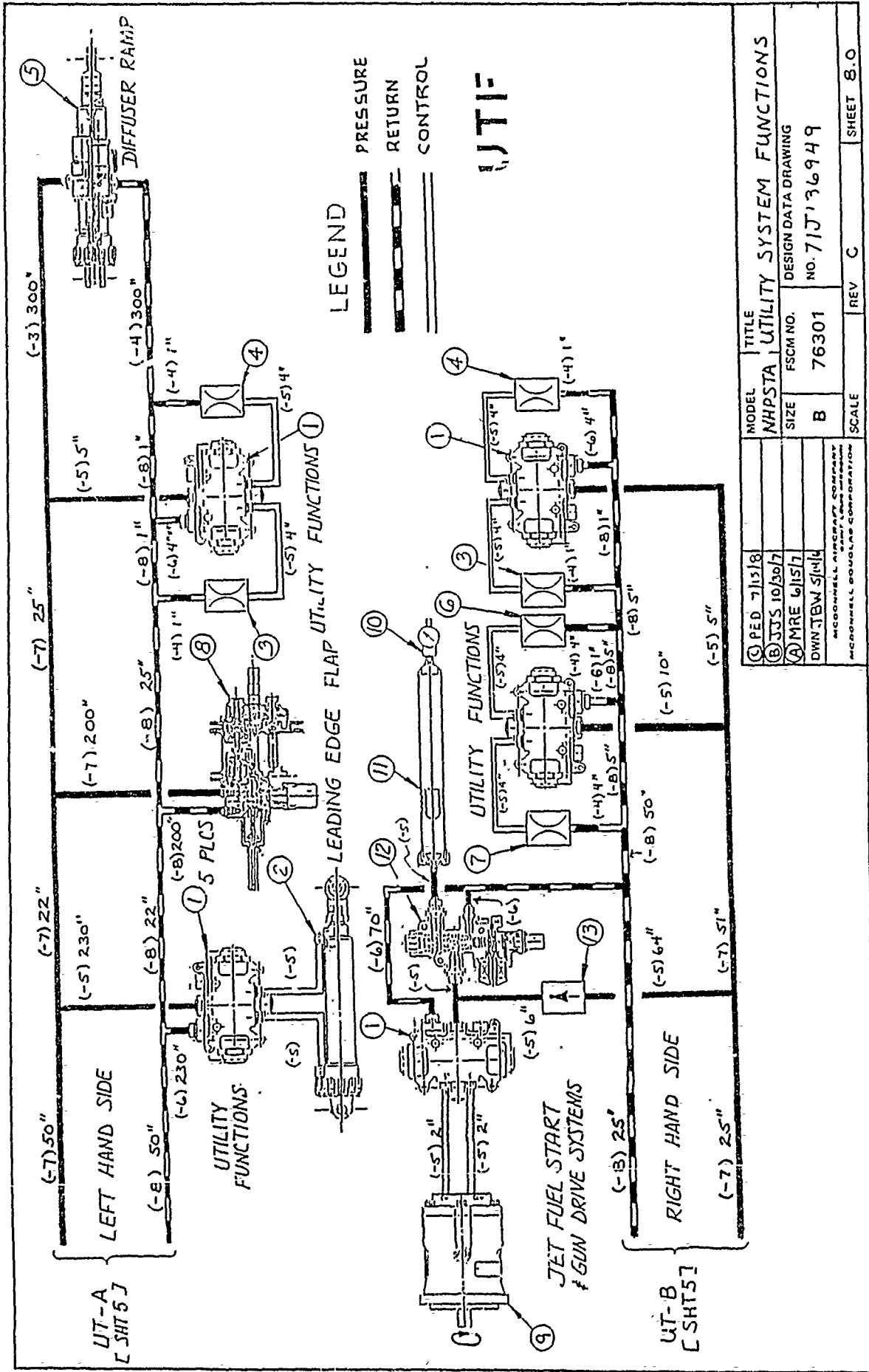


- ① OUTPUT RAM - HYDRAULIC, DIVERGENT FLAP  
P/N 71-136907-205, MOOG P/N L-4735
- ② SERVO CONTROL UNIT - HYDRAULIC, DIVERGENT FLAP  
P/N 71-136907-201, MOOG P/N
- ③ OUTPUT RAM - HYDRAULIC, CONVERGENT FLAP  
P/N 71-136907-207, MOOG P/N L-4670
- ④ SERVO CONTROL UNIT - HYDRAULIC, CONVERGENT FLAP  
P/N 71-136907-203, MOOG P/N
- ⑤ SERVO CYLINDER - HYDRAULIC, REVERSE YANE  
P/N 71-136938-101, BERTEA P/N 314000
- ⑥ SERVO CYLINDER - HYDRAULIC, ARC VALVE  
P/N 71-136938-103, BERTEA P/N 324300
- ⑦ SIMULATOR - HYDRAULIC, DIVERGENT FLAP  
P/N 71-136907-209, MOOG P/N
- ⑧ RESTRICTOR FLUID FLOW (TBD GPM  $\Delta$ )

$\Delta$  SEE NOTES PAGE ii

ENVA

① JJS 10/30/71	MODEL	TITLE	ENGINE	NOZZLES	ACTUATION
② MRE 6/15/71	MHPSTA				
DWN JBN J/M/71	SIZE	FSCM NO.			DESIGN DATA DRAWING
	B	76301			NO. 71J136949
MCDONNELL AIRCRAFT COMPANY MCDONNELL AIRCRAFT DIVISION MCDONNELL DOUGLAS CORPORATION			SCALE	REV	B
				SHEET	7.2



**LEGEND**

————— PRESSURE  
 - - - - - RETURN  
 ······· CONTROL

# UTSF

MODEL		TITLE	
MHPSTA		UTILITY SYSTEM FUNCTIONS	
DESIGN NO.	FSCM NO.	SCALE	REV
	76301	C	C
NO. 71J136949		SHEET 8.0	

① VALVE - HYDRAULIC, LINEAR, DIRECTIONAL CONTROL, 4W-3P  
P/N 71-136915-101, PARKER P/N 3860029

② CYLINDER - HYDRAULIC, UTILITY  
CADILLAC GAGE P/N

③ RESTRICTOR - FLUID FLOW ( TBD GPM  $\Delta$  )

④ RESTRICTOR - FLUID FLOW ( TBD GPM  $\Delta$  )

⑤ SERVO CYLINDER - HYDRAULIC, DIFFUSER RAMP  
P/N 71-136904-101, CADILLAC GAGE P/N 300100

⑥ RESTRICTOR - FLUID FLOW ( TBD GPM  $\Delta$  )

⑦ RESTRICTOR - FLUID FLOW ( TBD GPM  $\Delta$  )

⑧ POWER DRIVE UNIT - LEADING EDGE FLAP  
P/N 71B136940-201, SUNDSTRAND P/N

⑨ MOTOR - HYDRAULIC, UTILITY  
P/N 71-136912-101, ABEX P/N AM2CH-1

⑩ VALVE - PNEUMATIC, FILL, GAUGE  
P/N 71-136932-101, CIRCLE SEAL P/N GP10-80

⑪ ACCUMULATOR - HYDRAULIC, CYLINDRICAL, 8000 PSI  
P/N 71-136936-101, PARKER P/N 3860012

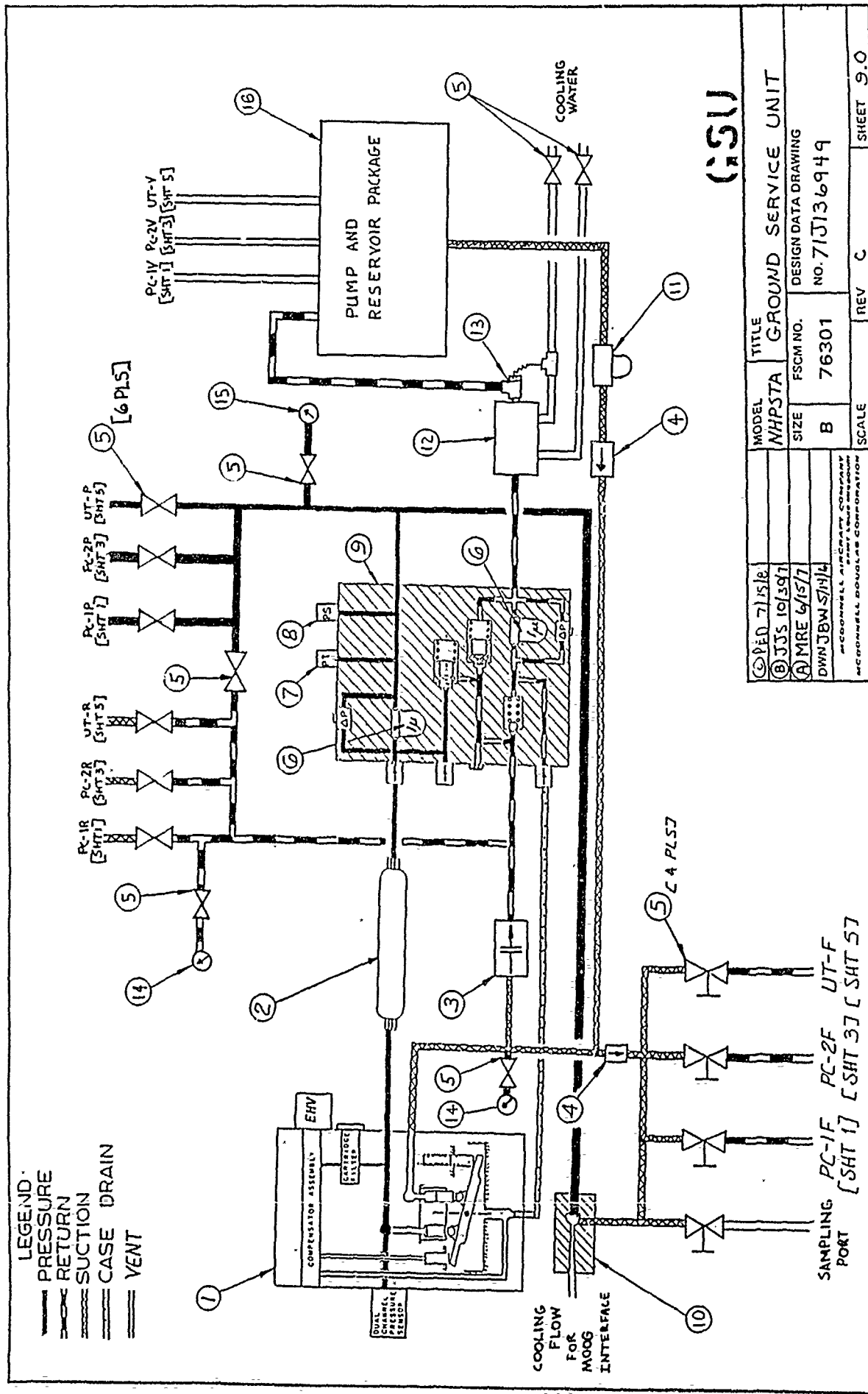
⑫ VALVE - HYDRAULIC, LINEAR, DIRECTIONAL CONTROL 3W-2P  
P/N 71-136917-101, PARKER P/N 3850075

⑬ VALVE - HYDRAULIC, CHECK (HIGH PRESSURE)

$\Delta$  SEE NOTES PAGE II

UTF

DESIGNED BY D.J.J.S. 10/30/71	MODEL MHPSTA	TITLE UTILITY SYSTEM FUNCTIONS
DRAWN BY D.W.N. 10/31/71	SIZE B	FSCM NO. 76301
DATE 11/11/71	SCALE	REV. C
MCDONNELL AIRCRAFT COMPANY A DIVISION OF MCDONNELL DOUGLAS CORPORATION		DESIGN DATA DRAWING NO. 71J136949
SHEET		SHEET 8.1



(GSU)

MODEL	TITLE
NHPSTA	GROUND SERVICE UNIT
SIZE	DESIGN DATA DRAWING
B	NO. 71J136949
SCALE	REV C
SHEET 9.0	

(A) MRE 6/15/71  
 (B) JJS 10/30/71  
 (C) ED 7/15/78  
 DW/JBN/S/H/4  
 MCCONNELL AIRCRAFT COMPANY  
 MCCONNELL AIRCRAFT COMPANY  
 MCCONNELL AIRCRAFT COMPANY  
 MCCONNELL AIRCRAFT COMPANY  
 MCCONNELL AIRCRAFT COMPANY

SAMPLING PORT PC-1F [SHT 17] PC-2F [SHT 37] UT-F [SHT 57]  
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**LEGEND**  
 PRESSURE  
 RETURN  
 SUCTION  
 CASE DRAIN  
 VENT



- ① PUMP-HYDRAULIC, VARIABLE PRESSURE AND DELIVERY  
ABEX P/N AFGVHP - L LECHT J
- ② ACOUSTIC FILTER, PULSCO P/N 840 40111
- ③ VALVE-HYDRAULIC, PRESSURE RELIEF [100PSI]
- ④ VALVE-HYDRAULIC, CHECK (LOW PRESSURE)
- ⑤ VALVE-HYDRAULIC, NEEDLE CONTROL
- ⑥ FILTER ELEMENT, 1 MICRON ABSOLUTE  
P/N 71-136910-233, APM P/N  
, PUROLATOR P/N
- ⑦ TRANSMITTER-HYDRAULIC, PRESSURE  
P/N 71-136931-101, CONDEC P/N 41SG252
- ⑧ SWITCH-HYDRAULIC, PRESSURE  
P/N 71-136930-101, ITT NEO-DYN P/N 1203P0018
- ⑨ MANIFOLD-HYDRAULIC, FILTER, 1 MICRON ABSOLUTE  
P/N 71-136910-101, APM P/N  
, PUROLATOR P/N
- ⑩ EDUCTOR-HYDRAULIC  
MCAIR P/N
- ⑪ FILTER, APM  
I.B. CABINET

- ⑫ PRATT AND WHITNEY  
STAINLESS STEEL OIL COOLER  
P/N F-100
- ⑬ PENN TEMP CONTROL VALVE  
I.B. CABINET
- ⑭ 500 PSI GAUGE, FROM CRIB
- ⑮ 10,000 PSI GAUGE, FROM CRIB
- ⑯ PUMP AND RESEVOIR PACKAGE  
SUPPLIED BY DEPT. 253  
PURCHASED FROM ENGINEERING SALES

(GSU)

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APPENDIX B  
GENERAL TEST PLAN AND PROCEDURES

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Report number MDC IR0434

GENERAL TEST PLAN AND PROCEDURES

FOR

LABORATORY TECHNOLOGY DEMONSTRATOR

Revision date 19 October 1988

Revision letter A

Issue date 20 May 88

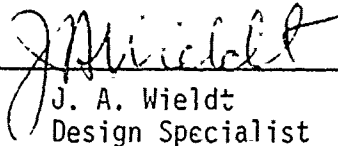
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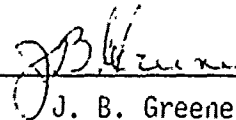
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**MCDONNELL DOUGLAS**

**CORPORATION**

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## 1.0 BACKGROUND

The development of nonflammable hydraulic fluids require an evaluation of their usage and effects, with regards to weight and volume savings, on current and future aircraft. This system will incorporate low energy consumption hydraulic concepts to minimize heat rejection and further reduce weight. These concepts will include the following:

- o Actuator Flow Augmentation
- o Overlapped Valves
- o Pressure Intensifiers
- o Variable Pressure Pumps

## 2.0 OBJECTIVE

The objective of this test is to demonstrate nonflammable hydraulic system technology for advanced fighter aircraft. The laboratory demonstrator will include variable pressure pumps and other low energy consumption components. Included in this testing will be a 500 hour durability test that simulates typical aircraft flight missions and conditions. In addition, a 50 hour durability test will be conducted after component removal and replacement, and will include line repair techniques. Test data will be analyzed to verify the computer model and modeling techniques. The computer model will then be modified to reflect the actual data.



### 3.0 TEST SYSTEM

The test system schematic is shown in Figure B-1 and is configured to simulate the F-15 S/MTD fighter aircraft. Concepts to be included in the evaluation are:

- o Variable pressure pumps, (capable of 3000 to 8000 psi on demand with capability of 40 gpm flow)
- o Reservoirs each having three reservoir level sensing (RLS) circuits
- o Pressure Intensifier to double system pressure at the control actuator
- o Hydraulic Integrity Monitor
- o Overlap valve Leakage reduction/heat rejection
- o Engine Nozzle cooling flow augmentation

The simulator will be divided into three sections, left hand, right hand and utility systems. The left hand system is baseline and includes actual flight control hardware and load fixtures to simulate flight parameters. The right hand system will consist mainly of simulators, with some unloaded actuators to simulate flow and pressure drop requirements to the pumps. The utility system will incorporate a left and right hand engine nozzle actuation system with the right side consisting of control valves with flow restrictors, and the left side consisting of actual engine nozzle actuators and reverser vane actuators. The utility functions will consist of a gun drive/JFS motor along with several control valves to simulate the landing gear, arresting hook, etc.

The facility layout will be of modular design with hydraulic lines that are equivalent to actual aircraft line lengths to obtain representative flow and pressure drops. Three pump manufacturers will be supplying variable pressure pumps that will be controlled using DDV position from all the flight control actuators. The flight control actuators will then direct the pump to either increase or decrease the output pressure.

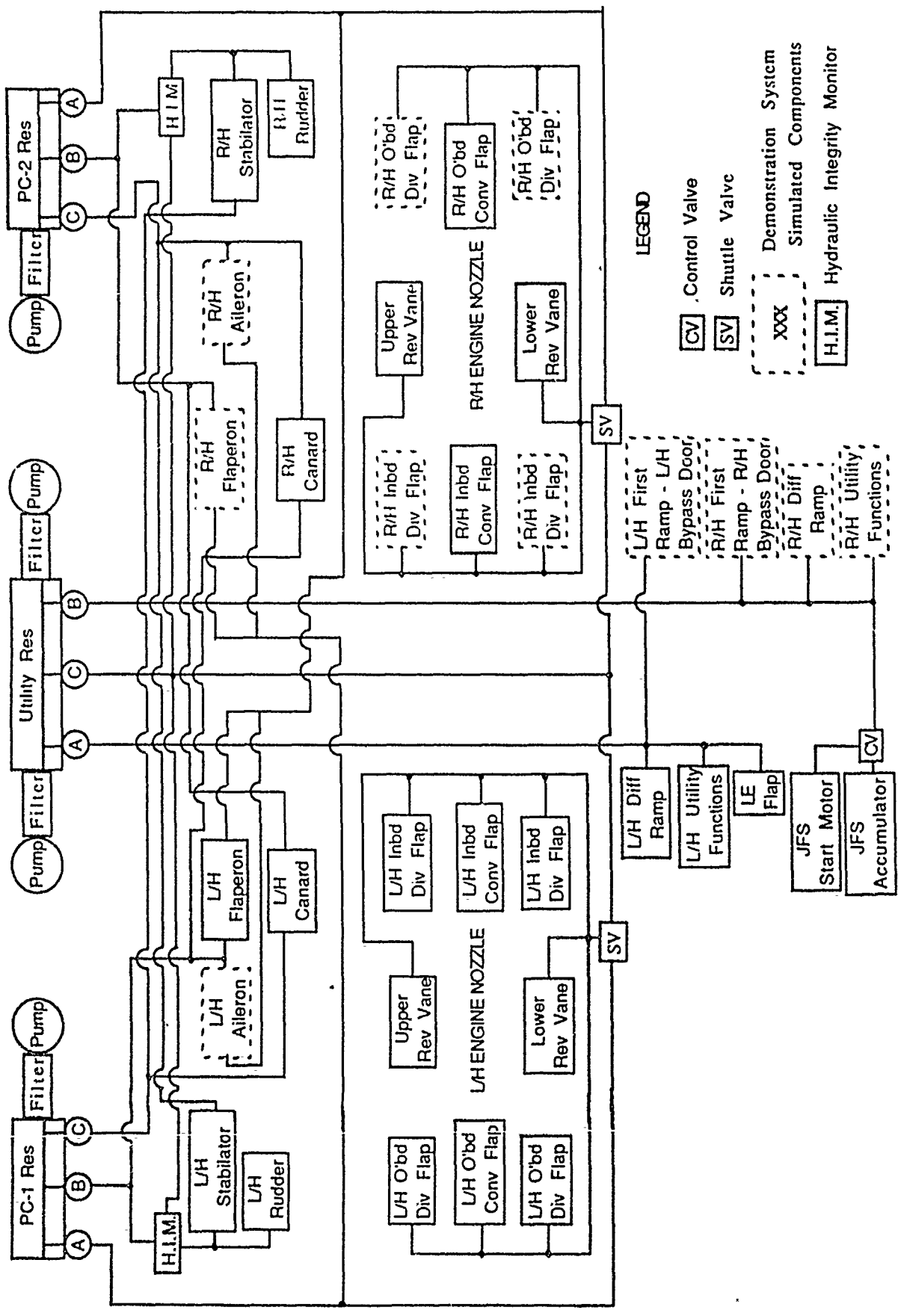


Figure B-1. NHPSTA Hydraulic System Block Diagram

#### 4.0 FACILITIES

The complete engine nozzle actuation system, including the right hand simulators, will be subject to a temperature environment. The temperature chamber will be capable of controlling ambient temperature from room temperature to 475°F and control fluid temperature to 350°F. The temperature chamber will not be required if fluid temperature is limited to 275°F.

## 5.0 INSTRUMENTATION

Instrumentation locations are noted in Attachment 1 with additional requirements noted below:

- o Instrumentation pickups are to be located as near as practical to the component ports.
- o Ambient temperature with a range of 50°F to 100°F will be utilized for all equipment with the exception of the nozzle actuators which require a range of 50°F to 475°F.
- o Pump discharge pressure, case drain temperature and case drain flow are to be utilized for automatic shutoff in the event of a pump or system failure.

Attachment 1 also includes the minimum range required for each device. The instrumentation/transducers have accuracies as follows:

- o Pressure -  $\pm 0.5\%$  full scale
- o Temperature -  $\pm 2^\circ\text{F}$
- o Load Cells -  $\pm 3\%$  full scale
- o LVDT -  $\pm 0.5\%$  full scale
- o Flow -  $\pm 1\%$  full scale (turbine flowmeter)
- o Pressure Gages -  $\pm 1\%$  full scale

In addition to these sensors, several measuring systems, conditioners, recorders and plotters will be required; some of the available systems are as follows:

- o A Lebow torsion measurement system to measure pump torques with nonlinearity  $\pm 0.1\%$  of rated output Hysteresis,  $\pm 0.1\%$  of rated output, Zero balance  $\pm 1.0\%$  of rated output, and Analog output nonlinearity  $\pm 0.1\%$  of full scale.
- o A Cyber signal conditioner for all parameters with 2% accuracy except for the flow conditioners which have 0.2% accuracy.
- o Three separate recorders will be utilized:

A Neff differential multiplexer digital data acquisition system with  $\pm 0.05\%$  accuracy and  $\pm 0.003^\circ\text{C}$ .

A strip chart recorder with eight channels and an accuracy of 1% full scale.

A Bafco recorder for frequency response testing with  $\pm 0.1$  dB amplitude accuracy and  $\pm 0.75$  degrees phase accuracy.

(A)

## 6.0 TESTING

Testing will be done in essentially three phases; individual component/performance tests, a system performance checkout and the 500 hour durability test. These will be followed by an additional 50 hour test after demonstration of component removal, replacement and line repair/ABDR. Failure modes will be demonstrated where applicable.

### 6.1 COMPONENT CHECKOUT/ATP

Each component will be thoroughly tested by the suppliers to insure that the basic parameters outlined in the specifications has been met. This includes but is not limited to the following tests:

- o Physical Defects Inspection
- o Proof Pressure
- o Leakage
- o Performance
  - Hysteresis
  - Frequency Response
  - Linearity
  - Flow

### 6.2 SYSTEM/INSTRUMENTATION CHECKOUT

A system checkout shall be performed to insure the instrumentation and load/inertia systems are operating correctly and properly calibrated. This checkout does not include any operation of the flight control actuators and shall be done to familiarize personnel with equipment and controllers.

### 6.3 SYSTEM/EQUIPMENT LEAK CHECK

The next phase of the system checkout will include flight control and the main system checkout for operational problems and leaks. This test shall be done using the ground support cart as the power unit to prevent any large oil spills or possible damage of components due to improper installation. The system will be filled and flushed at low pressure. Air will be bled by operating the ground cart open loop, and then the system will be flushed with a minimum of ten (10) gallons of CTFE fluid. Final checkout should be completed after approximately one hour of operation by removing and inspecting the system filters. In addition, fluid samples shall be taken from each circuit and submitted for evaluation and shall then be taken every 50 hours thereafter to monitor the fluid contaminants.

(A)

### 6.4 PERFORMANCE VERIFICATIONS

Equipment shall be tested for its particular installed performance requirements as stated in the following paragraphs for the applicable component.

6.4.1 Hydraulic System Transient Test - The hydraulic system shall have all circuits subjected to transient tests by operating and reversing the appropriate actuators at no load rates. Pressure transducers and recording equipment used to measure the transient pressure waves will have a sampling rate of at least 200 measurements per second, this will determine accurate transient pressures throughout the system. In addition, steady state flow and temperature conditions will be monitored to provide complete validation of the computer analysis that was conducted. (A)

6.4.2 Pump Pulsation Test - A sixty-four inch line length of 11/16 X .076 wall tubing will be used for pulsation testing, this is the length designated by our computer model as the correct length between the pump and filter manifold. Wet Transducers will be located every four inches along the line, the line can be reversed to obtain readings for every two inches. This testing shall be conducted at both 3000 psi and 8000 psi on all pumps with filter manifolds to insure that pump pulsations will not cause line fatigue/failure. This test may be performed as a bench test. Pulsations will be compared to those on the LTD with the Pulsco attenuator installed by utilizing a similar test tube for the 39" between the attenuator and filter package. (A)

6.4.3 Control System Electronics Testing - All the aircraft actuators, including the eight nozzle actuators, the inlet ramp actuator and the flight control actuators, will have the following tests performed to verify the actual design parameters.

- o Static Gain to provide actuator position vs electrical input.
- o Electrical Threshold test to determine the lowest input required to achieve a measurable output. This should be conducted at 0.1 Hz.
- o Frequency response will be performed using simulated stick signal and control surface or load position. Response sweep will be between 0.1 Hz and 100 Hz, conducted closed loop with no load with 1% and 10% strokes. Results should be in the form of Bode plots of amplitude and phase lag.
- o Combined hysteresis and deadband shall be measured with respect to its electrical input at 0.01 Hz over the full operating strokes (extend and retract).

6.4.4 Heat Rejection Test - Heat rejection is measured in Hp or BTU/min and will be completed by measuring the individual pump torques, speed, case drain flow and system leakage flow. This should be done with the neat exchanger in the circuits and with the heat exchanger isolated.

6.4.5 Stability Test - Actuator stability shall be evaluated for step inputs ranging from 5% to 75% of surface travel. The system shall be instrumented to record main ram position; this signal will be analyzed and compared to the actual input to the actuator for signs of erratic motion or instabilities.

6.4.6 Actuator Low Temperature Test - Cold soak tests of -40°F will be performed on selected actuators and components in the MCAIR bench test facility. Pressurization and slow rate operation will be performed to evaluate external leakage performance at -40°F. Units removed from the LTD for other reasons may be subjected to the cold soak test before reinstallation in the LTD. Spares, in some instances may be used for low temperature testing.

#### 6.5 ENGINE NOZZLE THERMAL TESTING

Engine nozzle thermal testing and rod cooling will be evaluated by performing a portion of the required endurance test. The inlet and outlet oil temperatures, cooling oil temperatures along with the actuator temperature will be monitored to show the effectiveness of the cooling system along with the total effect on system temperature.

#### 6.6 FAILURE MODE EFFECTS

The system shall be evaluated for component redundancy as well as circuit and system redundancies; this can be accomplished by initiating various failures at both the component and system levels.

6.6.1 Component Failure Modes - Servoactuators will be operated with one or two channels disabled to evaluate the no load frequency response.

Hydraulic Integrity Monitor and Shuttle valves will be operated to verify hydraulic redundancy by reducing and increasing pressures in the primary circuits.

6.6.2 System Failure Modes - Reservoir level sensing will be demonstrated by opening one of the three circuits and allowing it to drain. Fluid can then be measured to show at what reservoir levels the circuits are shut off and turned back on. Fluid drained will be recycled for later use in the system.

#### 6.7 ENDURANCE TESTING (500 HOURS)

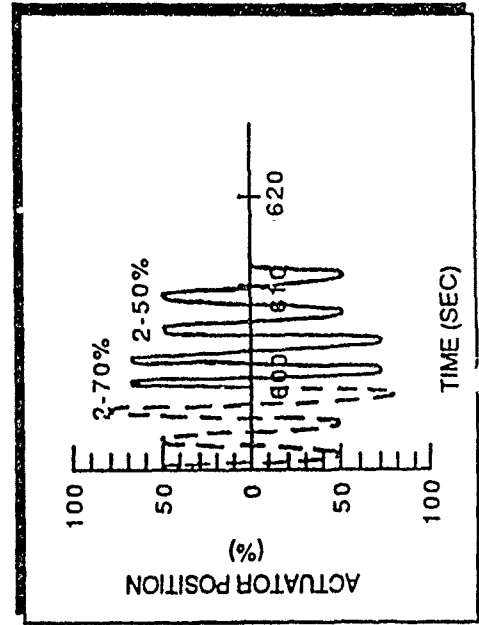
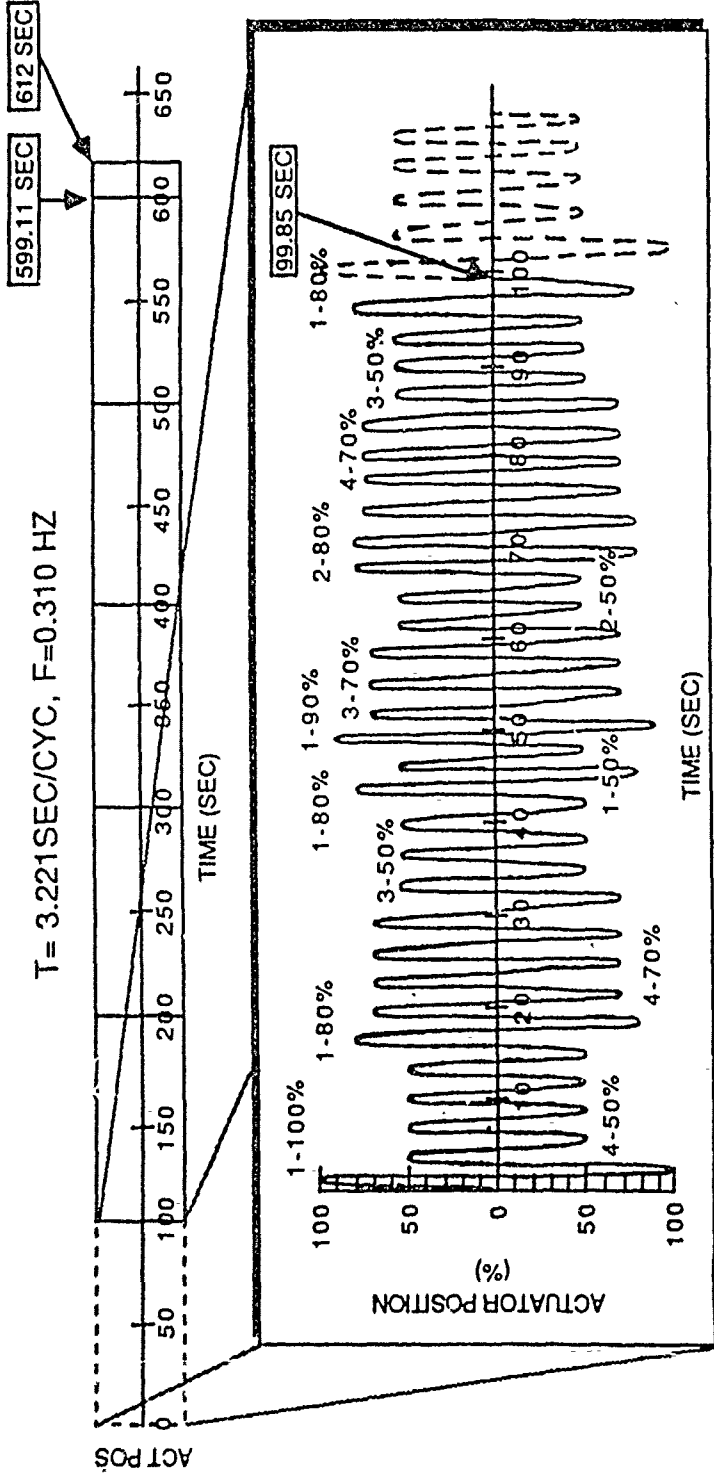
500 hours of endurance testing will be conducted to demonstrate the reliability of the flight actuators and hydraulic equipment. The system will be shut down and restarted to exercise the JFS accumulator and start motor between each 120 minute mission profile. Simulated air loads and inertias will be applied to the left hand actuators and will vary between 0% and 100% of the stall loads in accordance with the duty cycle as shown in Attachment 2, (100% stroke = 100% load).

6.7.1 Operating Duty Cycle - The duty cycle is shown in Attachment 2 with a graphic interpretation of a 100 second portion of the stabilator/rudder combat duty cycle illustrated in Figure B-2 This profile is based upon reduced stability fighter aircraft duty cycles information. Figure B-3 is a breakdown of the total cycles that each actuator will see for the 2 hour mission profile and the total for the 500 hour endurance test.

(A)

RUDDER/STABILATOR \* - COMBAT DUTY CYCLE

T = 3.221 SEC/CYC, F = 0.310 HZ



\* CANARD DUTY CYCLE, EXCEPT  
2 - 90% CYCLES IN FINAL SECONDS  
AND A FREQUENCY OF 0.314 HZ



Figure B-2. Duty Cycle Profile  
100 Seconds of Combat Phase



COMPONENTS	NO. OF CYCLES	
	2 HRS FLIGHT TIME	500 HRS ENDURANCE TEST
STABILATOR/RUDDER	8956	2,239,000
CANARD	8454	2,113,500
AILERON	9196	2,299,000
FLAPERON	8966	2,241,500
DIVERGENT/ CONVERGENT FLAP/ ARC VALVE/DIFFUSER RAMP	2989	747,250
REVERSER VANE	418	104,500
LEADING EDGE FLAP	3456	864,000

Figure B-3. Component Endurance Cycles

6.7.2 Fluid Sampling - Fluid sampling will be done to insure the physical properties of the fluid have not been degraded. Samples will be taken after the initial fill and flush and every 50 hours of operation thereafter. These samples are to be dynamic samples taken downstream of the pump and filter packages for each pump circuit. Two 8 oz. samples shall be taken at each sample port, one to be analyzed at MCAIR and the second to be sent to AFWAL/POOS for complete analysis.

6.7.3 Supportability Records - An accurate log of the following parameters will be maintained to conduct a supportability assessment including any detailed failure analysis:

- o System maintenance and repairs
- o Component failures and replacement
- o Running log of "ON" time for major components by serial number
- o Running log of downtime with complete description of component malfunction

6.7.4 Engine Nozzle High Temperature - A minimum of 10% of the total engine nozzle actuator cycling shall be performed with the ambient temperature of 450°F and fluid temperature of 350°F if 350°F CTFE becomes available; otherwise nozzle fluid temperature will be limited to 275°F for at least 10% of the cycling. The remaining time as well as the remainder of the system will be operated with a maximum oil temperature of 275°F.

6.7.5 Downtime - If it is not possible to run all three systems simultaneously throughout the 550 hours due to failures and lack of spares, or if downtime is expected to be excessive, the operative system(s) will be kept running. The Air Force Manager will be consulted in such instances.

## 6.8 AIRCRAFT BATTLE DAMAGE REPAIR (ABDR)

After completion of the 500 hour endurance test, the ability to perform aircraft battle damage repair (ABDR) will be demonstrated. This shall include the removal and replacement of components and line repairs.

6.8.1 Component Removal/Installation - A minimum of 10 components shall be removed and replaced to demonstrate and evaluate removal and replacement techniques; these components shall be replaced with spare components when available. In addition, the removal and installation will be done using only simple handtools.

6.8.2 Line/Tubing Repairs - Repairs will consist of evaluating all promising fittings and shall be performed on line sizes representing the largest and smallest used in the high pressure system, (i.e., 3/16 and 11/16). Damage to the tubing shall be done so as to require some additional tubing to make the repair.

#### 6.9 REPAIR INTEGRITY TEST (50 HOUR DURABILITY)

After the completion of the ABDR portion of the testing, an additional 50 hours of endurance testing will be performed, this will use the same duty cycles as was used in the 500 hour endurance test. Prior to starting up the system, the ground support cart will be hooked up and a system check out performed at 3000 psi to verify the integrity of the repairs.

#### 6.10 COMPONENT TEARDOWN AND INSPECTION

After completion of all endurance testing, a detailed teardown and inspection shall be performed. Components will be analyzed for wear and condition with measurements. Photographs will be taken to record their final condition.

**8000 psi IRON BIRD  
PARAMETERS LIST**

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8000 PSI IRON BIRD TEMPERATURE PARAMETERS LIST

TEMPERATURE PARAMETER

PARA  
NO

401 PC-1 PUMP OUTLET TEMPERATURE  
402 PC-1 PUMP SUCTION TEMPERATURE  
403 PC-1 PUMP CASE DRAIN TEMPERATURE  
404 PC-1 HEAT EXCHANGER INLET TEMPERATURE  
405 PC-1 HEAT EXCHANGER OUTLET TEMPERATURE  
406 PC-2 PUMP OUTLET TEMPERATURE  
407 PC-2 PUMP SUCTION TEMPERATURE  
408 PC-2 PUMP CASE DRAIN TEMPERATURE  
409 PC-2 HEAT EXCHANGER INLET TEMPERATURE  
410 PC-2 HEAT EXCHANGER OUTLET TEMPERATURE  
411 UTILITY 1 PUMP OUTLET TEMPERATURE  
412 UTILITY 1 PUMP SUCTION TEMPERATURE  
413 UTILITY 1 PUMP CASE DRAIN TEMPERATURE  
414 UTILITY 2 PUMP OUTLET TEMPERATURE  
415 UTILITY 2 PUMP SUCTION TEMPERATURE  
416 UTILITY 2 PUMP CASE DRAIN TEMPERATURE  
417 UTILITY PUMP HEAT EXCHANGER INLET TEMPERATURE  
418 UTILITY PUMP HEAT EXCHANGER OUTLET TEMPERATURE  
419 L/H STABILATOR PC-2C2 RETURN LINE TEMPERATURE  
420 L/H STABILATOR PC-1B1 RETURN LINE TEMPERATURE  
421 L/H FLAPERON PC-2A2 RETURN LINE TEMPERATURE  
422 L/H FLAPERON PC-1B1 RETURN LINE TEMPERATURE  
423 L/H CANARD PC-1C1 RETURN LINE TEMPERATURE  
424 L/H CANARD PC-2B2 RETURN LINE TEMPERATURE  
425 R/H STABILATOR PC-1C2 RETURN LINE TEMPERATURE  
426 R/H STABILATOR PC-2B1 RETURN LINE TEMPERATURE  
427 R/H AILERON PC-1A2 RETURN LINE TEMPERATURE  
428 R/H AILERON PC-2C1 RETURN LINE TEMPERATURE  
429 R/H CANARD PC-2C1 RETURN LINE TEMPERATURE  
430 R/H CANARD PC-1B2 RETURN LINE TEMPERATURE  
431 PRESSURE INTENSIFIER INLET LINE TEMPERATURE  
432 PRESSURE INTENSIFIER OUTLET LINE TEMPERATURE  
433 JET PUMP COOLING LINE TEMPERATURE  
434 DIVERGENT FLAP CYLINDER HOUSING TEMPERATURE  
435 DIVERGENT FLAP MAIN RAM TEMPERATURE  
436 CONVERGENT FLAP CYLINDER HOUSING TEMPERATURE  
437 CONVERGENT FLAP MAIN RAM TEMPERATURE  
438 REVERSE VANE CYLINDER HOUSING TEMPERATURE  
439 REVERSE VANE MAIN RAM TEMPERATURE  
440 L/H ENGINE NOZZLE INLET PRESSURE LINE TEMPERATURE  
441 L/H ENGINE NOZZLE RETURN PRESSURE LINE TEMPERATURE  
442 R/H ENGINE NOZZLE INLET PRESSURE LINE TEMPERATURE  
443 R/H ENGINE NOZZLE RETURN PRESSURE LINE TEMPERATURE  
444 ARC VALVE CYLINDER HOUSING TEMPERATURE  
445 ARC VALVE CYLINDER RAM TEMPERATURE  
446 LEADING EDGE FLAP UT-A PRESSURE LINE TEMPERATURE  
447 LEADING EDGE FLAP UT-A RETURN LINE TEMPERATURE  
448 DIFFUSER RAM INLET PRESSURE LINE TEMPERATURE  
449 DIFFUSER RAM RETURN PRESSURE LINE TEMPERATURE

## 8000 PSI IRON BIRD PRESSURE PARAMETERS LIST

PARA NO	PRESSURE PARAMETER	RANGE (PSI)	SIG COND	NEFF CHAN
1	PC-1 PUMP OUTLET PRESSURE	0 - 15K	1-1	0
2	PC-1 PUMP CASE DRAIN PRESSURE	0 - 1K	1-2	1
3	PC-1 PUMP SUCTION PRESSURE	0 - 1K	1-3	2
4	PC-1 FILTER MANIFOLD OUTLET PRESSURE	0 - 15K	1-4	3
5	PC-2 PUMP OUTLET PRESSURE	0 - 15K	1-5	4
6	PC-2 PUMP CASE DRAIN PRESSURE	0 - 1K	1-6	5
7	PC-2 PUMP SUCTION PRESSURE	0 - 1K	1-7	6
8	PC-2 FILTER MANIFOLD OUTLET PRESSURE	0 - 15K	1-8	7
9	UTILITY 1 PUMP OUTLET PRESSURE	0 - 15K	2-1	8
10	UTILITY 1 PUMP CASE DRAIN PRESSURE	0 - 1K	2-2	9
11	UTILITY 1 PUMP SUCTION PRESSURE	0 - 1K	2-3	10
12	UTILITY 1 FILTER MANIFOLD OUTLET PRESSURE	0 - 15K	2-4	11
13	UTILITY 2 PUMP OUTLET PRESSURE	0 - 15K	2-5	12
14	UTILITY 2 PUMP CASE DRAIN PRESSURE	0 - 1K	2-6	13
15	UTILITY 2 PUMP SUCTION PRESSURE	0 - 1K	2-7	14
16	UTILITY 2 FILTER MANIFOLD OUTLET PRESSURE	0 - 15K	2-8	15
17	L/H STABILATOR PC-1B1 SUPPLY PRESSURE	0 - 15K	3-1	16
18	L/H STABILATOR PC-1B1 RETURN PRESSURE	0 - 3K	3-2	17
19	L/H STABILATOR PC-2C2 SUPPLY PRESSURE	0 - 15K	3-3	18
20	L/H STABILATOR PC-2C2 RETURN PRESSURE	0 - 3K	3-4	19
21	L/H RUDDER PC-1B1 SUPPLY PRESSURE	0 - 15K	3-5	20
22	L/H RUDDER PC-1B1 RETURN PRESSURE	0 - 3K	3-6	21
23	L/H FLAPERON PC-1B1 SUPPLY PRESSURE	0 - 15K	3-7	22
24	L/H FLAPERON PC-1B1 RETURN PRESSURE	0 - 3K	3-8	23
25	L/H FLAPERON PC-2A2 SUPPLY PRESSURE	0 - 15K	4-1	24
26	L/H FLAPERON PC-2A2 RETURN PRESSURE	0 - 3K	4-2	25
27	L/H CANARD PC-1C1 SUPPLY PRESSURE	0 - 15K	4-3	26
28	L/H CANARD PC-1C1 RETURN PRESSURE	0 - 3K	4-4	27
29	L/H CANARD PC-2B2 SUPPLY PRESSURE	0 - 15K	4-5	28
30	L/H CANARD PC-2B2 RETURN PRESSURE	0 - 3K	4-6	29
31	R/H STABILATOR PC-1C2 SUPPLY PRESSURE	0 - 15K	4-7	30
32	R/H STABILATOR PC-1C2 RETURN PRESSURE	0 - 3K	4-8	31
33	R/H STABILATOR PC-2B1 SUPPLY PRESSURE	0 - 15K	5-1	32
34	R/H STABILATOR PC-2B1 RETURN PRESSURE	0 - 3K	5-2	33
35	R/H RUDDER PC-2B1 SUPPLY PRESSURE	0 - 25K	5-3	34
36	R/H RUDDER PC-2B1 RETURN PRESSURE	0 - 3K	5-4	35
37	R/H AILERON PC-2B1 SUPPLY PRESSURE	0 - 15K	5-5	36
38	R/H AILERON PC-2B1 RETURN PRESSURE	0 - 3K	5-6	37
39	R/H AILERON PC-1A2 SUPPLY PRESSURE	0 - 15K	5-7	38
40	R/H AILERON PC-1A2 RETURN PRESSURE	0 - 3K	5-8	39
41	R/H CANARD PC-2C1 SUPPLY PRESSURE	0 - 15K	6-1	40
42	R/H CANARD PC-2C1 RETURN PRESSURE	0 - 3K	6-2	41
43	R/H CANARD PC-1B2 SUPPLY PRESSURE	0 - 15K	6-3	42
44	R/H CANARD PC-1B2 RETURN PRESSURE	0 - 3K	6-4	43
45	JET PUMP COOLING PRESSURE	0 - 3K	6-5	44
46	L/H ENGINE NOZZLE SUPPLY PRESSURE	0 - 15K	6-6	45
47	L/H ENGINE NOZZLE RETURN PRESSURE	0 - 3K	6-7	46

48	R/H ENGINE NOZZLE SUPPLY PRESSURE	0 - 15K	6-8	47
49	R/H ENGINE NOZZLE RETURN PRESSURE	0 - 3K	7-1	48
50	LEADING EDGE FLAP UT-A SUPPLY PRESSURE	0 - 15K	7-2	49
51	LEADING EDGE FLAP UT-A RETURN PRESSURE	0 - 3K	7-3	50
52	DIFFUSER RAMP UT-A SUPPLY PRESSURE	0 - 15K	7-4	51
53	DIFFUSER RAMP UT-A RETURN PRESSURE	C - 3K	7-5	52

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8000 PSI IRON BIRD SYSTEM FLOW PARAMETERS LIST

PARA NO	FLOWMETER	RANGE
101	PC-1 PUMP CASE DRAIN FLOW	0 - 10 GPM
102	PC-1A SYSTEM RETURN FLOW	0 - 10 GPM
103	PC-1B SYSTEM RETURN FLOW	0 - 25 GPM
104	PC-1C SYSTEM RETURN FLOW	0 - 10 GPM
105	PC-1 HEAT EXCHANGER OUTLET FLOW	0 - 50 GPM
106	PC-2 PUMP CASE DRAIN FLOW	0 - 10 GPM
107	PC-2A SYSTEM RETURN FLOW	0 - 10 GPM
108	PC-2B SYSTEM RETURN FLOW	0 - 25 GPM
109	PC-2C SYSTEM RETURN FLOW	0 - 25 GPM
110	PC-2 HEAT EXCHANGER OUTLET FLOW	0 - 50 GPM
111	UTILITY 1 PUMP CASE DRAIN FLOW	0 - 10 GPM
112	UTILITY 2 PUMP CASE DRAIN FLOW	0 - 10 GPM
113	UTILITY SYSTEM HEAT EXCHANGER OUTLET FLOW	0 - 50 GPM
114	UTILITY A SYSTEM RETURN FLOW	0 - 25 GPM
115	UTILITY B SYSTEM RETURN FLOW	0 - 25 GPM
116	UTILITY C-3 SYSTEM RETURN FLOW	0 - 25 GPM
117	UTILITY C-4 SYSTEM RETURN FLOW	0 - 25 GPM
118	JET PUMP COOLING SYSTEM FLOW	0 - 25 GPM
119	JET PUMP SYSTEM RETURN FLOW	0 - 10 GPM



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8000 PSI IRON BIRD ACTUATOR PARAMETER

201 L/H CANARD ACTUATOR PILOT VALVE POSITION  
202 L/H CANARD ACTUATOR MAIN RAM POSITION  
203 L/H CANARD ACTUATOR TOTAL FORCE MOTOR CURRENT  
204 L/H CANARD ACTUATOR INPUT COMMAND  
205 L/H CANARD ACTUATOR HYDRAULIC SYSTEM #1 ON/OFF STATUS  
206 L/H CANARD ACTUATOR HYDRAULIC SYSTEM #2 ON/OFF STATUS  
207 L/H FLAPERON ACTUATOR PILOT VALVE POSITION  
208 L/H FLAPERON ACTUATOR MAIN RAM POSITION  
209 L/H FLAPERON ACTUATOR TOTAL FORCE MOTOR CURRENT  
210 L/H FLAPERON ACTUATOR INPUT COMMAND  
211 L/H FLAPERON ACTUATOR HYDRAULIC SYSTEM #1 ON/OFF STATUS  
212 L/H FLAPERON ACTUATOR HYDRAULIC SYSTEM #2 ON/OFF STATUS  
213 L/H STABILATOR ACTUATOR PILOT VALVE POSITION  
214 L/H STABILATOR ACTUATOR MAIN RAM POSITION  
215 L/H STABILATOR ACTUATOR TOTAL FORCE MOTOR CURRENT  
216 L/H STABILATOR ACTUATOR INPUT COMMAND  
217 L/H STABILATOR ACTUATOR HYDRAULIC SYSTEM #1 ON/OFF STATUS  
218 L/H STABILATOR ACTUATOR HYDRAULIC SYSTEM #2 ON/OFF STATUS  
219 L/H RUDDER ACTUATOR PILOT VALVE POSITION  
220 L/H RUDDER ACTUATOR MAIN RAM POSITION  
221 L/H RUDDER ACTUATOR TOTAL FORCE MOTOR CURRENT  
222 L/H RUDDER ACTUATOR HYDRAULIC SYSTEM ON/OFF STATUS  
223 L/H RUDDER ACTUATOR INPUT COMMAND  
224 PC-1A RLS PRESSURE SWITCH STATUS  
225 PC-1B RLS PRESSURE SWITCH STATUS  
226 PC-1C RLS PRESSURE SWITCH STATUS  
227 PC-1 FILTER MANIFOLD PRESSURE SWITCH STATUS  
228 PC-2A RLS PRESSURE SWITCH STATUS  
229 PC-2B RLS PRESSURE SWITCH STATUS  
230 PC-2C RLS PRESSURE SWITCH STATUS  
231 PC-2 FILTER MANIFOLD PRESSURE SWITCH STATUS  
232 R/H CANARD ACTUATOR PILOT VALVE POSITION  
233 R/H CANARD ACTUATOR MAIN RAM POSITION  
234 R/H CANARD ACTUATOR TOTAL FORCE MOTOR CURRENT  
235 R/H CANARD ACTUATOR INPUT COMMAND  
236 R/H CANARD ACTUATOR HYDRAULIC SYSTEM #1 ON/OFF STATUS  
237 R/H CANARD ACTUATOR HYDRAULIC SYSTEM #2 ON/OFF STATUS  
238 R/H AILERON ACTUATOR PILOT VALVE POSITION  
239 R/H AILERON ACTUATOR MAIN RAM POSITION  
240 R/H AILERON ACTUATOR TOTAL FORCE MOTOR CURRENT  
241 R/H AILERON ACTUATOR INPUT COMMAND  
242 R/H AILERON ACTUATOR HYDRAULIC SYSTEM #1 ON/OFF STATUS  
243 R/H AILERON ACTUATOR HYDRAULIC SYSTEM #2 ON/OFF STATUS  
244 R/H STABILATOR ACTUATOR PILOT VALVE POSITION  
245 R/H STABILATOR ACTUATOR MAIN RAM POSITION  
246 R/H STABILATOR ACTUATOR TOTAL FORCE MOTOR CURRENT  
247 R/H STABILATOR ACTUATOR INPUT COMMAND  
248 R/H STABILATOR ACTUATOR HYDRAULIC SYSTEM #1 ON/OFF STATUS  
249 R/H STABILATOR ACTUATOR HYDRAULIC SYSTEM #2 ON/OFF STATUS  
250 R/H RUDDER ACTUATOR PILOT VALVE POSITION

251 R/H RUDDER ACTUATOR MAIN RAM POSITION  
252 R/H RUDDER ACTUATOR TOTAL FORCE MOTOR CURRENT  
253 R/H RUDDER ACTUATOR INPUT COMMAND  
254 R/H RUDDER ACTUATOR HYDRAULIC SYSTEM ON/OFF STATUS  
255 UT-A RLS PRESSURE SWITCH STATUS  
256 UT-B RLS PRESSURE SWITCH STATUS  
257 UT-C RLS PRESSURE SWITCH STATUS  
258 UT-1 FILTER MANIFOLD PRESSURE SWITCH STATUS  
259 UT-2 FILTER MANIFOLD PRESSURE SWITCH STATUS  
260 L/H ENGINE NOZZLE DIVERGENT FLAP ACTUATOR PILOT VALVE POSITION  
261 L/H ENGINE NOZZLE DIVERGENT FLAP ACTUATOR MAIN RAM POSITION  
262 L/H ENGINE NOZZLE DIVERGENT FLAP ACTUATOR CURRENT  
263 L/H ENGINE NOZZLE DIVERGENT FLAP ACTUATOR INPUT COMMAND  
264 L/H ENGINE NOZZLE CONVERGENT FLAP ACTUATOR PILOT VALVE POSITION  
265 L/H ENGINE NOZZLE CONVERGENT FLAP ACTUATOR MAIN RAM POSITION  
266 L/H ENGINE NOZZLE CONVERGENT FLAP ACTUATOR CURRENT  
267 L/H ENGINE NOZZLE CONVERGENT FLAP ACTUATOR INPUT COMMAND  
268 L/H ENGINE NOZZLE REVERSER VANE ACTUATOR PILOT VALVE POSITION  
269 L/H ENGINE NOZZLE REVERSER VANE ACTUATOR MAIN RAM POSITION  
270 L/H ENGINE NOZZLE REVERSER VANE ACTUATOR CURRENT  
271 L/H ENGINE NOZZLE REVERSER VANE ACTUATOR INPUT COMMAND  
272 LEADING EDGE FLAP HYDRAULIC MOTOR DISPLACEMENT  
273 LEADING EDGE FLAP HYDRAULIC MOTOR SPEED  
274 LEADING EDGE FLAP POSITION  
275 LEADING EDGE FLAP POSITION COMMAND  
276 LEADING EDGE FLAP FAILURE COMMAND  
277 LEADING EDGE FLAP DDV POSITION  
278 DIFFUSER RA'P ACTUATOR PILOT VALVE POSITION  
279 DIFFUSER RAMP ACTUATOR MAIN RAM POSITION  
280 DIFFUSER RAMP ACTUATOR FORCE MOTOR CURRENT  
281 DIFFUSER RAMP ACTUATOR INPUT COMMAND  
282 DIFFUSER RAMP ACTUATOR HYDRAULIC SYSTEM ON/OFF STATUS  
283 R/H REVERSE VANE ACTUATOR PILOT VALVE POSITION  
284 R/H REVERSE VANE ACTUATOR MAIN RAM POSITION  
285 R/H REVERSE VANE ACTUATOR FORCE MOTOR CURRENT  
286 R/H REVERSE VANE ACTUATOR INPUT COMMAND  
287 R/H REVERSE VANE ACTUATOR HYDRAULIC SYSTEM ON/OFF STATUS  
288 R/H ARC VALVE SERVO POSITION  
289 R/H ARC VALVE MAIN RAM POSITION  
290 R/H ARC VALVE CURRENT  
291 R/H ARC VALVE INPUT COMMAND  
292 R/H ARC VALVE HYDRAULIC SYSTEM ON/OFF STATUS

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**ADP DUTY CYCLES  
SYSTEM REQUIREMENTS**

PC - 1 AVG FLOWS, CYCLES, SYSTEM PRESSURE VS. PHASE

Mission Phase	Warm Up	Taxi	STOL	Climb	Cruise	Combat	Cruise	Descent	STOL	Reverse	Taxi	Cool Down
Actuator	0	2-100%	2-80%	30-50%	500-10%	6-100%	1000-10%	90-50%	2-90%	0	0	0
Stabilator			2-70%	30-30%	2000-2%	6-90%	3500-2%	70-30%	8-80%			
				400-2%		30-80%		1000-2%	30-70%			
Ave Flow LH/RH	.100/.100	.141/.148	1.73/2.01	.833/.958	698/.803	1.96/2.27	.691/.795	.834/.959	1.69/1.96	100/.100	.100/.100	.100/.100
Canard	0	2-100%	2-80%	30-50%	700-10%	6-100%	1300-10%	90-50%	8-80%	0	0	0
			2-70%	30-30%	1400-2%	8-90%	2800-2%	70-30%	30-70%			
				600-2%		30-80%		1200-2%				
Ave Flow LH/RH	.100/.100	.141/.148	1.73/2.01	.920/1.06	756/.870	80-50%	.750/.863	.866/.997	1.50/1.74	100/.100	.100/.100	.100/.100
Aileron	0	2-100%	1-100%	2-90%	400-10%	4-100%	800-10%	4-90%	1-100%	0	0	0
			4-80%	40-70%	2100-2%	20-80%	3900-2%	100-70%	2-90%			
				60-50%		60-70%		240-50%	56-80%			
				120-30%		180-30%		300-30%				
Ave Flow RH	.100	.141	2.403	2.325	0.643	3.040	0.647	2.552	2.566	.100	.100	.100
Flapeton	0	2-100%	2-100%	2-90%	500-10%	2-100%	1000-10%	4-90%	2-100%	0	0	0
			10-80%	100-70%	1750-2%	50-80%	3250-2%	250-70%	2-90%			
				50-50%		150-70%		200-50%	140-80%			
				100-30%		150-30%		250-30%				
Ave Flow (Both)	.100	.103	.547	.312	.121	.392	.122	.322	.592	.100	.100	.100
Rudder	0	2-100%	2-80%	30-50%	500-10%	6-100%	1000-10%	90-50%	2-90%	0	0	0
			2-70%	30-30%	2000-2%	6-90%	3500-2%	70-30%	8-80%			
				400-2%		30-80%		1000-2%	30-70%			
						68-70%			100-2%			
Ave Flow LH	.100	.106	.329	.195	.162	.360	.162	.196	.311	.100	.100	.100
Total Time (Sec)	60	450	17	399	1336	612	2557	1072	180	7	450	60
Ave Pump Pressure (Psi)	3000	3133	8000	8000	3000	8000	3000	8000	8000	3000	3000	3000
Ave Total Flow (Gpm)	0.800	1.031	11.308	6.915	4.174	12.705	4.152	7.048	10.95	0.800	0.800	0.800

PC - 1 PUMP HEAT REJECTION/CASE DRAIN FLOW

Mission Phase	Warm Up	Taxi	STOL	Climb	Cruise	Combat	Cruise	Descent	STOL	Reverse	Taxi	Cool Down
Pump Heat Rejection (Btu/Min)	362.7	393.2	532.8	404.1	282.5	577.6	279.6	392.7	486.2	394.9	383.4	362.7
Pump Case Drain Flow (Gpm)	2.86	2.96	3.01	3.13	3.09	3.00	2.84	3.00	2.72	3.03	2.96	2.86
CD+Ave Fw	3.66	3.99	14.32	10.05	7.26	15.71	6.99	10.05	13.67	3.83	3.76	3.86
Engine Speed (Rpm)	2500	2890	4210	4170	3710	4340	2810	3710	3115	3115	2890	2500
Total Time (Sec)	60	450	17	399	1336	612	2557	1072	180	7	450	60
Ave Pump Pressure (Psi)	3000	3133	8000	8000	3000	8000	3000	8000	8000	3000	3000	3000
Ave Total Flow (Gpm)	0.800	1.031	11.308	6.915	4.174	12.705	4.152	7.048	10.95	0.800	0.800	0.800

UTILITY SYSTEM AVERAGE FLOW

Mission Phase	Warm Up	Taxi	STOL	Climb	Cruise	Combat	Cruise	Descent	STOL	Reverse	Taxi	Cool Down
Engine Actuators	0	2-100% 50-10%	1-100% 1-50%	2-80% 120-30% 300-2%	150-10%	3-90% 8-80% 40-70% 30-50% 1000-2%	250-10%	10-80% 48-50% 200-30% 700-2%	1-100% 1-90% 20-70%	1-50%	50-10%	0
Divergent Flap	.350	.752	2.728	3.249	.635	3.353	.598	2.972	2.666	2.275	.632	.350
Tot Flow, 2 act + valve	0	2-100% 50-10%	1-100% 1-50%	2-80% 120-30% 300-2%	150-10%	3-90% 8-80% 40-70% 30-50% 1000-2%	250-10%	10-80% 48-50% 200-30% 700-2%	1-100% 1-90% 20-70%	1-50%	50-10%	0
Convergent Flap	.350	.895	3.539	4.254	.738	4.437	.688	3.881	3.479	2.932	.734	.350
Tot Flow, 2 act + valve	0	2-100% 25-10%	1-100% 1-50% 20-2%			2-90% 6-70% 8-50% 15-30% 100-2%			1-100% 2-90% 8-80% 4-70% 5-50% 5-30% 180-2% .201	1-50% 5-30%	2-80% 25-10%	0
Reverser Vanes	.110	.118	.201	.110	.110	.133	.110	.110	.420	.420	.117	.110
Total Flow/ actuator	0	2-100% 50-10%	1-100% 1-50%	2-80% 120-30% 300-2%	150-10%	9-90% 8-80% 40-70% 30-50% 1000-2%	250-10%	10-80% 48-50% 200-30% 700-2%	1-100% 1-90% 20-70%	1-50%	50-10%	0
Arc Valve Actuator	.110	.188	.580	.680	.165	.691	.158	.625	.563	.490	.165	.110
Total Flow/ actuator	0	2-100% 50-10%	1-100% 1-50%	2-80% 120-30% 300-2%	150-10%	9-90% 8-80% 40-70% 30-50% 1000-2%	250-10%	10-80% 48-50% 200-30% 700-2%	1-100% 1-90% 20-70%	1-50%	50-10%	0
Flap Simulator (Accounts for 4 Div Flaps)	.13	.984	5.023	6.167	.744	6.578	.665	5.592	4.997	4.091	.738	.130
Total Time (Sec)	60	450	17	399	1336	612	2557	1072	180	7	450	60

UTILITY SYSTEM AVERAGE FLOW (cont.)

Mission Phase	Warm Up	Taxi	STOL	Climb	Cruise	Combat	Cruise	Descent	STOL	Reverse	Taxi	Cool Down
Utility 4W-3P Values												
First Ramp/ Bypass Door Mn Lndg Gear		2	1	5		10		12	4			
Ave Flow (Gpm)	.430	.518	1.593	.710	.430	.753	.430	.663	.869	.430	.430	.430
Arresting Hook Lndg Gear Uplock				1				1			1	
Ave Flow (Gpm)	.430	.430	.430	.432	.430	.430	.430	.431	.430	.430	.483	.430
First Ramp/ Bypass Door Main/ Nose Lndg Gear		2	1	5		10		12	4			
Ave Flow (Gpm)	.430	.518	1.593	.755	.430	.753	.430	.680	.869	.430	.430	.430
Utility Actuator w/ 4W-3P Valve		17								1	17	
Ave Flow (Gpm)	.430	.862	.430	.430	.430	.430	.430	.430	.430	2.165	.916	.430
Gun Drive Jet Fuel Start(3W-2P & 4W-3P)	(8sec burst) 2					10 (2sec burst)						
Ave Flow (Gpm)	1.33	.490	.490	.490	.490	.829	.490	.490	.490	.490	.490	.490
Total Time (Sec)	60	450	17	399	1336	612	2557	1072	180	7	450	60



UTILITY SYSTEM AVERAGE FLOW (cont.)

Mission Phase Utility	Warm Up	Taxi	STOL	Climb	Cruise	Combat	Cruise	Descent	STOL	Reverse	Taxi	Cool Down
Misc. Utility	0	2-100% 50-10%	1-100% 1-50%	2-80% 120-30% 300-2%	150-10%	3-90% 8-80% 40-70% 30-50% 1000-2%	250-10%	10-80% 48-50% 200-30% 700-2%	1-100% 1-90% 20-70%	1-50%	50-10%	0
Diffuser Ramps	.040	.253	1.249	1.538	.194	1.655	.174	1.395	1.251	1.019	.192	.040
Leading Edge Flap	0	2-100%	1-100% 2-30%	2-90% 20-70% 20-50% 40-30%	200-10% 700-2%	4-100% 10-80% 30-70% 60-30% 400-10%	400-10% 1300-2%	4-90% 50-70% 80-50% 100-30%	1-100% 2-90% 28-80%	0	0	0
Shuttle Value Leakage	.500	.515	1.009	.815	.585	.995	.586	.837	.966	.500	.500	.500
From Pump	.120	.105	.021	.046	.107	.000	.108	.053	.027	.000	.107	.120
Augmented	.208	.213	.299	.270	.200	.292	.200	.268	.300	.300	.210	.200
TOTALS	1.87	1.92	2.69	2.43	1.80	2.63	1.80	2.42	2.70	2.70	1.89	1.80
Cooling Flow "Brute Force"	2.080	2.133	2.988	2.698	2.000	2.922	2.000	2.684	3.000	3.000	2.097	2.000
Total Time (Sec)	.655	.681	1.002	.905	.616	.980	.616	.901	1.067	1.041	.663	.616
Ave Pump Pressure (Psi)	60	450	17	399	1336	612	2557	1072	180	7	450	60
Total Pump Flow 3 pgs (Gpm)	3400	3667	7941	6489	3000	7608	3000	6420	8000	8000	3483	3000
	6.41	8.82	24.10	25.11	7.43	26.75	7.20	23.25	22.46	21.05	7.96	5.53

APPENDIX C  
PRELIMINARY HAZARD ANALYSIS

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Report number MDC IR0429

SYSTEM SAFETY HAZARD ANALYSIS REPORT  
PRELIMINARY HAZARD ANALYSIS FOR  
NON FLAMMABLE HYDRAULIC POWER  
SYSTEM FOR TACTICAL AIRCRAFT  
LABORATORY TECHNOLOGY DEMONSTRATOR

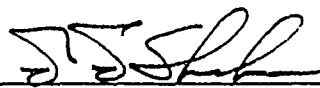
Revision date 07 June 1988

Revision letter A

Issue date 01 April 1988

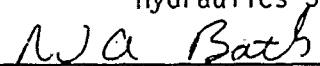
Contract number F33615-86-C-2600

Prepared by



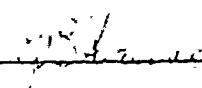
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PRELIMINARY HAZARD ANALYSISABSTRACT

This Preliminary Hazard Analysis (PHA) is the assessment of the hazardous risks associated with the Nonflammable Hydraulic Power System for Tactical Aircraft (NHPSTA) Laboratory Technology Demonstrator (LTD), submitted in accordance with the Air Force Contract F33615-86-C-2600.

ABBREVIATIONS

CTFE	Chlorotrifluoroethylene
LTD	Laboratory Technology Demonstrator
MCAIR	McDonnell Aircraft Company
NHPSTA	Nonflammable Hydraulic Power System for Tactical Aircraft
PHA	Preliminary Hazard Analysis
RLS	Reservoir Level Sensing
USAF	United States Air Force

APPLICABLE DOCUMENTS

MIL-STD-882B 30 March 1984	System Safety Program Requirements
AFSC DH 1-6 20 December 1978	System Safety
AFSC DH 1-X 07 January 1981	Checklist of General Design Criteria
MIL-H-5440G 28 November 1975	Hydraulic Systems, Aircraft, Types 1 and 2, Design and Installation Requirements for

## 1.0 INTRODUCTION

A Preliminary Hazard Analysis (PHA) was conducted for the 8000 psi hydraulic test system per MIL-STD-882B Task 202 and prepared in accordance with the Air Force Contract F33615-86-C-2600. The 8000 psi test system program was reviewed by qualified System Safety engineers to identify and assess hazards and hazardous situations associated with the LTD and the use of hydraulic fluid system pumps, plumbing, fluid, accumulators, actuators and environmental test chamber. The potential for personnel injury during operations was also considered. The PHA was limited to potential hazards associated with the personnel, test equipment, test installation, operation and facility at McDonnell Douglas. No attempt was made in the PHA to address potential hazards which could exist due to application of 8000 psi hydraulic technology outside of the laboratory. Results of the Preliminary Hazard Analysis will be used to guide subsequent Operating and Support analysis and risk assessment activities.

### 1.1 OBJECTIVE

The primary concern of this analysis is to identify any potentially hazardous problems with an 8000 psi nonflammable hydraulic power system and utilize different methods of detection so that a corrective action can be implemented.

### 1.2 SCOPE

The PHA is conducted to identify potentially hazardous elements and conditions, and determine their effects. With the hazards identified the design and/or the safety procedures can be modified to eliminate or reduce the risks. This analysis has been done on the basis of the system being used in the LTD.

### 1.3 SUMMARY

The PHA risk assessment concluded that all identified risks can be controlled within the ACCEPTABLE range of the risk assessment criteria. No Critical single point system failures were identified. No risks were identified during the PHA which would preclude continuation of the test system design and installation.

## 2.0 TEST SYSTEM DESCRIPTION

A complete description of the test system is included in the body of this report. The following system description is provided to assist with understanding the hazards which are discussed in subsequent paragraphs.

The LTD schematic, shown in Figure C-1, is based on the current F-15 STOL/Maneuvering Technology Demonstrator (S/MTD). The system will be split into two basic halves, the left hand of the aircraft uses flight hardware mounted on modular test fixtures that will simulate loads and inertias of the control surfaces, the right hand will be comprised of mostly simulators to relay the appropriate flow and pressure requirements and demands to the pumps. A third system was utilized for system redundancy, utility functions and nozzle actuation. Modular test fixtures are possible because of the total elimination of cable and pulley controls in preference of fly-by-wire technology.

Fluid is supplied to the three systems by four 40 GPM pumps, one each for the left and right systems and two combined for the utility system. Each pump has a separate filter manifold and each system has a reservoir sized for its system requirements and equipped with a three circuit Reservoir Level Sensing (RLS) system.

Nozzle actuators are another item being incorporated into the test system. Left hand nozzle actuators and right hand simulators will utilize an environmental test chamber which simulates operating temperatures of 450°F. This requires additional flow and cooling for the system. This cooling is accomplished by a flow augmentation technique which increases flow to the actuators without increasing pump demand.

The test set-up as shown in Figure C-2 will be installed at MCAIR in Building 102 in the area known as the Iron Bird/Hydraulic Lab. This facility routinely tests actuators, pumps, lines, etc. associated with aircraft hydraulic systems. The 8000 psi test system will be installed in an area of the lab where its operation will not interfere with other ongoing tests. The facility consists of an enclosed control room and control panels, hydraulic pump and reservoir supply area, an environmental chamber, and floor mounted actuator modules. Hydraulic plumbing interconnects the actuators with the hydraulic reservoir supply and pumps. The actuators are installed in floor mounted test fixtures and are to be controlled by a central simulator control computer. Cycling sequence for the actuator will be determined as required by the test program and is initiated from the control room. Variable hydraulic pressure pumps are utilized to vary the system operating pressures and flow in response to the demand of the actuators. These pumps are variable in the 3000-8000 psi range. Heat exchangers are utilized to cool the hydraulic fluid.

A hydraulic pressure intensifier will be installed in a separate test loop to evaluate a 16,000 psi rudder actuator. Separate plumbing capable of these pressures will be used for this particular test set-up.

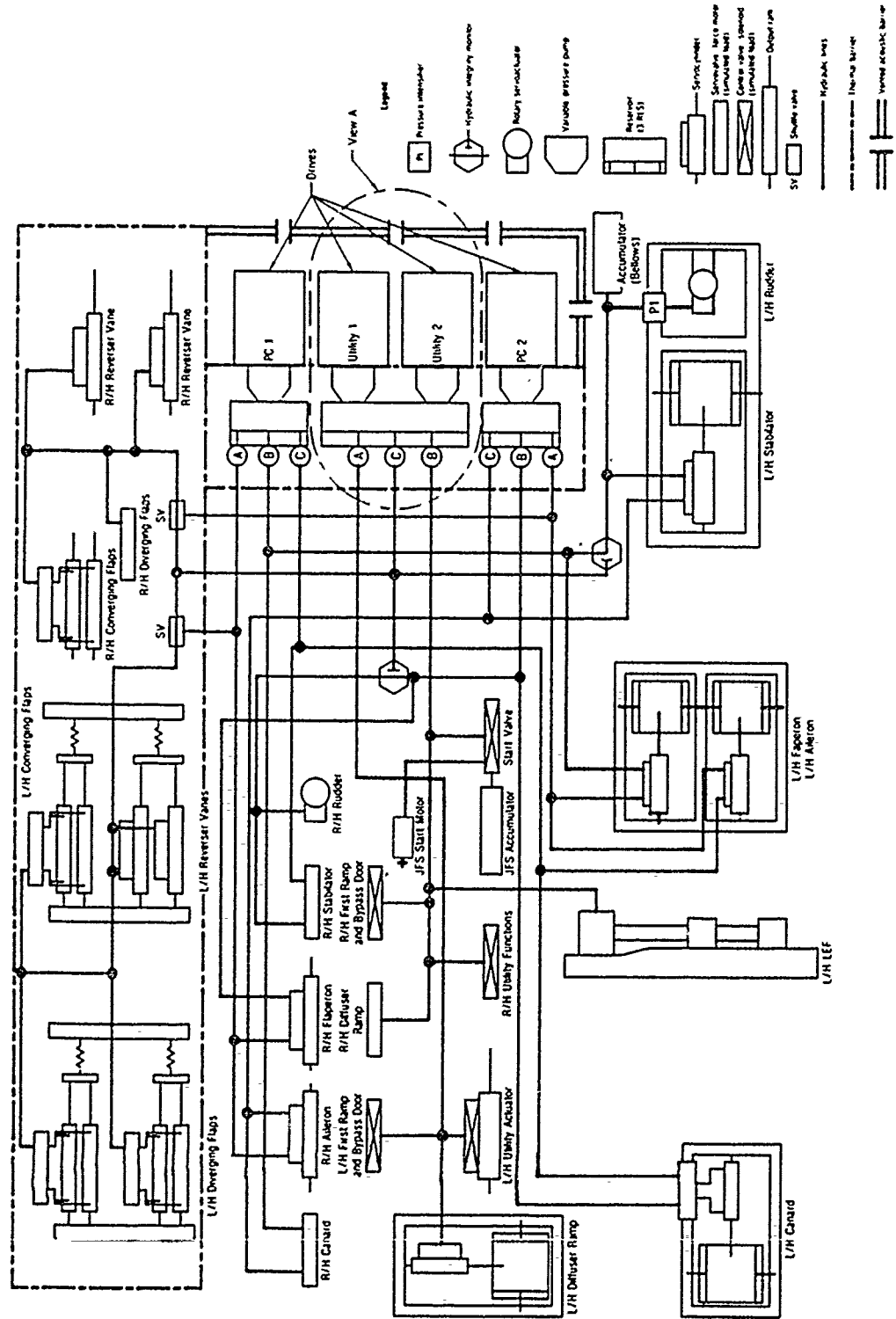


Figure C-1. Laboratory Technology Demonstrator Hardware Schematic



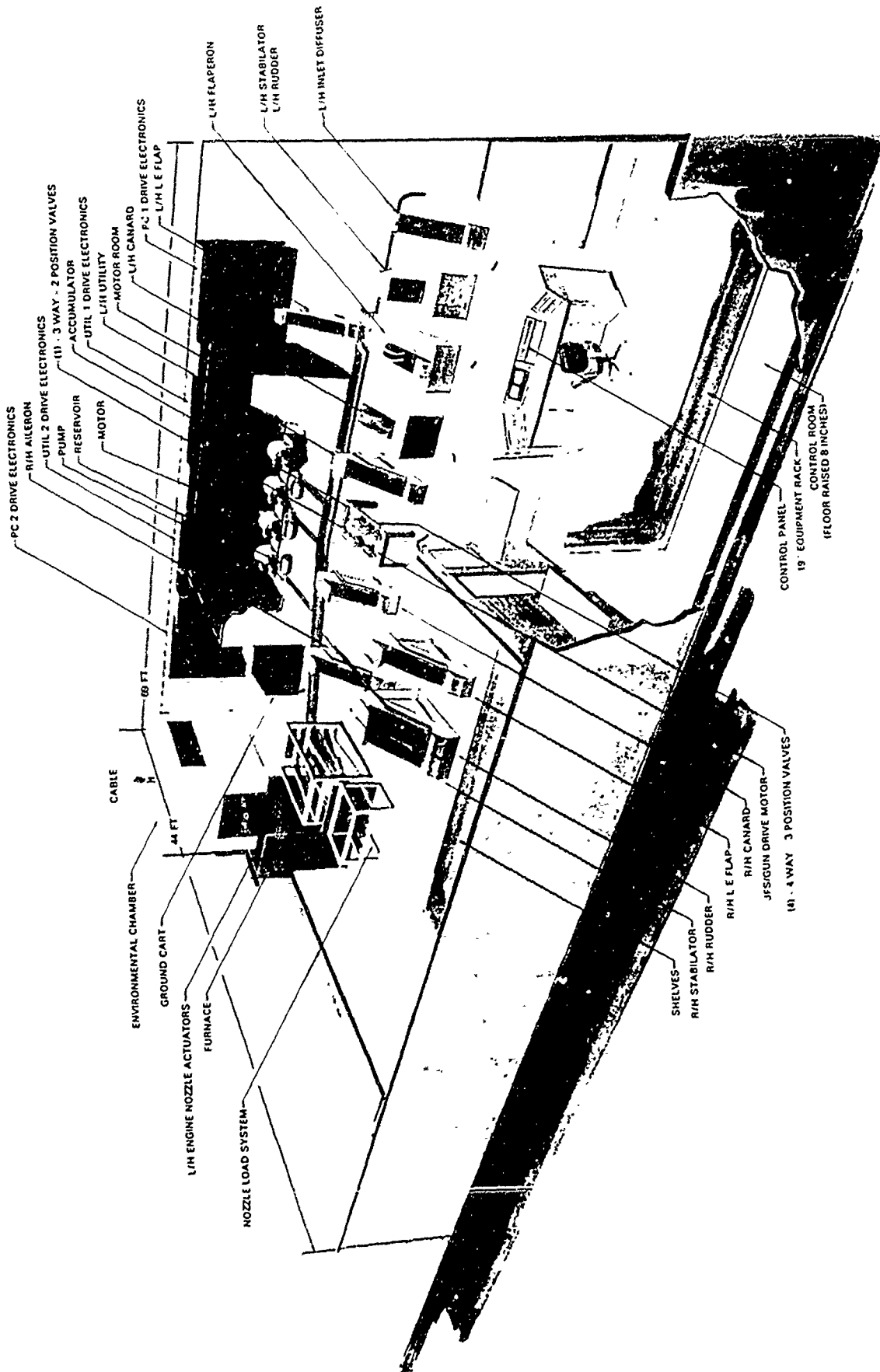


Figure C-2. Layout of LTD Facility

### 3.0 ANALYSIS PROCESS

The Preliminary Hazard Analysis (PHA) was prepared to determine if the concepts utilized will present hazardous conditions in the LTD application. The study is general in nature and establishes an initial assessment of system and subsystem effects on safety. This is achieved by comparing the system to known potential hazard sources.

The PHA was performed as a change analysis using experience on 3000 psi hydraulic test set-ups as a baseline. Safety checklists and lessons learned were utilized to identify typical hazards with hydraulic and hydromechanical systems. The 8000 psi test set-up was reviewed for applicability of these known hazards. The potential for new hazards or hazards with increased severity was evaluated from research into high pressure systems. Only hazards which were assessed to be significantly different from those of 3000 psi system or which were unique to the test set-up were addressed.

The first step in performing the hazard analysis was to define and describe potential hazardous situations unique to the concepts being used. Several factors were taken into consideration, human error, material failure and environmental factors are the main contributors. Additionally the hazardous situations were looked at to determine what effects would result relative to each failure.

### 3.1 HAZARD CLASSIFICATION

To determine specific areas with hazardous concerns a safety design checklist was utilized. Each hazard was then assigned a hazard classification based on the end effect of each condition. The criteria for classification is listed in MIL-STD-882B and outlined below:

Category I - CATASTROPHIC

- o Will cause death and/or system loss

Category II - CRITICAL

- o Will cause severe injury/illness to personnel and/or major system damage

Category III - MARGINAL

- o May cause minor injury to personnel and/or minor system damage

Category IV - NEGLIGIBLE

- o Will not cause injury even minor to personnel and/or any system damage

### 3.2 PROBABILITY FACTORS

Hazard probability is defined as the potential occurrence per unit of time, events, items, or activity during the planned life expectancy of the system. These probabilities may be derived from research, analysis and historical data. In this case the probability will be based on other aircraft/lab hydraulics and CTFE testing programs. Probability rankings are outlined in the MIL-STD-882B and as follows:

- FREQUENT (level A) Likely to occur on a frequent/regular basis during each test for individual items.
- PROBABLE (level B) Could occur several times during each test run.
- CCASIONAL (level C) Likely to occur sometime in the installation life time.
- REMOTE (level D) Could occur during installation lifetime but unlikely.
- IMPROBABLE (level E) Very unlikely to occur.

### 3.3 RISK ASSESSMENT

To properly assess the risk of any system you must quantify the real hazard index which is determined by indexing the class and probability then multiplying the two. Risk assessment was conducted by referencing the matrix outlined in Figure C-3, with this assessment a corrective action can be established that will eliminate, reduce or control the problem. The following is the Real Hazard Index with risk level and corrective actions required:

RHI	Risk	CORRECTIVE ACTION
I A,B, C, II A	UNACCEPTABLE	Mandatory/immediate correction, elimination or control.
I D, II B,C	UNDESIRABLE	Immediate attempt should be made to eliminate or control. Program management approval required for acceptance.
I E, II E,D III A,B,C,D,E IV A,B,C,D,E	ACCEPTABLE	No correction required.

HAZARD CLASS		PROBABILITY LEVEL				
		FREQUENT	REASONABLY PROBABLE	OCCASIONAL	REMOTE	EXTREMELY IMPROBABLE
RHI VALUE		A	B	C	D	E
CATASTROPHIC	I	IA	IB	IC	ID	IE
CRITICAL	II	IIA	IIB	IIC	IID	IIIE
MARGINAL	III	IIIA	IIIB	IIIC	IIID	IIIE
NEGLIGIBLE	IV	IVA	IVB	IVC	IVD	IVE

Figure C-3. Risk Assessment Matrix (MIL-STD-882B)

The hazards and their associated risk factors are shown on the accompanying Safety Assessment Report Worksheets. These contractor format worksheets utilize a fault hazard analysis approach to risk assessment. Each worksheet lists the component, function, or task under study; the fault or hazard description associated with that component; the possible hazard effects on personnel or equipment; the phase of operation when the hazard is present; the hazard severity, frequency or probability, and assessed risk index; method of hazard detection and correction; actions anticipated or recommended to control risk; and remarks to assist in understanding the risk. The effect of any recommendations is included within the risk index for the PHA. Status of recommended hazard control measures will be provided within the subsequent Operating and Support Hazard Analysis. The bottom section of each worksheet lists the hazard severity categories, probability levels, and phases of operation where the risk is present.

The following paragraphs contain a narrative discussion of each hazard identified within the worksheets.

#### 4.0 ANALYSIS

Since this is an actual fighter aircraft system all the same hazards are present that have been analyzed for the F-15. There are however several additional hazards unique to this system and the F-15 S/MTD. These differences are due to the 8000 psi supply pressure and the CTFE hydraulic fluid.

#### 4.1 CTFE FLUID

This hydraulic fluid while eliminating the possibility of some fires creates its own unique problems. High temperatures and contamination will cause a change in the fluid properties and would therefore change the spring rate of the flight control actuators and reduce aircraft control abilities; while this effect is not hazardous to this test it was considered in the design. High temperatures have another hazard effect and that is the possibility of seal degradation and leaking, this could result in burns and breathing of CTFE vapors.

#### 4.2 PUMPS/PUMPING SYSTEMS

This system utilizes a variable pressure pumping system which will operate between 3000 and 8000 psi if a failure would occur that the pump would "run away" the maximum system pressure would be controlled by the high pressure relief valve in the filter manifold and the pressure switch that would shut down the pump drive, therefore it would be improbable that a failure like this will occur.

##### 4.2.1 PRESSURE INTENSIFIER

In addition to the 8000 psi system there is a special circuit that will incorporate an intensifier that doubles the system pressure. Since this is new technology a good hazard analysis is unavailable and maximum safety guidelines should be used to protect personnel.

#### 4.2.2 NOISE LEVEL

Pumps are inherently noisy and therefore require special ear protection for personnel. With the LTD the motors and pumps are to be operated inside a acoustically insulated room and would therefore only require ear protection when in the "pump room" and not for the rest of the iron bird area.

#### 4.3 DISTRIBUTION SYSTEM

With 8000 psi a unique distribution system has to be utilized since the return system will only be rated for 3000 psi; this resulted in odd size high pressure lines and fittings to "Murphy Proof" the system.

##### 4.3.1 LINES

There are two types of lines to be considered, flexible or braided and hard lines or tubing. Tubing is not a major concern and does not have any effect on the hazard analysis, whereas braided hoses do. Hoses can swell and act as accumulators which would cause backflows into the system large enough to reverse pumps or move control surfaces. In addition the CTFE fluid can permeate thru the teflon liner and soak the hose to further reduce its rigidity.

##### 4.3.2 FITTINGS

Several types of fittings are being used for this program including Rosan adapters, Permaswage, Cryofit, Welded, etc. The detachable portion of the fittings will be lipseal exclusively. Problems with these fittings is usually related to the human factors; over torquing, misalignment and under torquing are a few that can lead to leaks and failures. In addition leaks have shown to be no more dangerous at 8000 psi as compared to 3000 psi.

##### 4.3.3 LEE PLUGS

LEE plugs have always been a concern, and at 8000 psi a hazardous situation is even more predominant. The installation is a critical process and improperly installed plugs can be ejected at high velocities and result in personal injury and/or equipment damage.

#### 4.4 ACTUATORS

Flight control actuators for 8000 psi have incorporated several performance options including, flow augmentation, load recovery valves and overlapped control valves. Some of these concepts have caused unique problems which have been further addressed.

#### 4.4.1 FLOW AUGMENTATION/LOAD RECOVERY VALVES

Jet pumps and load recovery valves are always used together in the flow augmentation concept. The jet pump is a nozzle type orifice that augments the inlet flow with return flow during high rat/low load conditions. The load recovery valves are implemented to increase actuator rates. Any hazards that result are due to the nozzle (jet pump) clogging or the valves failing either open or closed. As these problems cannot be detected by visual inspection, the only means of elimination is to maintain adequate filtration. Thus, the possibility of a failure can be drastically reduced.

A

#### 4.4.2 TEST FIXTURES

Test fixtures for this IRON BIRD are of a modular design with a self contained loading apparatus. The only possible hazard is during shut down and start up when the actuators can make a sudden movement to a null or the currently commanded position. Personnel should be clear of all fixtures during these two phases.

#### 4.5 ACCUMULATORS

Accumulators contain stored gas at a high pressure and are inherently the most hazardous items in the test setup. They are strategically placed to protect all personnel and equipment in case of any mishap even though design has made this very unlikely.

#### 4.6 NOZZLE ACTUATORS

The engine nozzle actuators are subject to a unique environment and as such have special parameters that have to be considered with respect to the hazard analysis. The temperature of these units will be as high as 450°F with the fluid temperature of 350°F, this requires the units to include a special cooling flow circuit to maintain a lower rod temperature. If the temperature of the rod, when extended, would raise beyond that which the seals can tolerate the actuator when retracted would destroy the seals and severe leakage would result. Although the system is designed to shut off any failed circuit and the fluid is nonflammable, the fluid which is lost would vaporize. The environmental chamber is also a hazardous area and an adequate cool down time is required prior to working on these actuators.

#### 5.0 RESULTS

No Catastrophic hazards were identified by this analysis.

The only Critical hazards identified were associated with potential for test personnel injury from fluid spray, fragments from failed components, or contact with moving components.

Marginal hazards were identified with test equipment damage potential from conditions such as overpressurization, overheating, structural failure, or fluid spray. Marginal hazard also existed from personnel contact with hot fluid or hot components, overexposure to noise, and vapor inhalation.

Negligible hazards are not contained within the worksheets since in all cases they caused neither injury or damage and only resulted in loss of test data or other non-hazardous events.

The Critical hazard of personnel injury during test operations was the most significant finding of the hazard analysis. Injury could occur from mechanical failure of the accumulators, hydraulic pumps, plumbing or fluid lines. Hydraulic systems utilizing 8000 psi have only a slight increase in personnel injury risks over existing systems using 3000 psi. Studies indicate that a line failure, component failure, etc. causing a fluid leak at 8000 psi are just as likely to cause injury to proximate personnel as line failures at 3000 psi. Personnel contact with a small leak at 8000 psi can cause injection of hydraulic fluid under the skin in the same manner as a leak at 3000 psi. The increase in pressure is not a very significant factor with respect to this hazard. The 8000 psi hydraulic system could cause fluid depletion at a faster rate than 3000 psi systems. Personnel in contact with such a leak could therefore receive increased volume of fluid. The personnel danger from any fluid injection under the skin is significant regardless of the relative amount or rate of fluid injection. Prompt medical treatment would be required in either case.

The probability level of Remote (D) was assigned to the Critical hazard of personnel contact with high pressure fluid based upon experience working with high pressure hydraulics. Personnel assigned to the Hydraulics Lab are very aware of the hazard from contact with high pressure leaks and do not handle lines, fittings, or plumbing during pressurized operation. Leak source identification is not conducted by personnel handling lines or using rags to wipe away suspected leakage.

The Hydraulic Laboratory facility is constructed to limit access to the test area, thereby restricting unfamiliar personnel from casual contact with pressurized assemblies. A risk index of IID was assigned to the Critical category hazards of personnel injury from fluid or fragment impact. Additional safety measures such as shielding, or fully enclosing the test actuator and all plumbing would serve to further reduce risk. Laboratory safety policies require personnel to wear approved safety glasses and appropriate work attire in the area. For the majority of test operations, personnel will be located in the enclosed control room which offers significant protection from component failures as well as from operation noise levels.

Critical personnel injury from fragments of failed components or ejected components such as Lee plugs is not likely. Many of the components utilized within the test set-up are either qualified for use at 8000 psi or have satisfactorily demonstrated this capability during previous tests. Anti-ballistic design techniques such as rip-stop construction of actuators minimizes the potential for injury

| A



as well as system damage in the event of failure. The actuator installation within the air-loading simulation device housing would also help stop any fragments or fluid spray from reaching personnel. Failure of lines, components, or actuators due to inadvertent overpressure from the hydraulic pump supply is unlikely since the pump control pressure compensator has a back-up high pressure relief valve.

Testing with the 16,000 psi actuator and pressure intensifier will require shielding or procedures restricting personnel access since neither the actuator or plumbing has been qualified to operate at 16000 psi or burst pressure tested to 4 times the maximum operating pressure.

The other identified Critical hazard identified with personnel working in the test lab is the potential for injury due to physical contact with moving components such as the air-load simulation device and actuator. Forces generated by this assembly could crush, pinch, or sever personnel hands or limbs if movement occurred during maintenance or adjustment. Assigned personnel are familiar with this potential since it exists on similar installations within the F-15 and F-18 Iron Bird test fixtures. The probability of this hazard was assessed as remote (D) based on the accident free record of the laboratory to date. The risk index is therefore a IID. Nevertheless, personnel will be instructed to remain clear during pressurized operations and ensure the actuator/simulator is locked or at a stable, rest position before performing maintenance such as actuator removal. | A

Marginal category hazards of personnel injury were identified with the potential for burns due to contact with hot components, fluid, or surfaces in the lab and the noise levels in the lab when the pumps are running. Fluid and component temperatures are likely to exceed 180°F which can result in scalding or first and second degree burns. Personnel clothing requirements and safety glasses would prevent major injury. Recommendations include instructing lab personnel to avoid contacting any line or component during or immediately following operation.

One test objective will involve environmentally testing an actuator at temperatures of up to 450°F in a heated chamber. Contact with components at these temperatures could cause third degree burns and personnel will be restricted from entering the chamber and handling components until cool. A fluid leak in the chamber will not cause ignition due to the properties of the hydraulic fluid, but could generate fluid vapor or smoke which is irritating and unpleasant to breathe.

The operation of the lab test set-up can cause a noise hazard due to the noise generated by the pumps and actuators under test. Personnel assigned to the lab are aware of the noise hazard and have appropriate hearing protection available. Headsets/intercommunications devices are used in the lab when communication is essential with personnel outside the control room. The control room insulation will provide adequate noise protection to allow communications and operations. Personnel could be momentarily exposed to loud noise when entering and leaving the lab areas during a test sequence.

The probability of the Marginal category personnel hazards was assessed to be Occasional (C) based upon experience with the Iron Bird installations.

The remainder of the identified Marginal category hazards were associated with the potentials for minor test system damage due to leakage, rupture, overpressure, overheating, or fluid contamination.

Minor system damage and fluid loss would result from any line or component failures such as cracking or rupture. The probability of leak or rupture was assessed to be Remote (D) for the 8000 psi test equipment based on previous vendor qualification testing and experience. The probability was assessed as Occasional (C) for the 16000 psi test equipment since these components are not qualified and little experience base exists with aircraft actuators at these pressures.

Overpressurization of the test equipment was assessed to be a Marginal, Remote risk based upon the operation of the pump pressure compensator. A high pressure relief valve (safety valve) exists to prevent excessive operating pressures in the event of a compensator failure. Pressure monitoring will also be available via instrumentation in the control room where the pumps can be shutdown if a failure is recognized.

Overtemperature was also assessed to be a Marginal category hazard due to the adverse effect on system response and possible changes in fluid properties resulting in contamination damage. Temperature is automatically controlled by a thermostat and heat exchanger. Failure probability resulting in overtemperature was assessed to be Remote (D) since the temperature will also be monitored in the control room during the testing and shutdown is possible in the event it exceeds limits.

Contamination of the test fluid with other fluids or solids was considered a Marginal hazard due to possible degraded actuator performance or damage/ reduced operating life. This potential was considered Remote (D) since the test fixture is isolated from other lab activities and fluid will be periodically assessed for degradation.

The hazard analysis is summarized in Attachment 1 utilizing a matrix format to document the analysis on a USAF approved MAC form 3413D.

## 6.0 CONCLUSIONS AND EVALUATIONS

Analyses were performed to assess the methods of identifying hazards or hazardous situations and corrective actions were established to eliminate, reduce or control the identified hazard. In some cases there is no means to eliminate the hazard and a recommended action was established to minimize the risk to both personnel and hardware. The results and recommendations of the PHA are shown on the Safety Assessment Report Worksheets (Attachment 1), in accordance with these findings all the identified hazards of this PHA are of an acceptable risk.

The Preliminary Hazard Analysis identified both system and operating hazards likely to be encountered during laboratory testing of the 8000 and 16000 psi hydraulic components. All identified hazards can be adequately controlled by the installation design or through adherence to laboratory operating procedures. Specific laboratory and test operating procedures were unavailable for review during the Preliminary Hazard Analysis and will be the subject of separate review during the Operating/Support Hazard Analysis task.

**SAFETY ASSESSMENT  
REPORT WORKSHEETS**

SAFETY ASSESSMENT REPORT WORKSHEET  
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PROGRAM AIRPORT COMPONENT/FUNCTION/TASK	SYSTEM 8000 PSI TEST SYSTEM HAZARD EFFECTS	PH/HAZ PRB PRI OF CLS LVL	REFERENCE		PREPARED BY M. P. RUEBNER	DATE 25 MAR 1988
			(A) METHOD OF DETECTION (B) CORRECTIVE ACTION	RECOMMENDED ACTION		
HYDRAULIC FLUID	ERRATIC SYSTEM OPERATION OR CONTAMINATION CAUSED BY CHANGES IN FLUID PROPERTIES.	T III D 3D	(A) TEMPERATURE INSTRUMENTATION. (B) THERMOSTAT OPENS AND FLOWS MORE FLUID TO HEAT EXCHANGER. STOP TESTING IF TEMP GOES OUT OF LIMITS.	1. TEST OPERATION PROCEDURE SHOULD DEFINE MAXIMUM ALLOWABLE OPERATING TEMPERATURE.		
	CHANGES IN SYSTEM PERFORMANCE, FLUID PROPERTIES, OR MINOR DAMAGE	A III C 3C	(A) PERFORMANCE INSTRUMENTATION OR PERIODIC ANALYSIS OF FLUID. (B) PURGE AND REFILL SYSTEM.	1. ENSURE SERVICING PROCEDURES SPECIFY TYPE OF FLUID REQUIRED.		
ENVIRONMENTAL TEST CHAMBER	PERSONNEL BURNS FROM CONTACT WITH HOT CHAMBER, FLUID, OR COMPONENTS. VAPOR OR SMOKE GENERATION AND INHALATION.	A III C 3C	(A) TEMPERATURE INSTRUMENTATION (B) STOP TEST IF SMOKE OR LEAK OBSERVED	1. RESTRICT ACCESS UNTIL TEMPERATURE IS SAFE.		ENVIRONMENTAL TEST CHAMBER WILL BE USED TO HEAT TEST ACTUATOR TO 450 DEGREES F. FLUID OPERATING TEMPERATURES ARE HIGH ENOUGH TO SCALD UNPROTECTED FLESH. FLUID WILL NOT IGNITE IF SPILLED IN CHAMBER BUT VAPOR AND SMOKE GENERATION IS LIKELY. FLUID SMOKE/VAPOR IS UNPLEASANT TO BREATHE. FLUID MATERIAL SAFETY DATA SHEET INDICATES THAT SHORT TERM EXPOSURE TO FLUID VAPOR IS NOT HAZARDOUS.
PHASE OF OPERATION T-TEST N-MAINTENANCE A-ALL						HAZARD PROBABILITY LEVELS A-FREQUENT C-OCCASIONAL E-IMPROBABLE B-PROBABLE D-REGRETE

MCDONNELL AIRCRAFT COMPANY

SAFETY ASSESSMENT REPORT WORKSHEET

PROGRAM RHPSTA	SYSTEM 8000 PSI TEST SYSTEM	FAULT/HAZARD DESCRIPTION	HAZ/PRB/HSI CLS LVL	PREPARED BY M. P. RUEBNER	DATE 25 MAR 1988	REMARKS
ACCUMULATORS	RUPTURE	EQUIPMENT DAMAGE FROM FRAGMENTS.  PERSONNEL INJURY FROM FLUID SPRAY OR FRAGMENTS.	T III D 3D  T II D 2D	(A) OBSERVATION (B) STOP TEST  (A) OBSERVATION (B) SHUTDOWN TEST	1. VERIFY BURST PRESSURE TESTING OR QUALIFICATION.  1. MINIMIZE PERSONNEL ACCESS OR PROXIMITY TO PRESSURIZED SYSTEM.  2. CONSIDER USING SHIELDS WHEN CLOSE OBSERVATION REQUIRED.	ANTIBALLISTIC DESIGN TECHNIQUES ARE USED IN HYDRAULIC COMPONENTS TO MINIMIZE BOTH THE POTENTIAL FOR INJURY OR DAMAGE IN THE EVENT OF FAILURE. ACTUATOR MOUNTING WITHIN THE AIRLOAD SIMULATOR HOUSING WILL HELP CONTAIN FAILURES.
PUMPS	PUMP COMPENSATOR ASSEMBLY FALLS TO REGULATE PRESSURE CAUSING OVERPRESSURE CONDITION.	PUMP DAMAGE, OR SYSTEM DAMAGE FROM OVERPRESSURE  PERSONNEL INJURY FROM FLUID SPRAY OR FRAGMENTS.	T III D 3D  T II D 2D	(A) MONITOR SYSTEM PRESSURE GAGES OR INSTRUMENTATION, (B) STOP TEST  (A) SAME AS ABOVE (B) SAME AS ABOVE	OVERPRESSURE CONDITION COULD DAMAGE COMPONENTS OR SYSTEM PLUMBING. PROTECTION AGAINST A PUMP COMPENSATOR FAILURE IS PROVIDED BY A HIGH PRESSURE RELIEF VALVE.	
T-TEST M-MAINTENANCE	PHASE OF OPERATION A-ALL		HAZARD SEVERITY CATEGORIES 1-MARGINAL 2-CRITICAL	HAZARD PROBABILITY LEVELS A-FREQUENT B-PROBABLE C-OCCASIONAL D-REMOTE		

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SAFETY ASSESSMENT REPORT WORKSHEET

PROGRAM AREA	SYSTEM	SYSTEM TEST SYSTEM HAZARD EFFECTS	REFERENCE		PREPARED BY	DATE	REMARKS
			PH/HAZ OP	CLS LVL			
COMPONENT/FUNCTION/TASK	FAULT/HAZARD DESCRIPTION	80000 psi TEST SYSTEM HAZARD EFFECTS	(A) METHOD OF DETECTION (B) CORRECTIVE ACTION	(A) PRESSURE MONITORING OR OBSERVATION OF LEAK (B) STOP TEST	M. P. HUEBNER	25 MAR 1988	
PLUMBING, FITTINGS, AND FLUID DISTRIBUTION COMPONENTS	FLUID LEAK FROM TUBING, HOSE, OR FITTINGS. HOSE OR LEE PLUG FAILURE CAUSES UNSECURED DEBRIS.	EQUIPMENT DAMAGE FROM UNSECURED HOSE, OR EJECTED LEE PLUG.	T III D 3D	(A) PRESSURE MONITORING OR OBSERVATION OF LEAK (B) STOP TEST	M. P. HUEBNER	25 MAR 1988	STUDIES INDICATE THAT EFFECT OF LEAK WILL NOT BE MORE SEVERE THAN 3000 PSI SYSTEM. EJECTED LEE PLUGS OR WHIPPING LINES OR HOSE COULD INJURE NEARBY PERSONNEL. PUMP RESEVOIR MAY DEplete MORE RAPIDLY THAN 3000 PSI SYSTEM FOR THE SAME SIZE LEAK.
	PERSONNEL INJURY FROM IMPACT OF FLUID SPRAY OR FAILED COMPONENTS.		T II D 2D	(A) SAME AS ABOVE (B) SAME AS ABOVE			RESTRICTING UNNECESSARY PERSONNEL ACCESS TO THE TEST EQUIPMENT OR TECHNIQUES SUCH AS ORIENTING LEE PLUGS TOWARD THE FLOOR OR INSTALLING SIMPLE PLASTIC SHIELDS WILL MINIMIZE THE HAZARD FROM COMPONENT FAILURE. COMPONENTS WILL BE SELECTED WHICH HAVE PROVEN CAPABILITY TO OPERATE IN HIGH PRESSURE HYDRAULIC APPLICATIONS. LEE PERSONNEL ARE AWARE THAT DIRECT CONTACT WITH A SMALL LEAK COULD CAUSE FLUID INJECTION UNDER SKIN. COMPONENTS AND PLUMBING WILL NOT BE HANDLED OR WIPED WITH A RAG DURING OPERATION. STANDARD LABORATORY SAFETY POLICIES REQUIRE THE WEARING OF APPROVED EYE PROTECTION AND APPROPRIATE WORK ATTIRE WHICH WOULD MINIMIZE THE POTENTIAL FOR SERIOUS INJURY.
							1. VERIFY BURST PRESSURE TEST OR QUALIFICATION OF COMPONENTS.  2. RESTRICT PERSONNEL ACCESS TO OPERATING SYSTEM.  3. CONSIDER USING SHIELDING AROUND TEST EQUIPMENT.  4. ENSURE USE OF PROTECTIVE EYEWEAR AND CLOTHING FOR CLOSE OBSERVATION OF OPERATING SYSTEM.
T-TEST MAINTENANCE A-ALL	PHASE OF OPERATION		HAZARD SEVERITY CATEGORIES 1-CATASTROPHIC 2-CRITICAL	HAZARD PROBABILITY LEVELS A-FREQUENT B-PROBABLE C-OCCASIONAL D-REMOTE E-IMPROBABLE			

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SAFETY ASSESSMENT REPORT WORKSHEET

PROGRAM		SYSTEM		REFERENCE		PREPARED BY		DATE
MPSIA		8000 PSI TEST SYSTEM		HAZ/PRB/HR/OP		M. P. HUEBNER W. A. BATH		25 MAR 1988
COMPONENT/FUNCTION/TASK		FAULT/HAZARD DESCRIPTION		(A) METHOD OF DETECTION (B) CORRECTIVE ACTION		RECOMMENDED ACTION		REMARKS
ACTUATORS AND TEST SURFACES	UNEXPECTED ACTUATOR POSITION CHANGES DURING START-UP OPERATION, SHUTDOWN OR MAINTENANCE.	A	II	D	2D	(A) OBSERVATION (B) NONE	1. RESTRICT PERSONNEL ACCESS TO PRESSURIZED TEST SYSTEM.  2. USE CONTROL SYSTEM BRAKES OR LOCK TO PREVENT DROOP OR UNWANTED MOVEMENT IN SYSTEM DURING MAINTENANCE.	
16000 PSI PRESSURE INTENSIFIER, ACTUATOR, AND FLOWBING.	RUPTURE AND LEAKAGE	T	III	C	3C	(A) PRESSURE MONITORING OR OBSERVATION OF LEAK (B) STOP TEST	1. NONE	16000 PSI COMPONENTS AND LINES HAVE NOT BEEN BURST PRESSURE TESTED AT 4 TIMES OPERATING PRESSURE. ANALYSIS INDICATES THAT OPERATION AT 16000 PSI MAY BE ACCEPTABLE. PERSONNEL ACCESS TO THESE COMPONENTS WHILE PRESSURIZED WILL BE PROHIBITED PENDING BURST PRESSURE VERIFICATION.
ENTIRE TEST SYSTEM	HIGH NOISE LEVEL	T	II	E	2E	(A) SAME AS ABOVE (B) SAME AS ABOVE	1. PROHIBIT PERSONNEL ACCESS TO PRESSURIZED SYSTEM.	THE NOISE HAZARD IS NOT BELIEVED TO BE SIGNIFICANTLY GREATER THAN EXISTING 3000 PSI TEST INSTALLATIONS. INDUSTRIAL HEALTH AND SAFETY WILL BE REQUESTED TO SURVEY THE LAB AND RECOMMEND ADDITIONAL PROTECTION IF APPROPRIATE.
T-TEST M-MAINTENANCE	PHASE OF OPERATION A-ALL	HAZARD SEVERITY CATEGORIES 1-CATASTROPHIC 2-CRITICAL		HAZARD PROBABILITY LEVELS A-FREQUENT B-PROBABLE C-OCCASIONAL D-REMOTE		HAZARD PROBABILITY LEVELS A-FREQUENT B-PROBABLE C-OCCASIONAL D-REMOTE		



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APPENDIX D  
OPERATION AND SUPPORT HAZARD ANALYSIS

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Report number MDC IR0433

OPERATION AND SUPPORT HAZARDS ANALYSIS FOR  
NONFLAMMABLE HYDRAULIC POWER  
SYSTEM FOR TACTICAL AIRCRAFT  
LABORATORY TECHNOLOGY DEMONSTRATOR

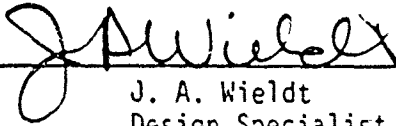
Revision date 22 August 1988

Revision letter A

Issue date 20 May 1988

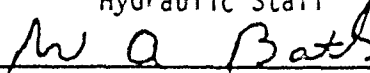
Contract number F33615-86-C-2600

Prepared by



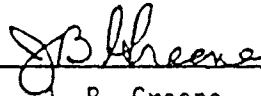
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OPERATION AND SUPPORT HAZARDS ANALYSIS

ABSTRACT

This Operation and Support Hazard Analysis (O&SHA) is the assessment of the hazardous risk control by facility enhancements and personnel associated with the Nonflammable Hydraulic Power System for Tactical Aircraft (NHPSTA) Laboratory Technology Demonstrator (LTD), submitted in accordance with the Air Force Contract F33615-86-C-2600.

ABBREVIATIONS

CTFE	Chlorotrifluoroethylene
LTD	Laboratory Technology Demonstrator
MCAIR	McDonnell Aircraft Company
NHPSTA	Nonflammable Hydraulic Power System for Tactical Aircraft
O&SHA	Operation and Support Hazard Analysis
PHA	Preliminary Hazard Analysis
RLS	Reservoir Level Sensing
USAF	United States Air Force

APPLICABLE DOCUMENTS

MIL-STD-882B 30 March 1984	System Safety Program Requirements
AFSC DH 1-6 20 December 1978	System Safety
AFSC DH 1-X 07 January 1981	Checklist of General Design Criteria
MIL-H-5440G 28 November 1975	Hydraulic Systems, Aircraft, Types 1 and 2, Design and Installation Requirements for
MDC Rpt A9803 Volume IV	Hydraulics and Flight Controls Laboratory Procedures and Guidelines

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1.0 Introduction.

An Operation and Support Hazard Analysis (O&SHA) was conducted for the 8000 psi hydraulic test system per MIL-STD-982B Task 205 and prepared in accordance with the Air Force Contract F33615-86-C-2600. The 8000 psi test system program was reviewed by qualified system safety engineers to identify and assess hazards control by personnel associated with the LTD and the use of hydraulic fluid system pumps, plumbing, fluid, accumulators, actuators and environmental test chamber. The emphasis was placed on systems and procedures in effect to prevent personnel injury during operations. A Preliminary Hazards Analysis performed earlier was limited to potential hazards associated with the personnel, test equipment, test installation, operation and facility at McDonnell Douglas. Results of the Preliminary Hazard Analysis were used to guide this Operating and Support Hazard Analysis.

1.1 Objective

The primary concern of this analysis is to identify personnel controls and procedures to eliminate or reduce to an acceptable risk level any potentially hazardous problems with an 8000 psi nonflammable hydraulic power system.

1.2 Scope.

The O&SHA is conducted to identify procedures, regulations and system operating conditions and facility enhancements to negate potentially hazardous elements and conditions. With the hazards identified, the design and/or the safety procedures can be modified to eliminate or reduce the risks. This analysis is based on the system being used in the LTD.

1.3 Summary.

This O&SHA concluded that all risks identified in the PHA can be adequately controlled with the operating procedures, regulations and facilities which are currently in place. No critical single point system failures were identified in the PHA. Furthermore no risks were identified during the PHA which are not adequately addressed for personnel interaction and procedures.

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## 2.0 Test System Description.

The following system description is provided to assist with understanding the hazards which are discussed in subsequent paragraphs.

The LTD schematic, shown in Figure C-1 is based on the current F-15 STOL/Maneuvering Technology Demonstrator (S/MTD). The system will be split into two basic halves, the left hand of the aircraft uses flight hardware mounted on modular test fixtures that will simulate loads and inertias of the control surfaces, the right hand will be comprised of mostly simulators to relay the appropriate flow and pressure requirements and demands to the pumps. A third system was utilized for system redundancy, utility functions and nozzle actuation. Modular test fixtures are possible because of the total elimination of cable and pulley controls in preference of fly-by-wire technology.

Fluid is supplied to the three systems by four 40 GPM pumps, one each for the left and right systems and two combined for the utility system. Each pump has a separate filter manifold and each system has a reservoir sized for its system requirements and equipped with a three circuit Reservoir Level Sensing (RLS) system.

Engine nozzle actuators are another item being incorporated into the test system. Left hand nozzle actuators and right hand simulators will utilize an environmental test chamber which simulates operating temperatures of 450°F. This requires additional flow and cooling for the system. This cooling is accomplished by a flow augmentation technique which increases flow to the actuators without increasing pump demand.

The test set-up as shown in Figure C-2 will be installed at MCAIR in Building 101 in an area known as the Flight Controls Laboratory. This facility routinely tests actuators, pumps, lines, etc. associated with aircraft hydraulic systems. The 8000 psi test system will be installed in an area of the lab where its operation will not interfere with other ongoing tests. The facility consists of an enclosed control room and control panels, hydraulic pump and reservoir supply area, an environmental chamber, and floor mounted actuator modules. Hydraulic plumbing interconnects the actuators with the hydraulic reservoir supply and pumps. The actuators are installed in floor mounted test fixtures and are to be controlled by a central simulator control computer. Cycling sequence for the actuator will be determined as required by the test program and is initiated from the control room. Variable hydraulic pressure pumps are utilized to vary the system operating pressures and flow in response to the demand of the actuators. These pumps are variable in the 3000-8000 psi range. Heat exchangers are utilized to cool the hydraulic fluid.

A hydraulic pressure intensifier will be installed in a separate test loop to evaluate a 16,000 psi rudder actuator. Separate plumbing capable of these pressures will be used for this particular test set-up.

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### 3.0 Analysis Process.

This Operation and Support Hazards Analysis (OSH&A) has been developed to insure that the Laboratory Technology Demonstrator operating procedures will insure a safe environment for the operating personnel. A Preliminary Hazards Analysis (PHA) has been performed and is documented in MCAIR Report MDC IR0429 which was submitted as CDRL Item No. 0001 Sequence No. 0014.

### 3.1 Hazards Evaluation Considerations.

MIL-STD-882B Task 205 identifies several criteria to be considered when evaluating personnel hazards. These criteria are reviewed in turn for applicability in this task.

#### 3.1.1 Planned System Configuration.

The system configuration is described in Section 2.0. This configuration is typical of tactical aircraft hydraulic systems which have been previously duplicated in the Flight Controls Laboratory. The equipment to be tested is intended to be functionally equivalent to the production F-15 and the F-15 S/MTD Iron Bird which is co-located in the same facility. The fundamental difference is the operating pressure and the fluid being used.

The state of the configuration may vary at each phase of the test activity for the following reasons. Equipment deliveries will have a profound influence on how much of the system can be initially operated in the early test periods. As such there may be a need to work around certain portions of the systems which haven't been completed in order to perform functional tests on the equipment which is ready. This is mandatory in order to preserve the program schedule. The work around provisions taken must be of such integrity as to negate any additional hazard to personnel performing the work around. Capped lines and unused systems must be carefully reviewed to insure that they will not introduce additional hazard.

#### 3.1.2 Facility Interfaces.

Physical facility interfaces such as electrical power interface, and water supplies for cooling are under the jurisdiction of the McDonnell Douglas Facilities Division and are constructed within strict guidelines in order to be state-of-the-art in personnel safety and to be in compliance with the regulations of the State of Missouri.

Functional facility interfaces include limited exposure of dedicated test personnel to the following laboratories which operate with the McDonnell facility. Program personnel will on occasion throughout the program have the opportunity to interface with personnel in these labs or manufacturing areas.

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3.1 Hazards Evaluation Considerations. (Cont.)

3.1.2 Facility Interfaces. (Cont.)

(a) Analytical Chemistry Laboratory.

This laboratory has the responsibility for analysis of hydraulic fluid samples taken during the program. Program personnel do not perform any tasks in this laboratory other than delivery of samples and coordination of test results. This lab is under the strict guidance of its own operating codes. They may also be called upon for analysis of corrosion products in the test equipment or identification of foreign material.

(b) Failure Analysis Laboratory.

This laboratory has state of the art equipment for performing failure analysis of typical aircraft equipment and structure. This lab can perform both nondestructive and destructive failure analysis depending on the nature of the investigation and whether or not the specimens are considered repairable. Typically, material permitting, the usage of this facility will likely be limited to passive x-ray techniques to view internal parts of failed equipment prior to disassembly by the supplier or lab personnel. Again, this lab has a strict operating code to limit hazards (from x-ray) to an acceptable level.

(c) Metallurgical Laboratory.

This facility is capable of making very accurate determination of the properties of metallic materials. It is unlikely to be used unless assistance is required by the program suppliers.

(d) Environmental Simulation Laboratory.

Personnel from this laboratory will assist in the development of the environmental oven which will house the high temperature nozzle actuators. Since those personnel are thoroughly familiar with material thermal limitation, thermal conditioning controls and measurements their participation will greatly enhance the safety of the high pressure hydraulics facilities. Their laboratory will not be used directly.

(e) Instrumentation Laboratory.

The Instrumentation Laboratory is responsible for the calibration status of all instrumentation used at McDonnell Douglas. Every piece of instrumentation bears a calibration certification and is routinely returned for recalibration. Program personnel may on occasion visit this facility to exchange instrumentation and other equipment.

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3.1 Hazards Evaluation Considerations. (Cont.)

3.1.2 Facility Interfaces. (Cont.)

(f) Manufacturing Facilities.

Personnel are routinely required to visit manufacturing areas. Very strict guidelines are employed in these areas to limit personal risk and insure the quality of company products. Eye safety glasses are required in most areas as they are in the Flight Controls Laboratory. These areas receive the close scrutiny of several groups who are responsible for various aspects of plant personnel safety.

3.1.3 Planned Environments.

There are essential three environments which will exist in various time period and all of these are thermal with one exception. A thermal oven will be used for testing several high temperature actuators in the program. This will not be occupied by personnel. It is strictly a thermal enclosure for the equipment. It also has outside ventilation. Generally, most other high temperature work will occur with the surface of the hydraulic equipments at certain locations in the system rising to no higher than 275 degrees F. Most of the testing will be conducted at laboratory ambient. Time and resources permitting, there will be low temperature performance testing on certain items later in the program. The technique which will be used to effect the chilldown to -40 deg F will be to introduce liquid nitrogen boiloff vapor into an insulated facility (Igloo). As such the area will be nitrogen rich and personnel will be required to avoid exposure. Personnel assigned to the program are experienced in handling liquid nitrogen which is a common material at this facility.

3.1.4 Supporting Tools and Equipment.

There are no special tools and equipment which are developed special for the facility other the the "hydraulic ground cart." All tools and equipment are standards which could be used in any of the iron bird efforts regardless of pressure level or configuration. The ground cart is used for initial filling and servicing of the demonstrator and for leak check and initial instrumentation and performance checkout. Operation of the ground cart, which is a MDC capital asset, is conducted from a control panel and instructions mounted on the unit.

3.1.5 Operational / Task Sequences.

The bulk of the test effort is the 550 hour endurance test. During this effort, the test sequence is programmed on a computer and the test operators monitor and collect data, monitor the test and watch for failure of equipment or degrading conditions. The task sequences which represent the greatest hazards potential are the initial performance tests which require multiple variations of test set-ups in order to make all of the performance determinations. During these tests, hazards introduced by personnel operations are of the greatest concern and therefor require the greatest preparation measures.

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3.1 Hazards Evaluation Considerations. (Cont.)

3.1.6 Concurrent Task Effects and Limitations.

In many environments, simultaneous performance of concurrent task introduce unacceptable hazard levels. The flight controls laboratory will be performing concurrent tasks in that the other iron birds may be operated at the same time. There is no additional risk introduced by this except for additional noise from the hydraulic pumps or the occasion for personnel from one effort walking through another operating area unknown to those test operators. Both of these concerns will be addressed. Limitations may be introduced to prevent danger level hydraulic pump noise or to prevent personnel walk through.

3.1.7 Biotechnological Factors.

The biotechnological factors to be considered are the effects of hydraulic fluid vapors. Both types of fluids, MIL-H-83282 and CTFE will be present and small leaks will produce vapors. Since the demonstrator is located in an open hanger environment, concentration of vapor which could support a health hazard is unlikely. However, since CTFE fluid is relatively new and the effects of long term exposure have not been established, operating personnel will be cautioned to avoid exposure to vapors. Project personnel will be responsible for monitoring all work in the industry involving CTFE, both our subcontract efforts as well as research conducted on behalf of the Air Force and the fluid manufacturer. Any abnormal developments will be reported for assessment.

3.1.8 Regulatory Safety and Health Requirements.

Regulatory safety and health requirements which are in effect are the same as those in effect for the McDonnell Douglas Corporation. There have been no additional regulatory measures put in effect for the laboratory however it is expected that the use, handling and disposal of halogenated materials throughout the companies facility will be severly curtailed during the period of performance of the contract as well as into the future.

3.1.9 Contractual Safety and Health Requirements.

The contract statement of work has imposed no particular safety and health requirements on the contractor.

3.1.11 Potential For Unplanned Events.

Performance of tests or demonstration events which have not been planned by the project and without the knowledge of program management is strictly forbidden. Only the contract statement of work may govern what tests are performed. Damage to equipment and personnel at great expense to programs has occurred in the past at other facilities when tests have been conducted which were outside of the operating range of the affected equipment. This type of activity constitute a gross misconduct in judgement when performed without appropriate technical evaluation and planning.

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3.1.12 Hazards Introduced By Human Error.

This hazard potential is the greatest single category for high probability. Personnel training, familiarization briefings, warning signs and safety equipment provisions are all required to minimize the attendant risk.

4.0 Personnel Operation of the Test Facility.

All personnel are assigned to operation of the facility based on experience and the distribution of workload among the test efforts underway. In no instance is it necessary for a key individual to split time hourly between two or more effort. Workmen may however be required to do so in order to permit continuous work flow. The facility is designed so that all functions are in the immediate control of the test conductor.

4.1 Pump control panel.

Typically, the center of operation for the facility is the hydraulic pump control panel. When seated or standing at the pump control panel, the operator has a complete view of the test area. Only one pump operator is designated per shift. Prior to starting the pumps, it is his responsibility to insure that all work personnel are clear of the test area and that the LTD is capable of being pressurized. He is required to perform a walk around of the facility to check for leaks, reservoir levels, filter status, condition of test fixtures and the presence of misplaced tools and instruments. Pumps are started at low speed and slowly increased until the rated operating speed is reached. Two pumps are controlled on one speed control however a differential control pot allows the Primary Controls pumps to operate at a reduced speed ratio to the Utility pumps. A master kill switch (button) is placed on the console which will immediately cut electrical power to all drive motors simultaneously. All personnel assigned to the control room will be aware of the master kill switch and be authorized to engage it in the event an individual detects an apparant hazard.

4.2 Pump room noise protection.

The electric drives, pumps, filter manifolds and reservoirs will reside in an acoustic enclosure which will be provisioned to eliminate the extremely intense noise level of the pumps. Windows will be provided to allow the operator to at least be able to determine if the room is occupied. A room electrical capacitance system is being considered for leak detection in the piping circuits which are not protected by the systems reservoir level sensing (RLS) valves. An outside ventilation system also serves the pump room since the room could otherwise have a concentration of CTFE vapor.

4.3 Communication techniques.

It is often necessary to operate systems with personnel on the lab floor to make adjustments to instrumentation with the system pressurized. Procedures have been established wherein wireless headsets are used for two-way communication between the system operator and engineering technicians on the lab floor. Two-way verbal communication is established prior to starting the pumps. In addition, the operator monitors the floor activity visually for the entire period.

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4.0 Personnel Operation of the Test Facility. (Cont.)

4.4 Personnel training.

The personnel who are assigned to the laboratory fall into three job classifications. Test engineers have the responsibility for conducting the tests. Laboratory technicians are assigned to assist with instrumentation work, conducting the tests and perform data retrieval. Manufacturing shop personnel are assigned as required to remove and install equipment and plumbing. Safety training is a routine procedure. Eye wash and emergency shower facilities are located near the LTD facility. Shop personnel are experienced in the proper procedures for attaching hydraulic fittings, lines and hoses. They are also familiar with typical equipment or tubing damage which would constitute a hazard.

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5.0 Operating Procedures and Regulatory Measures.

MIL-STD-882B identifies several categories where measures may be implemented to enhance safety. These will be reviewed in turn prior to addressing the effects of the conditions which may exist in the Laboratory which were described in Section 2.0.

5.1 Activities Occuring Under Hazardous Conditions.

Since this facility tests flightweight flightworthy aircraft equipment there is a fundamental increase in risk compared to commercial hydraulic equipment installations. The difference is, however, that the equipment is not normally approached by personnel during operation where with commercial hydraulics such as that found in automated factory machinery where the operators are continuously exposed to the pressurized components and lines. In the context of this category identified in MIL-STD-882B, there is then no lab test activities which occur under abnormally hazardous conditions.

5.2 Changes Needed in Functional or Design Requirements.

No requirements for changing the design approach were identified in the PHA and this effort concludes the same. The design of the test equipment is governed by the requirements which would apply to incorporation of the systems in a flight vehicle.

5.3 Requirements for Safety Devices and Equipment.

There are in place two 8000 psi test benches or set ups in the laboratory other than the planned LTD and its associated ground power cart. Lucite shields are used on the test bench because the equipment is operated with the lab personnel nearby. No projectile shields are used on the system level set up, however a lucite shield is used on the side which is viewed from the test control room which is also equipped with lucite windows. There are also the standard equipment such as showers with eye flushing provisions and fire extinguishers. Additional provisions which will be incorporated in the LTD are a special acoustic enclosure for the high horsepower hydraulic pumps which are to be tested in the program. No special provisions are required for the other equipment on test other than the high temperature nozzles. Provisions will be required on the thermal chamber to prevent personnel from casually coming in contact with the enclosure.

5.4 Warnings, Cautions and Special Emergency Procedures.

A flashing red light is installed at the entrances to the facility to indicate that testing is in progress. Although the pump noise is normally enough, this provision is required to warn employees who are deaf or have partial hearing loss. Additional lights may be required depending if addition access is created for the LTD area.

No additions caution signs are required.

No new special emergency procedures are required.

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5.0 Operating Procedures and Regulatory Measures. (Cont.)

5.5 Requirements for Handling, Storage, Transportation, Maintenance and Disposal of Hazardous Materials.

The CTFE hydraulic fluid requires a minimal of special handling. Because it can evaporate at elevated temperatures (greater than 110 deg F), spills should be cleaned up immediately. Because of the relatively high cost of the fluid, the Air Force is studying techniques for recycling. Any contaminated fluid which is deemed unsuitable for use in the LTD or the subcontractors test facilities will be returned to the Air Force for reclamation.

5.6 Requirements for Safety Training and Personnel Certification.

Company manuals on safety and operating procedures are well known to the operating personnel. One particular manual, MDC A9803, covers instructions and safety measures for the flight control laboratory. It will require revision to add the LTD and its associated ground power supply. Personnel certification has not been required for any tasks in this facility in the past and this effort has not identified any peculiar characteristics of any equipment being used which would require certification at a system level. A level of expertise is required to install many hydraulic fittings and certification is required for working on airborne installations. Installation of fittings is an early on program task and will be supported by the fitting manufacturers.

## 6.0 Analysis of Operational Hazards.

Several items were identified and categorized in the Preliminary Hazards Analysis and are analyzed with respect to measures being taken on a personnel or facility enhancement level.

### 6.1 CTFE Fluid.

The fluid is a light amber color which makes small leaks difficult to detect except for wetting of surfaces. High system temperature may cause other hazardous effects such as possible seal degradation and leakage which could result in burns and breathing of CTFE vapors. As stated previously, contaminated fluid will be returned to the Air Force for reclamation.

### 6.2 Pumps / Pumping Systems.

The pumping systems must be shut down as quickly as possible in the event of a leak or malfunction. Emergency switches to shut down the pump drives are located at the pump control panel, just outside the control room and in the pump enclosure. Only one test operator is authorized to start the pumps however all personnel are authorized to shut them down if an impending hazard is recognized.

#### 6.2.1 Pressure Intensifier.

In addition to the 8000 psi system there is a special circuit that will incorporate an intensifier that doubles the system pressure. Since this is new technology a good hazard analysis is unavailable and maximum safety guidelines should be used to protect personnel. Special hydraulic tubing will be used in this system. The point can be made that a high pressure leak can be expected to totally atomize the fluid leaving no kinetic energy for damage. There is virtually no stored energy in this system and a leak would drop the internal pressure to normal operating pressure in the system instantly. The design of the test set-up will recognize the higher pressure and include lucite shielding if potential leak paths appear to create an hazard.

#### 6.2.2 Noise Level.

Pumps are inherently noisy and therefore require special ear protection for personnel. With the LTD the motors and pumps are to be operated inside a acoustically insulated room and would therefore only require ear protection when in the "pump room" and not for the rest of the iron bird area. The noise level is an adequate indication that the pumps are running however a flashing red light is located at each entrance to the facility for the benefit of those with impaired hearing.



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6.0 Analysis of Operational Hazards (Cont.)

6.3 Distribution System.

The distribution system components will not be flight qualified for this program. They are designed to a safety factor of three (24,000 psi burst pressure) however the total test hours on the LTD (550 hours) will not deplete a significant amount of fatigue life in the fittings or the tubing. No additional measures as outlined in Section 5.0 are deemed necessary.

6.3.1 Hydraulic Lines.

No special provisions will be required at the facility to reduce the hazards associated with hydraulic tubing and hose assemblies. When the system is pressurized no one is supposed to be on the test floor unless absolutely necessary to make an adjustment or check for a suspected leak. When on the test floor with the system operating, personnel are required to wear special glasses with safety lenses.

6.3.2 Hydraulic Line Fittings.

Several types of fittings are being used for this program including Rosan adapters, Permaswage, Cryofit, Welded, etc. Problems with these fittings is usually related to the human factors; over torquing, misalignment and under torquing are a few that can lead to leaks and failures. In addition leaks have shown to be no more dangerous at 8000 psi as compared to 3000 psi. Installation and repair of fittings and lines will be supported with technicians and special installation equipment from the fitting supplier's facilities. No additional procedures identified in Section 5.0 will be required.

6.3.3 Hydraulic Manifold Porting Plugs.

Recent development of a new high pressure plugs for 8000 psi operation has eliminated a concern expressed in the PHA. The new plugs have a factor of safety which is several times the rating of conventional plugs. Proper installation is still critical however this operation is performed by the equipment subcontractors who have the proper equipment and personnel training and certification.

6.4 Flight Control Actuators.

Flight control actuators for 8000 psi have incorporated several performance options including, flow augmentation, load recovery valves and overlapped control valves. The only operational hazard introduced by test personnel comes about as a result of the actuators being fly-by-wire. Because the commanded position is introduced electronically, steps must be taken by the operator to insure that the actuators are commanded to or near their static position at the time hydraulic power is applied. This hazard will be minimized if the computer control functions being created to control the actuators can be overridden to a very slow rate control on startup.

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6.0 Analysis of Operational Hazards (Cont.)

6.4 Flight Control Actuators (Cont.)

(a) Flow Augmentation and Load Recovery Valves.

These items addressed in the PHA are details within the actuator and do not constitute a hazard which is addressed by and O&SHA.

(b) Test Fixtures.

Test fixtures for the LTD are of a modular design with a self contained loading apparatus. The only possible hazard is, again, during shut down and start up when the actuators could make a sudden movement to a null or the currently commanded position. Personnel should be clear of all fixtures during these two phases.

6.5 Accumulators.

Accumulators contain stored gas at a high pressure and are inherently the most hazardous items in the test setup. They are strategically placed to protect all personnel and equipment in case of any mishap even though design has made this very unlikely.

6.6 Engine Nozzle Actuators.

The engine nozzle actuators are tested in a high temperature environment and as such have special parameters that have to be considered with respect to the hazard analysis. The ambient temperature of the test chamber will be as high as 450°F. The local fluid temperature can be higher than 275°F because the actuators have a special cooling flow circuit to maintain rod temperature at acceptable levels. If the temperature of the rod becomes excessive when extended, the seals could be damaged when the actuator retracts and severe leakage would result. Although the system is designed to shut off any failed circuit and the fluid is nonflammable, the fluid which is lost would vaporize. The environmental chamber used for testing of these actuators is also a hazardous area and an adequate cool down time is required prior to working on this equipment.

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7.0 Results.

No catastrophic hazards introduced by personnel or facilities were identified by this analysis.

The only critical hazards identified in the PHA were associated with potential for test personnel injury from fluid spray, fragments from failed components, or contact with moving components.

Marginal hazards were identified in the PHA which could be compounded as an operational and support hazard for conditions such as overpressurization, overheating, structural failure, or fluid spray. Marginal hazard also exists from personnel contact with hot fluid or hot components, overexposure to noise, and vapor inhalation.

Negligible hazards are most prevalent for operation and support. This includes minor fluid spills, electrical circuit problems, etc. which only serve to cause time delays.

The critical hazard of personnel injury during test operations was the most significant finding of the PHA and Operation and Support measures are the most effective for minimizing these risks. As identified in the PHA, injury could occur from mechanical failure of the accumulators, hydraulic pumps, plumbing or fluid lines. Hydraulic systems utilizing 8000 psi have only a slight increase in personnel injury risks over existing systems using 3000 psi. Studies indicate that a line failure, component failure, etc. causing a fluid leak at 8000 psi are no more likely to cause injury to proximate personnel than line failures at 3000 psi. Personnel contact with a small leak at 8000 psi could cause injection of hydraulic fluid under the skin in the same manner as a leak at 3000 psi but only if ejected from a properly shaped nozzle. The increase in pressure is not a very significant factor with respect to this hazard. The personnel danger from any fluid injection under the skin is significant regardless of the fluid or operating pressure. Prompt medical treatment would be required in either case.

Successful operation of the test facility and completion of the test program without incurring injuries to personnel or damage to equipment requires continuous attention to the safety measures which this laboratory has set in place over thirty five years of hydraulic iron bird testing. The laboratory personnel are solely responsible for the operation of the LTD, safety of the facility, integrity of the equipment, accuracy of the test effort and data collection. As such, a strongly professional attitude toward maintaining a steady and deliberate course of action is instilled in this laboratory. Outside direction comes only through controlled channels with a heavy emphasis on work planning and review of technical tasks to insure success prior to committing time and material.

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