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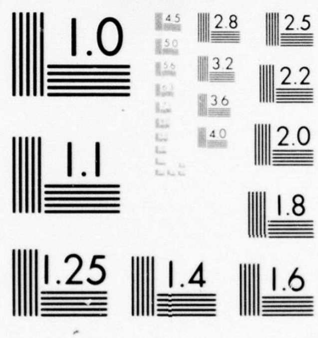

MICROCOPY RESOLUTION TEST CHART

TECHNICAL REPORT

NADC 78033-60

FLUIDICS

FEASIBILITY STUDY ELECTRO / HYDRAULIC / FLUIDIC DIRECT DRIVE SERVO VALVE

Rockwell International
Columbus Aircraft Division
4300 East Fifth Avenue
PO Box 1259
Columbus, Ohio 43216

MARCH 1979

FINAL REPORT

Approved for Public Release
Distribution Unlimited

PREPARED FOR

NAVAL AIR SYSTEMS COMMAND
WASHINGTON,D.C. 20361

NAVAL AIR DEVELOPMENT CENTER (6013)
WARMINISTER, PENNSYLVANIA 18974

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DIRECT DRIVE SERVO VALVE

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

THE FEASIBILITY OF PROVIDING A FLUIDIC BACK-UP CONTROL FOR THE NAVY'S ADVANCED FLIGHT CONTROL ACTUATION SYSTEM (AFCAS) WAS INVESTIGATED AND POTENTIAL DESIGN CONCEPTS WERE EVALUATED. A PRELIM. SPEC. FOR AN ELECTRO/HYDRAULIC/FLUIDIC DIRECT DRIVE SERVO VALVE WAS PROPOSED. TECHNICAL DATA AND SUPPLIER HARDWARE WAS REVIEWED. A DESIGN CONCEPT FOR AN ELECTRO/HYDRAULIC/FLUIDIC SERVO CONTROL VALVE WAS SELECTED AND A PRELIM. DESIGN DRAWING WAS PREPARED. THE STUDY CONFIRMS THE FEASIBILITY OF PROVIDING A FLUIDIC BACK-UP FOR THE AFCAS DIRECT DRIVE SERVO VALVE.

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EXECUTIVE SUMMARY

1.0 PURPOSE OF THE PROGRAM

Current state-of-the-art fly-by-wire flight control systems have been developed to meet the ever increasing demands for increased performance required by today's sophisticated aircraft. Some concern has been voiced in regard to the reliability of the electronic flight controls to function in severe environments such as that associated with EMP, lightening strikes and even high energy fields associated with advanced radar systems. One approach to solving this problem is to provide a back-up control method utilizing an entirely different power medium (other than electrical) for aircraft control, such as fluidics. The purpose of this program is to establish the feasibility of utilizing an Electro/Hydraulic/Fluidic direct drive servo control valve with the Navy's AFCAS fly-by-wire concept.

2.0 BENEFITS TO THE NAVY

The addition of a fluidic back-up control provision for the AFCAS Direct Drive Control Valve will greatly improve the vulnerability of the overall system. The fluidic back-up concept, requiring no electrical power, would have minimum impact in regard to cost effectiveness, maintainability, weight, etc.

3.0 PROGRAM TASKS

The feasibility study was conducted through accomplishment of three (3) basic tasks; (I) a technical data and hardware review, (II) establishment of configuration concepts and preliminary specification, and (III) establishment of a preliminary control valve design.

Technical Data and Hardware Review (Task I)

Since fluidics is essentially a new technology no single source can provide all of the necessary technical information for formulation of system or component design concepts. A technical data review was conducted during Task I, which searched against files of over an estimated 1,000,000 documents for information relative to fluidics, including systems and components. The identification of literature provided by this search has been collected in a central file by the contractor. Copies of selected technical data directly related to this program were requested for review. This data provided for the identification of technical information, related development programs, candidate component suppliers, agencies of the government and prime aircraft contractors involved in fluidic system and component development efforts which would be relevant to this program.

Supplier visitations and continued coordination was accomplished during this task. Current production hardware as well as laboratory development type components and systems were reviewed.

Configuration Concepts and Preliminary Specifications (Task II)

Task II efforts were directed primarily toward development of design concept configurations for an Electro/Hydraulic/Fluidic servo control valve, evaluation of these concepts and selection of a design concept for further development. Evaluation of design concepts included consideration of the total fluidic control system which it would require in regards to fluid media (gaseous or liquid), power source and signal transmission requirements. This effort was necessary to establish feasibility of meeting system to control valve interface requirements and the potential of integrating the selected design into a total fluidic control system in a future program.

Preliminary Control Valve Design (Task III)

A preliminary design of an Electro/Hydraulic/Fluidic control valve was generated as part of the Task III efforts. This design incorporated the selected fluidic design concept into an existing Direct Drive Valve Module. This module is a part of the AFCAS actuator which was developed and flight tested in the T-2C rudder control system. The design is illustrated in Section 5, Figure 5-2 of this report. The selected design concept is a gaseous type fluidic element. The concept, which utilizes existing AFCAS hardware to the maximum extent possible, will provide the Navy with laboratory test hardware and test results with a minimum of wasted effort with regards to cost and schedule.

4.0 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The following conclusions were derived as a result of the feasibility study effort:

1. A fluidic back-up control concept which will be compatible with the Navy's AFCAS Direct Drive Fly-by-Wire Control Valve approach is feasible.

2. The gaseous fluidic type system has been further developed than the liquid type system, although both possess unique advantages and disadvantages. Gaseous is considered to offer the most benefits for the design concept selected during this study.

3. Gaseous power sources are readily available for aircraft systems; however, pressure regulation and filtering may require further evaluation.

4. Further development in a future program should be directed toward signal transmission techniques.

Recommendations

The following recommendations reflect the findings and evaluations resulting from this study effort:

1. It is recommended that a fluidic back-up control design concept such as selected and described in Section 4.0 of this report be further developed.

2. Further development of an Electro/Hydraulic/Fluidic control valve should include design, fabrication and laboratory testing.

3. The design should be directed to an existing system application, such as the T-2C AFCAS rudder installation, which would allow for flight test and evaluation at a future time.

PREFACE

This report documents work performed by the Columbus Aircraft Division of Rockwell International Corporation in Columbus, Ohio, 43216, for the Naval Air Development Center at Warminster, Pennsylvania, 18974, under Contract N62269-78-C-0176. Technical direction was administered by Mr. T. Jansen, R. McGiboney, Aircraft and Crew Systems Technology Directorate (6013) and D. Houck (AIR 52022), Naval Air Systems Command.

This report documents the findings and recommendations of a Feasibility Study for improving the Navy's Advanced Flight Control Actuation System (AFCAS) by the addition of a fluidic back-up control valve.

Discussions in this report of information supplied by various manufacturers shall not be construed as either an endorsement or criticism of any supplier. The government incurs no liability or obligation to any supplier from the information presented herein.

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1.0 INTRODUCTION

1.1 BACKGROUND INFORMATION

NADC has initiated a program to conduct a study for establishing the feasibility of improving control systems for the Navy's fly-by-wire AFCAS concept by providing a fluidic back-up. This concept utilizes the existing direct drive electro/mechanical servo valve for control of the primary flight control actuator. A fluidic servo control valve would be used as a back-up for actuator control in the event of a total loss of aircraft electrical power, and with hydraulic power still available from at least one system.

This back-up fluidic control system would be capable of providing acceptable aircraft control in an environment such as associated with EMP or electrical discharge from lightning strikes or other conditions detrimental to satisfactory operation of the normal fly-by-wire control system. The performance requirements for such a fluidic back-up system would be sufficient to meet the level 3 as defined per MIL-F-8785 for primary flight controls.

In dealing with fluidic systems, two general types of fluid media must be considered; gaseous and liquid. Fluidics is based upon the dynamic characteristics of fluid flow to provide the desired output and control. Therefore, the fluid media may be either gaseous or liquid. Research and development programs have been conducted in the area of both fluid mediums; however, each are faced with their own set of peculiar problem areas. The original development work and the largest percentage of overall development efforts have been directed toward the gaseous systems. Most, if not all, of the recent applications in aircraft have utilized gaseous fluidic elements. Some recent development efforts and flight testing have been conducted utilizing liquid systems in Army helicopter actuation systems; however, this has been limited to development test efforts.

The current trend towards fly-by-wire systems, regardless of implementation techniques, presents a failure mode which did not exist in most hydro-mechanical systems: Loss of control of surface actuators after a complete electrical system failure. Occurrence can be minimized through redundancy and isolation techniques common in hydraulic systems; however, exposure to electromagnetic interference (EMI) can render the most efficient, reliable, redundant electrical system useless unless the system has been hardened against such a threat. Continued use of fly-by-wire control systems is highly desirable for many valid reasons, therefore methods to maintain control of the aircraft with no available electrical power must be devised. One approach is to provide this capability through the use of fluidics. There have been various programs involving fluidic flight control system with varying degrees of success, however most dealt with doing the entire job with a fluidic system, completely eliminating the fly-by-wire system.

1.2 OBJECTIVE

The primary objective of this feasibility study is to establish an acceptable design concept for a direct drive electrical/hydraulic/fluidic servo control valve which is compatible with the Navy's AFCAS actuator. This control valve would provide a back-up fluidic control capability in the event all electrical control channels are lost. This capability will improve the vulnerability characteristics of the overall actuation system.

A secondary objective of this program is to evaluate the integration of this fluidic back-up system into a complete flight control system. This overall evaluation must include the type of fluid medium (liquid or gaseous), power source, pressure levels, and general system characteristics.

1.3 TECHNICAL APPROACH

The initial phase of the program was a comprehensive technical literature search utilizing the contractor's technical information center. The resulting bibliography was evaluated and selected reports which appeared to contain information pertinent to the program were obtained and reviewed. In addition to obtaining technical information about current and past fluid programs, identification of the candidate suppliers participating in these programs was made possible. Contact with many of these companies was subsequently made. A fluidic backup control system arrangement was developed (Figure 1-1).

After a review of the data collected in the literature search, preliminary requirements for the fluidic back-up system were defined and a preliminary specification was prepared. Visits were made to various potential fluidic valve/system designers/manufacturers to discuss the specification and its requirements and to solicit their recommendation/comments and to establish their interest in participating in the future development of an electro/hydraulic/fluidic direct drive servo control valve and associated fluidic elements.

Based on the information gathered, several candidate concepts including hydrofluidics and pneumatic fluidics were studied to determine their feasibility. Considerations were given to performance, packaging, interface with the direct drive valve, and with the aircraft, as well as impact on aircraft system selected as the baseline for this program and defined in paragraph 3.5. From the candidate concepts evaluated, selection of the fluidic media (gaseous) was made and the most promising fluidic configuration concepts were determined. Design concept drawings depicting packaging arrangements were prepared for each concept by participating suppliers.

A design concept drawing of the selected approach and which is compatible with the AFCAS actuator is included in section 5 of this report.

The technical approach taken and key elements involved in accomplishment of the study are illustrated in Figure 1-2.

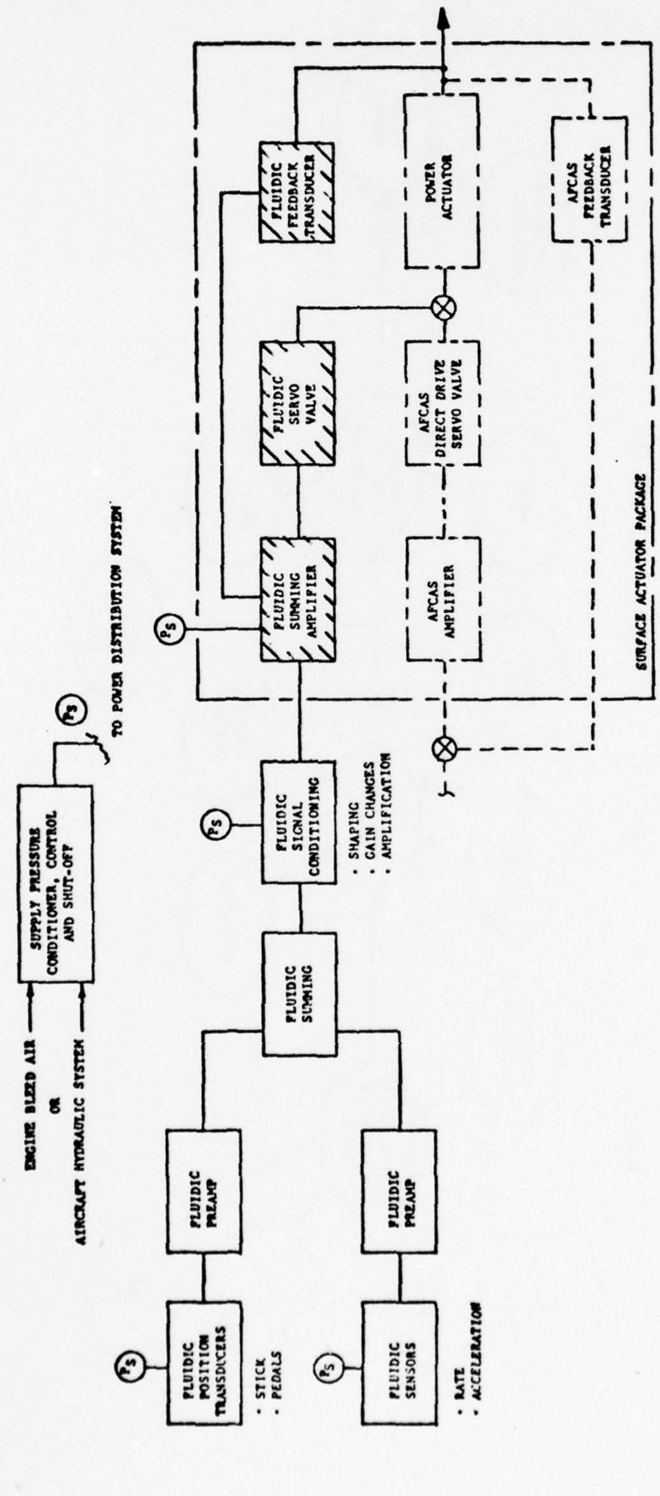


Figure 1-1. Fluidic Backup Control System

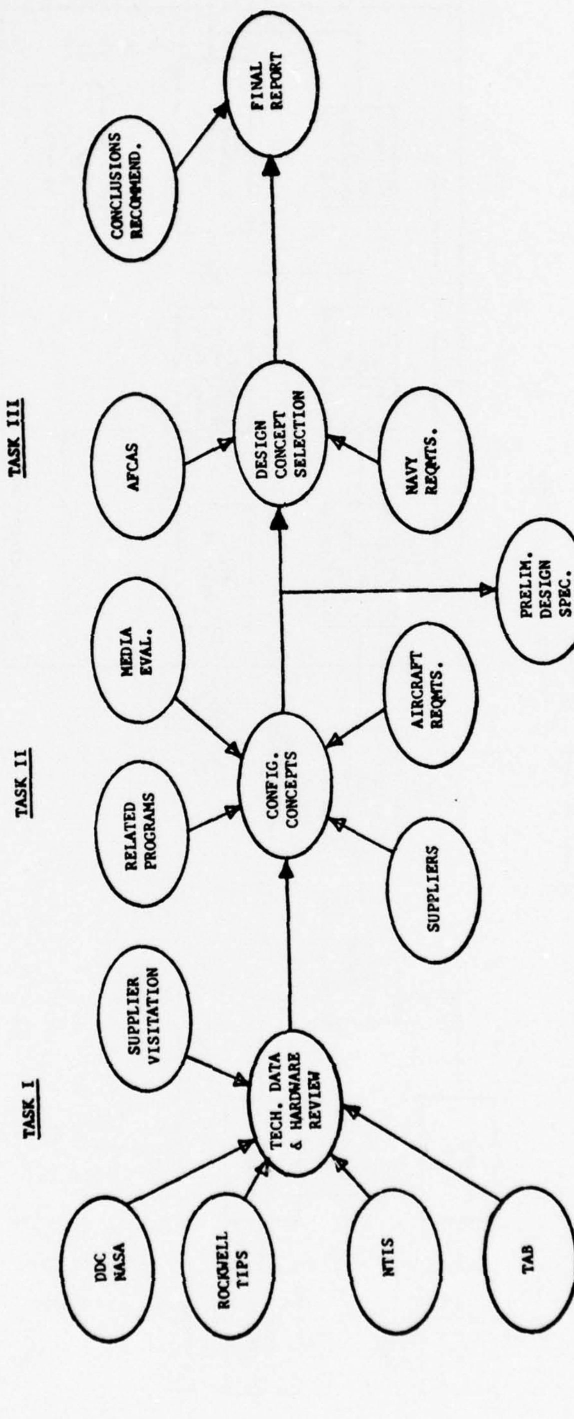


Figure 1-2. Fluidic Feasibility Study Program

2.0 TECHNICAL DATA REVIEW

2.1 LITERATURE SEARCH

A comprehensive literature search was conducted using the contractor's Technical Information Center (TIC). The literature search included: (1) A Defense Documentation Center (DDC) Abstract Bibliography Request covering reports of defense sponsored programs and Work Unit Summaries covering related defense sponsored research and technology projects currently in progress; (2) A NASA literature search including abstracts of reports and a search of AIAA data bank of journal articles and conference papers; (3) A literature search of Rockwell's Technical Information Processing System (TIPS); (4) On-line searches of the National Technical Information Service (NTIS) for reports and Compendix (data base produced by Engineering Index, Inc.) for journal articles and conference papers; and (5) A manual search of the Technical Abstract Bulletin (TAB). The above search covered both classified and non-classified material from government agencies, contractors, and public domain.

A listing of approximately 250 citations resulted from the search. These citations were reviewed and those which appeared to relate to the current study were obtained for review. The documents obtained and currently on hand at Rockwell are listed in Appendix A. A total of 44 documents was obtained. Two of these documents were bibliographies which provided additional sources of information. Six of the documents were summaries of the State-of-the-Art Review Conference held in 1974 at Harry Diamond Labs in Washington, DC.

2.2 SUPPLIER COORDINATION

A review of pertinent literature accumulated during the initial phase of this program indicated those suppliers who were currently, or who had previously been, actively involved in fluidic system and/or component development program. Personal visitations and meetings were conducted with representative suppliers of both gaseous and liquid type fluidic systems and components, who had previously indicated a potential desire to participate in fluidic control systems and/or component development efforts.

The following is a list of suppliers contacted and type of system or component of which they have been mostly associated with:

Supplier	Type Fluidics
AiResearch Manufacturing Phoenix, Arizona	Gaseous
Honeywell, Inc.	Liquid (currently) Gaseous (early efforts)
MOOG, Inc.	Liquid
Hydraulic Research	Liquid
Hydraulic Servo Controls, Inc.	Liquid

As a result of the industry review, it was concluded that fluidic back-up control of a fly-by-wire (AFCAS) primary flight control actuator is certainly feasible; however, it was noted by most that much work is yet to be done before a total fluidic back-up control system can be developed which will provide acceptable performance in an operational aircraft application.

3.0 REQUIREMENTS

3.1 DIRECT DRIVE VALVE DESCRIPTION

The direct drive valve is the key element in the Advanced Flight Control Actuation System (AFCAS). The advanced actuation concept employs control of the primary surface actuators directly by an onboard digital computer or by a standby analog system. Command signals are applied directly to the single stage control valve mounted on the surface actuator thereby eliminating augmentation actuators. Hydraulic power is provided by an 8000 psi hydraulic system.

The direct drive control valve employs a highly reliable single stage design combining high performance with simplicity and ruggedness. A single moving part consisting of a 4-way spool is driven by a spring centered, high output torque motor. Figure 3-1 is a schematic representation of the concept. The basic valve is compatible with single and dual actuators.

The concept has been demonstrated through the design, fabrication, laboratory testing, and flight testing of experimental hardware. Figures 3-2 and 3-3 show a direct drive valve controlled 8000 psi rudder surface actuator which has successfully completed 12 flight hours in a T-2C aircraft. Effort is continuing to refine the concept, i.e., size, packaging, etc., for production applications.

The concept to be employed in this study is to improve the AFCAS system by the addition of the fluidic system as a back-up control for the fly-by-wire system.

3.2 FLUIDIC BACK-UP SYSTEM GENERAL REQUIREMENTS

Although this study is devoted primarily to the direct drive/fluidic valve actuator portion of the system, the general overall system concept must be identified to assure that a system can be designed to provide the inputs to, and be compatible with, the valve/actuator. The fluidic back-up control system should be capable of meeting the following general requirements:

(a) A complete failure of the electrical system shall not prevent operation of the back-up system.

(b) The back-up system shall not utilize active or passive electrical hardware.

(c) In a standby mode, the back-up system shall not degrade the performance of the primary fly-by-wire AFCAS system.

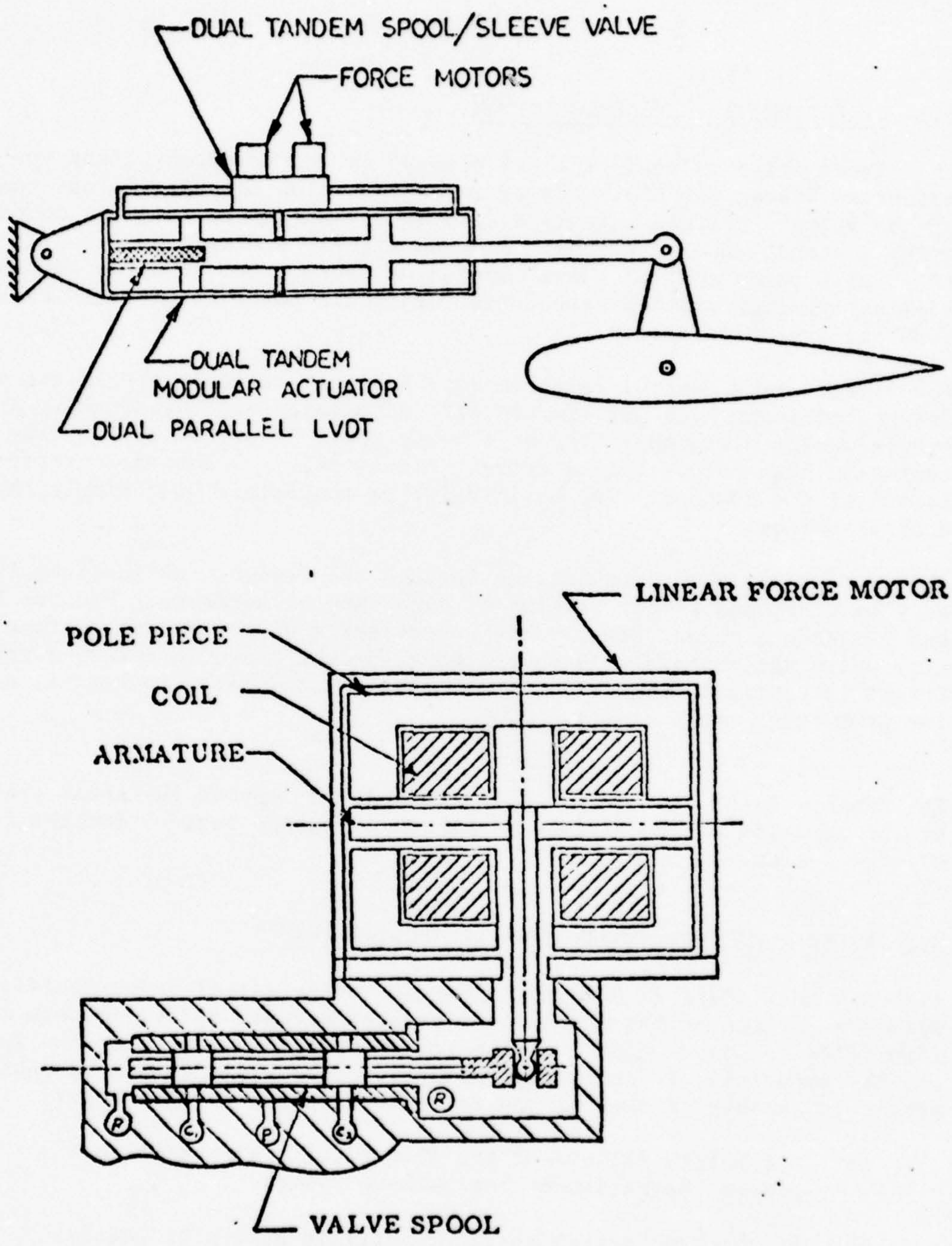
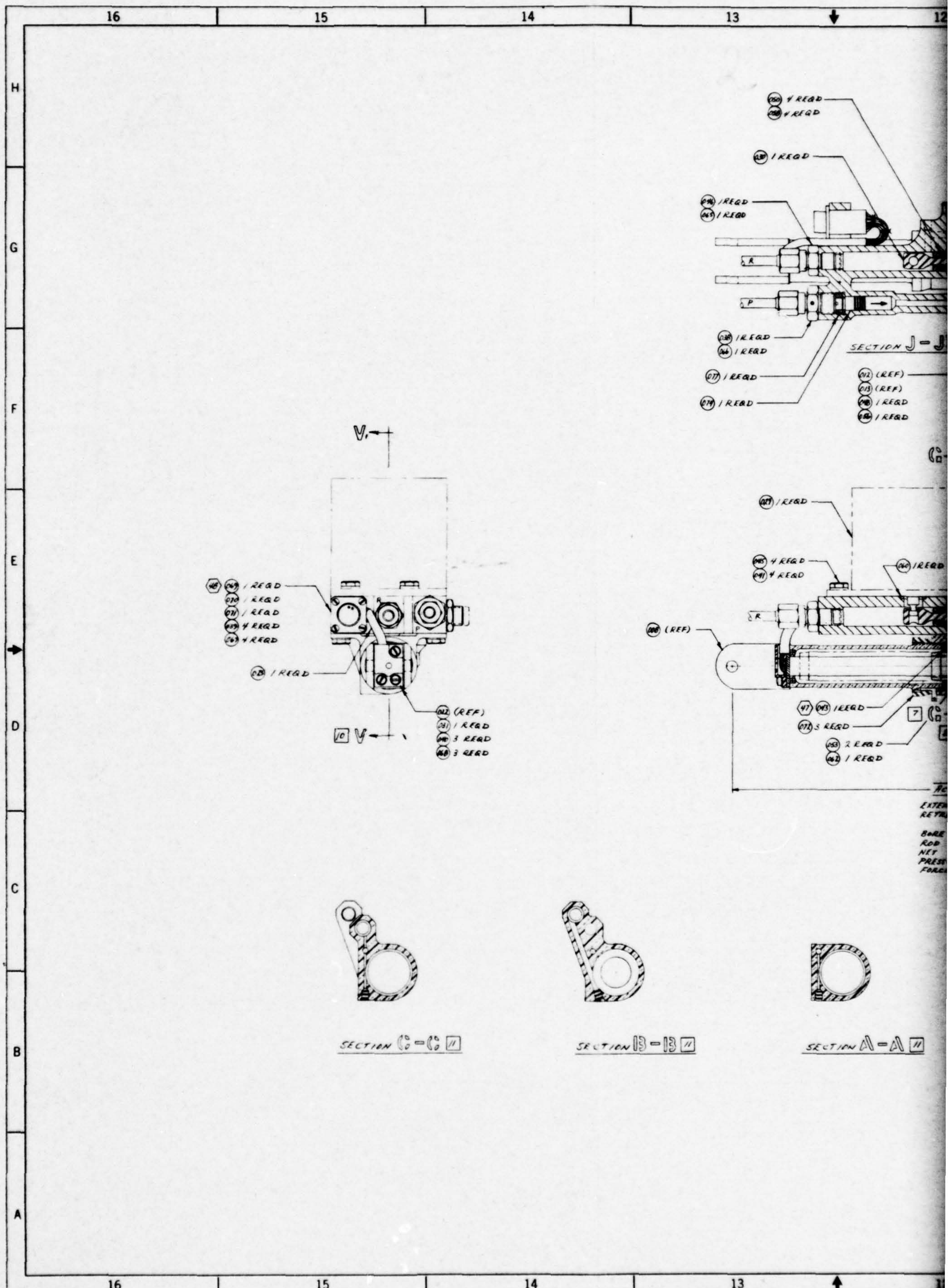


Figure 3-1. Direct Drive Control Valve Conceptual Arrangement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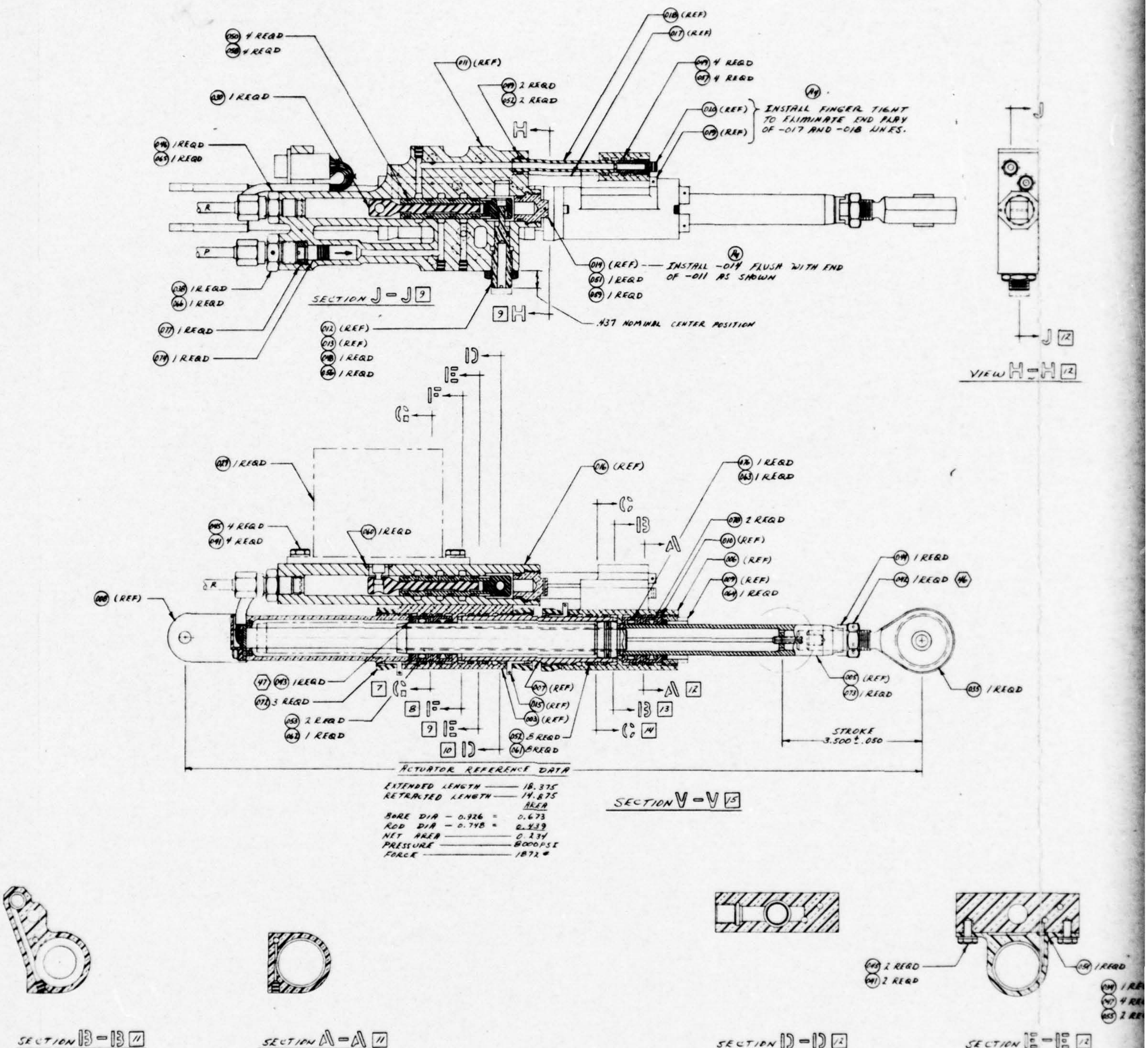

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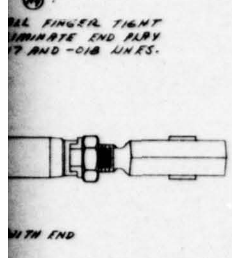

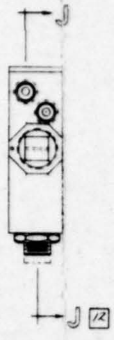

VIEW H-H 12

(48) 13. FABRICATE RECEPTACLE PER SPEC ST0113HA0054 AND ORIENT PIN "A" AS SHOWN.

(47) 12. REMOVE SHIMS AS REQUIRED TO OBTAIN KEYWAY ORIENTATION.

11. MAXIMUM SERVICE TEMPERATURE 275°F.

10. IDENTIFY PER SPEC LA0104-003, DO NOT METAL IMPRESSION STAMP.

(46) 9. DO NOT LOCKWIRE UNTIL INSTALLATION.

8. LOCKWIRE WITH MS20995NC32 WIRE PER SPEC LA0101-001.

7. TEST AND ADJUST PER PROCEDURES IN ZONE 15.

6. PURGE AND PROTECT PER SPEC HA0615-025.

5. RATED PRESSURE 3000 PSI.

4. INSTALL HYDRAULIC FITTINGS PER SPEC FA6-20.

3. INSTALL THREADED FASTENERS PER SPEC LA0101-001.

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1. SEE SHEET 2 FOR DETAIL PART NOTES.

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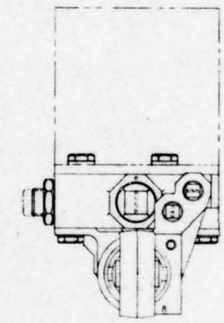

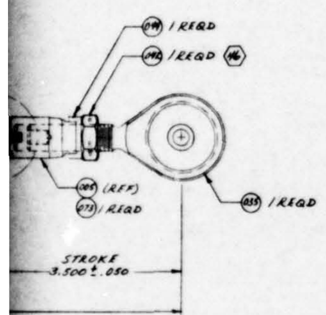

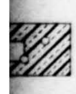

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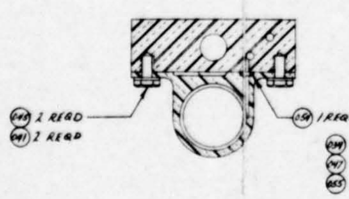

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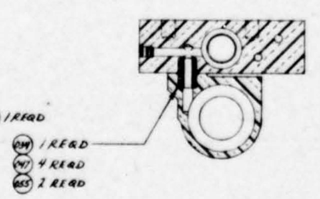

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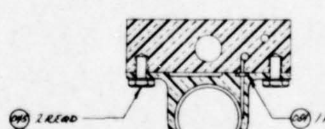

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REVISIONS

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46D		.60 (WAS) .50		
44B		.5000 (WAS) .3750		
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072						3		NAS699S20	CYL LOCK NUT						13
071						1		MS27666F-10-6	CLAMP					MIL-C-38999	15
070						1		MS27473T10F35S	PLUG					MIL-C-38999	15
069						1		MS27472T10F35P	RECEPTACLE					MIL-C-38999	15
068						3		MS35265-28	SCREW						14
067						4		MS35265-13	SCREW						15
066			1					MS28778-6	PACKING						13
065			1					MS28778-4	PACKING						13
064						1		MS28776M2-5	SCRAPER						10
063						1		MS28775-214	PACKING						10
062						1		MS28775-210	PACKING						13
061						8		MS28775-024	PACKING						11
060						1		MS28775-015	PACKING						12
059			1					MS28775-014	PACKING						11
058			4					MS28775-012	PACKING						13
057			2			4		MS28775-011	PACKING						11/12
056			1					MS28775-010	PACKING						12
055						2		MS28775-009	PACKING						9
054						2		MS28775-006	PACKING						7/9
053						2		MS28774-210	RETAINER						13
052						8		MS28774-024	RETAINER						11
051			1					MS28774-014	RETAINER						11
050			4					MS28774-012	RETAINER						13
049			2			4		MS28774-011	RETAINER						11/12
048			1					MS28774-010	RETAINER						12
047						4		MS28774-009	RETAINER						9
046			1					MS21902-4	UNION						13
045						8		AN174H3A	BOLT						7,10,13
044						1		2W15-8	LOCK WASHER						10
043						1		2W1L8-52-38-62	WASHER						13
042						1		1N7-8A	CHECK NUT						10
041						8		LD153-0016-1004	WASHER						7,10,13
040						3		LD153-0002-2201	WASHER						14
039						4		LD153-0002-2200	WASHER						15
038			1					MF286-0006-0001	FILTER					VENDOR ITEM, SEE SPEC CONT DWG	13

PARTS LIST

CODED	ITEM OR FIND NO	QUANTITY	REQUIRED	031	021	011	BASIC	CODE IDENT	PART OR IDENTIFYING NUMBER	NOMENCLATURE	MATERIAL	THKNS GAUGE	WIDTH OD/ID	LG	DRAWING OR SPECIFICATION NUMBER
	037														
	036														
	035						1		249-58736-11	ROD END					
	034						1		247-587529	CONNECTOR					
	033														
	032														
	031						1		504262-04	LVDT					
	030			1					504262-03-21	SPOOL & SLEEVE					
	029						1		504262-02	TORQUE MOTOR					
	028														
	027														
	026														
	025														
	024														
	023						1		045	CONDUIT	6061-T6 AL ALY TUBE	.035 WALL	.250 OD	4.00	MIL-T-
	022						1		043	WIRING COVER	2024-T42 AL ALY BAR	.375	.675	1.25	QQ-A-
	021														
45	020						1		039	CYLINDER PLUG	PH13-8Mo CRES ROD	—	0.75 DIA	1.50	ST0160
45	019						1		037	RETURN PLUG	PH13-8Mo CRES ROD	—	0.75 DIA	1.75	ST0160
45	018						1		035	CYLINDER LINE	PH13-8Mo CRES ROD	—	0.75 DIA	2.75	ST0160
45	017						1		033	RETURN LINE	PH13-8Mo CRES ROD	—	0.75 DIA	2.50	ST0160
	016						1		031	VALVE ASSY					
45	015						3		029	KEY	PH13-8Mo CRES BAR	0.50	0.75	0.75	ST0160
45	014			1					027	SLEEVE PLUG	PH13-8Mo CRES ROD	—	1.25 DIA	1.25	ST0160
45	013			1					025	JAM NUT	PH13-8Mo CRES ROD	—	1.25 DIA	0.50	ST0160
45	012			1					023	ADJUSTING SCREW	PH13-8Mo CRES ROD	—	0.75 DIA	2.50	ST0160
	011			1					021	VALVE BODY ASSY OF					
	010						2		019	SEAL RETAINER	BE CUP ROD	—	1.25 DIA	1.25	LB 01 COND
45	009						1		017	LOCKNUT	PH13-8Mo CRES ROD	—	2.00 DIA	1.00	ST0160
45	008						1		015	TAILSTOCK	PH13-8Mo CRES ROD	—	2.00 DIA	6.50	ST0160
45	007						1		013	CYLINDER	PH13-8Mo CRES ROD	—	2.00 DIA	4.50	ST0160
	006						1		011	CYL HEAD ASSY OF					
44	005						1		009	ROD	4340 STEEL ROD	—	1.50 DIA	12.00	COND MIL-S-
45	004				1				007	VALVE BODY	PH13-8Mo CRES BAR	1.25	4.00	6.75	ST0160
45	003						1		005	VALVE MTG HEAD	PH13-8Mo CRES BAR	3.00	4.00	3.50	ST0160
45	002					1			504262-01-003	CYLINDER HEAD	PH13-8Mo CRES BAR	3.00	4.00	3.50	ST0160
	001								504262-01	ACTR ASSY					

PARTS LIST

ITEM	QTY REQD PER END ITEM	NEXT ASSY	USED ON	END ITEM NO.	THRU
		APPLICATION		EFFECTIVITY	

HEAT TREAT
CODED 44 45
SHEET 2

FINISH

INSPECT PER MIL-I-6870 (ST0501LT0007 CLASS)

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
MFG TOLERANCES ON:
UNDIMENSIONED ± .03
XX (DECIMALS) ± .03
XXX (DECIMALS) ± .010
ANGLES ± 30'
HOLES NOTED "DRILL"
.013 THRU .040 + .001 − .001
.041 THRU .130 + .002 − .001
.131 THRU .229 + .003 − .001
.230 THRU .500 + .004 − .001
.501 THRU .750 + .005 − .001
.751 THRU 1.000 + .007 − .001
1.001 THRU 2.000 + .010 − .001
DO NOT SCALE PRINT

CONTR NO
DWN BY GRIESMER 6-11-75
CHK BY
APVD

Columbus Aircraft Division
North American Rockwell
COLUMBUS OHIO 43216

ACTUATOR ASSY - DIR
HYD. FLT. CONT.
8,000 PSI

SIZE J | CODE IDENT NO 89372 | 50426

SCALE FULL SIZE

6	5	4	3	2	1

FIGURE 3-2

5

3	2	1

REVISIONS

ZONE	LTR	DESCRIPTION	DISPN	DATE	APPROVED
		1 MAY BE REWORKED 2 CANNOT BE REWORKED 3 RECORD CHANGE 4 NOW SHOP PRACTICE 5 PARTS MADE OK			
	A	1. CHANGED FOLLOWING DIMS.:	1		
63D		2.059 (WAS) 2.094			
63D		1.489 (WAS) 1.524			
62D		.919 (WAS) .954			
46D		.60 (WAS) .50			
44B		.5000 (WAS) .3750			
36B		.044 +.000/−.010 (WAS) .050 ±.005			
52F		2. FULL THREAD .250 DEEP (WAS) THRU	1		
43D		3. ADDED DIMENSIONS	3		
10G		4. ADDED NOTES	3		
		EFFECT ON: CONTRACT		1-5-76	GRIESZMER

H

G

F

E

D

C

B

A

ITEM OR FIND NO	QUANTITY REQUIRED		031	021	011	BASIC	CODE IDENT	PART OR IDENTIFYING NUMBER	NOMENCLATURE	MATERIAL	THKNS GAUGE (MATERIAL SIZE)	WIDTH OD/ID (MATERIAL SIZE)	LG	DRAWING OR SPECIFICATION NUMBER	ZONE
037															
036															
035						1		249-58736-11	ROD END						9
034						1		247-587529	CONNECTOR						9
033															
032															
031						1		S04262-04	LVDT						15
030			1					S04262-03-21	SPOOL & SLEEVE						13
029						1		S04262-02	TORQUE MOTOR						13
028															
027															
026															
025															
024															
023						1		045	CONDUIT	6061-T6 AL ALY TUBE	.035 WALL	.250 OD	4.00	MIL-T-7081	15
022						1		043	WIRING COVER	2024-T42 AL ALY BAR	.375	.875	1.25	QQ-A-225/6	34
021															
020						1		039	CYLINDER PLUG	PH13-8Mo CRES ROD	—	0.75 DIA	1.50	ST0160LB0013	36
019						1		037	RETURN PLUG	PH13-8Mo CRES ROD	—	0.75 DIA	1.75	ST0160LB0013	36
018						1		035	CYLINDER LINE	PH13-8Mo CRES ROD	—	0.75 DIA	2.75	ST0160LB0013	40
017						1		033	RETURN LINE	PH13-8Mo CRES ROD	—	0.75 DIA	2.50	ST0160LB0013	40
016						1		031	VALVE ASSY						
015						3		029	KEY	PH13-8Mo CRES BAR	0.50	0.75	0.75	ST0160LB0013	36
014			1					027	SLEEVE PLUG	PH13-8Mo CRES ROD	—	1.25 DIA	1.25	ST0160LB0013	50
013			1					025	JAM NUT	PH13-8Mo CRES ROD	—	1.25 DIA	0.50	ST0160LB0013	50
012			1					023	ADJUSTING SCREW	PH13-8Mo CRES ROD	—	0.75 DIA	2.50	ST0160LB0013	50
011			1					021	VALVE BODY ASSY OF						52
010						2		019	SEAL RETAINER	BE COP ROD	—	1.25 DIA	1.25	LB0170-137 COND A	40
009						1		017	LOCKNUT	PH13-8Mo CRES ROD	—	2.00 DIA	1.00	ST0160LB0013	35
008						1		015	TAILSTOCK	PH13-8Mo CRES ROD	—	2.00 DIA	6.50	ST0160LB0013	43
007						1		013	CYLINDER	PH13-8Mo CRES ROD	—	2.00 DIA	4.50	ST0160LB0013	45
006						1		011	CYL HEAD ASSY OF						23
005						1		009	ROD	4340 STEEL ROD	—	1.50 DIA	12.00	COND C1 MIL-S-5000	46
004				1				007	VALVE BODY	PH13-8Mo CRES BAR	1.75	4.00	6.75	ST0160LB0013	57
003						1		005	VALVE MTG HEAD	PH13-8Mo CRES BAR	3.00	4.00	3.50	ST0160LB0013	31
002					1			S04262-01-003	CYLINDER HEAD	PH13-8Mo CRES BAR	3.00	4.00	3.50	ST0160LB0013	23
001								S04262-01	ACTR ASSY						

PARTS LIST

	HEAT TREAT CODED (49)(45) SHEET 2	UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES MFG TOLERANCES ON: UNDIMENSIONED ±.03 XX (DECIMALS) ±.03 XXX (DECIMALS) ±.010 ANGLES ±30'	CONTR NO.	Columbus Aircraft Division North American Rockwell COLUMBUS, OHIO 43216
	FINISH	HOLES NOTED "DRILL"	DWN BY GRIESZMER 8-11-75	ACTUATOR ASSY - DIRECTIONAL, HYD. FLT. CONT. 8000 PSI
		013 THRU 040 +.001 −.001 041 THRU 130 +.002 −.001 131 THRU 229 +.003 −.001 230 THRU 500 +.004 −.001 501 THRU 750 +.005 −.001 751 THRU 1.000 +.007 −.001 1.001 THRU 2.000 +.010 −.001	CHK BY	
THRU	INSPECT PER MIL-I-6870 (ST0501LT0007 CLASS)		APVD	SIZE J · CODE IDENT NO. 89372 · S04262-01
VITY		DO NOT SCALE PRINT		SCALE FULL & NOTED · SHEET 1 OF 4

3	2	1

30-G-3 REV 11-72

FIGURE 3-2

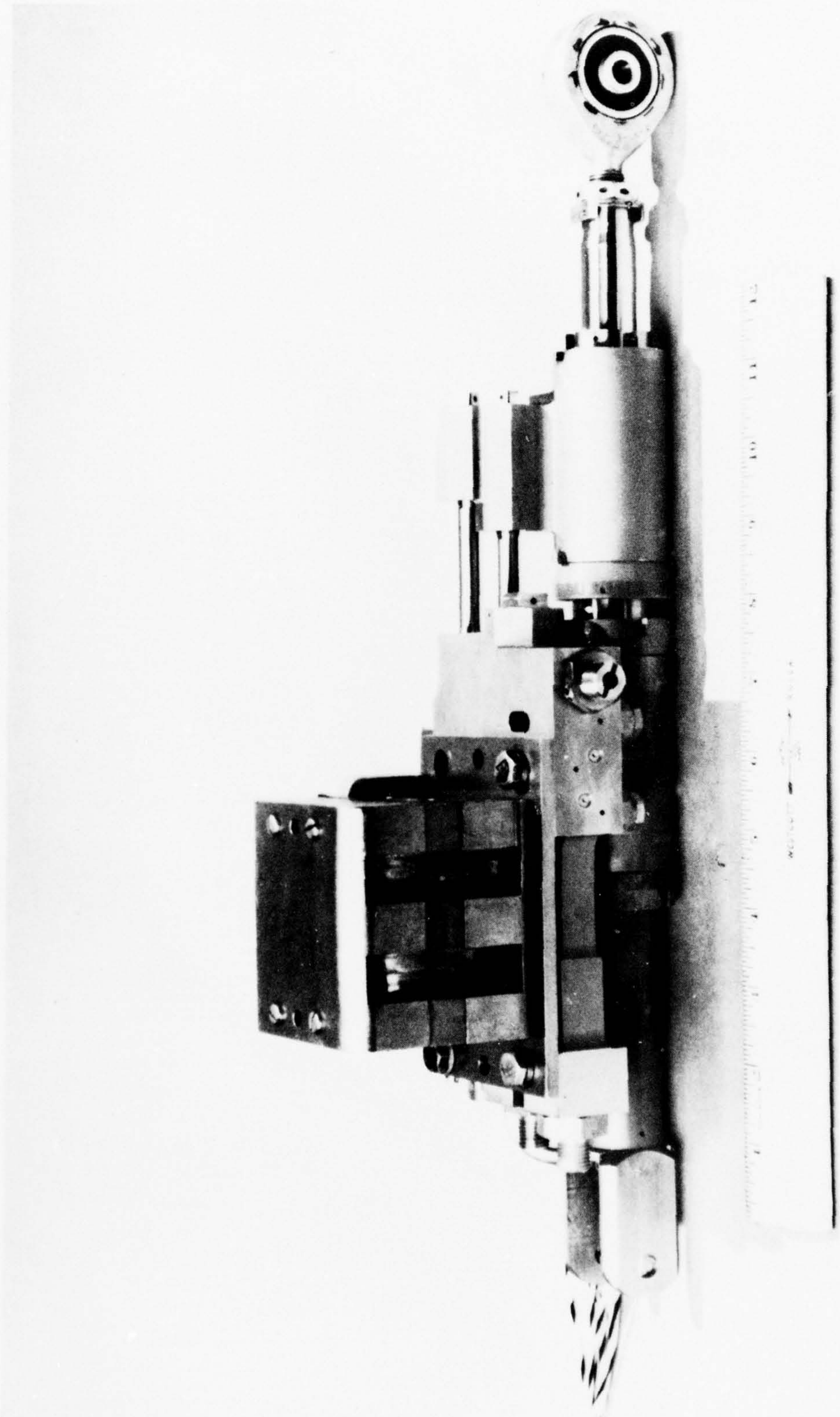


Figure 3-3. Control-By-Wire Rudder Actuator

(d) Transfer of control to the back-up system must be positive with minimum control transient.

(e) The back-up system must provide the minimum performance requirements dictated by flying qualities and flight safety.

3.3 INTERFACE REQUIREMENTS

Interfacing of the fluidic control with the AFCAS direct drive valve will require consideration of several areas such as: the force motor and hydraulic valve, the aircraft system fluidic power sources, as well as other aircraft systems.

As shown in Figure 1-1, all the necessary elements to close the control loop around the actuator will be included. Packaging of these elements will be considered to the extent of determination of compatibility with the existing T-2 AFCAS rudder actuator/installation.

Direct Drive Valve Characteristics

The operating/physical characteristics of the existing torque motor, spool/sleeve and actuator which must be operated by the fluidic control are summarized in Table 3-1.

3.4 PERFORMANCE REQUIREMENTS

Minimum Bandwidth

Back-up flight control systems are designed to utilize the smallest levels of aerodynamic surface control deflections, rates, bandwidth, and torque for maintaining safe flight. Normally, these levels are best quantified by piloted simulation tests of a specific aircraft/back-up control configuration; however, by using the F-4 airframe dynamics as being representative of a high performance fighter, and estimating the allowable control system phase lag according to the guidelines contained in MIL-F-8785B, the minimum control surface actuator bandwidth can be approximated.

Dynamic Characteristics

The response of the control surfaces in flight shall not lag the cockpit control force inputs by more than the angles shown in Table 3-2 for frequencies equal to or less than the frequencies shown in Table 3-2.

Table 3-1. Component Characteristics

Torque Motor P/N S.O. 4262-02	
Output Member Spring Rate (±.020 in.)	±820 lb/in
Torque Motor Armature Inertia Reflected at Spool	* .00922 in-#-sec^2
Spool/Sleeve P/N S.O. 4262-03	
Spool Weight	* .0334#
Spool Type	* 2 Land
Spool Land Diameter	0.250 in
Spool Travel (Rated)	±0.20 in
Flow Gain (nom)	127 in^3/sec/in
Pressure Gain	2,000,000 psi/in
Rated Flow (at ±.020 in)	.33 GPM
Internal Leakage at Null, Max	130 cc/min
Design Overlap	±.002 in
Actuator (Balanced) P/N S.O. 4262-01	
Effective Piston Area	0.234 in^2
Stroke	3.5 in
Rod Diameter	0.748 in
Piston Diameter	0.926 in
Extended Length	18.375 in

* May change due to addition of fluidic interface.

Table 3-2. Allowable Control Surface Lags

Level	Allowable Lag ~ deg	
	Category A and C Flight Phases	Category B Flight Phases
1 and 2	30	45
3	60	

Control	Upper Frequency ~ rad/sec
elevator	$\omega_{n_{sp}}$
rudder & aileron	ω_{n_d} or $1/\tau_r$ (whichever is larger)

The highest short period frequency ($\omega_{n_{sp}}$) of the F-4 is 7.0 rad/sec and occurs at Mach 1.2 at 5000 feet. Assuming that the control surface valve/actuation dynamics are second order, a minimum control cut-off frequency of 11 rad/sec at .7 damping would be required.

A valve/actuator transfer function would take the form of:

$$\frac{1}{\frac{S^2}{\omega_n^2} + \frac{2\zeta}{\omega_n} + 1} \qquad \omega_n = 11 \text{ rad/sec} \qquad \zeta = .7$$

(Desired Level 2 Requirements - 2 Hz.)

Engage Transients

Transfer of control authority from the primary mode to the fluidic back-up control mode should be positive with minimum control transient.

3.5 AIRCRAFT SYSTEM

In order to establish baseline requirements of an electro/hydraulic/fluidic direct drive control valve, to be defined in a preliminary design procurement specification, it was necessary to select a specific system application. The AFCAS rudder actuator installation in the Rockwell CAD T-2C aircraft was selected as the logical choice. This system, which includes the fly-by-wire AFCAS actuator and direct drive control valve, satisfactorily completed a series of flight tests in the early part of 1978.

Selection of the T-2C rudder actuator provides an excellent existing technical data base for performance evaluation of a fluidic control valve.

This approach is considered to be logical and cost effective inasmuch as it would utilize existing AFCAS actuator hardware to the maximum extent possible. It would be compatible with previously used lab test arrangements and it offers the potential of utilizing an existing flight test vehicle for future flight test development efforts, with minimum modification to existing aircraft hardware.

The T-2C flight test vehicle is a twin engine jet aircraft utilizing J-85 engines. It has the capability of providing hydraulic power at 3000 psi from engine driven pumps or 8000 psi from a localized hydraulic power unit which is an electric motor driven pump. A fluidic power supply source, either gaseous (engine bleed air) or liquid (hydraulic system fluid) would be easily available.

4.0 EVALUATION

4.1 FLUIDIC MEDIA

Fluidic systems may be divided into two (2) general categories based upon the fluid media being utilized; (1) pneumatic or gaseous, and (2) liquid. Both of these mediums are normally readily available in most aircraft. While power consumption of fluidic systems is generally thought of as being low in comparison with other aircraft fluid power systems, it is not necessarily true for a total fluidic flight control system when compared to the normal quiescent flow associated with typical electro/hydraulic systems and spool/sleeve control valves.

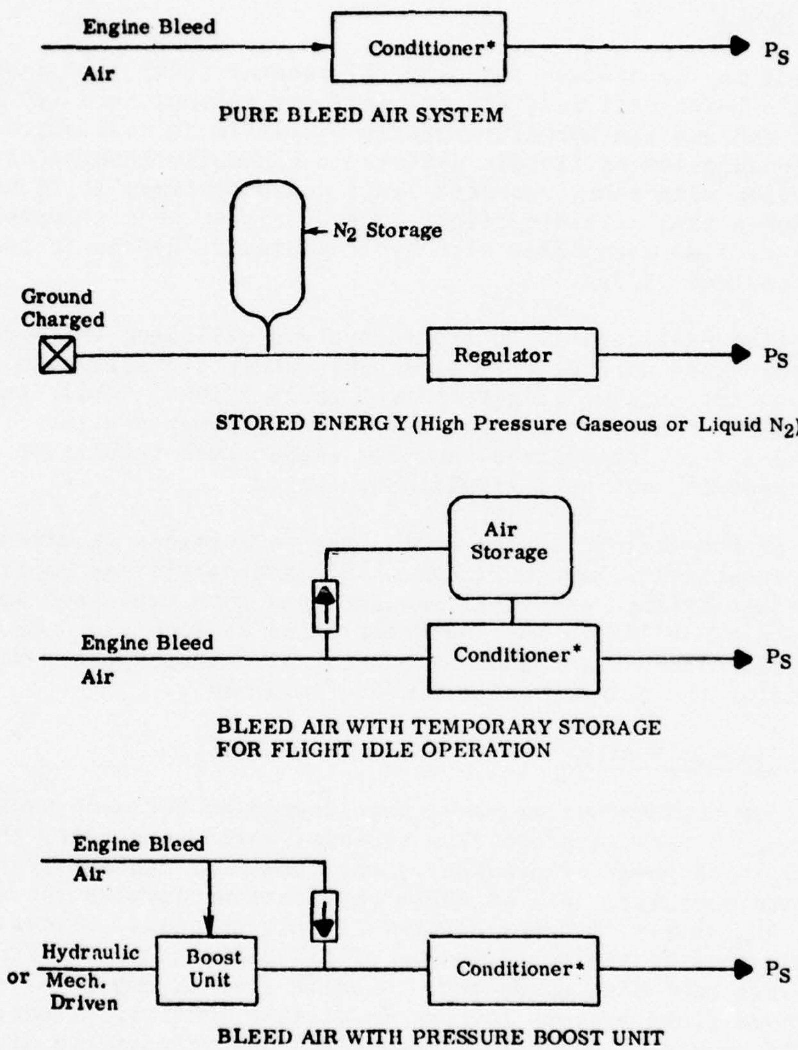
Power consumption particularly in liquid systems utilizing the aircraft hydraulic supply must carefully consider this aspect in selection of a type of system, even for back-up flight control applications. While gaseous systems generally consume less power per element, power availability at higher altitudes from jet engines, and low temperature requirements for fixed supply sources, may be a significant factor.

In selection of the fluidic system media, the performance requirements, physical characteristics, and environment of each particular application must first be established and these requirements then evaluated against the performance capabilities and characteristics of each fluid medium. In addition, signal transmission and environmental characteristics must be considered during the primary selection of fluid media.

Gaseous Fluidic Systems

Airborne gaseous fluidic systems have been developed for many uses in aircraft including integrated propulsion systems, engine controls, thrust reversers, approach power compensators, environmental control system valving, and an air data computer. All of these applications involve the use of engine bleed air as the source of power for the fluidic circuit. Several studies involve evaluations of the conditioning of bleed air and its affect on the fluidic circuits have been conducted. Missile systems employ stored high pressure gaseous fluid systems for use in missile control, primarily as thrusters. It should be noted that many citations relating to missile application were found during the survey of Section 2, but were not considered to be applicable to this application.

Although stored energy systems are feasible for aircraft applications, use of engine bleed air is the most attractive because of its inexhaustible source and insensitivity to low levels of external leakage. There are, however, limitations associated with using engine bleed air which will be discussed in the following paragraphs. Figure 4-1 shows several potential gaseous supply system concepts.



*Conditioner regulates pressure, reduces temperature, and dehumidifies and filters the bleed air.

Figure 4-1. Potential Gaseous Supply Systems

Pressure - Most airborne gaseous systems require a pressure source in the range of 20 to 31 psia depending on the type of system utilized. Supply pressure is maintained by a pressure regulator which uses an altitude compensated vent pressure as its reference.

The required bleed pressure of 20 to 31 psia can be easily met by current aircraft engines at high power settings at altitudes up to and exceeding 40,000 feet. The available bleed pressure throughout the total flight envelope becomes marginal during aircraft idle descent portion of the flight mission. If the bleed pressure temporarily falls below the regulated pressure, changes in the fluidic system performance (gain change and change in set points and frequency response) will occur. If these changes are not tolerable, techniques are available to maintain the pressure level during these brief periods. Devices to boost bleed air pressure have been designed for this specific purpose. Also, the technique employing the temporary storage of bleed air when at higher power settings for use during aircraft idle descent periods can also be employed.

Temperature - Temperature variations in fluidics is not a serious design problem. However, this can cause circuit problems if not taken into consideration in the design of the system. Large temperature excursions cause variations in the gains and set points of fluidic systems and constitute a major factor in circuit selection--especially when computation is done in the analog mode. Digital elements can be operated over broad temperature ranges, however analog devices are quite sensitive to temperature variation. This sensitivity is caused by factors such as viscosity, sonic velocity, and changes in orifice and nozzle size due to thermal expansion or contraction. Differential circuits can be used to compensate for small temperature changes and temperature sensitive gain changing networks are required for compensation over broad temperature ranges. Both techniques are commonly used in airborne gaseous fluidic systems.

Depending on the line size, material, distance to the regulation devices, flow rates, and local ambient temperatures, the flowing gas temperature will change before it reaches the supply regulation circuitry. At the relatively low flow rate, the change may be significant. In one application (6 feet of line from engine bleed port to regulator), regulator inlet temperature was calculated to vary from 310 to 575°F for several flight conditions. The circuitry was designed to accept these temperatures and performed within the allowable limits.

Contamination - Fluidic elements can be designed to be relatively insensitive to contamination by using large nozzle widths. However, the resulting power consumption would be unacceptable for a continuously operating airborne system. It is therefore common practice to compromise the nozzle widths to obtain a contaminant insensitive system, and minimize the power loss. Blockage or restriction of a passage or orifice can result in performance degradation or loss of control of the device, therefore, control of contamination entering a fluidic system is of the utmost importance. When designing the system, the concentration of solid contaminants in the media should be assumed to be no greater than that present at the source.

Engine bleed air, the power source generally used, is generally 3.7 PPM of unburned hydrocarbons and can be considered normal. Whether this concentration is significant depends on many factors; operating mode (full time or back-up), local temperatures, and residence times (flow). Should condensation occur, a portion of this oil would be deposited in the passages within the fluidic circuit. Although failure may not occur due to the oil alone, solid contaminants coming in contact with the oil could adhere to the oil and eventually cause partial or complete blockage of the passage.

One study reported deposits found in the circuit tested were tenaciously adhered to the fluidic passages by oil breakdown products. Another study recommended that line/gas temperature should be maintained above 170°F to prevent condensation. Water vapor in the bleed air was found to be of prime consideration requiring careful attention to the selection, location, and heat transfer characteristics of connecting lines. It is recommended that the potential of oil and water concentrations be minimized.

It is concluded that contamination control in a bleed air system supplying a fluidic controlled flight control system, either back-up or primary, is of utmost importance. A bleed air conditioner is required to filter solid contaminants, and remove oil and water vapors or reduce the dew points to a temperature below that of the lowest ambient temperature encountered in the application.

Flow - The flow consumption of a gaseous fluidic system is generally not a significant factor in airborne systems. Most fluidic devices in the 5 to 10 psig range consume from .005 to .08 lbs/minute of air. One system reviewed during this study involved an integrated propulsion system with approximately 70 fluidic elements and consumed less than 15 SCFM (1.1 lbs/minute). This would represent less than 2% of the available bleed flow from a typical jet engine at idle and less than 1/2% at higher power settings.

Stored Energy Vs. Engine Bleed Systems - The stored energy gaseous system has advantages over the bleed air concept, but also has several disadvantages. A comparison of the two approaches is presented in Table 4-1.

Liquid Fluidic Systems

Airborne liquid fluidic systems or hydrofluidic systems have been developed, tested, and flown in several helicopter applications including surface control actuation, stability augmentation systems, and armament control systems. All such programs are still in the R&D and prototype test phase.

Since virtually all airborne aircraft, which would be a candidate for a fluidic back-up will have one or more hydraulic systems, the use of the hydraulic system as the source of supply for the fluidic system appears to be a viable approach. The following paragraphs present discussions of the impact of this approach on the 8000 psi hydraulic system along with discussion on various aspects of the hydrofluidic systems.

Table 4-1. Stored Energy Gaseous Systems Vs. Bleed Air System

STORED ENERGY

ADVANTAGES

- READILY AVAILABLE PRE-CONDITIONED AND INERT MEDIA (CLEAN, DRY, OIL FREE)
- TEMPERATURE IS AFFECTED BY ENVIRONMENT ONLY
- SYSTEM SUPPLY PRESSURE RELATIVELY CONSTANT
- RELATIVELY SIMPLE REGULATING SYSTEM

DISADVANTAGES

- REQUIRES SERVICING PREFLIGHT CHECK
- REQUIRES STORAGE BOTTLE
- MISSION TIME SENSITIVE
- EXTERNAL LEAKAGE
- SERVICING TIME
- GSE AFFECTED

BLEED AIR

ADVANTAGES

- UNLIMITED SOURCE OF SUPPLY
- UNAFFECTED BY MINOR EXTERNAL LEAKAGE
- UNLIMITED OPERATING TIME
- EASILY AVAILABLE
- NO PREFLIGHT SERVICING CHECK

DISADVANTAGES

- ADDITIONAL CAPACITY FOR A/C CONDITIONING AND/OR COOLING SYSTEM (CLEAN, DRY, REMOVE OIL VAPOR)
- WIDELY FLUCTUATING TEMPERATURES OVER RANGE OF POWER SETTINGS
- A/C IDLE DESCENT MODE
- POSSIBLE PRESSURE DEFICIENCY

Most of the concepts reviewed utilized low signal pressures and low power amplifiers and networks for mixing, etc., ultimately providing a conditioned low pressure signal to a bellows driven flapper type device.

Pressure - The hydrofluidic systems reviewed were utilized in a 1500 psi aircraft system or 1500 psi circuit in a 3000 psi aircraft system. Regulators are used to further reduce the pressure to the desired fluidic supply pressure level which ranged from 500 to 1000 psi. Concepts with low signal pressures ranged from ± 1 to ± 4 psid up to ± 100 psid, which is used in the fly-by-tube concept.

Figure 4-2A is a simplified schematic of the typical hydrofluidic system as it interfaces with an existing system. In an 8000 psi system, the pressure reducer required to obtain the desired supply pressure would generate 267 percent more heat than the equivalent circuit in a 3000 psi system. This would represent 20 to 30 percent of the heat load in a typical 8000 psi, 10 gpm system. An alternative approach using a separate pressure generating source is shown on Figure 4-2B. This approach, or variations of it, would reduce the heat dissipation penalty for the hydrofluidic system to virtually zero.

Temperature - Hydraulic system operating temperature levels impose no unusual restrictions on hydrofluidic components, however, fluid viscosity changes due to temperature variation is considered to be a major deficiency and will affect circuit performance. Compensating networks and differential circuits have been employed, somewhat successfully, to provide satisfactory operation over a temperature range of approximately 100 to 160°F. The bulk of the temperature sensitive elements can be located in the aircraft/system where the fluid temperatures will fall within this range. However, components such as wing surface control actuators and their signal transmission lines far from heat generation sources other than aerodynamic, may create special problems. The same can be said for component located in high temperature areas of the system. Existing hydrofluidic systems for helicopters have not been faced with this problem.

The fly-by-tube concept, a version of which is shown in Figure 4-3, is a departure from the typical fluidic system in that it contains no fluidic amplifiers, operates at a higher signal pressure level, and has only two fluidic signal lines to the surface actuator. This concept might offer a solution to remotely located surface actuators in extreme temperature environments. The surface actuator contains only dead ended force capsules which are controlled by two signal lines filled with a low viscosity oil. These two signal lines originate at a fluid to fluid interface with the remainder of the system.

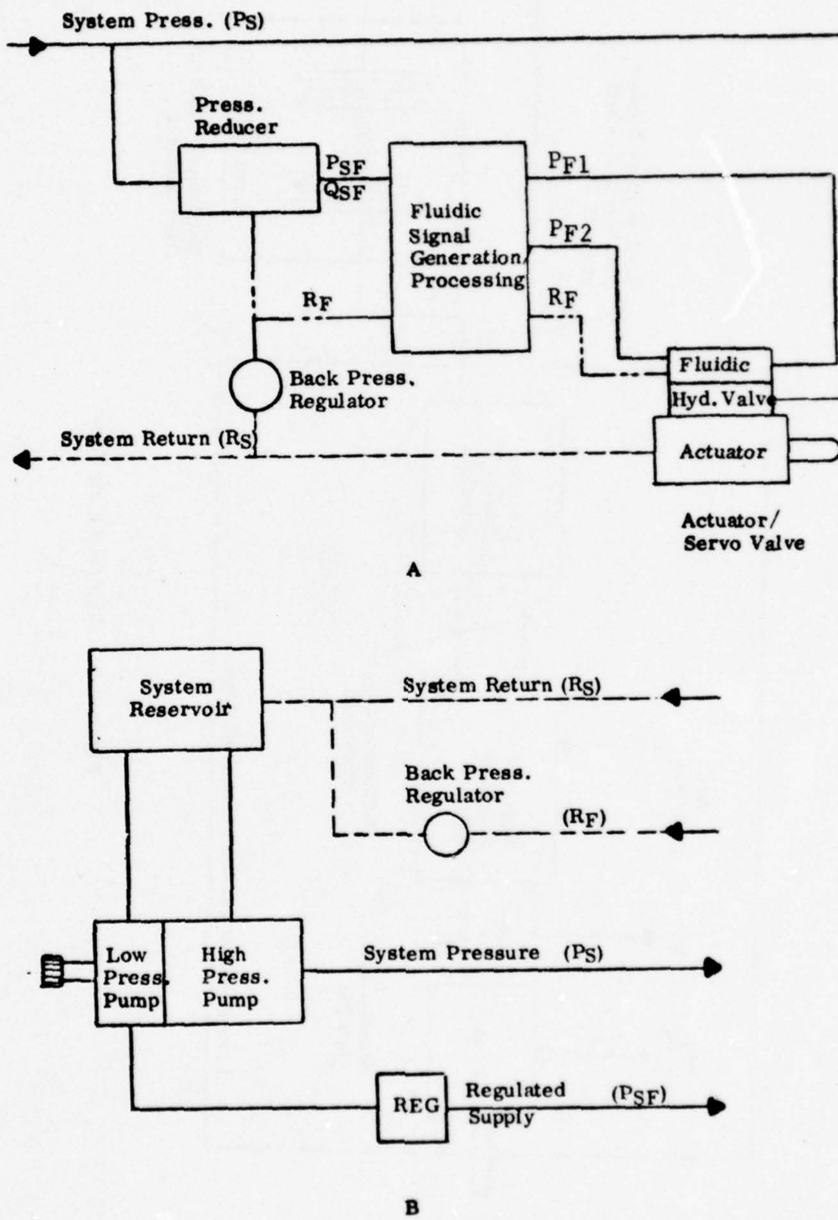


Figure 4-2. Potential Liquid Fluidic Supply Systems

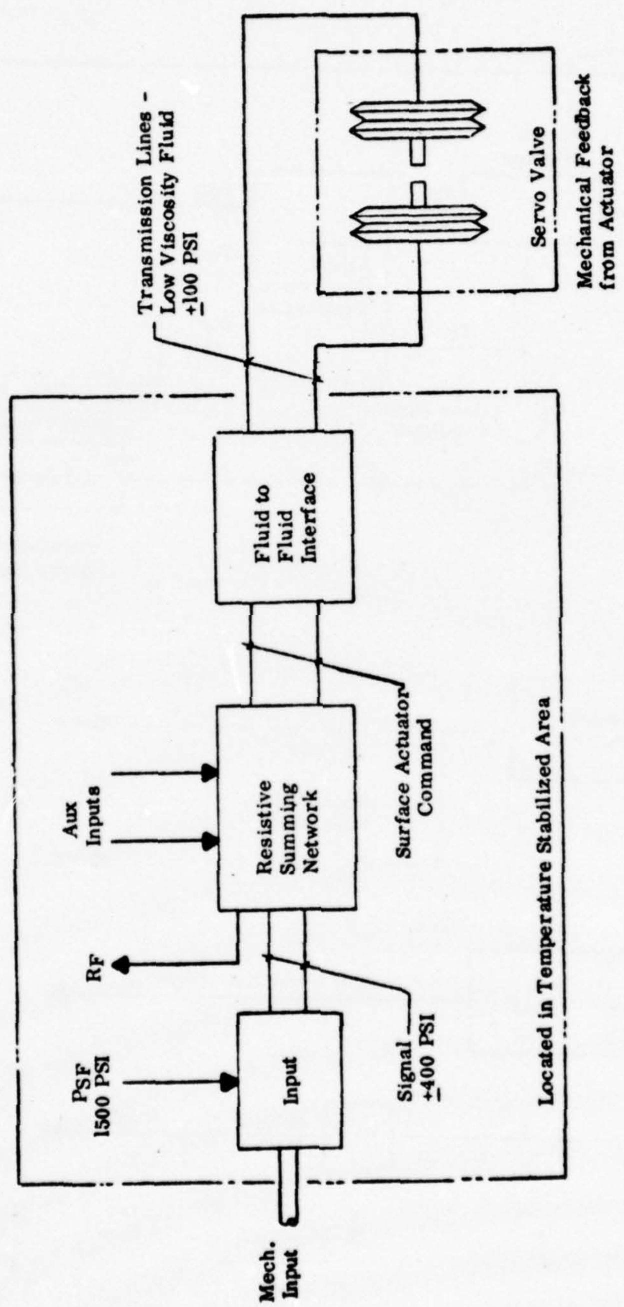


Figure 4-3. Typical Fly By Tube

Contamination - Most existing and all new Navy aircraft contain or will contain 5 micron absolute filtration. Filtration to this level is more than adequate for any hydrofluidic system. The addition of 10 micron or coarser filters (or screens) may be required ahead of more sensitive components to protect them from built in contaminants or contaminants generated within the system by mechanical regulators, reducers, etc.

Although not generally considered contamination, the presence of entrained or dissolved air in the liquid fluidic system can produce results similar to particulate contamination. The presence of air in present day hydraulic system operation can cause erratic operation of actuators by chattering, flutter, reduced stiffness, etc., but never loss of control. In hydrofluidic systems of the effect higher than normal amounts of entrained air, a slug of air or dissolved air outgassing in the low pressure portions of the fluidic circuits must be considered to assure that the transient effect is nothing more severe than performance degradation. Air in hydraulic systems has always been of concern, but will undoubtedly be given more attention in systems which include hydrofluidics.

4.2 POTENTIAL CONFIGURATIONS

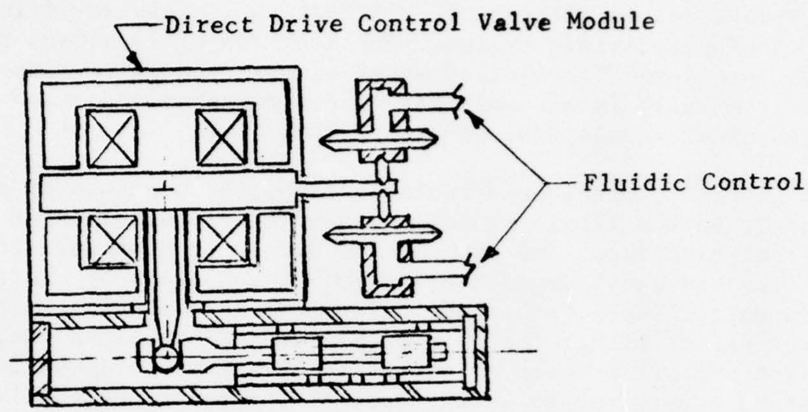
Basic Conceptual Approach

Four (4) basic conceptual approaches for integrating a fluidic back-up control function into the AFCAS actuator direct drive control valve module were conceived by Rockwell CAD as illustrated in Figures 4-4 and 4-5. These concepts were developed to act as a design point of departure for discussions with various speciality suppliers and to motivate innovative applications of relative technologies in each of their areas of expertise. The approaches were devised such that functionally it is possible to utilize either gaseous or liquid type fluidic systems.

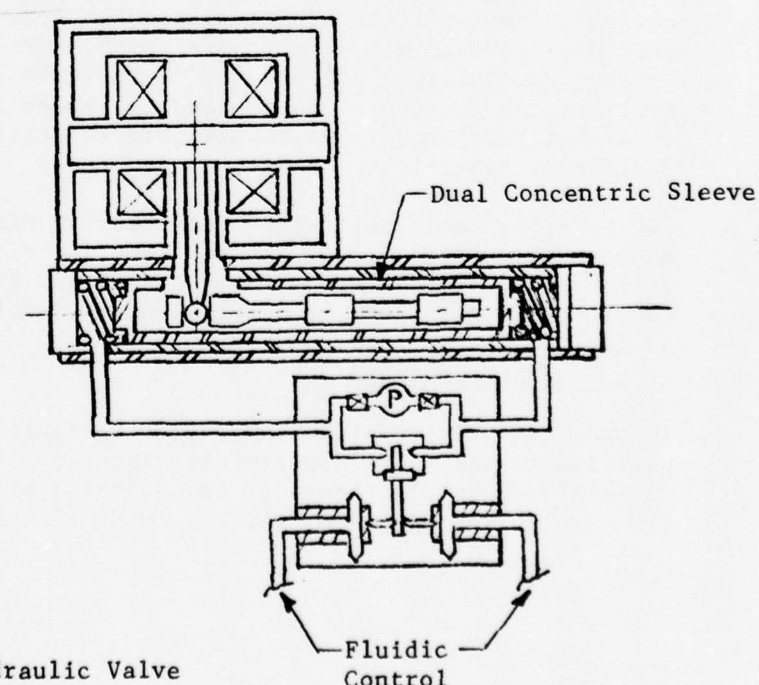
The four (4) basic approaches presented in Figures 4-4 and 4-5 illustrate two methods (I and IV) for mechanical coupling of fluidic control with the direct drive valve. The other two methods (II and III) illustrate a means of hydraulic coupling of the fluidic control element with the direct drive valve.

Feedback Concepts

In order to provide a fluidic feedback signal for determining the actuator position, a mechanical-to-fluidic transducer is a commonly utilized method. It is also possible, however, to utilize a mechanical linkage feedback which can provide for torque or force summing at the fluidic control element.

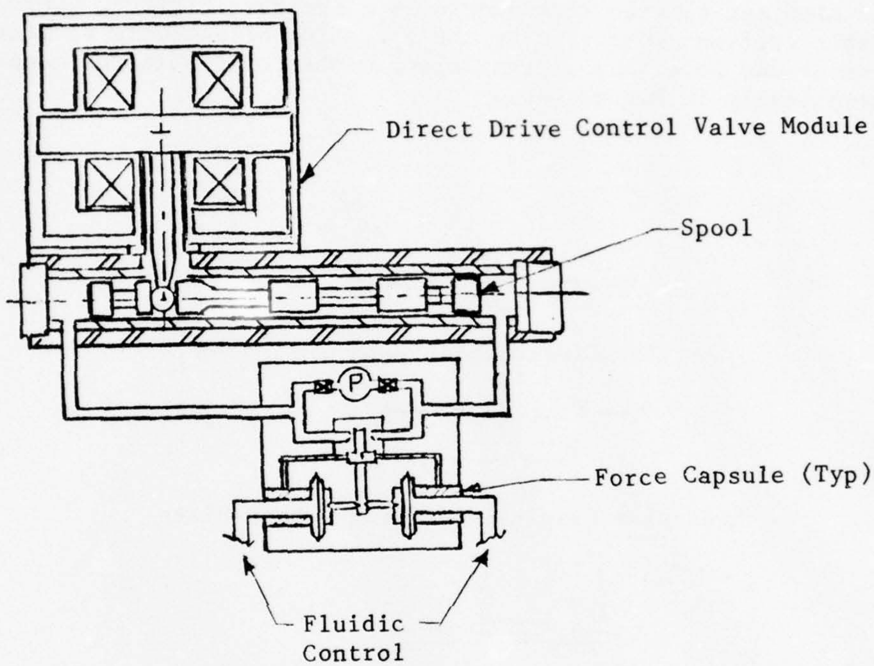


I Fluidic Direct Drive - Mechanical Couple
(Pneumatic/Mechanical)

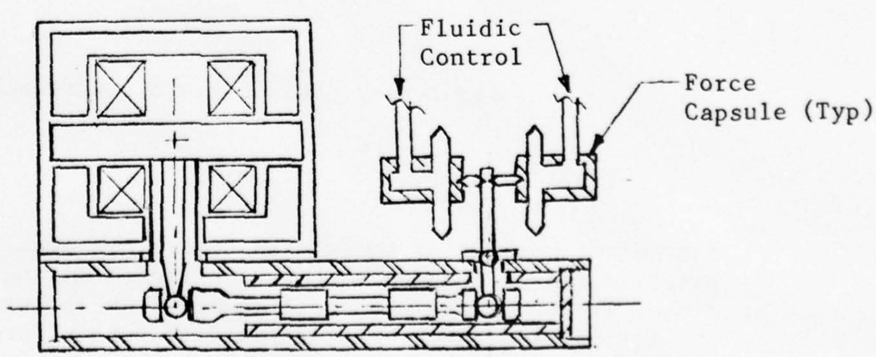


II Dual Concentric Hydraulic Valve
(Pneumatic/Hydraulic)

Figure 4-4. Fluidic Control Concepts I & II



III Fluidic to Hydraulic Spool Drive
(Pneumatic/Hydraulic)



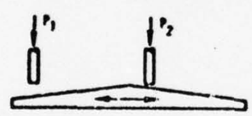
IV Fluidic Direct Drive - Mechanical
(Pneumatic/Mechanical)

Figure 4-5. Fluidic Control Concepts III & IV

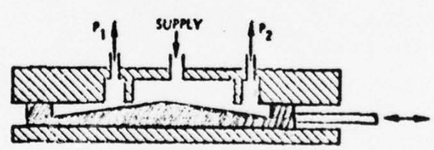
One of the simplest fluidic transducers is a pressure divider, where the exit is a variable orifice controlled by the operation of a moving element. The moving element can be either a translating member or a rotating member as shown schematically in Figure 4-6.

Angular Displacement with Cam

Angular Displacement with Wobble Plate



Linear Displacement with Up-Down Ramp



Linear Displacement with Variable Orifices

Figure 4-6. Basic Fluidic Feedback Concepts

The output nozzles of these transducers are each supplied from a constant pressure source through a choked orifice. As the displacing member moves closer to one nozzle and further away from the other, the resulting changes in back pressure are reflected in differential pressure signals at the output P_1 and P_2.

A mechanical feedback approach, as previously mentioned, is illustrated in Figure 4-7.

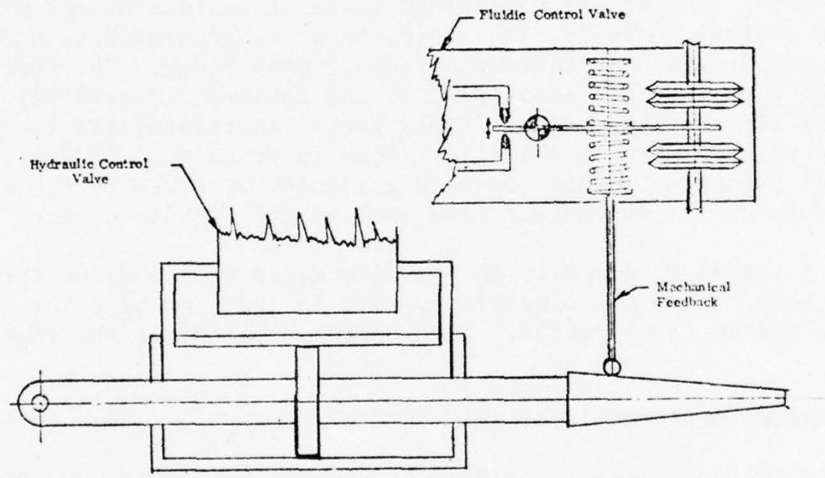


Figure 4-7. Mechanical Feedback Concept

This device mechanically provides a force directly related to actuator piston position which is reflected back to the fluidic input force elements and force summing is accomplished at that point.

Supplier Design Concepts

Fluidic (Gaseous) Control Concept - A gaseous fluidic control concept integrated with an AFCAS actuator utilizing a direct drive control valve is shown schematically in Figure 4-8. This design concept was presented by AiResearch Manufacturing Co. of Phoenix, Arizona.

The fluidic control concept shown in Figure 4-8 would modify the direct drive force motor to provide an alternate force input which would become active following loss of all electrical power or failure of all primary fly-by-wire control channels. The force input is generated by a pair of force capsules driven by a pneumatic fluidic gain block. The force produced in the force capsules is proportional to the applied differential pressure and provides the required torque. This torque is transmitted to the hydraulic spool valve which displaces and allows flow to enter the actuator. The differential pressure fluidic feedback transducer, driven by the actuator, is utilized to close the control loop back to the fluidic control element.

This back-up system is normally in the disengaged mode and the forward gain reduced to zero. When all electrical power is lost, or by pilot selection, the back-up system is energized. This approach minimizes the engage transient.

A block diagram (math model) of this control concept is shown in Figure 4-9.

Hydrofluidic Control Concept - A control concept utilizing hydrofluidics and integrated into an AFCAS actuator with a direct drive control valve is shown schematically in Figure 4-10. This approach is essentially as proposed by Hydraulic Servocontrols Corporation of Buffalo, New York; a candidate supplier who provided support during this study program.

The design approach features the use of mechanical feedback which is a well proven technique and highly reliable. The input and feedback forces are summed at relatively high levels which permits the use of larger orifices, nozzles and nozzle to flapper clearances in the hydraulic amplifier stage than are normally found in conventional electrohydraulic servo valves.

The differential fluidic input signal is summed at the flapper assembly through the use of force capsules. Most of the features incorporated in this design concept have been used previously by Hydraulic Servocontrols Corp.

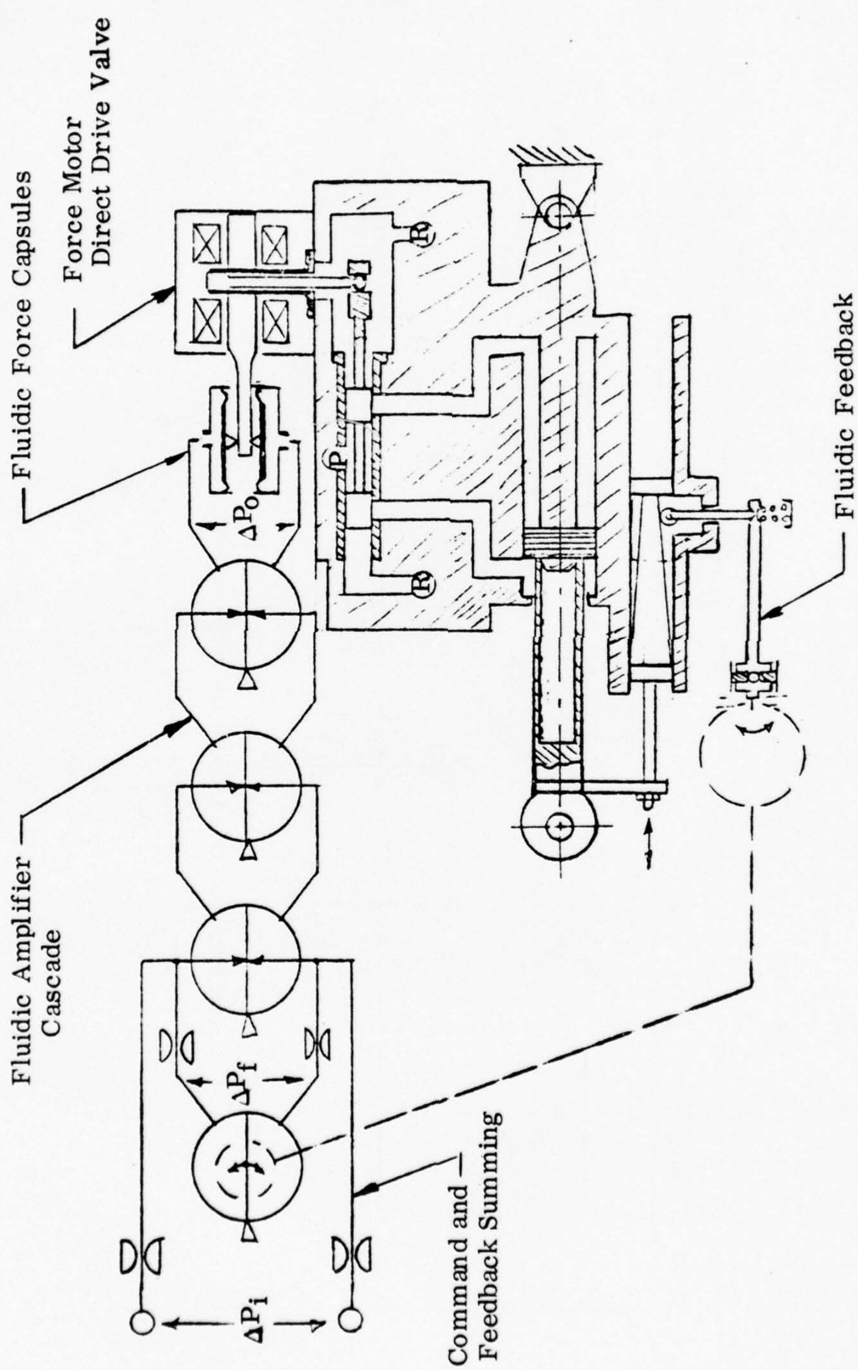


Figure 4-8. Fluidic (Gaseous) Control Concept

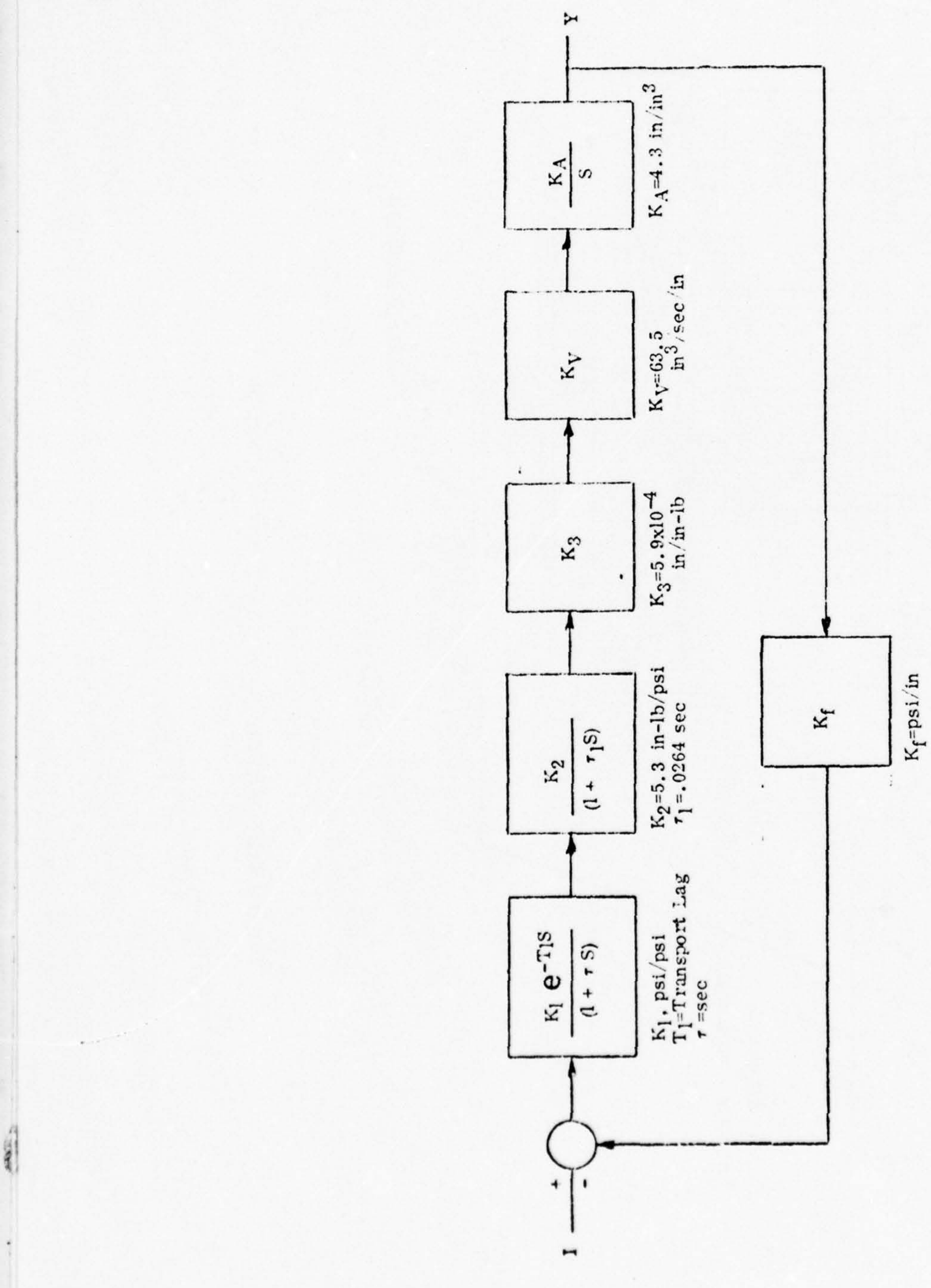


Figure 4-9. Math Model Fluidic Controlled Actuator

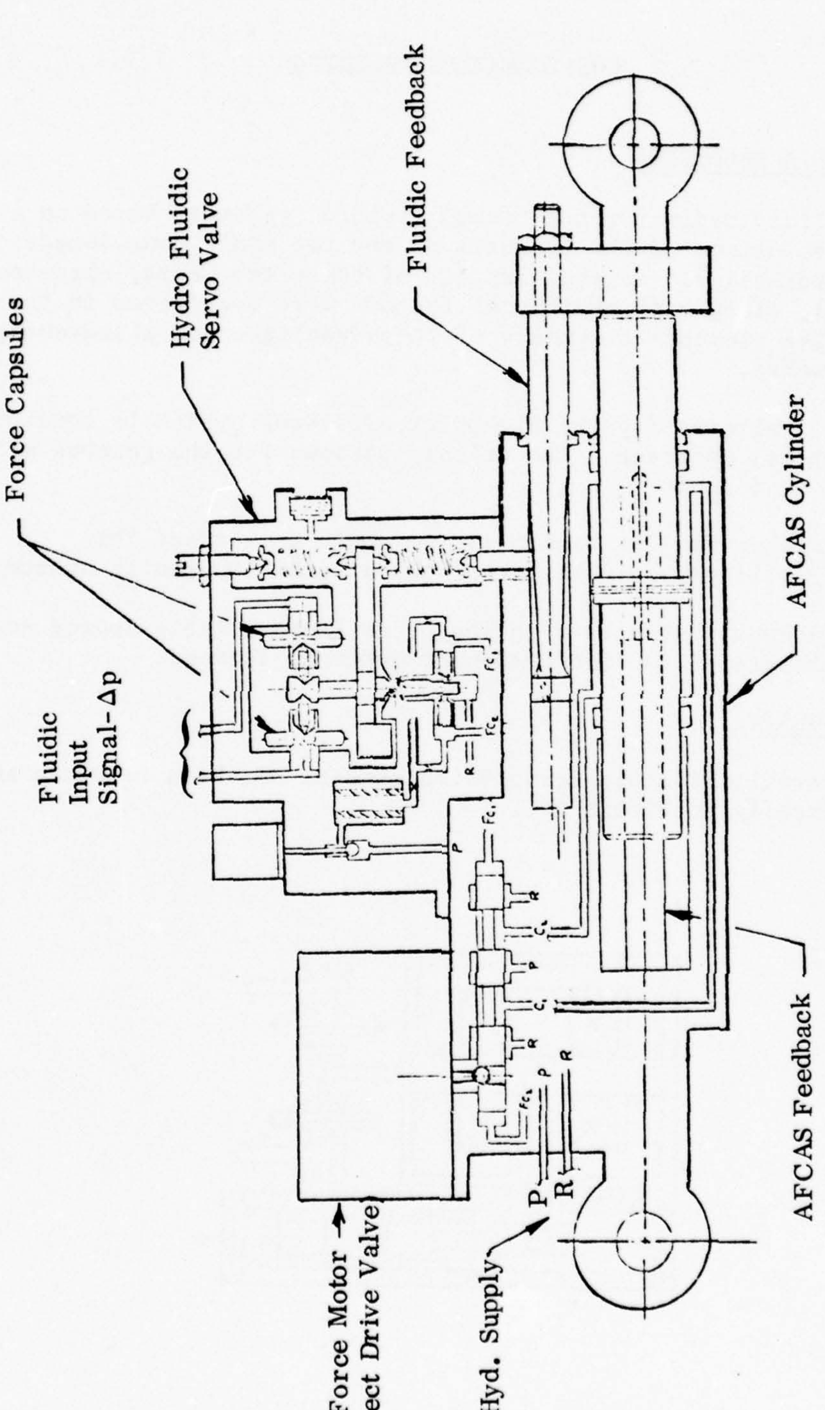


Figure 4-10. Hydro Fluidic Control Concept

5.0 CONFIGURATION SELECTION

5.1 FLUID MEDIA SELECTION

Selection of fluid media for the backup fluidic system is based on a qualitative evaluation of the features of the two media considered: gaseous vs. liquid (hydraulic). Several aspects of these two media, discussed in paragraph 4-1, along with additional factors were considered in the selection. Table 5-1 presents a summary of the advantages and disadvantages of the two approaches.

From an overall aircraft/system viewpoint a gaseous system is considered the most practical approach. The primary reasons for the gaseous media selection are as follows:

- The gaseous fluidic backup system would not affect the vulnerability/survivability of the aircraft hydraulic system.
- The gaseous system is supplied by an inexhaustable source and is insensitive to line/component external leakage.

5.2 VALVE CONCEPT

An Electro/Hydraulic/Fluidic Servo Valve concept has been selected and is shown schematically in Figure 5-1.

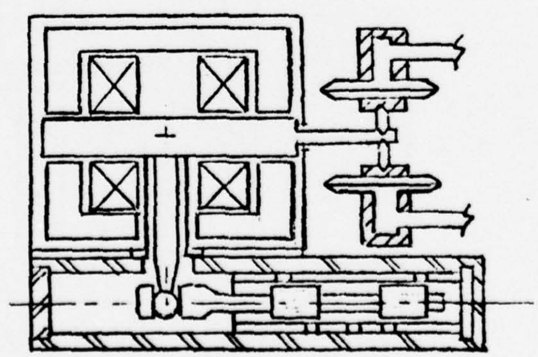


Figure 5-1. Electro/Fluidic, Hydraulic Servo Control Valve

Table 5-1. System Media Comparison

LIQUID

ADVANTAGES

- o HIGHER SIGNAL PRESSURES FEASIBLE
- o USES AIRCRAFT FILTRATION
- o HIGHER SIGNAL TRANSMISSION PERFORMANCE POTENTIAL
- o POTENTIAL FLY-BY-TUBE APPLICATION FOR REMOTELY LOCATED ACTUATORS

DISADVANTAGES

- o ADDED HEAT LOAD IN 8000 PSI SYSTEM
  OR
- o AUXILIARY PUMP FOR FLUIDIC SUPPLY REQUIRED
- o HEAVIER TRANSMISSION LINES
- o POTENTIAL PROBLEMS WITH ENTRAINED AIR
- o WILL INCREASE AIRCRAFT HYDRAULIC SYSTEM VULNERABILITY TO GUN FIRE
- o WILL REDUCE AIRCRAFT HYDRAULIC SYSTEM RELIABILITY
- o MORE SENSITIVE TO TEMPERATURE CHANGES
- o INCREASES AIRCRAFT PUMP AND RESERVOIR CAPACITY REQUIREMENTS
- o NOT EXTERNAL LEAKAGE TOLERANT
- o NO PRODUCTION HARDWARE FOR DATA BASE

GASEOUS

ADVANTAGES

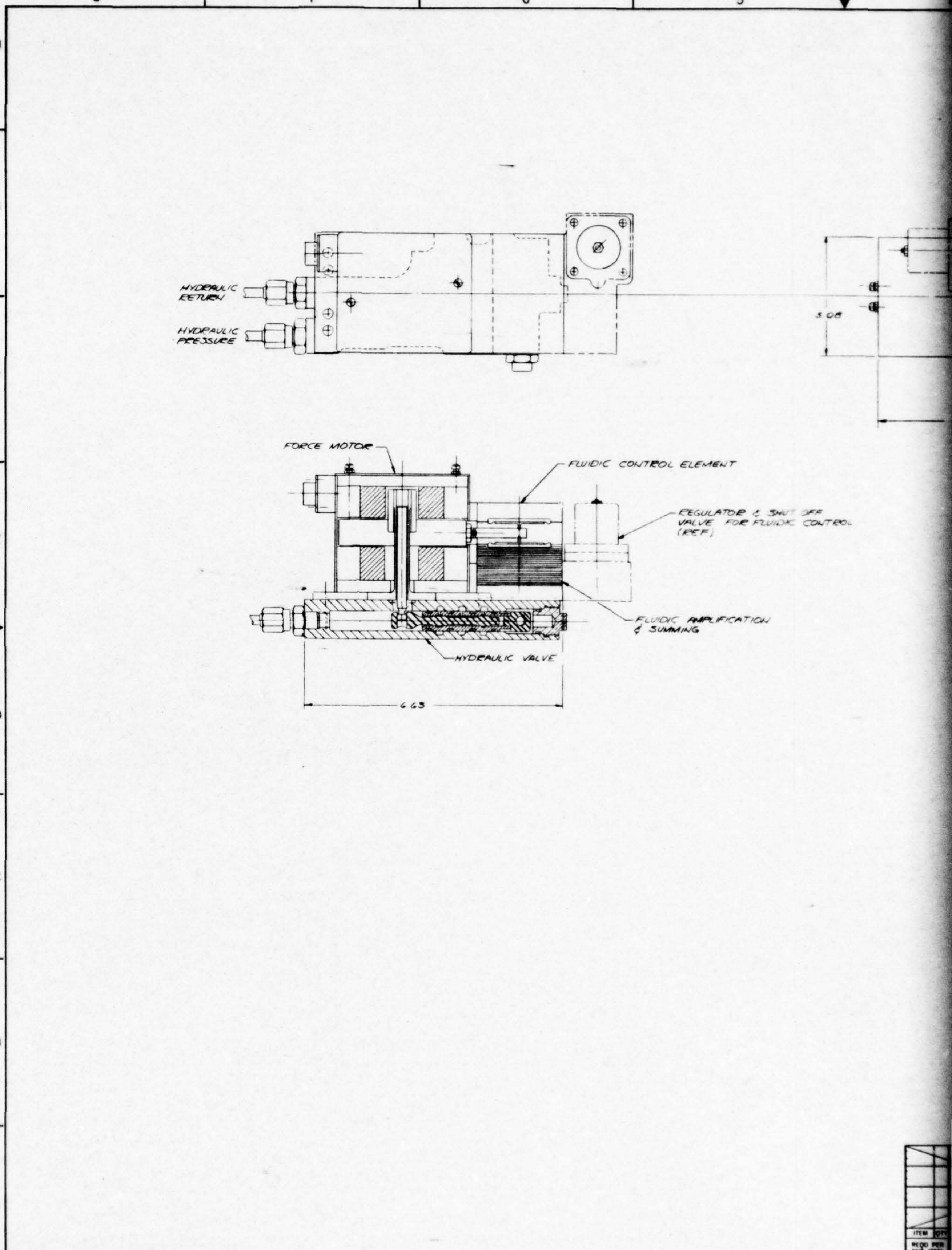
- o INEXHAUSTIBLE SUPPLY
- o EXTERNAL LEAKAGE TOLERANT
- o TOLERANT OF HARSH ENVIRONMENT
- o GOOD DATA BASE
- o EASY TO HANDLE
- o COMPATIBLE WITH POTENTIAL GASEOUS FLUIDIC ENGINE CONTROL, INTEGRATED PROPULSION SYSTEMS
- o EASIER TO MAINTAIN (REMOVE & REPLACE)
- o NO AFFECT ON EXISTING HYDRAULIC SYSTEM RELIABILITY OR VULNERABILITY

DISADVANTAGES

- o LOW SIGNAL PRESSURE LEVELS RESULTING IN LARGER FORCE CAPSULE
- o LOW SUPPLY PRESSURE AT LOW POWER SETTINGS
- o REQUIRES CONDITIONER-MOISTURE REMOVAL, FILTRATION, PRESSURE REGULATION, ETC
- o LONG LENGTH SIGNAL TRANSMISSION-PERFORMANCE NOT YET DEFINED (APPROX 1 MILLISECOND/FT DELAY)

5.3 PRELIMINARY DESIGN

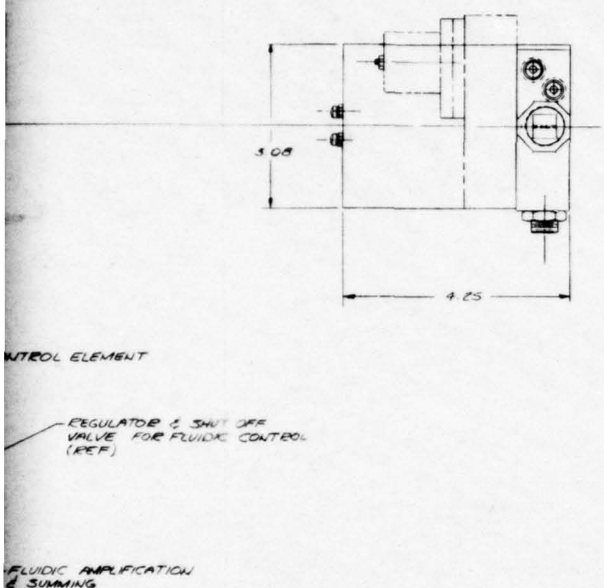
A preliminary design was developed for the Electro/Hydraulic/Fluidic servo control valve, utilizing the selected concept. The design, P/N S.O. 4294-1, is shown in Figure 5-2. The pressure regulator and shut-off valve is shown on the drawing for reference purposes since it may not necessarily be a part of the valve module. Overall dimensions have been shown for envelope definition. This is the envelope of the existing R&D AFCAS Direct Drive Valve Module.



HYDRAULIC RETURN
HYDRAULIC PRESSURE
3.08
FORCE MOTOR
FLUIDIC CONTROL ELEMENT
REGULATOR & SHUT OFF VALVE FOR FLUIDIC CONTROL (REF)
FLUIDIC AMPLIFICATION & SUMMING
HYDRAULIC VALVE
6.63

1

2



REVISIONS					
ZONE	LTR	DESCRIPTION	DISPN	DATE	APPROVED
		1 MAY BE REWORKED 2 CANNOT BE REWORKED 3 RECORD CHANGE 4 NOW SHOP PRACTICE 5 PARTS MADE OK			

QTY REQD		FSCM NUMBER	PART OR IDENTIFYING NUMBER	NOMENCLATURE	MATERIAL	THKNS GAUGE	WIDTH OD/ID	LG	DRAWING OR SPECIFICATION NUMBER	ZONE	ITEM OR FIND NO
											012
											011
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PARTS LIST

ITEM	QTY	NEXT ASSY	USED ON	END ITEM NO.	THRU
REQD PER END ITEM		APPLICATION		EFFECTIVITY	

HEAT TREAT

FINISH

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
MFG TOLERANCES ON
UNDIMENSIONED ± .03
XX (DECIMALS) ± .03
XXX (DECIMALS) ± .010
ANGLES ± 30'
HOLES NOTED "DRILL"
013 THRU 040 + 001 - 001
041 THRU 130 + 002 - 001
131 THRU 229 + 003 - 001
230 THRU 500 + 004 - 001
501 THRU 750 + 005 - 001
751 THRU 1.000 + 007 - 001
1.001 THRU 2.000 + 010 - 001
DO NOT SCALE PRINT

CONTR NO
DWN BY C. Brown 10/13/78
CHK BY
APVD L. SIAPORK

Rockwell International Corporation
Columbus Aircraft Division
Columbus, Ohio 43216

ELECTRO/FLUIDIC, HYDRAULIC DIRECT DRIVE CONTROL VALVE

SIZE E | FSCM NO 89372 | SO 4294-1
SCALE | SHEET

NA-6-2 REV 7-78

FIGURE 5-2

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The results of this feasibility study, as documented herein, have resulted in the following conclusions:

1. A fluidic back-up control concept which will be compatible with the Navy's AFCAS (Direct Drive Fly-by-Wire Control Valve) approach is feasible.

2. The gaseous fluidic type system has been further developed than the liquid type system, although both possess unique advantages and disadvantages. Gaseous is considered to offer the most benefits for the design concept selected during this study.

3. Power sources for a gaseous system are readily available for aircraft systems; however, pressure regulation and filtering may require further evaluation.

4. An area for further evaluation and development efforts is the long signal transmission lines normally associated with an aircraft system installation and the techniques associated with signal transmission.

6.2 RECOMMENDATIONS

The following recommendations are proposed as a result of the findings of this feasibility study:

1. It is recommended that a fluidic back-up control design concept, such as selected and described in Section 4.0 of this report, be further developed.

2. Further development of an Electro/Hydraulic/Fluidic control valve should include design, fabrication and laboratory testing.

3. The design should be directed to an existing system application, such as the T-2C AFCAS rudder installation, which would allow for flight test and evaluation at a future time period.

APPENDIX "A"

REFERENCE	ACCESSION NUMBER TITLE AUTHOR DATE	REPORT NUMBER PERFORMING ORGANIZATION
1	AD INVESTIGATION OF A LOW COST SERVO ACTUATOR FOR HYSAS JAMES O. HEDEEN JULY 1978	USARTL-TR-78-30 HONEYWELL ST. LOUIS PARK, MINN.
2	AD A055854 THE SMALL SIGNAL RESPONSE OF FLUID TRANSMISSION LINES, INCLUDING DEVELOPED MEAN FLOW EFFECTS ERNEST F. MOORE MARCH 1978	AFFDL-TR-78-12 AIR FORCE FLIGHT DYNAMICS LAB WRIGHT-PATTERSON AFB, OHIO
3	AD A049256 FLUIDICS - BASIC COMPONENTS AND APPLICATIONS JAMES W. JOYCE, RICHARD N. GOTTRON OCTOBER 1977	HDL-SR-77-6 HARRY DIAMOND LABS ADELPHI, MD
4	AD A047643 HYDROFLUIDIC STABILITY AUGMENTATION SYSTEM (HYSAS) DEMONSTRATION LLOYD J. BANASZAK, WALTER M. POSINGIES OCTOBER 1977	USAAMRDL-TR-77-31 OPERATIONAL SUITABILITY HONEYWELL ST. LOUIS PARK, MINN
5	AD A041145 HANDBOOK OF FLUIDIC SENSORS LEONARD M. SIERACKI MAY 1977	HDL-CR-77-787-1 LORELEI CORPORATION GAITHERSBURG, MD
6	AD B018420L DESIGN STUDY OF A FLIGHT CONTROL SYSTEM JAMES O. HEDEEN, WALTER M. POSINGIES JANUARY 1977	W0593-FR HONEYWELL ST. LOUIS PARK, MINN
7	AD A035724 RELIABILITY DATA FOR FLUIDIC SYSTEMS WALLIS T. FLEMING, HARRY R. GAMBLE DECEMBER 1976	HDL-CR-76-092-1 AIRESEARCH PHOENIX, AZ
8	AD A030893 HYDROFLUIDIC SERVOACTUATOR DEVELOPMENT J. ROBERT SJOLUND SEPTEMBER 1976	USAAMRDL-TR-76-25 HONEYWELL MINNEAPOLIS, MINN
9	AD A023466 DEVELOPMENT AND FLIGHT TEST OF AN ADVANCED HYDROFLUIDIC STABILIZATION SYSTEM DARROLL BENGSTON, JAMES HEDEEN, ROBERT HELFINSTINE FEBRUARY 1976	USAAMRDL-TR-76-2 HONEYWELL MINNEAPOLIS, MINN
10	AD A016932 ROLL AXIS HYDROFLUIDIC STABILITY AUGMENTATION SYSTEMS DEVELOPMENT DARROLL BENGSTON, THOMAS DICKOVITCH, ROBERT HELFINSTINE SEPTEMBER 1975	USAAMRDL-TR-75-43 HONEYWELL MINNEAPOLIS, MINN
11	AD A014571 PROGRAM TO DEVELOP A FLUIDIC APPROACH POWER COMPENSATOR FOR NAVAIRDEVCEN THOMAS R. TIPPETS, WILLIAM F. RYAN JUNE 1975	75-411029 AIRESEARCH PHOENIX, AZ
12	AD A012235 HYDROFLUIDIC SERVOVALVE DEVELOPMENT HOLGER C. KENT JUNE 1975	USAAMRDL-TR-75-21 HONEYWELL MINNEAPOLIS, MINN

REFERENCE	ACCESSION NUMBER TITLE AUTHOR DATE	REPORT NUMBER PERFORMING ORGANIZATION
13	AD 787546 PROCEEDINGS OF THE FLUIDIC STATE-OF-THE-ART SYMPOSIUM, 30 SEPT - 3 OCT 74, VOL 1 VARIOUS OCTOBER 1974	NONE HARRY DIAMOND LABS WASHINGTON, DC
14	AD 787547 PROCEEDINGS OF THE FLUIDIC STATE-OF-THE-ART SYMPOSIUM, 30 SEPT - 3 OCT 74, VOL 2 VARIOUS OCTOBER 1974	NONE HARRY DIAMOND LABS WASHINGTON, DC
15	AD 787548 PROCEEDINGS OF THE FLUIDIC STATE-OF-THE-ART SYMPOSIUM, 30 SEPT - 3 OCT 74, VOL 3 VARIOUS OCTOBER 1974	NONE HARRY DIAMOND LABS WASHINGTON, DC
16	AD 787549 PROCEEDINGS OF THE FLUIDIC STATE-OF-THE-ART SYMPOSIUM, 30 SEPT - 3 OCT 74, VOL 4 VARIOUS OCTOBER 1974	NONE HARRY DIAMOND LABS WASHINGTON, DC
17	AD 787550 PROCEEDINGS OF THE FLUIDIC STATE-OF-THE-ART SYMPOSIUM, 30 SEPT - 3 OCT 74, VOL 5 VARIOUS OCTOBER 1974	NONE HARRY DIAMOND LABS WASHINGTON, DC
18	AD A043737 PROCEEDINGS OF THE FLUIDIC STATE-OF-THE-ART SYMPOSIUM, 30 SEPT - 3 OCT 74, VOL 6 VARIOUS OCTOBER 1974	NONE HARRY DIAMOND LABS WASHINGTON, DC
19	AD 777804 HYDROFLUIDIC YAW SAS ANALYSIS, DESIGN AND DEVELOPMENT HARVY D. OGREN MARCH 1974	W0517-FR HONEYWELL MINNEAPOLIS, MINN
20	AD 778764 HYDRAULIC TO PNEUMATIC POWER SUPPLY FOR AIRCRAFT FLUIDIC SYSTEMS R. S. McCARTY, J. T. COX FEBRUARY 1974	74-410484 AIRESEARCH MANUFACTURING CO. PHOENIX, AZ
21	AD 919588 HYDROFLUIDIC FLY-BY-TUBE PRIMARY FLIGHT CONTROL SYSTEM ROBERT F. HELFINSTINE, HOLGER C. KENT FEBRUARY 1974	WO 561-FR HONEYWELL ST. LOUIS PARK, MINN
22	AD A002483 EVALUATION PROGRAM ON USING COMPRESSOR BLEED AIR AS A SOURCE OF PNEUMATIC POWER FOR FLUIDIC CIRCUITS R. S. McCARTY OCTOBER 1973	73-410307 AIRESEARCH PHOENIX, AZ
23	AD 768772 STATIC TEST PERFORMANCE CHARACTERISTICS OF SEVERAL FLUIDIC CONTROL VALVE CONFIGURATIONS TROY A. STREET, THOMAS L. KILLOUGH, ROBERT E. BECHT SEPTEMBER 1973	RD-TR-73-29 ARMY MISSILE COMMAND REDSTONE ARSENAL, AL
24	AD 766308 HYDROFLUIDIC SERVOACTUATOR DEVELOPMENT HOLGER C. KENT, J. ROBERT SJOLUND MAY 1973	USAAMRDL-TR-73-12 HONEYWELL MINNEAPOLIS, MINN

REFERENCE	ACCESSION NUMBER TITLE AUTHOR DATE	REPORT NUMBER PERFORMING ORGANIZATION
25	 NASA CONTRIBUTIONS TO FLUIDIC SYSTEMS - A SURVEY TERRY M. WEATHERS 1972	NASA SP-5112 COMPUTER SCIENCES CORPORATION FALLS CHURCH, VA
26	N73-12041 FLUIDIC EMERGENCY THRUSTER FOR AIRCRAFT T. S. HONDA NOVEMBER 1972	NASA-CR-114490 GENERAL ELECTRIC SCHENECTADY, NY
27	AD 754602 ADVANCED HYDROFLUIDIC STABILIZATION SYSTEM MARK E. EBSEN, JAMES O. HEDEEN OCTOBER 1972	USAAMRDL-TR-72-46 HONEYWELL MINNEAPOLIS, MINN
28	AD 743800 FLUERICS 23. A BIBLIOGRAPHY VONDELL CARTER, DAVID S. MARSH APRIL 1972	HDL-TR-1495 HARRY DIAMOND LABS WASHINGTON, DC
29	AD B025067L FLUIDICS FOR ADVANCED HIGH PERFORMANCE AIRCRAFT (HIPAF) WILLIAM BRENNER, THOMAS W. CONWAY, MICHAEL F. CYCON, JR. DECEMBER 1971	 GRUMMAN AEROSPACE CORPORATION BETHPAGE, NY
30	AD 726094 INVESTIGATION OF FLUIDIC HIGH INTENSITY SOUND GENERATOR B. R. TEITELBAUM, L. B. TAPLIN MAY 1971	AFFDL-TR-70-98 BENDIX RESEARCH LAB SOUTHFIELD, MI
31	AD 722267 DESIGN STUDY OF A FLUIDIC ARMAMENT CONTROL SYSTEM MECHANIZATION FOR HELICOPTER GUN TURRETS J. O. HEDEEN MARCH 1971	21577-FR HONEYWELL MINNEAPOLIS, MINN
32	AD 717247 FLUERICS: 29. TRANSIENT RESPONSE OF SOME FLUIDIC COMPONENTS TO STEP WAVES AND APPLICATION TO MATCHING JORMA R. KATO SEPTEMBER 1970	HDL-TR-1531 HARRY DIAMOND LABS WASHINGTON, DC
33	AD 714200 A TECHNIQUE TO OBTAIN THE INPUT TO A FLUID TRANSMISSION LINE FROM MEASUREMENT OF THE OUTPUT NORMAN A. EISENBERG MAY 1970	HDL-TR-1499 HARRY DIAMOND LABS WASHINGTON, DC
34	AD 877308 DESIGN EVALUATION OF FLUID DEVICES SAMUEL J. SPURGEON, JR. MARCH 1970	RG-TR-70-9 ARMY INERTIAL GUIDANCE AND CONTROL LABORATORY AND CENTER REDSTONE ARSENAL, AL
35	AD 875483 FLUIDS - THE FIRST TEN YEARS. A BIBLIOGRAPHY WITH INDEXES H. S. RAWCLIFFE OCTOBER 1969	DREV. TN 1836/69 DEFENCE RESEARCH BOARD OF CANADA, QUEBEC
36	AD 864376 MARS II FLUIDIC CONTROL SYSTEM EVALUATION V. H. AYRE, J. G. WILLIAMS JUNE 1969	RG-TR-69-10 ARMY INERTIAL GUIDANCE AND CONTROL LABORATORY AND CENTER REDSTONE ARSENAL, AL
37	AD 856834 DEVELOPMENT AND FLIGHT TEST OF A POWER SUPPLY CONDITIONER FOR A FLUIDIC COMPUTER WILLIAM P. GARWOOD, JR. JULY 1969	NADC-AM-6911 NAVAL AIR DEVELOPMENT CENTER WARMINSTER, PA

REFERENCE	ACCESSION NUMBER TITLE AUTHOR DATE	REPORT NUMBER PERFORMANCE ORGANIZATION
38	AD 503309 ADVANCED FLUIDIC CONTROLS FOR INTEGRATED PROPULSION SYSTEMS - PART IV, DEMONSTRATION OF AN INTEGRATED PROPULSION SYSTEM CONTROL AT SIMULATED FLIGHT CONDITIONS USING FLUIDIC CONTROL TECHNIQUES R. H. PAMPERIN, R. D. SCHMIDT SEPTEMBER 1968	AFAPL-TR-68-31 (PART IV) HONEYWELL MINNEAPOLIS, MINN
39	AD 503306 ADVANCED FLUIDIC CONTROLS FOR INTEGRATED PROPULSION SYSTEMS - PART I, FLUIDIC SENSING, COMPUTATION AND LOGIC COMPONENTS E. G. JOHNSON, R. F. WATERS, R. H. PAMPERIN, ET AL SEPTEMBER 1968	AFAPL-TR-68-31 (PART I) HONEYWELL MINNEAPOLIS, MINN
40	A68-33311 A THEORETICAL INVESTIGATION OF FLUIDIC TRANSMISSION LINES WITH RECTANGULAR CROSS SECTION H. SCHAEDEL MAY 1968	CRANFIELD FLUIDICS CONF. TURIN, ITALY
41	AD 503307 ADVANCED FLUIDIC CONTROLS FOR INTEGRATED PROPULSION SYSTEMS - PART II, MATERIALS AND FABRICATION TECHNIQUES FOR HIGH TEMPERATURE ENGINE CONTROLS K.E. SOLIE, L. L. SHERWOOD, R. F. WATERS APRIL 1968	AFAPL-TR-68-31 (PART II) HONEYWELL MINNEAPOLIS, MINN
42	AD 503308 ADVANCED FLUIDIC CONTROLS FOR INTEGRATED PROPULSION SYSTEMS - PART III, FLUIDIC TECHNIQUES FOR MULTIPLE ENGINE THRUST STABILITY CONTROL R. F. WATERS, J. L. HAUGEN APRIL 1968	AFAPL-TR-68-31 (PART III) HONEYWELL MINNEAPOLIS, MINN
43	AD 659415 FLUIDIC SYSTEMS DESIGN MANUAL CHARLES A. BELSTERLING JULY 1967	USAAVLABS-TR-67-32 CONRAC CORPORATION ASTROMECHANICS RES. DIV. MALVERN, PA
44	AD 810265 INVESTIGATION OF FLUID STATE DEVICES FOR INSTRUMENTATION AND COMPUTATION OF AIR DATA (FLICA) J. S. SULICH, D. D. BARNARD, E. RAPPAPORT DECEMBER 1966	AFFDL-TR-66-133 BENDIX CORPORATION SOUTHFIELD, MI

APPENDIX "B" HC284-XXXX

PRELIMINARY DESIGN SPECIFICATION

FLUIDIC CONTROL VALVE

1.0 APPLICATION

The fluidic control valve described in this specification is intended to be used as part of a backup fluidic control system concept (Figure 1-1) for the AFCAS (Advanced Flight Control Actuation System) fly-by-wire actuator, which normally functions with a direct-drive single-stage control valve. The backup fluidic control valve concept will also include a feedback transducer and/or concept for closing the loop around the actuator and fluidic valve.

1.1 AFCAS DESCRIPTION

The AFCAS program, sponsored by the Navy, is predicated upon the philosophy that primary flight controls should be as simple, direct, fool-proof, and rugged as possible. In accordance with this philosophy, an actuation system, illustrated in Figure 1-2 is being developed which is compatible with control of the primary surface actuators directly by an onboard digital computer or by a standby processor. Command signals are applied directly to the single stage control valve. Direct control of the surface actuator eliminates augmentation actuators. Actuator power is provided by 8000 psi localized, electrically or mechanically, driven hydraulic packages. Flexible building block components provides single or dual system surface actuators having the desired simplicity and hardware commonality for standard modularized actuators. A ruggedized direct drive single stage servo valve is utilized to eliminate contaminant sensitive small nozzles, flappers, and jet-pipes. The control

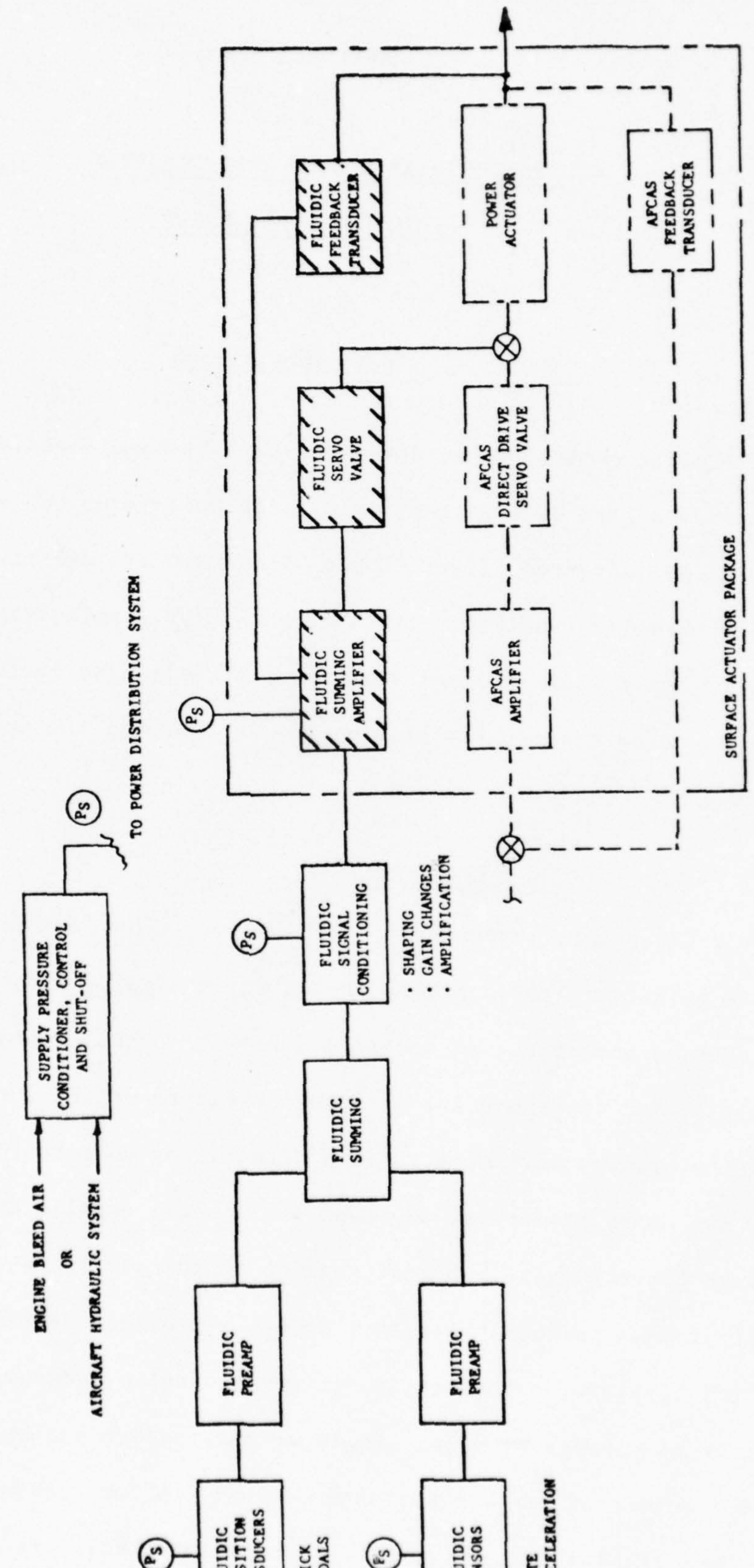


Figure 1-1. Fluidic Backup Control System

valve, a highly reliable single stage design combining high performance with simplicity and ruggedness, consisting of a spring centered 4-way spool, is driven by a high output torque motor. Replacement of the conventional two-stage hydraulic servo valve (8 ma control current) with a high force single stage concept results in a significant improvement in reliability because small moving parts that are susceptible to contamination and damage are eliminated, and the fragile fine wire wound torque motor is replaced with a large rugged unit employing advanced magnetic materials. The direct drive control valve conceptual arrangement is shown in Figure 1-3.

The AFCAS actuator shown in Figures 1-4 and 1-5 is to be used as a baseline for development of design concepts for a fluidic backup control valve.

1.2 FLUIDIC BACKUP CONTROL SYSTEM

The fluidic backup control system, of which the fluidic control valve described herein is a part of, will be designed to meet the following requirements:

1) A complete failure of the aircraft electrical system shall not prevent operation of the fluidic backup system.

2) In Standby mode, the fluidic backup system must not degrade the performance of the primary fly-by-wire AFCAS system.

3) The fluidic system should provide high reliability with minimum maintenance.

4) It must be possible to ground check operation of the backup system; however, electrical power may be used during ground check, if required.

5) Transfer of control to the backup system should be positive, with minimum control transient.

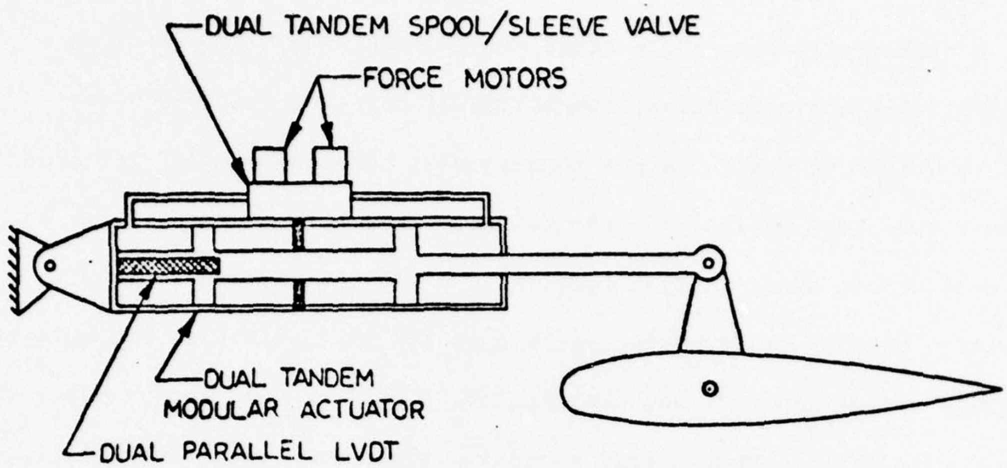


Figure 1-2. Advanced Flight Control Actuator

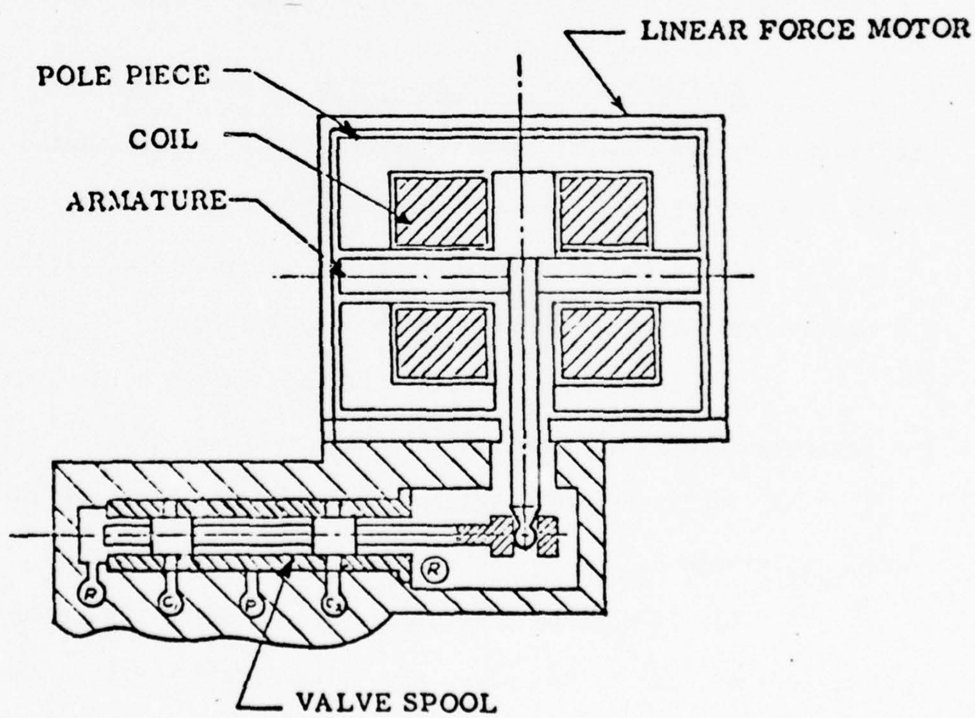


Figure 1-3. Direct Drive Control Valve Conceptual Arrangement

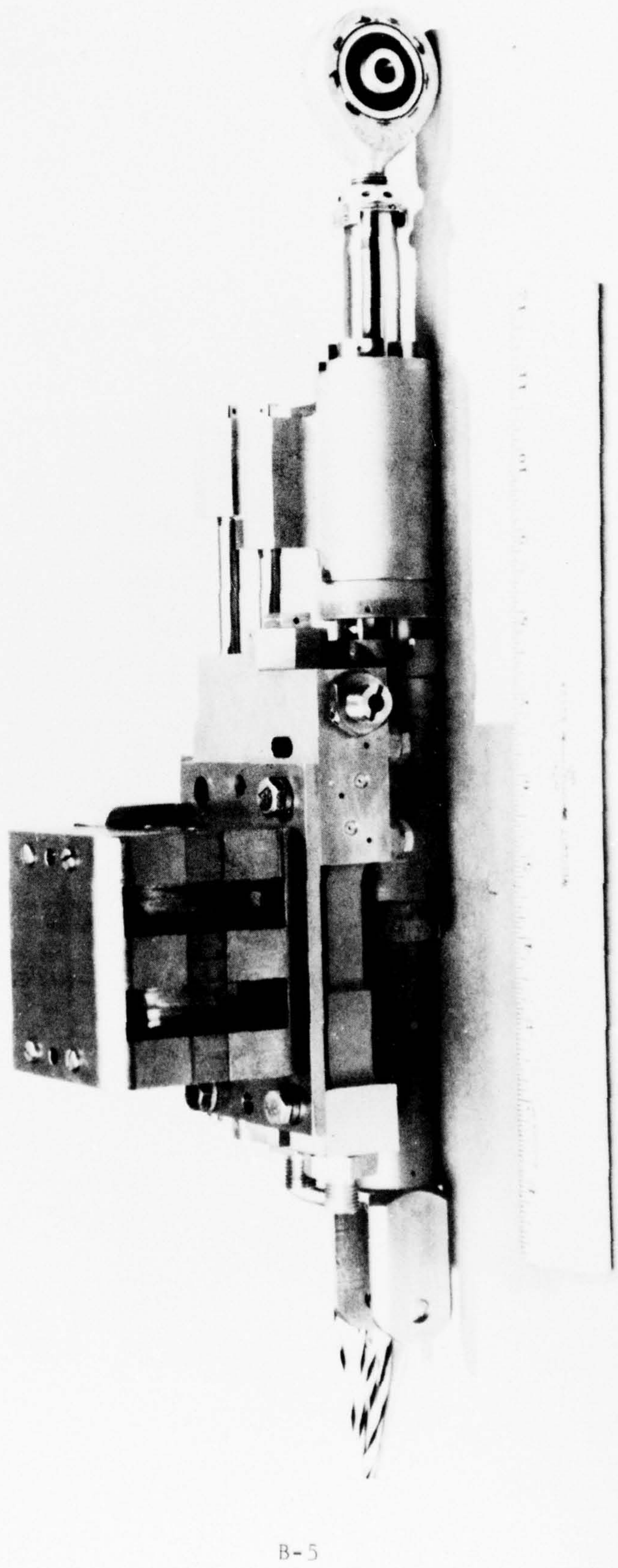
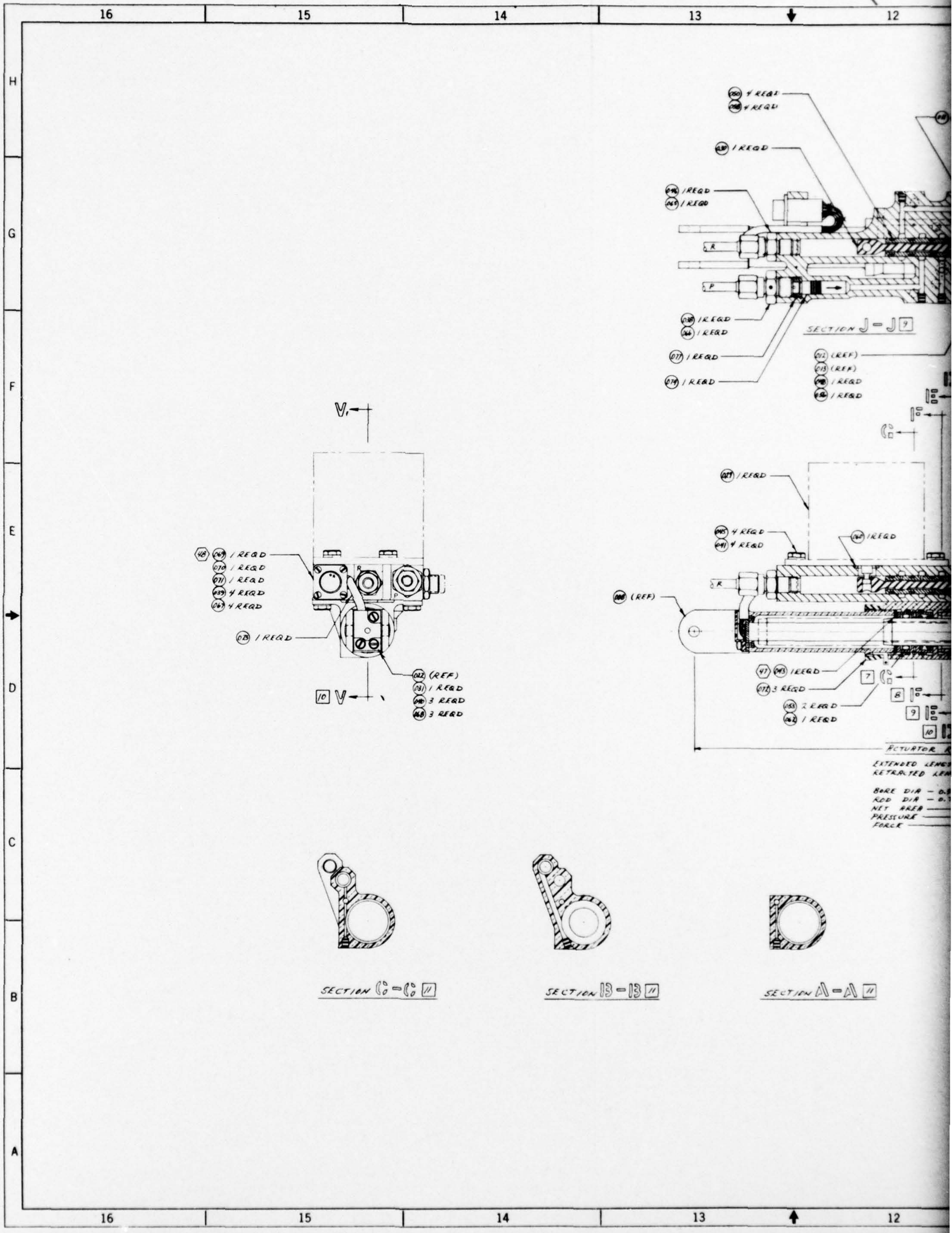
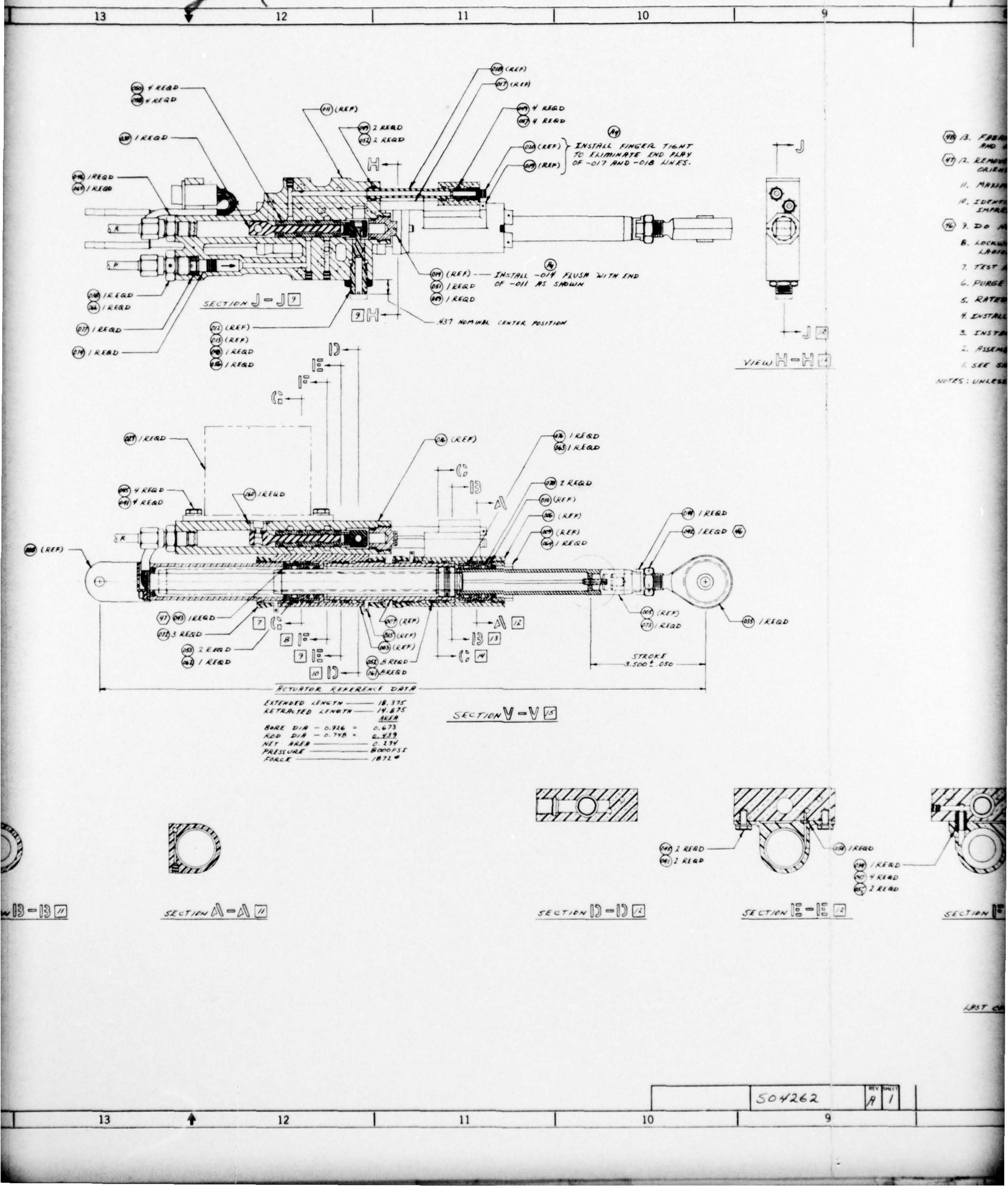


Figure 1-4. AFCAS Actuator P/N S.O. 4262-01


16
15
14
13
12
H
G
F
E
D
C
B
A
SECTION J - J 9
(REF)
1 REQD
4 REQD
3 REQD
2 REQD
V
10 V
7
8
9
10
ACTUATOR
BORE DIA
ROD DIA
NET AREA
PRESSURE
FORCE
SECTION C - C 11
SECTION B - B 11
SECTION A - A 11



INSTALL FINGER TIGHT TO ELIMINATE END PLAY OF -017 AND -018 LINES.
INSTALL -014 FLUSH WITH END OF -011 AS SHOWN
SECTION J-J
.437 NOMINAL CENTER POSITION
VIEW H-H
NOTES: UNLESS
ACTUATOR REFERENCE DATA
EXTENDED LENGTH 18.375
RETRACTED LENGTH 14.875
AREA
BORE DIA - 0.926 = 0.673
ROD DIA - 0.748 = 0.439
NET AREA 0.234
PRESSURE 8000PSI
FORCE 1872#
STROKE 3.500 ± .050
SECTION V-V
SECTION B-B
SECTION A-A
SECTION D-D
SECTION E-E
504262
REV A
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(48) 13. FABRICATE RECEPTACLE PER SPEC ST0113HA0054 AND ORIENT PIN "A" AS SHOWN.

(47) 12. REMOVE SHIMS AS REQUIRED TO OBTAIN KEYWAY ORIENTATION.

11. MAXIMUM SERVICE TEMPERATURE 275°F.

10. IDENTIFY PER SPEC LA0104-003, DO NOT METAL IMPRESSION STAMP.

(46) 9. DO NOT LOCKWIRE UNTIL INSTALLATION.

8. LOCKWIRE WITH MS20995NC32 WIRE PER SPEC LA0101-001.

7. TEST AND ADJUST PER PROCEDURES IN ZONE 15.

6. PURGE AND PROTECT PER SPEC HA0615-025.

5. RATED PRESSURE 8000 PSI.

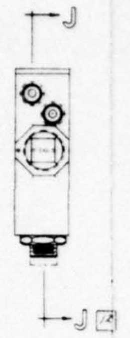
4. INSTALL HYDRAULIC FITTINGS PER SPEC FA6-20.

3. INSTALL THREADED FASTENERS PER SPEC LA0101-001.

2. ASSEMBLE AND DATE PER SPEC HY3.

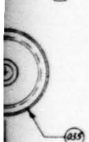
1. SEE SHEET 2 FOR DETAIL PART NOTES.

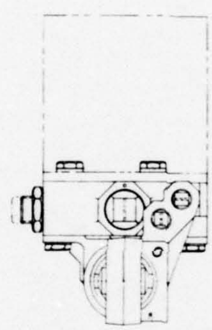
NOTES: UNLESS OTHERWISE NOTED (ASSY)

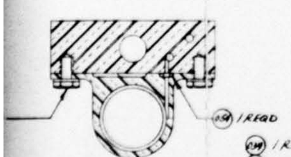


VIEW H-H 12

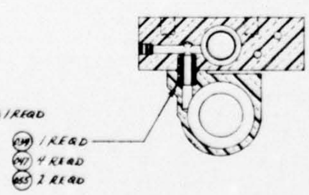
REQD
REQD (46)



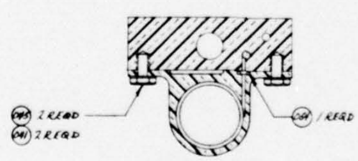




SECTION E-E 12



SECTION F-F 12



SECTION G-G 12

ITEM OR FIND NO	QUANTITY		031	021	011	BASIC REQUIRED	CODE IDENT	PART OR IDENTIFYING NUMBER	NOMENCLATURE	MATERIAL	THICK GAUGE MATERIAL
082											
081											
080											
079											
078						2	72902	7210FT-160-9009	SEAL SYS		
077			1				81873	100163	FILTER SCREEN		
076						1	97820	S20937	SEAL SYS		
075				4	4		92555	PLGA1871020	PLUG		
074			1				92555	CKFA3756005	CHECK VALVE		
073						1	71687	ANA-12777	PISTON RING		
072						3		NAS679S20	CYL LOCK NUT		
071						1		MS27666F-10-6	CLAMP		
070						1		MS27473T10F35S	PLUG		
069						1		MS27472T10F35P	RECEPTACLE		
068						3		MS35265-28	SCREW		
067						4		MS35265-13	SCREW		
066			1					MS28778-6	PACKING		
065			1					MS28778-4	PACKING		
064						1		MS28776M2-5	SCRAPER		
063						1		MS28775-214	PACKING		
062						1		MS28775-210	PACKING		
061						8		MS28775-024	PACKING		
060						1		MS28775-015	PACKING		
059			1					MS28775-014	PACKING		
058			4					MS28775-012	PACKING		
057			2			4		MS28775-011	PACKING		
056			1					MS28775-010	PACKING		
055						2		MS28775-009	PACKING		
054						2		MS28775-006	PACKING		
053						2		MS28774-210	RETAINER		
052						8		MS28774-024	RETAINER		
051			1					MS28774-014	RETAINER		
050			4					MS28774-012	RETAINER		
049			2			4		MS28774-011	RETAINER		
048			1					MS28774-010	RETAINER		
047						4		MS28774-009	RETAINER		
046			1					MS21902-4	UNION		
045						8		AN174H3A	BOLT		
044						1		2W15-6	LOCK WASHER		
043						1		2W1LB-52-38-62	WASHER		
042						1		1N7-8A	CHECK NUT		
041						8		LD153-0016-1004	WASHER		
040						3		LD153-0002-2201	WASHER		
039						4		LD153-0002-2200	WASHER		
038			1					ME286-0006-0001	FILTER		

PARTS LIST

LAST CODES USED: DD (ASSY)
GA (ACTR)
WV (VALVE)
(48) (NUMBER)

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4

5	4	3	2	1

REVISIONS

ZONE	LTR	DESCRIPTION	DSGN	DATE	APPROVED
		1 MAY BE REWORKED 2 CANNOT BE REWORKED 3 RECORD CHANGE 4 NOW SHOP PRACTICE 5 PARTS MADE OK			
	A	1. CHANGED FOLLOWING DIMS.:	1		
63D		2.059 (WAS) 2.094			
63D		1.489 (WAS) 1.524			
62D		.919 (WAS) .954			
46D		.60 (WAS) .50			
44B		.5000 (WAS) .3750			
36B		.044 ±.000/.010 (WAS) .050 ±.005			
52F		2. FULL THREAD .250 DEEP (WAS) THRU	1		
43D		3. ADDED DIMENSIONS	3		
10G		4. ADDED NOTES	3	1-5-76	GRIESEMER
		EFFECT ON: CONTRACT			

CODE IDENT	PART OR IDENTIFYING NUMBER	NOMENCLATURE	MATERIAL	THICK GAUGE	WIDTH OD/ID	LG	DRAWING OR SPECIFICATION NUMBER	ZONE
72902	7210FT-160-9003	SEAL SYS						10
81873	100163	FILTER SCREEN						13
37820	S20337	SEAL SYS						10
92555	PLGA1871020	PLUG						18,24, 16,[illegible] 53,[illegible] 12
92555	CKFA3756005	CHECK VALVE						13
71687	ANA-12777	PISTON RING						10
	NAS6995 20	CYL LOCK NUT						13
	MS27666F-10-6	CLAMP					MIL-C-38999	15
	MS27473T10F35S	PLUG					MIL-C-38999	15
	MS27472T10F35P	RECEPTACLE					MIL-C-38999	15
	MS35265-28	SCREW						14
	MS35265-13	SCREW						15
	MS28778-6	PACKING						13
	MS28778-4	PACKING						13
	MS28776M2-5	SCRAPER						10
	MS28775-214	PACKING						10
	MS28775-210	PACKING						13
	MS28775-024	PACKING						11
	MS28775-015	PACKING						12
	MS28775-014	PACKING						11
	MS28775-012	PACKING						13
	MS28775-011	PACKING						11/12
	MS28775-010	PACKING						12
	MS28775-009	PACKING						9
	MS28775-006	PACKING						7/9
	MS28774-210	RETAINER						13
	MS28774-024	RETAINER						11
	MS28774-014	RETAINER						11
	MS28774-012	RETAINER						13
	MS28774-011	RETAINER						11/12
	MS28774-010	RETAINER						12
	MS28774-009	RETAINER						9
	MS21902-4	UNION						13
	AN174H3A	BOLT						7,10, 13
	2W15-8	LOCK WASHER						10
	2W118-52-38-62	WASHER						13
	1H7-8A	CHECK NUT						10
	LD153-0016-1004	WASHER						7,10, 13
	LD153-0002-2201	WASHER						14
	LD153-0002-2200	WASHER						15
	MF286-0006-0001	FILTER					VENDOR ITEM, SEE SPEC CONT DWG	13

PARTS LIST

HEAT TREAT CODE	ITEM OR FIND NO	QTY	QTY	QTY 031	QTY 021	QTY 011	QTY BASIC	CODE IDENT	PART OR IDENTIFYING NUMBER	NOMENCLATURE	MATERIAL	THKNS GAUGE	WIDTH OD/ID	LG	DRAWING OR SPECIFICATION NUMBER	ZONE
	037															
	036															
	035						1		249-58736-11	ROD END						9
	034						1		247-587529	CONNECTOR						9
	033															
	032															
	031						1		504262-04	LVDT						15
	030			1					504262-03-21	SPOOL & SLEEVE						13
	029						1		504262-02	TORQUE MOTOR						13
	028															
	027															
	026															
	025															
	024															
	023						1		045	CONDUIT	6061-T6 AL ALY TUBE	.035 WALL	.250 OD	4.00	MIL-T-7081	15
	022						1		043	WIRING COVER	2024-T42 AL ALY BAR	.375	.875	1.25	QQ-A-225/6	34
	021															
45	020						1		039	CYLINDER PLUG	PH13-8Mo CRES ROD	—	0.75 DIA	1.50	ST0160LB0013	36
45	019						1		037	RETURN PLUG	PH13-8Mo CRES ROD	—	0.75 DIA	1.75	ST0160LB0013	36
45	018						1		035	CYLINDER LINE	PH13-8Mo CRES ROD	—	0.75 DIA	2.75	ST0160LB0013	40
45	017						1		033	RETURN LINE	PH13-8Mo CRES ROD	—	0.75 DIA	2.50	ST0160LB0013	40
	016						1		031	VALVE ASSY						
45	015						3		029	KEY	PH13-8Mo CRES BAR	0.50	0.75	0.75	ST0160LB0013	36
45	014			1					027	SLEEVE PLUG	PH13-8Mo CRES ROD	—	1.25 DIA	1.25	ST0160LB0013	50
45	013			1					025	JAM NUT	PH13-8Mo CRES ROD	—	1.25 DIA	0.50	ST0160LB0013	50
45	012			1					023	ADJUSTING SCREW	PH13-8Mo CRES ROD	—	0.75 DIA	2.50	ST0160LB0013	50
	011			1					021	VALVE BODY ASSY OF						52
	010						2		019	SEAL RETAINER	BE CUP ROD	—	1.25 DIA	1.25	LB0170-137 COND A	40
45	009						1		017	LOCKNUT	PH13-8Mo CRES ROD	—	2.00 DIA	1.00	ST0160LB0013	35
45	008						1		015	TAILSTOCK	PH13-8Mo CRES ROD	—	2.00 DIA	6.50	ST0160LB0013	43
45	007						1		013	CYLINDER	PH13-8Mo CRES ROD	—	2.00 DIA	4.50	ST0160LB0013	45
	006						1		011	CYL HEAD ASSY OF						23
44	005						1		009	ROD	4340 STEEL ROD	—	1.50 DIA	12.00	COND C1 MIL-S-5000	46
45	004				1				007	VALVE BODY	PH13-8Mo CRES BAR	1.25	4.00	6.75	ST0160LB0013	57
45	003						1		005	VALVE MTG HEAD	PH13-8Mo CRES BAR	3.00	4.00	3.50	ST0160LB0013	31
45	002					1			504262-01-003	CYLINDER HEAD	PH13-8Mo CRES BAR	3.00	4.00	3.50	ST0160LB0013	23
	001								504262-01	ACTR ASSY						

PARTS LIST

ITEM	QTY REQD PER END ITEM	NEXT ASSY	USED ON	END ITEM NO.	THRU
		APPLICATION		EFFECTIVITY	

HEAT TREAT CODED 44 45 SHEET 2

FINISH

INSPECT PER MIL-I-6870 (ST0501LT0007 CLASS)

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
MFG TOLERANCES ON UNDIMENSIONED ± .03
XX (DECIMALS) ± .03
XXX (DECIMALS) ± .010
ANGLES ± 30'

HOLES NOTED	DRILL
.013 THRU .040	+ .001 - .001
.041 THRU .130	+ .002 - .001
.131 THRU .229	+ .003 - .001
.230 THRU .500	+ .004 - .001
.501 THRU .750	+ .005 - .001
.751 THRU 1.000	+ .007 - .001
1.001 THRU 2.000	+ .010 - .001

DO NOT SCALE PRINT

CONTR NO.
DWN BY GRIESEMER 8-11-75
CHK BY
APVD

Columbus Aircraft Division
North American Rockwell
COLUMBUS, OHIO 43216

ACTUATOR ASSY - DIRECTIONAL, HYD. FLT. CONT. 8000 PSI

SIZE	CODE IDENT NO.	
J	89372	S04262-01

SCALE FULL | SHEET 1 OF 4

5	4	3	2	1

NR-G-3 REV 11-72

FIGURE 1-5

2.0 BASIC REQUIREMENTS

2.1 DEFINITION

The term "fluidic control valve" (FCV) in this document shall include all the fluidic devices required to provide a closed loop fluidic circuit around the hydraulic actuator.

2.2 ELECTRIC POWER

The fluidic control valve shall be capable of operating in the absence of all electric power.

2.3 FLUID MEDIA

The fluid media used in the fluidic circuit may be gaseous and/or hydraulic.

2.3.1 Gaseous fluidic circuits shall utilize aircraft engine bleed air. The selected pressures shall be compatible with existing military aircraft engines including the GE J85-4.

2.3.2 Hydraulic fluidic circuits shall utilize the existing hydraulic system as its power source. The system utilizes MIL-H-83282 hydraulic fluid and operates at a pressure level of 8000 psi.

2.4 HYDRAULIC INTERFACE

The FCV shall control the single stage spool/sleeve type hydraulic flow control valve which is controlling the 8000 psi hydraulic fluid to the power actuator cylinder.

2.5 INTEGRATION

Integration of the FCV into the AFCAS control loop may require changes to the primary direct drive spool/sleeve and/or torque motor detail design. Hardware design changes for interfacing are permissible; however, the direct drive concept must be maintained and the fluidic system must not compromise the performance of the primary fly-by-wire AFCAS system. The power actuator design should be considered flexible to accommodate a position transducer. See Paragraph 3.2 for further discussion on interface requirements.

3.0 DETAIL REQUIREMENTS

3.1 ENVIRONMENTAL

The FCV shall be capable of satisfactory performance when exposed to the following environmental conditions:

Ambient Temperature	-65° to +160°F
Vibration	Per MIL-STD-810
Sand and Dust	Per MIL-STD-810
Altitude	Sea Level to 40,000 Feet

3.2 INTERFACE REQUIREMENTS

3.2.1 Existing Torque Motor/Spool - The AFCAS concept for interfacing the torque motor output member with the valve spool shall be maintained; however, the spool and output may be reconfigured to facilitate the fluidic/spool interface.

3.2.2 Torque Motor - The FCV may interface directly with the torque motor armature if desired; however, the fluidic system must not compromise the performance of the primary fly-by-wire system.

3.2.3 Envelope - All components of the FCV shall fall within the envelope of Figure 3-1. If desired, the fluidic position transducer may replace one of the existing electrical position transducers with modifications as required.

3.2.4 Valve Housing - The existing valve housing may be redesigned as required to accommodate the FCV.

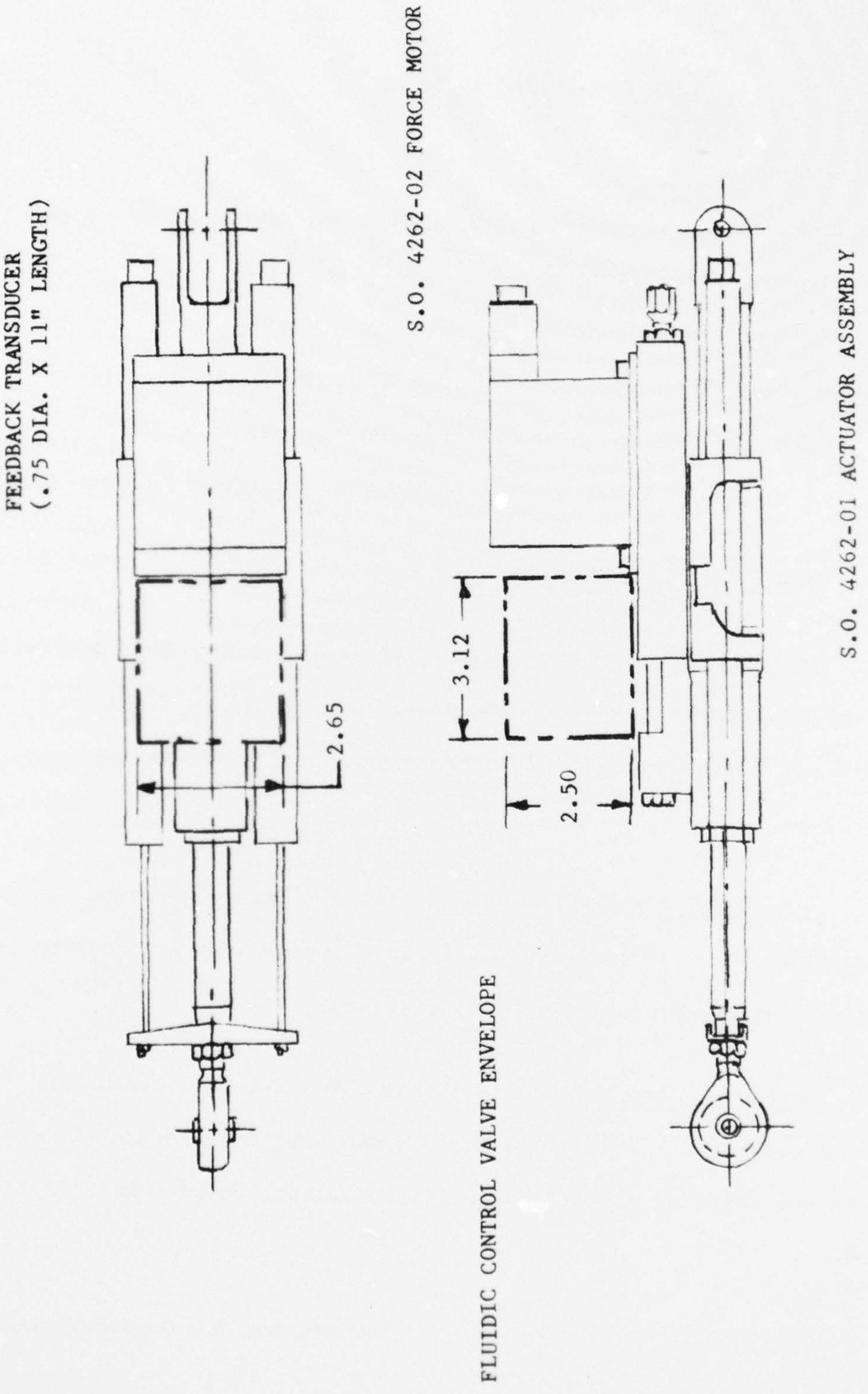


Figure 3-1. Fluidic Control Valve - Envelope Control Drawing

3.2.5 Operating/Physical Characteristics - The operating and physical characteristics of the torque motor, spool/sleeve and actuator which shall be operated by the FCV are summarized in Table 3-1.

3.2.6 Hydraulic System - Hydraulic power is available for use in the FCV. System pressure level is 8000 psi with a return pressure of 40 to 100 psig. MIL-H-83282 hydraulic fluid is used. Fluid temperatures shall range from -40°F to +275°F. The FCV shall be controllable with inlet fluid temperature from -40° to +80°F and shall meet the performance requirements of Paragraph 3.3 between 80°F and +275°F fluid temperatures. Supply, control, and vent pressures shall be defined for the particular FCV concept.

3.2.7 Engine Bleed Air - Engine bleed air may be assumed to be filtered, dried, and pressure regulated; however, values for these and other parameters shall be determined for the particular FCV configuration. Gaseous supply pressure, control pressure, vent pressure, etc., shall be sufficient to meet the performance requirements of Paragraph 3.3 at cruise engine power settings at any altitude up to 40,000 feet. At power settings below cruise down to idle, performance degradation is permitted as specified in Paragraph 3.3.

3.2.8 Power Consumption - Power consumed by the FCV shall be minized.

3.2.9 Transmission Lines - Transmission lines, supply, control and vent lines, except for those located on the actuator, are not included in the FCV package. However, the concept and control signal form shall be such that transmission distances up to 50 feet may be utilized while maintaining performance within the requirements of Paragraph 3.3.

Table 3-1. Component Characteristics

Torque Motor P/N S.O. 4262-02	
Output Member Spring Rate (±.020 in.)	±820 lb/in
Torque Motor Armature Inertia Reflected at Spool	.00922 in-#-sec^2
Spool/Sleeve P/N S.O. 4262-03	
Spool Weight	.0334# (Existing)
Spool Type	2 Land (Existing)
Spool Land Diameter	0.250 in
Spool Travel (Rated)	±0.20 in
Flow Gain (nom)	127 in^3/sec/in
Pressure Gain	2000,000 psi/in
Rated Flow (at ±.020 in)	.33 GPM
Internal Leakage at Null, Max	130 cc/min
Design Overlap	±.002 in
Actuator (Balanced) P/N S.O. 4262-01	
Effective Piston Area	0.234 in^2
Stroke	3.5 in
Rod Diameter	0.748 in
Piston Diameter	0.926 in
Extended Length	18.375 in

3.3 PERFORMANCE REQUIREMENTS

3.3.1 Minimum Bandwidth - Backup flight control systems are designed to utilize the smallest maximum levels of aerodynamic surface control deflections, rates, bandwidth, and torque for maintaining safe flight. These levels are best quantified by piloted simulation tests of a specific aircraft/backup control configuration. The smallest maximum level of control surface actuation bandwidth can be approximated, however, by using the F-4 airframe dynamic as being representative of a high performance fighter, and estimating the allowable control system phase lag according to the guidelines contained in MIL-F-8785B.

3.3.2 Dynamic Characteristics - The response of the control surfaces in flight shall not lag the cockpit control force inputs by more than the angles shown in Table 3-2, for frequencies equal to or less than the frequencies shown in Table 3-2.

Table 3-2. Allowable Control Surface Lags

Level	Allowable Lag ~ deg	
	Category A and C Flight Phases	Category B Flight Phases
1 and 2	30	45
3	60	

Control	Upper Frequency ~ rad/sec
elevator	$\omega_{n_{sp}}$
rudder & aileron	ω_{n_d} or $1/\tau_r$ (whichever is larger)

The highest short period frequency (ω_{nsp}) of the F-4 is 7.0 rad/sec and occurs at Mach 1.2 at 5000 feet. Assuming that the control surface valve/actuation dynamics are second order, a minimum control cutoff frequency of 11 rad/sec at .7 damping would be required.

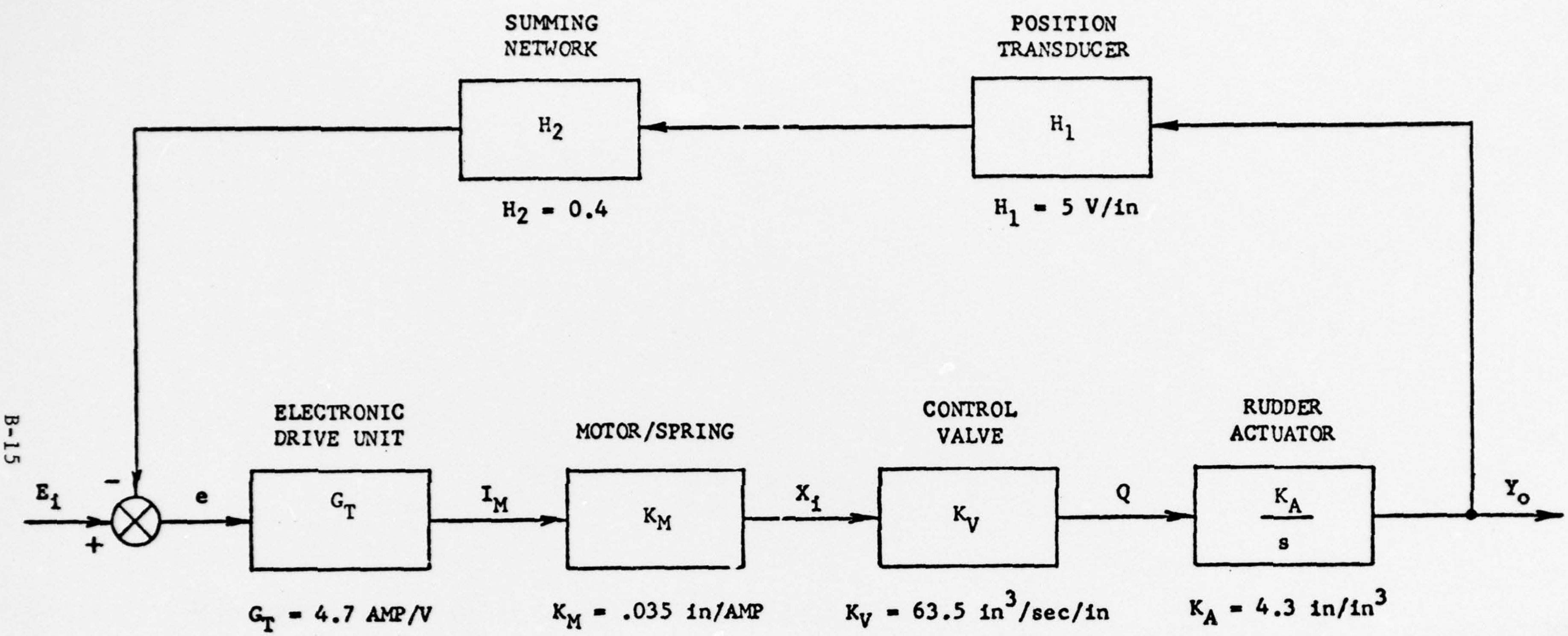
A valve/actuator transfer function would take the form of:

$$\frac{1}{\frac{S^2}{\omega_n^2} + \frac{2\zeta}{\omega_n} + 1} \qquad \omega_n = 11 \text{ rad/sec} \qquad \zeta = .7$$

(Desired Level 2 Requirements - 2 Hz.)

3.3.3 Math Model - AFCAS Actuator - A math model of the existing AFCAS actuator is shown in Figure 3-2.

3.3.4 Engage Transients - Transfer of control authority from the primary mode to the fluidic backup control mode should be positive with minimum control transient.



$$\text{LOOP GAIN} = G_T K_M K_V K_A H_1 H_2 = 90$$

$$\text{BAND WIDTH} = \frac{90}{2\pi} = 14.3 \text{ Hz}$$

METRIC CONVERSION: in X 2.54 = cm

Figure 3-2. Math Model AFCAS Actuator

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