CR-135161
EDR 9020

Final Report
Definition of Propulsion System for V/STOL Research and Technology Aircraft

by

Detroit Diesel Allison
Division of General Motors Corporation

(NASA-CR-135161) DEFINITION OF PROPULSION SYSTEM FOR V/STOL RESEARCH AND TECHNOLOGY AIRCRAFT Final Report (Detroit Diesel Allison, Indianapolis, Ind.) 109 p HC A06/MF A01 CSCL 21E G3/07 N77-20110 Unclas 22828

January 1977

Prepared for
National Aeronautics and Space Administration

NASA Lewis Research Center
Contract NAS 3-20034

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CR-135161		

4. Title and Subtitle	5. Report Date
DEFINITION OF PROPULSION SYSTEM FOR V/STOL RESEARCH AND TECHNOLOGY AIRCRAFT	JANUARY 1977
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
	EDR 9020
	10. Work Unit No.
9. Performing Organization Name and Address	11. Contract or Grant No.
DETROIT DIESEL ALLISON DIVISION OF GENERAL MOTORS CORPORATION INDIANAPOLIS, INDIANA 46206	NAS 3-20034
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	CONTRACTOR REPORT
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION WASHINGTON, D.C. 20546	14. Sponsoring Agency Code

15. Supplementary Notes

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16. Abstract

Work tasks included 40 x 80 wind tunnel test support, aircraft contractor support, preparing a propulsion system computer card deck, preliminary design studies and preparing a propulsion system development plan. The propulsion system consists of two lift/cruise turbofan engines, one turboshaft engine and one lift fan connected together with shafting into a combiner gearbox. Distortion parameter levels from 40 x 80 test data were within the established XT701-AD-700 limits. The three engine-three fan system card deck calculates either vertical or conventional flight performance, installed or uninstalled. Design study results for XT701 engine modifications, bevel gear cross shaft location, fixed and tilt fan frames and propulsion system controls are described. Optional water-alcohol injection increases total net thrust 10.3% on a 305.3°K (90°F) day. Engines have sufficient turbine life for 500 hours of the RTA duty cycle. Flight rated hardware can be delivered to the aircraft contractor 30 months after program go-ahead.

17. Key Words (Suggested by Author(s))		18. Distribution Statement
V/STOL	TURBOFAN	
SYSTEM CARD DECK	TURBOSHAFT	
FIXED NACELLE	LIFT/CRUISE	UNCLASSIFIED - UNLIMITED
TILT NACELLE	FAN	
	ENGINE	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
UNCLASSIFIED	UNCLASSIFIED		

* For sale by the National Technical Information Service, Springfield, Virginia 22151

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Summary

The program objective was to provide engineering services in the definition of a turboshaft propulsion system for a V/STOL Research and Technology Aircraft. These services included engineering support of a large scale variable pitch, lift/cruise fan engine test in the 40 x 80 wind tunnel at NASA Ames Research Center, technical support to Boeing Aerospace Company and McDonnell Aircraft Company, preparing a propulsion system performance computer card deck, preliminary design studies of system components and the preparation of a program plan for propulsion system development.

The propulsion system consists of two lift/cruise turbofan engines, one turboshaft engine and one lift fan connected with shafting through a combiner gearbox. The turbofan engines are modified Detroit Diesel Allison XT701-AD-700 turboshafts integrated with Hamilton Standard variable pitch fans. The turboshaft engine is also an XT701-AD-700.

Very low core inlet distortion parameter levels were calculated from the limited 40 x 80 test data. The levels were well within the established XT701-AD-700 limits and were not affected by nacelle angle-of-attack changes.

Aircraft contractors were provided propulsion system performance and physical characteristics for use in their research aircraft studies. Three engine-three fan system card decks were delivered to NASA Lewis Research Center, Naval Air Development Center, Boeing Company and McDonnell Aircraft Company. System steady state performance can be calculated for either vertical or conventional flight. Also the card deck will calculate either installed or uninstalled performance. The user can determine system performance at the following optional modes:

- Pitch and roll attitude control
- All engines operating
- One engine inoperative, either a turbofan or the turboshaft
- Water-alcohol injection
- Contingency power level above intermediate

Detroit Diesel Allison and Hamilton Standard completed an agreement on the interface between the HS variable pitch fan rotor and the DDA turboshaft engine, gearbox and fan frame assembly.

The VTOL mode of operation was selected as the design point using the more severe conditions of 3 engines and 3 fans operating or 2 engines and 3 fans operating with one lift/cruise engine inoperative.

PD370-25A, the lift/cruise engine designed for a fixed nacelle installation, weighs 1066 kg (2351 lbs). The lightest tilt nacelle installation engine, PD370-25E, weighs 1196 kg (2637 lbs). The turboshaft center engine weighs 515 kg (1135 lbs).

The existing XT701-AD-700 engine requires modifications before being fitted with the variable pitch fan. Components requiring removal or modification include: inlet housing, compressor anti-icing, accessory gearbox, oil system, torquemeter and engine controls.

Optional water-alcohol injection would add 4.5 kg (10 lbs) to each engine's weight and 10.3% total net thrust increase to a one lift/cruise engine inoperative system on a 305.3°K (90°F) day.

Current engines have sufficient turbine life to operate satisfactorily for 500 hours on the RTA duty cycle and one hour at a contingency power level.

Bevel gear cross shaft drive location study revealed that lightest gearbox arrangement for a fixed nacelle engine wasn't the lightest for a tilt nacelle engine. A cross shaft forward of the reduction gear is used in the fixed nacelle engine and an aft cross shaft is used in the tilt nacelle.

T56 turboprop engine reduction gearbox components can be used in the lift/cruise gearbox without a modification in the ratio.

A conceptual design of the RTA propulsion system controls was undertaken with the XT701 control system being utilized. After meetings with the airframe manufacturers and analysis of the problem, it was decided that the XT701 electronics had to be replaced. A digital engine controller is required to achieve the added control tasks and fail operational requirement. The XT701 hydromechanical control is retained with minor modifications.

Propulsion system flight tested hardware can be delivered to the aircraft contractor 30 months after program go-ahead. The hardware would have completed 245 hours of turbofan engine testing and 680 hours of fan testing.

1.0 Introduction

Detroit Diesel Allison (DDA) Division of General Motors Corporation provided engineering support to aircraft company studies of V/STOL aircraft during 1975. These studies established that the DDA XT701-AD-700 turboshaft engine was a logical choice for use in a research and technology aircraft program and the need for additional propulsion system definition. The contract work defined the various components of the propulsion system shown in Figure 1, assessed the compatibility of the existing XT701 engine in the V/STOL operational modes and expanded propulsion system support to other aircraft contractors. The information obtained from this work can be used as the baseline in the design of components for a research and technology aircraft propulsion system as well as provide system performance to aircraft companies. DDA Model PD370-30 defines the system with separate jet turbofan engines. PD370-32 describes the system using confluent flow turbofan engines. Lift/cruise turbofan engines are designated PD370-25 with a suffix identifying aircraft installation.

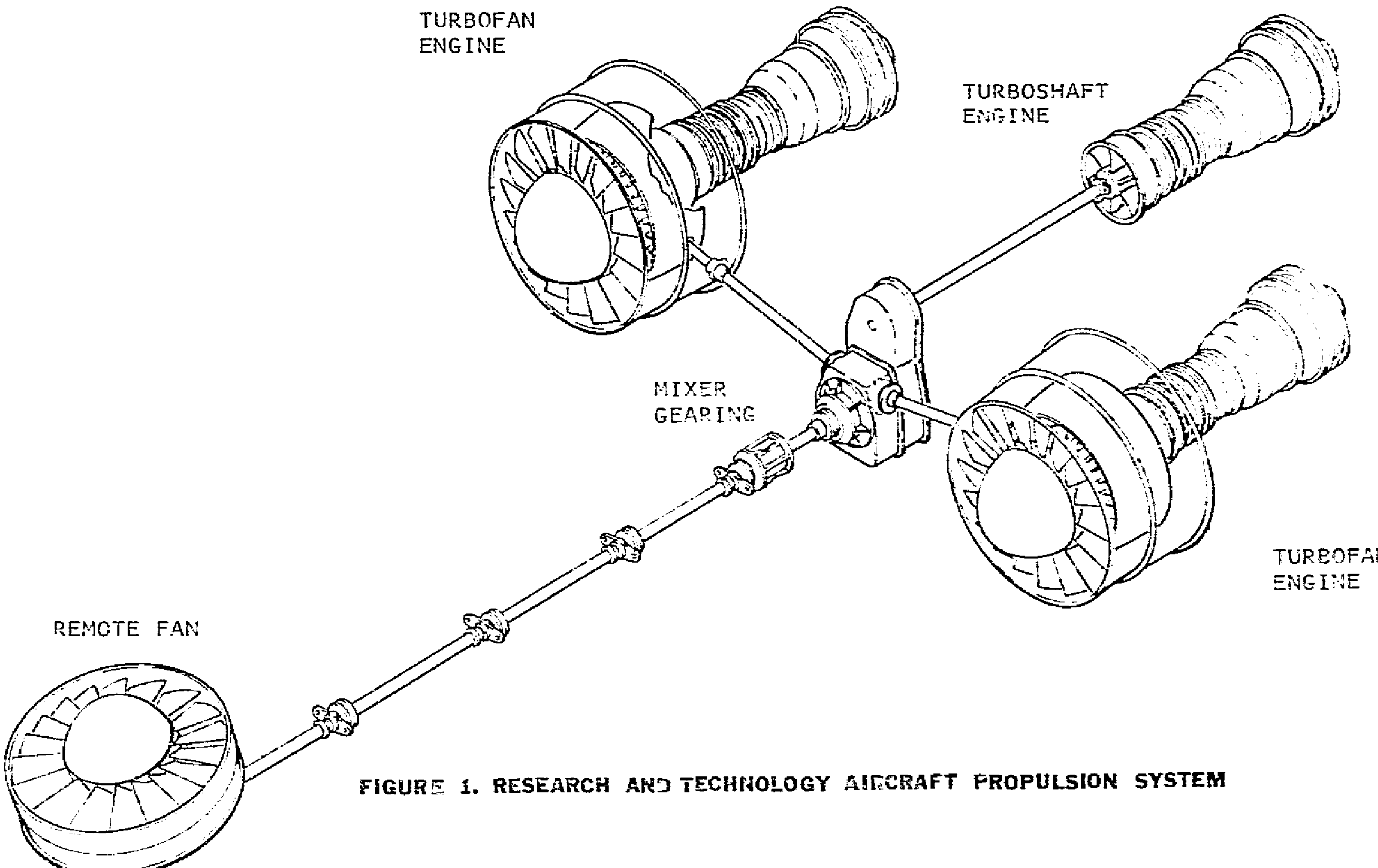


FIGURE 1. RESEARCH AND TECHNOLOGY AIRCRAFT PROPULSION SYSTEM

2.0 Wind Tunnel Test Support

An abbreviated large scale variable pitch lift/cruise fan inlet test was conducted in the Ames 40 x 80 wind tunnel in late July and early October 1976. The hardware used in the test included a Boeing Company designed inlet and a nacelle that incorporated a Hamilton Standard 1.4 metre (4.6 feet) diameter variable pitch fan driven by a Lycoming T55-L-11 gas turbine core engine. The test was abbreviated due to hardware failures on the 26th of July and the 4th of October 1976. The fan engine drive train was rebuilt after the first failure and only a limited number of test conditions were run on the second test before another mechanical failure.

DDA personnel reviewed the test plan and test instrumentation prior to the test and determined that sufficient operating conditions and test data would be available to evaluate the conditions which would exist at the inlet of the core engine. This data was to be used in estimating the effects of a variable pitch fan on an XT701 core engine in a research aircraft by relating these data to prior XT701 engine test experience.

Distortion limits are defined for the core engine inlet air pressure profiles in order to avoid three potential detriments to acceptable engine operation (1) compressor stall, (2) performance degradation and (3) excessive compressor blade vibration.

Three parameters, circumferential distortion (Kθ), radial distortion (KR), and harmonic components of the inlet pressure distribution are used for evaluating distortion. The test data from the wind tunnel was used to calculate the distortion parameters.

The test was terminated with only seven of thirty-six test conditions completed. However, the limited data was reviewed and typical points with the higher compressor face total pressure distortion (DISC) values were selected for analysis. It should be noted that the condition where inlet separation occurred, $\alpha = 60°$, Vo = 39 M/S (75 knots), was not selected for analysis because of the low compressor face distortion.

Table 1 shows parameters of the selected points and the analytical results of distortion parameter calculations. The negative KRE values calculated indicate a hub oriented distortion. The XT701 engine is sensitive to tip oriented distortion and expected to be insensitive to the hub distortion. Acceptable limits of KθE and KRE are shown in Figure 2 . The limits of the first four harmonic components are as follows: $A_1 \leq 1.6$, $A_2 \leq .32$, $A_3 \leq .20$, and $A_4 \leq .20$. Comparisons show that the distortion levels obtained during the abbreviated test were well within the limits established for the XT701-AD-700 engine and were not affected by the angle-of-attack changes.

The distortion transfer coefficient is described by the ratio of the circumferential distortion coefficient at the core engine (KθE) to the circumferential distortion coefficient at the fan inlet hub (KθFH). The fan inlet hub distortion is obtained from the readings of the hubmost radial element when WE/WI is near 6%. When WE/WI is near 10%, the readings of the two radial elements closest to the hub are used for calculating distortion. A few values of

TABLE 1. WIND TUNNEL TEST RESULTS

RUN	V_0 m/s	ALPHA deg.	WK1 kg/s	FLOW RATIO WE/W1	ENGINE DISTORTION KθE	KRE	DISTORTION TRANSFER KθE/KθFH	HARMONIC CONTENT A1	A2	A3	A4
21.1	0	0	41.2	.124	.044	-.022	.89	.058	.021	.023	0.
22.1	8.9	0	149.9	.0655	.061	-.013		.057	.064	.057	.0436
30.1	20.1	45.	182.5	.063	.039	-.020		.095	.123	.045	.036
30.3	20.7	45.	83.1	.1039	.041	-.020		.081	.081	.081	.014
31.1	20.0	90.	181.1	.0633	.044	-.029	.50	.087	.093	.055	.0055
31.3	20.5	90.	82.6	.09	.036	-.020		.063	.080	.060	.030
38.1	38.9	75.	205.4	.0596	.067	-.028	.91	.106	.010	.033	.013

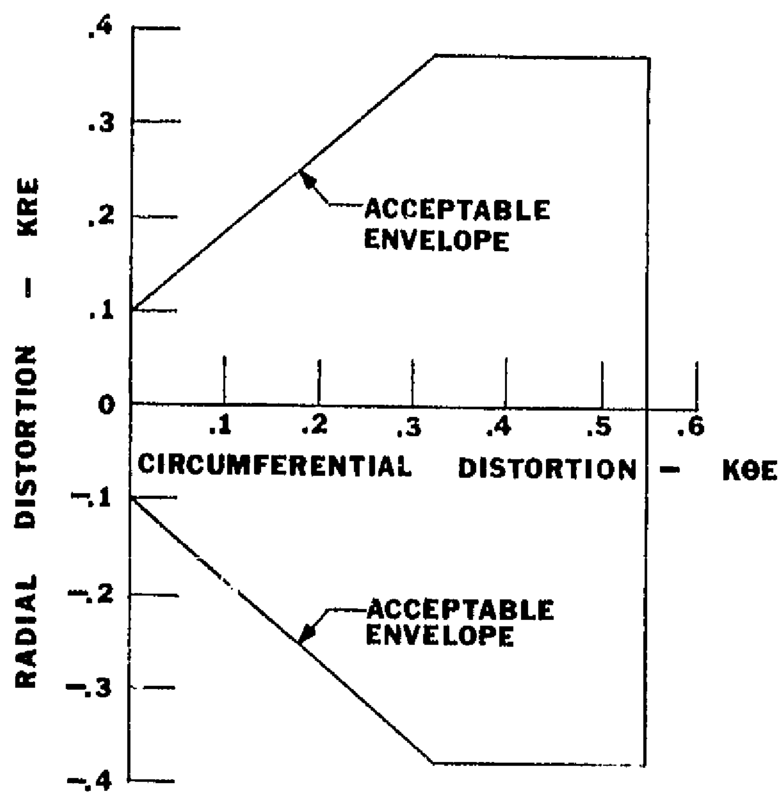


FIGURE 2. XT701-AD-700 COMPRESSOR INLET DISTORTION LIMIT

KΘE/KΘFH are shown in Table 1 . These values show large variations in the transfer coefficient. However, the very low values of both the KΘE and KΘFH make this coefficient highly susceptible to experimental error and no conclusions regarding the distortion transfer characteristics of the fan can be drawn from this data.

3.0 Aircraft Contractor's Support

Detroit Diesel Allison provided shaft driven propulsion system information to the Boeing Company and McDonnell Aircraft Company for use in their research and technology aircraft studies.

Installation drawings for the lift/cruise engine in a fixed nacelle installation (PD 370-25A) and the two lift/cruise engines in a tilt nacelle installation (PD370-25D, shaft forward and PD370-25E, shaft aft) have been provided. These drawings show envelope dimensions, accessory mounting pads and engine weights. These drawings are shown in Figures 3 - 5 .

A large amount of installed propulsion system performance has been provided Boeing and McDonnell during this work. Data at the following conditions has been supplied:

VTOL MODE

1. 3E-3F, SLS, 305.3°K (90°F) DAY, Intermediate Power Rating
2. 3E-3F, SLS, 305.3°K (90°F) DAY, Intermediate Power, Attitude Control
3. 2E-3F, SLS, 305.3°K (90°F) DAY, Intermediate Power, One Lift/Cruise Engine Inoperative, DRY
4. 2E-3F, SLS, 305.3°K (90°F) DAY, Intermediate Power, One Lift/Cruise Engine Inoperative, Dry, Attitude Control
5. 2E-3F, SLS, 305.3°K (90°F) DAY, Intermediate Power, One Lift/Cruise Engine Inoperative, 3% W/A injection
6. 2E-3F, SLS, 305.3°K (90°F) DAY, Intermediate Power, One Lift/Cruise Engine Inoperative, 3% W/A injection, attitude control
7. 3E-3F, SLS, 305.3°K (90°F) DAY, Requested Thrust Levels below Intermediate Power
8. 2E-3F, SLS, 305.3°K (90°F) DAY, One Lift/Cruise Engine Inoperative, Requested Thrust Levels

CRUISE MODE

1. 1E-1F, 0.M, (0. FT) ALTITUDE, 0 MACH NUMBER, Standard Day
2. 1E-1F, 0.M, (0. FT) ALTITUDE, .2 MACH NUMBER, Standard Day
3. 1E-1F, 3048.M, (10,000 FT) ALTITUDE, .3 MACH NUMBER, Standard Day
4. 1E-1F, 6096.M, (20,000 FT) ALTITUDE, .5 MACH NUMBER, Standard Day
5. 1E-1F, 6096.M, (20,000 FT) ALTITUDE, .7 MACH NUMBER, Standard Day
6. 1E-1F, 11000.M, (36,089 FT) ALTITUDE, .7 MACH NUMBER, Standard Day
7. 1E-1F, 11000.M, (36,089 FT) ALTITUDE, .9 MACH NUMBER, Standard Day

Tables 2 - 5 show performance parameters of typical operational modes. The above data was calculated using DDA inhouse performance techniques before the propulsion system card deck was complete.

Control margin is defined as the thrust available for aircraft attitude control while the engines are operating at intermediate power. With horsepower transfer and fan pitch angle adjustment, thrust from one turbofan can be increased as much as the control margin while the thrust from the other turbofan is decreased the same amount. The attitude control thrust values given in Tables 2-5 are for either the high (+) or low (-) turbofan.

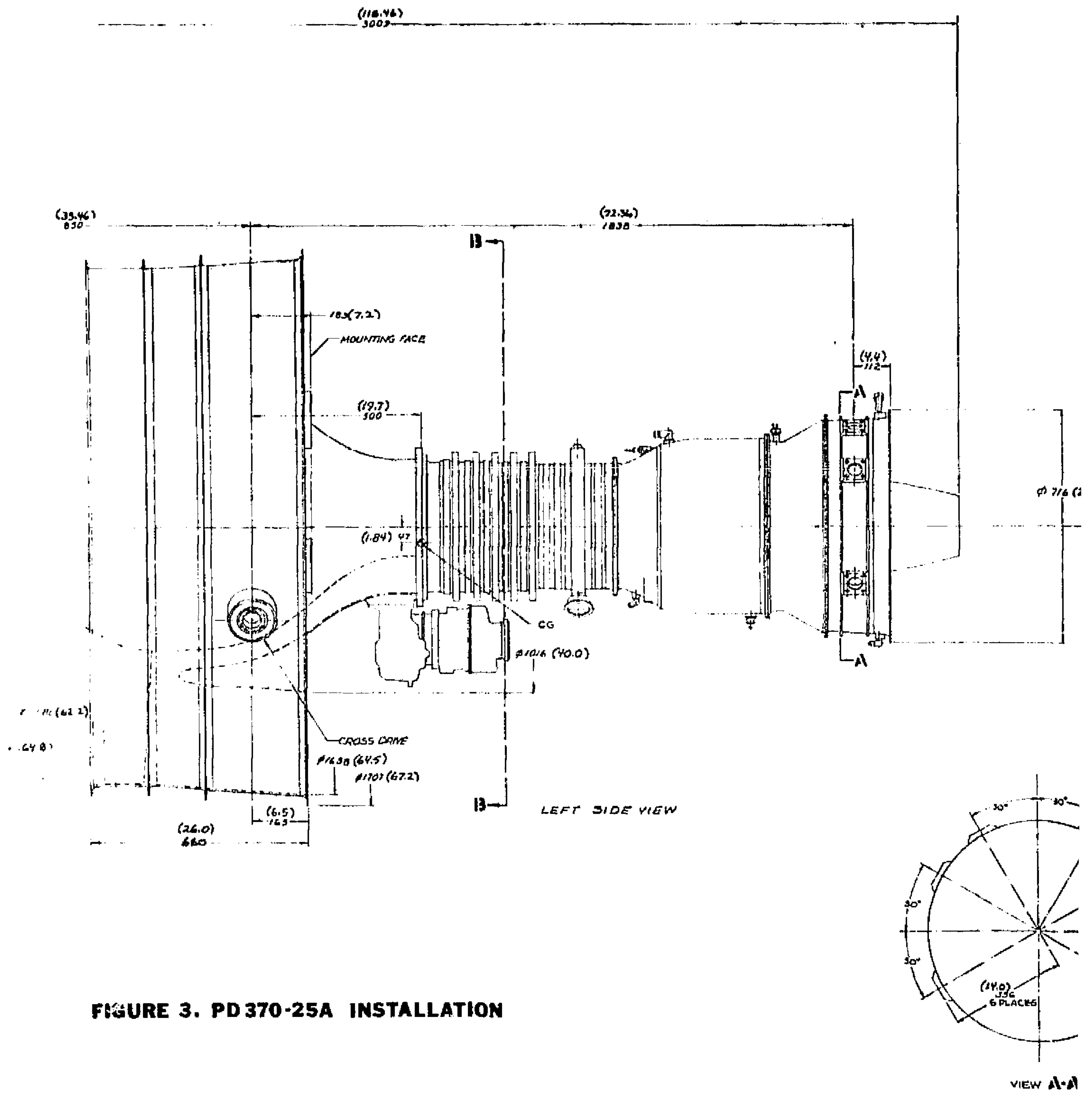
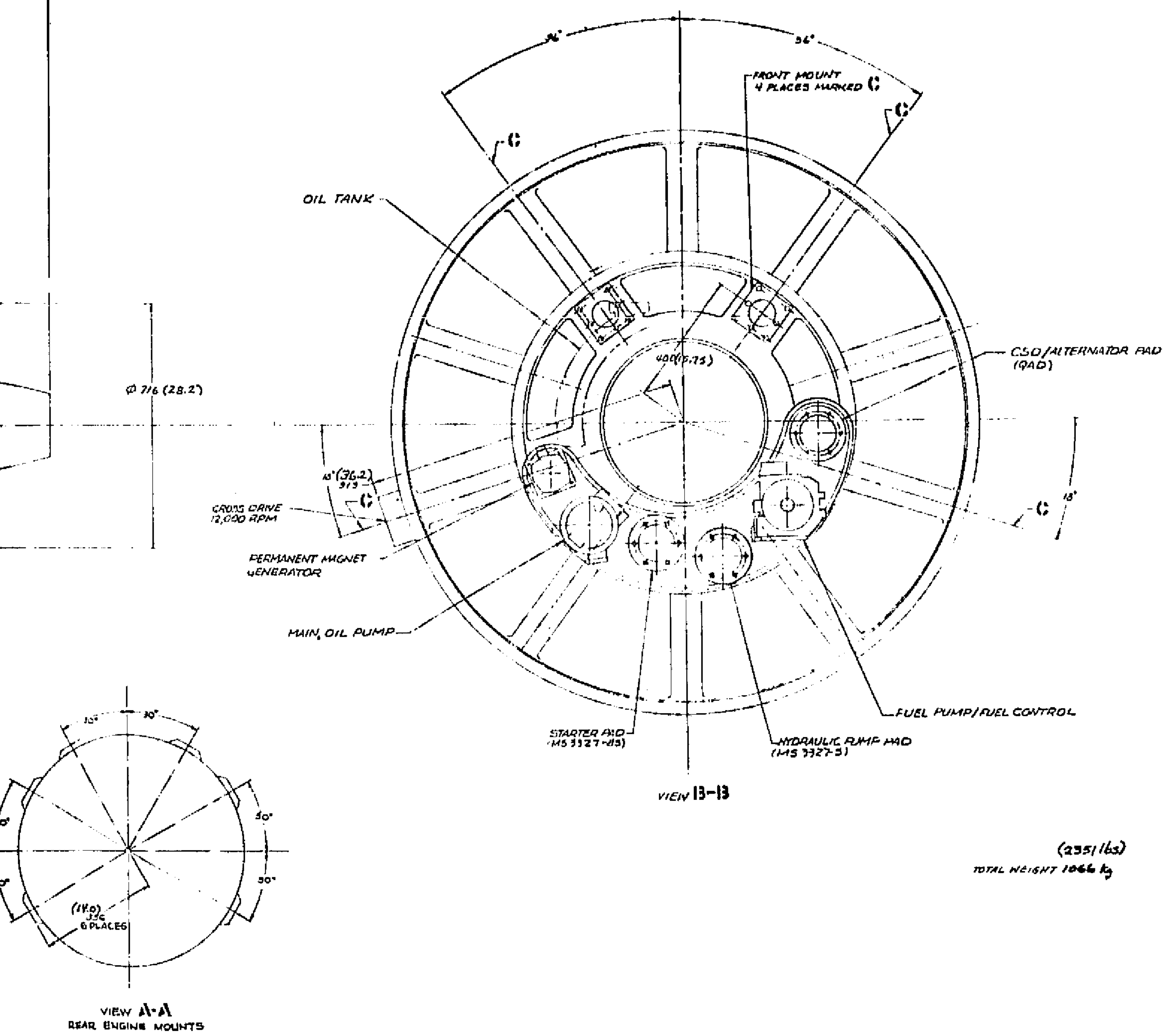


FIGURE 3. PD 370-25A INSTALLATION

FOLDOUT FRAME



FRONT MOUNT
4 PLACES MARKED C
OIL TANK
CSD/ALTERNATOR PAD (PAD)
Φ 7/6 (28.2)
CROSS DRIVE 12,000 RPM
PERMANENT MAGNET GENERATOR
MAIN OIL PUMP
FUEL PUMP/FUEL CONTROL
STARTER PAD (MS 3327-85)
HYDRAULIC PUMP PAD (MS 3327-3)
VIEW B-B
(2351 lbs)
TOTAL WEIGHT 1066 kg
6 PLACES
VIEW A-A
REAR ENGINE MOUNTS

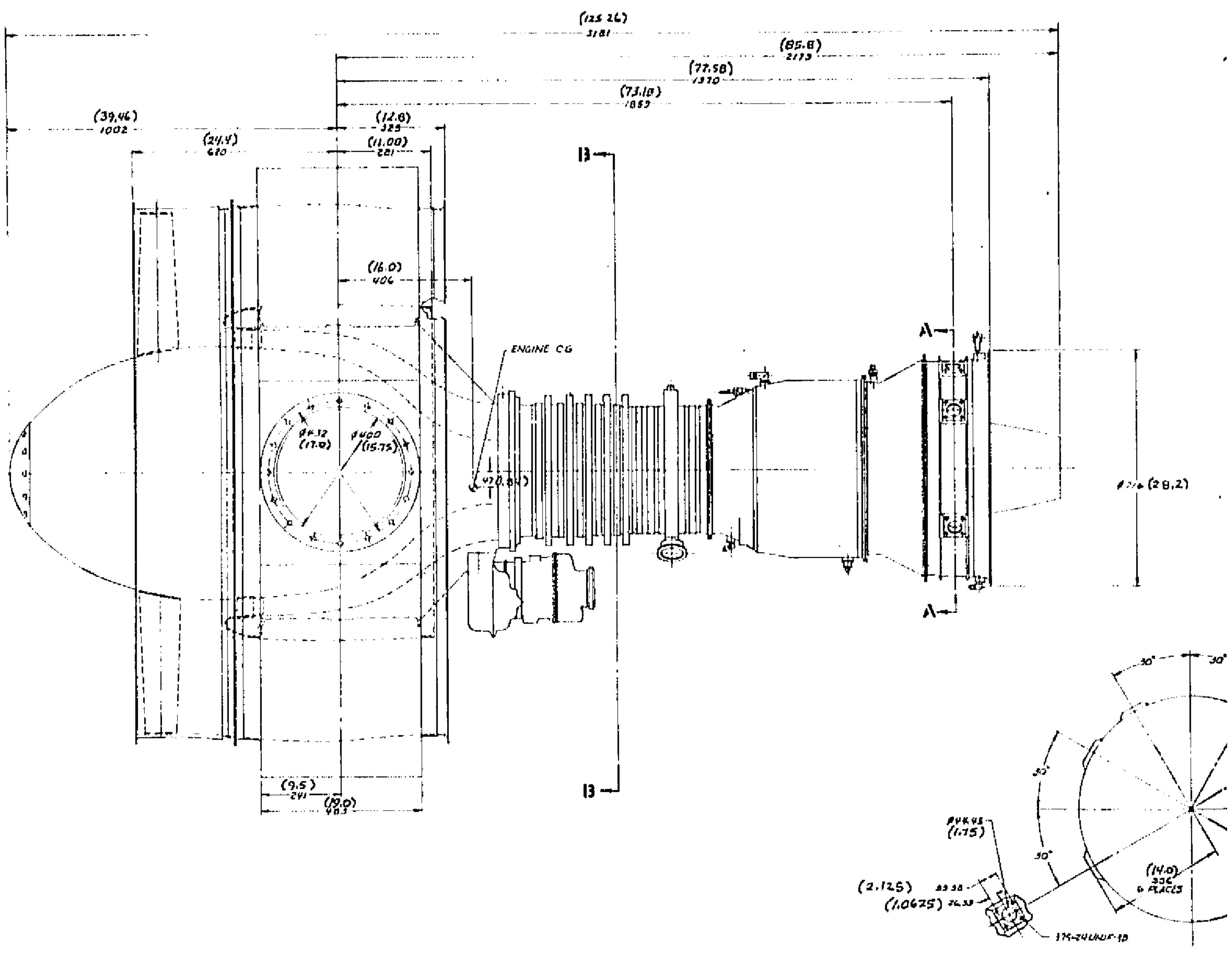
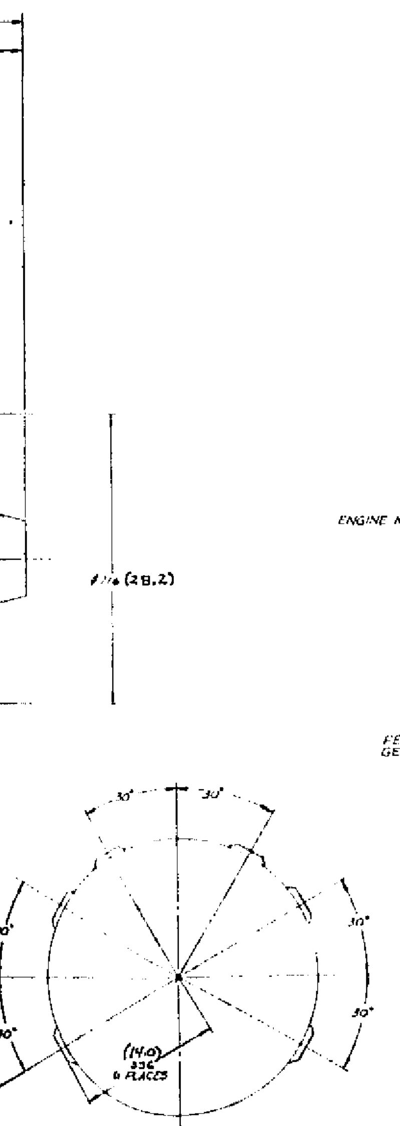
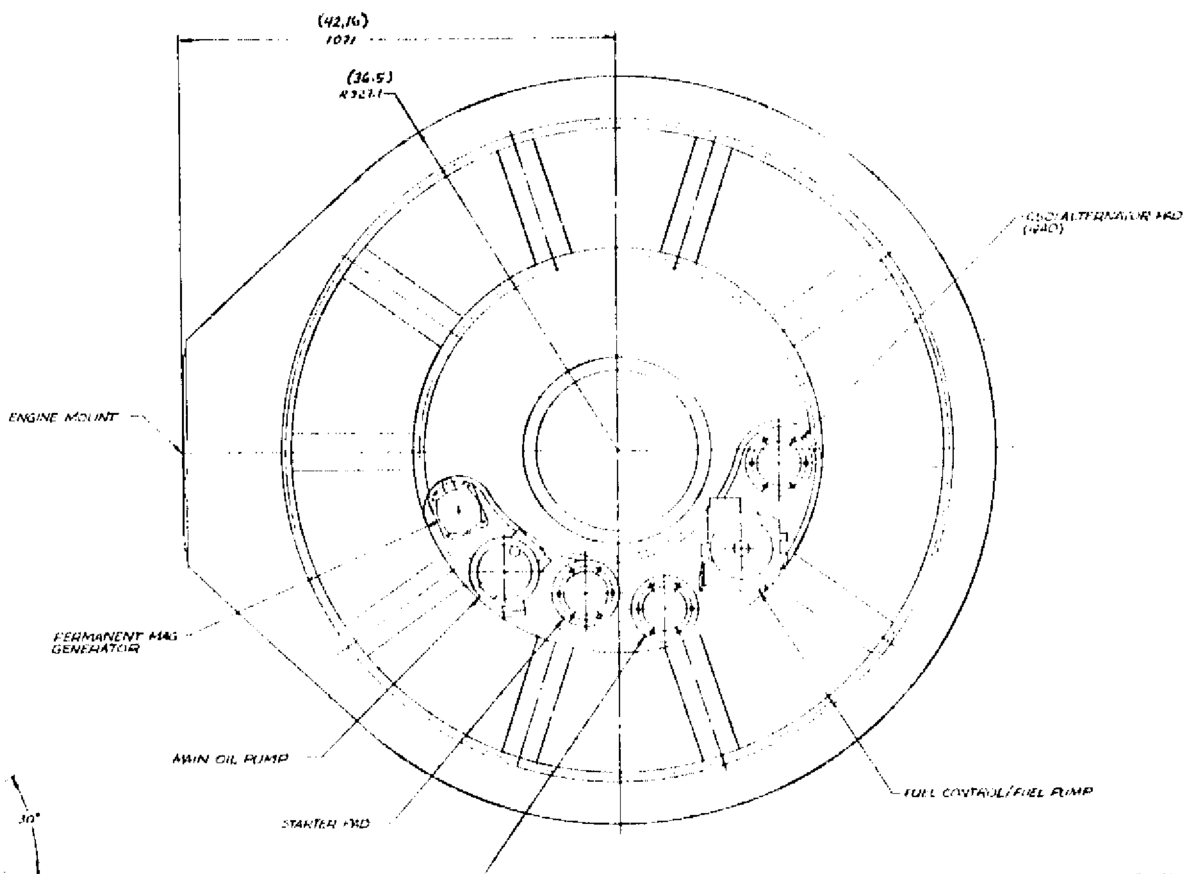


FIGURE 4. PD 370-25D INSTALLATION



SECTION A–A



VIEW B–B

(2783 lbs)
TOTAL WEIGHT = 1262 kg

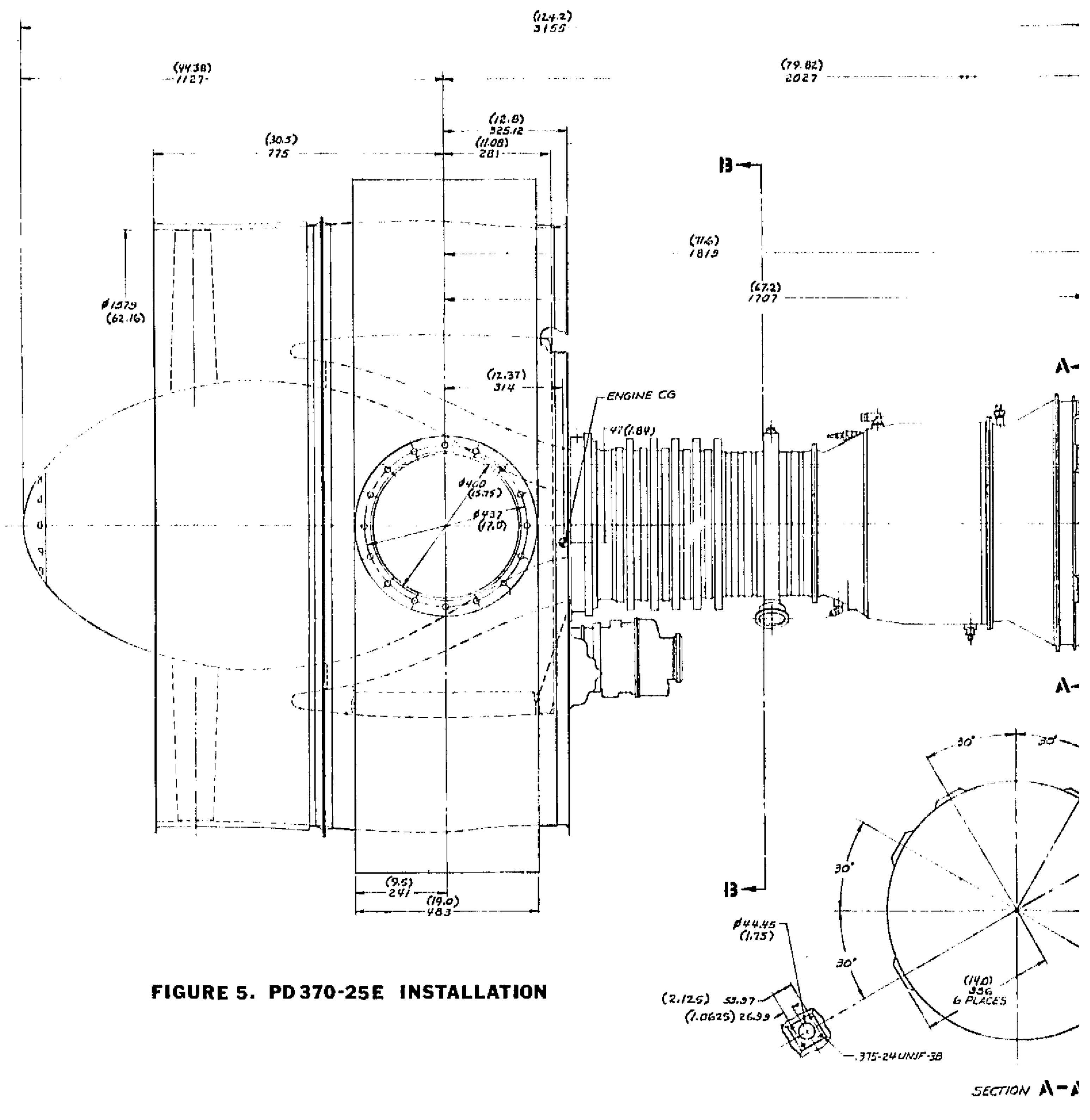
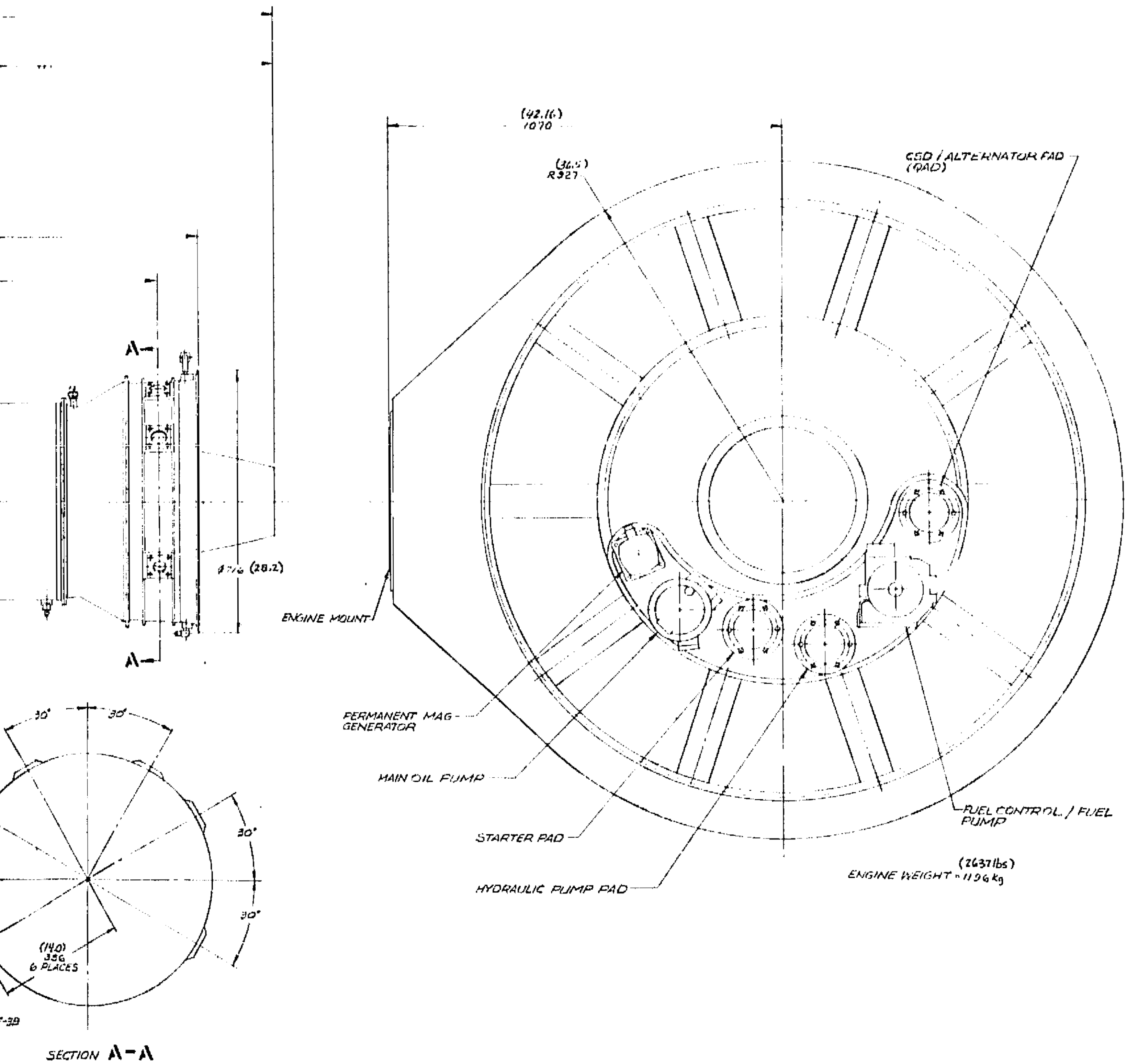


FIGURE 5. PD 370-25E INSTALLATION



FOLD-OUT FRAME 2

Table 2. PD370-25A Installed Performance

UNIT	PR	WT kg/s	BPR	FPR	WP kg/s	TP °K	PP kPa	FNP N	WS kg/s	TS °K	PS kPa	FNS N	WF kg/hr	FNT N	SFCT mg/N-s
VTOL Mode, Sea Level Static, 305.3°K day, AEO, Dry, Maximum Thrust Available															
TF	IP	295.56	13.02	1.215	21.50	930.9	112.1	4670.6	274.47	325.0	120.4	45687.7	1751.3	151057.2	9.55
TSE	IP				19.31	941.8	104.4	2317.5					1585.3		
LF		297.31		1.218					297.28	325.0	120.7	50340.5			
TF	FNCM	319.71	13.96	1.255	21.79	929.8	112.4	4790.7	298.33	328.9	124.1	54148.2	1768.1	17.0% (a)	
VTOL Mode, Sea Level Static, 305.3°K day, AEO, Dry, 22% Control Margin															
TF		289.44	13.15	1.206	20.83	912.8	111.3	4310.3	268.98	324.4	119.6	43850.6	1641.1	144558.3	9.23
TSE					19.12	921.7	104.3	2233.0					1517.7		
LF		291.12		1.209					291.12	324.4	119.8	48236.5			
TF	FNCM	319.60	14.36	1.255	21.19	911.7	111.6	4448.2	295.78	328.9	124.2	54290.5	1660.6	22.0% (a)	
VTOL Mode, Sea Level Static, 305.3°K day, OEI, 3% Water Alcohol Injection, Maximum Thrust Available															
TF	IP	255.58	11.20	1.168	21.95	929.4	112.6	4857.5	234.69	320.0	115.[illegible]	33330.5	1776.3	114563.3	12.5[illegible]
TSE	IP				19.96	939.4	104.7	2486.6					1623.4		
LF		259.23		1.166					259.23	320.6	115.8	38192.4			
Cruise Mode, 3048 Metre, 0.3 Mach Number, 288.15°K day, One Engine and One Fan															
(b)															
105		237.43	13.66		16.44	802.8	77.6	1970.6	221.26	291.7	88.7	20824.4	1139.0	22895.0	
100		230.07	13.91		15.65	778.9	77.0	1623.6	214.64	289.4	87.4	1899[illegible].4	1023.3	20622.0	
95		221.04	14.13		14.79	753.3	75.6	1276.6	206.43	267.8	86.0	16747.6	905.4	18029.6	
85		202.96	14.52		13.20	708.3	74.1	756.2	189.87	285.0	83.3	12619.6	709.4	13375.8	
75		181.01	15.10		11.32	658.9	72.7	293.6	169.78	281.7	80.4	8264.8	513.5	6558.4	
65		162.75	15.66		9.82	623.3	71.8	44.5	153.00	278.9	78.3	5200.0	366.5	5244.5	

(a) Thrust Control Margin
(b) Power Turbine Speed in Percent

Table 3. PD370-25A Installed Performance, Customary Units

UNIT	PR	WT lb/s	BPR	FPR	WP lb/s	TP °F	PP psia	FNP lb	WS lb/s	TS °F	PS psia	FNS lb	WF lb/hr	FNT lb	SFCT lb/hr/lb
VTOL Mode, Sea Level Static, 90 F day, AEO, Dry, Maximum Thrust Available															
TF	IP	651.6	13.02	1.215	47.40	1215.6	16.26	1050.	605.1	125.0	17.46	10271.	3861.	33953.	0.339
TSE	IP				42.57	1235.2	15.15	521.					3495.		
LF		655.45		1.218					655.4	125.0	17.50	11517.			
TF	ENCM	704.85	13.96	1.255	48.04	1213.6	16.30	1077.	657.7	132.0	18.00	12175.	38[illegible].	17.0[illegible] (a)	
VTOL Mode, Sea Level Static, 90°F day, AEO, Dry, 22% Control Margin															
TF		638.1	13.15	1.206	45.93	1183.0	16.14	969.	593.0	124.0	17.34	9858.	3618.	32498.	0.326
TSE					42.16	1199.0	15.13	502.					3346.		
LF		641.8		1.209					641.8	124.0	17.37	10844.			
TF	ENCM	704.6	14.36	1.255	46.71	1161.0	16.16	1000.	653.7	132.0	18.02	12205	3661.	22.0[illegible] (a)	
VTOL Mode, Sea Level Static, 90 F day, OEI, 3% Water-Alcohol Injection, Maximum Thrust Available															
TF	IP	563.46	11.20	1.168	48.40	1213.0	16.33	1092.	517.4	116.0	16.68	7492.	3910.	25755.	0.443
TSE	IP				44.00	1231.0	15.18	559.					3579.		
LF		571.5		1.166					571.5	117.0	16.79	8568.			
Cruise Mode, 10,000 feet, 0.3 Mach Number, 59 F day, One Engine and One Fan															
(b)															
105		523.45	13.66		36.25	985.	11.26	443.	487.8	65.0	12.86	4704.	2511.	5147.	
100		507.23	13.91		34.50	942.	11.17	365.	473.2	61.0	12.68	4271.	2256.	4636.	
95		487.32	14.13		32.61	896.	10.97	287.	455.1	58.0	12.47	3765.	1936.	4053.	
85		447.46	14.52		29.11	815.	10.75	170.	418.6	53.0	12.08	2927.	1564.	3097.	
75		399.06	15.10		24.96	726.	10.55	66.	374.3	47.0	11.68	1858.	1122.	1924.	
65		358.81	15.66		21.04	662.	10.42	10.	337.3	42.0	11.35	1169.	852.	1179.	

(a) Thrust Control Margin

(b) Power Turbine Speed in Percent

Table 4. PD370-25E Installed Performance

UNIT	PR	WT kg/s	BPR	FPR	WP kg/s	TP °K	PP kPa	FNP N	WS kg/s	TS °K	PS kPa	FNS N	WF kg/hr	FNT N	SFCT mg/N-s
VTOL Mode, Sea Level Static, 305.3 K, AEO, Dry, Maximum Thrust Available															
TF	IP	298.9	12.88	1.218	22.0	926.7	112.6	5084.3	277.4	325.6	121.1	48854.8	1781.3	161826.3	6.59
TSE	IP				19.7	935.0	105.3	2762.3					1612.9		
LF		302.8		1.225					302.8	326.1	121.6	53948.0			
TF	FNCM	325.2	13.68	1.263	22.3	925.0	112.9	5235.6	303.3	330.0	125.5	58694.3	1801.2	+18.5%[a]	
VTOL Mode, Sea Level Static, 305.3 K day, OEI, Dry, Maximum Thrust Available															
TF	IP	252.9	11.14	1.152	21.3	930.6	111.9	4790.7	232.1	319.4	115.0	34175.7	1734.1	116908.2	12.06
TSE	IP				19.7	936.1	110.4	2762.3					1612.9		
LF		257.6		1.162					257.6	320.6	115.7	36975.3			
TF	FNCM	239.5	10.59	1.135	21.1	931.1	111.8	4719.6	218.8	317.8	113.3	30327.9	1720.9	-10.0%[a]	
VTOL Mode, Sea Level Static, 305.3 K day, OEI, 3% Water-Alcohol Injection, Maximum Thrust Available															
TF	IP	257.7	11.18	1.158	22.3	926.1	113.1	5204.4	236.5	320.0	115.5	35432.4	1792.6	122130.4	11.90
TSE	IP				20.4	932.8	105.5	2940.3					1650.6		
LF		263.3		1.169					263.3	321.1	116.4	40736.8			
TF	FNCM	244.1	10.65	1.141	22.0	927.2	112.7	5106.6	223.1	318.3	113.8	31537.9	1777.6	-10.0%[a]	
Cruise Mode, 3048 Metre, 0.3 Mach Number, 288.15 K day, One Engine and One Fan															
(b)															
100		221.4	13.64		15.4	756.7	76.2	1463.5	206.2	288.9	86.2	18028.6	954.8	19492.1	
94.5		211.6	13.85		14.5	730.0	75.2	1125.4	197.3	287.2	85.5	15613.3	834.6	16738.7	
89.0		201.5	14.04		13.6	705.6	74.4	840.7	188.1	285.6	84.9	13300.2	728.0	14140.9	
83.5		190.9	14.27		12.7	680.6	73.6	587.2	178.4	283.9	83.2	11036.0	626.4	11623.2	
78.0		179.0	14.56		11.6	653.9	72.9	342.5	167.5	282.2	81.6	8682.9	522.5	9025.4	
72.5		168.9	14.63		10.5	631.7	72.3	177.9	158.2	280.6	80.2	6859.1	444.5	7037.1	

(a) Thrust Control Margin
(b) Power Turbine Speed in Percent

Table 5. PD370-25E Installed Performance, Customary Units

UNIT	PR	WT lb/s	BPR	FPR	WP lb/s	TP °F	PP psia	FNP lb	WS lb/s	TS °F	PS psia	FNS lb	WF lb/hr	FNT lb	SFCT lb/hr/lb
VTOL Mode, Sea Level Static, 90 F day, AEO, Dry, Maximum Thrust Available															
TF	IP	658.96	12.88	1.218	48.5	1208.	16.33	1143.	611.5	126.	17.57	10983.	3327.	[illegible]	0.314
TSE	IP				43.4	1223.	15.27	621.					3556.		
LF		667.6		1.225					667.6	127.	17.64	12126.			
TF	FNCM	716.96	13.88	1.263	49.26	1205.	16.33	1177.	668.7	134.	18.20	13135.	3371.	+18.5 (a)	
VTOL Mode, Sea Level Static, 90 F day, OEI, Dry, Maximum Thrust Available															
TF	IP	557.7	11.14	1.152	46.95	1215.	16.23	1077.	511.8	113.	16.66	7662.	3628.	26282.	0.426
TSE	IP				43.39	1225.	16.01	621.					3556.		
LF		567.3		1.162					567.9	117.	16.76	8762.			
TF	FNCM	527.9	10.59	1.135	46.53	1216	16.21	1061.	482.4	112.	16.44	6819.	3794.	-10.0 (a)	
VTOL Mode, Sea Level Static, 90 F day, OEI, 3 [illegible] Water-Alcohol Injection, Maximum Thrust Available															
TF	IP	568.1	11.16	1.158	49.09	1207.	16.40	1170.	521.6	116.	16.75	7979.	3952.	27456.	0.420
TSE	IP				44.30	1219.	15.30	661.					3689		
LF		580.5		1.169					560.5	118.	16.63	9156.			
TF	FNCM	538.1	10.65	1.141	48.60	1209.	16.34	1148.	491.9	113.	16.51	7090.	3919.	-10.0 (a)	
Cruise Mode, 10,000 feet, 0.3 Mach Number, 59 F day, One Engine and One Fan															
(b)															
100		488.0	13.64		33.88	902.	11.05	329.	454.7	[illegible]	12.79	[illegible]	2135.	[illegible]	
94.5		466.4	13.65		31.88	854.	10.91	253.	435.0	57.	12.55	[illegible]	1840.	[illegible]	
89.0		444.2	14.04		29.93	810.	10.79	189.	414.7	54.	12.31	2990.	1605.	3179.	
83.5		420.9	14.27		27.91	765.	10.68	132.	393.4	51.	12.07	2437	1361.	2613.	
78.0		394.7	14.56		25.65	717.	10.57	77.	363.3	48.	11.83	1952.	1152.	2029.	
72.5		372.3	14.83		23.76	677.	10.49	40.	348.8	45.	11.63	1542.	939.	1582.	

(a) Thrust Control Margin

(b) Power Turbine Speed in Percent

4.0 Digital Computer Simulation Program

The Detroit Diesel Allison Division of General Motors Corporation has prepared a program in the form of a deck of cards for use in calculating the steady state performance of the DDA Model PD370-30 and PD370-32 propulsion systems.

The program considers the propulsion system as an arrangement of power producers and thrusting units coupled together by shafting through a centrally mounted mixer gear box as shown by the sketch of Figure 1.

The Model PD 370-30 three engine-three fan system has two turbofan engines which are considered to be separate jet engines (i.e., primary and secondary streams exit from separate nozzles).

Model PD 370-32 system turbofan engines are considered to be confluent flow jet engines (i.e., primary and secondary streams are combined before exiting from jet nozzle). Mixing is accomplished by equal static pressures of the streams.

The remote fan and the two fans of the turbofan engines are identical Hamilton Standard variable pitch fans of 157.48 CM (62 inch) tip diameter. The turboshaft engine and the two gas generators of the turbofan engines are Detroit Diesel Allison XT701 turboshaft engines.

With this program, the user may, for a given set of flight conditions, calculate steady state performance by entering the proper values of the program input data.

Steady state performance can be calculated for either vertical or conventional flight. Vertical flight performance is calculated with the remote fan producing vertical thrust and the turbofan engines configured to produce vertical thrust. Conventional flight performance is calculated with only the turbofans producing normal forward thrust.

Vertical flight performance calculations are performed under the following constraints:

- o equality of fan rotational speeds
- o equality of turbine inlet temperature, turbofan and turboshaft units
- o power balance in shafting
- o equality of lift thrust, turbofan and remote fan units (non-attitude control only)

Fan rotational speed is fixed at a preset value for all vertical flight calculations. Equality of lift thrust from the remote fan and the two turbofan units is achieved by adjustment of the individual fan pitch angles, along with power transfer within the shafting for delivery of required power to each lift unit. Gearing losses are considered during the calculation of power transfer.

The thrust of a turbofan is calculated as the total net thrust, the sum of the primary and secondary thrusts. However, the residual thrust of the turboshaft engine is not considered during thrust balancing.

The system performance can be calculated during vertical modes of level flight and pitch and roll attitude control. For each of these modes, performance can be calculated with all engines operative or with one engine inoperative. Either a turbofan or the turboshaft engine can be inoperative. Performance can be calculated either "dry" or with a preset amount of water/alcohol injection augmentation.

Attitude control performance is calculated on the basis of a thrust increment, which is input by the user. For roll control, this increment is applied to one of the turbofan engines by adjustment of its fan pitch angle. The fan pitch angles of the opposite turbofan engine and the remote fan are then adjusted until a solution is achieved which simultaneously balances power transferred through the shafting and causes the thrust of the remote fan to be an average of the two turbofan thrusts. Thus, no pitching moment exists.

For pitch control, the input thrust increment is applied to the remote fan. The fan pitch angles of the turbofan engines are then adjusted until a solution is achieved which simultaneously balances power transferred through the shafting and maintains equality of the turbofan engine thrusts. Thus, no roll moment occurs during pitch control.

When a turbofan engine is inoperative, power is transferred through the shafting to sustain the fan of the inoperative engine. Again, fan pitch angles of both turbofan engines and the remote fan are adjusted until thrust equality of the three units or the proper roll or pitch control thrust is achieved.

With the turboshaft engine inoperative, sufficient power is transferred through the shafting to drive the remote fan. All fan pitch angles are adjusted to achieve equal thrust or control thrust.

Normally, vertical flight performance is calculated at "intermediate" power level. However, the user can request a thrust level for any vertical flight operational mode. This thrust must be lower than that obtained at the intermediate power. The program will calculate the fan pitch angles. A "contingency" power level greater than intermediate is also available. The performance calculated at this power level is to be used for information purposes only. The intermediate power level is the qualified rating of the XT701-AD-700 engine. Any higher rating such as contingency would require development and testing beyond the scope of the baseline Research and Technology Aircraft development program.

The system performance during conventional flight is calculated with the turboshaft engine unpowered and disengaged, and the remote fan disengaged. The turbofan engines are configured so as to produce normal forward thrust and are considered equal in all respects. The center mixing gear is still coupled to the system. Thus, the calculation becomes one of a conventional turbofan with the addition of a small amount of power flowing to the center gear from the cross-shaft. This power is composed of the center gearing losses and any requested customer power extraction from the center gearbox.

Predefined power levels of "intermediate" and "maximum continuous," and also lower undefined power levels are available for the study of climb and cruise performance in the conventional flight mode.

Certain temperature and rotational speed limiters are built into the program. At any flight condition and operational mode, system performance is limited by whichever of these limiters is in effect. This is in accordance with standard procedure for engine performance calculations. Additionally, for this propulsion system, the fan pitch angle is limited to within a range bounded by a minimum (negative pitch) and a maximum (positive pitch). This effectively limits the torque moment available for roll and pitch maneuvers in this analytical performance model.

The card deck as delivered to users calculates the performance of an uninstalled propulsion system. The user can input his own installation factors such as inlet losses, nozzle coefficients, and flow bleeds and power extractions. The details of the method of entering these and other inputs into the program are described in a users manual report, which accompanies each card deck.

5.0 Design Information and Analyses of Shaft Driven Lift/Cruise Fan Propulsion System

5.1 General Description

The shaft driven lift/cruise fan propulsion system for the V/STOL Research and Technology Aircraft shown in Figure 1 consists of two lift/cruise (L/C) turbofan engines, one turboshaft engine and one lift fan connected together with shafting through a combiner gearbox. A disengaging clutch permits the disconnection of the lift fan during cruise operations.

Design work under this contract was limited to the definition of the lift/cruise turbofan engines and the turboshaft engine. The lift/cruise engine, Detroit Diesel Allison Model PD 370-25, is a modified DDA XT701-AD-700 turboshaft engine integrated with a Hamilton Standard variable pitch fan in a conventional front fan arrangement. A significant portion of the engine's power can also be transferred through a radial drive gear set and cross shaft to the other lift/cruise fan or the lift fan during V/TOL operations, attitude control operations or emergency engine out operations. The center engine shown in Figure 6 is a standard XT701 except for oil system and control modifications. This arrangement weighs 515 kg (1135 lbs).

Two basic concepts of vectoring the thrust from the lift/cruise engine were considered. The "fixed nacelle" engines (PD 370-25A) have the thrust vectored by use of a deflector exhaust nozzle that is nacelle mounted. The "tilt nacelle" engines (PD 370-25E) have the thrust vectored by tilting the nacelle including the engine. This necessitates a single point mount about which the engine rotates. The rotation centerline is coincident with the radial drive centerline.

Figure 7 shows the fixed nacelle lift/cruise engine PD370-25A general arrangement and Figure 8 shows PD 370-25E the lift/cruise engine used in a tilt nacelle installation. In both engines the power turbine drives the fan through a planetary reduction gear set to provide the proper speed match. The L/C engine gearbox also incorporates an overrunning clutch to allow the fan of an inoperable engine to be driven by the cross drive without the necessity of driving the inoperable power turbine. The engine and aircraft accessories are driven by a core mounted accessory box aft of the fan support assembly.

An interface agreement has been reached between Detroit Diesel Allison and Hamilton Standard on the interface of the HS variable pitch fan rotor and the DDA turboshaft engine, gearbox assembly and fan frame assembly which all together form the lift/cruise turbofan engine. Appendix A is the interface definition between DDA and HS with the latest revisions included. This interface will be updated and refined as the definition and design of the V/STOL Research and Technology aircraft propulsion system continues.

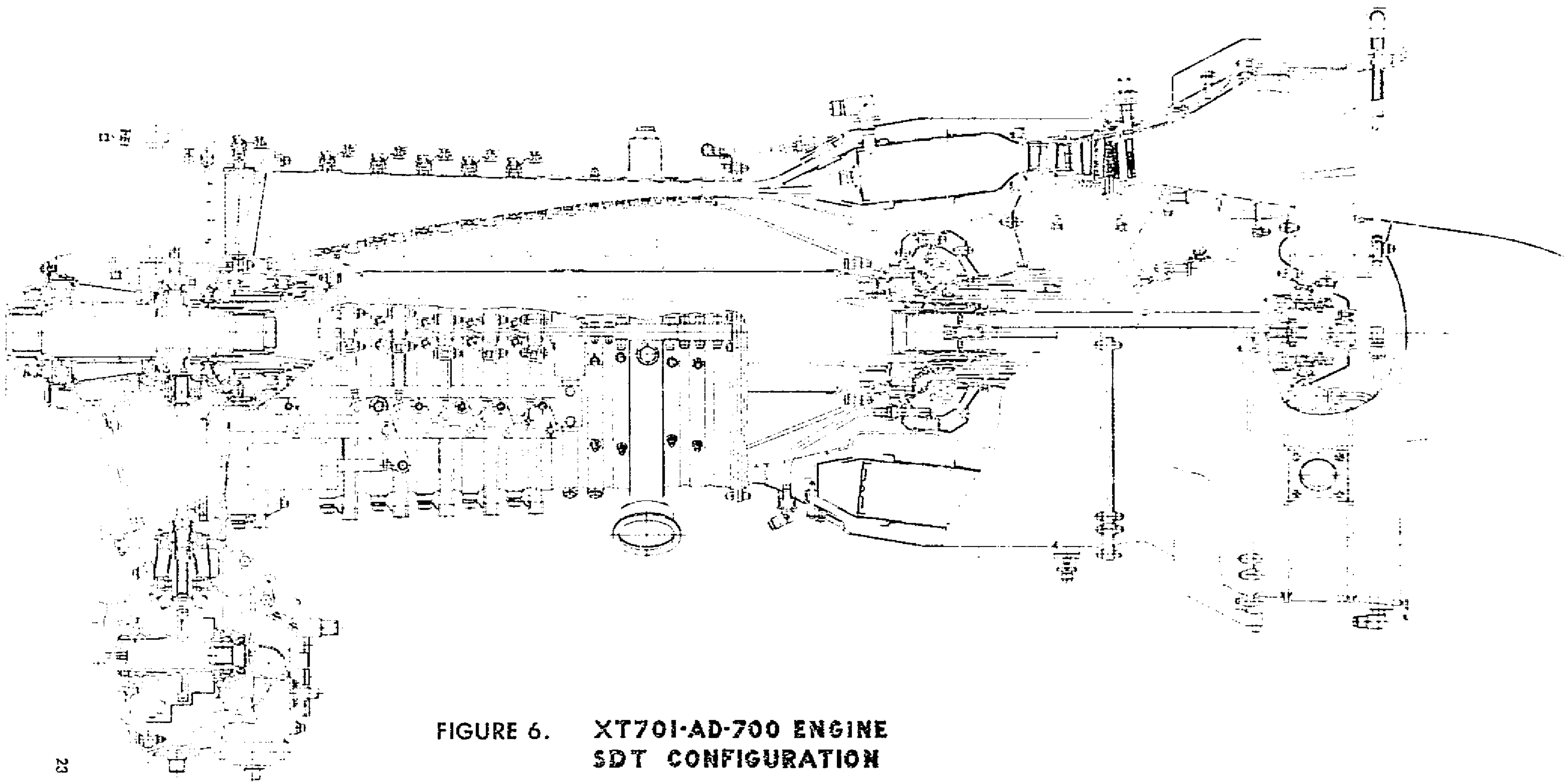
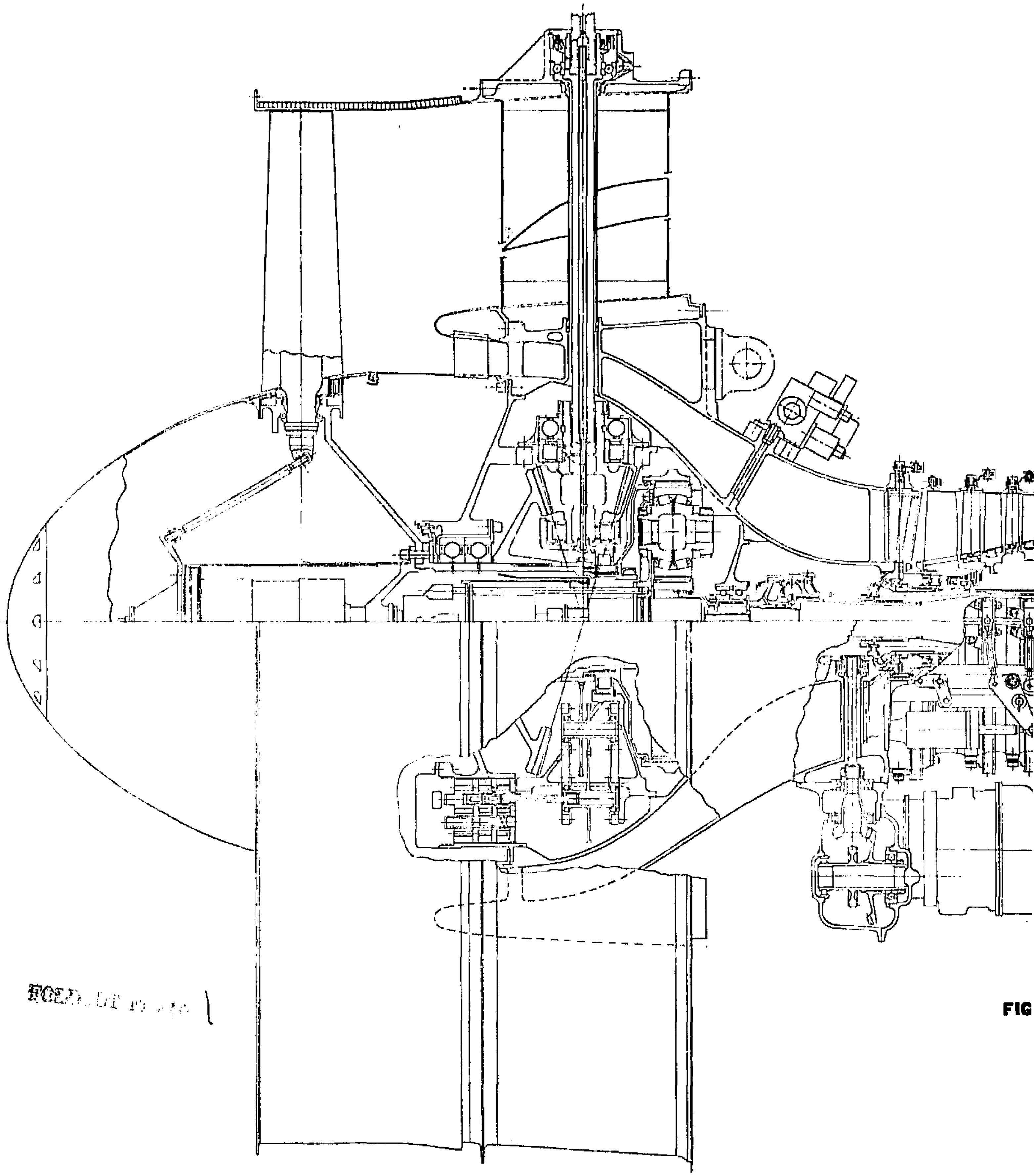


FIGURE 6. XT701-AD-700 ENGINE
SDT CONFIGURATION



FIG

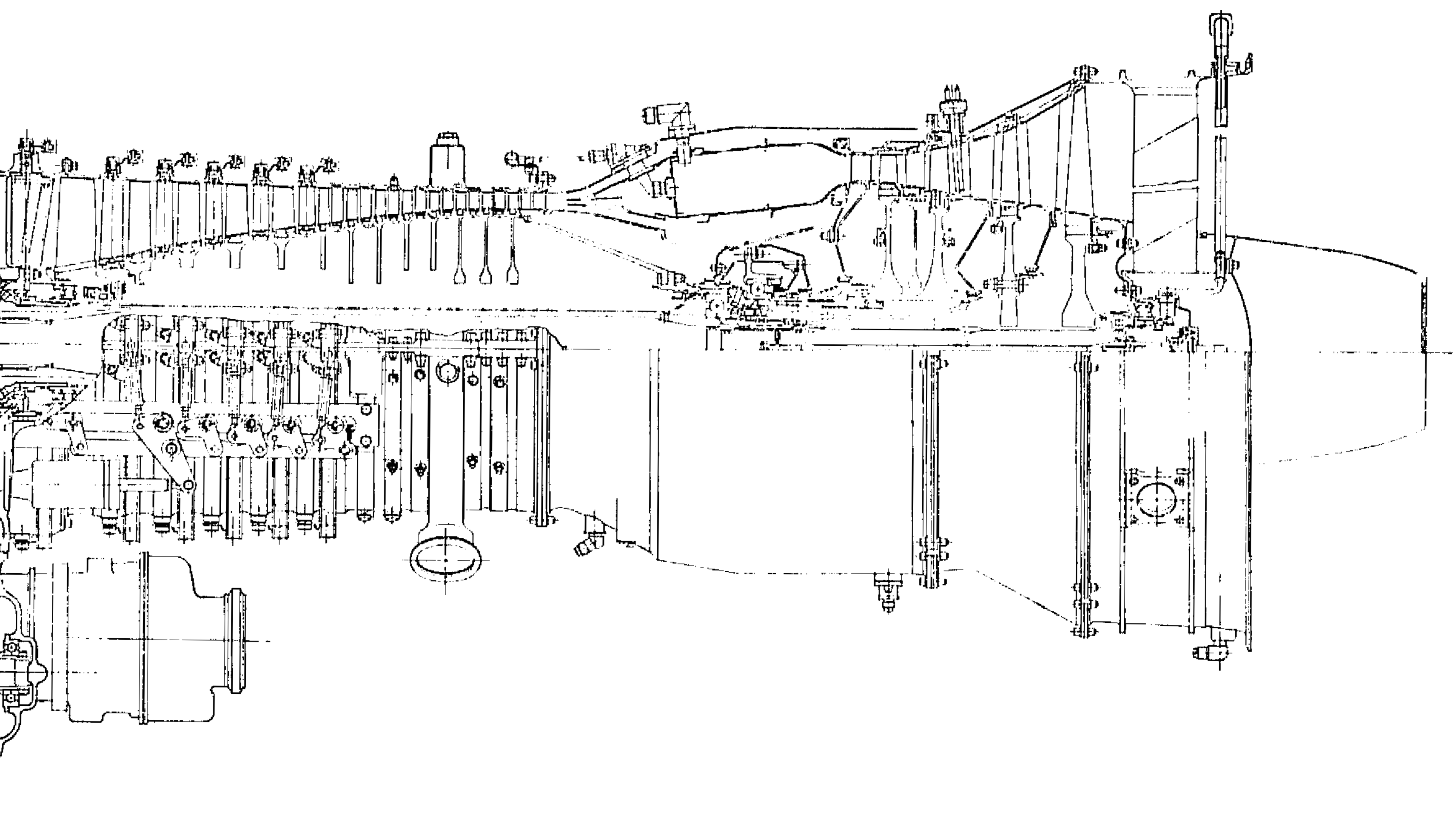


FIGURE 7. PD 370-25A LIFT/CRUISE ENGINE

FOLDOUT FRAME 2

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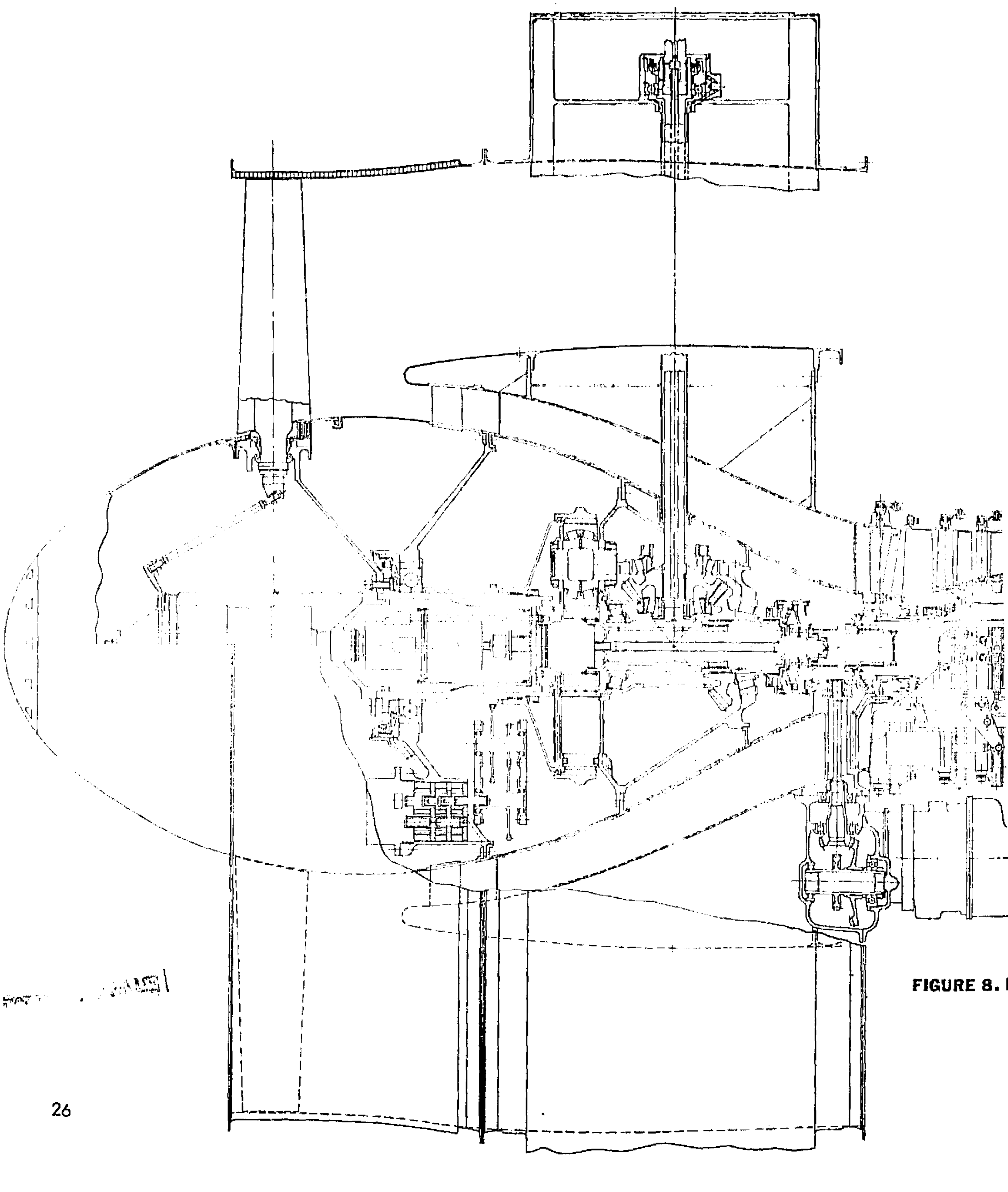


FIGURE 8. I

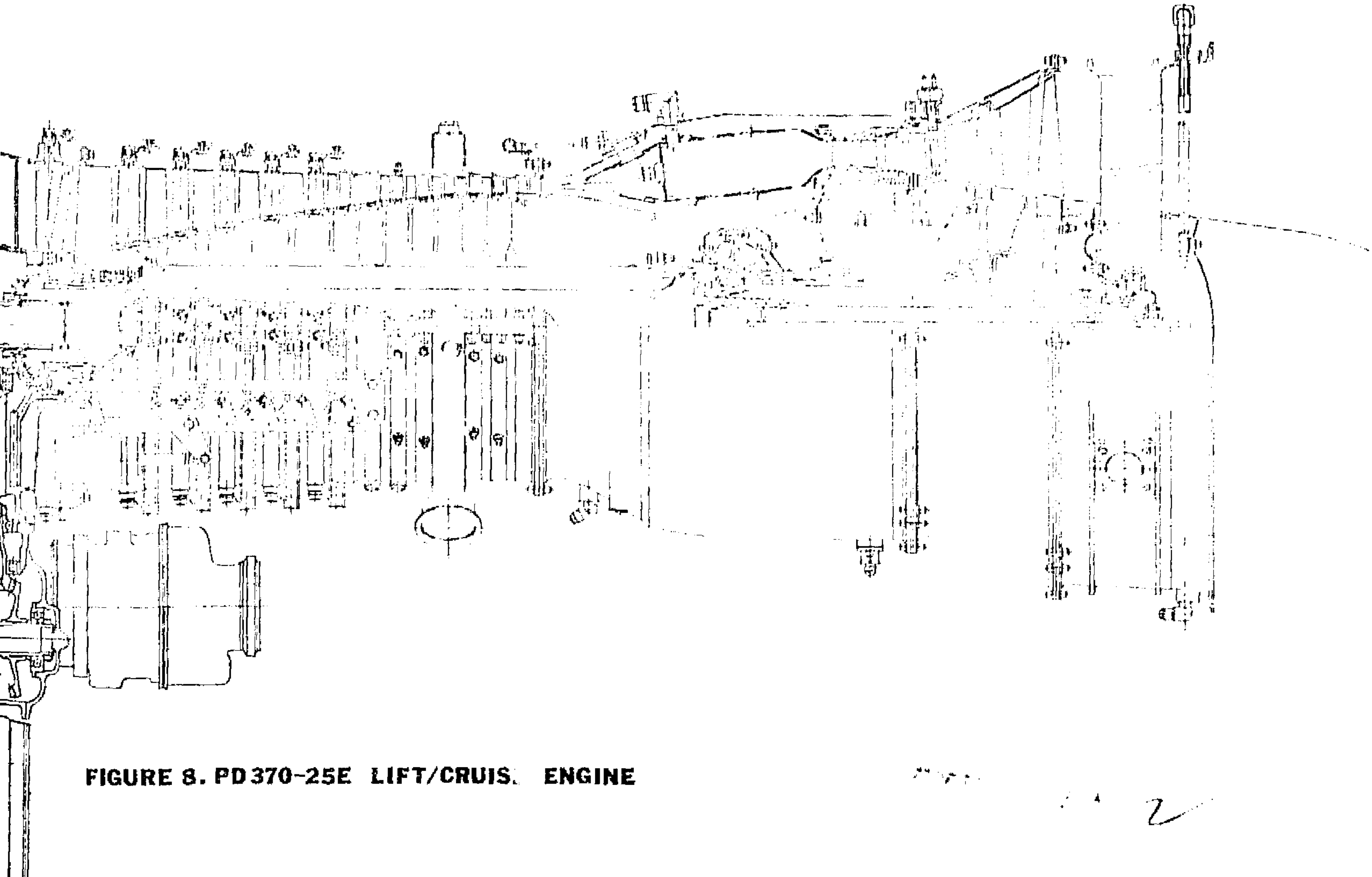


FIGURE 8. PD370-25E LIFT/CRUIS. ENGINE

5.2 Design Requirements

The design requirements for the propulsion system are as follows:

5.2.1 Design Point

VTOL mode of operation (Design for the more severe condition of 3 engines and 3 fans operating or 2 engines and 3 fans operating with one lift-cruise engine inoperative).

Sea level static, 305.6°K (90°F) day conditions. Intermediate Power (maximum thrust condition). Nominal maximum thrust horsepower distribution for all engines operating, one lift cruise engine inoperative without water alcohol, and one L/C engine inoperative with 3% water alcohol, are shown in Figures 9 , 10 , and 11 respectively.

5.2.2 Operating Envelope

The propulsion system shall be designed for operation in a cruise mode up to 11887.2 metres (39,000 feet) and a VTOL mode up to 609.6 metres (2000 feet). The temperature range for operation shall be 219.4° to 347.2°K (-65° to +165°F).

5.2.3 Dynamic Thrust Response

The propulsion system shall have a thrust response characteristic (time constant) of 0.2 seconds or less. Time constant as used here is defined as the time required to change thrust by 63.2% of the total thrust change after a step change in the power (or control) level.

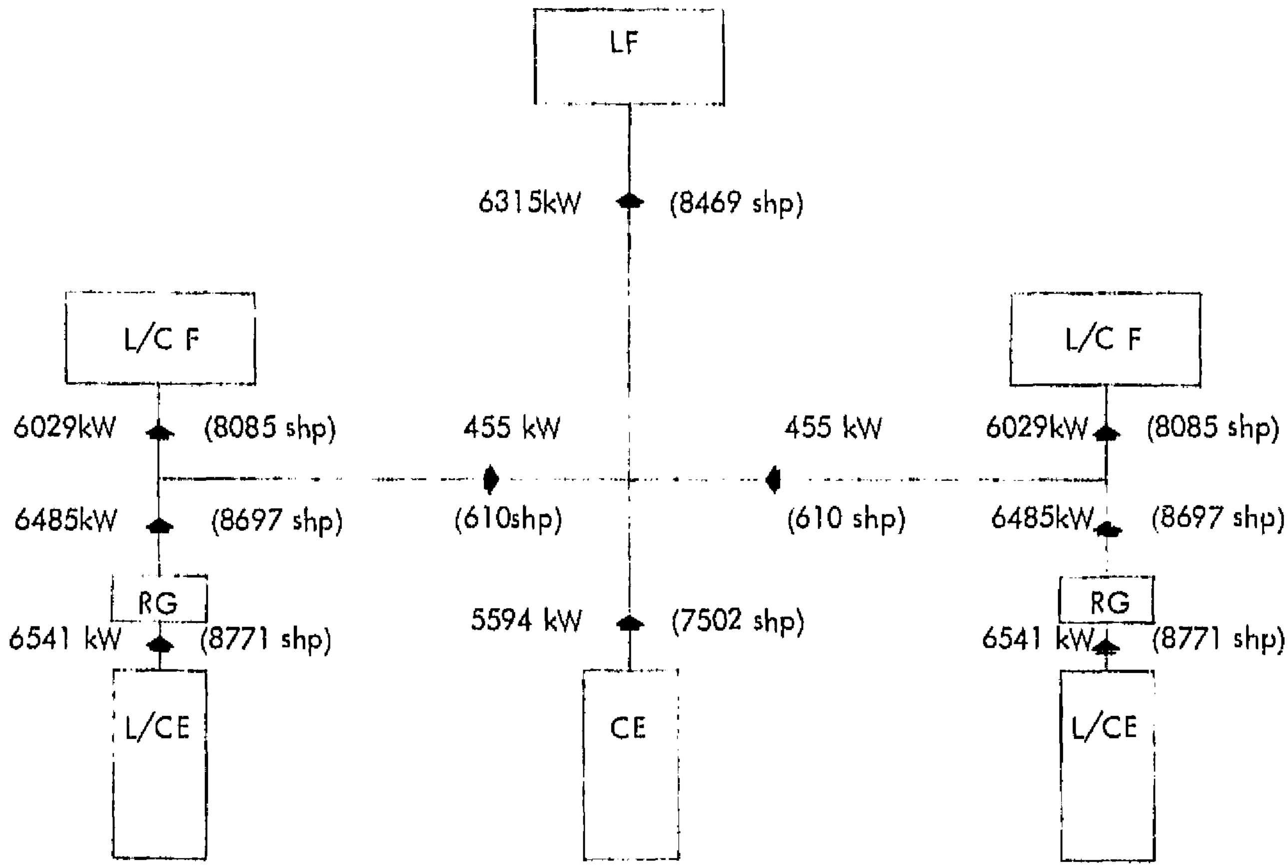
5.2.4 Stall Margin

The fan stall margin requirements for the lift fan and the lift/cruise fans shall not be less than:

20% for takeoff and landing
20% for cruise
10% for Maximum Control

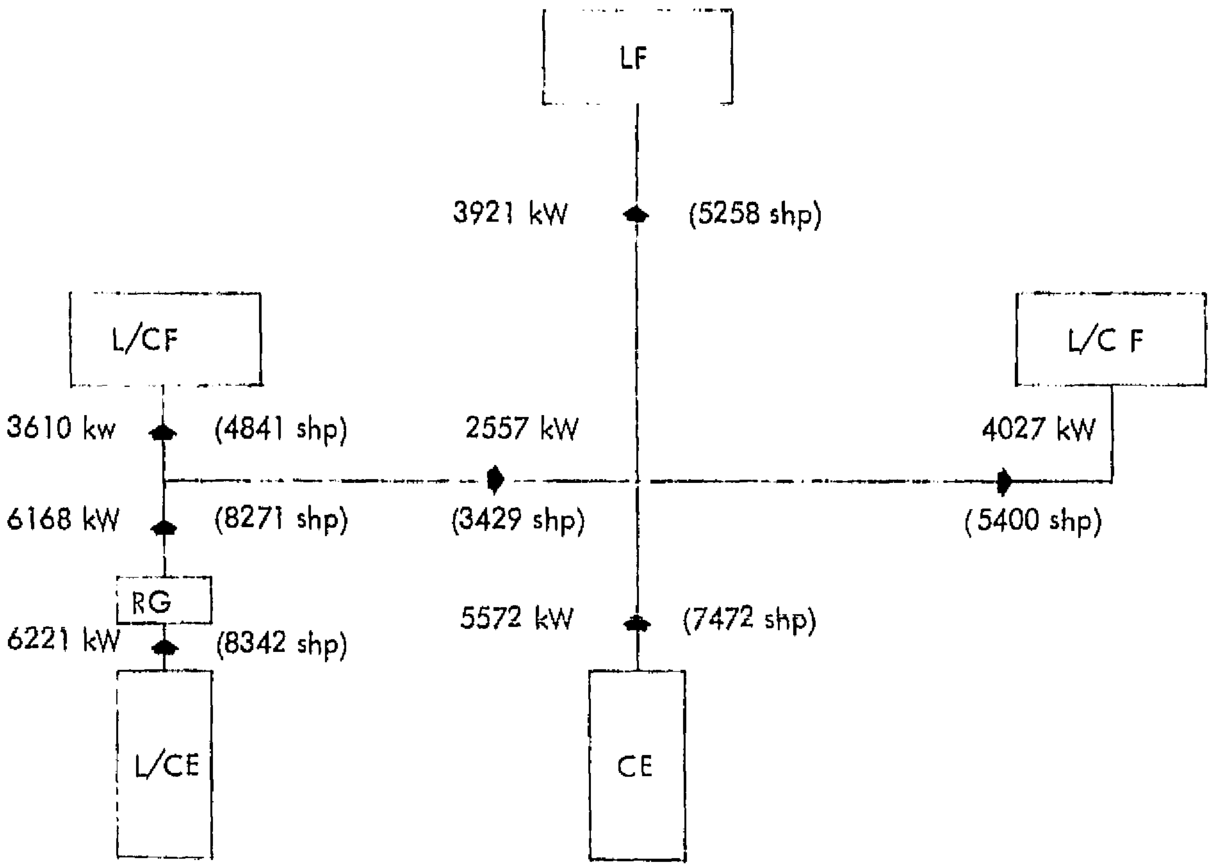
$$\text{STALL MARGIN} = \frac{P_{SURGE}}{P_{op\ pt}} \times \frac{W_{A}\ op\ pt}{W_{A_{SURGE}}} - 1$$

P_{SURGE} = Total pressure at surge
$P_{op\ pt}$ = Total pressure at operating point
W_A op pt = Air Flow at operating point
$W_{A_{SURGE}}$ = Air Flow at surge



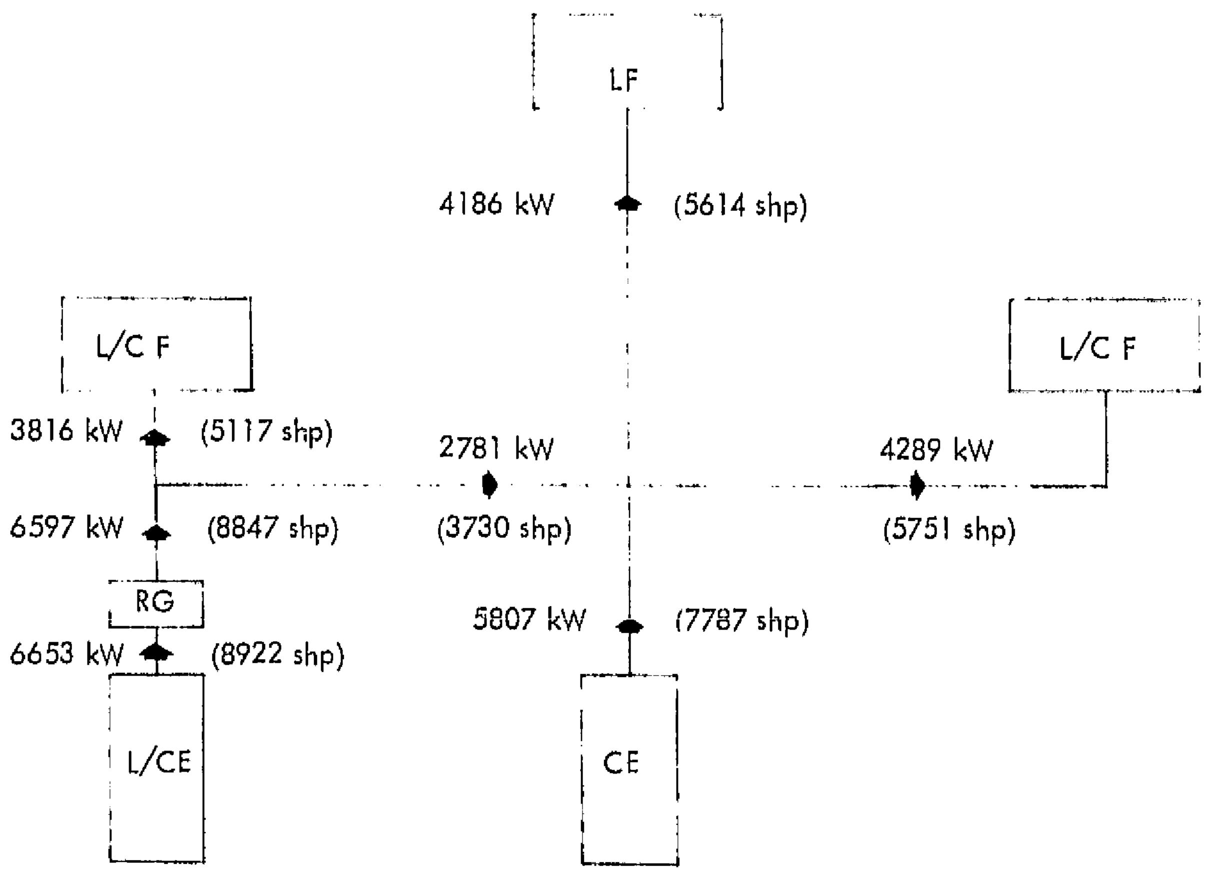
CONDITIONS: INTERMEDIATE POWER, 305.3°K (90°F) DAY, INSTALLED

FIGURE 9. NORMAL POWER DISTRIBUTION, ALL ENGINES OPERATING



CONDITIONS: INTERMEDIATE POWER, 305.3°K (90°F) DAY, INSTALLED

FIGURE 10. NORMAL POWER DISTRIBUTION, ONE ENGINE INOPERATIVE WITHOUT WATER/ALCOHOL



CONDITIONS: INTERMEDIATE POWER, 305.3°K (90°F) DAY, INSTALLED

FIGURE 11. NORMAL POWER DISTRIBUTION, ONE ENGINE INOPERATIVE, 3% WATER/ALCOHOL

5.2.5 Specifications

The propulsion system shall be designed in accordance with Military Specifications MIL-E-5007D and MIL-P-26366.

Detroit Diesel Allison Prime Item Development Specification 844B covers the requirements of the XT701-AD-700 engine.

5.2.6 Design Life

The lift fan assembly and the lift/cruise turbofan engine and all components thereof shall be designed for 500 hours of operation with 500 research and technology aircraft duty cycles. The duty cycle is shown in Figure 12.

All propulsion system components shall have a design life of 50 hours or more at a VTOL maximum thrust condition.

Maximum thrust is defined as the thrust available from 3 engines and 3 fans operating at the intermediate power rating or from the intermediate power operation of 2 engines and 3 fans with one lift/cruise engine inoperative.

All propulsion system components shall have a design life of 5 minutes or more during VTOL maximum attitude control operations.

5.2.7 Mechanical Limits

	RPM
Engine Gas Generator Turbine Speed	15450
Engine Power Turbine Speed	12300

5.2.8 Structural Limits

The propulsion system shall be designed to operate with the acceleration loading envelopes shown in Figure 13.

The engine, gearing, clutch, shafting, front frame, bearings and all components of both lift and lift/cruise fans shall be capable of withstanding all loadings imposed by the loss of a blade shell, leading edge sheath and fill.

5.3 Design Goals

5.3.1 Design Approach

Designs for engine modifications and new components shall conform to a philosophy where weight is minimized (within state-of-the-art technology) while minimizing cost and

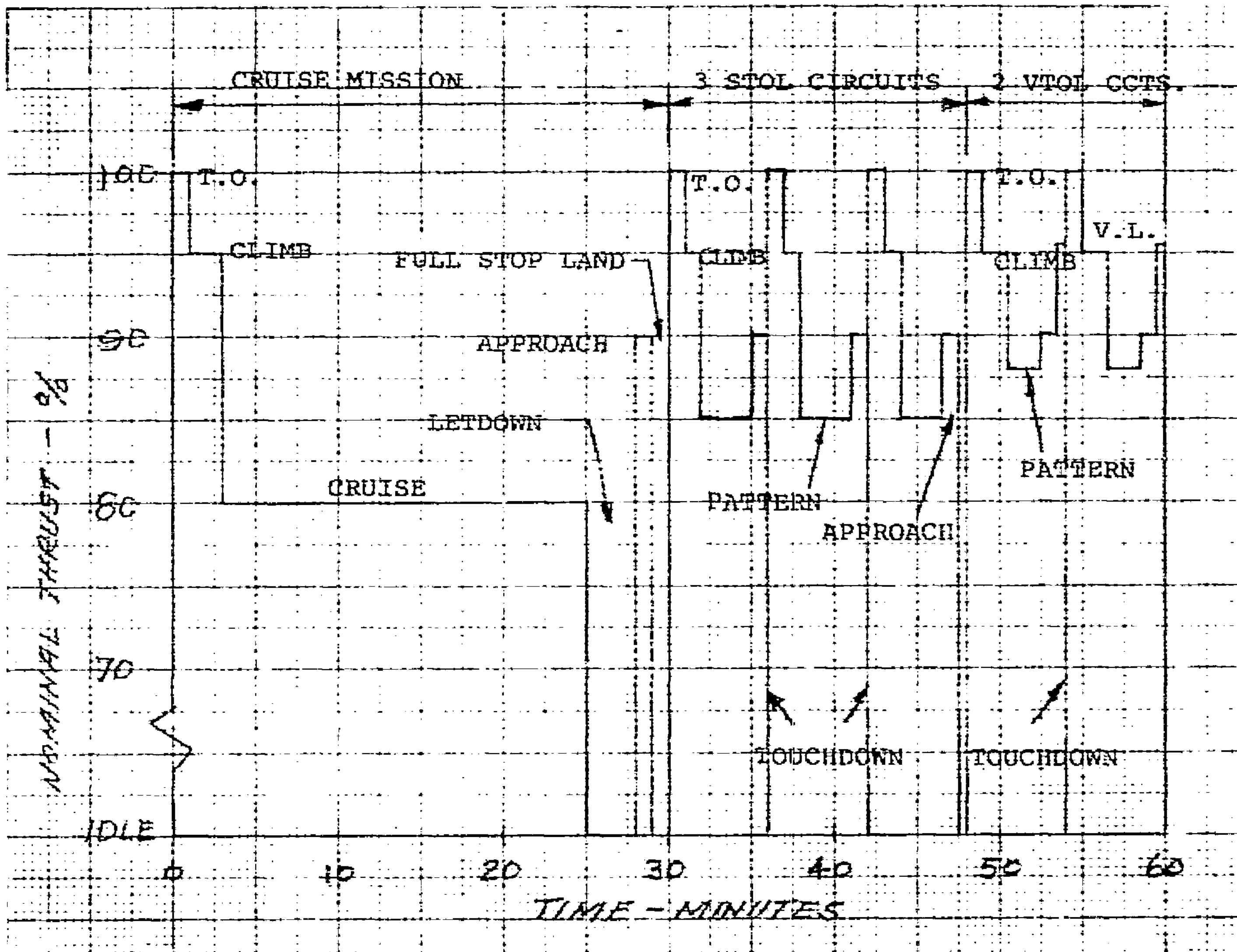


FIGURE 12. RTA DUTY CYCLE

o MANEUVER LOADING CRITERIA

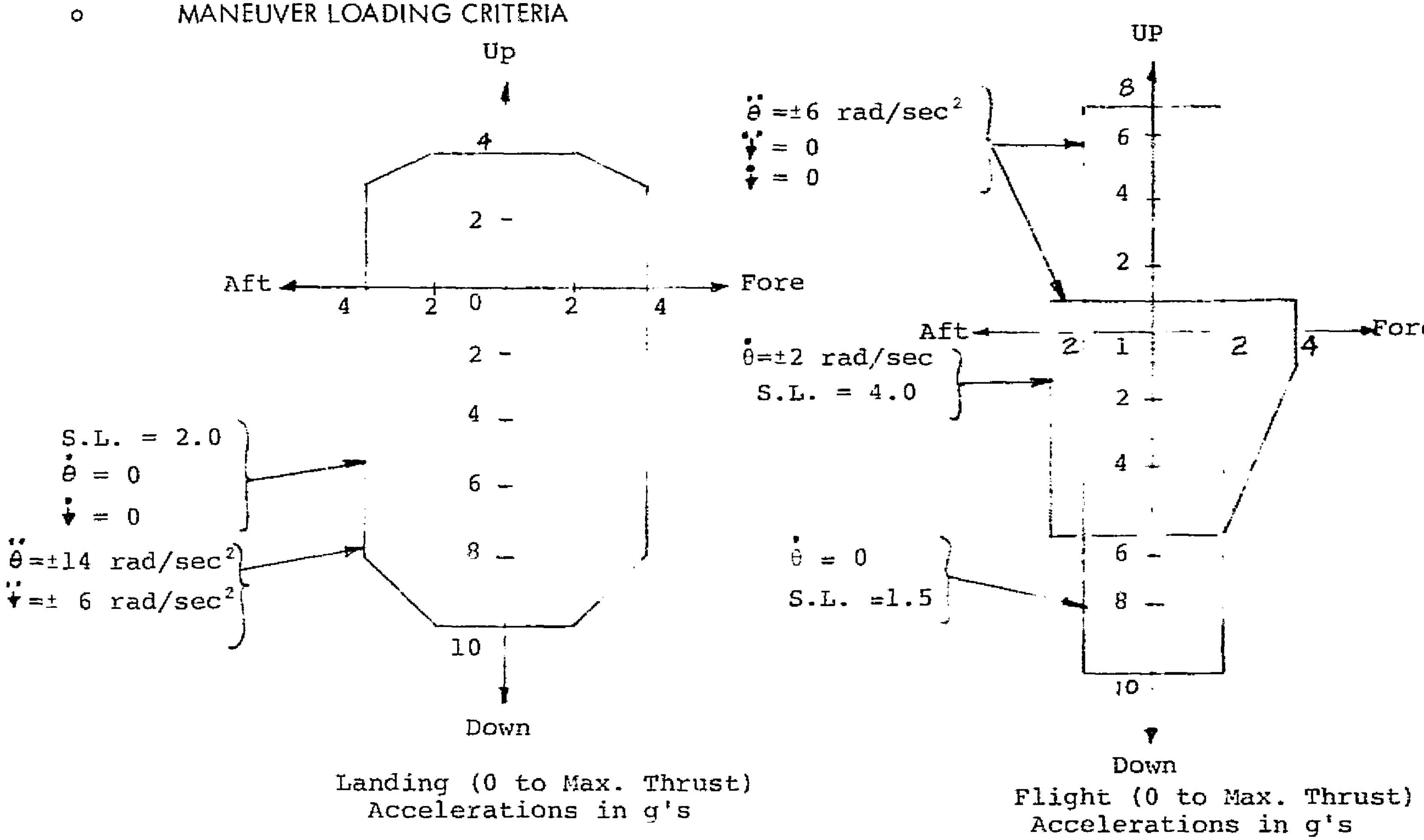


FIGURE 13. MANEUVER LOADING CRITERIA

maintaining adequate safety margins. The engine modifications shall provide engine and drive capability which is consistent with operational requirements of the fans. Interchangeability of lift fan and lift/cruise fan components shall be accomplished in the design.

5.3.2 Maintainability

In designing the propulsion system hardware, maintainability shall be considered. Provisions shall be included for easy access to hardware requiring service, inspection and/or repair. "High risk" parts (those vulnerable for FOD, or those where life expectancy may be reduced due to severe operating conditions) should have field joints to preclude the need for major teardown during a repair cycle. Also, access ports should be located in strategic areas of the assembly where borescope or other routine nondestructive tests may be performed. Self-contained lube/hydraulic/electrical systems shall be used.

5.3.3 Fan Distortion

The fan shall have no greater than a 5% thrust loss due to the following distortions, considered separately:

a. Pressure Distortion

(1) Inlet total pressure distortions, * (152.4 MM (six inches) forward of fan face) of 15 percent

or

(2) Exit static pressure distortions * (152.4 MM (six inches) aft of fan stator exit) of 15 percent

b. Temperature Distortion

(1) Temperature over 50 percent of inlet face at least 283°K (50°F) above ambient inlet temperature

or

(2) Changes of average temperature of 283°K/sec (50°F/sec) for 1/2 second

$$*\text{Distortion} = \frac{P_{MAX} - P_{MIN}}{P_{AVG}}$$

5.4 XT701-AD-700 Engine Modifications

When used as the center engine in a three engine aircraft, the existing turboshaft engine may be used without modification. However, when the existing engines are fitted with variable pitch fans as shown in Figures 7 or 8 some additional modifications are required.

5.4.1 Inlet Housing and Compressor

The inlet housing on the XT701 engine is removed before incorporating the variable pitch fan and fan frame assembly. The removed inlet guide vanes, front compressor bearing and related hardware from the inlet housing are incorporated into the fan frame for use on the lift/cruise fan engine.

The PD 370-25 compressor discharge reaches a maximum temperature of 713°K (823°F) at sea level intermediate on a 305°K (90°F) day. Compressor discharge total pressure is 1406kPa (204 psia) for this point. The compressor discharge total pressure of the PD 370-25 reaches a maximum of 1482 kPa (215 psia) at .4 Mn at sea level intermediate with a compressor discharge temperature of 681°K (767°F). This compares to design maximums of 1431 kPa (207.5 psia) compressor discharge total pressure and 757°K (903°F) compressor discharge temperature for the XT701 engine. Preliminary analysis indicates no compressor modification is required for the lift/cruise engines.

Compressor anti-icing will not be provided on the PD 370-25 L/C engines. It is felt that the nature of the flying envisioned for the RTA does not warrant its inclusion.

Modifications to the compressor inlet to accept the water/alcohol injection option are discussed in Sections 5.5.

5.4.2 Diffuser/Combustor

Preliminary studies indicate there is no requirement for modification to the present XT701 diffuser/combustor components for use in the lift/cruise engines.

5.4.3 Turbines

There are no present requirements for modifying the XT701 turbines for use in the PD 370-25 unless additional cooling is desired for the H.P. turbine for short term contingency operation. Modified turbine cooling is discussed in Section 5.6.

5.4.4 Shafting and Rotor Dynamics

To provide for growth, the XT701 mainshafting was sized for 15,000 LCF cycles from 0 to 7457 Nm (5500 ft-lb). This would provide 9,000 KW (12,000 hp) capability without modification.

The rotor dynamics are dependent upon rotor mass, rotor construction, mainshaft span and stiffeners and bearing support rates. As these parameters remain unchanged, the rotor dynamics for the L/C engines should be acceptable.

5.4.5 Mainshaft Bearings and Thrust Balance

The mainshaft bearings remain unchanged. Preliminary vent system and thrust balance analysis indicates that thrust loads remain at acceptable levels.

5.4.6 Accessory Gearbox

The new fan frame used on the L/C engines does not provide clearance for the starter when mounted on the present accessory gearbox. This, and the probable requirement for providing power from the high pressure rotor for driving aircraft hydraulic and electrical power systems, necessitate the design of a new accessory gearbox for the PD 370-25. A tentative accessory arrangement can be seen from the installation drawings, Figures 3 and 5 . The arrangement shown can be modified to suit the individual airframer's requirements when they are better defined.

5.4.7 Oil System

The present XT701 Oil System is driven by the high pressure rotor. In the PD 370 it is possible to have a power section failure but to have the lift/cruise gearbox driven via the cross shafting from the remaining operable engines, and in this case, the present system would not provide gearbox lubrication. Therefore the XT701 oil system must be modified to provide a lube pump driven by the L/C gearbox.

The present oil system for the power section must also be retained to assure proper lubrication when the interconnected low pressure rotors are dropped off in speed.

The two pump system can have some components in common, however, such as the supply tank, the filters, and the oil coolers.

The labyrinth seals for the L/C gearbox-compressor inlet assembly must be replaced by carbon face seals because in the case where the L/C gearbox is operable and its power section is not operating, there may not be sufficient air pressure available to pressurize the gearbox labyrinth seals.

Also in the case of the tilt nacelle engine sump, modification must be accomplished to allow scavenging and to prevent leakage when the engine is operated or shut down in the vertical position.

The fuel consumption of the lift/cruise engines is insufficient to provide use of the fuel as a solitary cooling medium with the additional cooling load of the lift/cruise gearbox. Therefore supplemental cooling must be supplied by either an airframe mounted airfoil cooler or airfoil surface coolers mounted in the fan flowpath in the nacelle.

5.4.8 Torquemeter

The present PD 370-25 engines have the XT701 torquemeter deleted. It is thought that the lives of the engines can be enhanced and a lighter installation obtained if the engines are matched on turbine temperature in lieu of torque. The additional gear and cross shaft loads incurred as a result should not noticeably affect gear/bearing/shaft system life.

5.4.9 Controls

XT701-AD-700 engine controls require modification and these are described in Section 5.10.

5.5 Water-Alcohol Injection

5.5.1 Introduction

The RTA 3 engine-3 fan propulsion system does not include a water-alcohol injection system. However, the addition of the system to the turbofan and turboshaft engines can be accomplished. The system would be added for the purpose of providing additional power and thrust to the system when one engine becomes inoperable in V/TOL flight modes. The augmentation would add to the output of two engines and three fans.

5.5.2 Effects on Propulsion System Performance

The effect of water-alcohol injection on the horsepower and thrust augmentation of the RTA lift/cruise engines and center turboshaft engine is obtained using an empirical method. This method is based on civil T56 (501-D13) turboprop engine tests with water-alcohol injection. Briefly, the method is based on the experimental observation that the 501-D13 augmented shaft horsepower, at a given compressor inlet temperature, can be calculated by running the engine nonaugmented but at a reduced compressor inlet temperature. This temperature is defined as the equivalent inlet temperature.

The water-alcohol mixture implied in the equivalent temperature correlation consists of 2/3 water, 1/3 methanol by volume and is injected immediately upstream of the compressor in the case of the lift/cruise engines, and at the compressor inlet for the center (turboshaft) engine. It was assumed that the 501-D13 equivalent temperature values could be directly applied to the RTA engines based on a general similarity of compressor characteristics. To simulate water-alcohol injection on the customer card deck cycle, the inlet temperature into the compressor is automatically reduced to the equivalent temperature value from the actual compressor inlet temperature according to the experimental correlation. In the case of the lift/cruise engines, these values correspond to the fan discharge temperature and pressure. The resulting cycle calculation produces an increase in the horsepower delivered to the fans with a corresponding increase in engine thrust.

Typical results of the simulated water-alcohol operation are shown in Figure 14 for the lift/cruise engines and turboshaft engine for a range of engine inlet temperatures; also shown for comparison is the 501-D13 engine test data.

The RTA propulsion system computer card deck can be used to calculate OEI performance with water-alcohol augmentation. On a standard day, the total net thrust of a dry, uninstalled system is calculated to be 131325N (29523 lbs) and when water-alcohol is injected into the remaining turbofan and turboshaft engines the total net thrust increases to 138197N (31068 lbs) an increase of 5.2%. On a 305.3°K (90°F) day, the total net thrust of a dry, uninstalled system is 120556N (27102 lbs). With water-alcohol injection, the total net thrust is 132953N (29889 lbs), an increase of 10.3%.

5.5.3 Addition of Water-Alcohol System to the Propulsion System

The addition of a water-alcohol system to the lift/cruise turbofan and the XT701-AD-700 turboshaft engine requires minor modifications to the fan frame at the compressor inlet and inlet housing, plus the addition of the required plumbing, valves, pumps, tank, etc. as described below.

Water-Alcohol Mixture

A 33% methanol, 67% distilled water mixture by volume is used.

General Arrangement of the System

Figure 15 shows the water-alcohol system general arrangement for a 3 engine V/STOL configuration. Figure 16 shows the injection components installed in the turboshaft engine. Figure 17 shows the nozzles installed in the fan frame at the inlet of the turbofan compressor.

Tables 6 and 7 show the water-alcohol flow capacity and weight breakdown, respectively.

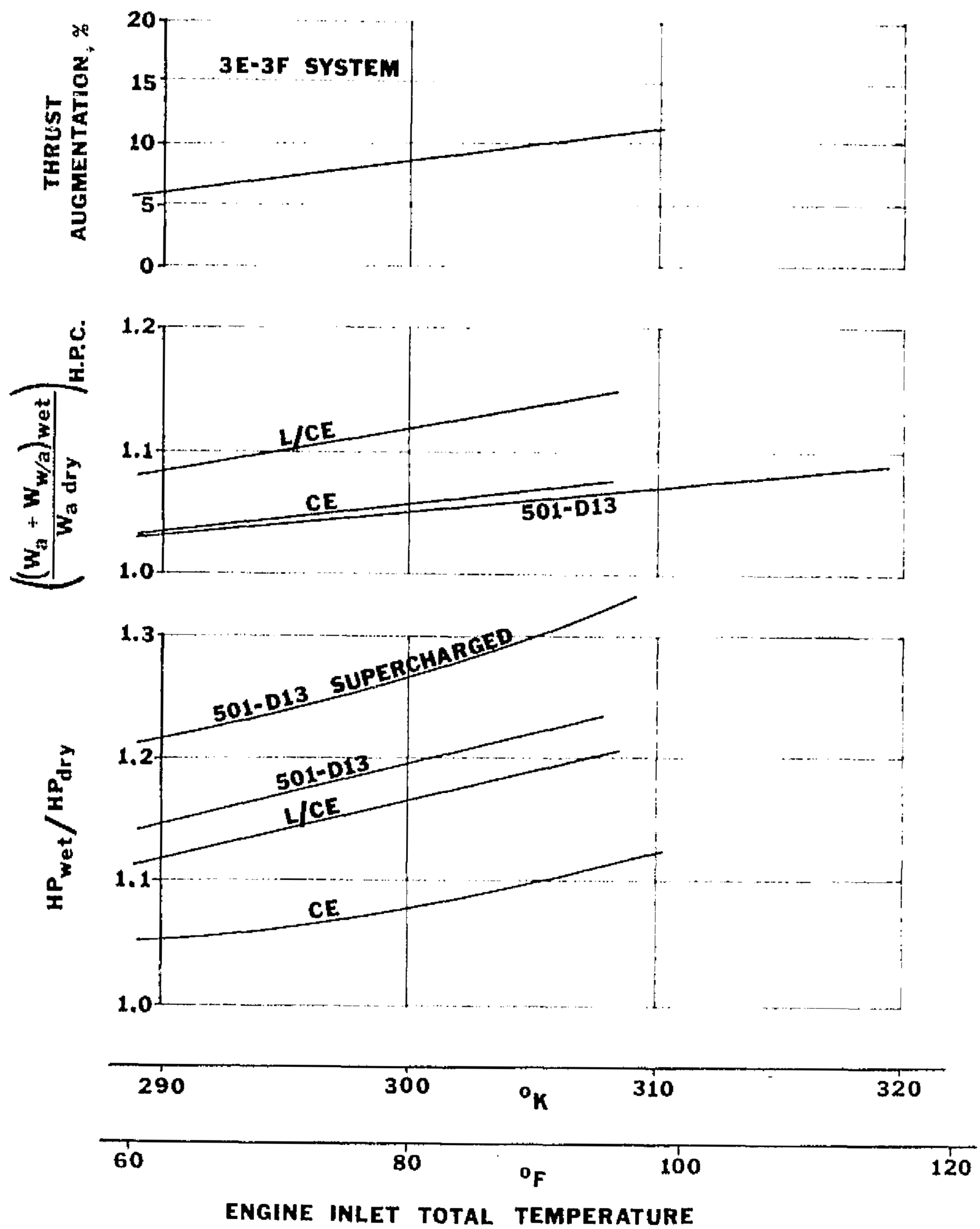


FIGURE 14. EFFECTS OF WATER/ALCOHOL INJECTION ON RTA ENGINES

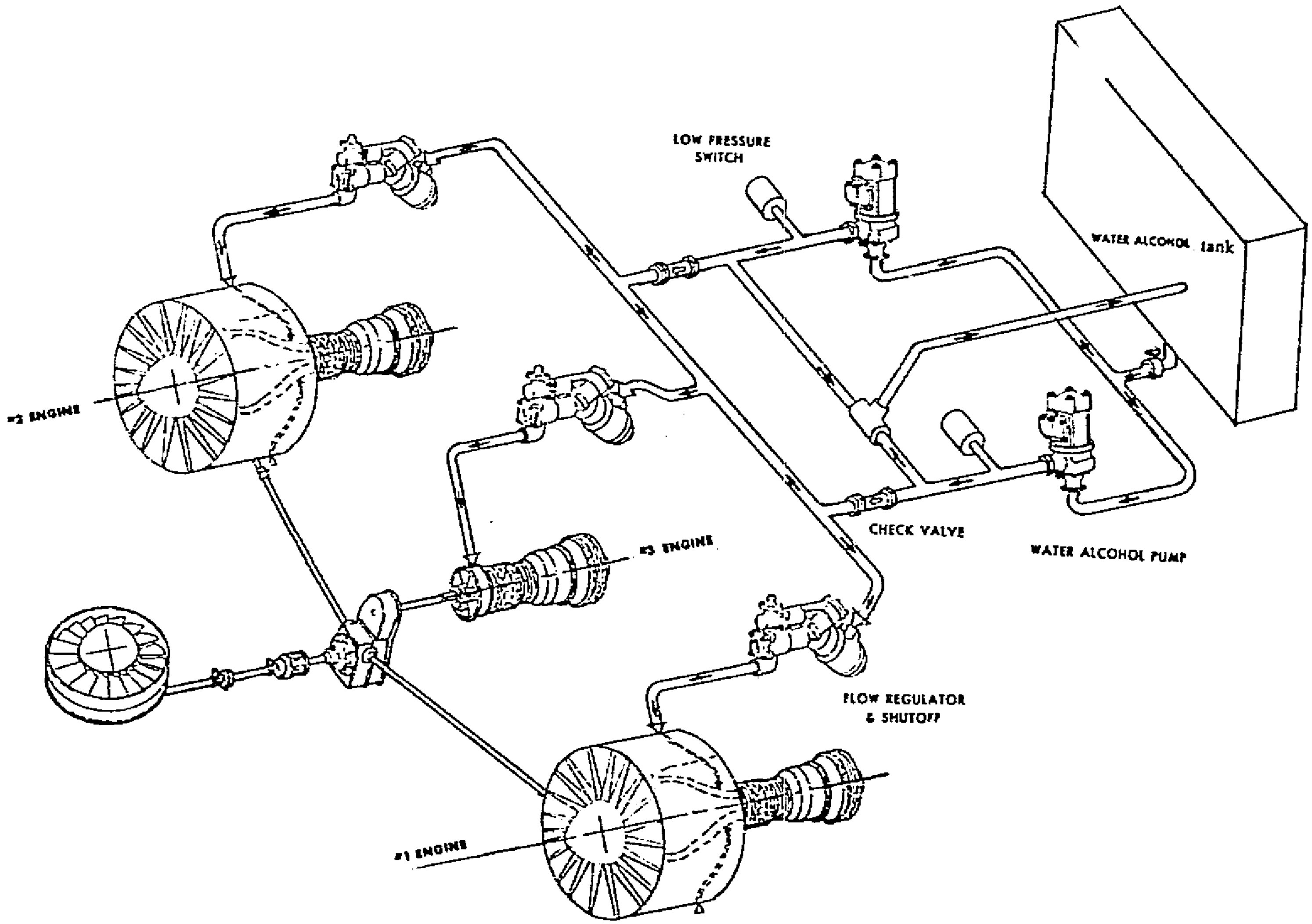


FIGURE 15. WATER/ALCOHOL SYSTEM SCHEMATIC

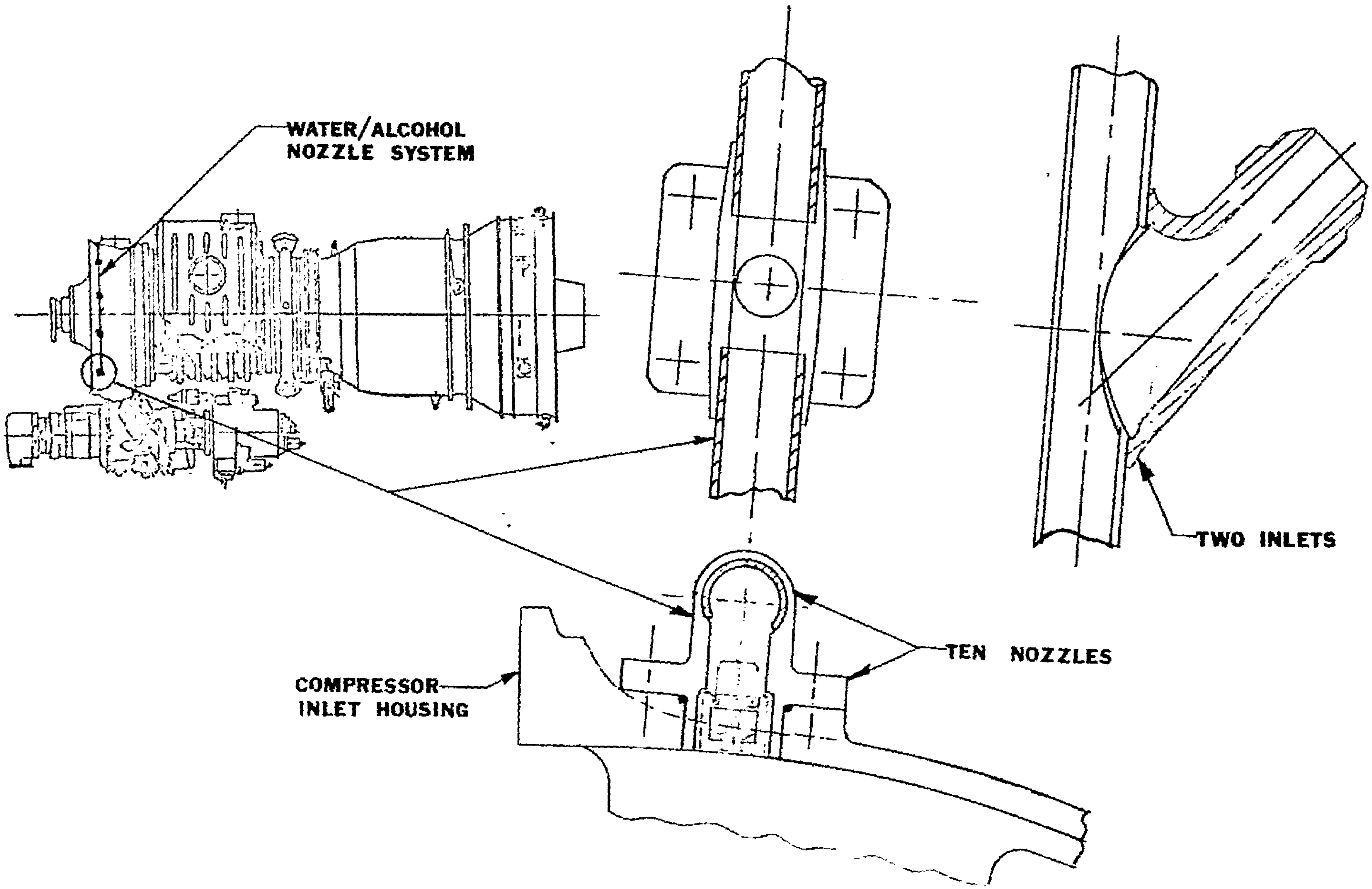


FIGURE 16. COMPRESSOR INLET WITH WATER/ALCOHOL MODIFICATIONS

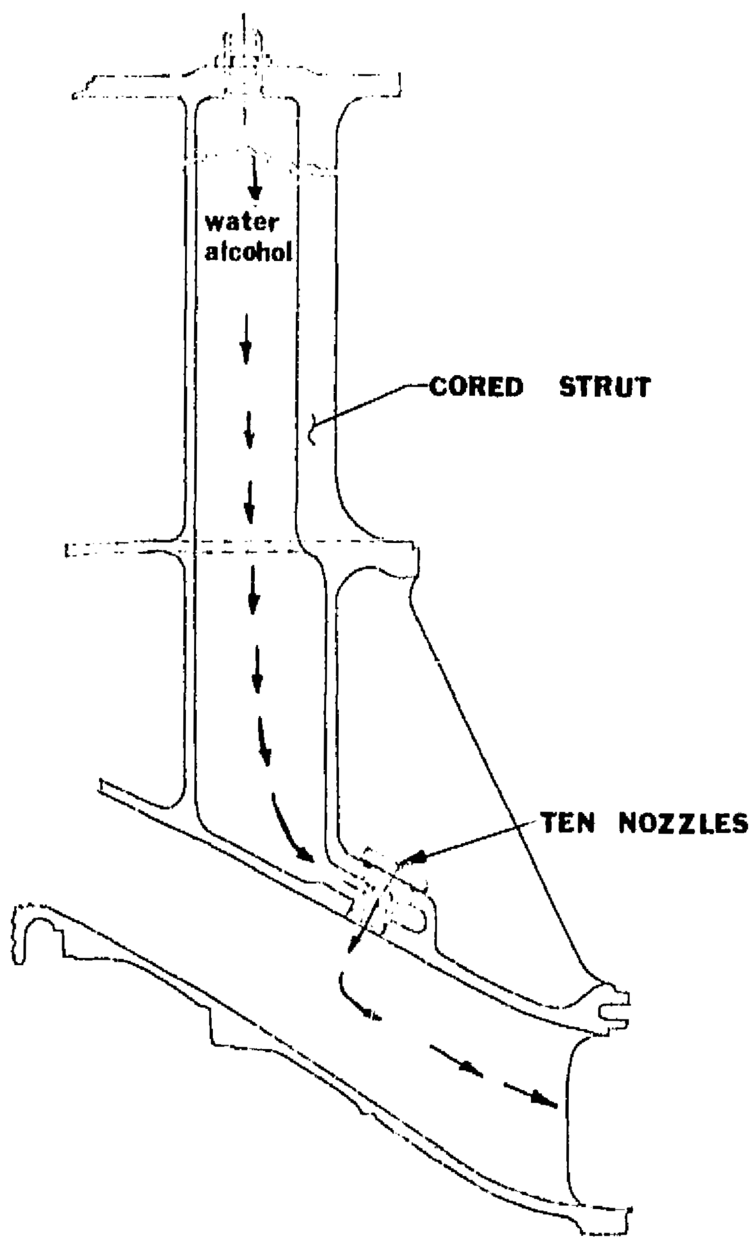


FIGURE 17. TURBOFAN INLET WITH WATER/ALCOHOL MODIFICATIONS

TABLE 6.

RTA Water/Alcohol Flow Capacity

	T56-A-10W	RTA V/STOL
WATER ALCOHOL MIXTURE RATIO		
Methanol	33%	33%
Water	67%	67%
ENGINE REQUIREMENT		
No. Engines	4	3
Required Engine Flow, litre/sec (GPM)	.5 (8)	.7 (10.6)
Total Required Flow, litre/sec (GPM)	2 (32)	2 (31.8)
MOTOR DRIVEN PUMP		
No. Used	2	2
Single Pump Capacity @ 1034 kPa, litre/sec (150 PSI, GPM)	2 (32)	2 (32)
FLOW REGULATOR AND SHUTOFF (DDA SUPPLIED)		
Required Flow, litre/sec (GPM)	.5 (8)	.7 (10.6*)

* NOTE: T56 Flow Regulator Will be Modified Internally To Provide Required Regulated Flow Output

TABLE 7.

Estimated Weight Breakdown of Water Alcohol System for RTA

Quantity	Item	Kg	lb
2	W/A Pumps	11	(25)
2	Pressure Switches	.9	(2)
2	Check Valves	.9	(2)
3	Regulators and Shutoff	9.5	(21)
30	Nozzles	4	(9)
	Tank, Wiring, Piping and Mounts	44	(96)

NOTE: An interface definition will be established between airframer and DDA on supply of W/A system components. Therefore, the above components, except for regulators and nozzles, have not been included in engine weights.

Components

The engine furnished system consists of an aircraft mounted flow regulator and ten injector nozzles. The regulator control valve solenoid is energized to open the regulator valve. The regulator controls the flow at .669 litre/second (10.6 gallons per minute) per engine. The ten nozzles are mounted on the inlet housing, in the front of the HP compressor inlet. Each nozzle has a plug in the center which produces a widely diffused spray. An inlet screen incorporated in each nozzle protects the nozzle from contamination.

The fuselage-mounted tank has a useable capacity of 121 to 148 litres (32 to 39 gallons). This results in a flow duration of over one minute, sufficient for one hot day takeoff or an emergency landing.

The centrifugal pumps are motor-driven and each has a capacity of 2.0 litre/second (32 gallons per minute). One pump is capable of supplying the required volume of flow. Two pumps mounted in parallel are desirable for reliability. The pump outlets connect into a distribution manifold which delivers water-alcohol to each engine.

5.6 XT701-AD-700 Engine Short-Term Contingency Operations

5.6.1 Introduction

The XT701-AD-700 engine is qualified at an intermediate power rating and this is the maximum rating used for the engines in the RTA propulsion system. Any higher rating such as contingency would require development and testing beyond the scope of the baseline RTA development program. However, since aircraft total weight and thrust to weight ratio requirements at VTOL modes of operation might exceed the thrust available in a one lift/cruise engine inoperative condition, a feasibility of operating the XT701-AD-700 engine at short term contingency levels above intermediate powers has been studied.

5.6.2 Component Life

A preliminary study ha[illegible] that the XT701-AD-700 engine has sufficient turbine life to operate satisfactorily fo[illegible]0 hours to the duty cycle shown in Figure 12, with the intermediate power rating of 1561°K (2350°F) burner out temperature, plus one hour of contingency operation at a burner out temperature of 1617°K (2450°F). This study considered two types of engine environment, a lift/cruise engine with a 1.218 pressure ratio fan forward of the compressor, and a center engine without the ram effect of the fan.

The HP1 vane showed the highest surface temperatures, with maximum local temperatures of 1397°K (2054°F) and 1439°K (2130°F), at burner out temperatures of 1561°K (2350°F) and 1617°K (2450°F) respectively. With current cooling levels, some vane deterioration would be expected at the higher temperature.

The analysis indicated that the HP2 blade has the lowest stress rupture life, but would meet the above requirements with current cooling levels.

5.6.3 Modifications Required

The preliminary study has shown that the existing XT701-AD-700 engines have sufficient turbine life to meet the goals defined above. However, slight increases in 1st vane and 2nd blade cooling flows, which could be accomplished by increasing metering hole sizes, would provide reduced metal temperatures for additional operating margin.

5.6.4 Contingency Performance Augmentation

The RTA propulsion system computer card deck can be used to calculate one level of contingency. This level is a 57°K (100°F) increase in burner outlet temperature (BOT).

Using Boeing installation factors, one lift/cruise engine inoperative performance on a 305.3°K (90°F) day has been calculated with the new card deck. The total net thrust available at intermediate power is 116908N (26282 lbs) while at the contingency level the total net thrust is 120182N (27018 lbs). The increased BOT provides a 2.8% increase in thrust.

To evaluate the effects of water-alcohol injection and contingency level turbine temperatures on total system thrust, calculations were made using Boeing installation factors on a 305.3°K (90°F) day. With one lift/cruise engine inoperative, the total net thrust was 133745N (30067 lbs), an increase of 14.4% over the intermediate power setting total thrust.

5.7 Bevel Gear Cross Shaft Location Study

It became obvious early in the V/STOL studies that the general arrangement that afforded the lightest weight for the fixed nacelle engine (Figure 7) with the cross shaft drive located in front of the reduction gear was probably not the optimum arrangement for the tilt nacelle engine installations.

It is necessary in the tilt nacelle engine for the engine to rotate about the centerline of the cross shaft. Placing the cross shaft forward on the engine leads to three distinct disadvantages:

- o The distance from the pitch axis to the exhaust nozzle is greater, which would result in longer landing gear for an equal nozzle ground clearance. While not possible for the engine manufacturer to evaluate the impact on system weight it is believed to be considerable.

- o The distance from the engine pitch axis to the engine CG is greater, resulting in a larger CG shift when the engine is rotated and also resulting in larger engine mount loads.

- The engine must be lengthened over the fixed nacelle engine with the same gear arrangement to provide a load path for the engine mount loads to be distributed into the fan housing. This increases engine weight.

With these factors in mind, two lift/cruise gearboxes were designed; Figure 18 shows the optimum cross shaft forward arrangement modified to a tilt nacelle mounting. Figure 19 shows the optimized cross shaft aft design. The designs were coupled with an engine to form the PD370-25D shaft-forward and PD370-25E shaft-aft turbofan engines. Installation envelopes are shown in Figures 4 and 5. Pertinent data is summarized below:

	Shaft Fwd	Shaft Aft
Engine Model	PD370-25D	PD370-25E
Cross Shaft to exhaust flange length mm (in)	1971(77.6)	1819(71.6)
Overall length mm (in)	3183(125.3)	3155(124.2)
Cross Shaft to C/G mm (in)	406(16.0)	315(12.4)
Weight Kg (pounds)	1262(2783)	1196(2637)
Mount Moment N-m (Ft.Lb.)	5030(3710)	3695(2725)

It can be concluded therefore, that for a tilt nacelle installation, the aft shaft engine is lighter, shorter, and should also result in substantial savings in airframe weight.

5.8 Preliminary Design Studies of Lift/Cruise Engine Unique Components

Since the purpose of the Research Technology Aircraft is to prove a flight concept and not hardware technology, the criterion for the design of the components unique to the lift/cruise engines is to design within the present state-of-the-art using present design concepts, materials, material allowables, and making the maximum use of existing hardware where possible.

5.8.1 Reduction Gear

Probably the best example of the use of existing hardware is the reduction gear. The T56 turboprop engine reduction gearbox shown in Figure 20 has a planetary output stage with a ratio of 4.33 to 1. The input is to the sun gear at a speed of 4424 RPM and the output is from the planet carrier at 1021 RPM. This gearbox has accumulated over 65 million flight hours and is capable of continuous operation up to 4101 kw (5500 horsepower). The operating parameters for the T56 planetary set are shown in Table 8 .

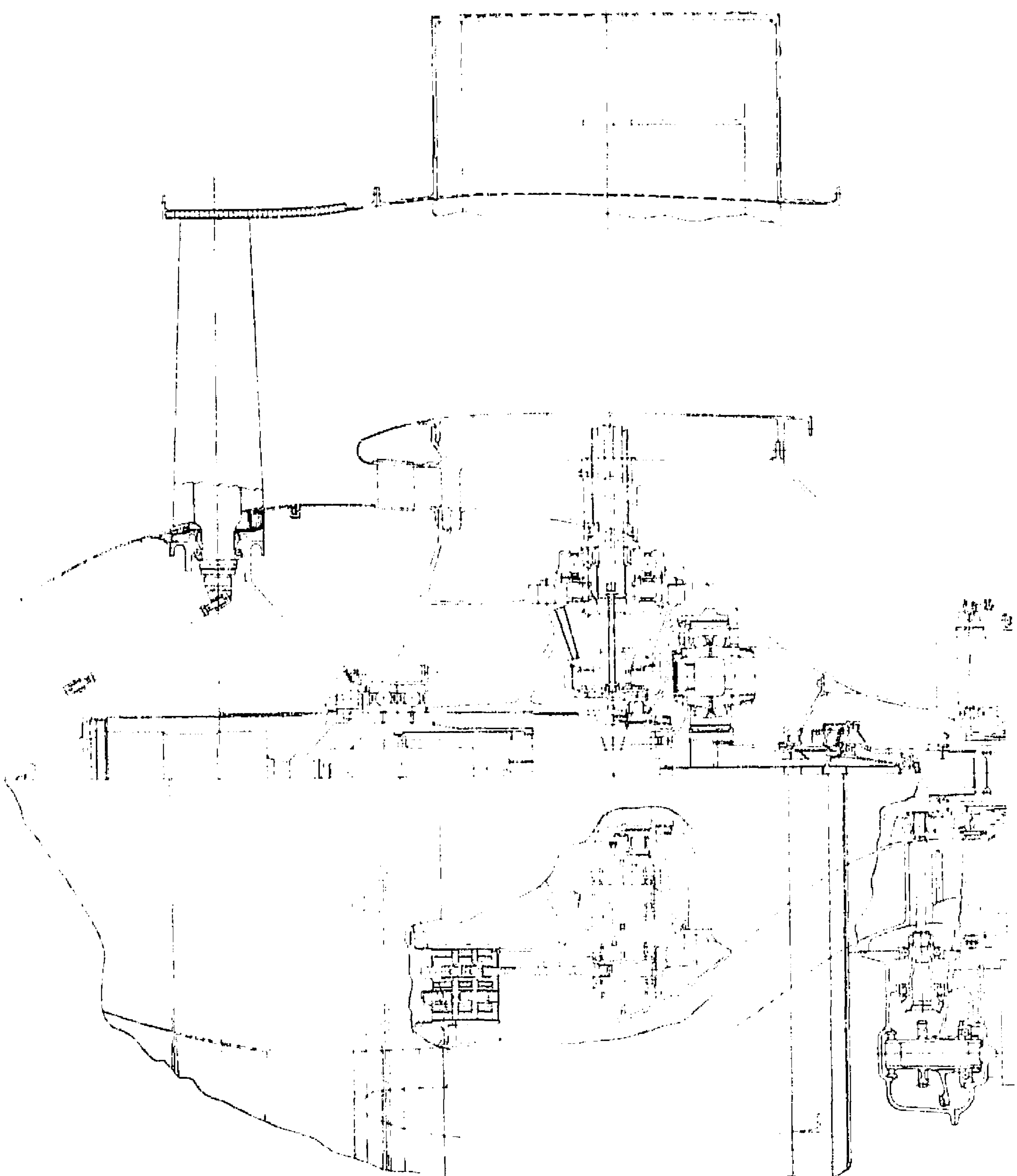


FIGURE 18. PD370-25D LIFT/CRUISE GEARBOX GENERAL ARRANGEMENT

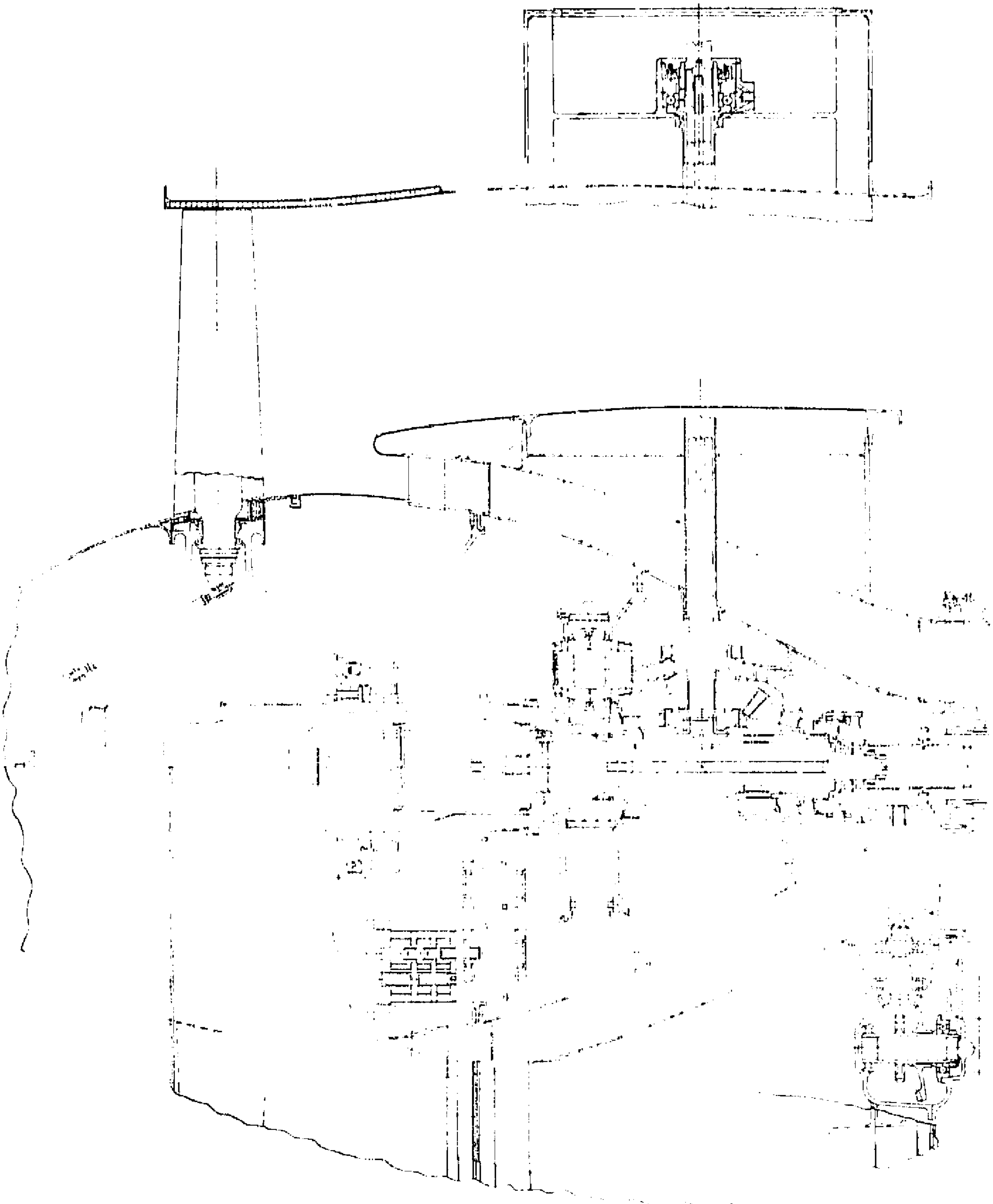


FIGURE 19. PD 370-25E LIFT/CRUISE GEARBOX GENERAL ARRANGEMENT

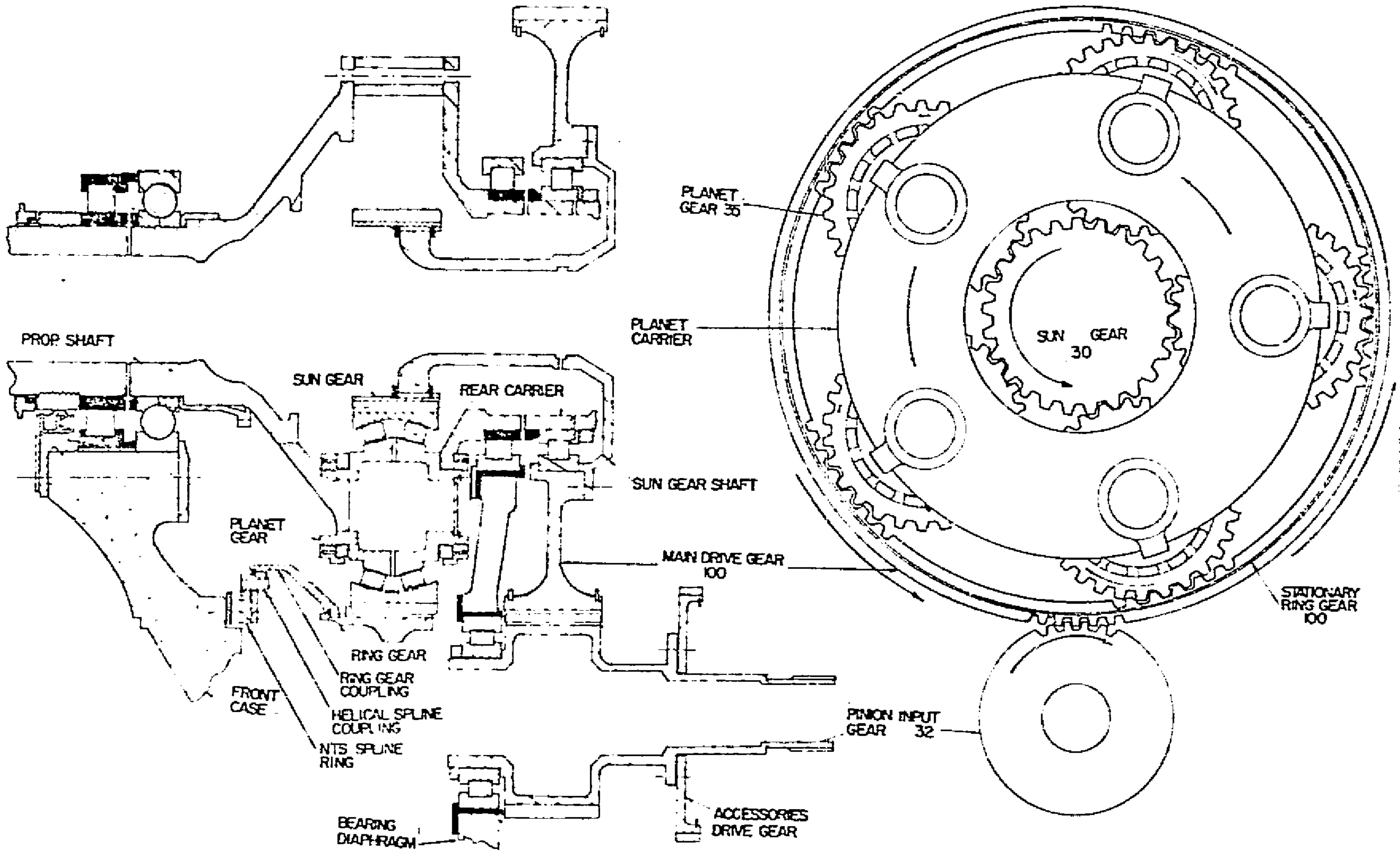


FIGURE 20. T56-A-7 REDUCTION GEAR TRAIN SCHEMATIC

TABLE 8. T56 PLANETARY PARAMETERS

	SUN	PLANETS (5)	RING
NUMBER OF TEETH	30	35	100
DIAMETRAL PITCH	6	6	6
PRESSURE ANGLE	25°	25°	25°
PITCH DIAMETER-mm	131.2	148.2	427.6
(in)	(5.1667)	(5.8333)	(16.8333)
FACE WIDTH-mm	60.7	56.9	53.2
(in)	(2.39)	(2.24)	(2.095)
RPM	4424	2916	0

The design speed of the 1575 mm (62 inch) diameter Hamilton Standard Fan is 3543 rpm and the design speed of the XT701 power turbine is 12,000 RPM, therefore the required reduction ratio is 12,000/3543 or 3.38/1.

When the existing T56 planetary gear set is used as a "star" or fixed planet set the resultant ratio is 100/30 or 3.33 to 1. This provides a match at a turbine speed (N_T) of 11,810 RPM and a fan speed of 3543 RPM according to present component and cycle analysis and the reduction in performance parameters was negligible. Therefore, when the gear set is used in this manner, operating parameters shown in Table 9 are applicable.

TABLE 9

T56 PLANETARY PARAMETERS WHEN USED IN PD370-25

	SUN	PLANETS (5)	RING
NUMBER OF TEETH	30	35	100
DIAMETRAL PITCH	6	6	6
PRESSURE ANGLE	25°	25°	25°
PITCH DIAMETER - mm	131.2	148.6	427.6
(in)	(5.1667)	(5.8333)	(16.8333)
FACE WIDTH - mm	60.7	56.9	53.2
(in)	(2.39)	(2.24)	(2.095)
RPM	11,810	10,123	3543
BENDING STRESS * - MPa (S_B)		101	106
(PSI)		(14,691)	(15,170)
CRUSHING STRESS * - MPa (S_C)		914	518
(PSI)		(132,558)	(75,157)
MATERIALS	AMS 6265	AMS 6265	AMS 6265

* ALL ENGINES OPERATING - 6540 kw (8771 HP)

It is also easy to attain other reduction ratios by changing the number of teeth in the sun and ring gears while keeping the planet bearings unchanged; in this manner existing tooling can be used and the T56 experience is still applicable. Ratios attainable are shown in Table 10.

TABLE 10

RTA V/STOL POTENTIAL
RATIOS USING EXISTING T56 PLANET ASSEMBLIES

RATIO	3.182:1	3.258:1	3.333:1	3.414:1	3.592:1
RING GEAR TEETH	105	101	100	99	97
SUN GEAR TEETH	33	31	30	29	27
PLANET GEAR TEETH	35	35	35	35	35
NUMBER OF PLANETS	5	4	5	4	4
MAX.POWER KILOWATTS	10482	7878	9530	7332	6861
(HORSEPOWER)	(14,057)	(10,564)	(12,780)	(9,883)	(9,201)

N_T = 11,810 RPM S_C = 1103 MPa (160,000 PSI) S_B = 193 MPa (28,000 PSI)

5.8.2 Planet Gear Bearings

The only bearings seeing an appreciable gear load in the planetary set are the planet bearings. The planets in the T56 reduction gear box, and thus the PD 370-25, are supported by a pair of spherical bearings.

At 4101 kw (5,500 horsepower) in the T56 gearbox these bearings have a radial load of 2844 rg (6270 pounds) each and, for a C130 aircraft long range mission, a cubic mean load of 1529 kg (3371 pounds). In each case the rotational speed is 2916 RPM.

In the PD370-25 application the bearing load is 1698 kg (3744 pounds) at 6540 kw (8771 horsepower) (all engines operating) and 1193 kg (2630 pounds) for the cubic mean load for a typical V/STOL mission. In the V/STOL application the bearing rotates at 10,123 RPM.

5.8.3 Planet Carrier

The only reduction gear member having a major change from the T56 is the planet carrier. The planet carrier has been changed from a rotating steel member in the T56 to a stationary aluminum casting in the V/STOL application. This change in materials is permitted since the carrier no longer carries propeller moment loads as in the T56. The use of an aluminum cast carrier also allows the use of cored passages for variable pitch fan services.

5.8.4 Overrunning Clutch

Test data from the XT701 indicates that it requires about 462 kw (620 horsepower) to rotate the L.P. rotor with the gas generator not operating. With an inoperable engine on the V/STOL aircraft this would represent an unacceptable loss to the propulsion system, therefore a means of uncoupling the power turbine on an inoperable engine is required. This is accomplished with an overrunning clutch in the PD370 engines.

The T56 incorporates a "safety coupling," Figure 21 , that uncouples the reduction gearbox from the power section in the event power section failure to allow the propeller to windmill.

The T56 safety coupling consists of a set of helical drive splines held in engagement by the axial force generated by the spline helix angle and suplemented by a preloaded set of Belleville springs. When the helical splines generate sufficient axial force from a negative torque to balance the Belleville preload and spline friction the intermediate member moves axially as shown in Figure 21 and disengages. The Belleville springs continue to exert an axial load on the disengaged splines which "rachet" until the speed of the intermediate member reaches that of the inner member when engagement is again accomplished. The spline ratcheting wears the spline ends where this type of coupling is overrun for long periods of time.

A centrifugal anti-ratcheting device was incorporated into the T56-A-18 gearbox safety coupling.

The safety coupling, shown in Figure 22 is comprised of these major parts:

- o Helical sp ned pinion drive shaft, B
- o Outer helical splined coupling, C
- o Aft helical splined coupling, D
- o Belleville springs, F
- o Centrifugal hydraulic dams, A and E

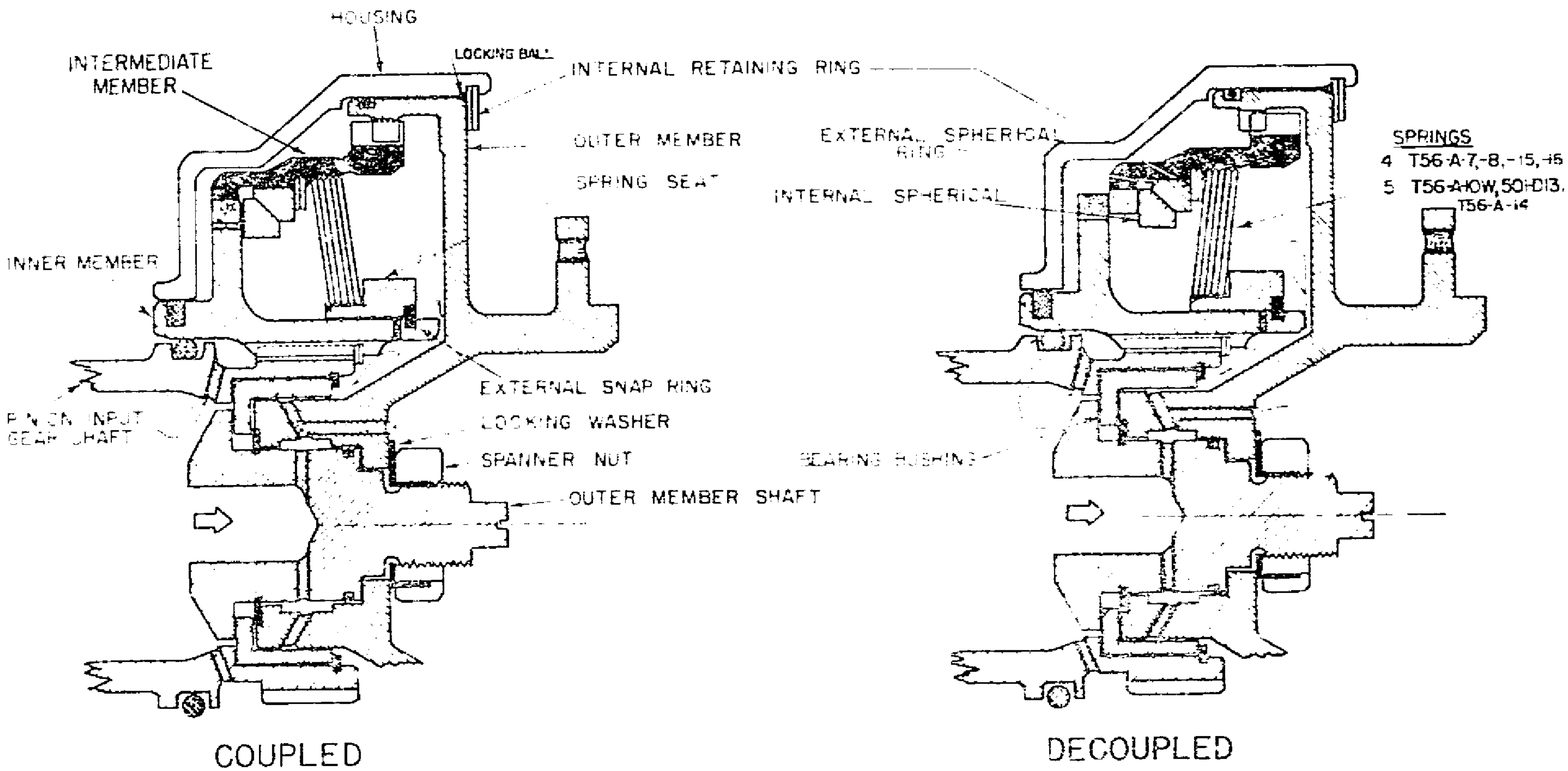
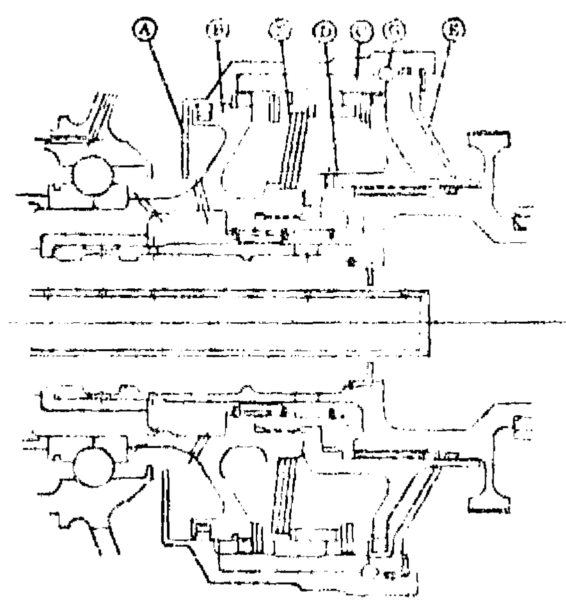


FIGURE 21. T56 SAFETY COUPLING SCHEMATIC

Coupled Position



Decoupled Position

FIGURE 22. T56-A18 SAFETY COUPLING

o Ball lock, G

Positive torque is transmitted through helical splines on members B, C, and D. The aft motion of coupling C is limited during positive torque transmission by the aft retaining ring against member D. Negative torque, acting through the helical splines, produces a forward motion on coupling C. Decoupling occurs when the Belleville springs F force is exceeded by this axial component and coupling C is moved forward out of engagement with splined member D. Hydraulic centrifugal action then holds the splines of C and D separated until speed is almost equalized, at which time the parts ratchet briefly and recouple.

The hydraulic anti-ratcheting features of this safety coupling are unique to the T56-A-18. The front and rear hydraulic dams (or cups) are attached to the outer splined member to retain the rotation oil. Axial force generated by this rotating oil is used in the following manner to reduce ratcheting load and differential speed during decoupling operation.

During normal running, an annulus of oil is retained by cups A and E which fill the entire coupling assembly outward from the inner diameters of the cups. When decoupled, the aft member D, which is coupled to the power section, rotates at a lower speed than outer coupling C which is coupled to the gearbox. The viscous or "spoiling" effects resulting from the reduced speed of the aft member D decreases the hydraulic pressure in the area of cup E. Hydraulic pressure against cup A is maintained at a higher level due to the higher speed of the gearbox. During flight, the speed of cup A remains unchanged. The unbalanced centrifugal head is sufficient to keep the helical spline teeth separated on members C and D, thus eliminating ratcheting. As speeds of members C and D equalize, the hydraulic unbalance is decreased allowing ratcheting to occur only briefly at reduced differential speed prior to recoupling.

The V/STOL overrunning clutch is identical in operation to the T56-A-18 clutch except in the source of the oil for anti-ratcheting. In the V/STOL clutch the oil in the annular retained by cup E will be provided by the power section and the oil retained by cup A will be provided by the L/C gearbox supply. When the power section oil supply is removed (as in the case of a power section failure) and the clutch uncouples, the oil drains from cup E and the pressure generated in cup A drives the outer splined coupling C to the left and prevents ratcheting until the power section becomes operable and the oil is restored to cup E. When the power section oil is restored the Belleville springs can move the outer coupling C to the right and re-engage the clutch.

5.8.5 Right Angle Drive

In both the fixed nacelle and tilt nacelle engines there is a requirement to extract and absorb power from the propulsion system via a right angle gear set. While the nominal power transferred for normal operation is slight, the power may reach a peak transient condition of 2587 kilowatt (3468 horsepower) with all engines operating and 5170 kilowatt (6931 horsepower) during a transient with a L/C engine inoperable.

5.8.5.1 Bevel Gears

The bevel gears for both the tilt nacelle and the fixed nacelle engines are designed to provide infinite life during normal V/TOL operation including its control transients. In the proposed gear material AMS 6265 (9310 CEVM), the design conditions for infinite life are considered to be:

Crushing Stress MPa (PSI)	1724 (250,000)
Bending Stress MPa (PSI)	241 (35,000)
Pitch Line Velocity M/S (Ft/Min)	127 (25,000)
Allowable Scoring Index * °K (°F)	422 (300)

* Assuming a maximum oil in temperature of 422°K (300°F) with MIL-L-23699 oil.

The choice of 9310 CEVM materials was made because the slight improvement in scoring and/or bending strength exhibited in other materials is not felt to be of sufficient magnitude to overcome the extensive experience in the manufacture of gears made of 9310.

5.8.5.2 Lift/Cruise and Lift Fan Bevel Gear Commonality

It would be desirable, from a logistics point of view, to use the same bevel gear set for the L/C engine that is used in the lift fan. If this could be accomplished it might become possible to devise a fan/gear module that is common to all three locations.

In the tilt nacelle engine the pinion turns at power turbine speed, or 11,810 rpm, and to obtain the needed gear capacity it is necessary to run the pitch line velocity at or near the 127 m/s (25,000 FPM) limit. The available envelope allowed by the engine flow path dictates that the ratio is near unity. This combination does not afford sufficient capacity when used at the lower speed of the lift fan (3543 RPM), therefore a common set of bevel gears for the tilt nacelle L/C engine and the lift fan are not practical.

As the gear member rotates at the same speed (3543 RPM) in both the lift fan and the fixed nacelle lift/cruise fan gearboxes and the power requirements of both sets are similar, it is possible to use the same gear set in both locations. There is a problem with shaft angles. Most present airframe designs have a shaft angle approaching 102° with the lift fan gearbox and 90° with the lift/cruise gearbox.

It was concluded that the gearsets can be common when a forward cross-shaft design is used but the gains therefrom would probably be slight when compared to forces compromised elsewhere in the system. As this trade is sensitive to the design of the airframe, any serious study should be delayed until an airframe layout is selected.

5.8.5.3 Bevel Gear Bearings

The bearings incorporated into the design of the lift/cruise gearbox will take advantage of the Detroit Diesel Allison high speed bearing experience and as a result, conventional ball and roller bearings will be predominant. However, tapered roller bearings have been used to an advantage in the PD370-25E lift/cruise gearbox where space is limited.

The gearbox bearings in the PD 370-25 are designed to provide an L-life in excess of the requirements of paragraph 5.2.6.

The materials for the races and rolling elements for the ball and cylindrical roller elements will be CEVM 52100 or M50 steel with the separators for these bearings being silver plated one piece steel fabricated from AISI 4340.

The materials used for the tapered roller bearings will be a proprietary carburizing steel used by the Timken Company.

5.8.5.4 Shafting

The shafting for the lift/cruise gearbox will be made from Allison Specification EMS64500 nitriding steel with the material properties derated by 3 sigma. The shafting will be sized for 10,000 LCF cycles at the maximum normal transient load. The splines on the shafting will be designed to a maximum of 138 MPa (20,000 psi) crushing stress if the spline is fixed and maximum of 103 MPa (15,000 psi) if the spline are subject to relative motion. Splines subject to relative motion will be hardened, ground, and lubricated.

The end treatment of the cross shaft shall be such that either a dry flexible coupling or an oil lubricated spline can be used by the airframer for the cross drive.

5.9 Fan Frame and Engine Mounts

5.9.1 Tilt Nacelle

The design of a tiltable nacelle presents some unique structural design problems. The tilt feature dictates a single point mount attachment to the aircraft. The axis of rotation must be located at the center line of the radial drive output shaft. With these requirements in mind it was deemed necessary that a number of fan frame and engine inlet housing configurations should be studied. A preliminary weight versus strength trade-off study of the various configurations was made. Several design facets were considered as items to be studied. These included the general type of construction - casting versus welded fabrication, location of the radial drive output shaft relative to the planetary gear set and various methods of transferring the loads from the engine carcass across the fan flowpath to the single point mount.

A frame consisting of a cast mount attachment welded into a sheet metal ring, formed from a box section, was considered. The loads from the engine carcass are conducted across the fan flowpath through ten aerodynamic shaped struts into the sheet metal ring and into the cast mount which is attached to the aircraft. Preliminary type stress and weight analysis indicated that this was not an efficient structure for the loads encountered in this application. Calculated lift/cruise engine weight with this fan frame was 1310 kg (2889 lbs). A second approach utilized a single structural pylon extending from the aircraft mount pad directly to the engine core (engine inlet housing). This configuration proved to give a lower weight to strength ratios than the previous scheme. The single pylon presented a sizeable local aerodynamic blockage immediately aft of the fan rotor. This undesirable feature dictated the elimination of this configuration as an optimum design. Calculated lift/cruise engine weight with this design was 1284 kg (2830 lbs). A third configuration utilizes a full ring type construction with ten aerodynamic struts which conduct the loads across the fan flowpath, similar to the first frame described. The ring detail construction is quite different, four stiff rings form the corners of the box section. The rings are tied together by thin sheet metal cylinders at the inner and outer circumference and flat plates at the fore and aft ends. In addition, hollow stiffening posts span between the rings in a longitudinal and radial direction to prevent the rings from rolling. The thickness of the rings and the shear webs are increased as the loads are gathered in approaching the mounting pad, thus providing a more favorable weight to strength ratio. This scheme also utilizes a welded engine inlet housing, which affords an additional weight saving. Calculated lift/cruise engine weight with this design is 1196 kg (2637 pounds). This fan frame and engine inlet housing was judged to be the optimum configuration after preliminary weight and stress analyses and is used on the PD370-25E engine.

In order to perform the preliminary feasibility and trade-off studies, the following loading imposed by Boeing airframe requirements was used instead of the maneuver loading criteria shown in Figure 13. Boeing's requirements were considered to be more realistic and helpful in minimizing the structure's weight.

Multiple loading criteria were used to sort out maximum vertical and gyroscopic conditions since thrust can either increase or decrease total loads depending on the nacelle attachment. Positive values are for up loading and negative values for down loading.

Engines in Conventional Flight Position

Vertical:	$+4.0g$ (acceleration of gravity) $+ 1.5\ T_{MAX}$ (Maximum Nacelle Thrust) $+4.0g$ $-3.5g + 1.5\ T_{MAX}$ $-3.5g$
Lateral:	$\pm 2.5g$
Longitudinal:	$\pm 3.0g$ 9g (crash)
Thrust:	$1.5T_{MAX} + 1.5g$ Vertical
Engine Seizure:	Equivalent to stopping rotating mass in 0.6 seconds 6022 N-m (53,300 in-lb)
Gyroscopic:	± 2.5 Rad/sec yaw $+ 1.5\ T_{MAX} + 1.5g$ vertical ± 2.5 Rad/sec. pitch $+ 1.5\ T_{MAX} + 4.5g$ vertical

Engines in Vertical Flight Position

Vertical:	$5.0g + 1.5\ T_{MAX}$ $5.0g$ $-3.0g + 1.5\ T_{MAX}$ $-3.0g$
Lateral:	$\pm 2.5g$
Longitudinal:	$\pm 3.0g$
Thrust:	$1.5T_{MAX} + 1.5g$ vertical
Engine Seizure:	Equivalent to stopping rotating mass in 0.6 seconds 6022N-m(53,300 in-lb)
Gyroscopic:	± 2.5 Rad/sec yaw $+ 1.5T_{MAX} + 1.5g$ vertical ± 2.5 Rad/sec pitch $+ 1.5T_{MAX} + 1.5g$ vertical

The limit load design conditions are 2/3 of these values.

The fan case and engine inlet housing are Ti 6-4 welded fabrications. The following material properties and criteria were used:

Matl - Ti 6-4 (Annealed)

Yield - 3σ @ 422°K (300°F) 610 MPa (88,500 psi)

Ultimate - 3σ @ 422°K (300°F) 758 MPa (110,000 psi)

Fan Frame -

a) Web - allow elastic buckling up to yield
b) Rings - to yield with no buckling
c) Stiffners - to yield with no buckling
d) Struts - no buckling or yield

Inlet Housing - no yield

5.9.2 Fixed Nacelle

The fixed nacelle fan frame provides the support for the fan shroud and the fan inlet cowl. The inner bypass duct is also mounted on the fan frame. Aerodynamic and maneuver loads on the outer bypass flowpath members are conducted across the bypass annulus by ten aerodynamic shaped struts to an inner structural ring which is mounted on the inlet housing at fore and aft flanges. The radial drive shaft is conducted across the flowpath within one of the struts as are the necessary engine services. The fan tip treatment ring is an aluminum honeycomb fabrication. The outer and inner bypass flowpaths and struts are fabricated as a single aluminum weldment. A saddle type structure mounted between the outer ring flanges provides an outboard bearing support for the radial drive shaft.

The fan frame is mounted on the engine inlet housing. This inlet housing is an aluminum casting which incorporates the flowpath entry to the high pressure compressor, compressor rotor front bearing support, compressor inlet guide vanes, and front engine mount pads. Provision is also made to mount the fan Beta regulators. The inlet housing is designed such that it is capable of being mounted as either a right hand or left hand installation.

Preliminary stress analysis has been performed in order to determine the feasibility of the scheme and to size components for engine weight calculations. The flight maneuver loads defined in Figure 13 were used in the analysis. The PD370-25A lift/cruise engine with this fan frame weighs 1066 kg (2351 pounds).

5.10 Propulsion System Control Studies

Introduction

The RTA controls effort was directed at the conceptual design of the RTA propulsion control system. The program approach was to analyze the control problem and meet with Hamilton Standard, NASA LeRC, Boeing and McDonnell Douglas to establish operational requirements. This information was used to formulate a problem statement upon which the conceptual design was based.

A basic constraint in the design was the maximum use of XT701 control system components to minimize development cost. However, the relationship of the propulsion and flight control systems in vertical and transition modes necessitates a similar degree of reliability. In order to achieve high operational reliability, the propulsion control incorporates triple redundant, digital logic. The XT701 hydromechanical control is retained with minor modifications.

Control Problem

Two lift/cruise engines with integral, variable pitch fans, a fuselage mounted turboshaft engine, a clutched lift fan and appropriate power transmission system comprise the RTA propulsion system as depicted in Figure 23 . Controlled variables and controlling parameters are shown in Table 11 .

Table 11

Controlled Variables

Controlled Variable	Symbol	Controlling Parameter
Engine fuel flow	W_F	Power level, fan pitch, engine limits, compressor discharge pressure
Compressor Variable Geometry	CVG	High pressure rotor speed, inlet temperature
Fan Pitch	β	Flight control input
Lift fan clutch	---	Transition input
Lift/cruise nozzle area	A_N	Mach number
Water alcohol		Engine out

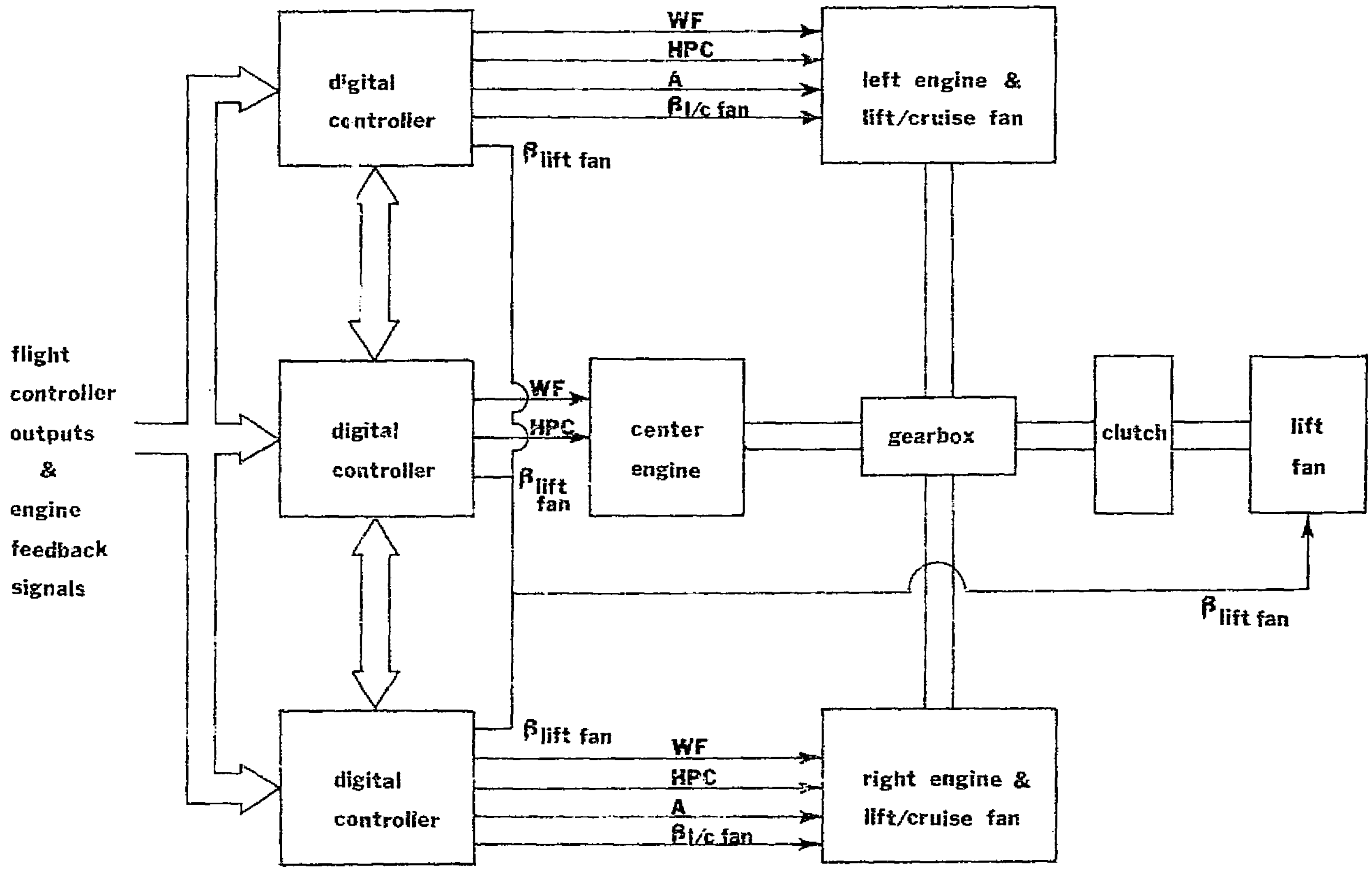


FIGURE 23. PROPULSION SYSTEM CONTROL SCHEMATIC

The RTA propulsion control system performs the following functions:

Engine starting

Engine limiting - pressure, speed, temperature

Stabilize system

Fan pitch control
Clutch control
Load sharing

Airframe interface

Condition monitoring
Engine out operation

Engine starting is initiated upon request from the flight deck. The control monitors engine speed and temperatures during the start sequence and aborts the start if ignition and normal run characteristics are not achieved. This logic is used on the XT701 and will be continued.

The control system limits engine pressure, speed and temperature at maximum power conditions to prevent the exceedance of engine operating limits. This is required to eliminate engine overstress conditions with attendant rapid loss of life.

Past experience with shaft and rotor systems on helicopters has shown that it will be necessary to compensate the system in order to achieve proper transient response and eliminate engine supported oscillations at the propulsion system natural frequency. This is achieved through phase and gain compensation in the control.

The Hamilton Standard Division of United Technologies (HS) fan pitch actuator is a dual redundant system, ref. Figure 24 , that incorporates two electrohydraulic servovalves, EHV, with position feedback on the spools, a solenoid controlled bypass valve, a pitch changing mechanism and a three winding linear variable differential transformer, LVDT, that senses blade pitch.

Triple redundancy on the servovalve is achieved by a model in the electronics. To illustrate operation assume a fan pitch, β , command from the flight control system. The propulsion control will send a current to the two EHV's and the model. The two EHV LVDT's and the modeled EHV and LVDT will be compared. If the three do not agree, the bypass valve will switch the malfunctioning EHV off line and transmit a

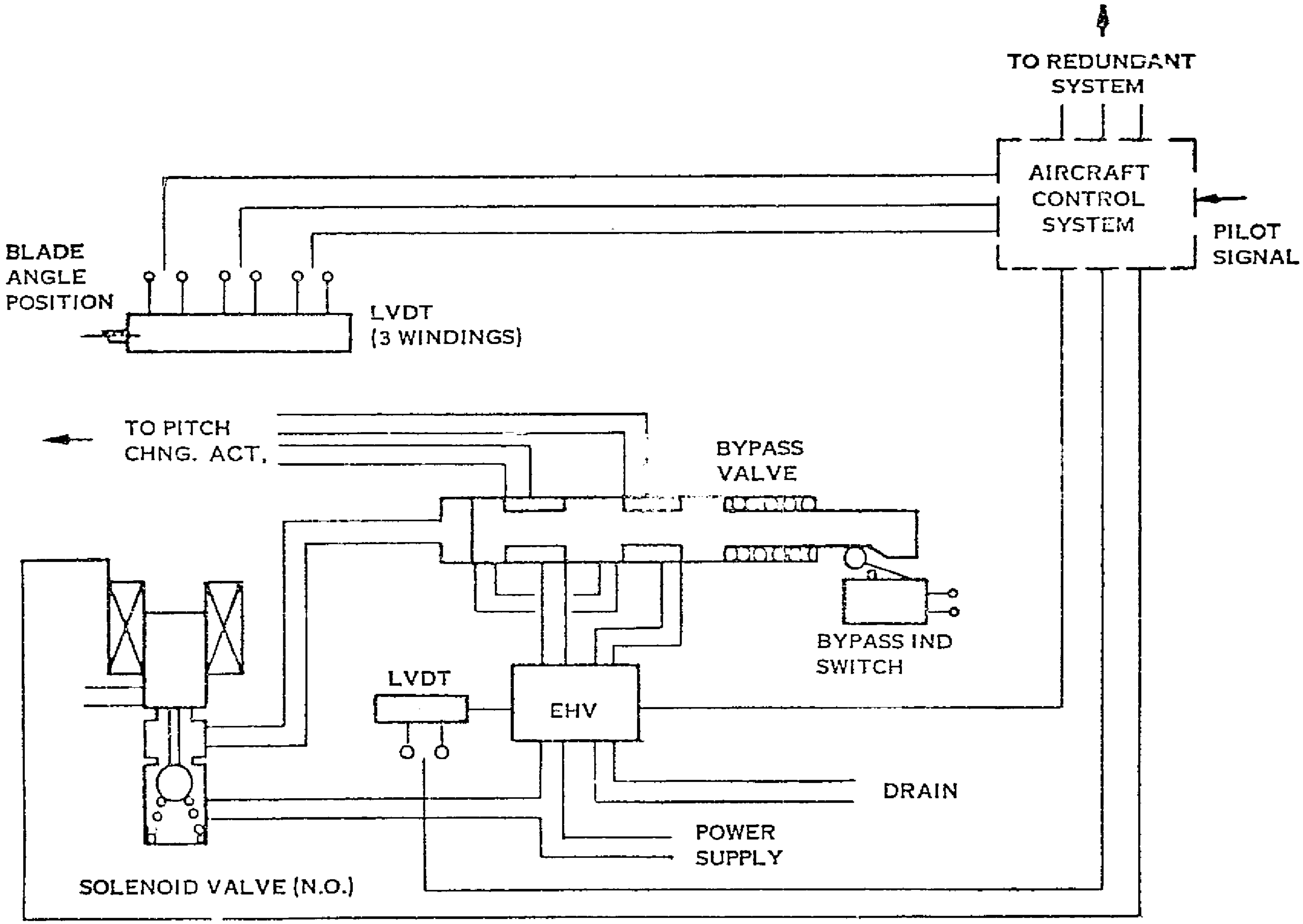


FIGURE 24. PITCH CHANGE CONTROL SCHEMATIC

warning discrete. The flow through the EHV will cause the pitch mechanism to drive which will be sensed by the blade angle position LVDT's. The propulsion control will sense this movement and compare it to the flight control commanded β.

The propulsion control system provides compensation and condition monitoring for this position control loop.

Power flow to the lift fan is controlled by a clutch. Although definition of lift fan on/off operation control is not complete, it could be a function of transition condition, aircraft Mach number, etc. Some modulation of clutch actuation pressure will be necessary to reduce shock loads on the drive system. This clutch actuation pressure modulation and lockup logic will be incorporated in the propulsion control system.

The propulsion control system will operate the three engines at approximately the same power level to balance engine loads. The XT701 control system balanced engine loads on output torque; however, the XT701 torquemeter was eliminated to reduce engine length. The engines will be matched on turbine temp[illegible]re. For an operational system, the torquemeter must be reconsidered as it makes [illegible]ssible to operate the engines to a measured rather than an implied output param[illegible], and it is a valuable condition monitoring tool. It permits a very close match on power, but that is not an RTA requirement.

The propulsion control is the airframe/propulsion system interface unit. Boeing and McDonnell Douglas plan triple redundant, digital, fly-by-wire flight control systems. Therefore, all propulsion control inputs - fan, pitch, power level and transition - will be triplicated. The propulsion control will incorporate majority voting on these inputs.

Although each engine incorporates an alternator for control electronic power, aircraft critical bus power will be supplied to the control for backup. The airframe hydraulic system will supply power to the fan pitch change mechanism.

The details of the interface have not been worked out as conceptual designs have not progressed that far. Analog and digital interfaces transmitted electrically or optically have been considered.

Condition monitoring is incorporated to reduce the possibility of sudden power losses. The performance of the three engines is monitored and compared to standard set of performance conditions. In an operational system, this would be expanded in diagnostic scope and depreciation compensation would be implemented. The condition monitoring system is used to detect an engine out condition and trigger a contingency operation when required.

Engine out operation requires increased power from the remaining engines. The propulsion control will increase fuel flow until the required power level is obtained consistent with engine limits. Where necessary, a water alcohol injection system could be used to achieve an increased power level for engine out vertical operation. Initiation of water alcohol would be automatic and under propulsion system control. A fault indication would be transmitted to the aircraft.

Control Mode Logic

Figure 25 depicts the control activities necessary for each of the three engines on the V/STOL RTA application. Interfacing with the aircraft flight controller is a digital controller on each engine. With outputs from the flight controller and engine feedback signals, each digital controller is responsible for its own engine control inputs, those being fuel flow and compressor variable geometry.

In addition the two engines with lift/cruise fans rely on their respective digital controllers to position the fan variable geometry position commanded by the flight controller and to schedule the corresponding duct nozzle areas. A data bus between the three digital controllers permits positioning of the lift fan variable geometry as well as determining load sharing and water/alcohol injection activities. Condition monitoring of engine signals provides additional failsafe operation.

Fuel Flow Control

The fuel flow required to run each of the three engines is provided by a hydromechanical unit on each engine interfacing with the digital controller. The hydromechanical unit is the one used on the XT701. This digital controller relies on the following engine feedback signals:

Gasifier rotor speed (N_G)

Fan rotor speed (N_F)

Fan inlet temperature (FIT)

Compressor inlet temperature (CIT)

Fan inlet pressure (FIP)

Compressor inlet pressure (CIP)

Compressor discharge pressure (CDP)

With these and flight controller output signals of power lever angle (PLA), aircraft Mach number ($MN_{A/C}$), and condition lever (CL), the fuel flow required for engine operation is obtained.

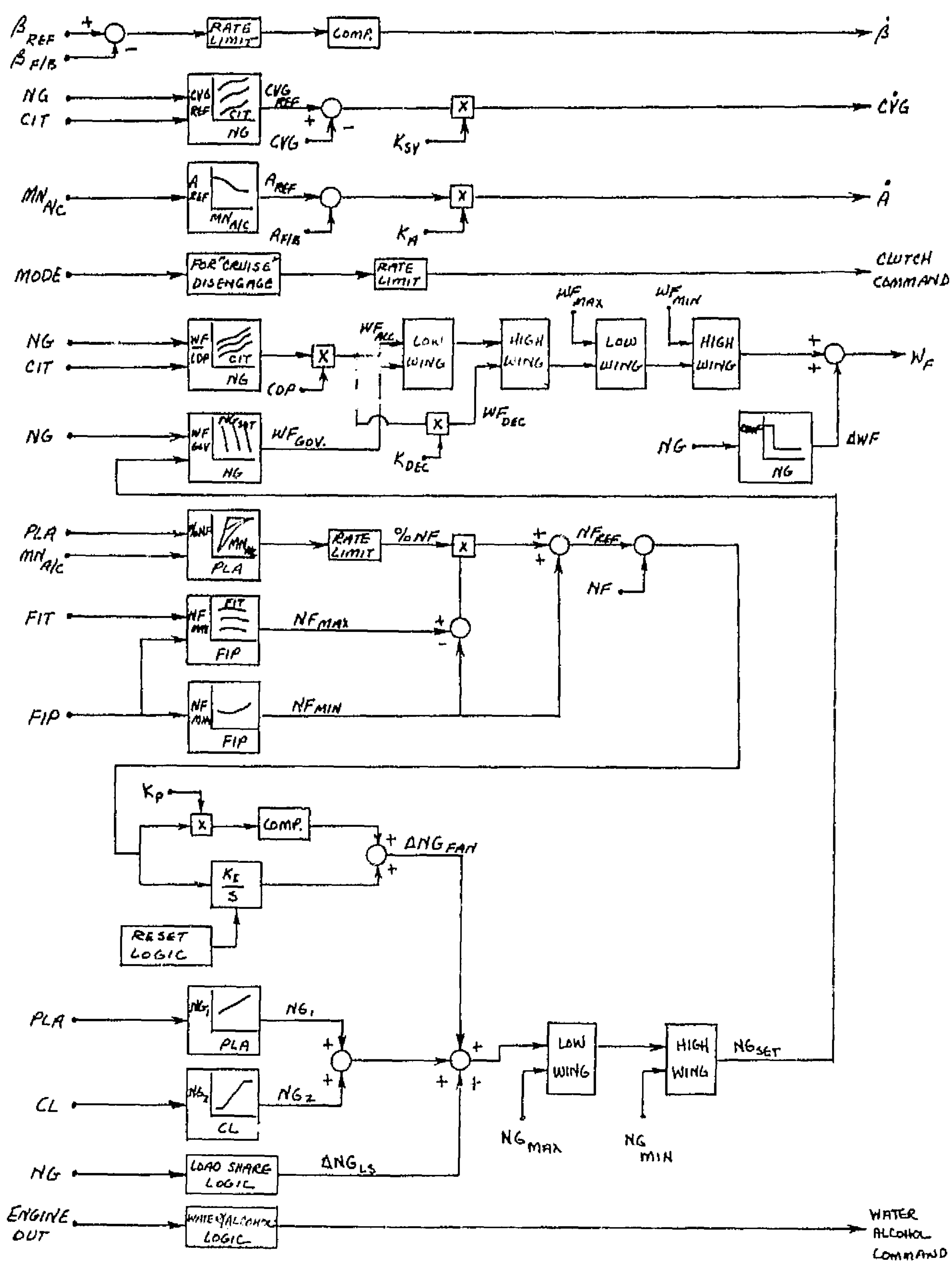


FIGURE 25. RTA CONTROL ACTIVITIES

Fan rotor speed is controlled on a closed loop compensated proportional plus integral basis using inputs of PLA and ambient conditions ($MN_{A/C}$, FIP, and FIT). It is desired to operate the fan at a constant speed in the vertical mode. In a cruise condition it is necessary to coordinate the fan speed schedule with fan variable geometry position to yield optimum specific fuel consumption.

The error in fan speed is used to adjust the gasifier set speed (NG_{SET}) for each engine. NG_{SET} is the sum of this adjustment and two scheduled values, one NG valve scheduled on condition lever and the other scheduled PLA. Another delta factor to NG_{SET} is made to assure equal sharing of the load between the three engines. The load sharing option will be accomplished by establishing the highest of the three gasifier speeds as a reference value and increasing the other two gasifiers to approximately match this reference speed. The resulting NG from these previous actions, after being compared to the maximum and minimum gasifier speeds, is passed on to the fuel flow modulation loop.

The governor fuel flow (WF_{GOV}) is controlled on a proportional plus integral basis using NG AND NG_{SET}. A schedule of acceleration fuel flow as a function of NG and CIT assumes the transient limiting responsibilities. After a series of comparisons among WF_{GOV}, WF_{ACC}, WF_{DEC}, WF_{MAX}, and WF_{MIN}, the appropriate fuel flow value is chosen. Further adjustments to the fuel flow signal aid engine starting characteristics.

Compressor Variable Geometry Control

Positioning of the compressor variable geometry (CVG) is handled by the hydromechanical unit. The desired CVG setting is scheduled on gasifier speed biased by CIT. The scheduled CVG setting is compared to an LVDT feedback to assure positioning accuracy.

Lift/Cruise Fan Variable Geometry Control

The determination of the fan variable geometry setting (β) on each of the two lift/cruise fans is the responsibility of the flight controller in the vertical mode. By comparing the reference signal to the feedback assures correct positioning.

In aerodynamic flight the condition lever functions as a normal flight deck input to the control system. The system will establish the proper fan speed and β relationships for best propulsion efficiency.

Duct Nozzle Control

The duct nozzle area on each of the two lift/cruise engines is to be scheduled versus aircraft Mach number. Positioning to achieve this proper nozzle area is the responsibility of the digital controller by comparison of the scheduled area with a feedback signal.

Lift Fan Variable Geometry Control

The lift fan variable geometry setting is determined by the flight controller and positioned in the same manner as were the β's for the two lift/cruise engines.

Water/Alcohol

The possibility exists for automating water/alcohol injection in the case of an engine out condition. If only two engines are operable and a particular high thrust point cannot be achieved, injection of a water/alcohol mixture would allow increased power for a short duration.

Condition Monitoring

All signals fed back from the engine and all inputs from the flight controller are condition monitored. This includes range and rate checks to insure reasonableness, logic to detect an engine out condition, and start sequencing of the engine.

Clutch Command

When the transition is made from vertical flight to horizontal flight, it is necessary to disengage the front lift fan from the gearbox drive. This clutch command is assumed by the digital controller. To prevent sudden disengagement, and therefore possible shock loading, the clutch command is rate limited.

Mechanization

In the course of the RTA propulsion control system study the mechanization evolved considerably from the XT701. The XT701 system incorporates a hydromechanical control on HP rotor speed and compressor variable geometry. This unit has no direct interface with the aircraft and receives its inputs from the Engine Electronic Control, EEC, a single channel electronic assembly.

An electronic power management control is incorporated to match the three engines' power output and provide isochronous rotor speed governing.

After meetings with the airframe manufacturers and analysis of the problem, it was decided that the XT701 electronics must be replaced to accomplish the added fan pitch control task and to achieve fail safe operation consistent with that of the flight control system.

In order to achieve this, a triply redundant, digital engine controller is required. A fail operate requirement in the vertical mode is necessary because of potential damage to the RTA. It would not be acceptable for a single electronic failure to cause an engine shutdown or loss of fan pitch control.

The triply redundant system achieves the fail operate requirement. A digital system is used because of its more powerful logic and computational functions as well as continually decreasing cost.

The XT701 hydro units are modified to incorporate new CVG and fuel schedules and to increase the authority of the twin input. This provides satisfactory tolerance to servovalve failure. The hydro unit itself has demonstrated very high reliability so that no backup fuel metering system is planned.

6.0 Program Plan

6.1 Introduction

Detroit Diesel Allison (DDA) has prepared a program plan for the development of variable pitch, shaft driven, lift/cruise propulsion units and lift fan units for a V/STOL research and technology aircraft. The propulsion system consists of the integration of a Hamilton Standard variable pitch fan and a Detroit Diesel Allison XT701-AD-700 turboshaft engine.

6.2 Assumptions

The following is the list of assumptions made while developing the program plan·

A. The five new XT701-AD-700 engines owned by the U.S. Army would be available for use in the program.

B. DDA will subcontract to Hamilton Standard the definition, design and hardware of the variable pitch lift fan assembly and the lift/cruise variable pitch fan rotor assembly.

C. The program plan is based on the program starting at the conclusion of the currently defined Phase I preliminary design.

D. A one aircraft program will be the baseline.

E. The aircraft will have 3 engines and 3 fans.

6.3 Development Plan

The baseline engine used in the plan is the standard XT701-AD-700 engine with intermediate power as the highest rating. As directed by NASA, a two aircraft program and three alternate uprated engine configuration programs were evaluated. These are presented as "deltas" to the baseline.

The engine development plan is divided into four specific tasks: Design, Fabrication, Testing and Support. Each task is described below.

Design

The design task is divided into two subtasks. First is the propulsion system design through detailed manufacturing drawings. Subtask two is engine design and control system design followup. This subtask would provide the manpower required during the period of hardware fabrication, component testing and engine testing.

Fabrication

Five functions are included in the fabrication of the lift/cruise, variable pitch turbofan propulsion system. One task is the design and fabrication of a lift/cruise engine mockup. Manufacturing tooling fabrication and/or procurement is included. Fabrication also requires manufacturing liaison and material control support. Lastly manpower and material required to fabricate components and to modify existing XT701 engines are included. New components required for the lift/cruise turbofan engine include:

- o Fan housing
- o Drive gears
- o Engine accessory drive gears
- o Overrunning clutch
- o Oil system for vertical attitude
- o Fan drive lubrication system
- o Mount structure
- o External plumbing
- o Modified hydromechanical control
- o Modified electronic control

New components required for the turboshaft center engine to make it interchangeable with lift/cruise engine include:

- o Oil system for vertical attitude
- o Modified hydromechanical control
- o Modified electronic control

Testing

Included in this task is the design and procurement of component test equipment and the following component tests:

Components	Test
Inlet Housing and Engine	Static Deflection
Main Drive Gears	Vibration and Deflection
Control Components	Flow Bench and Electronics Checkout
Oil Pump	Calibration

Engine test equipment must also be designed and procured in order to run the followi . tests:

Type	Est. Hours	Est. Builds	Special Conditions
Inlet Distortion	15	2	Rammed & Heated, Blade Instrumentation
Vertical Lube System Testing	20	4	Ambient, Power Extraction
Control System Evaluation	10	2	Ambient, Power Extraction
Gas Generator Inlet Survey	10	1	Ambient, Power Extraction
Starting Tests	10	2	Ambient
Endurance Testing	120	4	Ambient, Power Extraction
Flight Clearance Test	60	1	Ambient, Power Extraction

Two engines would be used in the development testing. Engine number one would have 115 hours of testing including the 60 hour flight clearance. Engine number two would have 130 hours of testing including 100 hours of endurance to be completed before the flight clearance test.

Also included in the task is the buildup, acceptance test, partial teardown and inspection, reassembly and final run, and shipment of lift/cruise turbofan engines and turboshaft engines for use in the Research and Technology Aircraft.

Support

This task includes the overall management of the program by the Chief Project Engineer, schedule and budget control and other administrative efforts by various service groups. Also included is the manpower and material required to design and procure engine ground support equipment and to provide training materials and user classes. Project engineering, design engineering, test engineering and other technical service support begins after the delivery of flight hardware and will continue for a projected 12 months while the airframer completes ground and flight tests of the RTA.

Uprated Engine Configurations Considered

Level 1. Standard XT701-AD-700 with water/alcohol injection.

Level 2. XT701 with a short term contingency rating and water/alcohol injection. Contingency achieved by throttle bending and rework of existing engine hardware.

Level 3. XT701 with a contingency rating and water/alcohol injection. Major internal modifications and new hardware for engines are required.

The fan development plan is also divided into four specific tasks: Design, Manufacturing, Development and Field Support. The activities and participating disciplines of tasks are outlined below:

Design

- Design Engineering
- Drafting
- Project Engineering
- Aerodynamic Design
- Dynamic Analysis
- Structural Analysis
- Program Management

Manufacturing

- Project Engineering
- Production Control
- Program Management
- Tooling Design & Manufacture
- Test Hardware

  1 Lift Fan

  2 Lift/Cruise Fans

- Component Test Hardware

  Equivalent of 1 Fan

  <u>Development and Testing</u>

- Test Equipment
- Project Engineering
- Design Support
- Program Management
- Component Tests
- Structural Tests

  Blade

  Rotor Disk

  Mount

  Vibration

- Subsystem Tests - Total of 250 hours of testing

  Whirl

  Tiltlube

- Lift Fan System Test - Total of 200 hours of te-ting

  <u>Field Support</u>

- DDA Lift/Cruise Engine Testing
- Aircraft Ground Tests
- Aircraft Flight Test

6.4 Engine and Hardware Requirements

For a one aircraft program, the five available XT701-AD-700 engines would be used as follows:

Engine I	-	A/C Engine
Engine II	-	A/C Engine
Engine III	-	A/C Engine
Engine IV	-	Development Engine
Engine V	-	Development Engine

The following hardware must be obtained for a one aircraft program:

2 Sets of L/C engine development hardware

2 Sets of L/C engine hardware for A/C useage

2 Sets of L/C engine hardware for refurbishing development engines to spare status

1 Set of hardware for modification of XT701 center engine

1 Lift Fan for Development Testing

Lift Fan Hardware for Refurbishing Test Fan

2 Lift/Cruise Fans for Development Testing

Lift/Cruise Fan Hardware for Refurbishing Test Fans

1 Lift Fan Assembly for A/C Useage

2 Lift/Cruise Fan Rotor Assemblies for A/C Useage

A two aircraft program would require the following engines:

Engine I	-	A/C #1 Engine
Engine II	-	A/C #1 Engine
Engine III	-	A/C #1 Engine
Engine IV	-	Development Engine and A/C #2 Engine

Engine V	-	Development Engine and Spare
Engine VI	-	A/C #2 Engine (to be manufactured)
Engine VII	-	A/C #2 Engine (to be manufactured)

In addition to manufacturing two additional engines (one L/C engine and one center engine), the following hardware must be obtained for a two aircraft program:

2 Sets of L/C Engine Development Hardware

2 Sets of L/C Engine Hardware for A/C Useage

1 Set of L/C Engine Hardware to Refurbish One Development Engine for A/C Useage

1 Set of L/C Engine Hardware for Refurbishing One Development Engine to a Spare

2 Sets of Hardware for Modification of XT701 Center Engines

1 Lift Fan for Development Testing

Lift Fan Hardware for Refurbishing Test Fan

2 Lift/Cruise Fans for Development Testing

Lift/Cruise Fan Hardware for Refurbishing Test Fans

2 Lift Fan Assemblies for A/C Useage

4 Lift/Cruise Fan Rotor Assemblies for A/C Useage

6.5 Schedule

The schedule of the development program is shown in Figure 26. The schedule is for the "baseline" one aircraft program. Two lift/cruise turbofan engines, one turboshaft engine and one lift fan would be delivered to the airframer after 30 months and 245 hours of engine testing and 680 hours of fan testing. Similar components for the second aircraft would be available after 33 months and the spares available after 35 months.

Total length of the baseline program is 42 months. Twelve months of technical support will be provided to the RTA builder during the ground and flight test programs.

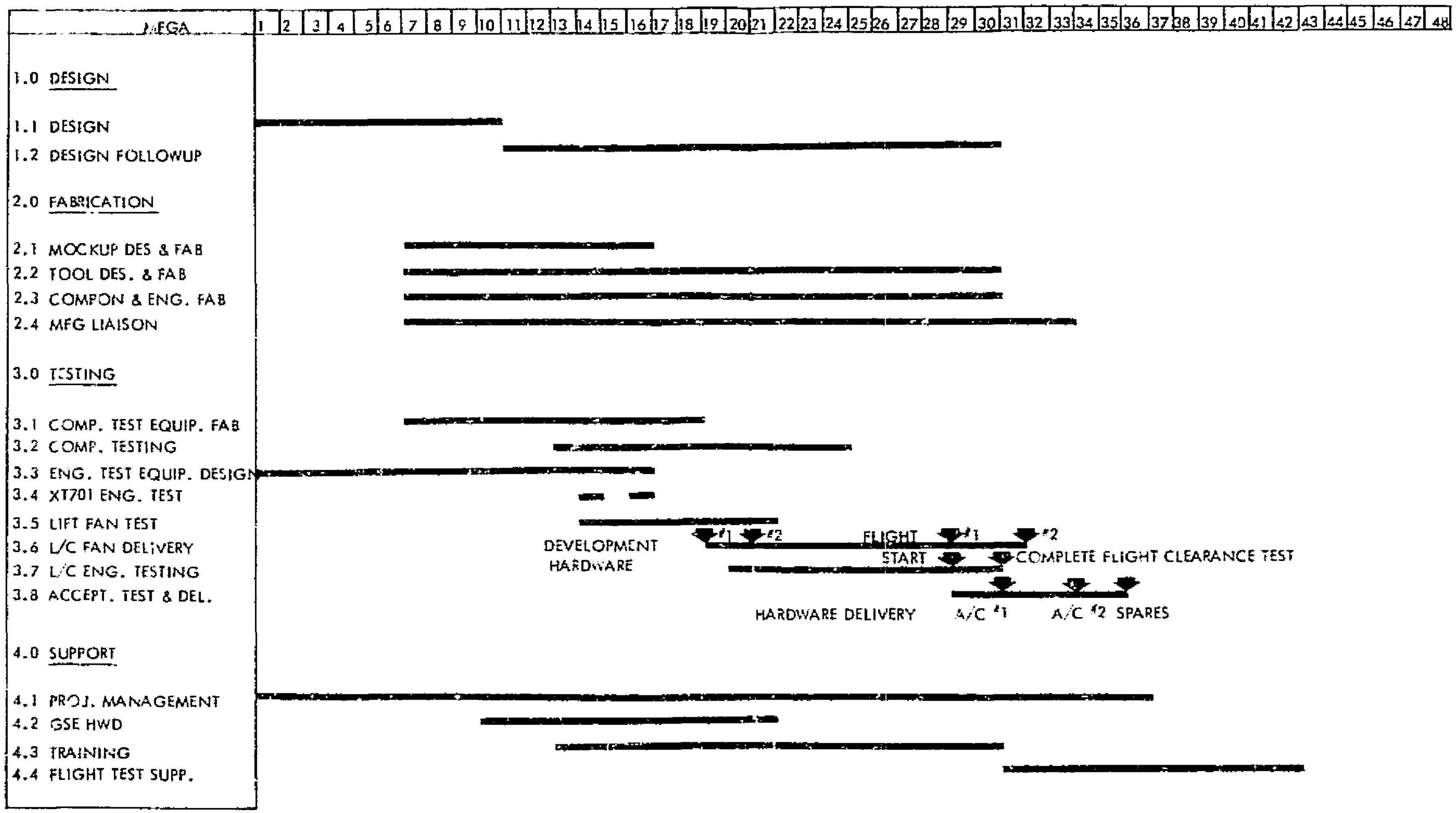


FIGURE 26. RTA PROPULSION SYSTEM DEVELOPMENT PLAN SCHEDULE

With uprated engine level 1, the delivery times would also be 30, 33 and 35 months. All engine testing would include water/alcohol injection and ten additional hours of engine testing would be required.

Fifty additional hours of engine testing from the baseline would be required on uprated engine level 2 and the delivery dates would be increased to 32, 35 and 37 months for one and two aircraft programs.

A total of 355 engine test hours would be necessary before delivery of uprated engine level 3. Delivery dates would be 36, 39 and 41 months from go-ahead.

6.6 Program Options

Detroit Diesel Allison believes that the power management control of the RTA should be supplied with the propulsion system but the design, fabrication and test elements were not included in the program plan due to the current definition of propulsion system component suppliers (i.e., power management control to be airframer supplied).

Component testing of new hardware can add reliability and shorten development schedules. DDA has identified the lift/cruise gearbox as a component where additional testing would be beneficial. 200 hours of back to back testing with the equipment shown in Figure 27 is suggested.

Boeing Aerospace Company and McDonnell Aircraft Company have both defined iron-bird tests or ground tie down tests for RTA propulsion system hardware before the first flight of the research and technology aircraft. The currently defined program does not have hardware identified for those tests. As a minimum 3 engines and 3 fans would require overhauling back to zero time for flight test use. A maximum addition to the program would be a requirement to manufacture three additional engines and fans for the ground testing.

An alternative would be to use the Army's 501M62B engines from the Boeing Vertol dynamic system test rig. Engines would likely require overhaul and would require modification to accept a lift/cruise fan. However, the turbofan engine would not be flight qualified hardware.

The aircraft contractor's testing schedules are incompatible with the development schedule shown in Figure 26 and would have to be worked out during the proposal phase of the program.

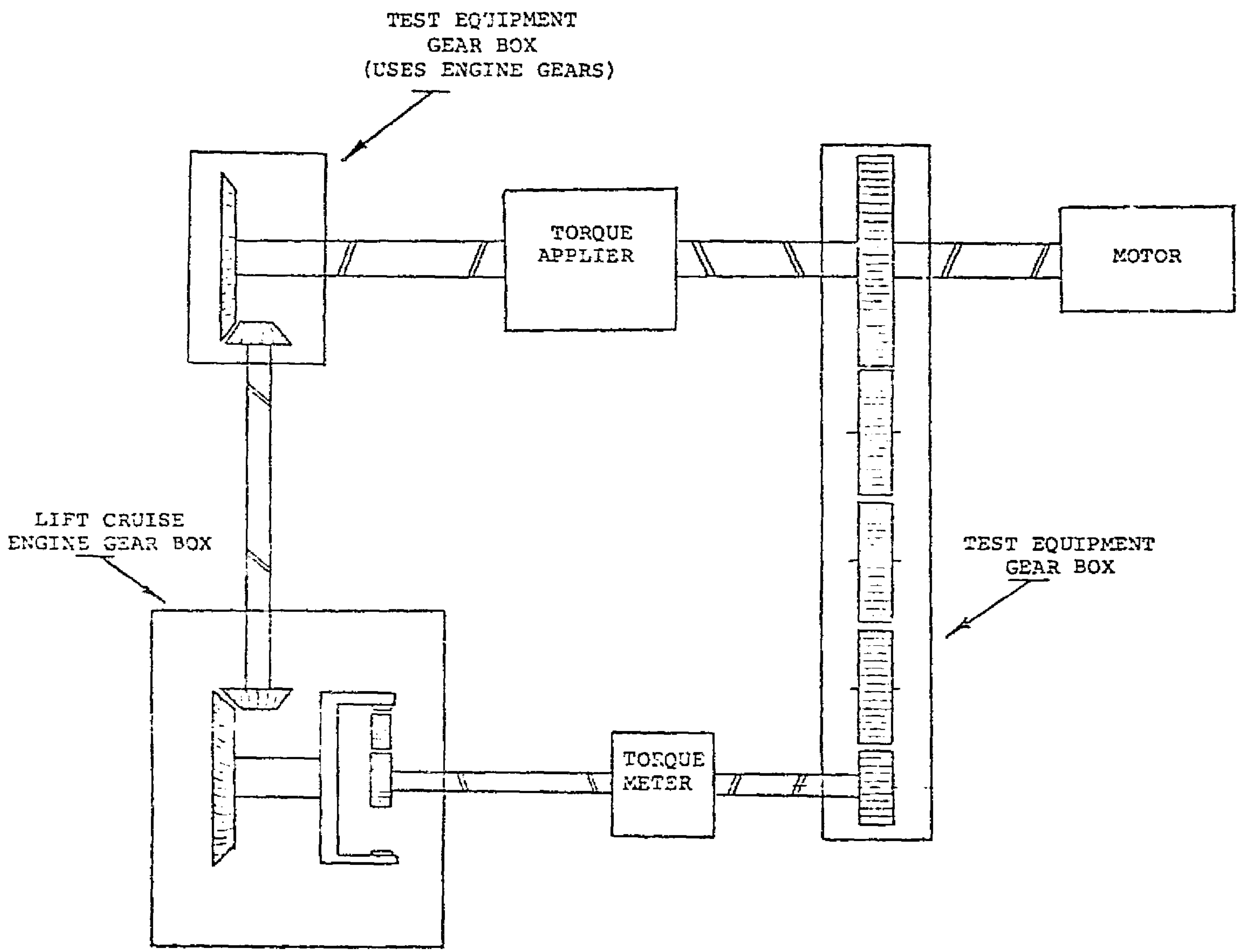


FIGURE 27. BACK TO BACK TEST RIG

7.0 Conclusions

The work under this contract has defined the V/STOL Research and Technology Aircraft turboshaft propulsion system. Two lift/cruise turbofan engines, one turboshaft engine and a lift fan interconnected with shafting and a combiner gearbox form the system. Conclusions derived from this program are:

1. XT701-AD-700 turboshaft engines and Hamilton Standard 1.57 metre (62 inch) diameter fans provide the required VTOL and cruise thrust.

2. Modifications required to integrate a fan and engine and produce a VTOL engine are straightforward applications of existing technology.

3. Production hardware will be used in the L/C reduction gears. This will reduce development costs and add reliability to the program.

4. The propulsion system card deck allows airframe contractors and other users to generate performance formally provided in tabular form.

5. Propulsion system development will be paced by the lift and lift/cruise fans.

8.0 APPENDICES

APPENDIX A

INTERFACE DEFINITION

FOR

LIFT/CRUISE TURBOFAN ENGINE COMPONENTS

NASA/NAVY V/STOL RESEARCH AND TECHNOLOGY AIRCRAFT PROPULSION SYSTEM

HAMILTON STANDARD DIVISION
UNITED TECHNOLOGIES CORPORATION

DETROIT DIESEL ALLISON DIVISION
GENERAL MOTORS CORPORATION

JULY 1976
REVISION "B" JANUARY 1977

APPROVED:

R. M. LEVINTAN
HAMILTON STANDARD

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DETROIT DIESEL ALLISON

CONTENTS

I. INTRODUCTION (REVISION B)

The Hamilton Standard (HS) Division of United Technologies Corporation and the Detroit Diesel Allison (DDA) Division of General Motors Corporation are engaged in concept definition studies of lift/cruise propulsion systems for a NASA/Navy V/STOL research aircraft under NASA contracts NAS3-19414 and NAS3-20033 with HS, and NAS3-20034 with DDA. These contracts require that the interfaces between the HS fan components and the DDA engine components be defined. This document defines the interface details which have been identified to date and the responsibility for components resulting from these interface details.

The refinement of details of the interfaces between the HS and DDA components defined herein will be recorded in revisions to this interface definition document as the program progresses. Any major interface changes from this document shall be identified in writing to the NASA Project Manager.

The lift fan interface definition agreed to between the airframe contractors and Hamilton Standard as part of HS's work under Contract NAS 3-20033 is incorporated into this document as Addendum.

II. GENERAL DEFINITIONS AND RESPONSIBILITIES (REVISION A)

The V/STOL propulsion system consists of two turbofan engines, a remote lift fan and the associated gearing and shafting required to couple these components. Identical variable pitch fan rotors are used in the turbofan engines and the lift fan. This document deals with the interface between the Hamilton Standard variable pitch fan rotor and the Allison turboshaft engine, gearbox assembly and fan frame and case, which together form the turbofan engine

DDA is responsible for the gas turbine components and the resulting complete turbofan engine. Hamilton Standard is responsible for the single stage variable pitch fan and the actuators and controls associated with blade movement. This fan responsibility includes defining the overall fan stage performance and operating envelope, and providing the aerodynamic definition for rotating and stationary components within the stage. Hamilton Standard is also responsible for all mechanical components and functions of the fan rotor assembly and will therefore coordinate the aero-mechanical design. DDA will be responsible for the mechanical design of the stationary fan components since these will be integrated into the turbofan engine forward frame structure.

Signals for the positioning of the fan blade may come from the engine fuel control and the aircraft flight control. Hamilton Standard is responsible for the components required to condition these signals and convert them into blade angle settings on the variable pitch fan rotor. DDA will provide the power in the form of hydraulic pressure and flow for use in the HS actuators. The gearing, lubrication, accessory drives and aircraft structural interfaces are the responsibility of DDA. Overall lift/cruise turbofan engine performance is the responsibility of DDA.

III. REFERENCE DRAWINGS, DOCUMENTS AND SPECIFICATIONS (REVISION B)

DRAWINGS - The following drawings define the components and the associated interfaces which are the subject of this document:

HS DRAWINGS

SK 92249	Beta Regulator Envelope
SK 92250	Lift/Cruise Fan Installation
L-13081-8	Control Schematic

Preliminary Aero Lines - DB 4/14/75

DDA DRAWINGS

SK 20163	PD370-25 A RTA Fan Engine Installation
SK 20148	RTA Engine-Fan Interface Definition
SK 20219	PD370-25A RTA General Arrangement
SK 20249	PD370-25E RTA General Arrangement
SK 20276	PD370-25E RTA Fan Engine Installation

DOCUMENTS - The following documents provide definition of the subject interfaces:

Statement of Work for NASA Contracts NAS3-19414, NAS3-20033 and NAS3-20034 with Hamilton Standard and DDA respectively.

A coordination memo system exists between HS and DDA which will be used to define interfaces for this program as the fan and engine component designs progress. Data such as rotor speeds, pressure profile, and flow rates will be coordinated using this system. These interface coordination memos will be included in this Interface Definition Document as an addendum.

SPECIFICATIONS -

The following specifications apply or may be used by reference to define the subject interface:

MIL-E-5007D - General engine requirements.

AS3694, 31 May 1973, "Transmission Systems, VTOL-STOL General Requirements for."

A DDA engine specification will be issued to cover the selected lift/cruise turbofan engine which will cover both the Hamilton Standard and DDA components as a unit. This specification will be issued after the engine design characteristics are established.

IV. INTERFACE DEFINITIONS (REVISION B)

The following table defines the responsible contractor for the various components of the lift/cruise turbofan engine and in turn the interfaces between mating Hamilton Standard and DDA components:

		RESPONSIBLE CONTRACTOR	REFERENCE DRAWING
1.0 MECHANICAL INTERFACE			
1.1	Fan - Engine Installation		
1.1.1	Fan Installation Drawing	HS	SK92250
1.1.2	Engine-Fan Interface Drawing	DDA	SK20148
1.1.3	Fan Engine Installation Drawing	DDA	SK20163 & SK20276
1.1.4	Fan Engine General Arrangement Drawings	DDA	SK 20219 & SK 20249
1.2	Fan-Engine External Envelope		
1.2.1	Fan External Envelope	HS	SK 92250
1.2.2	Engine External Envelope	DDA	SK 20163
1.2.3	Fan-Engine Envelope	DDA	SK 20163
1.3	Fan Drive		
1.3.1	Fan Drive Shaft Flange	DDA	SK 20148
1.3.2	Fan Wheel Rear Flange	HS	SK 92250
1.3.3	Fan Drive Shaft	DDA	SK20148
1.3.4	Fan Drive Shaft Bearings and Support	DDA	SK20148
1.4	Actuator		
1.4.1	Actuator Envelope	HS	SK92250
1.4.2	Transfer Bearing Envelope	HS	SK92250
1.4.3	Inner LVDT Envelope	HS	SK92250
1.4.4	Beta Regulator Envelope	HS	SK92249
1.5	Fan Parameters		
1.5.1	Fan Design Speed	HS	NA
1.5.2	Fan Blade Tip Clearance	HS	SK20148
1.5.3	Fan Speed Pickup	DDA	SK20148
1.6	L/C Rotor Assembly	HS	SK92250
1.6.1	L/C Rotor Component Weight and CG	HS	NA
1.6.2	L/C Rotor Component Polar Moment	HS	NA
1.6.3	L/C Power Requirements	HS	NA
1.7	L/C Gearbox Assembly	DDA	SK20219 & SK20249
1.7.1	Reduction & Bevel Gears & Cross Shaft	DDA	SK20219 & SK20249
1.8	Stationary Components		
1.8.1	Fan Duct Stator Definition	DDA	SK20148
1.8.2	Engine Inlet Stator Definition	DDA	SK20148
1.8.3	Fan-Engine Transition Definition	DDA	SK20148
1.8.4	Primary-Secondary Flow Splitter	DDA	SK20148

		RESPONSIBLE CONTRACTOR	REFERENCE DRAWING
1.0	**MECHANICAL INTERFACE (Continued)**		
1.9	Forward Frame		
1.9.1	Forward Frame Materials	DDA	SK20148
1.9.2	Forward Frame Temperatures	DDA	NA
1.9.3	Fan Blade Tip Seal Material	DDA/HS	SK20148
1.10	L/C Modules		
1.10.1	L/C Fan Module Definition	HS	SK92250
1.10.2	L/C Fan Turboshaft Engine Module Def.	DDA	TBD
2.0	**AERODYNAMIC INTERFACE**		
2.1	Component Design Responsibility	HS	NA
2.2	Fan Stage Maps	HS	NA
2.3	Engine Inlet Vane Aero Parameters	HS	NA
2.4	Fan Duct Stator Aero Parameters	HS	NA
2.5	Primary-Secondary Flow Splitter	HS	NA
3.0	**ELECTRICAL INTERFACE**		
3.1	Pitch Control Schematic	HS	L-13081-8
3.2	Electrical Connection Definition	HS	SK92250
3.3	Redundance Requirements	HS	NA
3.4	Wiring Definition		
3.4.1	Wiring Diagram	HS	NA
3.4.2	Amperage in Wires	HS	NA
3.4.3	Voltage in Wires	HS	NA
3.5	L/C Fan Control Modes	HS/DDA	NA
3.6	L/C Fan Instrumentation Requirements	HS	NA
3.7	L/C Fan Turboshaft Engine Control System	HS/DDA/AC	NA
3.8	Fan Speed Pickup	DDA	SK20148
4.0	**HYDRAULIC INTERFACE**		
4.1	Hydraulic Connections	HS	SK92250
4.2	Type of Oil	DDA	NA
4.3	Oil System		
4.3.1	Type & Size of Oil Supply Lines	DDA	SK20148
4.3.2	Oil Pressures	HS	NA
4.3.3	Oil Flow Rates	HS	NA
4.4	L/C Fan Oil Filter Requirements	HS	NA
4.5	Redundance Requirements	HS	NA
4.6	Fan Rotor Lubrication Requirements	HS	NA
4.7	Pump Drive Locations	DDA	TBD
4.8	Leakage Allowables	HS	NA

ABBREVIATIONS:

TBD - To be determined as the program progresses.

NA - Not applicable, this notation applies in this table to the form of transmitting data. The majority of the data so noted will be supplied in the form of interface coordination memo which will become a part of this interface document.

ADDENDUM A

LIFT FAN INTERFACE DEFINITION

ADDENDUM A

LIFT FAN INTERFACE DEFINITION

The lift fan interface which has been coordinated with the airframe study contractors, Boeing and McDonnell, is provided by the installation drawings noted below. These drawings will be updated during the fan detail design to define all mechanical interfaces.

Airframe Contractor	Drawing No.
Boeing	SK 92252
McDonnell	SK 92251

The beta regulator envelope as defined by drawing SK 92249 is common to both airframe contractors and DDA for the lift/cruise fan.

Additional data pertaining to the lift fan interface which will be established during the fan detail design is as follows:

1.0 Fan Operational Parameters

- 1.1 Fan Design Horsepower
- 1.2 Fan Design Speed

2.0 Fan Characteristics

- 2.1 Weight
- 2.2 Polar Moment of Inertia
- 2.3 Center of Gravity
- 2.4 Vibration Limits
- 2.5 Gear Ratio

3.0 Aerodynamic Characteristics

- 3.1 Fan Stage Maps

4.0 Electrical Interface

- 4.1 Wiring Diagram
- 4.2 Voltage Requirements
- 4.3 Power Requirements
- 4.4 Instrumentation Requirements

5.0 Hydraulic Interface

5.1 Pressure Requirements
5.2 Flow Requirements
5.3 Filtration Requirements
5.4 Pitch Control Schematic
5.5 Leakage Allowables
5.6 Heat Load
5.7 Type of Fluid

APPENDIX B

LIST OF SYMBOLS

SYMBOL	DEFINITION	UNITS
A	Centrifugal Hydraulic Dam	-
AEO	All Engines Operating	-
A_N	Lift/Cruise Nozzle Area	m^2 (in^2)
A_1	First Harmonic Component	-
A_2	Second Harmonic Component	-
A_3	Third Harmonic Component	-
A_4	Fourth Harmonic Component	-
B	Helical Splined Pinion Drive Shaft	-
BPR	Bypass Ratio	-
C	Outer Helical Splined Coupling	-
CDP	Compressor Discharge Pressure	kPa (psia)
CE	Center Engine	-
CEVM	Consumable Electrode Vacuum Melt	-
CG	Center of Gravity	-
CIP	Compressor Inlet Pressure	kPa (psia)
CIT	Compressor Inlet Temperature	°K(°R)
CL	Condition Lever	-
CVG	Compressor Variable Geometry	-
D	Aft Helical Splined Coupling	-

LIST OF SYMBOLS (Cont'd)

SYMBOL	DEFINITION	UNITS
DDA	Detroit Diesel Allison	-
E	Centrifugal Hydraulic Dam	-
EHV	Electrohydraulic Servovalve	-
F	Belleville Springs	-
FIP	Fan Inlet Pressure	kPa (psia)
FIT	Fan Inlet Temperature	°K(°R)
FNCM	Thrust Control Margin	-
FNP	Primary Nozzle Thrust	N (lb)
FNS	Secondary Nozzle Thrust	N (lb)
FNT	System Total Net Thrust	N (lb)
FOD	Foreign Object Damage	-
FPR	Fan Pressure Ratio	-
G	Ball Lock	-
g	Acceleration of Gravity	m/sec^2(ft/sec^2)
G/B	Gearbox	-
H.P.	High Pressure	-
HS	Hamilton Standard	-
IP	Intermediate Power Level	-
KR	Radial Distortion Parameter, $\frac{P_{TR\ MAX} - P_{TR\ MIN}}{P_{T\ AVG} - P_{S\ AVG}}$	-

SYMBOL	DEFINITION	UNITS
KRE	Engine Radial Distortion Parameter, $\frac{P_{TR\ MAX} - P_{TR\ MIN}}{P_{T\ AVG} - P_{S\ AVG}}$	-
$K\theta$	Circumferential Distortion Parameter, $\frac{P_{T\theta\ MAX} - P_{T\theta\ MIN}}{P_{T\ AVG} - P_{S\ AVG}}$	-
$K\theta E$	Engine Circumferential Distortion Parameter, $\frac{P_{T\theta\ MAX} - P_{T\theta\ MIN}}{P_{T\ AVG} - P_{S\ AVG}}$	-
$K\theta FH$	Fan Hub Circumferential Distortion Parameter, $\frac{P_{T\theta\ MAX} - P_{T\theta\ MIN}}{P_{T\ AVG} - P_{S\ AVG}}$	-
LCF	Low Cycle Fatigue	-
L/C	Lift/Cruise	-
L/CF	Lift/Cruise Fan	-
LF	Lift Fan	-
LVDT	Linear Variable Differential Transformer	-
$MN_{A/C}$	Aircraft Mach Number	-
N_F	Fan Rotor Speed	RPM
N_O	Gasifier Rotor Speed	RPM
N_G	Gasifier Set Speed	RPM
OEI	One Engine Inoperative	-
PLA	Power Lever Angle	Degrees
PP	Primary Nozzle Pressure	kPa (psia)
PR	Power Rating	-
PS	Secondary Nozzle Pressure	kPa (psia)

LIST OF SYMBOLS (Cont'd)

SYMBOL	DEFINITION	UNITS
$P_{S_{avg}}$	Arithmetic average of six equally spaced wall static pressure values measured in plane of the total pressures	kPa (psia)
$P_{T_{avg}}$	Inlet total pressure arithmetically averaged over the compressor inlet annulus	kPa (psia)
$P_{TR_{max}}$	Arithmetically averaged total pressure contained in an area bounded by the compressor inlet inner diameter and an outer diameter describing 60 percent of the compressor inlet annulus area	kPa (psia)
$P_{TR_{min}}$	Arithmetically averaged total pressure contained in an area bounded by the compressor inlet outer diameter and an inner diameter describing 40 percent of the compressor inlet annulus area	kPa (psia)
$P_{T\theta_{max}}$	Arithmetically averaged total pressure in any contiguous 240 degree sector of high-pressure measured at the compressor inlet annulus	kPa (psia)
$P_{T\theta_{min}}$	Arithmetically averaged total pressure in any contiguous 120 degree sector of low-pressure measured at the compressor inlet annulus	kPa (psia)
RG	Reduction Gear	-
RTA	Research and Technology Aircraft	-
SFCT	Total Specific Fuel Consumption	mg/N-S(lb/hr/lb)
SLS	Sea Level Static Conditions	-
TF	Turbofan Engine	-
Ti	Titanium	-
T_{MAX}	Maximum Nacelle Thrust	N (lbs)
TP	Primary Nozzle Temperature	°K (°R)
TS	Secondary Nozzle Temperature	°K(°R)
TSE	Turboshaft Engine	-

LIST OF SYMBOLS (Cont'd)

SYMBOL	DEFINITION	UNITS
V_O	Wind Tunnel Velocity	m/s (knots)
VTOL	Vertical Takeoff and Landing	-
V/STOL	Vertical/Short Takeoff and Landing	-
WE	Core Engine Compressor Airflow	kg/s (lb/sec)
WF	Fuel Flow	kg/hr (lb/hr)
WF_{ACC}	Acceleration Fuel Flow	kg/hr (lb/hr)
WF_{DEC}	Deceleration Fuel Flow	kg/hr (lb/hr)
WF_{GOV}	Governor Fuel Flow	kg/hr (lb/hr)
WF_{MAX}	Maximum Fuel Flow	kg/hr (lb/hr)
WF_{MIN}	Minimum Fuel Flow	kg/hr (lb/hr)
WK 1	Inlet Corrected Airflow	kg/s (lb/sec)
WP	Primary Nozzle Flow	kg/s (lb/sec)
WS	Secondary Nozzle Flow	kg/s (lb/sec)
WT	Total Flow In	kg/s (lb/sec)
W1	Inlet Flow	kg/s (lb/sec)
XT701	XT701-AD-700 Engine	-
1E-1F	One Engine and One Fan Operating	-
2E-3F	Two Engines and Three Fans Operating	-
3E-3F	Three Engines and Three Fans Operating	-
α	Nacelle Angle of Attack	Degrees
β	Fan Pitch Angle	Degrees