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STUDY OF UNCONVENTIONAL AIRCRAFT ENGINES DESIGNED FOR LOW ENERGY CONSUMPTION

Comprehensive Data Report

Volume II

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by

ADVANCED SYSTEMS PRELIMINARY DESIGN
AND TECHNICAL PLANS DEPARTMENT
GENERAL ELECTRIC COMPANY
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5.0 Screening Study - Turboprop

5.1 Introduction

Turboprop aircraft and propulsion systems were included in the screening study because of renewed interest in high speed propeller developments which allow a reexamination of their merits relative to turbofan.

A modern turboprop, to be competitive in commercial transport must be designed for efficient operation at high subsonic cruise conditions such as .8 Mach/35,000 feet.

Recent studies by propeller manufacturers show that the application of high speed aerodynamic principles to propeller design may bring about an 80% propeller efficiency at these conditions. The turboprop has a natural advantage of higher propulsive efficiency over a turbofan. In addition, the turboprop engine cycle and components were selected at advanced technology levels equal to the turbofan.

Hamilton Standard Division (HSD) of United Technology supplied advanced propeller and gear design data during the screening study. This included efficiency, weight, equisition cost, maintenance and installation requirements. General Electric combined this data with a suitable drive engine and an installation.

In the screening study, a single rotation propeller with and without advanced weight features and counter rotating propeller were studied.

In addition, at NASA suggestion a shrouded propeller, designed from fan principles by General Electric was studied as a hybrid, super high bypass turbofan.

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PART 2

5.2 1 Orthogonally Plane

5.2.2 Engine Inlet Conditions

In generating the engine cycle data, it was desired to take into account the effect of propellor supercharging of the engine. Based on an installation sketch, the engine inlet was found to be located radially between $r/r_{prop\ tip}$ = .25 and .35. Using Figure 5.2.2-1 supplied by HSD, an average P/P = 1.023 and T/T = 1.01 across the propellor hub exists. These values were applied to the free stream total pressure and temperature to arrive at conditions at the engine inlet.

An inlet ram recovery equal to .995 was assumed.

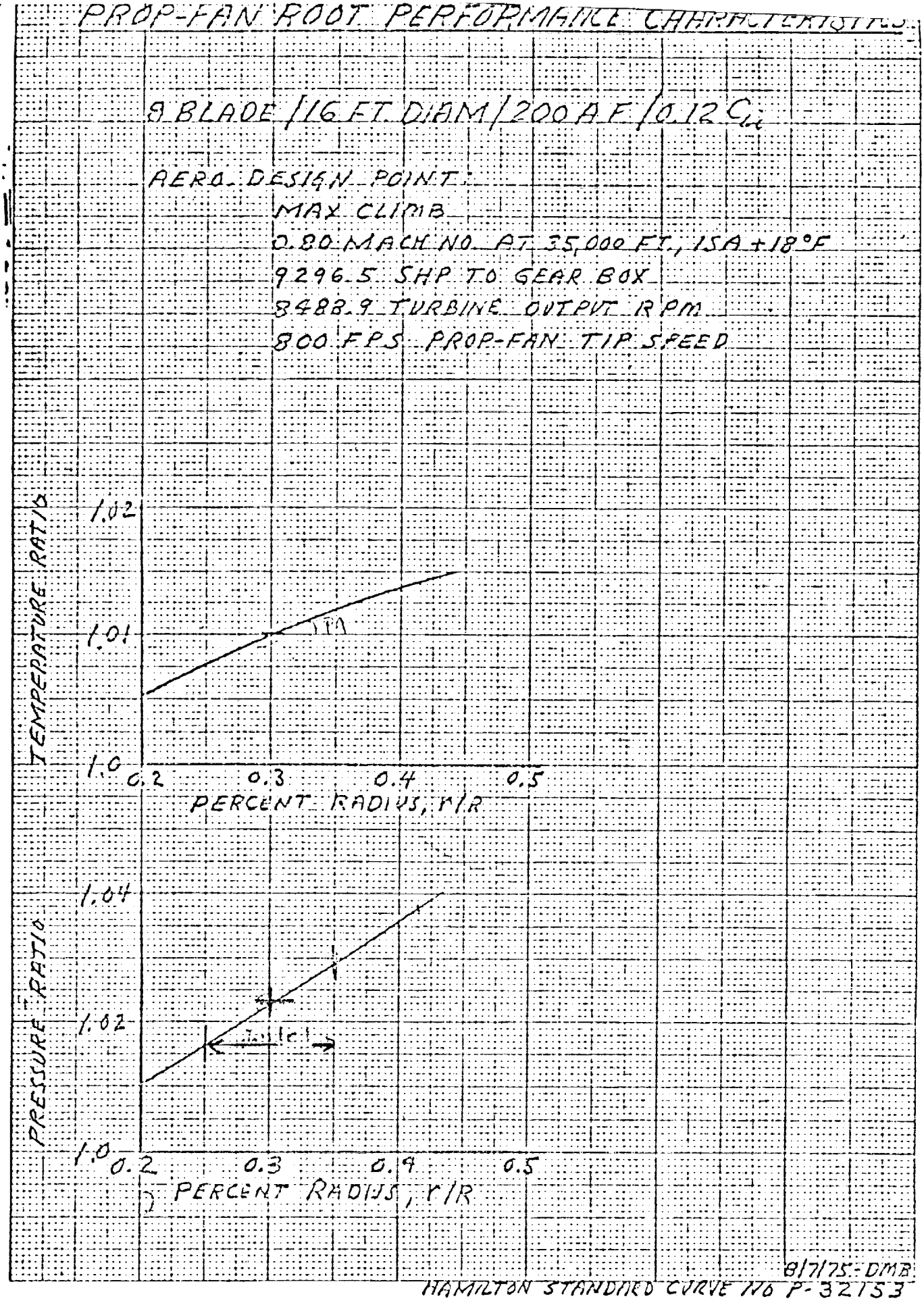

PROP-FAN ROOT PERFORMANCE CHARACTERISTICS
9 BLADE / 16 FT. DIAM / 200 A F / 0.12 Cl
AERO DESIGN POINT:
MAX CLIMB
0.80 MACH NO. AT 35,000 FT., ISA + 18°F
9296.5 SHP TO GEAR BOX
8488.9 TURBINE OUTPUT RPM
800 FPS PROP-FAN TIP SPEED
TEMPERATURE RATIO
1.02
1.01
1.0
0.2
0.3
0.4
0.5
PERCENT RADIUS, r/R
PRESSURE RATIO
1.04
1.02
1.0
0.2
0.3
0.4
0.5
PERCENT RADIUS, r/R
8/7/75 - DMB
HAMILTON STANDARD CURVE NO P-32153

Fig 5.2.2-1

5.2.3 Cycle Data

The engine cycle data attached was generated using a fan to simulate the propellor load. All data pertinent to the dummy fan has been xx out.

Sample Thrust Calculation

A $SP/D^2 = 36.$ was chosen for the design point @ 35K/.81/+18 MX CL

From cycle point #1

HP FAN = 16672 (Power to dummy fan)

$\eta_{gear} = .99$ (Fig 5.2.3-1)

HP prop = .99 × 16672 = 16505

$$\Rightarrow D_{prop} = \sqrt{\frac{16505}{36}} = 21.41$$

Prop tip speed chosen

to be $U_T = 800$

From HSD n supplied data $\eta_p = .797$
(Section

$$F_{prop} = \frac{\eta\ SHP\ (550)}{V_p}$$

$$V_p = M_0\, a = (.8)(995.75\ f/s) = 796.6$$

$$F_{prop} = (.797)\frac{(16505)(550)}{796.6} = \boxed{9082}$$

Core Gross Thrust

From cycle Data and assuming $C_v = .997$

$W_8 = 62.24$
$V_8 = 1375$

$$F_{g8} = (1375)(62.24)\frac{(.997)}{32.2} = 2650$$

Core ram drag is computed from cycle dummy bypass ratio (B) and Engine total ramdrag (F_D) which includes fan

$$F_{rem\ core} = \frac{F_D}{1+B} = \frac{15162}{1+8.999} = 1516$$

Total bare thrust

$$F = F_{prop} + F_{gcore} - F_{rem\ core}$$

$$= 9082 + 2650 - 1516 = \boxed{10216}$$

Fuel Flow (w_F) from cycle data $= 5110$

$$\therefore \text{Bare SFC} = \frac{5110}{10216} = \boxed{.50}$$

Initial installation drag estimates from HSD fixed $D = 634^{\#}$

$$\therefore \boxed{\begin{array}{ll} F_N = 9582 & \text{Installed} \\ SFC = .533 & \end{array}}$$

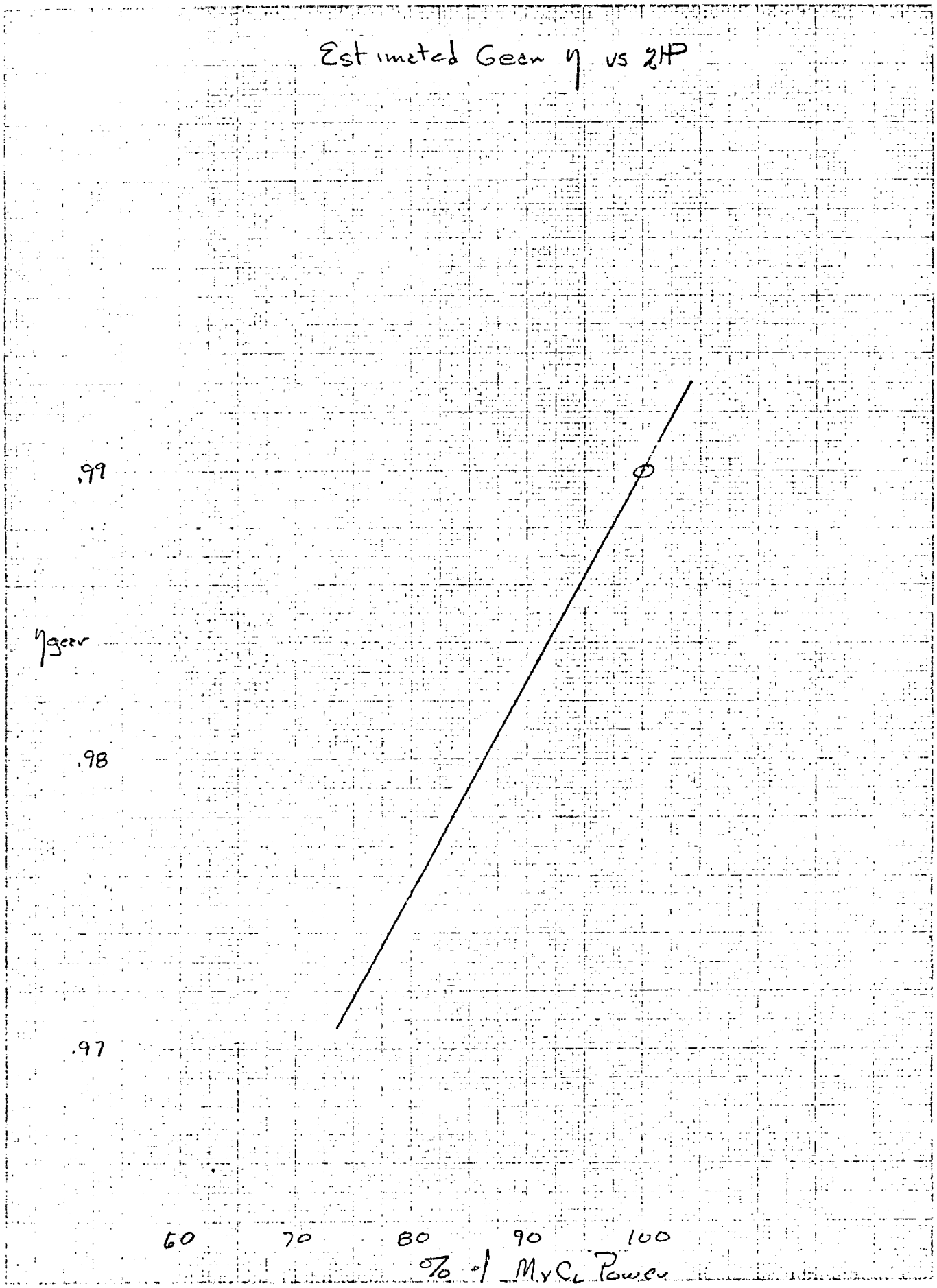

Estimated Gear η vs %HP
.99
ηgear
.98
.97
60
70
80
90
100
% of MxCL Power

Fig 5.2.3-1

a) WBD – COMPRESSOR BLEED, CUSTOMER DISCHARGE
b) WBI – CUSTOMER INTERSTAGE BLEED
c) HPE – CUSTOMER HOTICE POWER EXTRACTION

NASA-USTEDLEC / TP4 Cycle
Turboprop Core Engine Cycle Data

CASE	ALT	M_0	ΔT_0	DESCRIPTION	
1	35K	.8	+18	MX CL	
2	↓	↓	↓	↓	
3				MX CR	
1	0	0	+27	TKOF	
2		.1			
3		.2			
4				.8	TKOF FN
5				.6	
6				.4	
7				.2	
8		.25		TKOF	(a)
18		.30			WBD/2C = .04
19					.06
20		.25	+18	MXCL	
21			0		
22		.38	+18		
23			0		
24	5K	.25	+27	TKOF	
25			+31		
26			+43		
27	10K	.25	+27	TKOF	
28		.45	+18	MXCL	
29			0		
30		.57	+18		
31			0		

CASE	ALT	M_o	ΔT_o	DESCRIPTION		
32	15K	.40	+18	MXCR	WGI = 2 #/sec (b)	HPT = 100 (c)
33			0			
34				.8 MXCR FN		
35				.6		
36				.4		
37				.3		
38				.2		
39	20K	.60	+18	MXCR		
40			0			
41				.8 MXCR FN		
42				.6		
43				.4		
44		.70	+18	MXCL		
45			0			
46			+18	MXCR		
47			0			
48		.80	+18			
49			0			
50				.8 MXCR FN		
51				.6		
52				.4		
53		.85	+18	MXCR		
54			0			
55	25K	.75	+18	MXCL		
56			0			
57	30K	.60	+18	MXCR		
58						
59				.8 MXCR FN		
60				.6		
61				.4		
62		.70	+18	MXCR		
63			0			

CASE	ALT	Mo	ΔTo	DESCRIPTION
64	30K	.75	+18	MXCL
65	↓	↓	0	↓
66		.80	+18	MXCR
67		↓	0	↓
68			↓	.8 MXCR FN
69				.6 ↓
70		↓	↓	.4
71		.85	+18	MXCR
72	↓	↓	↓	↓
73	31K	.75	+18	MXCL
74	↓	↓	0	↓
75	32K		+18	
76	↓		0	
77	33K		+18	
78	↓		0	
79	34K		+18	
80	↓	↓	0	↓
81	35K	.60	+18	MXCR
82	↓	↓	0	↓
83			↓	.8 MXCR FN
84				.6 ↓
85		↓	↓	.4
86		.80	+18	MXCR
87		↓	0	↓
88			↓	.8 MXCR FN
89				.6 ↓
90			↓	.4
91			+18	MXCR FN
92			0	↓
93			↓	WBI/2C = .02
94				↓ .04
95	↓	↓	↓	↓ .06

CASE	ALT	M_0	ΔT_0	DESCRIPTION
96	35K	.80	0	MKCR FN HPE = 100

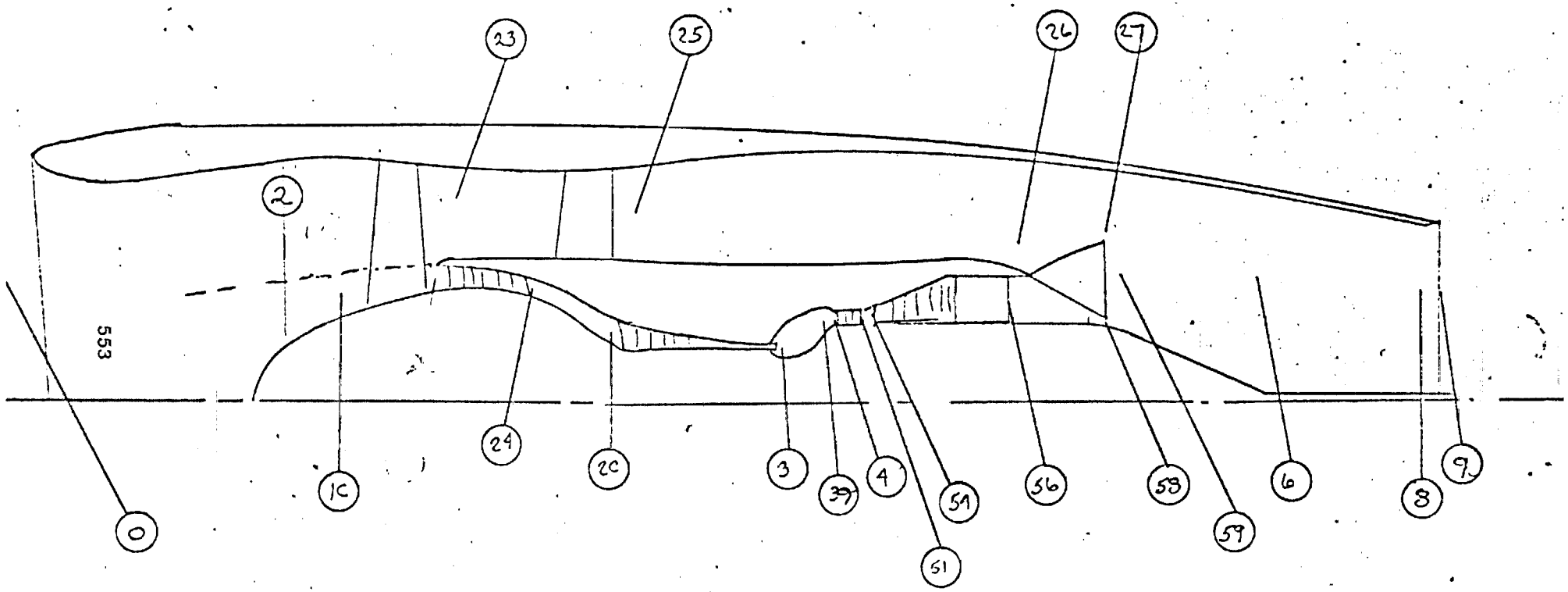
Turboprop Simulation
Batch ~~MF12~~ CYCLE NOMENCLATURE

Alt	Altitude, ft
M	Mach Number
P	Pressure, Psia
W	Flow, lb/sec
T	Temperature, ^{o}R
DELTO	To-Tstd day
ETAR	Ram Recovery
B, β	Bypass Ratio
~~FNG-MX~~	~~Fully Mixed Net Thrust, lbs~~
~~SFC-MX~~	~~Specific Fuel Consumption Based on FNG-MX lbm/hr/~~lb
~~FNG-PM~~	~~Partially Mixed Net Thrust, lbs~~
~~SFC-PM~~	~~Specific Fuel Consumption Based on FNG PM~~
~~PCNF~~	~~Fan Physical Speed, %~~
~~NF~~	~~Fan Physical Speed, RPM~~
~~ECNF~~*	~~Fan Corrected Speed~~
~~ETAF~~	~~Fan Tip Adiabatic Efficiency~~
Q	Dynamic Pressure
ETAIC	Fan Hub + Booster Adiabatic Efficiency
PCNG	Core Physical Speed, %
NG	Core Physical Speed, RPM
PCNG*	Core Corrected Speed, %
WFM	Fuel Flow, lb/hr
ETABM	Burner Efficiency
TFFC	HP Turbine Flow Function
NRT4	HP Turbine Corrected Speed

*Indicates a corrected flow

MF12 CYCLE NOMENCLATURE (Cont.)

DH/T4	HP Turbine Energy Function
TFF2TC	LP Turbine Flow Function
N/RT54	LP Turbine Corrected Speed
DH/T54	LP Turbine Energy Function
V	Velocity, ft/sec
CF	Flow Coefficient
AE	Effective Area, in^2
CV	Velocity Coefficient
FGG-MX	Mixed Gross Thrust, lb
FD	Ram Drag
~~FGG-PM~~	~~Partial Mixed Gross Thrust, lb~~
~~PC-MX~~	~~Mixing Effectiveness~~



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Station Designations

[redacted]

Note regarding DELTO and ETAR in Turboprop cycle printout.

The DELTO in printout includes the ΔT from std day in addition to the ΔT associated with the propellor hub supercharge. ie at sizing point

35K / .8 / +18 Mx C_L Pt #1

$\Delta T = 18^\circ + 4.15^\circ = 22.15$

Ambient Hub supercharge

ETAR includes propellor hub supercharge and .5% inlet total pressure loss

1.2

ETAR = 2.3% − .5% ⇒ P/P = 1.018

Prop hub P/P Inlet loss

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
10/20/75
RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER

CASE	1.00	2.00	3.00
ALT	35000.	35000.	35000.
MO	0.800	0.800	0.800
PC	50.00	50.00	50.00
RC	40.00	40.00	40.00
FNG	9095.1	9094.8	8702.1
SFCG	0.5619	0.5619	0.5617
DELTO	22.15	22.15	22.15
TO	416.00	416.00	416.00
PO	3.4580	3.4580	3.4580
T2	469.48	469.48	469.48
ETAR	1.0180	1.0180	1.0180
P2	5.369	5.369	5.369
P_{22}/P_2	0.9996	0.9996	0.9996
M21	0.6395	0.6393	0.6096
P22	5.367	5.367	5.367
B	8.9998	8.9995	9.2158
PATH	SEPR	SEPR	SEPR
WB/W2C	0.0020	0.0020	0.0020
WB	0.	0.	0.
PBD	199.15	199.15	187.01
TBD	1462.0	1462.0	1432.8
WBI	0.122	0.122	0.116
PBI	78.76	78.76	74.42
TBI	1156.8	1156.8	1135.3
HPE	0.	0.	0.
PCNF	95.140	95.141	92.289
NF	4482.1	4482.1	4347.7
PCNF*	100.000	100.001	97.003
W2*	1587.64	1587.62	1545.41
W2	609.46	609.45	593.25
P23/22	1.6999	1.7000	1.6506
Z22	0.6626	0.6628	0.6456
ETAF	0.8590	0.8590	0.8608
HPFAN	16672.	16674.	15266.
MN22	0.4152	0.4152	0.4152
M23	0.4500	0.4499	0.4485
P25P23	1.0000	1.0000	1.0000
M25P	0.4500	0.4499	0.4499
AE25P	3872.8	3872.8	3872.8

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
10/20/75
RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER

CASE	1.00	2.00	3.00
~~P25P~~	~~9.124~~	~~9.125~~	~~8.859~~
P2525P	1.0000	1.0000	1.0000
P25	9.124	9.124	8.859
Q25	1.1258	1.1258	1.0929
T25	559.2	559.2	553.7
M25	0.4500	0.4500	0.4499
W25	548.51	548.50	535.18
P28/25	0.9930	0.9930	0.9930
P28	9.060	9.061	8.797
T28	559.2	559.2	553.7
W28	548.51	548.50	535.18
CV29	0.9993	0.9993	0.9989
CF28	0.9863	0.9863	0.9862
AE28	2691.6	2691.5	2691.3
A28	2729.0	2728.9	2729.0
V28	1058.4	1058.4	1053.2
~~M28~~	~~1.0000~~	~~1.0000~~	~~1.0000~~
Z1C	0.6616	0.6617	0.6733
P24/1C	2.7500	2.7501	2.6493
W1C*	158.77	158.77	151.28
W1C	60.95	60.95	58.07
ETA1C	0.8620	0.8620	0.8640
HP1C	3779.	3779.	3441.
P24	14.760	14.761	14.220
T24	652.3	652.3	644.2
M24	0.4500	0.4499	0.4399
Q24	1.8185	1.8180	1.6848
P2C/24	0.9900	0.9900	0.9904
AE2D	0.	0.	0.
WB/W24	0.	0.	0.
P2C	14.612	14.613	14.083
T2C	652.3	652.3	644.2
PCNG	99.608	99.608	98.353
PCNG*	88.821	88.821	88.252
NG	14517.	14517.	14334.
PCNG*M	100.000	99.999	99.359
WARC2C	0.	0.	0.
W2C	60.95	60.95	58.07
W2C*	68.74	68.74	67.54

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
10/20/75
RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER

CASE	1,00	2,00	3,00
P3/P2C	14,0018	14,0014	13,6463
Z2C	0,5870	0,5870	0.5809
ETAC	0,8600	0,8600	0,8623
HPC	17050,	17050,	15789,
RNI2C	0,7457	0,7458	0,7299
P3/P2	38,1195	38,1202	35,8055
P3	204,60	204,60	192,18
PS3	193,44	193,45	181,60
T3	1462,0	1462,0	1432,8
WAR3	0,	0,	0,
W3	58,88	58,88	56,10
W31	51,59	51,59	49,15
M3	0,2890	0,2890	0.2902
P4/P3	0,9470	0,9470	0,9466
WFM	5110,3	5110,4	4663,2
ETABM	0,9875	0,9875	0,9875
FAR339	0,02752	0,02752	0,02635
T39	3054,5	3054,5	2971,7
T4	2960,0	2960,0	2879,9
WAR4	0,	0,	0,
FAR4	0,02566	0,02566	0,02457
P4	193,76	193,76	181,91
W4	56,75	56,75	54,01
TFFC	15,93	15,93	15,93
N/RT4	266,83	266,82	267,10
DH/T4	0,07185	0,07185	0,07185
ETAT	0,8980	0,8980	0,8980
HPT	17076,	17076,	15813,
HPAUX	25,60	25,60	24,03
P4/P51	3,8714	3,8713	3,8765
P51	50,048	50,050	46,926
T51	2217,3	2217,3	2152,6
FAR51	0,02436	0,02436	0,02332
WAR51	0,	0,	0,
W51	59,70	59,70	56,83
M51	0,4800	0,4800	0,4796
P54/51	1,0000	1,0000	1,0000
P54	50,048	50,050	46,926
T54	2217,3	2217,3	2152,6
FAR54	0,02436	0,02436	0,02332
WAR54	0,	0,	0,
W54	59,70	59,70	56,83
TFF2TC	56,17	56,17	56,19
N/RT54	95,19	95,19	93,71
DH/T54	0,10919	0,10920	0,10808

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
10/20/75
RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER

CASE	1.00	2.00	3.00
ETA2T	0.9210	0.9210	0.9192
HP2T	20451.	20453.	18707.
RNI54	0.6858	0.6859	0.6643
P54/56	9.3233	9.3257	9.1447
P56	5.368	5.367	5.132
T56	1353.8	1353.7	1317.5
W56	62.24	62.25	59.25
M56	0.5000	0.5002	0.4873
P8/56	0.9900	0.9900	0.9904
FAR8	0.02334	0.02334	0.02235
WAR8	0.	0.	0.
W8	62.24	62.25	59.25
T8	1353.8	1353.7	1317.5
P8	5.314	5.313	5.082
P8OP0	1.5368	1.5365	1.4697
M8	0.8200	0.8198	0.7735
V8	1375.4	1375.0	1287.9
CF8	1.0165	1.0165	1.0165
CV9	0.9970	0.9970	0.9970
AE8	846.73	846.99	846.99
A8	833.0	833.2	833.2
FD	15162.	15162.	14758.
~~FGG~~	~~24257.~~	~~24256.~~	~~23061.~~
~~FNU/W2~~	~~14.92~~	~~14.92~~	~~13.99~~
D/F-PC	5.0	5.0	5.3
CD	0.1843	0.1843	0.1843
FDI	453.3	453.3	441.3
SWFMG	1.00000	1.00000	1.00000
SFNG	1.0000	1.0000	1.0000
WC3/2C	0.0902	0.0902	0.0902
WC4/2C	0.0614	0.0614	0.0614
WC5I2C	0.0360	0.0360	0.0360
WC5D2C	0.0125	0.0125	0.0125
WC542C	0.	0.	0.
WC55I1	0.0050	0.0050	0.0050
WC55I2	0.0367	0.0367	0.0367
WC552C	0.0417	0.0417	0.0417
WCI/2C	0.0320	0.0320	0.0320
FIBAH	0.3880	0.3880	0.3880
FCAH51	0.2850	0.2850	0.2850
FCAH54	0.7500	0.7500	0.7500
FCH551	1.0000	1.0000	1.0000
FCH552	0.2770	0.2770	0.2770

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
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RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER
MISSION ANALYSIS CYCLE DATA PACKAGE

CASE	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00
ALT	0.	0.	0.	0.	0.	0.	0.	0.
MO	0.	0.100	0.200	0.200	0.200	0.200	0.200	0.250
PC	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
RC	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
FNG	35873.8	31712.9	28369.1	22695.4	17019.8	11349.6	5676.1	26946.7
SFCG	0.2985	0.3387	0.3816	0.3740	0.3669	0.3643	0.3799	0.4042
DELTO	32.50	32.50	32.50	32.50	32.50	32.50	32.50	32.50
TO	551.17	551.17	551.17	551.17	551.17	551.17	551.17	551.17
PO	14.6960	14.6960	14.6960	14.6960	14.6960	14.6960	14.6960	14.6960
T2	551.17	552.27	555.59	555.59	555.59	555.59	555.59	558.07
ETAR	1.0180	1.0180	1.0180	1.0180	1.0180	1.0180	1.0180	1.0130
P2	14.961	15.066	15.384	15.384	15.384	15.384	15.384	15.626
P22/P2	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996
M21	0.4778	0.4786	0.4806	0.4258	0.3694	0.3078	0.2358	0.4818
P22	14.955	15.060	15.378	15.378	15.378	15.378	15.378	15.620
B	9.4033	9.4422	9.5574	9.9999	10.5344	11.2742	12.5874	9.6395
PATH	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR
WB/W2C	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
WB	0.	0.	0.	0.	0.	0.	0.	0.
PBD	414.43	415.90	420.07	354.44	287.44	217.06	139.04	423.23
TBD	1544.1	1545.3	1548.5	1472.6	1385.8	1280.2	1132.6	1550.9
WBI	0.249	0.250	0.253	0.221	0.188	0.151	0.106	0.255
PBI	166.76	167.46	169.46	145.16	120.54	94.61	64.31	170.97
TBI	1230.7	1231.9	1235.3	1178.7	1115.3	1038.0	931.2	1237.8
HPE	0.	0.	0.	0.	0.	0.	0.	0.
PCNF	88.116	88.120	88.095	80.624	72.778	62.873	46.794	88.074
NF	4151.2	4151.3	4150.2	3798.2	3428.6	2961.9	2204.4	4149.2
PCNF*	85.479	85.397	85.118	77.899	70.319	60.748	45.212	84.908
W2*	1313.23	1314.86	1318.88	1202.42	1070.83	914.35	711.14	1321.35
W2	1296.34	1305.76	1333.44	1215.69	1082.65	924.44	718.99	1353.92
P23/22	1.4716	1.4696	1.4633	1.3713	1.2792	1.1868	1.0927	1.4537
Z22	0.6737	0.6678	0.6599	0.6436	0.6455	0.6580	0.5234	0.6392
ETAF	0.8535	0.8545	0.8572	0.8554	0.8522	0.8470	0.8430	0.8538
HPFAN	29981.	30126.	30526.	23006.	15943.	9476.	3822.	30831.
RNT22	0.9419	0.9461	0.9589	0.9589	0.9569	0.9589	0.9569	0.9635
M23	0.4125	0.4136	0.4170	0.3977	0.3702	0.3318	0.2704	0.4193
P25P23	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
M25P	0.4147	0.4161	0.4201	0.4027	0.3775	0.3397	0.2792	0.4228
AE25P	3872.8	3872.8	3872.8	3872.8	3872.8	3872.8	3872.8	3872.8

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CASE	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00
P25P	22.007	22.131	22.503	21.087	19.671	18.250	16.804	22.785
P2529P	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
P25	22.006	22.131	22.502	21.087	19.670	18.250	16.804	22.784
Q25	2.3518	2.3792	2.4601	2.1397	1.7779	1.3608	0.8686	2.5198
T25	626.6	627.5	630.1	616.9	603.1	588.5	572.5	632.1
M25	0.4147	0.4161	0.4201	0.4027	0.3775	0.3397	0.2792	0.4229
W25	1171.73	1180.71	1207.13	1105.17	988.77	849.12	666.07	1226.56
P28/25	0.9939	0.9939	0.9938	0.9942	0.9949	0.9958	0.9971	0.9937
P28	21.873	21.996	22.353	20.985	19.570	18.173	16.755	22.641
T28	626.6	627.5	630.1	616.9	603.1	588.5	572.5	632.1
W28	1171.73	1180.71	1207.13	1105.17	988.77	849.12	666.07	1226.56
CV29	0.9970	0.9970	0.9970	0.9970	0.9970	0.9970	0.9970	0.9970
CF28	0.9695	0.9696	0.9701	0.9687	0.9687	0.9697	0.9716	0.9706
AE28	2645.7	2646.0	2647.5	2643.6	2643.6	2646.2	2651.5	2648.7
A28	2729.0	2729.1	2729.1	2729.0	2728.9	2729.0	2729.0	2729.0
V28	899.1	905.8	925.0	845.8	754.5	645.1	502.9	939.2
M28	0.7756	0.7813	0.7981	0.7308	0.6529	0.5592	0.4368	0.8106
Z1C	0.6390	0.6419	0.6502	0.6643	0.6942	0.7268	0.7194	0.6552
P24/1C	2.2120	2.2105	2.2045	1.9861	1.7818	1.5522	1.2870	2.2000
W1C*	126.23	125.92	124.93	109.31	92.86	74.49	52.34	124.20
W1C	124.61	125.05	126.31	110.52	93.88	75.32	52.92	127.26
ETA1C	0.8744	0.8743	0.8742	0.8728	0.8670	0.8590	0.8461	0.8741
HP1C	6789.	6821.	6905.	5173.	3665.	2214.	881.	6969.
P24	33.080	33.289	33.901	30.542	27.400	23.870	19.791	34.354
T24	711.4	712.6	716.3	693.3	670.5	642.2	604.7	719.0
M24	0.4232	0.4222	0.4192	0.3961	0.3635	0.3221	0.2591	0.4171
Q24	3.6567	3.6645	3.6854	3.0039	2.3087	1.6111	0.8871	3.7017
P2C/24	0.9910	0.9911	0.9912	0.9920	0.9932	0.9945	0.9964	0.9913
AE2D	0.	0.	0.	0.	0.	0.	0.	0.
WB/W24	0.	0.	0.	0.	0.	0.	0.	0.
P2C	32.783	32.992	33.602	30.298	27.213	23.739	19.719	34.053
T2C	711.4	712.6	716.3	693.3	670.5	642.2	604.7	719.0
PCNG	102.246	102.275	102.355	99.297	95.591	90.288	82.512	102.417
PCNG*	87.307	87.254	87.100	85.889	84.075	81.143	76.417	86.985
NG	14901.	14906.	14917.	14472.	13931.	13159.	12025.	14925.
PCNG*M	98.295	98.235	98.062	96.698	94.657	91.356	86.034	97.933
WARC2C	0.	0.	0.	0.	0.	0.	0.	0.
W2C	124.61	125.05	126.30	110.52	93.86	75.32	52.92	127.25
W2C*	65.42	65.29	64.92	61.98	57.63	51.88	42.58	64.64

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CASE	1,00	2,00	3,00	4,00	5,00	6,00	7,00	8,00
P3/P2C	12,9947	12,9584	12,8518	12,0337	10,8758	9,4268	7,2839	12,7736
Z2C	0,5666	0,5660	0,5640	0,5457	0,5186	0,5100	0,5376	0,5624
ETAC	0,8665	0,8666	0,8671	0,8706	0,8732	0,8701	0,8524	0,8675
HPC	36140,	36267,	36627,	29840,	23113,	16416,	9447,	36900,
RNI2C	1,5044	1,5107	1,5291	1,4348	1,3425	1,2351	1,1055	1,5429
P3/P2	28,4868	28,3888	28,0822	23,7094	19,2457	14,5521	9,3401	27,8565
P3	426,01	427,52	431,85	364,60	295,96	223,78	143,63	435,11
PS3	402,31	403,73	407,76	343,80	278,53	210,04	134,24	410,80
T3	1544,1	1545,3	1548,5	1472,6	1385,8	1280,2	1132,6	1550,9
WAR3	0,	0,	0,	0,	0,	0,	0,	0,
W3	120,37	120,79	122,01	106,76	90,67	72,76	51,12	122,93
W31	105,47	105,84	106,90	93,54	79,45	63,75	44,79	107,71
M3	0,2924	0,2925	0,2929	0,2959	0,3003	0,3062	0,3154	0,2931
P4/P3	0,9461	0,9460	0,9459	0,9448	0,9431	0,9408	0,9373	0,9458
WFM	10708,8	10739,7	10825,9	8488,0	6244,6	4134,8	2156,2	10890,8
ETABM	0,9875	0,9875	0,9875	0,9875	0,9875	0,9875	0,9875	0,9875
FAR339	0,02820	0,02819	0,02813	0,02521	0,02183	0,01802	0,01337	0,02809
T39	3155,3	3155,4	3155,2	2945,5	2696,5	2397,9	2000,0	3155,0
T4	3060,0	3060,1	3060,1	2857,2	2617,0	2328,8	1945,5	3060,0
WAR4	0,	0,	0,	0,	0,	0,	0,	0,
FAR4	0,02630	0,02628	0,02623	0,02350	0,02036	0,01680	0,01247	0,02619
P4	403,02	404,44	408,49	344,46	279,12	210,54	134,63	411,54
W4	116,09	116,50	117,67	102,69	86,94	69,52	48,64	118,55
TFFC	15,93	15,93	15,93	15,93	15,93	15,93	15,93	15,93
N/RT4	269,38	269,45	269,66	270,74	272,33	272,68	272,63	269,83
DH/T4	0,07200	0,07199	0,07199	0,07198	0,07189	0,07176	0,07068	0,07199
ETAT	0,8982	0,8982	0,8982	0,8982	0,8982	0,8982	0,8984	0,8932
HPT	36186,	36314,	36674,	29878,	23142,	16438,	9462,	36947,
HPAUX	46,21	46,36	46,79	37,77	29,65	22,05	14,76	47,11
P4/P51	3,8774	3,8773	3,8770	3,8894	3,8994	3,9125	3,8548	3,8768
P51	103,941	104,310	105,363	88,564	71,581	53,813	34,925	106,154
T51	2298,0	2298,1	2298,2	2134,2	1942,9	1716,5	1425,5	2298,3
FAR51	0,02496	0,02495	0,02490	0,02231	0,01932	0,01595	0,01184	0,02486
WAR51	0,	0,	0,	0,	0,	0,	0,	0,
W51	122,14	122,57	123,79	108,05	91,50	73,17	51,20	124,72
M51	0,4824	0,4824	0,4824	0,4814	0,4793	0,4767	0,4620	0,4824
P54/51	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
P54	103,941	104,310	105,363	88,564	71,581	53,813	34,925	106,154
T54	2298,0	2298,1	2298,2	2134,2	1942,9	1716,5	1425,5	2298,3
FAR54	0,02496	0,02495	0,02490	0,02231	0,01932	0,01595	0,01184	0,02486
WAR54	0,	0,	0,	0,	0,	0,	0,	0,
W54	122,14	122,57	123,79	108,05	91,50	73,17	51,20	124,72
TFF2TC	56,33	56,33	56,32	56,36	56,34	56,34	55,35	56,32
N/RT54	86,60	86,60	86,57	82,22	77,78	71,49	58,39	86,55
DH/T54	0,09260	0,09271	0,09299	0,08637	0,07796	0,06578	0,04554	0,09321

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
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CASE	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00
ETA2T	0.9114	0.9113	0.9113	0.9041	0.8982	0.8901	0.8733	0.9112
HP2T	36771.	36947.	37431.	28179.	19608.	11690.	4703.	37800.
RNI54	1.3694	1.3742	1.3880	1.2657	1.1343	0.9773	0.7781	1.3934
P54/56	6.1964	6.2142	6.2594	5.4522	4.5497	3.5141	2.3331	6.2947
P56	16.774	16.786	16.833	16.244	15.733	15.313	14.969	16.854
T56	1544.7	1543.9	1541.8	1470.9	1386.4	1289.9	1168.8	1540.2
W56	127.33	127.78	129.06	112.66	95.41	76.31	53.41	130.02
M56	0.3231	0.3241	0.3265	0.2836	0.2368	0.1848	0.1241	0.3293
P8/56	0.9954	0.9954	0.9954	0.9964	0.9975	0.9984	0.9993	0.9953
FAR8	0.02392	0.02391	0.02386	0.02138	0.01852	0.01528	0.01134	0.02382
WAR8	0.	0.	0.	0.	0.	0.	0.	0.
W8	127.33	127.78	129.06	112.66	95.41	76.31	53.41	130.02
T8	1544.7	1543.9	1541.8	1470.9	1386.4	1289.9	1168.8	1540.2
P8	16.698	16.709	16.754	16.186	15.693	15.289	14.958	16.785
P8QP0	1.1362	1.1370	1.1401	1.1014	1.0678	1.0404	1.0178	1.1421
M8	0.4410	0.4422	0.4469	0.3820	0.3137	0.2425	0.1613	0.4500
V8	816.6	818.5	826.4	694.2	556.7	417.5	266.1	831.6
CF8	1.0165	1.0165	1.0165	1.0165	1.0165	1.0165	1.0165	1.0155
CV9	0.9970	0.9970	0.9970	0.9970	0.9970	0.9970	0.9970	0.9970
AE8	847.55	847.97	846.53	846.25	848.66	847.47	847.73	846.30
A8	833.8	834.2	832.8	832.5	834.9	833.7	834.0	832.6
FD	0.	4672.	9542.	8699.	7747.	6615.	5145.	12110.
FGG	35874.	36385.	37911.	31394.	24767.	17945.	10821.	39057.
FNU/W2	27.67	24.29	21.28	18.67	15.72	12.28	7.89	19.20
D/F-PC	0.	0.1	0.4	0.4	0.5	0.6	1.0	0.6
CD	0.1843	0.1843	0.1843	0.1843	0.1843	0.1843	0.1843	0.1843
FDI	0.	24.9	100.0	91.2	81.2	69.3	53.9	156.6
SWFNG	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
SFNG	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
WC3/2C	0.0902	0.0902	0.0902	0.0902	0.0902	0.0902	0.0902	0.0902
WC4/2C	0.0614	0.0614	0.0614	0.0614	0.0614	0.0614	0.0614	0.0614
WC512C	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360
WC5D2C	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125
WC542C	0.	0.	0.	0.	0.	0.	0.	0.
WC5511	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050
WC5512	0.0367	0.0367	0.0367	0.0367	0.0367	0.0367	0.0367	0.0367
WC552C	0.0417	0.0417	0.0417	0.0417	0.0417	0.0417	0.0417	0.0417
WCI/2C	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320
FIDAH	0.3880	0.3880	0.3880	0.3880	0.3880	0.3880	0.3880	0.3880
FCAH51	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850
FCAH54	0.7500	0.7500	0.7500	0.7500	0.7500	0.7500	0.7500	0.7500
FCH551	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
FCH552	0.2770	0.2770	0.2770	0.2770	0.2770	0.2770	0.2770	0.2770

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
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CASE	17.00	18.00	19.00	20.00	21.00	22.00	23.00	24.00
ALT	0.	0.	0.	0.	0.	0.	0.	5000.
MO	0.300	0.300	0.300	0.250	0.250	0.380	0.380	0.250
PC	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
RC	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
FNG	24050.5	22464.6	20983.2	25341.9	25338.6	22330.5	22332.9	24671.7
SFCG	0.4380	0.4494	0.4610	0.3980	0.3892	0.4613	0.4512	0.3939
DELTO	32.50	32.50	32.50	23.40	5.20	23.40	5.40	32.30
TO	551.17	551.17	551.17	542.07	523.87	542.07	524.07	533.14
PO	14.6960	14.6960	14.6960	14.6960	14.6960	14.6960	14.6960	12.2278
T2	561.11	561.11	561.11	548.86	530.44	557.76	539.24	539.82
ETAR	1.0180	1.0180	1.0180	1.0180	1.0180	1.0180	1.0180	1.0180
P2	15.925	15.925	15.925	15.626	15.626	16.530	16.529	13.001
P22/P2	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996
M21	0.4677	0.4526	0.4385	0.4663	0.4663	0.4697	0.4698	0.5084
P22	15.919	15.919	15.919	15.620	15.619	16.523	16.523	12.996
B	9.8352	9.9380	10.0362	9.7660	9.7560	10.0535	10.0451	9.4239
PATH	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR
WB/W2C	0.0220	0.0420	0.0620	0.0020	0.0020	0.0020	0.0020	0.0020
WB	2.485	4.802	6.966	0.	0.	0.	0.	0.
PBD	402.79	379.13	356.84	404.47	405.23	415.58	416.40	379.87
TBD	1530.0	1505.8	1482.4	1507.2	1461.9	1516.2	1471.2	1539.7
WBI	0.248	0.240	0.232	0.248	0.252	0.254	0.259	0.228
PBI	164.48	156.31	148.76	163.98	164.22	169.37	169.63	152.52
TBI	1223.1	1205.1	1188.0	1203.3	1165.9	1212.8	1175.5	1226.2
HPE	0.	0.	0.	0.	0.	0.	0.	0.
PCNF	85.930	83.763	81.797	85.258	83.820	85.220	83.813	89.835
NF	4048.2	3946.1	3853.4	4016.5	3948.8	4014.7	3948.4	4234.5
PCNF*	82.616	80.533	78.642	82.880	82.885	82.179	82.198	88.136
W2*	1292.59	1260.78	1230.35	1289.74	1289.81	1296.59	1296.95	1373.50
W2	1346.17	1313.04	1281.35	1332.57	1355.56	1405.78	1430.05	1190.51
P23/22	1.4263	1.3998	1.3749	1.4322	1.4323	1.4158	1.4160	1.5037
Z22	0.6210	0.6163	0.6121	0.6355	0.6356	0.5971	0.5970	0.6450
ETAF	0.8595	0.8586	0.8580	0.8584	0.8583	0.8604	0.8604	0.8590
HPFAN	28925.	26703.	24644.	28362.	27875.	29397.	28905.	28383.
RNT22	0.9803	0.9803	0.9803	0.9891	1.0328	1.0252	1.0699	0.8434
M23	0.4176	0.4128	0.4080	0.4146	0.4145	0.4224	0.4224	0.4263
P25P23	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
M25P	0.4221	0.4177	0.4133	0.4187	0.4186	0.4281	0.4280	0.4288
AE25P	3872.8	3872.8	3872.8	3872.8	3872.8	3872.8	3872.8	3872.8

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
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CASE	17.00	18.00	19.00	20.00	21.00	22.00	23.00	24.00
W25P	22.706	22.283	21.888	22.371	22.372	23.394	23.397	19.542
P2525P	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
P25	22.705	22.283	21.888	22.371	22.372	23.394	23.396	19.542
Q25	2.5032	2.4125	2.3254	2.4324	2.4321	2.6442	2.6449	2.2155
T25	630.8	627.1	623.4	618.0	597.3	625.5	604.8	617.6
M25	0.4221	0.4178	0.4133	0.4188	0.4186	0.4281	0.4281	0.4238
W25	1221.91	1193.00	1165.24	1208.78	1229.53	1278.60	1300.58	1076.40
P28/25	0.9937	0.9939	0.9940	0.9938	0.9938	0.9936	0.9936	0.9936
P28	22.563	22.146	21.756	22.233	22.234	23.244	23.246	19.416
T28	630.8	627.1	623.4	618.0	597.3	625.5	604.8	617.6
W28	1221.91	1193.00	1165.24	1208.78	1229.53	1278.60	1300.58	1076.40
CV29	0.9970	0.9970	0.9970	0.9970	0.9970	0.9970	0.9970	0.9970
CF28	0.9704	0.9698	0.9694	0.9699	0.9699	0.9716	0.9716	0.9717
AE28	2648.4	2646.5	2645.4	2647.3	2646.9	2651.4	2651.4	2651.9
A28	2729.0	2729.0	2729.0	2729.4	2729.0	2729.1	2729.0	2729.1
V28	934.8	912.6	891.1	910.1	894.7	960.5	944.5	958.2
M28	0.8071	0.7883	0.7700	0.7922	0.7922	0.8364	0.8364	0.8402
Z1C	0.6565	0.6507	0.6494	0.6577	0.6559	0.6806	0.6788	0.6495
P24/1C	2.1261	2.0593	2.0024	2.1350	2.1344	2.1217	2.1216	2.3106
W1C*	119.31	115.26	111.50	119.81	119.91	117.30	117.42	131.75
W1C	124.26	120.04	116.12	123.79	126.03	127.18	129.47	114.21
ETA1C	0.8741	0.8742	0.8740	0.8741	0.8742	0.8728	0.8730	0.8728
HP1C	6512.	5996.	5553.	6385.	6279.	6615.	6509.	6482.
P24	33.846	32.782	31.876	33.348	33.338	35.057	35.054	30.029
T24	715.1	707.9	701.7	700.6	677.1	710.7	687.2	706.8
M24	0.4112	0.4072	0.4024	0.4115	0.4119	0.4035	0.4040	0.4256
Q24	3.5554	3.3861	3.2238	3.5091	3.5169	3.5628	3.5714	3.3657
P2C/24	0.9915	0.9916	0.9918	0.9915	0.9914	0.9918	0.9917	0.9909
AE2D	0.	0.	0.	0.	0.	0.	0.	0.
WB/W24	0.	0.	0.	0.	0.	0.	0.	0.
P2C	33.557	32.507	31.614	33.063	33.053	34.768	34.764	29.755
T2C	715.1	707.9	701.7	700.6	677.1	710.7	687.2	706.8
PCNG	101.735	100.957	100.188	100.755	99.096	100.988	99.343	102.127
PCNG*	86.641	86.414	86.134	86.694	86.730	86.276	86.307	87.439
NG	14827.	14714.	14601.	14684.	14442.	14718.	14478.	14884.
PCNG*M	97.545	97.290	96.975	97.605	97.645	97.134	97.169	98.499
WARC2C	0.	0.	0.	0.	0.	0.	0.	0.
W2C	124.24	120.04	116.10	123.78	126.03	127.18	129.47	114.22
W2C*	63.89	63.40	62.78	63.94	64.02	62.93	63.00	65.35

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
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CASE	17.00	18.00	19.00	20.00	21.00	22.00	23.00	24.00
P3/P2C	12.4056	12.1196	11.8006	12.5791	12.6073	12.2931	12.3189	13.1219
Z2C	0.5345	0.5086	0.4821	0.5586	0.5598	0.5516	0.5529	0.5693
ETAC	0.8684	0.8687	0.8690	0.8684	0.8683	0.8696	0.8696	0.8658
HPC	35235.	33274.	31434.	34678.	34213.	35623.	35154.	33119.
RNI2C	1.5300	1.5005	1.4751	1.5458	1.6111	1.5974	1.6641	1.3763
P3/P2	26.1508	24.7484	23.4354	26.6265	26.6787	25.8668	25.9196	30.0431
P3	416.30	393.97	373.07	415.90	416.70	427.40	428.26	390.45
PS3	392.36	370.69	350.38	392.51	393.23	403.22	403.99	368.79
T3	1530.0	1505.8	1482.4	1507.2	1461.9	1516.2	1471.2	1539.7
WAR3	0.	0.	0.	0.	0.	0.	0.	0.
W3	120.02	115.96	112.16	119.57	121.74	122.86	125.07	110.34
W31	102.67	96.80	91.30	104.76	106.67	107.65	109.59	96.68
M3	0.2974	0.3015	0.3059	0.2939	0.2939	0.2949	0.2949	0.2920
P4/P3	0.9442	0.9427	0.9410	0.9455	0.9454	0.9452	0.9451	0.9462
WFM	10534.7	10094.6	9672.5	10085.8	9861.7	10301.5	10077.2	9841.7
ETABM	0.9875	0.9875	0.9875	0.9875	0.9875	0.9875	0.9875	0.9875
FAR339	0.02850	0.02897	0.02943	0.02674	0.02568	0.02658	0.02554	0.02328
T39	3158.7	3162.2	3166.2	3052.2	2961.1	3051.5	2961.7	3155.4
T4	3060.2	3060.0	3060.0	2960.2	2871.4	2960.0	2872.5	3059.9
WAR4	0.	0.	0.	0.	0.	0.	0.	0.
FAR4	0.02653	0.02692	0.02730	0.02493	0.02394	0.02478	0.02382	0.02637
P4	393.08	371.38	351.05	393.23	393.95	403.97	404.74	369.44
W4	113.23	106.98	101.12	115.17	117.15	118.32	120.34	106.42
TFFC	15.93	15.93	15.93	15.93	15.93	15.93	15.93	15.93
N/RT4	268.02	265.98	263.96	269.89	269.52	270.52	270.14	269.07
DH/T4	0.07197	0.07193	0.07189	0.07199	0.07198	0.07198	0.07197	0.07198
ETAT	0.8981	0.8979	0.8978	0.8982	0.8982	0.8982	0.8982	0.8981
HPT	35280.	33316.	31475.	34721.	34255.	35667.	35197.	33162.
HPAUX	45.05	42.67	40.44	43.71	42.41	44.79	43.48	42.30
P4/P51	3.8751	3.8726	3.8693	3.8831	3.8880	3.8830	3.8874	3.8759
P51	101.439	95.900	90.726	101.267	101.326	104.037	104.117	95.317
T51	2297.3	2296.0	2294.9	2217.1	2145.3	2217.2	2146.4	2297.9
FAR51	0.02516	0.02549	0.02582	0.02367	0.02273	0.02353	0.02261	0.02503
WAR51	0.	0.	0.	0.	0.	0.	0.	0.
W51	119.25	112.80	106.75	121.17	123.26	124.48	126.62	111.96
M51	0.4827	0.4829	0.4830	0.4819	0.4813	0.4819	0.4813	0.4822
P54/51	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
P54	101.439	95.900	90.726	101.267	101.326	104.037	104.117	95.317
T54	2297.3	2296.0	2294.9	2217.1	2145.3	2217.2	2146.4	2297.9
FAR54	0.02516	0.02549	0.02582	0.02367	0.02273	0.02353	0.02261	0.02503
WAR54	0.	0.	0.	0.	0.	0.	0.	0.
W54	119.25	112.80	106.75	121.17	123.26	124.48	126.62	111.96
TFF2TC	56.35	56.36	56.37	56.34	56.34	56.34	56.34	56.31
N/RT54	84.46	82.35	80.44	85.30	85.26	85.26	85.22	88.33
DH/T54	0.09142	0.08924	0.08712	0.09142	0.09129	0.09222	0.09210	0.09578

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
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CASE	17.00	18.00	19.00	20.00	21.00	22.00	23.00	24.00
ETA2T	0.9075	0.9036	0.9006	0.9092	0.9091	0.9089	0.9089	0.9138
HP2T	35437.	32699.	30197.	34747.	34154.	36012.	35414.	34865.
RNI54	1.3369	1.2647	1.1971	1.3878	1.4399	1.4257	1.4786	1.2558
P54/56	6.0762	5.8113	5.5563	6.0749	6.0780	6.2014	6.2061	6.6665
P56	16.695	16.502	16.328	16.670	16.671	16.776	16.777	14.298
T56	1553.3	1569.2	1584.6	1494.1	1441.5	1488.1	1436.5	1519.1
W56	124.43	117.81	111.59	126.33	128.51	129.79	132.01	116.72
M56	0.3176	0.3044	0.2917	0.3160	0.3153	0.3227	0.3220	0.3477
P8/56	0.9956	0.9959	0.9962	0.9956	0.9956	0.9954	0.9954	0.9948
FAR8	0.02408	0.02438	0.02467	0.02268	0.02178	0.02254	0.02166	0.02398
WAR8	0.	0.	0.	0.	0.	0.	0.	0.
W8	124.43	117.81	111.59	126.33	128.51	129.79	132.01	116.72
T8	1553.3	1569.2	1584.6	1494.1	1441.5	1488.1	1436.5	1519.1
P8	16.621	16.435	16.267	16.597	16.598	16.700	16.700	14.223
P8QP0	1.1310	1.1183	1.1069	1.1293	1.1294	1.1364	1.1364	1.1632
M8	0.4329	0.4126	0.3931	0.4297	0.4293	0.4406	0.4401	0.4802
V8	804.2	771.1	738.9	784.1	770.3	801.8	787.8	879.8
CF8	1.0165	1.0165	1.0165	1.0165	1.0165	1.0165	1.0165	1.0155
CV9	0.9970	0.9970	0.9970	0.9970	0.9970	0.9970	0.9970	0.9970
AE8	846.74	847.06	847.80	848.15	847.07	847.31	846.50	847.29
A8	833.0	833.3	834.0	834.4	833.3	833.6	832.8	833.5
FD	14449.	14093.	13753.	11821.	11823.	18955.	18962.	10475.
~~FGG~~	~~38500.~~	~~36558.~~	~~34737.~~	~~37163.~~	~~37161.~~	~~41286.~~	~~41292.~~	~~35147.~~
~~FNU/W2~~	~~17.87~~	~~17.11~~	~~16.38~~	~~19.02~~	~~18.69~~	~~15.88~~	~~15.62~~	~~20.72~~
D/F-PC	0.9	1.0	1.0	0.6	0.6	1.6	1.6	0.5
CD	0.1843	0.1843	0.1843	0.1843	0.1843	0.1843	0.1843	0.1843
FDI	220.6	215.2	210.0	152.8	152.9	355.0	355.1	135.4
SWFMG	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
SFNG	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
WC3/2C	0.0902	0.0902	0.0902	0.0902	0.0902	0.0902	0.0902	0.0902
WC4/2C	0.0614	0.0614	0.0614	0.0614	0.0614	0.0614	0.0614	0.0614
WC5I2C	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360
WC5D2C	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125
WC542C	0.	0.	0.	0.	0.	0.	0.	0.
WC55I1	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050
WC55I2	0.0367	0.0367	0.0367	0.0367	0.0367	0.0367	0.0367	0.0367
WC552C	0.0417	0.0417	0.0417	0.0417	0.0417	0.0417	0.0417	0.0417
WC1/2C	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320
FIBAH	0.3880	0.3880	0.3880	0.3880	0.3880	0.3880	0.3880	0.3880
FCAH51	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850
FCAH54	0.7500	0.7500	0.7500	0.7500	0.7500	0.7500	0.7500	0.7500
FCH551	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
FCH552	0.2770	0.2770	0.2770	0.2770	0.2770	0.2770	0.2770	0.2770

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
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RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER
MISSION ANALYSIS CYCLE DATA PACKAGE

CASE	25,00	26,00	27,00	28,00	29,00	30,00	31,00	32,00
ALT	5000,	5000,	10000,	10000,	10000,	10000,	10000,	1500,
MO	0,250	0,250	0,250	0,450	0,450	0,570	0,570	0,400
PC	50,00	50,00	50,00	50,00	50,00	50,00	50,00	50,00
RC	40,00	40,00	40,00	40,00	40,00	40,00	40,00	40,00
FNG	24152,6	22621,0	22356,2	17944,4	17952,7	16486,1	16489,3	18676,2
SFCG	0,4000	0,4037	0,3944	0,4754	0,4646	0,5331	0,5209	0,4730
DELTO	36,30	48,40	32,10	23,00	4,80	23,00	4,80	23,30
TO	537,14	549,24	515,11	506,01	487,81	506,01	487,81	536,52
PO	12,2278	12,2278	10,1065	10,1065	10,1065	10,1065	10,1065	13,9167
T2	543,87	556,12	521,57	526,56	507,64	538,99	519,62	553,83
ETAR	1,0180	1,0180	1,0180	1,0180	1,0180	1,0180	1,0180	1,0180
P2	13,002	13,002	10,746	11,822	11,821	12,825	12,823	15,820
P22/P2	0,9996	0,9996	0,9996	0,9996	0,9996	0,9996	0,9996	0,9996
M21	0,5022	0,4842	0,5365	0,5198	0,5199	0,5143	0,5146	0,4492
P22	12,996	12,996	10,741	11,817	11,817	12,820	12,818	15,814
B	9,4718	9,6231	9,2385	9,6912	9,6761	9,9625	9,9484	10,2499
PATH	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR
WB/W2C	0,0020	0,0020	0,0020	0,0020	0,0020	0,0020	0,0020	0,0192
WB	0,	0,	0,	0,	0,	0,	0,	0,
PBD	373,48	354,62	337,54	340,29	341,25	353,23	354,23	366,58
TBD	1542,3	1549,8	1526,3	1498,6	1450,6	1510,6	1462,3	1469,3
WBI	0,225	0,213	0,203	0,208	0,212	0,216	0,221	2,232
PBI	150,16	143,17	134,51	137,34	137,64	143,55	143,88	149,54
TBI	1228,9	1236,6	1212,3	1194,5	1154,9	1207,0	1167,1	1177,4
HPE	0,	0,	0,	0,	0,	0,	0,	100,0
PCNF	89,495	88,236	91,224	88,861	87,268	88,672	87,104	81,823
NF	4216,1	4156,8	4297,6	4186,2	4111,2	4177,3	4103,5	3854,7
PCNF*	87,397	85,213	90,971	88,193	88,211	86,985	87,024	79,133
W2*	1361,62	1326,21	1425,65	1395,14	1395,43	1384,79	1385,45	1253,72
W2	1175,92	1132,65	1039,11	1113,39	1134,15	1185,03	1207,33	1305,54
P23/22	1,4932	1,4628	1,5512	1,4959	1,4962	1,4734	1,4739	1,3743
Z22	0,6436	0,6397	0,6517	0,6027	0,6028	0,5794	0,5794	0,5802
ETAF	0,8590	0,8588	0,8584	0,8631	0,8631	0,8634	0,8634	0,8586
HPFAN	27748,	25896,	25838,	25480,	25042,	26719,	26265,	24765,
RNI22	0,8325	0,8094	0,7257	0,7887	0,8265	0,8307	0,8702	0,9900
M23	0,4248	0,4200	0,4324	0,4371	0,4371	0,4401	0,4401	0,4178
P25P23	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
M25P	0,4275	0,4235	0,4339	0,4411	0,4410	0,4456	0,4456	0,4243
AE25P	3872,8	3872,8	3872,8	3872,8	3872,8	3872,8	3872,8	3872,8

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
10/20/75
RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER
MISSION ANALYSIS CYCLE DATA PACKAGE

CASE	25,00	26,00	27,00	28,00	29,00	30,00	31,00	32,00
P25P	19,407	19,011	16,661	17,677	17,680	18,889	18,893	21,732
P2525P	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
P25	19,406	19,011	16,661	17,677	17,679	18,888	18,893	21,732
Q25	2,1885	2,1079	1,9288	2,1065	2,1065	2,2905	2,2913	2,4191
T25	620,8	630,5	602,9	601,0	579,5	612,1	590,3	615,2
M25	0,4275	0,4235	0,4339	0,4412	0,4411	0,4457	0,4456	0,4244
W25	1063,62	1026,02	937,62	1009,25	1027,92	1076,93	1097,06	1189,49
P28/25	0,9936	0,9937	0,9934	0,9932	0,9932	0,9931	0,9931	0,9937
P28	19,282	18,891	16,552	17,557	17,560	18,759	18,763	21,595
T28	620,8	630,5	602,9	601,0	579,5	612,1	590,3	615,2
W28	1063,62	1026,02	937,62	1009,25	1027,92	1076,93	1097,06	1189,49
CV29	0,9970	0,9970	0,9970	0,9970	0,9970	0,9970	0,9970	0,9970
CF28	0,9714	0,9707	0,9731	0,9758	0,9758	0,9789	0,9790	0,9708
AE28	2651,1	2649,2	2655,5	2663,1	2662,8	2671,5	2671,6	2649,6
A28	2729,0	2729,2	2729,0	2729,1	2728,7	2729,0	2729,0	2729,2
V28	953,9	940,8	975,7	1026,6	1008,2	1091,3	1071,8	933,7
M28	0,8335	0,8133	0,8697	0,9241	0,9242	0,9827	0,9829	0,8176
Z1C	0,6510	0,6543	0,6296	0,6812	0,6781	0,7111	0,7090	0,6744
P24/1C	2,2856	2,2097	2,4046	2,3281	2,3275	2,2956	2,2963	2,0275
W1C*	130,03	124,85	139,25	130,49	130,71	126,32	126,54	111,44
W1C	112,30	106,63	101,49	104,14	106,24	108,10	110,27	116,05
ETA1C	0,8729	0,8729	0,8715	0,8712	0,8716	0,8699	0,8704	0,8726
HP1C	6328,	5863,	5875,	5836,	5736,	6093,	5993,	5595,
P24	29,705	28,718	25,829	27,512	27,503	29,430	29,435	32,062
T24	709,6	717,7	692,0	691,5	666,7	704,8	679,6	695,6
M24	0,4244	0,4180	0,4386	0,4181	0,4190	0,4076	0,4083	0,3971
Q24	3,3005	3,1053	3,0415	2,9792	2,9910	3,0456	3,0564	3,1671
P2C/24	0,9910	0,9912	0,9904	0,9912	0,9912	0,9916	0,9916	0,9920
AE2D	0,	0,	0,	0,	0,	0,	0,	0,
WB/W24	0,	0,	0,	0,	0,	0,	0,	0,
P2C	29,437	28,466	25,582	27,270	27,261	29,183	29,187	31,805
T2C	709,6	717,7	692,0	691,5	666,7	704,8	679,6	695,6
PCNG	102,193	102,381	101,801	100,517	98,759	100,826	99,060	99,399
PCNG*	87,371	87,033	86,137	87,055	87,108	86,495	86,538	85,829
NG	14894,	14921,	14837,	14649,	14393,	14694,	14437,	14485,
PCNG*M	98,368	97,987	99,230	98,011	98,071	97,381	97,430	96,631
WARC2C	0,	0,	0,	0,	0,	0,	0,	0,
W2C	112,29	106,62	101,49	104,14	106,23	108,10	110,27	116,05
W2C*	65,57	64,75	67,34	64,80	64,93	63,46	63,56	62,10

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
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RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER
MISSION ANALYSIS CYCLE DATA PACKAGE

CASE	25,00	26,00	27,00	28,00	29,00	30,00	31,00	32,00
P3/P2C	13,0415	12,8070	13,5589	12,8291	12,8703	12,4469	12,4810	11,8567
Z2C	0,5678	0,5633	0,5775	0,5648	0,5662	0,5560	0,5575	0,5208
ETAC	0,8662	0,8672	0,8634	0,8672	0,8670	0,8689	0,8689	0,8728
HPC	32563,	30918,	29431,	29166,	28774,	30267,	29861,	30889,
RNI2C	1,3550	1,2922	1,2143	1,2955	1,3543	1,3544	1,4162	1,4999
P3/P2	29,5393	28,0511	32,2924	29,6055	29,6912	28,3335	28,4186	23,8463
P3	383,90	364,56	346,86	349,85	350,85	363,23	364,28	377,10
PS3	362,58	344,21	327,80	330,29	331,20	342,76	343,71	355,77
T3	1542,3	1549,8	1526,3	1498,6	1450,6	1510,6	1462,3	1469,3
WAR3	0,	0,	0,	0,	0,	0,	0,	0,
W3	108,48	103,00	98,04	100,60	102,62	104,42	106,53	110,10
W31	95,05	90,24	85,90	88,15	89,92	91,49	93,34	96,22
M3	0,2922	0,2930	0,2906	0,2930	0,2929	0,2943	0,2942	0,2946
P4/P3	0,9461	0,9459	0,9466	0,9458	0,9457	0,9454	0,9453	0,9452
WFM	9662,0	9131,9	8818,0	8531,4	8340,7	8788,0	8589,2	8926,5
ETABM	0,9875	0,9875	0,9875	0,9875	0,9875	0,9875	0,9875	0,9875
FAR339	0,02824	0,02811	0,02851	0,02689	0,02577	0,02668	0,02556	0,02577
T39	3155,6	3155,1	3156,3	3052,4	2956,3	3051,8	2955,3	2971,7
T4	3060,1	3060,1	3060,0	2960,0	2866,2	2960,0	2866,0	2880,1
WAR4	0,	0,	0,	0,	0,	0,	0,	0,
FAR4	0,02633	0,02621	0,02659	0,02507	0,02402	0,02488	0,02383	0,02399
P4	363,21	344,83	328,35	330,88	331,80	343,39	344,35	356,43
W4	104,62	99,33	94,58	96,91	98,76	100,57	102,49	105,33
TFFC	15,93	15,93	15,93	15,93	15,93	15,93	15,93	15,93
N/RT4	269,24	269,73	268,21	269,26	268,84	270,09	269,68	269,94
DH/T4	0,07198	0,07199	0,07197	0,07196	0,07194	0,07195	0,07194	0,07195
ETAT	0,8981	0,8982	0,8981	0,8982	0,8981	0,8982	0,8982	0,8982
HPT	32605,	30959,	29470,	29203,	28810,	30306,	29899,	31023,
HPAUX	42,20	40,43	38,73	37,75	36,61	38,97	37,79	39,12
P4/P51	3,8761	3,8770	3,8750	3,8805	3,8851	3,8803	3,8853	3,8851
P51	93,707	88,942	84,735	85,268	85,403	88,497	88,628	91,742
T51	2298,2	2298,3	2297,9	2217,0	2141,3	2217,4	2141,3	2152,0
FAR51	0,02499	0,02488	0,02524	0,02380	0,02281	0,02361	0,02262	0,02275
WAR51	0,	0,	0,	0,	0,	0,	0,	0,
W51	110,07	104,50	99,50	101,96	103,91	105,82	107,84	111,46
M51	0,4822	0,4824	0,4820	0,4815	0,4808	0,4815	0,4808	0,4815
P54/51	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
P54	93,707	88,942	84,735	85,268	85,403	88,497	88,628	91,742
T54	2298,2	2298,3	2297,9	2217,0	2141,3	2217,4	2141,3	2152,0
FAR54	0,02499	0,02488	0,02524	0,02380	0,02281	0,02361	0,02262	0,02275
WAR54	0,	0,	0,	0,	0,	0,	0,	0,
W54	110,07	104,50	99,50	101,96	103,91	105,82	107,84	111,46
TFF2TC	56,31	56,33	56,29	56,30	56,30	56,30	56,31	56,36
N/RT54	87,95	86,71	89,65	88,91	88,85	88,71	88,68	83,09
DH/T54	0,09521	0,09347	0,09803	0,09792	0,09777	0,09884	0,09873	0,08947

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
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RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER
MISSION ANALYSIS CYCLE DATA PACKAGE

CASE	25,00	26,00	27,00	28,00	29,00	30,00	31,00	32,00
ETA2T	0,9133	0,9114	0,9157	0,9145	0,9144	0,9141	0,9140	0,9051
HP2T	34076,	31759,	31713,	31316,	30779,	32812,	32258,	30361,
RNI54	1,2345	1,1717	1,1165	1,1686	1,2161	1,2127	1,2620	1,2992
P54/56	6,5812	6,3311	7,0221	7,0579	7,0646	7,2371	7,2509	5,8648
P56	14,239	14,048	12,067	12,081	12,089	12,228	12,223	15,643
T56	1523,9	1538,1	1500,7	1443,1	1389,1	1436,4	1382,1	1460,4
W56	114,75	108,95	103,74	106,30	108,34	110,32	112,44	116,30
M56	0,3433	0,3302	0,3667	0,3677	0,3668	0,3776	0,3771	0,3051
P8/56	0,9949	0,9953	0,9942	0,9942	0,9942	0,9939	0,9939	0,9956
FAR8	0,02395	0,02384	0,02418	0,02280	0,02185	0,02263	0,02168	0,02179
WAR8	0,	0,	0,	0,	0,	0,	0,	0,
W8	114,75	108,95	103,74	106,30	108,34	110,32	112,44	116,30
T8	1523,9	1538,1	1500,7	1443,1	1389,1	1436,4	1382,1	1460,4
P8	14,166	13,982	11,997	12,011	12,019	12,154	12,148	15,578
P8OPO	1,1585	1,1434	1,1871	1,1885	1,1892	1,2026	1,2021	1,1194
M8	0,4737	0,4519	0,5119	0,5129	0,5132	0,5304	0,5291	0,4132
V8	869,6	834,5	930,2	915,1	899,3	942,8	923,7	746,9
CF8	1,0165	1,0165	1,0165	1,0165	1,0165	1,0165	1,0165	1,0165
CV9	0,9970	0,9970	0,9970	0,9970	0,9970	0,9970	0,9970	0,9970
AE8	846,31	847,82	846,80	847,65	845,65	847,20	847,75	847,32
A8	832,6	834,1	833,1	833,9	831,9	833,5	834,0	834,1
FD	10384,	10113,	8987,	17180,	17184,	23162,	23171,	18437,
FGG	34537,	32734,	31343,	35125,	35137,	39648,	39660,	37114,
ENU/W2	20,54	19,97	21,51	16,12	15,83	13,94	13,66	14,31
D/F-PC	0,6	0,6	0,5	2,1	2,1	3,6	3,6	1,9
CD	0,1843	0,1843	0,1843	0,1843	0,1843	0,1843	0,1843	0,1843
FDI	134,3	130,8	116,2	368,4	368,5	586,7	587,0	360,2
SWFNG	1,00000	1,00000	1,00000	1,00000	1,00000	1,00000	1,00000	1,00000
SFNG	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
WC3/2C	0,0902	0,0902	0,0902	0,0902	0,0902	0,0902	0,0902	0,0902
WC4/2C	0,0614	0,0614	0,0614	0,0614	0,0614	0,0614	0,0614	0,0614
WC512C	0,0360	0,0360	0,0360	0,0360	0,0360	0,0360	0,0360	0,0360
WC5D2C	0,0125	0,0125	0,0125	0,0125	0,0125	0,0125	0,0125	0,0125
WC542C	0,	0,	0,	0,	0,	0,	0,	0,
WC55I1	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050
WC55I2	0,0367	0,0367	0,0367	0,0367	0,0367	0,0367	0,0367	0,0367
WC552C	0,0417	0,0417	0,0417	0,0417	0,0417	0,0417	0,0417	0,0417
WCI/2C	0,0320	0,0320	0,0320	0,0320	0,0320	0,0320	0,0320	0,0320
FIBAH	0,3880	0,3880	0,3880	0,3880	0,3880	0,3880	0,3880	0,3880
FCAH51	0,2850	0,2850	0,2850	0,2850	0,2850	0,2850	0,2850	0,2850
FCAH54	0,7500	0,7500	0,7500	0,7500	0,7500	0,7500	0,7500	0,7500
FCH551	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
FCH552	0,2770	0,2770	0,2770	0,2770	0,2770	0,2770	0,2770	0,2770

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
10/20/75
RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER
MISSION ANALYSIS CYCLE DATA PACKAGE

CASE	33.00	34.00	35.00	36.00	37.00	38.00	39.00	40.00
ALT	1500.	1500.	1500.	1500.	1500.	1500.	20000.	20000.
MO	0.400	0.400	0.400	0.400	0.400	0.400	0.600	0.600
PC	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
RC	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
FNG	18668.1	14937.2	11200.8	7473.1	5603.9	3736.4	12347.0	12351.4
SFCG	0.4674	0.4709	0.4804	0.5062	0.5375	0.6066	0.5215	0.5087
DELTO	5.10	5.10	5.10	5.10	5.10	5.10	22.60	4.50
TO	518.42	518.42	518.42	518.42	518.42	518.42	469.95	451.35
PO	13.9167	13.9167	13.9167	13.9167	13.9167	13.9167	6.7534	6.7534
T2	535.06	535.06	535.06	535.06	535.06	535.06	503.92	484.52
ETAR	1.0180	1.0180	1.0180	1.0180	1.0180	1.0180	1.0180	1.0180
P2	15.819	15.819	15.819	15.819	15.819	15.819	8.770	8.772
P22/P2	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996
M21	0.4493	0.4102	0.3691	0.3245	0.2997	0.2721	0.5417	0.5418
P22	15.813	15.813	15.813	15.813	15.813	15.813	8.767	8.769
B	10.2431	10.7328	11.4112	12.4187	13.1310	14.1187	9.6569	9.6430
PATH	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR
WB/W2C	0.0189	0.0210	0.0239	0.0284	0.0319	0.0369	0.0020	0.0020
WB	0.	0.	0.	0.	0.	0.	0.	0.
PBD	367.35	316.53	262.85	205.83	175.63	143.81	262.42	263.21
TBD	1424.4	1363.6	1292.8	1208.6	1155.8	1094.3	1457.5	1407.0
WBI	2.236	2.211	2.183	2.151	2.134	2.115	0.163	0.157
PBI	149.68	131.25	111.52	90.55	78.56	65.95	105.89	106.15
TBI	1140.3	1096.1	1044.5	983.7	945.2	901.1	1160.7	1119.1
HPE	100.0	100.0	100.0	100.0	100.0	100.0	0.	0.
PCNF	80.433	74.927	68.650	60.945	55.283	48.772	89.076	87.356
NF	3789.2	3529.8	3234.1	2871.1	2604.4	2297.6	4196.4	4115.4
PCNF*	79.192	73.771	67.590	60.005	54.430	48.019	90.370	90.383
W2*	1253.87	1167.16	1070.07	958.01	892.81	818.23	1434.90	1435.23
W2	1328.34	1236.50	1133.62	1014.90	945.83	866.83	868.39	886.06
P23/22	1.3744	1.3040	1.2329	1.1591	1.1211	1.0816	1.5270	1.5272
Z22	0.5802	0.5651	0.5552	0.5404	0.4862	0.3992	0.6006	0.6006
ETAF	0.8586	0.8572	0.8555	0.8510	0.8362	0.7924	0.8632	0.8632
HPFAN	24339.	18876.	13614.	8634.	6333.	4205.	20055.	19689.
RNT22	1.0342	1.0342	1.0342	1.0342	1.0342	1.0342	0.6189	0.6512
M23	0.4178	0.4036	0.3845	0.3582	0.3410	0.3194	0.4432	0.4432
P25P23	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
M25P	0.4242	0.4118	0.3946	0.3703	0.3539	0.3332	0.4471	0.4471
AE25P	3872.8	3872.8	3872.8	3872.8	3872.8	3872.8	3872.8	3872.8

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
10/20/75
RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER
MISSION ANALYSIS CYCLE DATA PACKAGE

CASE	33,00	34,00	35,00	36,00	37,00	38,00	39,00	40,00
P25P	21,733	20,620	19,489	18,328	17,727	17,103	13,387	13,392
P2525P	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
P25	21,733	20,620	19,489	18,328	17,727	17,103	13,386	13,391
Q25	2,4191	2,1785	1,9084	1,6007	1,4257	1,2316	1,6335	1,6344
T25	594,4	584,3	573,6	562,2	556,3	550,4	579,1	556,9
M25	0,4243	0,4119	0,3946	0,3703	0,3539	0,3332	0,4472	0,4472
W25	1210,19	1131,11	1042,28	939,27	878,90	809,49	786,90	802,31
P28/25	0,9937	0,9940	0,9944	0,9950	0,9954	0,9959	0,9931	0,9931
P28	21,595	20,497	19,381	18,237	17,646	17,033	13,294	13,299
T28	594,4	584,3	573,6	562,2	556,3	550,4	579,1	556,9
W28	1210,19	1131,11	1042,28	939,27	878,90	809,49	786,90	802,31
CV29	0,9970	0,9970	0,9970	0,9970	0,9970	0,9970	0,9970	0,9970
CF28	0,9708	0,9693	0,9684	0,9688	0,9693	0,9698	0,9814	0,9815
AE28	2649,4	2645,2	2642,9	2644,0	2645,2	2646,6	2678,3	2678,4
A28	2729,0	2729,0	2729,0	2729,0	2729,0	2729,0	2728,9	2729,0
V28	917,8	857,3	788,7	708,6	662,0	609,1	1077,1	1056,2
M28	0,8176	0,7645	0,7042	0,6335	0,5922	0,5450	1,0000	1,0000
Z1C	0,6731	0,6996	0,7232	0,7707	0,7722	0,7736	0,6991	0,6956
P24/1C	2,0273	1,8786	1,7133	1,5399	1,4328	1,3275	2,4168	2,4162
W1C*	111,53	99,48	86,22	71,39	63,18	54,12	134,65	134,33
W1C	118,15	105,39	91,34	75,63	66,93	57,33	81,49	83,24
ETA1C	0,8728	0,8685	0,8619	0,8514	0,8481	0,8403	0,8682	0,8687
HP1C	5502,	4352,	3202,	2118,	1551,	1044,	4606,	4521,
P24	32,057	29,706	27,092	24,349	22,656	20,992	21,187	21,187
T24	672,2	656,7	638,3	617,6	603,4	588,8	670,4	644,6
M24	0,3974	0,3741	0,3464	0,3094	0,2887	0,2613	0,4183	0,4190
Q24	3,1727	2,6384	2,0918	1,5258	1,2470	0,9566	2,2964	2,3049
P2C/24	0,9920	0,9928	0,9937	0,9949	0,9955	0,9963	0,9912	0,9912
AE2D	0,	0,	0,	0,	0,	0,	0,	0,
WB/W24	0,	0,	0,	0,	0,	0,	0,	0,
P2C	31,800	29,491	26,923	24,226	22,555	20,914	21,000	21,000
T2C	672,2	656,7	638,3	617,6	603,4	588,8	670,4	644,6
PCNG	97,736	95,172	91,803	87,254	84,603	81,417	98,990	97,125
PCNG*	85,855	84,583	82,751	79,960	78,439	76,415	87,069	87,119
NG	14244,	13870,	13379,	12716,	12330,	11866,	14427,	14155,
PCNG*M	96,660	95,228	93,166	90,023	88,311	86,033	98,027	98,084
WARC2C	0,	0,	0,	0,	0,	0,	0,	0,
W2C	118,15	105,39	91,34	75,63	66,93	57,33	81,49	83,25
W2C*	62,16	59,09	55,31	50,07	47,04	42,93	64,83	64,95

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
10/20/75
RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER
MISSION ANALYSIS CYCLE DATA PACKAGE

CASE	33,00	34,00	35,00	36,00	37,00	38,00	39,00	40,00
P3/P2C	11,8810	11,0455	10,0552	8,7598	8,0334	7,0994	12,8476	12,8866
Z2C	0,5225	0,5002	0,4852	0,4811	0,4814	0,4866	0,5665	0,5678
ETAC	0,8727	0,8753	0,8757	0,8695	0,8648	0,8550	0,8668	0,8667
HPC	30462,	25401,	20254,	15031,	12370,	9639,	22174,	21850,
RNI2C	1,5641	1,4927	1,4112	1,3229	1,2679	1,2122	1,0362	1,0875
P3/P2	23,8930	20,6002	17,1199	13,4202	11,4587	9,3898	30,7767	30,8615
P3	377,81	325,75	270,71	212,21	181,19	148,48	269,81	270,62
PS3	356,41	306,89	254,63	199,16	169,81	138,92	254,70	255,45
T3	1424,4	1363,6	1292,8	1208,6	1155,8	1094,3	1457,5	1407,0
WAR3	0,	0,	0,	0,	0,	0,	0,	0,
W3	112,13	99,81	86,23	71,06	62,66	53,39	78,72	80,42
W31	98,00	87,20	75,31	62,02	54,65	46,53	68,97	70,46
M3	0,2945	0,2974	0,3010	0,3060	0,3090	0,3126	0,2929	0,2929
P4/P3	0,9451	0,9440	0,9426	0,9407	0,9396	0,9382	0,9457	0,9456
WFM	8724,8	7034,7	5381,3	3782,7	3012,1	2266,4	6438,9	6283,3
ETABM	0,9875	0,9875	0,9875	0,9875	0,9875	0,9875	0,9875	0,9875
FAR339	0,02473	0,02241	0,01985	0,01694	0,01531	0,01353	0,02593	0,02477
T39	2881,3	2705,7	2511,0	2275,3	2134,9	1975,8	2970,4	2869,0
T4	2792,1	2625,5	2434,4	2207,2	2071,8	1918,4	2880,0	2781,2
WAR4	0,	0,	0,	0,	0,	0,	0,	0,
FAR4	0,02303	0,02086	0,01847	0,01576	0,01424	0,01258	0,02418	0,02309
P4	357,07	307,50	255,18	199,64	170,25	139,30	255,16	255,91
W4	107,68	95,63	82,41	67,71	59,60	50,68	75,76	77,32
TFFC	15,93	15,93	15,93	15,93	15,93	15,93	15,93	15,93
N/RT4	269,57	270,69	271,17	270,67	270,88	270,91	268,83	268,41
DH/T4	0,07194	0,07188	0,07180	0,07165	0,07148	0,07091	0,07193	0,07191
ETAT	0,8982	0,8982	0,8982	0,8982	0,8982	0,8983	0,8981	0,8981
HPT	30600,	25533,	20380,	15151,	12488,	9754,	22204,	21879,
HPAUX	37,96	31,86	25,94	20,21	17,47	14,74	30,13	29,17
P4/P51	3,8898	3,8974	3,9056	3,9136	3,9120	3,8778	3,8830	3,8833
P51	91,797	78,901	65,337	51,011	43,519	35,922	65,711	65,814
T51	2081,2	1948,6	1797,5	1620,9	1516,5	1401,2	2152,5	2073,0
FAR51	0,02184	0,01978	0,01751	0,01494	0,01349	0,01192	0,02295	0,02192
WAR51	0,	0,	0,	0,	0,	0,	0,	0,
W51	113,41	100,74	86,84	71,38	62,84	53,46	79,71	81,36
M51	0,4809	0,4796	0,4779	0,4755	0,4731	0,4656	0,4807	0,4800
P54/51	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
P54	91,797	78,901	65,337	51,011	43,519	35,922	65,711	65,814
T54	2081,2	1948,6	1797,5	1620,9	1516,5	1401,2	2152,5	2073,0
FAR54	0,02184	0,01978	0,01751	0,01494	0,01349	0,01192	0,02295	0,02192
WAR54	0,	0,	0,	0,	0,	0,	0,	0,
W54	113,41	100,74	86,84	71,38	62,84	53,46	79,71	81,36
TFF2TC	56,36	56,36	56,35	56,34	56,24	55,71	56,28	56,29
N/RT54	83,06	79,96	76,28	71,31	66,88	61,38	90,45	90,39
DH/T54	0,08936	0,08364	0,07614	0,06568	0,05846	0,04953	0,10158	0,10146

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
10/20/75
RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER
MISSION ANALYSIS CYCLE DATA PACKAGE

CASE	33,00	34,00	35,00	36,00	37,00	38,00	39,00	40,00
ETA2T	0,9051	0,9007	0,8958	0,8897	0,8835	0,8775	0,9165	0,9154
HP2T	29842,	23227,	16816,	10751,	7883,	5249,	24661,	24210,
RNI54	1,3487	1,2463	1,1278	0,9867	0,9057	0,8156	0,9303	0,9711
P54/56	5,8704	5,1842	4,4037	3,5175	3,0321	2,5259	7,7492	7,7657
P56	15,637	15,220	14,837	14,502	14,353	14,221	8,480	8,474
T56	1408,3	1350,4	1286,2	1214,0	1172,4	1126,4	1368,1	1312,2
W56	118,33	105,13	90,65	74,53	65,64	55,85	83,11	84,33
M56	0,3045	0,2685	0,2287	0,1845	0,1603	0,1342	0,4046	0,4041
P8/56	0,9959	0,9968	0,9976	0,9984	0,9988	0,9991	0,9931	0,9931
FAR8	0,02091	0,01894	0,01677	0,01430	0,01291	0,01140	0,02199	0,02101
WAR8	0,	0,	0,	0,	0,	0,	0,	0,
W8	118,33	105,13	90,65	74,53	65,64	55,85	83,11	84,33
T8	1408,3	1350,4	1286,2	1214,0	1172,4	1126,4	1368,1	1312,2
P8	15,573	15,170	14,801	14,479	14,335	14,209	8,421	8,415
P8OPO	1,1190	1,0901	1,0636	1,0404	1,0301	1,0210	1,2469	1,2461
M8	0,4121	0,3597	0,3031	0,2421	0,2091	0,1749	0,5805	0,5788
V8	732,3	628,9	519,7	405,3	344,8	283,3	1,004,0	981,7
CF8	1,0165	1,0165	1,0165	1,0165	1,0165	1,0165	1,0165	1,0155
CV9	0,9970	0,9970	0,9970	0,9970	0,9970	0,9970	0,9970	0,9970
AE8	848,32	846,83	846,84	847,36	849,23	846,72	845,94	846,75
A8	834,6	833,1	833,1	833,6	835,4	833,0	832,2	833,0
FD	18440,	17165,	15737,	14089,	13130,	12034,	17219,	17229,
FGG	37100,	32103,	26938,	21562,	18734,	15770,	29506,	29589,
FNU/W2	14,05	12,08	9,88	7,36	5,92	4,31	14,22	13,94
D/F-PC	1,9	2,2	2,7	3,7	4,6	6,3	3,6	3,6
CD	0,1843	0,1843	0,1843	0,1843	0,1843	0,1843	0,1843	0,1843
FDI	360,2	335,3	307,4	275,2	256,5	235,1	450,1	450,2
SWFMG	1,00000	1,00000	1,00000	1,00000	1,00000	1,00000	1,00000	1,00000
SFNG	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
WC3/2C	0,0902	0,0902	0,0902	0,0902	0,0902	0,0902	0,0902	0,0902
WC4/2C	0,0614	0,0614	0,0614	0,0614	0,0614	0,0614	0,0614	0,0614
WC512C	0,0360	0,0360	0,0360	0,0360	0,0360	0,0360	0,0360	0,0360
WC5D2C	0,0125	0,0125	0,0125	0,0125	0,0125	0,0125	0,0125	0,0125
WC542C	0,	0,	0,	0,	0,	0,	0,	0,
WC55I1	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050
WC55I2	0,0367	0,0367	0,0367	0,0367	0,0367	0,0367	0,0367	0,0367
WC552C	0,0417	0,0417	0,0417	0,0417	0,0417	0,0417	0,0417	0,0417
WC1/2C	0,0320	0,0320	0,0320	0,0320	0,0320	0,0320	0,0320	0,0320
FIBAH	0,3880	0,3880	0,3880	0,3880	0,3880	0,3880	0,3880	0,3880
FCAH51	0,2850	0,2850	0,2850	0,2850	0,2850	0,2850	0,2850	0,2850
FCAH54	0,7500	0,7500	0,7500	0,7500	0,7500	0,7500	0,7500	0,7500
FCH551	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
FCH552	0,2770	0,2770	0,2770	0,2770	0,2770	0,2770	0,2770	0,2770

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
10/20/75
RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER
MISSION ANALYSIS CYCLE DATA PACKAGE

CASE	41,00	42,00	43,00	44,00	45,00	46,00	47,00	48,00
ALT	20000,	20000,	20000,	20000,	20000,	20000,	20000,	20000,
MO	0,600	0,600	0,600	0,700	0,700	0,700	0,700	0,800
PC	50,00	50,00	50,00	50,00	50,00	50,00	50,00	50,00
RC	40,00	40,00	40,00	40,00	40,00	40,00	40,00	40,00
FNG	9874,1	7408,0	4940,1	12913,1	12913,5	11714,4	11716,1	11162,8
SFCG	0,5134	0,5276	0,5566	0,5649	0,5511	0,5665	0,5526	0,6133
DELTO	4,50	4,50	4,50	22,60	4,50	22,60	4,50	22,50
TO	451,85	451,85	451,85	469,95	451,85	469,95	451,85	469,95
PO	6,7534	6,7534	6,7534	6,7534	6,7534	6,7534	6,7534	6,7534
T2	484,52	484,52	484,52	516,18	496,31	516,18	496,31	530,32
ETAR	1,0180	1,0180	1,0180	1,0180	1,0180	1,0180	1,0180	1,0180
P2	8,772	8,772	8,772	9,537	9,540	9,537	9,540	10,480
P22/P2	0,9996	0,9996	0,9996	0,9996	0,9996	0,9996	0,9996	0,9996
M21	0,4945	0,4469	0,3967	0,5540	0,5540	0,5319	0,5320	0,5201
P22	8,769	8,769	8,769	9,533	9,536	9,533	9,536	10,476
B	10,2443	10,9907	12,1974	9,6380	9,6244	9,8871	9,8757	10,1710
PATH	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR
WB/W2C	0,0020	0,0020	0,0020	0,0020	0,0020	0,0020	0,0020	0,0020
WB	0,	0,	0,	0,	0,	0,	0,	0,
PBD	226,38	189,32	148,56	290,86	291,70	272,63	273,37	283,56
TBD	1344,6	1276,0	1190,8	1498,2	1446,5	1469,5	1418,6	1482,3
WBI	0,148	0,129	0,106	0,178	0,182	0,169	0,173	0,176
PBI	92,50	78,86	63,83	117,42	117,69	110,78	111,02	116,14
TBI	1072,6	1022,5	960,9	1194,2	1151,6	1173,2	1131,1	1186,5
HPE	0,	0,	0,	0,	0,	0,	0,	0,
PCNF	81,397	74,867	67,110	91,352	89,577	88,876	87,147	88,451
NF	3834,6	3527,0	3161,6	4303,6	4220,0	4187,0	4105,5	4166,9
PCNF*	84,217	77,461	69,435	91,573	91,572	89,091	89,088	87,474
W2*	1346,89	1249,11	1136,24	1456,25	1456,35	1417,41	1417,55	1395,54
W2	831,52	771,16	701,47	946,91	966,09	921,65	940,35	983,92
P23/22	1,4310	1,3323	1,2312	1,5480	1,5479	1,5043	1,5042	1,4732
Z22	0,5581	0,5143	0,4725	0,6059	0,6056	0,5874	0,5869	0,5732
ETAF	0,8615	0,8525	0,8431	0,8625	0,8625	0,8638	0,8638	0,8636
HPFAN	15611,	11664,	7755,	23173,	22742,	21009,	20618,	22055,
RNI22	0,6512	0,6512	0,6512	0,6527	0,6866	0,6527	0,6866	0,6929
M23	0,4381	0,4297	0,4145	0,4452	0,4452	0,4433	0,4434	0,4429
P25P23	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
M25P	0,4451	0,4399	0,4286	0,4490	0,4490	0,4485	0,4486	0,4496
AE25P	3872,8	3872,8	3872,8	3872,8	3872,8	3872,8	3872,8	3872,8

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
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RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER
MISSION ANALYSIS CYCLE DATA PACKAGE

CASE	41.00	42.00	43.00	44.00	45.00	46.00	47.00	48.00
P25P	12.548	11.683	10.796	14.757	14.761	14.341	14.344	15.436
P2525P	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
P25	12.548	11.682	10.796	14.756	14.761	14.340	14.344	15.435
Q25	1.5197	1.3863	1.2245	1.8138	1.8145	1.7594	1.7604	1.9074
T25	545.4	533.2	519.8	595.9	573.0	590.2	567.6	602.9
M25	0.4452	0.4399	0.4286	0.4491	0.4491	0.4486	0.4486	0.4497
W25	757.58	706.84	648.32	857.90	875.16	837.00	853.89	895.84
P28/25	0.9931	0.9933	0.9936	0.9930	0.9930	0.9930	0.9930	0.9930
P28	12.462	11.604	10.727	14.653	14.658	14.241	14.244	15.377
T28	545.4	533.2	519.8	595.9	573.0	590.2	567.6	602.9
W28	757.58	706.84	648.32	857.90	875.16	837.00	853.89	895.84
CV29	0.9970	0.9970	0.9970	0.9974	0.9974	0.9973	0.9973	0.9977
CF28	0.9787	0.9753	0.9717	0.9846	0.9846	0.9839	0.9839	0.9856
AE28	2670.2	2661.6	2651.8	2687.1	2687.1	2684.8	2685.1	2689.7
A28	2728.4	2729.0	2729.0	2729.0	2729.0	2728.8	2729.0	2729.0
V28	1025.6	958.0	879.3	1092.6	1071.4	1087.4	1066.3	1099.0
M28	0.9775	0.9141	0.8402	1.0000	1.0000	1.0000	1.0000	1.0000
Z1C	0.7139	0.7516	0.7932	0.7142	0.7112	0.7304	0.7279	0.7612
P24/1C	2.1991	1.9989	1.7681	2.4687	2.4674	2.3808	2.3798	2.3300
W1C*	119.77	104.17	86.10	136.89	137.08	130.18	130.34	124.94
W1C	73.94	64.31	53.15	89.01	90.93	84.65	86.46	88.08
ETA1C	0.8677	0.8614	0.8489	0.8675	0.8680	0.8668	0.8674	0.8646
HP1C	3541.	2689.	1822.	5298.	5200.	4814.	4724.	5014.
P24	19.284	17.528	15.505	23.534	23.530	22.696	22.695	24.410
T24	625.8	607.9	585.7	691.4	664.8	683.6	657.3	697.8
M24	0.3990	0.3716	0.3358	0.4177	0.4185	0.4075	0.4082	0.3963
Q24	1.9243	1.5400	1.1317	2.5435	2.5535	2.3488	2.3571	2.4033
P2C/24	0.9919	0.9929	0.9941	0.9912	0.9912	0.9916	0.9916	0.9920
AE2D	0.	0.	0.	0.	0.	0.	0.	0.
WB/W24	0.	0.	0.	0.	0.	0.	0.	0.
P2C	19.128	17.403	15.413	23.328	23.323	22.506	22.503	24.215
T2C	625.8	607.9	585.7	691.4	664.8	683.6	657.3	697.8
PCNG	94.540	91.583	87.361	100.483	98.591	99.305	97.427	99.639
PCNG*	86.070	84.597	82.210	87.032	87.084	86.500	86.543	85.902
NG	13778.	13347.	12732.	14644.	14369.	14473.	14199.	14521.
PCNG*M	96.902	95.244	92.556	97.985	98.044	97.386	97.435	96.713
WARC2C	0.	0.	0.	0.	0.	0.	0.	0.
W2C	73.95	64.31	53.15	89.01	90.93	84.66	86.46	88.08
W2C*	62.41	58.79	53.86	64.74	64.87	63.46	63.57	62.00

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
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RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER
MISSION ANALYSIS CYCLE DATA PACKAGE

CASE	41.00	42.00	43.00	44.00	45.00	46.00	47.00	48.00
P3/P2C	12.1754	11.1995	9.9333	12.8186	12.8589	12.4575	12.4930	12.0499
Z2C	0.5521	0.5274	0.5125	0.5654	0.5668	0.5573	0.5590	0.5472
ETAC	0.8698	0.8724	0.8718	0.8670	0.8669	0.8687	0.8686	0.8703
HPC	18215.	14652.	10904.	24917.	24553.	23035.	22688.	23958.
RNI2C	1.0276	0.9693	0.8993	1.1084	1.1628	1.0842	1.1376	1.1376
P3/P2	26.5582	22.2271	17.4594	31.3680	31.4487	29.4099	29.4803	27.8518
P3	232.89	194.91	153.10	299.03	299.91	280.36	281.13	291.78
PS3	219.58	183.48	143.80	282.31	283.11	264.54	265.24	275.17
T3	1344.6	1276.0	1190.8	1498.2	1446.5	1469.5	1418.6	1482.3
WAR3	0.	0.	0.	0.	0.	0.	0.	0.
W3	71.44	62.13	51.35	85.99	87.84	81.78	83.52	85.08
W31	62.59	54.43	44.99	75.34	76.96	71.65	73.18	74.55
M3	0.2954	0.2989	0.3038	0.2929	0.2929	0.2943	0.2942	0.2957
P4/P3	0.9447	0.9433	0.9414	0.9458	0.9457	0.9453	0.9452	0.9449
WFM	5069.6	3908.7	2749.7	7295.1	7116.1	6635.7	6474.5	6846.5
ETABM	0.9875	0.9875	0.9875	0.9875	0.9875	0.9875	0.9875	0.9875
FAR339	0.02250	0.01995	0.01698	0.02690	0.02568	0.02572	0.02458	0.02551
T39	2697.7	2502.2	2262.0	3052.6	2948.6	2969.6	2868.4	2969.1
T4	2615.9	2426.9	2195.6	2960.1	2858.8	2879.8	2781.3	2880.1
WAR4	0.	0.	0.	0.	0.	0.	0.	0.
FAR4	0.02098	0.01860	0.01583	0.02508	0.02395	0.02398	0.02291	0.02379
P4	220.00	183.86	144.14	282.82	283.62	265.02	265.73	275.69
W4	68.54	59.47	49.02	82.83	84.52	78.69	80.29	81.86
TFFC	15.93	15.93	15.93	15.93	15.93	15.93	15.93	15.93
N/RT4	269.39	270.94	271.72	269.16	268.73	269.69	269.24	270.59
DH/T4	0.07190	0.07186	0.07172	0.07192	0.07191	0.07194	0.07191	0.07192
ETAT	0.8982	0.8982	0.8982	0.8982	0.8981	0.8982	0.8982	0.8982
HPT	18240.	14673.	10921.	24950.	24585.	23066.	22718.	23990.
HPAUX	24.95	21.01	16.91	33.39	32.31	31.04	30.04	32.02
P4/P51	3.8999	3.9108	3.9204	3.8775	3.8832	3.8839	3.8880	3.8828
P51	56.411	47.013	36.766	72.938	73.037	68.238	68.347	71.005
T51	1940.8	1791.4	1611.5	2217.5	2135.5	2152.6	2073.4	2153.3
FAR51	0.01991	0.01765	0.01503	0.02381	0.02273	0.02277	0.02175	0.02258
WAR51	0.	0.	0.	0.	0.	0.	0.	0.
W51	72.13	62.59	51.59	87.15	88.93	82.80	84.48	86.13
M51	0.4792	0.4778	0.4754	0.4810	0.4804	0.4808	0.4800	0.4807
P54/51	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
P54	56.411	47.013	36.766	72.938	73.037	68.238	68.347	71.005
T54	1940.8	1791.4	1611.5	2217.5	2135.5	2152.6	2073.4	2153.3
FAR54	0.01991	0.01765	0.01503	0.02381	0.02273	0.02277	0.02175	0.02258
WAR54	0.	0.	0.	0.	0.	0.	0.	0.
W54	72.13	62.59	51.59	87.15	88.93	82.80	84.48	86.13
TFF2TC	56.33	56.35	56.33	56.26	56.27	56.30	56.29	56.29
N/RT54	87.04	83.33	78.76	91.39	91.32	90.24	90.16	89.30
DH/T54	0.09670	0.09048	0.08141	0.10413	0.10399	0.10240	0.10226	0.10316

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
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CASE	41.00	42.00	43.00	44.00	45.00	46.00	47.00	48.00
ETA2T	0.9115	0.9053	0.8986	0.9175	0.9174	0.9161	0.9160	0.9153
HP2T	19153.	14353.	9577.	28471.	27942.	25822.	25342.	27070.
RNI54	0.8950	0.8146	0.7157	0.9994	1.0431	0.9660	1.0083	1.0049
P54/56	7.0164	6.1332	5.0146	8.2298	8.2463	7.9284	7.9443	8.1108
P56	8.040	7.665	7.332	8.863	8.857	8.607	8.603	8.754
T56	1252.4	1187.2	1112.2	1394.6	1337.5	1362.1	1306.7	1357.0
W56	75.21	65.27	53.81	90.86	92.73	86.33	88.09	89.80
M56	0.3615	0.3138	0.2563	0.4335	0.4328	0.4152	0.4144	0.4259
P8/56	0.9943	0.9956	0.9970	0.9922	0.9922	0.9927	0.9928	0.9924
FAR8	0.01908	0.01692	0.01440	0.02281	0.02178	0.02182	0.02084	0.02154
WAR8	0.	0.	0.	0.	0.	0.	0.	0.
W8	75.21	65.27	53.81	90.86	92.73	86.33	88.09	89.80
T8	1252.4	1187.2	1112.2	1394.6	1337.5	1362.1	1306.7	1357.0
P8	7.994	7.632	7.310	8.793	8.788	8.544	8.541	8.688
P8QP0	1.1837	1.1300	1.0824	1.3021	1.3012	1.2652	1.2647	1.2864
M8	0.5044	0.4275	0.3423	0.6369	0.6352	0.5997	0.5984	0.6211
V8	842.4	700.3	547.0	1105.7	1081.4	1033.3	1011.1	1066.1
CF8	1.0165	1.0165	1.0165	1.0165	1.0165	1.0165	1.0165	1.0165
CV9	0.9970	0.9970	0.9970	0.9970	0.9970	0.9970	0.9970	0.9970
AE8	845.74	846.75	846.64	846.82	847.09	846.83	846.76	846.85
A8	832.0	833.0	832.9	833.1	833.3	833.1	833.0	833.1
FD	16168.	14994.	13640.	21906.	21915.	21322.	21332.	26014.
FGG	26042.	22402.	18580.	34819.	34829.	33036.	33048.	37175.
FNU/W2	11.87	9.61	7.04	13.64	13.37	12.71	12.46	11.35
D/F-PC	4.3	5.3	7.2	4.8	4.8	5.2	5.2	7.0
CD	0.1843	0.1843	0.1843	0.1843	0.1843	0.1843	0.1843	0.1843
FDI	422.5	391.8	356.4	621.8	621.8	605.2	605.2	778.3
SWFMG	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
SFNG	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
WC3/2C	0.0902	0.0902	0.0902	0.0902	0.0902	0.0902	0.0902	0.0902
WC4/2C	0.0614	0.0614	0.0614	0.0614	0.0614	0.0614	0.0614	0.0614
WC512C	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360
WC5D2C	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125
WC542C	0.	0.	0.	0.	0.	0.	0.	0.
WC5511	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050
WC5512	0.0367	0.0367	0.0367	0.0367	0.0367	0.0367	0.0367	0.0367
WC552C	0.0417	0.0417	0.0417	0.0417	0.0417	0.0417	0.0417	0.0417
WCI/2C	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320
FIBAH	0.3880	0.3880	0.3880	0.3880	0.3880	0.3880	0.3880	0.3880
FCAH51	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850
FCAH54	0.7500	0.7500	0.7500	0.7500	0.7500	0.7500	0.7500	0.7500
FCH551	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
FCH552	0.2770	0.2770	0.2770	0.2770	0.2770	0.2770	0.2770	0.2770

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
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RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER
MISSION ANALYSIS CYCLE DATA PACKAGE

CASE	49.00	50.00	51.00	52.00	53.00	54.00	55.00	56.00
ALT	20000.	20000.	20000.	20000.	20000.	20000.	25000.	25000.
MO	0.800	0.800	0.800	0.800	0.850	0.850	0.750	0.750
PC	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
RC	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
FNG	11163.0	8930.5	6698.4	4466.2	10908.7	10908.4	11462.0	11461.1
SFCG	0.5983	0.6136	0.6424	0.6998	0.6378	0.6222	0.5719	0.5573
DELTO	4.50	4.50	4.50	4.50	22.60	4.50	22.50	4.30
TO	451.85	451.85	451.85	451.85	469.95	451.85	452.02	433.82
PO	6.7534	6.7534	6.7534	6.7534	6.7534	6.7534	5.4535	5.4535
T2	509.92	509.92	509.92	509.92	538.10	517.40	503.08	482.83
ETAR	1.0180	1.0180	1.0180	1.0180	1.0180	1.0180	1.0180	1.0180
P2	10.483	10.483	10.483	10.483	11.027	11.029	8.065	8.068
P22/P2	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996
M21	0.5202	0.4819	0.4440	0.4055	0.5135	0.5136	0.5758	0.5759
P22	10.479	10.479	10.479	10.479	11.023	11.025	8.062	8.064
B	10.1570	10.7712	11.5901	12.9443	10.3268	10.3131	9.4613	9.4478
PATH	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR
WB/W2C	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
WB	0.	0.	0.	0.	0.	0.	0.	0.
PBD	284.46	247.91	210.27	168.73	289.63	290.41	259.73	260.51
TBD	1431.0	1374.9	1312.6	1235.7	1489.2	1437.7	1488.3	1434.5
WBI	0.180	0.161	0.142	0.119	0.180	0.184	0.159	0.163
PBI	116.40	102.80	88.94	73.60	119.06	119.32	104.27	104.51
TBI	1144.1	1102.5	1057.3	1001.2	1193.7	1151.0	1183.9	1139.7
HPE	0.	0.	0.	0.	0.	0.	0.	0.
PCNF	86.739	81.467	75.802	69.086	88.188	86.486	92.308	90.443
NF	4086.3	3837.9	3571.0	3254.6	4154.6	4074.3	4348.6	4260.8
PCNF*	87.480	82.163	76.450	69.676	86.582	86.592	93.728	93.740
W2*	1395.85	1321.76	1242.78	1156.69	1383.23	1383.42	1492.79	1493.10
W2	1003.80	950.52	893.72	831.81	1018.60	1039.15	831.54	849.20
P23/22	1.4782	1.3960	1.3101	1.2194	1.4643	1.4644	1.5892	1.5893
Z22	0.5730	0.5322	0.4849	0.4301	0.5666	0.5664	0.6219	0.6217
ETAF	0.8636	0.8574	0.8467	0.8275	0.8632	0.8632	0.8604	0.8604
HPFAN	21642.	17566.	13499.	9425.	22620.	22192.	21129.	20721.
RNT22	0.7287	0.7287	0.7287	0.7287	0.7157	0.7525	0.5704	0.5016
M23	0.4429	0.4393	0.4348	0.4286	0.4424	0.4424	0.4469	0.4469
P25P23	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
M25P	0.4496	0.4488	0.4477	0.4459	0.4498	0.4498	0.4497	0.4497
AE25P	3872.8	3872.8	3872.8	3872.8	3872.8	3872.8	3872.8	3872.8

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
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RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER
MISSION ANALYSIS CYCLE DATA PACKAGE

CASE	49,00	50,00	51,00	52,00	53,00	54,00	55,00	56,00
P25P	15,490	14,629	13,728	12,778	16,141	16,145	12,812	12,817
P25/25P	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
P25	15,489	14,628	13,728	12,778	16,141	16,144	12,812	12,816
Q25	1,9001	1,7973	1,6791	1,5526	1,9896	1,9902	1,5791	1,5799
T25	579,8	569,5	558,3	545,9	609,9	586,5	586,0	562,5
M25	0,4496	0,4489	0,4477	0,4460	0,4499	0,4498	0,4498	0,4498
W25	913,82	869,77	822,74	772,16	928,68	947,29	752,05	767,92
P28/25	0,9930	0,9930	0,9931	0,9931	0,9930	0,9930	0,9930	0,9930
P28	15,381	14,526	13,633	12,690	16,028	16,031	12,723	12,727
T28	579,8	569,5	558,3	545,9	609,9	586,5	586,0	562,5
W28	913,82	869,77	822,74	772,16	928,68	947,29	752,05	767,92
CV29	0,9977	0,9974	0,9970	0,9970	0,9979	0,9979	0,9978	0,9978
CF28	0,9856	0,9844	0,9824	0,9795	0,9859	0,9859	0,9859	0,9859
AE28	2689,7	2686,5	2681,0	2673,0	2690,7	2690,6	2690,4	2690,5
A28	2729,0	2729,0	2729,0	2729,0	2729,1	2729,0	2729,0	2729,1
V28	1077,7	1068,1	1057,6	1039,9	1105,4	1084,0	1083,5	1061,5
M28	1,0000	1,0000	1,0000	0,9932	1,0000	1,0000	1,0000	1,0000
Z1C	0,7587	0,7814	0,8242	0,8695	0,7770	0,7747	0,6985	0,6953
P24/1C	2,3295	2,1503	1,9790	1,7755	2,3011	2,3009	2,5434	2,5423
W1C*	125,11	112,29	98,71	82,95	122,11	122,29	142,70	142,91
W1C	89,97	80,75	70,99	59,65	89,92	91,85	79,49	81,28
ETA1C	0,8652	0,8611	0,8513	0,8356	0,8630	0,8636	0,8667	0,8672
HP1C	4921,	3971,	3109,	2203,	5117,	5023,	4790,	4697,
P24	24,410	22,532	20,737	18,605	25,365	25,367	20,506	20,502
T24	671,0	654,8	639,0	618,8	705,5	678,4	680,5	653,2
M24	0,3970	0,3780	0,3528	0,3211	0,3905	0,3911	0,4265	0,4274
Q24	2,4118	2,0391	1,6560	1,2491	2,4316	2,4401	2,2994	2,3090
P2C/24	0,9920	0,9927	0,9935	0,9946	0,9922	0,9922	0,9909	0,9909
AE2D	0,	0,	0,	0,	0,	0,	0,	0,
WB/W24	0,	0,	0,	0,	0,	0,	0,	0,
P2C	24,215	22,367	20,603	18,503	25,167	25,169	20,319	20,315
T2C	671,0	654,8	639,0	618,8	705,5	678,4	680,5	653,2
PCNG	97,757	95,427	92,558	88,557	99,823	97,935	100,219	98,246
PCNG*	85,945	84,931	83,387	81,075	85,592	85,633	87,493	87,549
NG	14247,	13908,	13489,	12906,	14548,	14273,	14606,	14313,
PCNG*M	96,762	95,620	93,882	91,279	96,365	96,410	98,504	98,557
WARC2C	0,	0,	0,	0,	0,	0,	0,	0,
W2C	89,97	80,75	70,99	59,65	89,93	91,85	79,49	81,28
W2C*	62,11	59,61	56,20	51,75	61,24	61,34	65,85	65,98

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
10/20/75
RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER
MISSION ANALYSIS CYCLE DATA PACKAGE

CASE	49.00	50.00	51.00	52.00	53.00	54.00	55.00	56.00
P3/P2C	12.0840	11.4081	10.5122	9.4016	11.8390	11.8712	13.1391	13.1819
Z2C	0.5488	0.5316	0.5150	0.5113	0.5415	0.5431	0.5717	0.5732
ETAC	0.8703	0.8722	0.8730	0.8698	0.8710	0.8710	0.8654	0.8653
HPC	23602.	19989.	16363.	12526.	24459.	24063.	22250.	21908.
RNI2C	1.1935	1.1361	1.0785	1.0080	1.1667	1.2239	0.9843	1.0351
P3/P2	27.9241	24.3501	20.6683	16.6011	27.0307	27.1007	33.1143	33.2064
P3	292.61	255.16	216.58	173.96	297.96	298.78	266.98	267.79
PS3	275.92	240.33	203.67	163.25	280.91	281.66	252.15	252.39
T3	1431.0	1374.9	1312.6	1235.7	1489.2	1437.7	1488.3	1434.5
WAR3	0.	0.	0.	0.	0.	0.	0.	0.
W3	86.91	78.00	68.57	57.62	86.87	88.73	76.78	78.52
W31	76.15	68.35	60.08	50.49	76.12	77.75	67.28	68.80
M3	0.2956	0.2982	0.3017	0.3063	0.2964	0.2964	0.2919	0.2918
P4/P3	0.9448	0.9438	0.9425	0.9407	0.9446	0.9445	0.9461	0.9460
WFM	6679.1	5480.0	4302.7	3125.5	6957.6	6786.9	6555.3	6387.8
ETABM	0.9875	0.9875	0.9875	0.9875	0.9875	0.9875	0.9875	0.9875
FAR339	0.02436	0.02227	0.01989	0.01720	0.02539	0.02425	0.02707	0.02579
T39	2867.6	2710.8	2530.1	2313.0	2968.7	2867.2	3053.0	2944.4
T4	2781.2	2629.9	2455.5	2246.3	2880.0	2781.1	2960.0	2854.1
WAR4	0.	0.	0.	0.	0.	0.	0.	0.
FAR4	0.02272	0.02077	0.01855	0.01603	0.02367	0.02261	0.02524	0.02405
P4	276.45	240.82	204.12	163.65	281.46	282.21	252.59	253.34
W4	83.53	74.83	65.64	55.02	83.57	85.27	73.98	75.56
TFFC	15.93	15.93	15.93	15.93	15.93	15.93	15.93	15.93
N/RT4	270.15	271.19	272.22	272.31	271.09	270.65	268.46	268.01
DH/T4	0.07190	0.07189	0.07186	0.07174	0.07192	0.07190	0.07192	0.07190
ETAT	0.8982	0.8982	0.8982	0.8982	0.8982	0.8982	0.8981	0.8981
HPT	23633.	20015.	16386.	12544.	24492.	24125.	22281.	21933.
HPAUX	31.00	26.78	22.69	18.45	32.56	31.51	30.68	29.55
P4/P51	3.8879	3.8981	3.9092	3.9176	3.8830	3.8881	3.8769	3.8824
P51	71.105	61.779	52.214	41.773	72.484	72.583	65.153	65.252
T51	2073.7	1952.9	1814.6	1651.7	2153.4	2073.8	2217.2	2131.7
FAR51	0.02156	0.01971	0.01761	0.01522	0.02247	0.02146	0.02396	0.02233
WAR51	0.	0.	0.	0.	0.	0.	0.	0.
W51	87.89	78.74	69.08	57.91	87.93	89.73	77.83	79.50
M51	0.4800	0.4792	0.4781	0.4760	0.4807	0.4800	0.4809	0.4802
P54/51	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
P54	71.105	61.779	52.214	41.773	72.484	72.583	65.153	65.252
T54	2073.7	1952.9	1814.6	1651.7	2153.4	2073.8	2217.2	2131.7
FAR54	0.02156	0.01971	0.01761	0.01522	0.02247	0.02146	0.02396	0.02233
WAR54	0.	0.	0.	0.	0.	0.	0.	0.
W54	87.89	78.74	69.08	57.91	87.93	89.73	77.83	79.50
TFF2TC	56.29	56.33	56.36	56.35	56.29	56.29	56.25	56.25
N/RT54	89.73	86.85	83.83	80.08	89.53	89.47	92.35	92.28
DH/T54	0.10301	0.09899	0.09365	0.08591	0.10354	0.10337	0.10615	0.10601

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
10/20/75
RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER
MISSION ANALYSIS CYCLE DATA PACKAGE

CASE	49,00	50,00	51,00	52,00	53,00	54,00	55,00	56,00
ETA2T	0,9153	0,9108	0,9057	0,9001	0,9149	0,9148	0,9184	0,9184
HP2T	26563,	21536,	16609,	11627,	27738,	27214,	25919,	25413,
RNI54	1,0489	0,9735	0,8920	0,7914	1,0257	1,0706	0,8928	0,9338
P54/56	8,1251	7,4627	6,6420	5,5804	8,2048	8,2174	8,6601	8,6816
P56	8,751	8,278	7,861	7,486	8,834	8,833	7,523	7,516
T56	1301,6	1245,4	1183,6	1115,2	1354,3	1299,1	1378,3	1319,1
W56	91,65	82,11	72,04	60,40	91,68	93,56	81,15	82,39
M56	0,4251	0,3862	0,3406	0,2847	0,4316	0,4307	0,4593	0,4586
P8/56	0,9924	0,9936	0,9949	0,9963	0,9922	0,9922	0,9914	0,9914
FAR8	0,02066	0,01889	0,01687	0,01458	0,02153	0,02057	0,02295	0,02137
WAR8	0,	0,	0,	0,	0,	0,	0,	0,
W8	91,65	82,11	72,04	60,40	91,68	93,56	81,15	82,39
T8	1301,6	1245,4	1183,6	1115,2	1354,3	1299,1	1378,3	1319,1
P8	8,685	8,225	7,821	7,458	8,766	8,764	7,458	7,451
P8QP0	1,2860	1,2180	1,1581	1,1044	1,2980	1,2977	1,3676	1,3663
M8	0,6198	0,5462	0,4690	0,3838	0,6323	0,6312	0,6953	0,6933
V8	1043,3	906,6	764,9	612,5	1083,2	1060,3	1193,3	1165,5
CF8	1,0165	1,0165	1,0165	1,0165	1,0165	1,0165	1,0165	1,0165
CV9	0,9970	0,9970	0,9970	0,9970	0,9970	0,9970	0,9970	0,9970
AE8	846,67	846,73	847,49	846,46	847,33	846,76	846,77	847,17
A8	832,9	833,0	833,7	832,7	833,6	833,0	833,0	833,4
FD	26024,	24643,	23170,	21565,	28614,	28624,	20214,	20224,
FQ8	37187,	36573,	29869,	26031,	39523,	39532,	31676,	31685,
ENU/W2	11,12	9,40	7,49	5,37	10,71	10,50	13,78	13,50
D/F-PC	7,0	8,3	10,3	14,4	8,0	8,0	5,2	5,2
CD	0,1843	0,1843	0,1843	0,1843	0,1843	0,1843	0,1843	0,1843
FDI	778,4	737,1	693,1	645,0	870,8	871,0	590,8	591,0
SWFMG	1,00000	1,00000	1,00000	1,00000	1,00000	1,00000	1,00000	1,00000
SFNG	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
WC3/2C	0,0902	0,0902	0,0902	0,0902	0,0902	0,0902	0,0902	0,0902
WC4/2C	0,0614	0,0614	0,0614	0,0614	0,0614	0,0614	0,0614	0,0614
WC5I2C	0,0360	0,0360	0,0360	0,0360	0,0360	0,0360	0,0360	0,0360
WC5D2C	0,0125	0,0125	0,0125	0,0125	0,0125	0,0125	0,0125	0,0125
WC542C	0,	0,	0,	0,	0,	0,	0,	0,
WC55I1	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050
WC55I2	0,0367	0,0367	0,0367	0,0367	0,0367	0,0367	0,0367	0,0367
WC552C	0,0417	0,0417	0,0417	0,0417	0,0417	0,0417	0,0417	0,0417
WCI/2C	0,0320	0,0320	0,0320	0,0320	0,0320	0,0320	0,0320	0,0320
FIBAH	0,3880	0,3880	0,3880	0,3880	0,3880	0,3880	0,3880	0,3880
FCAH51	0,2850	0,2850	0,2850	0,2850	0,2850	0,2850	0,2850	0,2850
FCAH54	0,7500	0,7500	0,7500	0,7500	0,7500	0,7500	0,7500	0,7500
FCH551	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
FCH552	0,2770	0,2770	0,2770	0,2770	0,2770	0,2770	0,2770	0,2770

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
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RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER
MISSION ANALYSIS CYCLE DATA PACKAGE

CASE	57,00	58,00	59,00	60,00	61,00	62,00	63,00	64,00
ALT	30000,	30000,	30000,	30000,	30000,	30000,	30000,	30000,
MO	0,600	0,600	0,600	0,600	0,600	0,700	0,700	0,750
PC	50,00	50,00	50,00	50,00	50,00	50,00	50,00	50,00
RC	40,00	40,00	40,00	40,00	40,00	40,00	40,00	40,00
FNG	10005,7	10003,1	8004,5	6003,7	4002,6	9585,7	9585,0	10332,3
SFCQ	0,4980	0,4848	0,4836	0,4908	0,5130	0,5379	0,5236	0,5568
DELTO	22,30	4,10	4,10	4,10	4,10	22,30	4,10	22,30
TO	433,98	415,78	415,78	415,78	415,78	433,98	415,78	433,98
PO	4,3641	4,3641	4,3641	4,3641	4,3641	4,3641	4,3641	4,3641
T2	465,36	445,85	445,85	445,85	445,85	476,70	456,71	483,02
ETAR	1,0180	1,0180	1,0180	1,0180	1,0180	1,0180	1,0180	1,0180
P2	5,669	5,668	5,668	5,668	5,668	6,166	6,165	6,456
P22/P2	0,9996	0,9996	0,9996	0,9996	0,9996	0,9996	0,9996	0,9996
M2	0,6045	0,6050	0,5430	0,4838	0,4229	0,5902	0,5907	0,6100
P22	5,667	5,666	5,666	5,666	5,666	6,164	6,163	6,453
B	9,1402	9,1274	9,6227	10,3958	11,5012	9,3026	9,2878	9,1921
PATH	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR
WB/W2G	0,0020	0,0020	0,0020	0,0020	0,0020	0,0020	0,0020	0,0020
WB	0,	0,	0,	0,	0,	0,	0,	0,
PBD	198,83	199,37	171,28	141,33	110,12	207,29	207,92	225,53
TBD	1425,0	1371,0	1306,7	1232,6	1145,5	1436,7	1382,3	1471,5
WBI	0,123	0,126	0,113	0,097	0,080	0,129	0,132	0,138
PBI	78,70	78,87	68,97	57,91	46,43	82,65	82,84	89,67
TBI	1127,0	1082,9	1036,7	981,8	918,8	1139,1	1094,6	1166,6
HPE	0,	0,	0,	0,	0,	0,	0,	0,
PCNF	91,451	89,550	83,913	76,688	68,392	91,179	89,284	93,641
NF	4308,2	4218,7	3953,2	3612,8	3222,0	4295,4	4206,1	4411,4
PCNF*	96,546	96,587	90,507	82,713	73,766	98,109	95,148	97,036
W2*	1537,87	1538,55	1437,40	1325,74	1196,32	1515,86	1516,58	1545,94
W2	626,06	639,82	597,75	551,31	497,50	663,15	677,76	703,47
P23/22	1,6437	1,6443	1,5293	1,4083	1,2833	1,6163	1,6168	1,6511
Z22	0,6452	0,6452	0,6012	0,5473	0,4934	0,6329	0,6328	0,6457
ETAF	0,8604	0,8605	0,8632	0,8595	0,8489	0,8594	0,8595	0,8608
HPFAN	15820,	15492,	12254,	9098,	6025,	16591,	16252,	18630,
RNI22	0,4434	0,4686	0,4688	0,4688	0,4688	0,4674	0,4941	0,4812
M23	0,4477	0,4477	0,4433	0,4366	0,4232	0,4476	0,4476	0,4436
P25P23	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
M25P	0,4486	0,4485	0,4470	0,4443	0,4352	0,4495	0,4494	0,4498
AE25P	3872,8	3872,8	3872,8	3872,8	3872,8	3872,8	3872,8	3872,8

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
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CASE	57.00	58.00	59.00	60.00	61.00	62.00	63.00	64.00
P25P	9.315	9.317	8.665	7.980	7.272	9.962	9.964	10.655
P2525R	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
P25	9.315	9.316	8.665	7.979	7.271	9.962	9.964	10.655
Q25	1.1435	1.1437	1.0578	0.9640	0.8473	1.2270	1.2274	1.3139
T25	548.1	525.2	512.7	499.3	484.7	558.5	535.2	569.7
M25	0.4487	0.4486	0.4471	0.4444	0.4352	0.4496	0.4495	0.4499
W25	564.32	576.64	541.48	502.94	457.70	598.78	611.88	634.45
P28/25	0.9930	0.9930	0.9931	0.9931	0.9934	0.9930	0.9930	0.9930
P28	9.250	9.252	8.605	7.925	7.223	9.892	9.894	10.530
T28	548.1	525.2	512.7	499.3	484.7	558.5	535.2	569.7
W28	564.32	576.64	541.48	502.94	457.70	598.78	611.88	634.45
CV29	0.9973	0.9973	0.9970	0.9970	0.9970	0.9977	0.9977	0.9981
CF28	0.9840	0.9840	0.9815	0.9780	0.9735	0.9855	0.9855	0.9860
AE28	2685.4	2685.3	2678.5	2668.9	2656.8	2689.5	2689.5	2690.9
A28	2729.0	2728.9	2729.0	2729.0	2729.0	2729.0	2728.9	2729.0
V28	1047.9	1025.7	1013.4	969.4	883.6	1057.7	1035.4	1068.3
M28	1.0000	1.0000	1.0000	0.9635	0.8795	1.0000	1.0000	1.0000
Z1C	0.6366	0.6339	0.6858	0.7127	0.7684	0.6673	0.6644	0.6690
P24/1C	2.6091	2.6086	2.4160	2.1498	1.8920	2.5776	2.5773	2.6478
W1C*	151.67	151.92	135.31	116.34	95.70	147.14	147.41	151.69
W1C	61.74	63.18	56.27	48.38	39.80	64.37	65.88	69.03
ETA1C	0.8654	0.8658	0.8670	0.8648	0.8537	0.8660	0.8664	0.8650
HP1C	3555.	3482.	2817.	2071.	1411.	3739.	3663.	4200.
P24	14.785	14.781	13.690	12.181	10.720	15.887	15.883	17.087
T24	635.2	608.5	593.6	572.2	550.5	648.0	620.8	662.3
M24	0.4486	0.4495	0.4208	0.3942	0.3552	0.4371	0.4381	0.4417
Q24	1.8127	1.8195	1.5022	1.1903	0.8681	1.8614	1.8690	2.0332
P2C/24	0.9900	0.9900	0.9911	0.9921	0.9934	0.9905	0.9904	0.9903
AE2D	0.	0.	0.	0.	0.	0.	0.	0.
WB/W24	0.	0.	0.	0.	0.	0.	0.	0.
P2C	14.638	14.633	13.568	12.084	10.650	15.736	15.732	16.922
T2C	635.2	608.5	593.6	572.2	550.5	648.0	620.8	662.3
PCNG	98.207	96.189	93.335	90.178	86.169	98.453	96.431	99.815
PCNG*	88.744	88.804	87.243	85.854	83.639	88.083	88.143	88.329
NG	14313.	14019.	13603.	13143.	12558.	14348.	14054.	14547.
PCNG*M	99.913	99.981	98.223	96.660	94.165	99.169	99.237	99.445
WARC2C	0.	0.	0.	0.	0.	0.	0.	0.
W2C	61.74	63.18	56.27	48.38	39.80	64.37	65.88	69.02
W2C*	68.59	68.72	65.21	61.80	56.58	67.19	67.33	67.74

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
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CASE	57.00	58.00	59.00	60.00	61.00	62.00	63.00	64.00
P3/P2C	13.9558	13.9998	12.9804	12.0334	10.6498	13.5381	13.5832	13.6932
Z2C	0.5863	0.5881	0.5708	0.5491	0.5175	0.5792	0.5808	0.5817
ETAC	0.8604	0.8602	0.8660	0.8699	0.8724	0.8631	0.8630	0.8622
HPC	16796.	16519.	13699.	10850.	7995.	17509.	17225.	19317.
RNI2C	0.7720	0.8140	0.7784	0.7260	0.6718	0.8097	0.8536	0.8475
P3/P2	36.0491	36.1552	31.0819	25.6640	20.0170	34.5635	34.6732	35.9110
P3	204.29	204.86	176.12	145.42	113.42	213.03	213.69	231.75
PS3	193.11	193.63	166.22	137.05	106.66	201.28	201.88	219.03
T3	1425.0	1371.0	1306.7	1232.6	1145.5	1436.7	1382.3	1471.5
WAR3	0.	0.	0.	0.	0.	0.	0.	0.
W3	59.64	61.03	54.36	46.73	38.44	62.18	63.64	66.57
W31	52.26	53.47	47.63	40.95	33.68	54.48	55.76	58.42
M3	0.2893	0.2892	0.2925	0.2956	0.3005	0.2906	0.2905	0.2900
P4/P3	0.9468	0.9467	0.9455	0.9443	0.9425	0.9464	0.9463	0.9457
WFM	4983.1	4849.1	3870.8	2946.5	2053.3	5156.1	5019.0	5753.0
ETABM	0.9875	0.9875	0.9875	0.9875	0.9875	0.9875	0.9875	0.9875
FAR339	0.02649	0.02519	0.02258	0.01999	0.01693	0.02629	0.02500	0.02735
T39	2972.2	2861.3	2670.5	2467.9	2220.5	2971.6	2860.8	3054.0
T4	2880.0	2772.0	2588.1	2392.1	2154.0	2880.0	2772.1	2960.0
WAR4	0.	0.	0.	0.	0.	0.	0.	0.
FAR4	0.02470	0.02349	0.02105	0.01864	0.01579	0.02451	0.02331	0.02550
P4	193.43	193.95	166.52	137.32	106.89	201.62	202.22	219.39
W4	57.43	58.70	52.16	44.74	36.70	59.87	61.20	64.26
TFFC	15.93	15.93	15.93	15.93	15.93	15.93	15.93	15.93
N/RT4	266.70	266.26	267.38	268.71	270.59	267.37	266.92	267.38
DH/T4	0.07188	0.07186	0.07184	0.07178	0.07162	0.07188	0.07186	0.07139
ETAT	0.8980	0.8980	0.8980	0.8981	0.8981	0.8980	0.8980	0.8930
HPT	16821.	16543.	13720.	10868.	8010.	17535.	17250.	19345.
HPAUX	24.91	24.03	20.72	17.56	14.42	25.61	24.72	27.77
P4/P51	3.8789	3.8849	3.8962	3.9070	3.9157	3.8794	3.8854	3.8744
P51	49.866	49.924	42.739	35.147	27.299	51.972	52.046	56.626
T51	2152.2	2065.3	1918.5	1763.9	1578.8	2152.5	2065.6	2217.1
FAR51	0.02344	0.02229	0.01998	0.01769	0.01499	0.02327	0.02213	0.02421
WAR51	0.	0.	0.	0.	0.	0.	0.	0.
W51	60.43	61.76	54.89	47.08	38.63	62.99	64.40	67.50
M51	0.4800	0.4793	0.4781	0.4765	0.4738	0.4801	0.4794	0.4805
P54/51	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
P54	49.866	49.924	42.739	35.147	27.299	51.972	52.046	56.626
T54	2152.2	2065.3	1918.5	1763.9	1578.8	2152.5	2065.6	2217.1
FAR54	0.02344	0.02229	0.01998	0.01769	0.01499	0.02327	0.02213	0.02421
WAR54	0.	0.	0.	0.	0.	0.	0.	0.
W54	60.43	61.76	54.89	47.08	38.63	62.99	64.40	67.50
TFF2TC	56.22	56.22	56.25	56.26	56.22	56.23	56.23	56.21
N/RT54	92.87	92.83	90.25	86.02	81.09	92.58	92.55	93.69
DH/T54	0.10529	0.10513	0.10116	0.09505	0.08617	0.10599	0.10582	0.10756

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
10/20/75
RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER
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CASE	57,00	58,00	59,00	60,00	61,00	62,00	63,00	64,00
ETA2T	0,9187	0,9188	0,9157	0,9089	0,9002	0,9184	0,9185	0,9197
HP2T	19374,	18974,	15071,	11168,	7435,	20330,	19916,	22830,
RNI54	0,7061	0,7397	0,6868	0,6194	0,5435	0,7358	0,7710	0,7760
P54/56	8,4912	8,5069	7,8073	6,8496	5,6373	8,6611	8,6771	8,9802
P56	5,873	5,869	5,474	5,131	4,843	6,001	5,998	6,306
T56	1338,6	1278,6	1204,5	1136,5	1058,9	1333,7	1273,9	1366,0
W56	63,00	64,40	57,23	49,10	40,29	65,57	67,14	70,48
M56	0,4469	0,4459	0,4031	0,3494	0,2858	0,4575	0,4564	0,4736
P8/56	0,9917	0,9917	0,9931	0,9946	0,9963	0,9914	0,9914	0,9907
FAR8	0,02246	0,02136	0,01915	0,01695	0,01436	0,02230	0,02120	0,02320
WAR8	0,	0,	0,	0,	0,	0,	0,	0,
W8	63,00	64,40	57,23	49,10	40,29	65,57	67,14	70,48
T8	1338.6	1278,6	1204,5	1136,5	1058,9	1333,7	1273,9	1366,0
P8	5,824	5,820	5,436	5,104	4,825	5,949	5,946	6,247
P8QP0	1,3346	1,3337	1,2457	1,1695	1,1055	1,3632	1,3626	1,4315
M8	0,6661	0,6644	0,5768	0,4842	0,3854	0,6909	0,6895	0,7462
V8	1130,8	1103,7	939,7	773,6	599,9	1167,8	1140,4	1268,0
CF8	1,0165	1,0165	1,0165	1,0165	1,0165	1,0165	1,0165	1,0155
CV9	0,9970	0,9970	0,9970	0,9970	0,9970	0,9970	0,9970	0,9970
AE8	846,95	846,72	846,99	846,35	846,57	846,96	846,46	847,06
A8	833,2	833,0	833,2	832,6	832,8	833,2	332,7	833,3
FD	11930,	11934,	11150,	10284,	9280,	14744,	14749,	16757,
FGG	21936,	21938,	19154,	16287,	13282,	24329,	24334,	27089,
FNU/W2	15,98	15,63	13,39	10,89	8,05	14,45	14,14	14,59
D/F-PC	3,1	3,1	3,6	4,5	6,1	4,4	4,4	4,7
CD	0,1843	0,1843	0,1843	0,1843	0,1843	0,1843	0,1843	0,1843
FDI	311,7	311,9	291,4	268,7	242,5	418,2	418,4	489,6
SWFMG	1,00000	1,00000	1,00000	1,00000	1,00000	1,00000	1,00000	1,00000
SFNG	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
WC3/2C	0,0902	0,0902	0,0902	0,0902	0,0902	0,0902	0,0902	0,0902
WC4/2C	0,0614	0,0614	0,0614	0,0614	0,0614	0,0614	0,0614	0,0614
WC5I2C	0,0360	0,0360	0,0360	0,0360	0,0360	0,0360	0,0360	0,0360
WC5D2C	0,0125	0,0125	0,0125	0,0125	0,0125	0,0125	0,0125	0,0125
WC542C	0,	0,	0,	0,	0,	0,	0,	0,
WC55I1	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050
WC55I2	0,0367	0,0367	0,0367	0,0367	0,0367	0,0367	0,0367	0,0367
WC552C	0,0417	0,0417	0,0417	0,0417	0,0417	0,0417	0,0417	0,0417
WCI/2C	0,0320	0,0320	0,0320	0,0320	0,0320	0,0320	0,0320	0,0320
FIBAH	0,3880	0,3880	0,3880	0,3880	0,3880	0,3880	0,3880	0,3880
FCAH51	0,2850	0,2850	0,2850	0,2850	0,2850	0,2850	0,2850	0,2850
FCAH54	0,7500	0,7500	0,7500	0,7500	0,7500	0,7500	0,7500	0,7500
FCH551	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
FCH552	0,2770	0,2770	0,2770	0,2770	0,2770	0,2770	0,2770	0,2770

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
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RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER
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CASE	65.00	66.00	67.00	68.00	69.00	70.00	71.00	72.00
ALT	30000.	30000.	30000.	30000.	30000.	30000.	30000.	30000.
MO	0.750	0.800	0.800	0.800	0.800	0.800	0.850	0.850
PC	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
RC	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
FNG	10330.8	9255.5	9255.8	7406.0	5555.9	3701.7	9113.7	9113.5
SFCG	0.5421	0.5778	0.5627	0.5677	0.5870	0.6300	0.5979	0.5823
DELTO	4.10	22.30	4.10	4.10	4.10	4.10	22.30	4.10
TO	415.78	433.98	415.78	415.78	415.78	415.78	433.98	415.78
PO	4.3641	4.3641	4.3641	4.3641	4.3641	4.3641	4.3641	4.3641
T2	462.76	489.77	469.23	469.23	469.23	469.23	496.96	476.12
ETAR	1.0180	1.0180	1.0180	1.0180	1.0180	1.0180	1.0180	1.0180
P2	6.456	6.776	6.776	6.776	6.776	6.776	7.130	7.130
P22/P2	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996
M21	0.6105	0.5746	0.5751	0.5254	0.4762	0.4274	0.5664	0.5667
P22	6.453	6.774	6.774	6.774	6.774	6.774	7.127	7.127
B	9.1770	9.4988	9.4836	10.0611	10.8532	12.0832	9.6145	9.5930
PATH	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR
WB/W2C	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
WB	0.	0.	0.	0.	0.	0.	0.	0.
PBD	226.25	216.92	217.64	188.06	157.52	125.04	222.07	222.81
TBD	1416.2	1450.2	1395.5	1335.3	1267.4	1187.3	1457.5	1402.6
WBI	0.141	0.135	0.138	0.123	0.107	0.089	0.138	0.141
PBI	89.90	87.20	87.43	76.74	65.40	53.47	89.65	89.39
TBI	1121.2	1153.3	1108.3	1064.5	1014.5	956.5	1160.8	1115.6
HPE	0.	0.	0.	0.	0.	0.	0.	0.
PCNF	91.701	90.973	89.089	83.869	77.376	70.053	90.858	88.962
NF	4320.1	4285.8	4197.0	3951.1	3645.2	3300.2	4280.3	4191.0
PCNF*	97.083	93.619	93.664	88.177	81.350	73.651	92.821	92.851
W2*	1546.73	1490.89	1491.78	1405.73	1310.43	1206.45	1477.33	1477.93
W2	719.02	707.17	722.90	681.21	635.03	584.63	731.92	748.11
P23/22	1.6518	1.5872	1.5879	1.4890	1.3833	1.2713	1.5717	1.5722
Z22	0.6456	0.6213	0.6212	0.5777	0.5252	0.4617	0.6152	0.6152
ETAF	0.8608	0.8605	0.8605	0.8638	0.8556	0.8410	0.8613	0.8613
HPFAN	18256.	17455.	17113.	13777.	10525.	7265.	17918.	17562.
RNT22	0.5086	0.4961	0.5243	0.5243	0.5243	0.5243	0.5122	0.5414
M23	0.4486	0.4467	0.4468	0.4434	0.4387	0.4323	0.4462	0.4462
P25P23	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
M25P	0.4498	0.4498	0.4498	0.4496	0.4486	0.4469	0.4499	0.4499
AE25P	3872.8	3872.8	3872.8	3872.8	3872.8	3872.8	3872.8	3872.8

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
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CASE	65,00	66,00	67,00	68,00	69,00	70,00	71,00	72,00
P25P	10,659	10,751	10,756	10,086	9,370	8,612	11,201	11,205
P2525P	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
P25	10,659	10,751	10,755	10,085	9,370	8,611	11,201	11,205
Q25	1,3144	1,3257	1,3266	1,2430	1,1508	1,0507	1,3816	1,3822
T25	545,9	570,3	546,5	534,9	522,7	509,0	576,7	552,7
M25	0,4498	0,4499	0,4499	0,4496	0,4487	0,4469	0,4500	0,4499
W25	648,37	639,82	653,95	619,63	581,45	539,95	662,97	677,52
P28/25	0,9930	0,9930	0,9930	0,9930	0,9930	0,9931	0,9930	0,9930
P28	10,584	10,676	10,680	10,015	9,305	8,552	11,123	11,126
T28	545,9	570,3	546,5	534,9	522,7	509,0	576,7	552,7
W28	648,37	639,82	653,95	619,63	581,45	539,95	662,97	677,52
CV29	0,9982	0,9983	0,9983	0,9977	0,9973	0,9970	0,9989	0,9989
CF28	0,9860	0,9861	0,9861	0,9858	0,9842	0,9813	0,9862	0,9862
AE28	2690,9	2690,9	2691,1	2690,1	2685,9	2677,8	2691,3	2691,3
A28	2729,0	2729,0	2729,1	2729,0	2729,0	2729,0	2729,0	2729,0
V28	1045,7	1068,9	1046,3	1035,1	1023,3	1009,8	1074,9	1052,2
M28	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
Z1C	0,6656	0,7055	0,7023	0,7463	0,7772	0,8370	0,7258	0,7224
P24/1C	2,6473	2,5427	2,5429	2,3518	2,1234	1,8939	2,5214	2,5211
W1C*	151,99	141,99	142,30	127,07	110,55	92,21	139,18	139,45
W1C	70,66	67,35	68,96	61,58	53,57	44,68	68,95	70,59
ETA1C	0,8654	0,8655	0,8660	0,8640	0,8585	0,8437	0,8649	0,8654
HP1C	4116,	3956,	3879,	3144,	2387,	1690,	4070,	3989,
P24	17,083	17,224	17,225	15,930	14,383	12,829	17,969	17,968
T24	634,6	662,9	635,1	619,9	600,8	580,9	670,8	642,8
M24	0,4428	0,4240	0,4250	0,4006	0,3757	0,3403	0,4172	0,4132
Q24	2,0475	1,9125	1,9215	1,6014	1,2889	0,9601	1,9391	1,9481
P2C/24	0,9903	0,9910	0,9909	0,9918	0,9927	0,9939	0,9912	0,9912
AE2D	0,	0,	0,	0,	0,	0,	0,	0,
WB/W24	0,	0,	0,	0,	0,	0,	0,	0,
P2C	16,917	17,069	17,069	15,800	14,279	12,751	17,812	17,810
T2C	634,6	662,9	635,1	619,9	600,8	580,9	670,8	642,8
PCNG	97,777	98,782	96,755	94,198	91,306	87,386	98,970	96,939
PCNG*	88,396	87,380	87,435	86,168	84,841	82,574	87,024	87,030
NG	14250,	14397,	14101,	13728,	13307,	12736,	14424,	14123,
PCNG*M	99,522	98,378	98,440	97,013	95,518	92,967	97,976	98,039
WARC2C	0,	0,	0,	0,	0,	0,	0,	0,
W2C	70,65	67,36	68,96	61,59	53,57	44,69	68,95	70,59
W2C*	67,89	65,56	65,70	62,62	59,34	54,50	64,70	64,84

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
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RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER
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CASE	65.00	66.00	67.00	68.00	69.00	70.00	71.00	72.00
P3/P2C	13.7437	13.0643	13.1083	12.2434	11.3559	10.1045	12.8179	12.8628
Z2C	0.5832	0.5707	0.5725	0.5539	0.5313	0.5122	0.5661	0.5679
ETAC	0.8620	0.8656	0.8655	0.8693	0.8719	0.8720	0.8668	0.8667
HPC	19010.	18321.	18030.	15085.	12169.	9182.	18754.	18457.
RNI2C	0.8932	0.8540	0.9003	0.8589	0.8071	0.7517	0.8782	0.9256
P3/P2	36.0303	32.9194	33.0314	28.5588	23.9375	19.0210	32.0393	32.1426
P3	232.50	222.99	223.74	193.45	162.15	128.84	228.31	229.09
PS3	219.72	210.57	211.26	182.41	152.68	121.06	215.53	216.24
T3	1416.2	1450.2	1395.5	1335.3	1267.4	1187.3	1457.5	1402.6
WAR3	0.	0.	0.	0.	0.	0.	0.	0.
W3	68.25	65.07	66.61	59.49	51.75	43.17	66.61	68.19
W31	59.80	57.01	58.36	52.13	45.35	37.82	58.36	59.75
M3	0.2900	0.2921	0.2920	0.2950	0.2982	0.3030	0.2929	0.2928
P4/P3	0.9466	0.9460	0.9459	0.9447	0.9435	0.9417	0.9457	0.9456
WFM	5600.3	5348.0	5208.1	4204.6	3261.6	2331.9	5449.0	5306.5
ETABM	0.9875	0.9875	0.9875	0.9875	0.9875	0.9875	0.9875	0.9875
FAR339	0.02601	0.02606	0.02479	0.02241	0.01998	0.01713	0.02593	0.02467
T39	2940.8	2970.8	2860.5	2685.0	2496.9	2267.5	2970.4	2860.2
T4	2849.8	2880.0	2772.5	2603.3	2421.4	2200.6	2880.0	2772.6
WAR4	0.	0.	0.	0.	0.	0.	0.	0.
FAR4	0.02425	0.02430	0.02311	0.02089	0.01863	0.01597	0.02418	0.02300
P4	220.08	210.94	211.63	182.76	152.99	121.34	215.92	216.53
W4	65.69	62.63	64.04	57.08	49.54	41.21	64.11	65.56
TFFC	15.93	15.93	15.93	15.93	15.93	15.93	15.93	15.93
N/RT4	266.94	268.27	267.80	269.06	270.43	271.49	268.77	268.31
DH/T4	0.07187	0.07189	0.07187	0.07186	0.07181	0.07168	0.07189	0.07187
ETAT	0.8980	0.8981	0.8981	0.8982	0.8982	0.8982	0.8981	0.8981
HPT	19037.	18347.	18055.	15107.	12188.	9198.	18780.	18483.
HPAUX	26.80	26.44	25.53	22.12	18.90	15.58	26.89	25.96
P4/P51	3.8807	3.8799	3.8856	3.8967	3.9073	3.9166	3.8799	3.8859
P51	56.713	54.368	54.466	46.901	39.155	30.980	55.650	55.748
T51	2128.0	2152.7	2066.3	1931.1	1787.3	1615.5	2152.9	2066.5
FAR51	0.02302	0.02306	0.02194	0.01983	0.01768	0.01516	0.02295	0.02194
WAR51	0.	0.	0.	0.	0.	0.	0.	0.
W51	69.12	65.90	67.39	60.06	52.14	43.30	67.45	68.98
M51	0.4798	0.4802	0.4795	0.4785	0.4771	0.4749	0.4802	0.4795
P54/51	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
P54	56.713	54.368	54.466	46.901	39.155	30.980	55.650	55.748
T54	2128.0	2152.7	2066.3	1931.1	1787.3	1615.5	2152.9	2066.5
FAR54	0.02302	0.02306	0.02194	0.01983	0.01768	0.01516	0.02295	0.02194
WAR54	0.	0.	0.	0.	0.	0.	0.	0.
W54	69.12	65.90	67.39	60.06	52.14	43.38	67.45	68.98
TFF2TC	56.22	56.24	56.24	56.28	56.30	56.28	56.24	56.25
N/RT54	93.65	92.37	92.33	89.91	86.22	82.11	92.25	92.19
DH/T54	0.10751	0.10667	0.10655	0.10311	0.09794	0.09031	0.10701	0.10656

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CASE	65,00	66,00	67,00	68,00	69,00	70,00	71,00	72,00
ETA2T	0,9198	0,9182	0,9183	0,9152	0,9092	0,9017	0,9181	0,9181
HP2T	22372,	21411,	20992,	16921,	12913,	8955,	21988,	21552,
RNI54	0,8131	0,7696	0,8066	0,7482	0,6802	0,6014	0,7877	0,8255
P54/56	9,0023	8,8314	8,8589	8,2351	7,3778	6,2347	8,9173	8,9403
P56	6,300	6,156	6,148	5,695	5,307	4,969	6,241	6,236
T56	1304,7	1328,8	1269,2	1200,1	1134,7	1061,2	1326,5	1267,1
W56	72,07	68,71	70,26	62,63	54,37	45,24	70,33	71,92
M56	0,4778	0,4683	0,4678	0,4282	0,3784	0,3166	0,4738	0,4731
P8/56	0,9907	0,9910	0,9910	0,9923	0,9938	0,9955	0,9909	0,9909
FAR8	0,02206	0,02210	0,02102	0,01900	0,01694	0,01452	0,02199	0,02092
WAR8	0,	0,	0,	0,	0,	0,	0,	0,
W8	72,07	68,71	70,26	62,63	54,37	45,24	70,33	71,92
T8	1304,7	1328,8	1269,2	1200,1	1134,7	1061,2	1326,5	1267,1
P8	6,241	6,101	6,093	5,651	5,274	4,947	6,184	6,179
P8QP0	1,4302	1,3980	1,3962	1,2949	1,2085	1,1335	1,4169	1,4158
M8	0,7441	0,7194	0,7170	0,6271	0,5336	0,4314	0,7343	0,7324
V8	1237,3	1210,2	1180,3	1014,8	848,4	670,0	1232,1	1202,6
CF8	1,0165	1,0165	1,0165	1,0165	1,0165	1,0165	1,0165	1,0155
CV9	0,9970	0,9970	0,9970	0,9970	0,9970	0,9970	0,9970	0,9970
AE8	847,19	846,31	847,19	846,36	845,77	847,37	846,40	846,59
A8	833,4	832,6	833,4	832,6	832,0	833,6	832,7	832,8
FD	16765,	17968,	17979,	16942,	15793,	14540,	19759,	19769,
FGG	27096,	27224,	27235,	24348,	21349,	18242,	28873,	28882,
FNU/W2	14,37	13,09	12,80	10,87	8,75	6,33	12,45	12,18
D/F-PC	4,7	5,8	5,8	6,8	8,5	11,7	6,6	6,6
CD	0,1843	0,1843	0,1843	0,1843	0,1843	0,1843	0,1843	0,1843
FDI	489,9	537,3	537,6	506,6	472,2	434,8	601,0	601,3
SWFMG	1,00000	1,00000	1,00000	1,00000	1,00000	1,00000	1,00000	1,00000
SFNG	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
WC3/2C	0,0902	0,0902	0,0902	0,0902	0,0902	0,0902	0,0902	0,0902
WC4/2C	0,0614	0,0614	0,0614	0,0614	0,0614	0,0614	0,0614	0,0614
WC512C	0,0360	0,0360	0,0360	0,0360	0,0360	0,0360	0,0360	0,0350
WC5D2C	0,0125	0,0125	0,0125	0,0125	0,0125	0,0125	0,0125	0,0125
WC542C	0,	0,	0,	0,	0,	0,	0,	0,
WC5511	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050
WC5512	0,0367	0,0367	0,0367	0,0367	0,0367	0,0367	0,0367	0,0367
WC552C	0,0417	0,0417	0,0417	0,0417	0,0417	0,0417	0,0417	0,0417
WCI/2C	0,0320	0,0320	0,0320	0,0320	0,0320	0,0320	0,0320	0,0320
FIBAH	0,3880	0,3880	0,3880	0,3880	0,3880	0,3880	0,3880	0,3880
FCAH51	0,2850	0,2850	0,2850	0,2850	0,2850	0,2850	0,2850	0,2850
FCAH54	0,7500	0,7500	0,7500	0,7500	0,7500	0,7500	0,7500	0,7500
FCH551	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
FCH552	0,2770	0,2770	0,2770	0,2770	0,2770	0,2770	0,2770	0,2770

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
10/20/75
RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER
MISSION ANALYSIS CYCLE DATA PACKAGE

CASE	73.00	74.00	75.00	76.00	77.00	78.00	79.00	80.00
ALT	31000.	31000.	32000.	32000.	33000.	33000.	34000.	34000.
MO	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750
PC	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
RC	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
FNG	10116.0	10115.0	9898.1	9897.5	9670.1	9671.6	9427.2	9426.8
SFCG	0.5537	0.5390	0.5509	0.5362	0.5485	0.5338	0.5466	0.5320
DELTO	22.30	4.10	22.20	4.00	22.20	4.00	22.20	4.00
TO	430.42	412.22	426.75	408.55	423.19	404.99	419.62	401.42
PO	4.1690	4.1690	3.9811	3.9811	3.8001	3.8001	3.6258	3.6258
T2	479.05	458.79	474.97	454.71	471.00	450.75	467.03	446.78
ETAR	1.0180	1.0180	1.0180	1.0180	1.0180	1.0180	1.0180	1.0180
P2	6.168	6.167	5.889	5.888	5.622	5.620	5.364	5.362
P22/P2	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996
M21	0.6178	0.6185	0.6260	0.6267	0.6339	0.6347	0.6414	0.6422
P22	6.165	6.164	5.887	5.886	5.619	5.618	5.361	5.360
B	9.1346	9.1214	9.0795	9.0640	9.0225	9.0065	8.9661	8.9497
PATH	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR
WB/W2C	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
WB	0.	0.	0.	0.	0.	0.	0.	0.
PBD	219.17	219.88	212.94	213.65	206.72	207.44	200.47	201.17
TBD	1468.5	1412.9	1465.3	1409.4	1462.2	1406.2	1459.1	1402.7
WBI	0.134	0.137	0.130	0.133	0.127	0.130	0.123	0.126
PBI	86.99	87.21	84.36	84.58	81.75	81.95	79.10	79.29
TBI	1163.5	1117.9	1160.2	1114.4	1157.0	1111.1	1153.8	1107.7
HPE	0.	0.	0.	0.	0.	0.	0.	0.
PCNF	93.998	92.055	94.382	92.415	94.758	92.771	95.097	93.091
NF	4428.2	4336.7	4446.4	4353.7	4464.0	4370.5	4480.0	4385.5
PCNF*	97.808	97.878	98.629	98.700	99.438	99.516	100.216	100.302
W2*	1557.35	1558.47	1569.10	1570.18	1580.21	1581.33	1590.36	1591.51
W2	679.80	695.04	656.85	671.64	634.07	648.44	611.44	625.38
P23/22	1.6644	1.6654	1.6781	1.6791	1.6912	1.6922	1.7039	1.7043
Z22	0.6505	0.6504	0.6552	0.6552	0.6596	0.6597	0.6640	0.6641
ETAF	0.8612	0.8612	0.8610	0.8610	0.8601	0.8600	0.8581	0.8577
HPFAN	18145.	17785.	17676.	17320.	17200.	16851.	16712.	16373.
RNI22	0.4646	0.4913	0.4486	0.4746	0.4329	0.4582	0.4176	0.4422
M23	0.4489	0.4490	0.4493	0.4494	0.4497	0.4497	0.4501	0.4501
P25P23	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
M25P	0.4498	0.4498	0.4498	0.4498	0.4498	0.4498	0.4498	0.4498
AE25P	3872.8	3872.8	3872.8	3872.8	3872.8	3872.8	3872.8	3872.8

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
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RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER
MISSION ANALYSIS CYCLE DATA PACKAGE

CASE	73.00	74.00	75.00	76.00	77.00	78.00	79.00	80.00
P25P	10.261	10.266	9.879	9.883	9.503	9.507	9.132	9.134
P2525P	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
P25	10.261	10.266	9.879	9.883	9.503	9.506	9.132	9.134
Q25	1.2654	1.2661	1.2184	1.2189	1.1721	1.1726	1.1263	1.1267
T25	566.5	542.6	563.2	539.3	560.0	536.0	556.7	532.8
M25	0.4499	0.4498	0.4499	0.4498	0.4499	0.4498	0.4499	0.4499
W25	612.75	626.37	591.69	604.90	570.80	583.64	550.09	562.52
P28/25	0.9930	0.9930	0.9930	0.9930	0.9930	0.9930	0.9930	0.9930
P28	10.189	10.194	9.810	9.814	9.437	9.440	9.068	9.070
T28	566.5	542.6	563.2	539.3	560.0	536.0	556.7	532.8
W28	612.75	626.37	591.69	604.90	570.80	583.64	550.09	562.52
CV29	0.9983	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986
CF28	0.9861	0.9861	0.9861	0.9861	0.9861	0.9861	0.9861	0.9861
AE28	2691.0	2691.0	2691.0	2691.0	2691.1	2691.1	2691.2	2691.2
A28	2729.0	2729.0	2729.0	2729.0	2729.0	2729.0	2729.0	2729.0
V28	1065.3	1042.6	1062.1	1039.4	1059.1	1036.2	1056.1	1033.1
M28	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Z1C	0.6658	0.6618	0.6611	0.6577	0.6570	0.6540	0.6538	0.6533
P24/1C	2.6736	2.6734	2.6999	2.7001	2.7262	2.7268	2.7525	2.7531
W1C*	153.60	153.98	155.67	156.03	157.67	158.02	159.56	159.95
W1C	67.05	68.67	65.17	66.74	63.27	64.80	61.35	62.85
ETA1C	0.8643	0.8647	0.8636	0.8639	0.8628	0.8631	0.8619	0.8622
HP1C	4096.	4015.	3995.	3915.	3893.	3815.	3788.	3712.
P24	16.483	16.479	15.895	15.893	15.320	15.319	14.757	14.756
T24	659.1	631.3	655.7	627.8	652.4	624.4	649.1	621.0
M24	0.4443	0.4456	0.4473	0.4484	0.4501	0.4511	0.4524	0.4536
Q24	1.9860	1.9969	1.9379	1.9473	1.8879	1.8964	1.8352	1.8443
P2C/24	0.9902	0.9902	0.9901	0.9901	0.9900	0.9900	0.9899	0.9899
AE2D	0.	0.	0.	0.	0.	0.	0.	0.
WB/W24	0.	0.	0.	0.	0.	0.	0.	0.
P2C	16.321	16.317	15.737	15.735	15.166	15.165	14.608	14.606
T2C	659.1	631.3	655.7	627.8	652.4	624.4	649.1	621.0
PCNG	99.753	97.700	99.681	97.617	99.619	97.549	99.560	97.476
PCNG*	88.491	88.560	88.655	88.729	88.823	88.904	88.997	89.081
NG	14538.	14239.	14527.	14227.	14519.	14217.	14510.	14205.
PCNG*M	99.628	99.706	99.813	99.896	100.002	100.094	100.198	100.293
WARC2C	0.	0.	0.	0.	0.	0.	0.	0.
W2C	67.08	68.67	65.17	66.74	63.26	64.80	61.35	62.85
W2C*	68.08	68.23	68.42	68.58	68.75	68.90	69.05	69.20

NASA-USTDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
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CASE	73.00	74.00	75.00	76.00	77.00	78.00	79.00	80.00
P3/P2C	13.7979	13.8470	13.9019	13.9519	14.0035	14.0545	14.0976	14.1504
Z2C	0.5834	0.5851	0.5854	0.5870	0.5871	0.5887	0.5882	0.5900
ETAC	0.8615	0.8613	0.8608	0.8606	0.8600	0.8596	0.8589	0.8585
HPC	18773.	18472.	18236.	17944.	17702.	17421.	17165.	16890.
RNI2C	0.8224	0.8672	0.7980	0.8420	0.7738	0.8169	0.7501	0.7921
P3/P2	36.5288	36.6540	37.1625	37.2973	37.7945	37.9391	38.4118	38.5626
P3	225.20	225.94	218.78	219.53	212.38	213.13	205.94	206.68
PS3	212.86	213.54	206.82	207.51	200.80	201.49	194.74	195.41
T3	1468.5	1412.9	1465.3	1409.4	1462.2	1406.2	1459.1	1402.7
WAR3	0.	0.	0.	0.	0.	0.	0.	0.
W3	64.80	66.34	62.95	64.47	61.11	62.60	59.27	60.72
W31	56.77	58.12	55.16	56.49	53.55	54.85	51.93	53.20
M3	0.2897	0.2897	0.2894	0.2893	0.2890	0.2890	0.2887	0.2886
P4/P3	0.9468	0.9467	0.9469	0.9468	0.9470	0.9469	0.9471	0.9470
WFM	5600.8	5452.2	5452.8	5306.8	5303.8	5162.4	5152.9	5014.8
ETABM	0.9875	0.9875	0.9875	0.9875	0.9875	0.9875	0.9875	0.9875
FAR339	0.02740	0.02606	0.02746	0.02610	0.02751	0.02614	0.02756	0.02618
T39	3054.0	2940.3	3054.3	2939.5	3054.5	2939.3	3054.5	2938.6
T4	2959.9	2849.1	2960.0	2848.2	2960.0	2847.8	2959.9	2846.9
WAR4	0.	0.	0.	0.	0.	0.	0.	0.
FAR4	0.02555	0.02429	0.02560	0.02433	0.02565	0.02438	0.02570	0.02441
P4	213.22	213.90	207.16	207.85	201.12	201.82	195.05	195.73
W4	62.45	63.85	60.67	62.06	58.91	60.26	57.13	58.45
TFFC	15.93	15.93	15.93	15.93	15.93	15.93	15.93	15.93
N/RT4	267.22	266.76	267.02	266.58	266.86	266.41	266.70	266.25
DH/T4	0.07189	0.07187	0.07187	0.07186	0.07186	0.07185	0.07186	0.07184
ETAT	0.8980	0.8980	0.8980	0.8980	0.8980	0.8980	0.8980	0.8980
HPT	18800.	18498.	18262.	17970.	17728.	17446.	17191.	16915.
HPAUX	27.24	26.28	26.72	25.78	26.21	25.28	25.70	24.78
P4/P51	3.8747	3.8801	3.8732	3.8794	3.8725	3.8788	3.8720	3.8783
P51	55.028	55.127	53.486	53.577	51.937	52.031	50.374	50.467
T51	2217.0	2127.4	2217.1	2126.7	2217.1	2126.4	2217.0	2125.7
FAR51	0.02425	0.02306	0.02430	0.02310	0.02435	0.02314	0.02440	0.02318
WAR51	0.	0.	0.	0.	0.	0.	0.	0.
W51	65.70	67.18	63.83	65.29	61.97	63.40	60.10	61.50
M51	0.4805	0.4797	0.4803	0.4796	0.4802	0.4795	0.4801	0.4794
P54/51	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
P54	55.028	55.127	53.486	53.577	51.937	52.031	50.374	50.467
T54	2217.0	2127.4	2217.1	2126.7	2217.1	2126.4	2217.0	2125.7
FAR54	0.02425	0.02306	0.02430	0.02310	0.02435	0.02314	0.02440	0.02318
WAR54	0.	0.	0.	0.	0.	0.	0.	0.
W54	65.70	67.18	63.83	65.29	61.97	63.40	60.10	61.50
TFF2TC	56.22	56.21	56.20	56.20	56.19	56.19	56.18	56.18
N/RT54	94.05	94.02	94.43	94.41	94.81	94.78	95.15	95.12
DH/T54	0.10792	0.10780	0.10823	0.10809	0.10850	0.10834	0.10876	0.10860

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
10/20/75
RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER
MISSION ANALYSIS CYCLE DATA PACKAGE

CASE	73,00	74,00	75,00	76,00	77,00	78,00	79,00	80,00
ETA2T	0,9201	0,9202	0,9204	0,9205	0,9207	0,9209	0,9210	0,9212
HP2T	22241,	21800,	21671,	21235,	21093,	20666,	20503,	20087,
RN154	0,7542	0,7906	0,7330	0,7687	0,7118	0,7466	0,6904	0,7244
P54/56	9,0351	9,0642	9,0994	9,1248	9,1569	9,1773	9,2116	9,2345
P56	6,091	6,082	5,878	5,872	5,672	5,670	5,469	5,455
T56	1363,7	1302,0	1361,4	1299,2	1359,2	1297,1	1357,0	1294,5
W56	68,50	70,05	66,55	68,08	64,61	66,11	62,66	64,12
M56	0,4820	0,4815	0,4858	0,4851	0,4893	0,4883	0,4927	0,4918
P8/56	0,9906	0,9906	0,9905	0,9905	0,9904	0,9904	0,9902	0,9902
FAR8	0,02324	0,02210	0,02329	0,02213	0,02333	0,02217	0,02338	0,02221
WAR8	0,	0,	0,	0,	0,	0,	0,	0,
W8	68,50	70,05	66,55	68,08	64,61	66,11	62,66	64,12
T8	1363,7	1302,0	1361,4	1299,2	1359,2	1297,1	1357,0	1294,5
P8	6,033	6,025	5,822	5,816	5,617	5,615	5,415	5,412
P8QP0	1,4472	1,4451	1,4624	1,4608	1,4782	1,4776	1,4935	1,4926
M8	0,7579	0,7553	0,7690	0,7668	0,7803	0,7788	0,7910	0,7892
V8	1285,2	1253,1	1301,2	1269,2	1317,5	1286,1	1332,9	1300,5
CF8	1,0165	1,0165	1,0165	1,0165	1,0165	1,0165	1,0165	1,0165
CV9	0,9970	0,9970	0,9970	0,9970	0,9970	0,9970	0,9970	0,9970
AE8	846,41	847,05	846,76	846,95	846,85	846,28	847,18	846,36
A8	832,7	833,3	833,0	833,2	833,1	832,5	833,4	833,1
FD	16127,	16136,	15516,	15524,	14915,	14922,	14322,	14323,
FGG	26242,	26251,	25414,	25421,	24585,	24593,	23749,	23754,
FNU/W2	14,88	14,55	15,07	14,74	15,25	14,92	15,42	15,07
D/F-PC	4,7	4,7	4,6	4,6	4,5	4,5	4,4	4,4
CD	0,1843	0,1843	0,1843	0,1843	0,1843	0,1843	0,1843	0,1843
FDI	471,2	471,5	453,4	453,7	435,8	436,1	418,5	418,8
SWFMG	1,00000	1,00000	1,00000	1,00000	1,00000	1,00000	1,00000	1,00000
SFNG	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
WC3/2C	0,0902	0,0902	0,0902	0,0902	0,0902	0,0902	0,0902	0,0902
WC4/2C	0,0614	0,0614	0,0614	0,0614	0,0614	0,0614	0,0614	0,0614
WC512C	0,0360	0,0360	0,0360	0,0360	0,0360	0,0360	0,0360	0,0350
WC5D2C	0,0125	0,0125	0,0125	0,0125	0,0125	0,0125	0,0125	0,0125
WC542C	0,	0,	0,	0,	0,	0,	0,	0,
WC5511	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050
WC5512	0,0367	0,0367	0,0367	0,0367	0,0367	0,0367	0,0367	0,0367
WC552C	0,0417	0,0417	0,0417	0,0417	0,0417	0,0417	0,0417	0,0417
WCI/2C	0,0320	0,0320	0,0320	0,0320	0,0320	0,0320	0,0320	0,0320
FIBAH	0,3880	0,3880	0,3880	0,3880	0,3880	0,3880	0,3880	0,3880
FCAH51	0,2850	0,2850	0,2850	0,2850	0,2850	0,2850	0,2850	0,2850
FCAH54	0,7500	0,7500	0,7500	0,7500	0,7500	0,7500	0,7500	0,7500
FCH551	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
FCH552	0,2770	0,2770	0,2770	0,2770	0,2770	0,2770	0,2770	0,2770

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
10/20/75
RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER
MISSION ANALYSIS CYCLE DATA PACKAGE

CASE	81.00	82.00	83.00	84.00	85.00	86.00	87.00	88.00
ALT	35000.	35000.	35000.	35000.	35000.	35000.	35000.	35000.
MO	0.600	0.600	0.600	0.600	0.600	0.800	0.800	0.800
PC	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
RC	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
FNG	8848.2	8847.9	7077.5	5309.0	3540.4	8306.0	8305.0	6643.3
SFCG	0.4886	0.4754	0.4719	0.4749	0.4947	0.5616	0.5464	0.5496
DELTO	22.10	3.90	3.90	3.90	3.90	22.10	3.90	3.90
TO	415.95	397.75	397.75	397.75	397.75	415.95	397.75	397.75
PO	3.4580	3.4580	3.4580	3.4580	3.4580	3.4580	3.4580	3.4530
T2	446.03	426.52	426.52	426.52	426.52	469.43	448.69	448.89
ETAR	1.0180	1.0180	1.0180	1.0180	1.0180	1.0180	1.0180	1.0130
P2	4.492	4.490	4.490	4.490	4.490	5.369	5.367	5.357
P22/P2	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996
M21	0.6437	0.6446	0.5714	0.5047	0.4375	0.6098	0.6106	0.5522
P22	4.490	4.488	4.488	4.488	4.488	5.367	5.365	5.355
B	8.8952	8.8805	9.3596	10.1032	11.1782	9.2147	9.1972	9.7180
PATH	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR
WB/W2C	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
WB	0.	0.	0.	0.	0.	0.	0.	0.
PBD	170.85	171.43	146.67	120.55	93.54	187.07	187.73	162.11
TBD	1409.8	1354.8	1285.4	1209.7	1121.4	1432.8	1376.5	1315.2
WBI	0.106	0.109	0.097	0.083	0.068	0.116	0.119	0.106
PBI	66.89	67.04	58.50	49.03	39.10	74.44	74.65	65.58
TBI	1111.5	1066.6	1016.1	960.8	896.8	1135.3	1089.2	1045.0
HPE	0.	0.	0.	0.	0.	0.	0.	0.
PCNF	93.192	91.217	84.681	77.635	68.973	92.298	90.333	84.935
NF	4390.3	4297.2	3989.3	3657.4	3249.3	4348.1	4255.6	4003.6
PCNF*	100.494	100.590	93.382	85.612	76.060	97.018	97.101	91.332
W2*	1593.54	1594.80	1485.81	1366.82	1228.88	1545.64	1546.98	1453.35
W2	524.99	537.09	500.38	460.31	413.86	593.37	607.07	570.33
P23/22	1.7081	1.7093	1.5839	1.4517	1.3133	1.6509	1.6521	1.5431
Z22	0.6672	0.6673	0.6230	0.5669	0.5062	0.6457	0.6458	0.6021
ETAF	0.8568	0.8564	0.8605	0.5627	0.8512	0.8608	0.8609	0.8628
HPFAN	13792.	13507.	10678.	7896.	5229.	15273.	14957.	12056.
RN122	0.3713	0.3936	0.3936	0.3936	0.3936	0.4153	0.4400	0.4430
M23	0.4498	0.4499	0.4455	0.4394	0.4272	0.4485	0.4466	0.4453
P25P23	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
M25P	0.4491	0.4491	0.4478	0.4457	0.4381	0.4499	0.4498	0.4497
AE25R	3872.8	3872.8	3872.8	3872.8	3872.8	3872.8	3872.8	3872.8

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
10/20/75
RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER
MISSION ANALYSIS CYCLE DATA PACKAGE

CASE	81,00	82,00	83,00	84,00	85,00	86,00	87,00	88,00
P25P	7,669	7,671	7,109	6,515	5,894	8,861	8,864	8,279
P2525P	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
P25	7,669	7,671	7,109	6,515	5,894	8,861	8,864	8,279
Q25	0,9436	0,9440	0,8703	0,7913	0,6948	1,0931	1,0935	1,0209
T25	532,3	509,2	496,3	482,2	467,2	553,7	529,6	517,8
M25	0,4492	0,4492	0,4478	0,4457	0,4381	0,4499	0,4499	0,4497
W25	471,94	482,73	452,08	418,85	379,87	535,28	547,54	517,11
P28/25	0,9930	0,9930	0,9931	0,9931	0,9933	0,9930	0,9930	0,9930
P28	7,615	7,618	7,059	6,470	5,854	8,798	8,802	8,221
T28	532,3	509,2	496,3	482,2	467,2	553,7	529,6	517,8
W28	471,94	482,73	452,08	418,85	379,87	535,28	547,54	517,11
CV29	0,9975	0,9975	0,9971	0,9970	0,9970	0,9989	0,9989	0,9979
CF28	0,9850	0,9850	0,9828	0,9793	0,9746	0,9862	0,9862	0,9850
AE28	2688,1	2688,1	2682,0	2672,5	2659,6	2691,4	2691,4	2690,8
A28	2729,0	2729,0	2729,0	2729,0	2728,9	2729,0	2729,0	2729,1
V28	1032,7	1010,0	997,1	974,3	885,3	1053,2	1030,0	1018,4
W28	1,0000	1,0000	1,0000	0,9896	0,9005	1,0000	1,0000	1,0000
Z1C	0,6253	0,6224	0,6526	0,6978	0,7530	0,6733	0,6701	0,7226
P24/1C	2,7407	2,7420	2,5062	2,2412	1,9580	2,6499	2,6509	2,4638
W1C*	161,02	161,41	143,43	123,10	100,91	151,31	151,70	135,50
W1C	53,05	54,36	48,30	41,46	33,98	58,09	59,53	53,21
ETA1C	0,8610	0,8611	0,8661	0,8652	0,8561	0,8640	0,8644	0,8644
HP1C	3116,	3054,	2425,	1800,	1217,	3442,	3372,	2758,
P24	12,305	12,306	11,248	10,059	8,788	14,223	14,222	13,218
T24	619,4	592,4	574,8	554,7	532,3	644,2	616,1	601,9
M24	0,4600	0,4611	0,4358	0,4047	0,3654	0,4400	0,4411	0,4136
Q24	1,5756	1,5830	1,3124	1,0304	0,7493	1,6854	1,6937	1,4055
P2C/24	0,9896	0,9896	0,9905	0,9917	0,9931	0,9904	0,9903	0,9914
AE2D	0,	0,	0,	0,	0,	0,	0,	0,
WB/W24	0,	0,	0,	0,	0,	0,	0,	0,
P2C	12,177	12,178	11,142	9,975	8,727	14,086	14,085	13,104
T2C	619,4	592,4	574,8	554,7	532,3	644,2	616,1	601,9
PCNG	97,924	95,865	92,697	89,393	85,443	98,354	96,255	93,577
PCNG*	89,612	89,702	88,057	86,438	84,343	88,254	88,319	86,869
NG	14271,	13971,	13510,	13028,	12452,	14334,	14028,	13633,
PCNG*M	100,890	100,991	99,140	97,317	94,958	99,362	99,435	97,803
WARC2C	0,	0,	0,	0,	0,	0,	0,	0,
W2C	53,05	54,36	48,30	41,46	33,98	58,09	59,53	53,21
W2C*	69,97	70,11	67,07	63,17	57,97	67,54	67,70	64,28

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
10/20/75
RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER
MISSION ANALYSIS CYCLE DATA PACKAGE

CASE	81,00	82,00	83,00	84,00	85,00	86,00	87,00	88,00
P3/P2C	14,4120	14,4607	13,5310	12,4314	11,0368	13,6478	13,6978	12,7221
Z2C	0,5929	0,5945	0,5806	0,5591	0,5229	0,5809	0,5829	0,5653
ETAC	0,8547	0,8542	0,8630	0,8680	0,8717	0,8623	0,8622	0,8671
HPC	14422,	14187,	11694,	9203,	6747,	15794,	15535,	12969,
RNI2C	0,6626	0,7005	0,6656	0,6232	0,5745	0,7301	0,7715	0,7390
P3/P2	39,0883	39,2367	33,5902	27,6298	21,4605	35,8171	35,9600	31,0735
P3	175,50	176,10	150,76	124,00	96,32	192,24	192,93	166,71
PS3	166,00	166,55	142,39	116,94	90,64	181,66	182,29	157,31
T3	1409,8	1354,8	1285,4	1209,7	1121,4	1432,8	1376,5	1315,2
WAR3	0,	0,	0,	0,	0,	0,	0,	0,
W3	51,25	52,51	46,66	40,05	32,83	56,12	57,51	51,40
W31	44,91	46,01	40,88	35,09	28,76	49,17	50,39	45,04
M3	0,2876	0,2875	0,2906	0,2940	0,2987	0,2902	0,2901	0,2933
P4/P3	0,9474	0,9473	0,9461	0,9448	0,9430	0,9466	0,9465	0,9453
WFM	4323,6	4206,3	3339,8	2521,3	1751,3	4664,9	4537,5	3651,4
ETABM	0,9875	0,9875	0,9875	0,9875	0,9875	0,9875	0,9875	0,9875
FAR339	0,02674	0,02540	0,02269	0,01996	0,01691	0,02635	0,02501	0,02252
T39	2973,0	2858,7	2659,1	2446,9	2198,7	2971,8	2856,6	2674,5
T4	2880,0	2768,7	2576,2	2371,1	2132,1	2880,0	2767,9	2592,3
WAR4	0,	0,	0,	0,	0,	0,	0,	0,
FAR4	0,02494	0,02368	0,02116	0,01861	0,01577	0,02457	0,02332	0,02100
P4	166,26	166,81	142,63	117,16	90,83	181,97	182,60	157,59
W4	49,36	50,51	44,78	38,34	31,34	54,03	55,30	49,32
TFFC	15,93	15,93	15,93	15,93	15,93	15,93	15,93	15,93
N/RT4	265,93	265,52	266,17	267,55	269,68	267,10	266,64	267,36
DH/T4	0,07181	0,07180	0,07177	0,07169	0,07152	0,07185	0,07184	0,07181
ETAT	0,8979	0,8979	0,8979	0,8979	0,8977	0,8980	0,8980	0,8981
HPT	14445,	14209,	11713,	9219,	6760,	15818,	15558,	12990,
HPAUX	22,71	21,90	18,89	16,07	13,33	24,03	23,17	20,17
P4/P51	3,8735	3,8804	3,8920	3,9019	3,9116	3,8765	3,8833	3,8933
P51	42,921	42,987	36,647	30,026	23,221	46,942	47,021	40,478
T51	2152,5	2062,8	1909,1	1747,7	1562,0	2152,7	2062,4	1922,3
FAR51	0,02367	0,02248	0,02008	0,01767	0,01497	0,02333	0,02214	0,01993
WAR51	0,	0,	0,	0,	0,	0,	0,	0,
W51	51,94	53,15	47,12	40,35	32,98	56,85	58,19	51,90
M51	0,4791	0,4785	0,4772	0,4754	0,4727	0,4796	0,4790	0,4778
P54/51	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
P54	42,921	42,987	36,647	30,026	23,221	46,942	47,021	40,478
T54	2152,5	2062,8	1909,1	1747,7	1562,0	2152,7	2062,4	1922,3
FAR54	0,02367	0,02248	0,02008	0,01767	0,01497	0,02333	0,02214	0,01993
WAR54	0,	0,	0,	0,	0,	0,	0,	0,
W54	51,94	53,15	47,12	40,35	32,98	56,85	58,19	51,90
TFF2TC	56,14	56,16	56,18	56,17	56,14	56,19	56,20	56,22
N/RT54	94,63	94,62	91,30	87,49	82,22	93,72	93,71	91,32
DH/T54	0,10690	0,10676	0,10295	0,09719	0,08842	0,10809	0,10795	0,10494

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
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RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER
MISSION ANALYSIS CYCLE DATA PACKAGE

CASE	81,00	82,00	83,00	84,00	85,00	86,00	87,00	88,00
ETA2T	0,9198	0,9201	0,9162	0,9102	0,9004	0,9192	0,9194	0,9166
HP2T	16908,	16561,	13103,	9696,	6446,	18715,	18330,	14813,
RNI54	0,6077	0,6378	0,5921	0,5346	0,4678	0,6645	0,6978	0,6490
P54/56	8,8335	8,8558	8,1851	7,2294	5,9750	9,1464	9,1713	8,6244
P56	4,859	4,854	4,477	4,153	3,886	5,132	5,127	4,693
T56	1326,1	1264,3	1185,0	1110,7	1033,0	1317,5	1255,7	1180,7
W56	54,15	55,42	49,13	42,08	34,40	59,27	60,67	54,12
M56	0,4668	0,4660	0,4235	0,3684	0,3018	0,4874	0,4867	0,4501
P8/56	0,9911	0,9911	0,9924	0,9941	0,9959	0,9904	0,9904	0,9916
FAR8	0,02268	0,02154	0,01929	0,01693	0,01434	0,02235	0,02121	0,01910
WAR8	0,	0,	0,	0,	0,	0,	0,	0,
W8	54,15	55,42	49,13	42,08	34,40	59,27	60,67	54,12
T8	1326,1	1264,3	1185,0	1110,7	1033,0	1317,5	1255,7	1180,7
P8	4,816	4,811	4,443	4,129	3,870	5,083	5,078	4,634
P8QP0	1,3926	1,3912	1,2850	1,1940	1,1192	1,4699	1,4684	1,3438
M8	0,7152	0,7131	0,6172	0,5156	0,4085	0,7737	0,7715	0,6735
V8	1202,3	1172,0	993,6	812,7	627,4	1288,1	1255,6	1076,2
CF8	1,0165	1,0165	1,0165	1,0165	1,0165	1,0165	1,0165	1,0165
CV9	0,9970	0,9970	0,9970	0,9970	0,9970	0,9970	0,9970	0,9970
AE8	846,46	846,76	846,61	846,59	848,08	847,07	847,23	847,37
A8	832,7	833,0	832,9	832,8	834,3	833,3	833,5	833,6
FD	9795,	9799,	9129,	8398,	7551,	14761,	14768,	13874,
FGG	16643,	16647,	16207,	13707,	11091,	23067,	23076,	20517,
ENU/W2	16,85	16,47	14,14	11,53	8,55	14,00	13,68	11,55
D/F-PC	2,9	2,9	3,4	4,1	5,6	5,3	5,3	6,2
CD	0,1843	0,1843	0,1843	0,1843	0,1843	0,1843	0,1843	0,1843
FDI	256,0	256,2	238,6	219,5	197,4	441,4	441,7	415,0
SWFMG	1,00000	1,00000	1,00000	1,00000	1,00000	1,00000	1,00000	1,00000
SFNG	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
WC3/2C	0,0902	0,0902	0,0902	0,0902	0,0902	0,0902	0,0902	0,0902
WC4/2C	0,0614	0,0614	0,0614	0,0614	0,0614	0,0614	0,0614	0,0614
WC512C	0,0360	0,0360	0,0360	0,0360	0,0360	0,0360	0,0360	0,0360
WC5D2C	0,0125	0,0125	0,0125	0,0125	0,0125	0,0125	0,0125	0,0125
WC542C	0,	0,	0,	0,	0,	0,	0,	0,
WC5511	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050	0,0050
WC5512	0,0367	0,0367	0,0367	0,0367	0,0367	0,0367	0,0367	0,0367
WC552C	0,0417	0,0417	0,0417	0,0417	0,0417	0,0417	0,0417	0,0417
WCI/2C	0,0320	0,0320	0,0320	0,0320	0,0320	0,0320	0,0320	0,0320
FIBAH	0,3880	0,3880	0,3880	0,3880	0,3880	0,3880	0,3880	0,3880
FCAH51	0,2850	0,2850	0,2850	0,2850	0,2850	0,2850	0,2850	0,2850
FCAH54	0,7500	0,7500	0,7500	0,7500	0,7500	0,7500	0,7500	0,7500
FCH551	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
FCH552	0,2770	0,2770	0,2770	0,2770	0,2770	0,2770	0,2770	0,2770

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
10/20/75
RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER
MISSION ANALYSIS CYCLE DATA PACKAGE

CASE	89.00	90.00	91.00	92.00	93.00	94.00	95.00	96.00
ALT	35000.	35000.	35000.	35000.	35000.	35000.	35000.	35000.
MO	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800
PC	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
RC	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
FNG	4984.1	3323.2	8306.0	8305.0	8304.9	8306.5	8305.9	8306.5
SFCG	0.5627	0.6003	0.5616	0.5464	0.5569	0.5684	0.5805	0.5492
DELTO	3.90	3.90	22.10	3.90	3.90	3.90	3.90	3.90
TO	397.75	397.75	415.95	397.75	397.75	397.75	397.75	397.75
PO	3.4580	3.4580	3.4580	3.4580	3.4580	3.4580	3.4580	3.4580
T2	448.89	448.89	469.43	448.89	448.89	448.89	448.89	448.89
ETAR	1.0180	1.0180	1.0180	1.0180	1.0180	1.0180	1.0180	1.0180
P2	5.367	5.367	5.369	5.367	5.367	5.367	5.367	5.367
P22/P2	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996
M21	0.4961	0.4407	0.6098	0.6106	0.6125	0.6141	0.6158	0.6102
P22	5.365	5.365	5.367	5.365	5.365	5.365	5.365	5.365
B	10.5133	11.6736	9.2147	9.1972	9.1174	9.0562	9.0034	9.2311
PATH	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR
WB/W2C	0.0020	0.0020	0.0020	0.0020	0.0220	0.0420	0.0620	0.0020
WB	0.	0.	0.	0.	0.	0.	0.	0.
PBD	134.75	106.50	187.07	187.73	186.75	185.55	184.23	187.40
TBD	1244.1	1162.5	1432.8	1376.5	1375.5	1376.2	1377.7	1375.2
WBI	0.092	0.077	0.116	0.119	1.322	2.544	3.781	0.119
PBI	55.47	45.08	74.44	74.65	73.60	72.17	70.24	74.62
TBI	992.7	933.7	1135.3	1089.2	1088.1	1088.2	1088.9	1088.6
HPE	0.	0.	0.	0.	0.	0.	0.	100.0
PCNF	78.310	70.617	92.298	90.333	90.475	90.606	90.740	90.309
NF	3689.2	3326.8	4348.1	4255.6	4262.3	4268.4	4274.8	4254.4
PCNF*	84.177	75.908	97.018	97.101	97.254	97.394	97.538	97.074
W2*	1350.14	1235.74	1545.64	1546.98	1549.71	1552.09	1554.48	1546.36
W2	529.82	484.93	593.37	607.07	608.14	609.08	610.01	606.33
P23/22	1.4270	1.3024	1.6509	1.6521	1.6538	1.6556	1.6575	1.6521
Z22	0.5475	0.4801	0.6457	0.6458	0.6448	0.6443	0.6439	0.6456
ETAF	0.8608	0.8457	0.8608	0.8609	0.8610	0.8610	0.8611	0.8609
HPFAN	9156.	6307.	15273.	14957.	15002.	15048.	15098.	14956.
RNT22	0.4400	0.4400	0.4153	0.4400	0.4400	0.4400	0.4400	0.4400
M23	0.4407	0.4342	0.4485	0.4486	0.4491	0.4494	0.4498	0.4493
P25P23	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
M25P	0.4490	0.4474	0.4499	0.4498	0.4498	0.4498	0.4498	0.4498
AE25P	3872.8	3872.8	3872.8	3872.8	3872.8	3872.8	3872.8	3872.8

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
10/20/75
RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER
MISSION ANALYSIS CYCLE DATA PACKAGE

CASE	89.00	90.00	91.00	92.00	93.00	94.00	95.00	96.00
P25P	7.656	6.987	8.861	8.864	8.873	8.883	8.892	8.864
P2525P	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
P25	7.656	6.987	8.861	8.864	8.873	8.882	8.892	8.863
Q25	0.9419	0.8543	1.0931	1.0935	1.0947	1.0958	1.0971	1.0934
T25	504.8	490.6	553.7	529.6	529.7	529.9	530.1	529.6
M25	0.4491	0.4475	0.4499	0.4499	0.4499	0.4499	0.4499	0.4499
W25	483.81	446.67	535.28	547.54	548.03	548.51	549.03	547.52
P28/25	0.9930	0.9931	0.9930	0.9930	0.9930	0.9930	0.9930	0.9930
P28	7.602	6.939	8.798	8.802	8.811	8.820	8.830	8.801
T28	504.8	490.6	553.7	529.6	529.7	529.9	530.1	529.6
W28	483.81	446.67	535.28	547.54	548.03	548.51	549.03	547.52
CV29	0.9975	0.9970	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989
CF28	0.9850	0.9822	0.9862	0.9862	0.9862	0.9862	0.9862	0.9862
AE28	2688.0	2680.5	2691.4	2691.4	2691.4	2691.3	2691.4	2691.3
A28	2729.0	2729.0	2729.0	2729.0	2729.1	2729.0	2729.0	2729.0
V28	1005.6	991.4	1053.2	1030.0	1030.1	1030.3	1030.5	1030.0
M28	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Z1C	0.7569	0.8192	0.6733	0.6701	0.6400	0.6168	0.5955	0.6828
P24/1C	2.2106	1.9624	2.6499	2.6509	2.6362	2.6244	2.6132	2.6577
W1C*	117.27	97.50	151.31	151.70	153.19	154.34	155.39	151.14
W1C	46.02	38.26	58.09	59.53	60.11	60.57	60.98	59.31
ETA1C	0.8608	0.8474	0.8640	0.8644	0.8649	0.8648	0.8645	0.8639
HP1C	2073.	1462.	3442.	3372.	3381.	3389.	3396.	3372.
P24	11.860	10.528	14.223	14.222	14.143	14.080	14.020	14.259
T24	581.9	561.7	644.2	616.1	614.9	614.0	613.2	616.7
M24	0.3871	0.3507	0.4400	0.4411	0.4493	0.4560	0.4624	0.4378
Q24	1.1219	0.8325	1.6854	1.6937	1.7394	1.7762	1.8111	1.6762
P2C/24	0.9923	0.9936	0.9904	0.9903	0.9900	0.9898	0.9895	0.9905
AE2D	0.	0.	0.	0.	0.	0.	0.	0.
WB/W24	0.	0.	0.	0.	0.	0.	0.	0.
P2C	11.769	10.461	14.086	14.085	14.002	13.936	13.873	14.123
T2C	581.9	561.7	644.2	616.1	614.9	614.0	613.2	616.7
PCNG	90.547	86.729	98.354	96.255	96.589	96.983	97.445	96.112
PCNG*	85.485	83.338	88.254	88.319	88.711	89.136	89.616	88.146
NG	13196.	12640.	14334.	14028.	14077.	14134.	14202.	14007.
PCNG*M	96.244	93.827	99.362	99.435	99.876	100.355	100.895	99.240
WARC2C	0.	0.	0.	0.	0.	0.	0.	0.
W2C	46.02	38.26	58.09	59.53	60.11	60.57	60.98	59.31
W2C*	60.87	55.94	67.54	67.70	68.69	69.49	70.24	67.30

NASA-USTEDLEC/TP4 CYCLE (TURBOPROP CORE CYCLE)
10/20/75
RESISED TO SIMULATE A PROPELLER IN FRONT OF THE BOOSTER
MISSION ANALYSIS CYCLE DATA PACKAGE

CASE	89,00	90,00	91,00	92,00	93,00	94,00	95,00	96,00
P3/P2C	11,7820	10,4874	13,6478	13,6978	13,7013	13,6728	13,6322	13,6345
Z2C	0,5423	0,5148	0,5809	0,5829	0,5485	0,5102	0,4699	0,5890
ETAC	0,8706	0,8722	0,8623	0,8622	0,8606	0,8567	0,8517	0,8630
HPC	10360,	7773,	15794,	15535,	15561,	15587,	15614,	15439,
RNI2C	0,6923	0,6433	0,7301	0,7715	0,7689	0,7666	0,7643	0,7727
P3/P2	25,8452	20,4479	35,8171	35,9600	35,7588	35,5155	35,2494	35,8913
P3	138,66	109,71	192,24	192,93	191,65	190,54	189,12	192,56
PS3	130,65	103,15	181,66	182,29	181,41	180,32	179,12	182,00
T3	1244,1	1162,5	1432,8	1376,5	1375,5	1376,2	1377,7	1375,2
WAR3	0,	0,	0,	0,	0,	0,	0,	0,
W3	44,45	36,96	56,12	57,51	56,86	56,09	55,25	57,30
W31	38,95	32,39	49,17	50,39	49,67	48,84	47,96	50,20
M3	0,2964	0,3011	0,2902	0,2901	0,2882	0,2860	0,2839	0,2894
P4/P3	0,9441	0,9423	0,9466	0,9465	0,9471	0,9478	0,9485	0,9457
WFM	2804,3	1994,9	4664,9	4537,5	4625,3	4721,6	4821,7	4562,2
ETABM	0,9875	0,9875	0,9875	0,9875	0,9875	0,9875	0,9875	0,9875
FAR339	0,02000	0,01711	0,02635	0,02501	0,02586	0,02685	0,02793	0,02524
T39	2478,2	2245,3	2971,8	2856,6	2899,9	2951,3	3007,3	2867,5
T4	2402,5	2178,4	2880,0	2767,9	2806,7	2853,3	2903,9	2778,1
WAR4	0,	0,	0,	0,	0,	0,	0,	0,
FAR4	0,01865	0,01595	0,02457	0,02332	0,02408	0,02495	0,02591	0,02354
P4	130,91	103,38	181,97	182,60	181,70	180,59	179,37	182,30
W4	42,55	35,29	54,03	55,30	54,65	53,87	53,04	55,11
TFFC	15,93	15,93	15,93	15,93	15,93	15,93	15,93	15,93
N/RT4	269,23	270,82	267,10	266,64	265,71	264,61	263,54	265,75
DH/T4	0,07174	0,07160	0,07185	0,07184	0,07181	0,07178	0,07176	0,07184
ETAT	0,8981	0,8981	0,8980	0,8980	0,8979	0,8979	0,8978	0,8979
HPT	10377,	7787,	15818,	15558,	15585,	15611,	15637,	15562,
HPAUX	17,26	14,37	24,03	23,17	23,33	23,51	23,72	23,12
P4/P51	3,9030	3,9121	3,8765	3,8833	3,8760	3,8722	3,8666	3,8831
P51	33,539	26,425	46,942	47,021	46,853	46,637	46,389	46,947
T51	1772,5	1598,2	2152,7	2062,4	2092,6	2129,0	2168,6	2070,5
FAR51	0,01770	0,01514	0,02333	0,02214	0,02283	0,02363	0,02450	0,02234
WAR51	0,	0,	0,	0,	0,	0,	0,	0,
W51	44,79	37,15	56,85	58,19	57,56	56,81	56,00	57,99
M51	0,4761	0,4738	0,4796	0,4790	0,4793	0,4797	0,4802	0,4791
P54/51	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
P54	33,539	26,425	46,942	47,021	46,853	46,637	46,389	46,947
T54	1772,5	1598,2	2152,7	2062,4	2092,6	2129,0	2168,6	2070,5
FAR54	0,01770	0,01514	0,02333	0,02214	0,02283	0,02363	0,02450	0,02234
WAR54	0,	0,	0,	0,	0,	0,	0,	0,
W54	44,79	37,15	56,85	58,19	57,56	56,81	56,00	57,99
TFF2TC	56,22	56,20	56,19	56,20	56,20	56,20	56,21	56,20
N/RT54	87,63	83,22	93,72	93,71	93,18	92,51	91,80	93,50
DH/T54	0,09998	0,09249	0,10809	0,10795	0,10787	0,10775	0,10764	0,10790

5.2.4 OFF Design Performance

Off design propellor η was provided by HSD to match key mission points. Table 5.3.1-1 The η was provided at a U_T consistend with the LP rotor speed calculated from the cycle.

35K/.8/0 Cruise

This flight condition represents the most significant segment of the aircraft mission with respect to fuel burned. A side study indicated that operation at U_T = constant to as low a power as possible provided an overall SFC benefit. Attached is a sample calculation of a speed adjustment.

For $U_T = 800$ $N_{LPT} = 4482$ rpm

Point #87

Alt = 35K, M = .8, $\Delta T_0 = 0$, Max Cruise

$N_{LPT\,cycle} = 4255 \Rightarrow U_T = \underline{760}$

Referencing attached turbine map Fig 5.2.4-1

U_T	N	$N/\sqrt{T_5}_{cycle}$	$N/\sqrt{T_5}_{map}$	$\Delta h/T_{cy}$	$\Delta h/T_{map}$	$\eta_{LPT\,map}$
760	4255	93.71	97.43	.10795	.07177	.911
800	4482	98.64	102.55			.92

$\therefore$ Increasing speed $\Rightarrow$ $\boxed{+ .9\%\ LPT}$

Booster Efficiency

U_T	$\% N/\sqrt{\theta}$	$\omega\sqrt{\theta}/\delta_{cycle}$	$\omega\sqrt{\theta}/\delta_{map}$	P/P_{cycle}	P/P_{map}	η
760	97.1	151.7	267.6	2.65	2.46	.858
800	102.2					.84

$\therefore$ Booster $\boxed{\Delta\eta = +1.8\%}$

Booster efficiency is manually increased 1.8% above cycle value.

Computing power available

HP2T is up by η_{LPT}

$$HP2T = 18330\left(\frac{.9194 + .9}{.9194}\right) = \underline{18510}$$

Booster power down by booster η

$$HP1C = 3372\left(\frac{.8644}{.8644 + .018}\right) = 3303$$

$\eta_{gear} = .983$ from attached curve

Prop Power $= (18510 - 3303)(.983) = 14948$

* Effect of lower core inlet temp neglected
* Effect of lower LPT discharge temp neglected

Propellor η

$$SHP/D^2 = \frac{14934}{(21.41)^2} = 32.62$$

$U_T = 800$

Entering HSD "Generalized Prop-Fan Performance"

$\eta = .815$

.897

$$F_{prop} = \frac{(15207)(.815)(550)(.983)}{778} = 8616$$

$$F_D = \frac{14768}{10.197} = 1448$$

$$F_{g8} = (60.67)(1256)\frac{(.997)}{32.2} = 2359$$

$$F_{N\,BARE} = 8616 + 2359 - 1448 = 9527$$

$$W_F = 4537$$

$$SFC_{BARE} = \frac{4537}{9527} =$$

$$D = 631\#$$

$$\boxed{\begin{array}{l} F_{N\,I} = 8896 \\ SFC_I = .51 \end{array}}$$

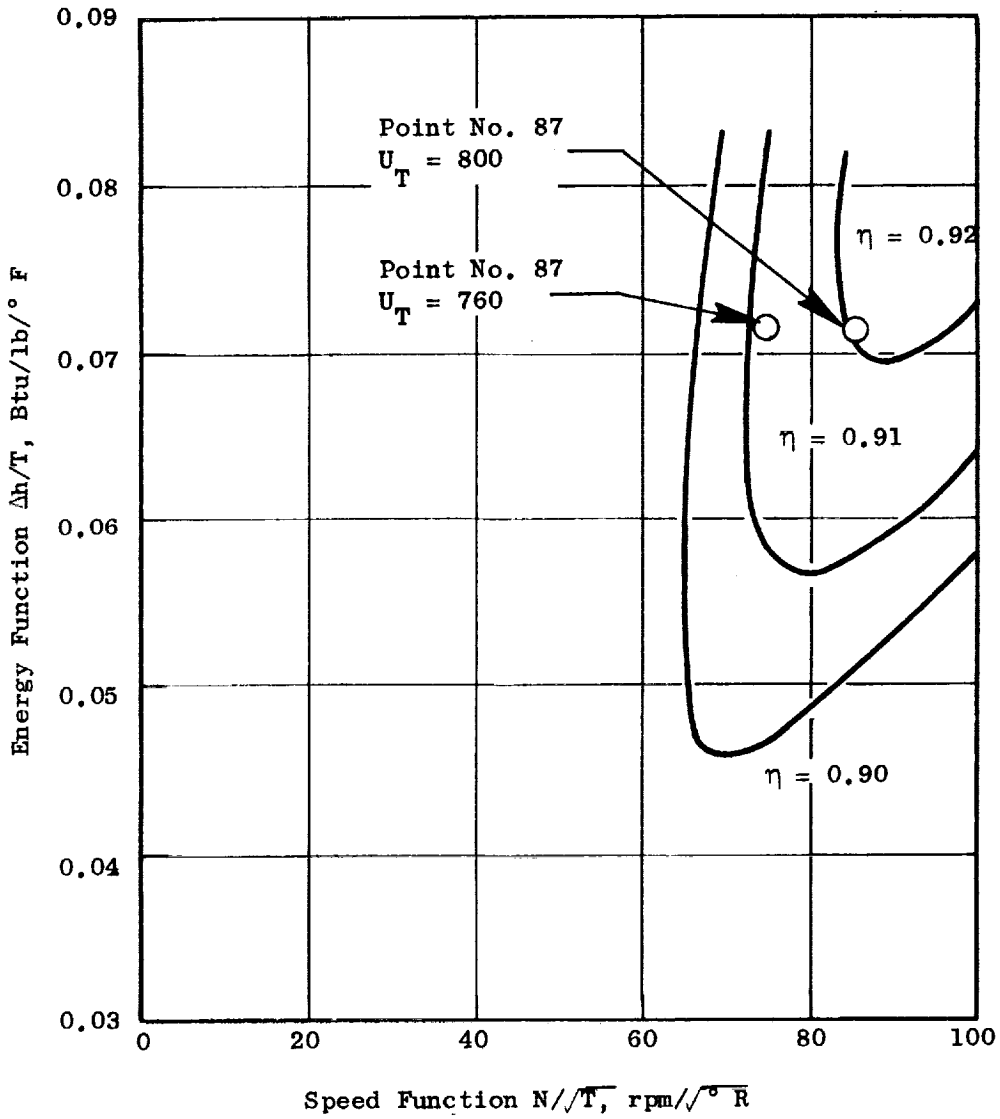

0.09
0.08
0.07
0.06
0.05
0.04
0.03
0
20
40
60
80
100
Point No. 87
U_T = 800
Point No. 87
U_T = 760
η = 0.92
η = 0.91
η = 0.90
Energy Function Δh/T, Btu/lb/° F
Speed Function N/√T, rpm/√° R

FIGURE 5.2.4-1

5.2.5 Installation Drag Adjustment

@ 35K/.8/+18 Mx Cl

Installation Drag = 634

Drag was assumed $\propto$ to q behind prop

From Actuator Disc Theory

$$\Delta V = \sqrt{V_0^2 + \frac{F}{\rho_0 A}} - V_0$$

$D_{prop} = 21.41$ ft

$r/r = .23$

$A = 341$ ft^2

@ 35K/.8/+18 Mx Cl

$V_0 = 796.6$

$F = 9086$ $\Rightarrow \Delta V = 46.2$

Using Point #87

$V_0 = 778$

$F = 8616$ $\Rightarrow \Delta V = 44.8$

$$\frac{D_1}{D_2} \propto \frac{(V_{01} + \Delta V_1)^2}{(V_{02} + \Delta V_2)^2} \left(\frac{T_{02}}{T_{01}}\right)$$

$$\therefore D = (634)\left(\frac{778 + 44.8}{796.6 + 46.2}\right)^2 \left(\frac{411.85}{393.85}\right) = \boxed{631}$$

5.2.6 Aircraft Mission Engine Data

The following is a tabulation of the engine performance used in the aircraft mission analysis. All data is presented on an installed basis

TABLE I

Basic H/S Performance

TP4 Turboprop Data / Drag Included 11/3/75

Pt	Alt	Mo	ΔT	FN		SFC		Rating
115	35K	.8	+18	9597		.533		Mx CL
86	↓	.8	+18	8796		.53		Mx Cr
87		.8	0	~~2918~~	8880	~~.507~~	.51	Mx Cr
88		.8	0	~~6993~~	6955	~~.522~~	.5218	80% Mx Cr
89		.8	0	5015		.559		60% Mx Cr
90		.8	0	3080		.648		40% Mx Cr
40	20K	.6	0	~~14718~~	14670	~~.427~~	.428	Mx Cr
41	↓	↓	↓	11863		.427		80% Mx Cr
42				8664		.451		60% "
43				5243		.524		40% "
2	0	.1	+27	41997		.256		T/O
3	↓	.2	↓	37113		.292		↓
8		.25		34827		.313		
9		.30		32608		.336		
36	1500	.4	0	8322		.455		* 40% Mx Cr
37	↓	↓	↓	5920		.509		* 30% "
38				3536		.641		* 20% "
29	10K	0	.45	24000		.347		Mx CL
31	10K	↓	.57	20511		.419		↓
45	20K		.7	14912		.477		
56	25K		.75	12617		.506		
65	30K		.75	11650		.481		
78	33K		.75	10505		.491		
21	0		.25	15249		.647		
23	0		.38	28504		.359		

* 100 HPX / 2#/S WBI

5.2.7 Final Adjustment of Cycle Data

At the .35K/.8/0 cruise the following adjustments were made to the cycle data used in the mission.

Booster $\Delta\eta = +1\%$

LPT $\Delta\eta = -.9$

LP Cooling $= -1.57\%$

Installed SFC was corrected by influence coefficients

$+1\%\ \eta_{Boost} = -.23\%\ SFC_I$

$+1\%\ \eta_{LPT} = -.9\%\ SFC_I$

$1\%\ W/W = .87\%\ SFC_I$

$$\Delta\%SFC = (.87)(-1.57) + (-.9)(.9) + (-.23)(1) = \boxed{-.78\%}$$

These three adjustments were based on a refined aerodynamic analysis of the booster and LPT. The cycle was run with preliminary efficiency and cooling flow different than those yielded by the analysis.

5.3.1 Hamilton Standard Prop Data

Table 5.3.1-1 was provided by HSD to define basic technology propeller performance at key flight conditions.

The data package titled "Generalized Prop-Fan Performance" was provided by HSD and was used for determining the effect of various speed schedules on η_{prop}

HSF-1227A

WORK SHEET

DATE

NAME ATTACH[illegible]NT

SHEET ___ OF ___

SUBJECT G.E. PROP-FAN PERFORMANCE SUMMARY Table 5.3.1-1 5.6.31

8 BLADE/16.0 FT. DIAM./200 AF/0.12 C_{li} PROP FAN

RATING	CASE	ALT.	TEMP.	M_N	SHP TO_{GB}	TURBINE RPM	TIP SPEED	η NET	T NET	$D_{NACELLE}$	S
Max. Climb	97	35,000	0	0.800	9,106.7	8,309.2	783	0.798	5,084	220	
Max. Climb	2	35,000	18	0.800	9,296.5	8,488.9	800	0.797	5,068	220	✓
Max. Cruise	3	35,000	18	0.800	8,498.5	8,230.2	776	0.804	4,695	219	✓
Max. Cruise	99	35,000	0	0.800	8,320.6	8,054.7	759	0.804	4,683	219	
80% Max. Cruise	100	35,000	0	0.800	6,732.1	7,587.2	715	0.812	3,675	216	
60% Max. Cruise	101	35,000	0	0.800	5,153.6	7,007.9	660	0.817	2,951	211	
40% Max. Cruise	102	35,000	0	0.800	3,603.1	6,342.1	598	0.803	2,027	206	
Max. Climb	107	20,000	18	0.600	12,227.9	8,137.8	767	0.815	8,553	240	
Max. Cruise	35	20,000	0	0.600	10,880.4	7,775.4	733	0.821	7,829	239	
80% Max. Cruise	36	20,000	0	0.600	8,695.5	7,259.4	684	0.839	6,392	235	
60% Max. Cruise	37	20,000	0	0.600	6,558.8	6,691.8	631	0.858	4,935	232	
40% Max. Cruise	38	20,000	0	0.600	4,448.0	6,027.5	568	0.871	3,398	228	
Takeoff	9	0	27	0.100	16,552.5	7,825.6	737	0.278	21,857	52	✓
Takeoff	10	0	27	0.200	16,787.6	7,825.3	737	0.484	19,304	93	
Takeoff	11	0	27	0.250	16,959.6	7,824.2	737	0.564	18,183	122	
Takeoff	12	0	27	0.300	17,171.1	7,822.4	737	0.629	17,123	157	
40% Takeoff	15	0	27	0.100	5,007.7	5,499.6	518	0.401	9,551	32	
40% Max. Cruise	79	1,500	0	0.400	5,031.9	5,487.3	517	0.857	5,256	214	
30% Max. Cruise	80	1,500	0	0.400	3,773.9	5,030.4	474	0.872	4,036	211	
20% Max. Cruise	81	1,500	0	0.400	2,629.6	4,449.0	419	0.863	2,783	209	
Max. Climb	21	10,000	0	0.450	13,798.6	7,756.5	731	0.754	11,691	212	
Max. Climb	23	10,000	0	0.570	14,488.4	7,745.4	730	0.823	10,590	322	
Max. Climb	25	20,000	0	0.700	12,595.1	7,977.5	752	0.837	7,924	330	
Max. Climb	27	25,000	0	0.750	11,505.1	8,060.9	760	0.814	6,711	305	
Max. Climb	91	30,000	0	0.750	10,150.1	8,175.0	770	0.809	5,999	246	
Max. Climb	93	33,000	0	0.750	9,379.0	8,273.3	780	0.803	5,570	216	
Max. Climb	95	34,900	0	0.750	8,884.3	8,327.6	785	0.793	5,263	198	
Max. Climb	17	0	0	0.250	15,321.5	7,443.7	701	0.574	17,163	120	
Max. Climb	19	0	0	0.380	15,911.6	7,444.6	702	0.725	14,828	226	

NOTES:
(1) 99% Gearbox Efficiency
(2) Cases Per G.E. (Hirschkron) Letter Dated 7/1/75
(3) Thrust and Drag units in pounds
(4) Reference Aero Calculation No. 2836(6)

GENERALIZED PROP-FAN PERFORMANCE ~~AND WEIGHT~~

PERFORMANCE

The attached aerodynamic data presents Prop-Fan parametric performance data covering a range of power loadings (SHP/D^2), number of blades, tip speeds and flight Mach numbers.

The cruise performance data is presented as uninstalled net efficiency. For this definition of efficiency, the increase in shaft thrust due to the Prop-Fan operating in the retarded velocity of the nacelle has been removed. This correction is required since this thrust increment is completely off-set by an equal pressure drag force on the nacelle. PRESSURE DRAG ONLY.

Installed propulsive thrust is obtained by adding the uninstalled net thrust and the core engine jet thrust and subtracting the viscous drag of the nacelle and the losses due to the nacelle/wing interference as illustrated in the following example:

Assume:
- 0.8 Mach number at 30,000 feet, ISA
- 12000 shaft horsepower
- 500 pounds of jet thrust
- 420 pounds of nacelle and wing interference drag
- 8 blades
- 16 foot Prop-Fan diameter

Then:
- At 800 feet per second tip speed and $SHP/D^2 = 12000/(16)^2 = 46.9$
- Net efficiency = 0.795 from curve P-32129 , or 79.5 net
- Net thrust = 550 SHP x η net / velocity (FPS)
- Speed of sound at 30,000 feet ISA = 994.4 FPS
- Net thrust = (550)(12000)(0.795)/(0.8)(994.4) = 6596 pounds
- Installed propulsive thrust = 6596 + 500 - 420 = 6676 pounds

$\frac{420}{6596} = .0637$

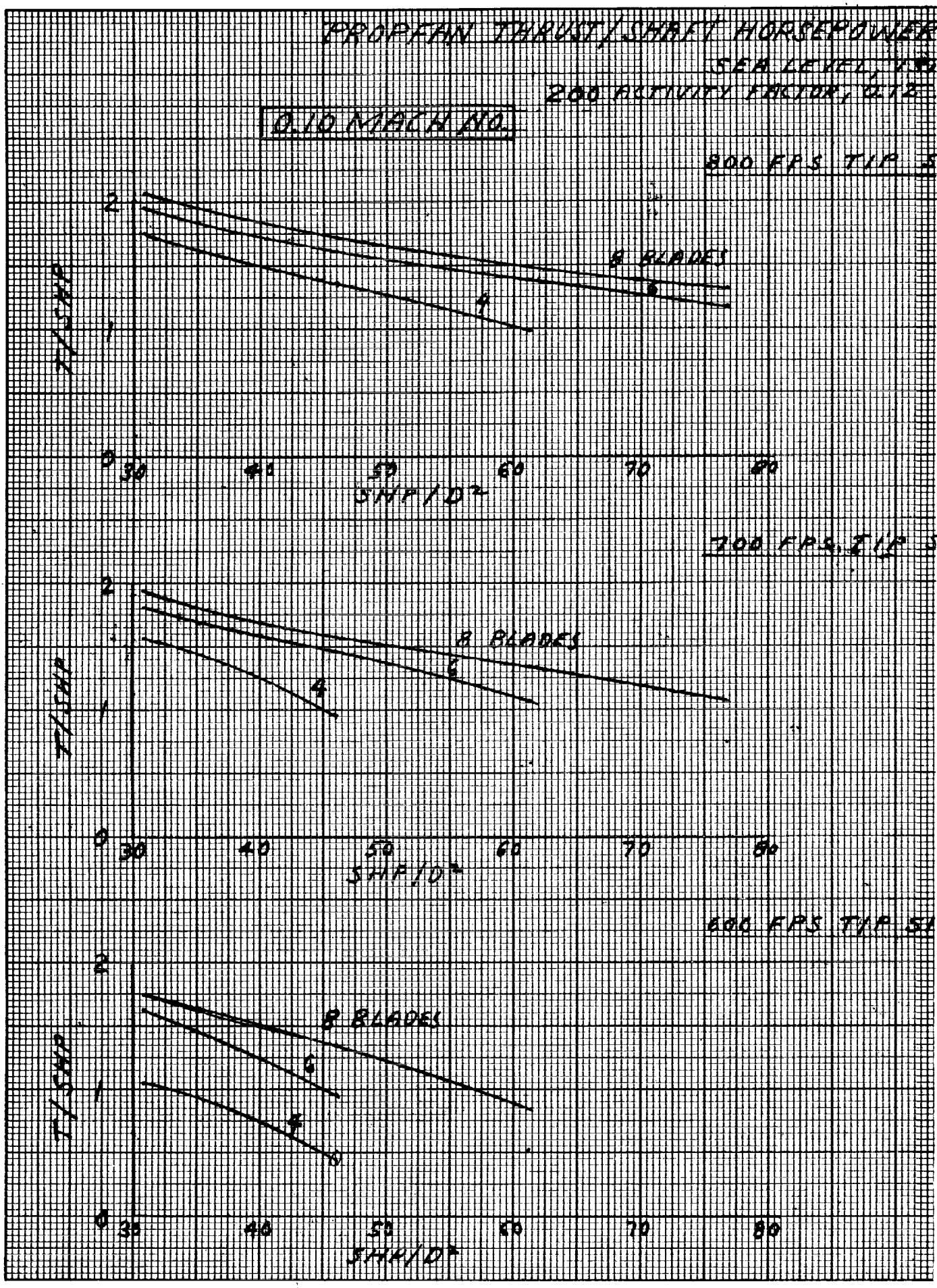
with $\frac{420}{\left(\frac{550}{.795}\right)} \cong 5$

WEIGHT

~~The attached weight data presents parametric dry weight for an 0.8M capability Prop-Fan. The data covers a range of fan diameters, number of blades, power loading and tip-speeds.~~

~~The rotor weight includes the blades, disk, spinner and pitch change system. The gearbox weight includes a gearbox integrated with the rotor components to provide the required engine-to-rotor speed (rpm) reduction and to provide structural support of the Prop-Fan system.~~

FOLDOUT FRAME



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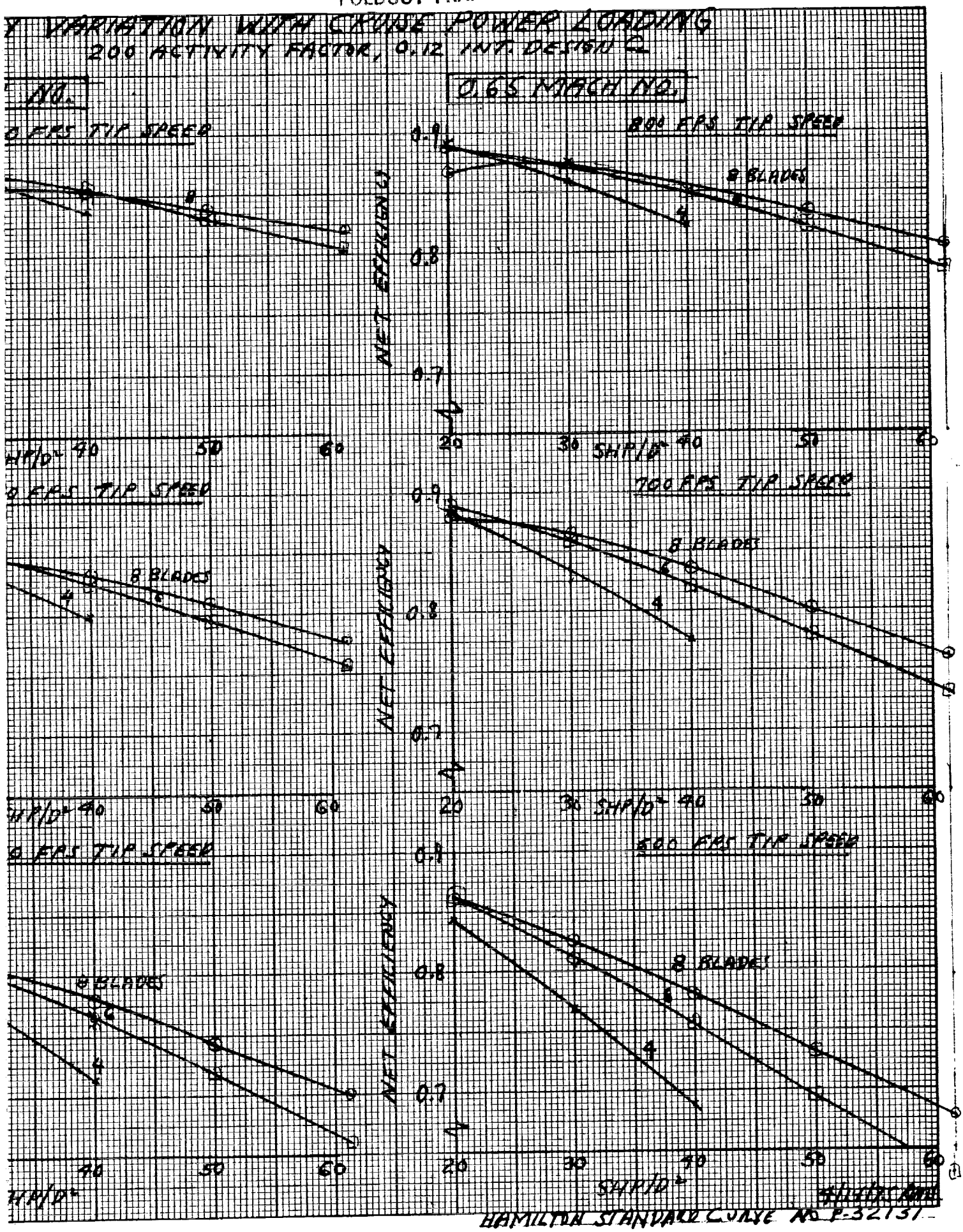

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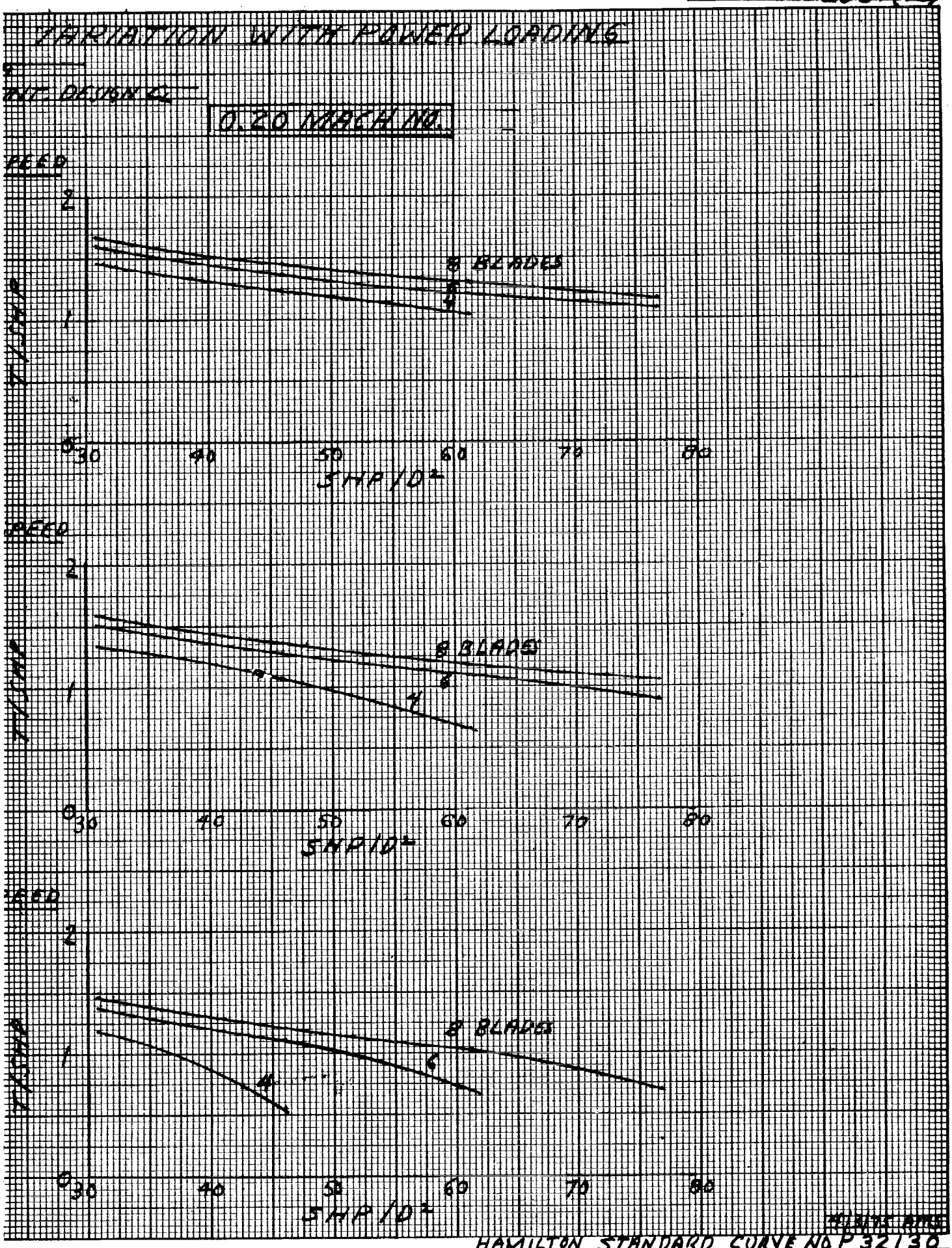

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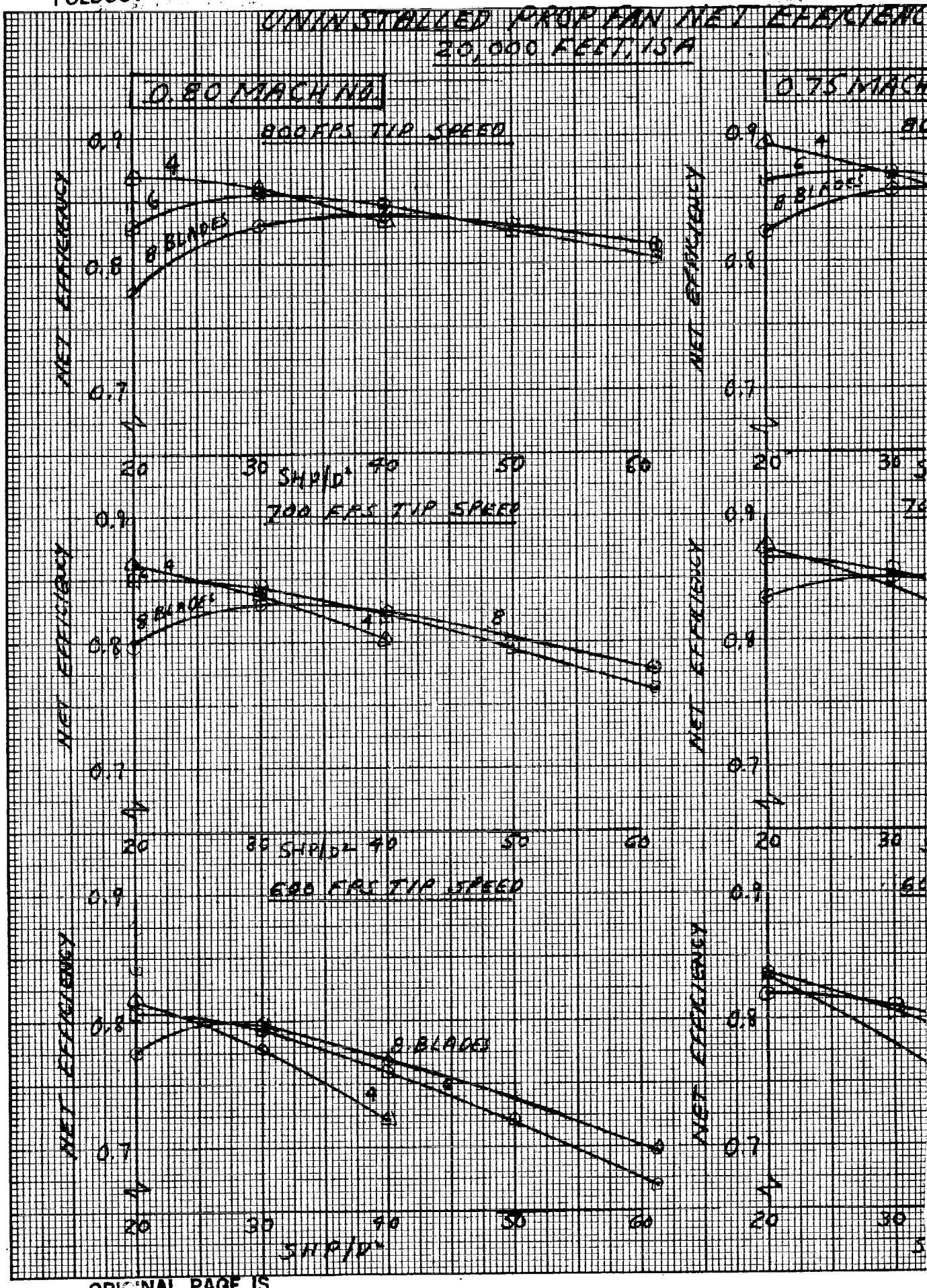

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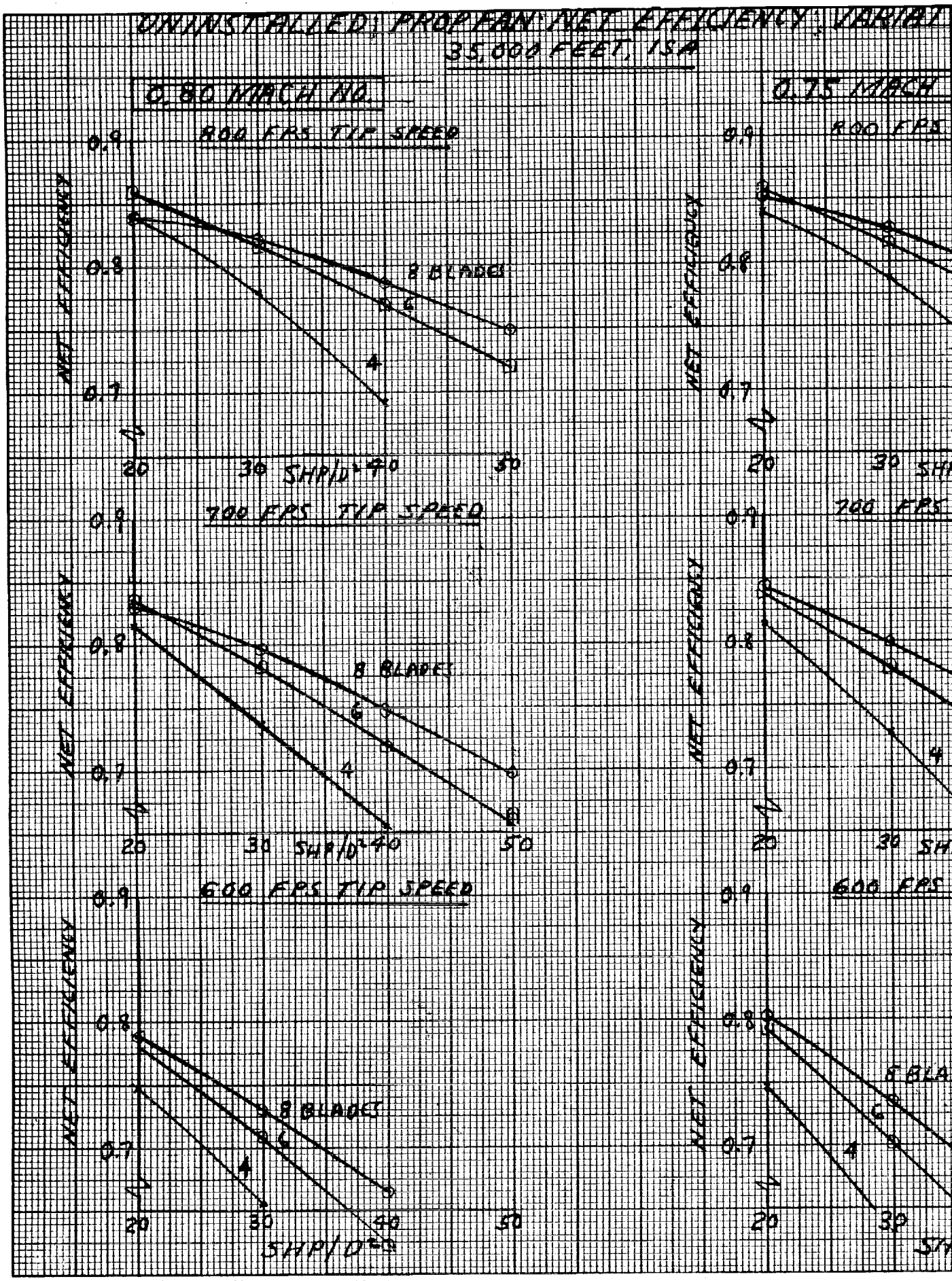

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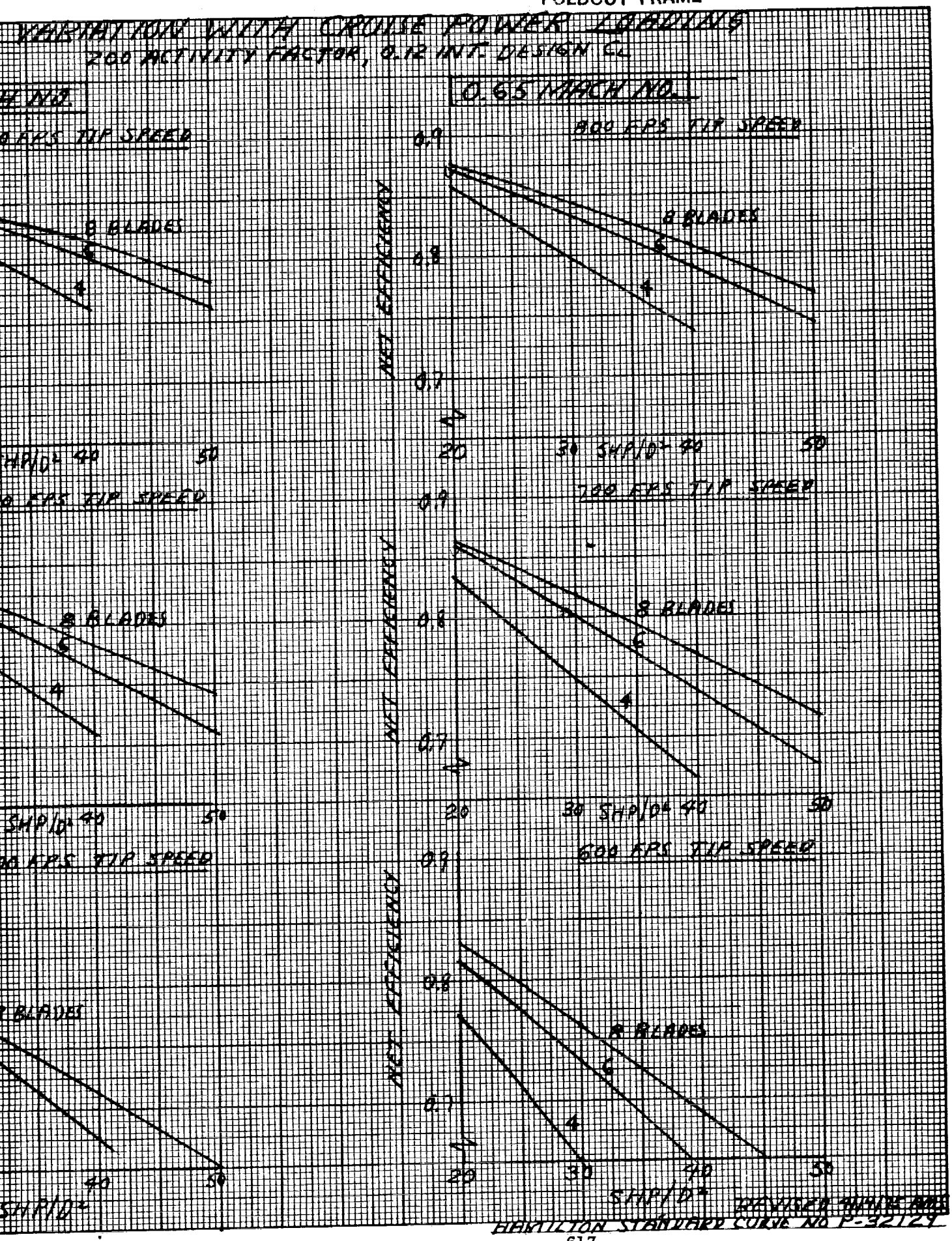

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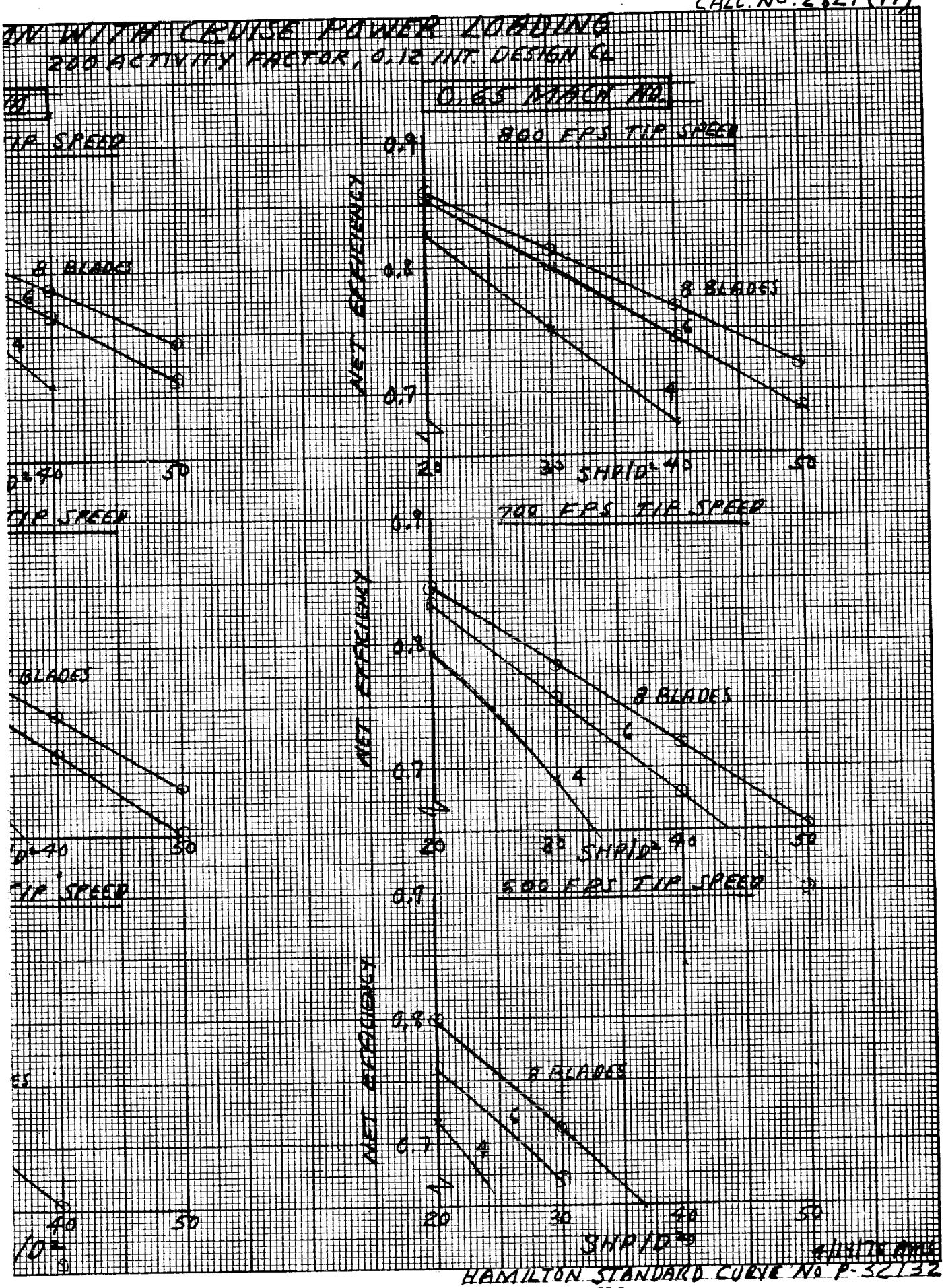

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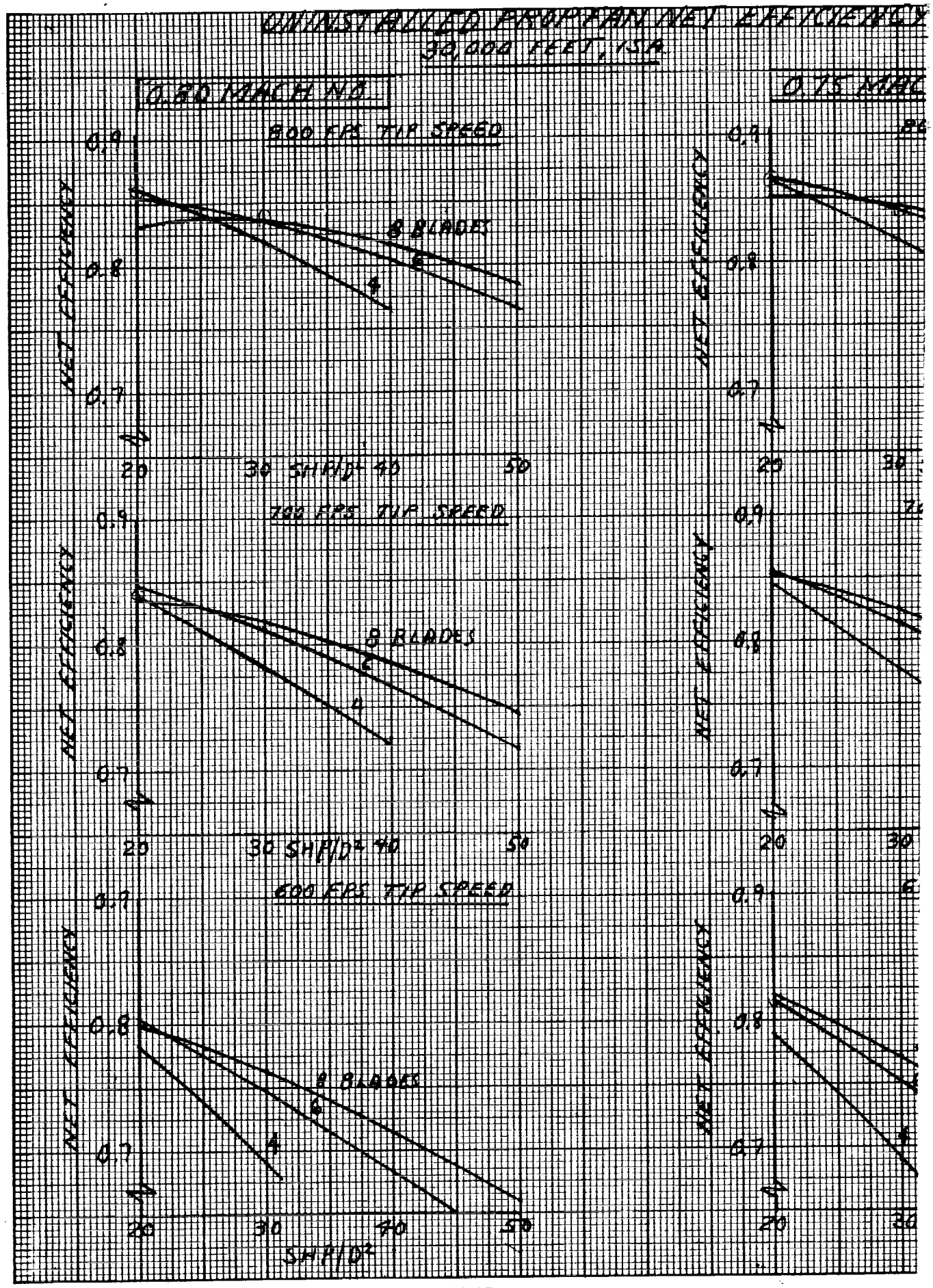

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5.3.2 Final HSD Prop Specification

The attached data covers all aspects of the propellor system proposed by Hamilton Standard.

HAMILTON STANDARD

Windsor Locks, Connecticut 06096

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RJ
GRW
SD

Please address answer to
Mail Stop No. 1A-3-1

September 23, 1975

General Electric Company
Aircraft Engine Group
1000 Western Avenue
Lynn, Massachusetts 01910

Attention: Mr. R. Hirschkron, Preliminary Design

Subject: Prop-Fan For USTEDLEC Study

Reference: (a) G.E. Order Number 200-4XX-14H48353
(b) HS/GE Technical Conference at G.E. on 9/4/75
(c) G.E. (Hirschkron) letter to HS (Gatzen), dated 8/19/75
(d) HS (Gatzen) letter to G.E. (Hirschkron) dated 8/8/75
(e) HS (Gatzen) letter to G.E. (Hirschkron) dated 8/29/75
(f) HS (Gatzen) letter to G.E. (Hirschkron) dated 9/2/75

Dear Bob:

This letter delivers all of the remaining data required by the G.E. Work Statement dated June 20, 1975 and completes the contractual obligation of Hamilton Standard. One additional data item has been requested by G.E. and this will be provided by HS. It is the performance loss associated with the gearbox oil cooler.

The SOW shall be referred to on a task by task basis in the discussion which follows:

Task 1 - A written description of the prop-fan, gearbox, and related equipment is enclosed as Attachment 1.

Task 2 - An installation sketch, SK91325, is enclosed. In addition a prop-fan system mounting concept, SK91314, is also enclosed.

Task 3 - The data required by this task was supplied in reference (e). Additional performance data at a different cruise tip speed was also supplied in reference (e). The performance of an advanced dual rotation prop-fan is supplied for selected conditions in Attachment 2.

Single rotation reverse performance at two operating conditions is supplied on curves number P-31256 and P-31257. The second performance point was requested during reference (b). A revised performance breakdown chart is enclosed as Attachment 3. It was previously delivered in Reference (e).

Task 4 - Weight data for basic and advanced levels of technology on a single rotation prop-fan were supplied earlier in references (d) and (f). A revised procedure for weight calculation as well as revised parametric weights have

Division of UNITED TECHNOLOGIES

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been completed. Enclosed as Attachment 4 for your use is the weight parametric package. More specifically, the final weights for the design point prop-fan (single rotation, basic and advanced technology and dual rotation, advanced technology) are delineated in Attachment 1.

Task 5 - Prop-fan far-field noise estimates at the operating conditions defined in reference (c) are provided in Attachment 5. For near field noise minimization, HS has selected a prop-fan blade tip to fuselage clearance of 0.8 times diameter. With this clearance the cabin interior noise level near the plane of prop-fan rotation is estimated to be 85 dB(A) at maximum cruise (case 3). This level can be reduced by increasing the fuselage wall treatment (See last paragraph).

Task 6 - Sell price estimates for the prop-fan, gearbox, and related equipment are provided on Figure 1.

Task 7 - Maintenance man-hours and parts costs per engine flight hour are provided on Figures 2 and 3. Prop-fan, gearbox and related equipment are covered.

Task 8 - As stated in Reference (e), the control description provided in Reference (d) should be considered final.

Task 9 - The estimated engine inlet face flow conditions were provided in Reference (d). The final contour lines for the prop-fan nacelle are shown on SK91325. This supersedes that provided in Reference (d).

In addition to the above data, the following are provided:

1. Increase in aircraft gross weight due to more fuselage acoustic treatment is estimated to be 0.25% to achieve 77 dB(A) interior cabin noise level.
2. List of installation items in nacelle requested in Reference (b) is provided in Attachment 4.
3. Prop-fan control functional logic diagram, Figure 4.

Very truly yours,

HAMILTON STANDARD DIVISION
United Technologies Corporation

B. S. Gatzen
Preliminary Design

BS/cal

cc: Mr. R. Thomas, G.E. (no attachments)

ATTACHMENT 1

.8 Mn PROP-FAN DESCRIPTION

Configuration

The Prop-Fan nacelle arrangement shown in SK 91325 is one of several potential concepts for installation on a 0.8 Mach aircraft. These concepts include over-the-wing and under-the-wing engines, inline gearbox and engine, offset gearbox and engine, and several Prop-Fan locations with respect to the wing.

The drawing depicts an under-the-wing engine with an offset gearbox. This was selected for further study based on several features: The under-the-wing location of the engine allows easier access to the engine and engine accessories for normal inspection and maintenance. In addition, an offset gearbox arrangement is shown rather than an inline since it allows an inlet which provides a higher pressure ratio at the engine compressor face and it allows easy access for the pitch control input.

The nacelle downtilt angle and the distance between the rotor plane and wing quarter chord are shown so as to minimize 1P excitation factor due to the wing wash and steady aeroelastic effects while maintaining whirl flutter stability. The nacelle and spinner shapes were selected to provide more nearly optimized installed prop-fan performance. With the nacelle frontal area dictated by aerodynamic requirements, wide latitude is available in gearbox and engine installation arrangement.

Point Design

The weights given below describe a Prop-Fan consisting of an eight bladed rotor assembly and a gearbox assembly and the lubrication/cooling system. The rotor assembly consists of the Prop-Fan blades, spinner, disk, and pitch control system. The weights were calculated on the basis of $SHP/D^2 = 67.07$ and TS = 737 ft/sec.

Weight For Equal Thrust Prop-Fans
@ .8Mn, 35,000 feet

	"Basic" Wt. For Basic Perf.	"Advanced" Wt. For Basic Perf.	"Advanced" Wt. For Adv. Perf.
16' dia. rotor (basic)	1888	1685	--
15.5' dia. rotor (adv. counterrotating)	1745 --	--	1651
Gearbox wt.	1449	1363	1521
Oil, tankage, and heat exchanger	108	58	65
0.1	42	31	35
Total	3445	3106	3240

The "basic" weights represent a level of technology which is expected to be available for commercial service in the mid 1980's based on currently expected R&D funding. An "advanced" level of technology would offer further improvements in weight and performance which could be available in the same time period if additional R&D funding is applied. Column two shows the estimated weight of the basic configuration utilizing advanced material and manufacturing technology. Additionally, the advanced level of technology could also allow development of a counterrotating configuration which results in an aerodynamic efficiency increase. The improved performance allows the Prop-Fan diameter to be reduced from 16 to 15.5 feet at constant SHP/D^2, tip speed, and installed thrust at 0.8 Mach number and 35,000 feet altitude. The weight of this configuration utilizing advanced technology for both aerodynamic and mechanical improvements is shown in column three.

Blades and Spinner

The "basic" blades consist of a hollow high strength steel structural member or spar, an external carbon epoxy hybrid shell shaped to the correct airfoil contour, aluminum honeycomb fill between shell and spar, and a titanium leading edge erosion sheath. The spinner is a fiberglass composite structure. Advanced technology would lead to development of a hollow titanium spar with an attendant weight reduction.

Disk

The "basic" disk assembly consists of the disk, blade retention balls and integral races, clamps and pitch change trunnions. The steel disk is integral with the fan tailshaft which transfers Prop-Fan loads to the gearcase and mounts. Studies between titanium disks and steel disks with integral retention have shown little differences in weight based on present day fracture mechanic allowables. With advance in the state-of-the-art of fracture mechanics titanium weight saving in the disk and tailshaft is envisioned.

Pitch Change System

The"basic"weights are based on a mechanical pitch change actuator utilizing a harmonic drive, although other concepts including hydraulic pistons and vane motors would be considered before arriving at a final concept. Theharmonic drive concept is presently being developed for the QCSEE program and has the advantages of high reliability, light weight, reasonable production cost and good maintainability. The system features an in-place blade angle lock and a redundant remote blade angle control. Advanced development of the harmonic drive and improved manufacturing technique would show weight saving.

Reduction Gearing

The reduction gearing is sized for infinite life based on maximum engine torque with maximum allowable stresses consistent with today's state-of-the-art gearboxes. The weight is based on the use of a titanium welded housing, vacuum melt AMS 6265 steel for gears and Vimvar double vacuum melt M50 for bearings. The gearing system module has a calculated MTBF of approximately 40,000 hours. For advanced technology, improvements in gear and bearing geometry and materials are envisioned.

Cooling and Lubrication

Gearbox cooling is accomplished by use of a separate heat exchanger. An overall gearbox efficiency of 99% is obtained by the use of proper oil management, baffling and scavenging techniques. A centrifugal air oil separator is used to minimize oil

tankage weight. Advanced technology weight saving would be based on the development of high temperature (450°F) gearboxes and lubricants.

Accessories

Weight for accessory drives such as aircraft hydraulics and electrical power were not included in the gearbox weight. It is felt that powering the accessory drives from the Prop-Fan gearbox would increase these gearbox weights but would maximize overall engine cycle efficiency and would simplify the engine accessory gearbox and may simplify accessory cooling.

Installation

While not contractually a responsibility of HS, a study was made to evaluate overall nacelle installed weight. For purposes of this study the gearbox and engine are considered to be rigidly coupled to maintain a minimum misalignment angle for the engine output shaft. Another possible advantage for rigid coupling of engine and gearbox is the use of helical gears to balance engine turbine and propeller thrust loads. One way of achieving rigid coupling is to utilize the engine inlet in the structural loop. To minimize engine case deflection, it is assumed the entire gearbox/engine structure is mounted to the wing by the primary isolation mounts at the gearbox and only a steady rest at the aft end of the engine. The nacelle buildup weight includes all the structure and fairings that couple the Prop-Fan and engine to the wing, engine inlet, engine shaft, exhaust, fire control systems, gearbox cooling system, starting and fuel system, aircraft hydraulics, electrical power, and pneumatic systems and finally the Prop-Fan control and engine linkage.

The total uninstalled weight was obtained by adding the Prop-Fan/gearbox weight to an engine weight of 6 SHP/lb. (including the engine accessory gearbox). A ratio of total installed weight to uninstalled weight of 1.3 has been established for a Prop-Fan based on the above study.

ATTACHMENT 2

PROP-FAN ADVANCED PERFORMANCE STUDY

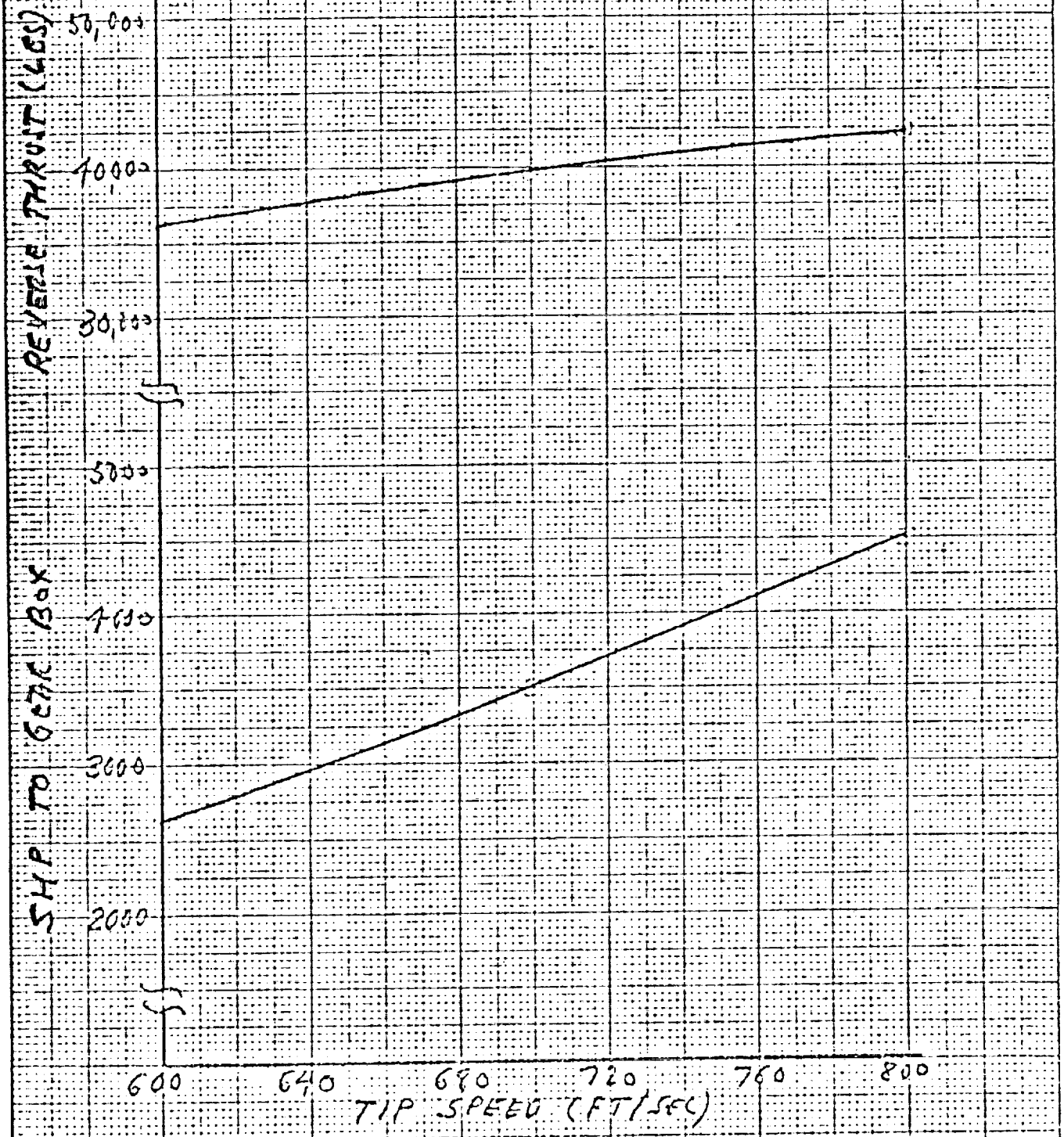
(16' DIA., 8 BLADES, 200 AF, .12 Cli)

Case No.	2	9	10	11	12
Rating	Max. Climb	Takeoff	Takeoff	Takeoff	Takeoff
Altitude, Ft.	35,000	SL	SL	SL	SL
ΔT_o, °F	+18	+27	+27	+27	+27
M_N	0.8	0.1	0.2	0.25	0.3
SHP To GB	9296.5	16552.5	16787.6	16959.6	17171.1
Tip Speed, FPS	800	737	737	737	737
8 BLADE SINGLE ROTATION					
η Net	0.797	0.278	0.484	0.564	0.629
T Net, Lbs.	5068	21,857	19,304	18,183	17,123
8 BLADE DUAL ROTATION					
η Net	0.846	0.292	0.514	0.597	0.667
T Net, Lbs.	5380	22,958	20,501	19,247	18,157

CALC. No. 2836 (11)

PROP-FAN REVERSE PERFORMANCE AS A FUNCTION OF TIP SPEED

8 BLADE / 16 FT DIAM / 205 AF / 0.12 C_{Li}
$\beta_{3/4}$ = −10°
0.23 MACH NUMBER
SEA LEVEL, ISA + 27°F



9/3/75 AMS
HAMILTON STANDARD CURVE NO P-32156

C-2

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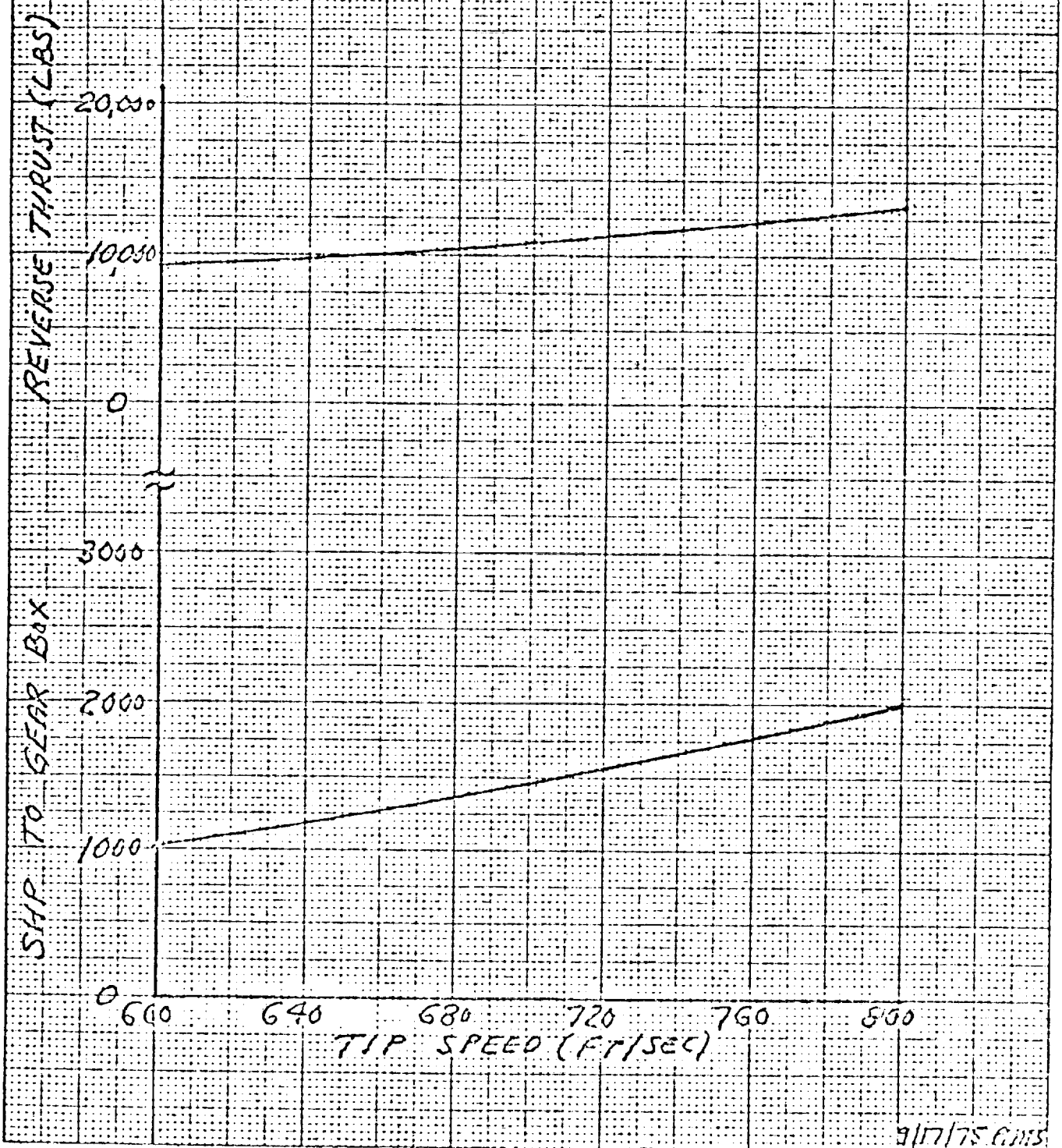
PROP-FAN REVERSE PERFORMANCE AS A FUNCTION OF TIP SPEED

2 BLADE / 16 FT. DIAM. / 200 AF / 0.12 C_L

$\beta_{3/4} = -10°$

60 KNOTS TRUE AIRSPEED

SEA LEVEL, ISA +27°F.



9/17/75 GMS

627 HAMILTON STANDARD CURVE NO P-32157

ATTACHMENT 3

PERFORMANCE BREAKDOWN FOR AERO DESIGN POINT

CONDITION: Max. Climb (Case 2)
0.8 Mach Number at 35,000 Ft., ISA + 18°F
9296.5 SHP To Gearbox
594.3 Lb. of Net Core Thrust
8488.9 Turbine Output RPM

PROP FAN: 8 Blade/16 Ft. Diam./200 AF/0.12 C_{li}
800 Ft./Sec. Tip Speed.

PERFORMANCE BREAKDOWN:

Ideal Propulsive Efficiency	0.973
Swirl Loss For Infinite Blades	0.064
Ideal Propeller Efficiency for ∞ Blades	0.909
Blade Tip Loss For 8 Blades	0.043
Ideal Propeller Efficiency for 8 Blades	0.866
Profile & Compressibility Loss	0.069
Net Efficiency (Uninstalled)	0.797

PRELIMINARY

PROP-FAN PROPULSION SYSTEM WEIGHT ESTIMATES

The weight information provided herein supersedes the weight information contained in the Hamilton Standard document SP05A75 entitled "Generalized Prop-Fan Performance and Weight", dated April 18, 1975.

The attached curves provide weight estimates for a Prop-Fan (high speed turboprop and gearbox system) designed for 0.8 Mach No. cruise commercial aircraft. The curves are not appropriate for lower speed aircraft. The performance for the Prop-Fan is contained in SP05A75. Both the weights and performance represent a "Basic" level of technology which is expected to be available for commercial service in the mid 1980's based on currently expected R&D funding. An"Advanced" level of technology would offer further improvements in weight and would be available in the same time period if additional R&D funding is applied. It is estimated that"Advanced" technology would reduce the rotor and gearbox weights 11% and 6% respectively for the same configuration Prop-Fan.

The power loading (SHP/D^2) term used on the rotor weight curves refers to the maximum power (SHP delivered to the rotor)and the rotor diameter (D in feet). The term T.S. refers to the rotor tip speed (TS in fps). The TS that should be used for rotor weights is that at which the maximum SHP occurs. Gearbox weights are simply based on the maximum torque it delivers.

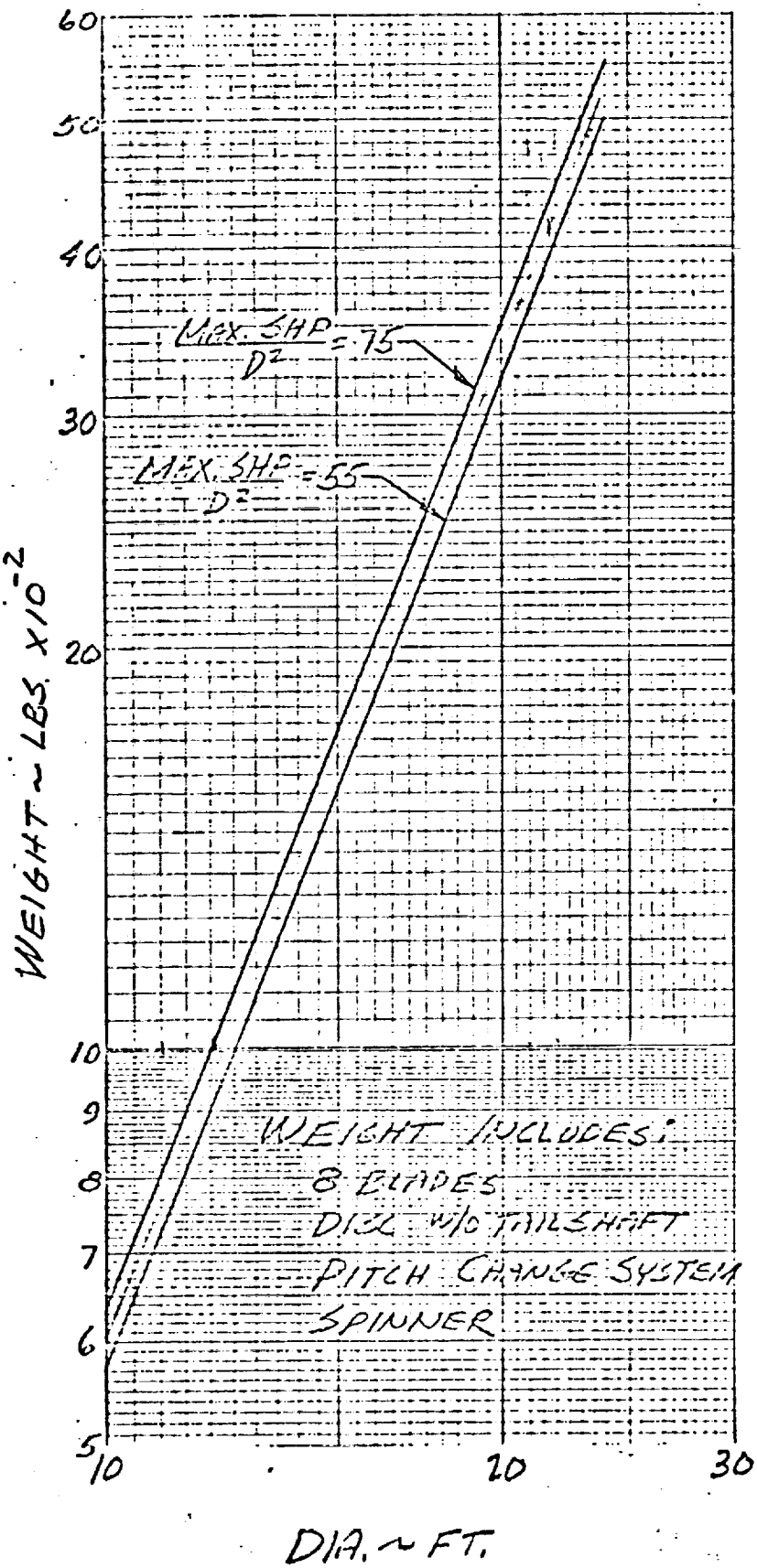
The curves provide uninstalled rotor and gearbox weight estimates and the major components included are defined on the curves. An assessment has been made of the additional components and weight required for a fully installed Prop-Fan propulsion nacelle package. The additional components included:

- Nacelle cowling and fairings
- Nacelle structure for attachment to wing
- Engine-to-gearbox coupling structure and shaft
- Engine/gearbox mounting to nacelle structure
- Engine air inlet ducting
- Engine exhaust system
- Fire control system
- Gearbox cooling and oil tankage system
- Engine starting system
- Hydraulic system and hydraulic fluid
- Electrical system
- Fuel system
- Pneumatic system
- Engine and prop-fan control linkage

It is estimated that the fully installed Prop-Fan propulsion nacelle package (Prop-Fan rotor and gearbox, turboshaft engine and above listed additional components) would weigh 1.3 times the sum of the rotor, gearbox and engine weight. This factor is based on a turboshaft engine weight of 0.167 lbs. per SHP.

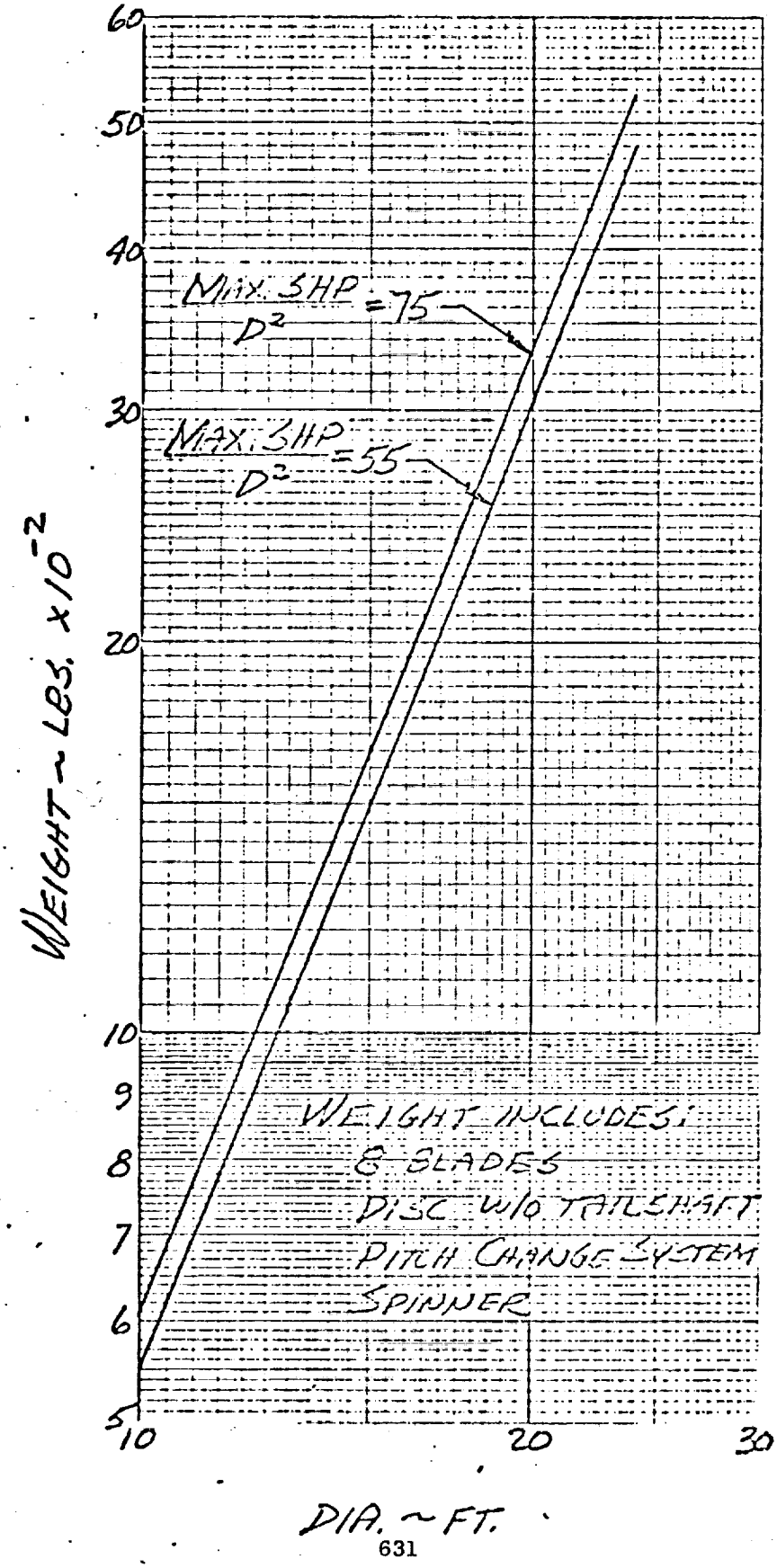
.8 MW ROTOR WEIGHT

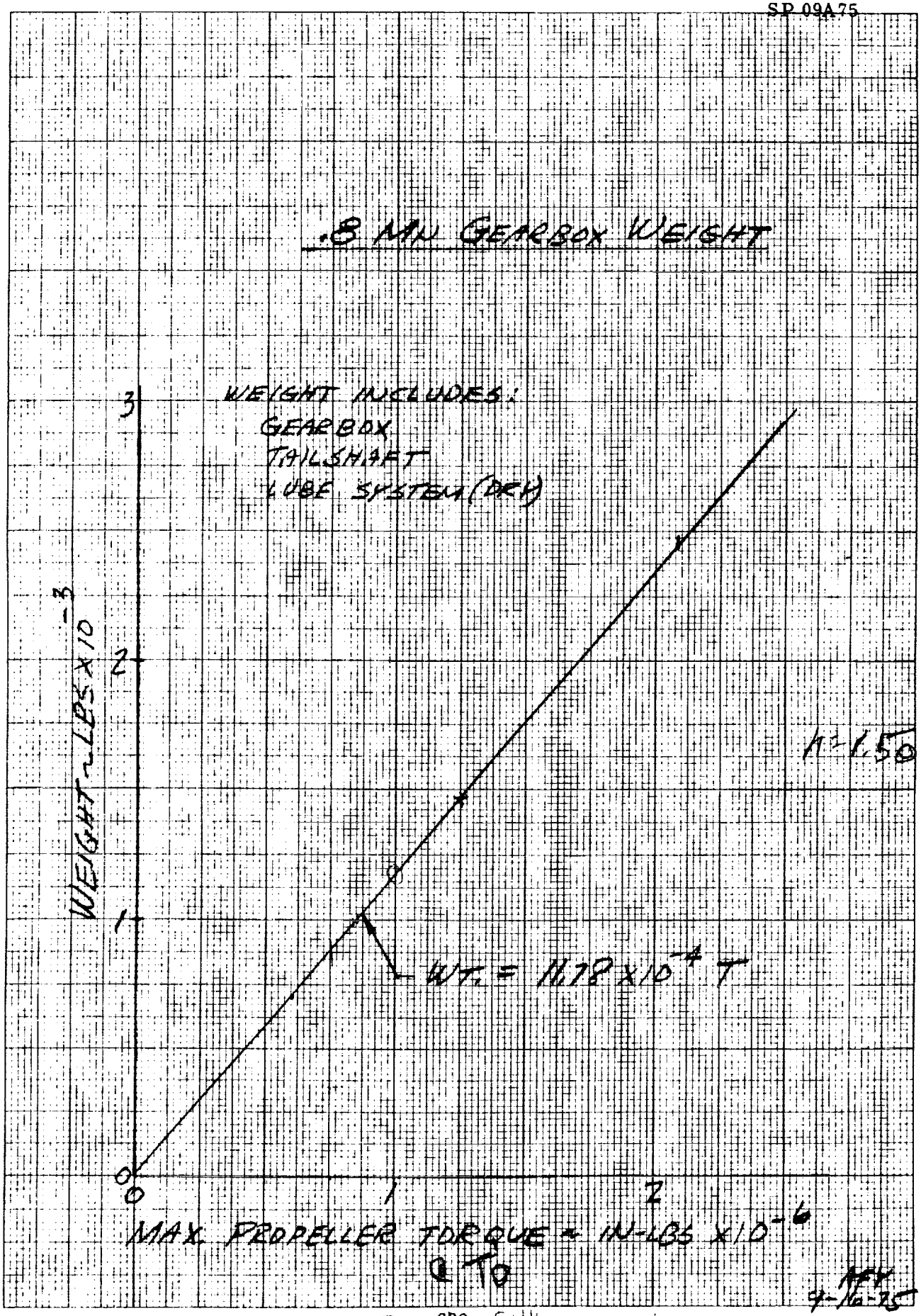
T.S. = 800 FPS



.8 MIN ROTOR WEIGHT

T.S. = 700 FPS




.8 MW GEARBOX WEIGHT
WEIGHT INCLUDES:
GEARBOX
TAILSHAFT
LUBE SYSTEM (DRY)
WEIGHT ~ LBS X 10^-3
3
2
1
0
0
1
2
n = 1.50
WT. = 11.78 X 10^-4 T
MAX PROPELLER TORQUE ~ IN-LBS X 10^-6
@ TO

ATTACHMENT 5

PROP-FAN ACOUSTIC DATA
(16' DIA., 8 BLADES)

CONDITION	TAKEOFF	APPROACH (32% T.O.)	TAKEOFF	APPROACH (34% T.O.)
Altitude, Ft.	1600	370	1300	370
ΔT_o, °F	+18	+18	+18	+18
M_N	0.26	0.22	0.27	0.23
SHP to GB	16130	4150	16240	4510
Prop-Fan Tip Speed, FPS	736	491	735	504
PNL, One Engine	88.2	83.2	90.6	84.2
EPNL, Four Engines	92.2	85.2	94.6	86.2

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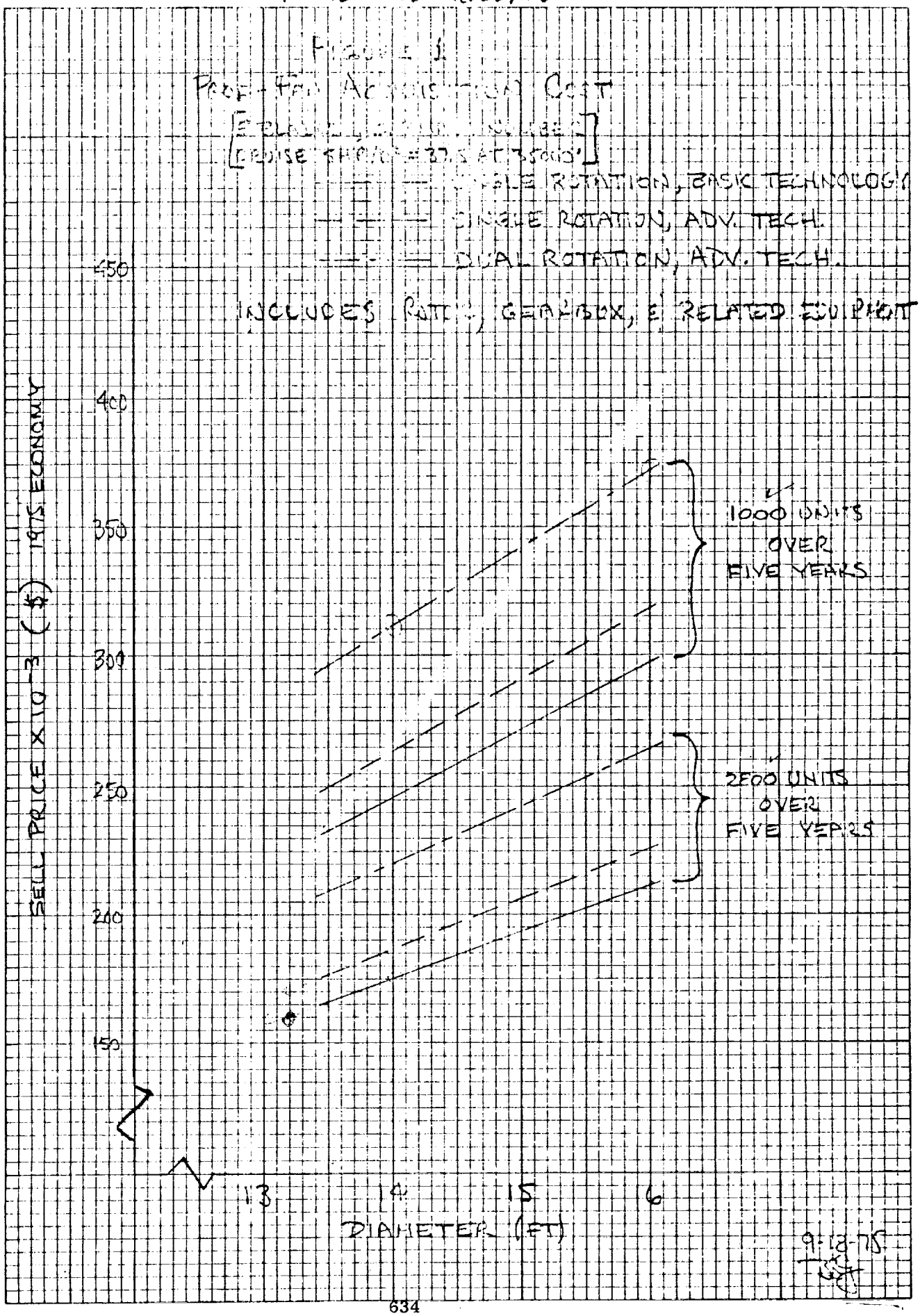

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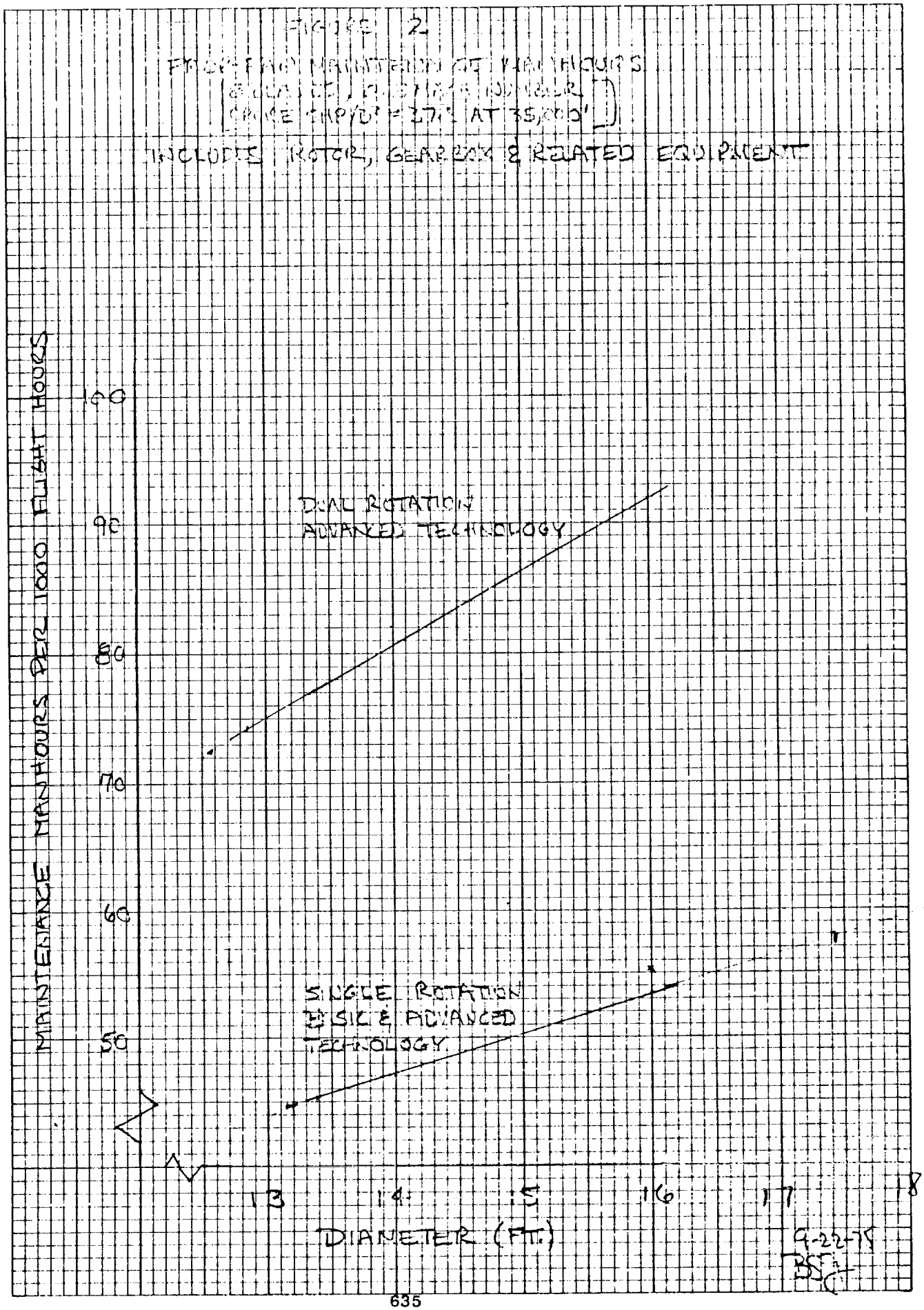

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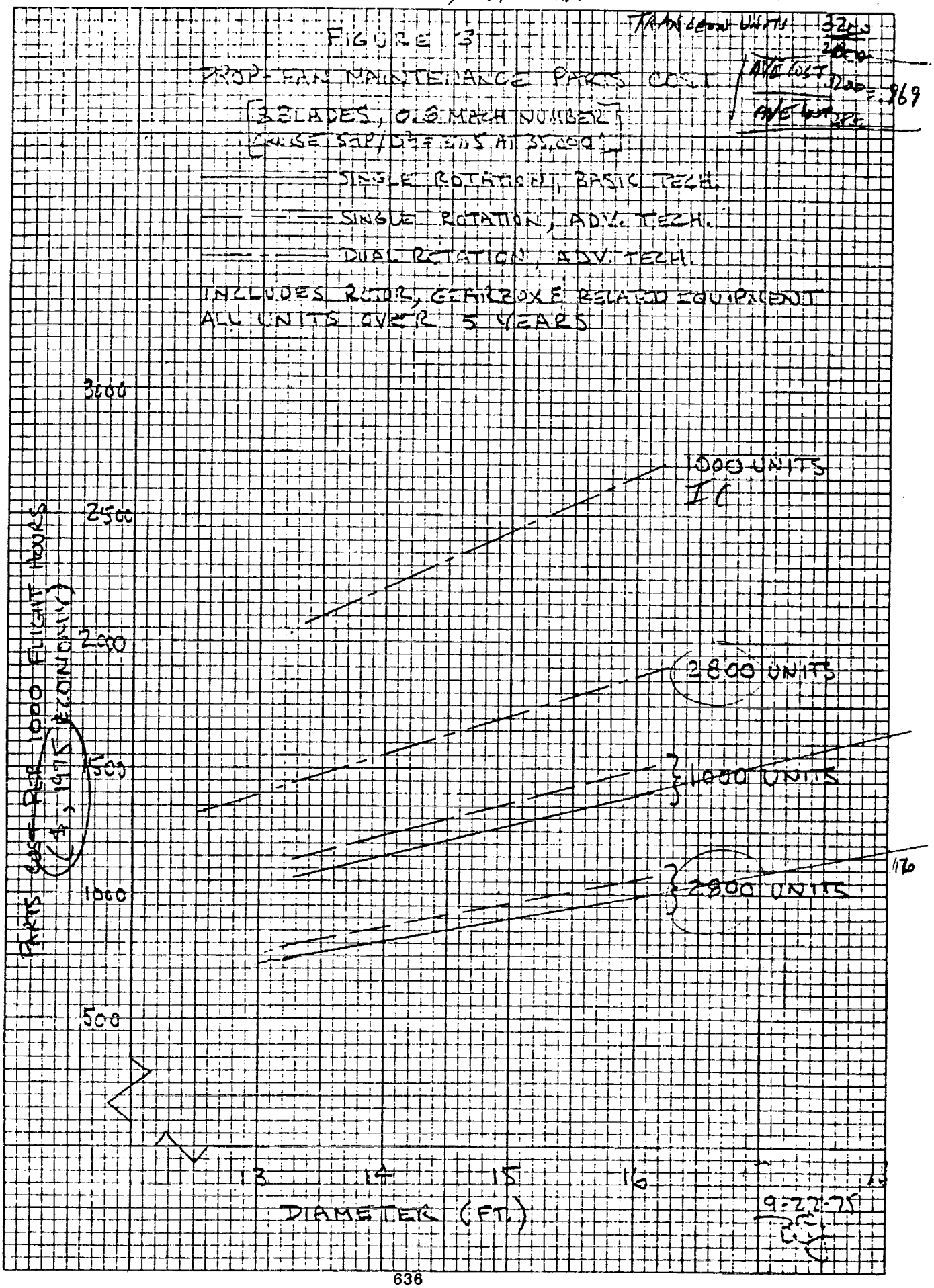
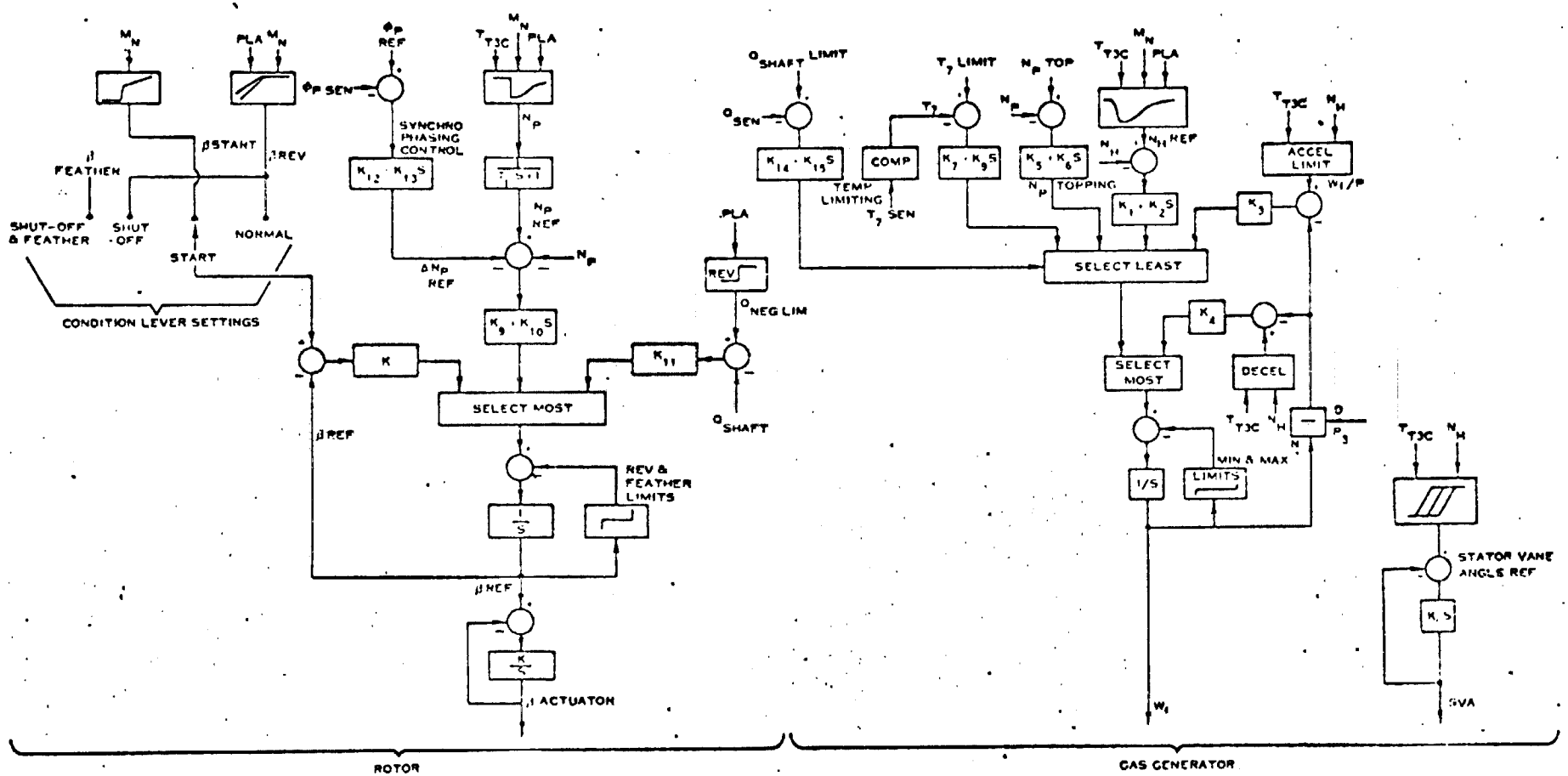


FIGURE 4

PRELIMINARY LOGIC DIAGRAM FOR PROP-FAN PROPULSION SYSTEM CONTROL



5.4.1 Booster Aerodynamic Design

The following is the aerodynamic definition and efficiency build up of the turboprop booster at 351K/1.8/+18 MxCu

No. Stages	3
$U_T/\sqrt{\theta}$	1285 f/s
r_{Hub}/r_{tip}	.77
$P/P_{overall}$	2.75
P/P_{stage}	1.41

Efficiency

η_{stage}	.877
$\Delta\eta$ Variable Stator	-.01
$\Delta\eta$ Advanced Technology	+.03
$\Delta\eta$ Reheat	-.014
$\Delta\eta$ Radius Ratio	-.011
$\Sigma\Delta\eta$	-.005
η_{Boost}	.872

5.4.2 LP Turbine Aerodynamic Definition

1) Attached computer output #1 shows aero design.
2) Table I presents the blade number calculation as per calculation shown.
3) Computer output #2 presents cooling flow analysis.
4) Table II presents the efficiency build-up.

TURBINE AERO PROGRAM NOMENCLATURE

TTØ - total temperature
PTØ - total pressure
MØ - Mach number
} At station Ø (Nozzle inlet)

PS1 - Static pressure
PTS1 = PTØ/PS1
TS1 - static temperature
ALFA - angle of flow from axial
V1 - velocity of flow
M1 - mach number of flow
CZ1 - axial component of flow velocity
CU1 - tangential component of flow velocity
ZIN - incompressible Zweifel nbr. (tangential force coefficient)
FNA - axial force per unit nozzle height
FNT - tangential force per unit nozzle height
} At station 1R (Nozzle exit)

PTB - Total pressure relative to the bucket
TTB - Total temperature relative to the bucket
BET1 - angle of flow from axial relative to bucket
R1 - velocity of flow relative to bucket
MR1 - mach number of flow relative to bucket
W1 - wheel speed
} at station 1 (Bucket inlet)

PT2 - Total pressure
PS2 - Static pressure
PTS2 = PTØ/PS2
TT2 - Total temperature
TF - Test factor
TS2 - Static temperature
BET2 - angle of flow leaving bucket relative to bucket
DUBA - Turning angle
RX - Reaction
V2 - Velocity of flow
R2 - velocity of flow relative to bucket
MR2 - Mach number of flow relative to bucket
W2 - wheel speed
} at station 2 (Bucket exit)

TURBINE AERO PROGRAM NOMENCLATURE (CONT'D)

CZ2 - axial component of flow velocity
CU2 - tangential component of flow velocity
SWRL - swirl angle.
MF - Axial velocity Mach number
ZIB - Incompressible Zweifel nbr.
FBA - axial force per unit bucket height
FBT - tangential force per unit bucket height.
PSI - loading parameter
W/NO - velocity ratio.

} at station 2 (Bucket exit

ETATT - total efficiency
ETATS - static efficiency

STAGE 1

$\omega_{2c} = 37.1$

$\omega_{2c} \frac{\beta}{\delta} = 39.1$

	ROOT	PITCH	TIP
STA 0 NOZZLE INLET		WG= 35.00	
DIAMETER	19.700	20.950	22.200
ANNULUS AREA		82.27	
TT0		2220.0	
PT0		49.10	
M0		0.543	
STA 1PR NOZZLE EXIT		WG= 35.00	
DIAMETER	19.400	21.550	23.700
ANNULUS AREA		145.56	
FF (FLOW FUNCTION)		33.59	
PS1	28.03	30.79	32.91
PTS1	1.7486	1.5949	1.4918
TS1	1954.3	1995.7	2026.3
ALPHA	65.00	62.61	60.33
V1	1968.1	1808.4	1680.4
M1	0.939	0.854	0.787
CZ1		831.9	
CU1	1783.7	1605.7	1460.0
ZIN	0.766	0.817	0.860
FNA	979.2	912.0	850.9
FNT	1070.4	1104.1	1130.2
NOZZLE AXIAL FORCE= 1960.8		TANG FORCE= 2373.9	
STA 1 BUCKET INLET		WG= 35.00	
DIAMETER	19.400	21.700	24.000
ANNULUS AREA		156.80	
PTB	36.57	37.36	38.21
TTB	2079.6	2088.5	2098.4
BET1	54.54	46.19	36.08
R1	1307.6	1095.8	938.6
MR1	0.623	0.516	0.439
W1	718.6	803.3	889.0
STA 2 BUCKET EXIT		WG= 35.00	
DIAMETER	19.300	22.200	25.100
ANNULUS AREA		202.26	
PT2		29.74	
PS2	26.47	26.80	27.02
PTS2	1.8549	1.8321	1.8169
TT2		1996.6	
TF		0.960	
TS2	1933.6	1939.2	1943.0
BET2	62.70	63.26	64.09
DLBA	117.24	109.45	100.17
RX	0.100	0.253	0.364
V2	885.2	837.4	803.7
R2	1457.4	1455.6	1529.7
MR2	0.699	0.712	0.732
W2	714.9	822.3	929.8
CZ2		668.5	
CU2	580.2	504.4	446.1
SWRL	40.95	37.04	33.72
MF	0.321	0.320	0.320
ZIB	1.406	1.226	1.065
FBA	160.4	366.2	575.4
FBT	841.2	897.6	942.1
BUCKET AXIAL FORCE= 1041.9		TANG FORCE= 2603.0	
PSI	1.565	1.232	0.985
W/VD	0.346	0.392	0.438

GENERAL STAGE RESULTS

WORK= 65.05 ETATT=0.903 ETATS=0.757

STAGE 2

	ROOT	PITCH	TIP
STA 0 NOZZLE INLET		WG= 35.00	
DIAMETER	19.300	22.350	25.400
ANNULUS AREA		214.15	
TTO		1996.6	
PTO		29.74	
MO		0.374	
STA 1PR NOZZLE EXIT		WG= 35.00	
DIAMETER	19.200	22.800	26.400
ANNULUS AREA		257.86	
FF (FLOW FUNCTION)		52.59	
PS1	15.28	18.30	20.39
PTS1	1.9467	1.6251	1.4586
TS1	1709.9	1783.1	1828.5
ALPHA	69.53	66.15	62.89
V1	2023.7	1746.2	1549.5
M1	1.029	0.870	0.762
CZ1		706.1	
CU1	1896.8	1597.3	1379.5
ZIN	0.865	0.956	1.088
FNA	695.0	607.3	528.9
FNT	662.4	706.2	736.4
NOZZLE AXIAL FORCE= 2186.3		TANG FORCE= 2542.4	
STA 1 BUCKET INLET		WG= 35.00	
DIAMETER	19.200	22.950	26.700
ANNULUS AREA		270.37	
PTB	20.88	21.74	22.70
TTB	1843.1	1858.3	1876.2
BET1	60.67	47.88	29.38
R1	1359.9	993.2	764.4
MR1	0.691	0.494	0.375
W1	711.2	850.1	989.0
STA 2 BUCKET EXIT		WG= 35.00	
DIAMETER	19.100	23.500	27.900
ANNULUS AREA		324.84	
PT2		16.21	
PS2	13.37	14.24	14.45
PTS2	2.1447	2.0835	2.0575
TT2		1751.3	
TF		0.960	
TS2	1676.9	1687.6	1693.7
BET2	63.71	64.31	65.47
DLBA	124.38	112.19	94.85
RX	0.100	0.340	0.487
V2	957.7	873.9	822.7
R2	1539.3	1572.6	1642.1
MR2	0.790	0.805	0.839
W2	707.5	870.5	1033.5
CZ2		681.8	
CU2	672.6	546.6	460.4
SWRL	44.61	38.72	34.03
MF	0.350	0.349	0.348
ZIB	1.493	1.197	0.950
FBA	90.2	315.5	543.4
FBT	522.2	581.4	621.7
BUCKET AXIAL FORCE= 1388.3		TANG FORCE= 2558.1	
PSI	1.741	1.184	0.857
W/VO	0.330	0.400	0.470

GENERAL STAGE RESULTS

WORK= 69.97 ETATT=0.905 ETATS=0.757

STAGE 3

	ROOT	PITCH	TIP
STA 0 NOZZLE INLET		WG= 35.00	
DIAMETER	19.100	23.700	28.300
ANNULUS AREA		342.50	
TTO		1751.3	
PTO		16.21	
MO		0.418	
STA 1PR NOZZLE EXIT		WG= 35.00	
DIAMETER	18.800	24.000	29.200
ANNULUS AREA		392.07	
FF (FLOW FUNCTION)		90.36	
PS1	8.16	10.38	11.69
PTS1	1.9864	1.5615	1.3868
TS1	1486.8	1574.5	1619.7
ALPHA	67.88	62.58	57.74
V1	1919.6	1569.4	1354.0
M1	1.043	0.828	0.705
CZ1		722.8	
CU1	1778.8	1393.4	1145.2
ZIN	0.977	1.158	1.288
FNA	358.3	289.3	231.1
FNT	402.3	438.5	459.8
NOZZLE AXIAL FORCE= 1504.2		TANG FORCE= 2280.3	
STA 1 BUCKET INLET		WG= 35.00	
DIAMETER	18.700	24.150	29.600
ANNULUS AREA		413.49	
PTB	11.21	11.98	12.91
TTB	1607.9	1630.9	1659.8
BET1	58.29	35.91	2.82
R1	1287.8	835.7	677.6
MR1	0.699	0.440	0.352
W1	692.7	894.6	1096.4
STA 2 BUCKET EXIT		WG= 35.00	
DIAMETER	18.400	24.700	31.000
ANNULUS AREA		438.36	
PT2		8.48	
PS2	6.90	7.19	7.32
PTS2	2.3483	2.2556	2.2149
TT2		1517.7	
TF		0.960	
TS2	1433.2	1447.5	1454.1
BET2	60.32	61.42	63.52
DLBA	118.62	97.34	66.34
RX	0.150	0.448	0.597
V2	1020.2	917.3	866.4
R2	1554.9	1609.6	1726.7
MR2	0.840	0.886	0.948
W2	681.6	914.9	1148.3
CZ2		769.9	
CU2	669.3	498.6	397.2
SWRL	41.00	32.93	27.29
MF	0.426	0.424	0.423
ZIB	1.654	1.172	0.818
FBA	63.7	243.7	423.1
FBT	309.0	358.2	386.8
BUCKET AXIAL FORCE= 1535.5		TANG FORCE= 2256.9	
PSI	1.723	0.994	0.646
U/VO	0.326	0.430	0.533

GENERAL STAGE RESULTS

WORK= 64.99 ETATT=0.904 ETATS=0.734

STAGE 4

	ROOT	PITCH	TIP
STA 0 NOZZLE INLET		WG= 35.00	
DIAMETER	18.200	24.700	31.200
ANNULUS AREA		504.38	
TT0		1517.7	
PT0		8.43	
M0		0.484	
STA 1PR NOZZLE EXIT		WG= 35.00	
DIAMETER	17.700	25.000	32.300
ANNULUS AREA		573.34	
FF (FLOW FUNCTION)		160.75	
PS1	4.91	6.14	6.69
PTS1	1.7259	1.3813	1.2670
TS1	1328.3	1402.4	1432.3
ALPHA	62.39	53.54	46.33
V1	1605.8	1252.5	1077.9
M1	0.919	0.698	0.594
CZ1		744.3	
CU1	1423.3	1007.7	780.0
ZIN	1.195	1.413	1.491
FNA	131.2	89.0	58.8
FNT	218.8	239.8	249.8
NOZZLE AXIAL FORCE= 649.6		TANG FORCE= 1750.9	
STA 1 BUCKET INLET		WG= 35.00	
DIAMETER	17.600	25.100	32.600
ANNULUS AREA		591.40	
PTB	6.26	6.90	7.78
TTB	1411.8	1444.1	1487.7
BET1	47.44	5.90	-31.28
R1	1058.2	719.5	837.4
MR1	0.605	0.400	0.461
W1	651.9	929.8	1207.6
STA 2 BUCKET EXIT		WG= 35.00	
DIAMETER	16.700	24.850	33.000
ANNULUS AREA		636.26	
PT2		5.39	
PS2	4.61	4.62	4.63
PTS2	1.8418	1.8347	1.8322
TT2		1370.5	
TF		0.960	
TS2	1311.0	1312.3	1312.7
BET2	43.72	51.30	57.58
DLBA	91.16	57.20	26.31
RX	0.100	0.466	0.610
V2	852.5	842.2	838.5
R2	1153.4	1333.3	1555.1
MR2	0.665	0.763	0.895
W2	618.6	920.5	1222.4
CZ2		833.6	
CU2	178.6	120.0	90.4
SWRL	12.09	8.19	6.19
MF	0.480	0.480	0.480
ZIB	2.137	1.057	0.556
FBA	7.2	107.1	199.0
FBT	137.6	157.0	166.3
BUCKET AXIAL FORCE= 872.7		TANG FORCE= 1279.6	
PSI	1.241	0.585	0.339
W/V0	0.371	0.540	0.709

GENERAL STAGE RESULTS

WORK= 40.02 ETATT=0.899 ETATS=0.683

OVERALL TURBINE RESULTS

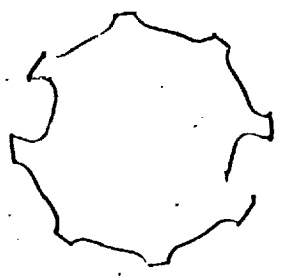
```
TTIN/TTEXIT= 1.620  PTIN/PTEXIT= 9.102  PTIN/PSEXIT=10.621
WORK= 240.03  ETATT=0.919  ETATS=0.874  PSI= 0.977


program stop at 3858
*LIST

1 TURBOPROP IPT   NLPT=8490
5 0,.0235,53.3,4,2220,49.1
10 1,0,35,8490,0,0,0
20 65,.96,.1,.97,.95,1,1,90,90,1
30 19.7,22.2,19.4,23.7,19.4,24,19.3,25.1
40 2,0,35,8490,0,0,0
50 70,.96,.1,.97,.95,1,1,90,90,1
60 19.3,25.4,19.2,26.4,19.2,26.7,19.1,27.9
70 3,0,35,8490,0,0,0
80 65,.96,.15,.97,.95,1,1,90,90,1
90 19.1,28.3,18.8,29.2,18.7,29.6,18.4,31
100 4,0,35,8490,0,0,0
110 40,.96,.1,.97,.95,1,1,90,90,1
120 18.2,31.2,17.7,32.3,17.6,32.6,16.7,33

ready

*
```



Turboprop LPT

Table I

8

	Height	Aspect Ratio	Axial Chord	Blade Exit ∠	Zweifel #	Zweifel Product	Pitch	Pitch Dia	Blade #	Exit M/r	N_{SLS} = 7877	
	h	AR	Cx	β	ψ	$2\omega_i$	P	Dp	#	r/r	AAN^2	T_3
1N	1.7	2	.85	62.6	.8	.817	.832	21.25	~~80~~ 57			
1R	2.6	2.7	.96	63.3	.84	1.226	.66	21.95	104	.769	1.245^{10}	2280
2N	3.33	2.7	1.23	66.2	.625	.986	.781	22.58	91			
2R	4.07	3	1.357	64.3	.795	1.197	.901	23.22	81	.684	1.99^{10}	2230
3N	4.9	3.15	1.56	62.58	.80	1.159	1.075	23.85	70			
3R	5.87	3.85	1.52	61.4	.91	1.172	1.18	24.43	55	.593	3^{10}	2165
4N	6.9	3.5	1.97	53.5	.975	1.413	1.36	24.85	57			
4R	7.83	4.5	1.74	51.3	1.07	1.057	1.76	24.925	46	.506	3.9^{10}	2110

Cooling Analysis

1530, .025, 2300, 59, .25, .1, 150, .987

Calculation

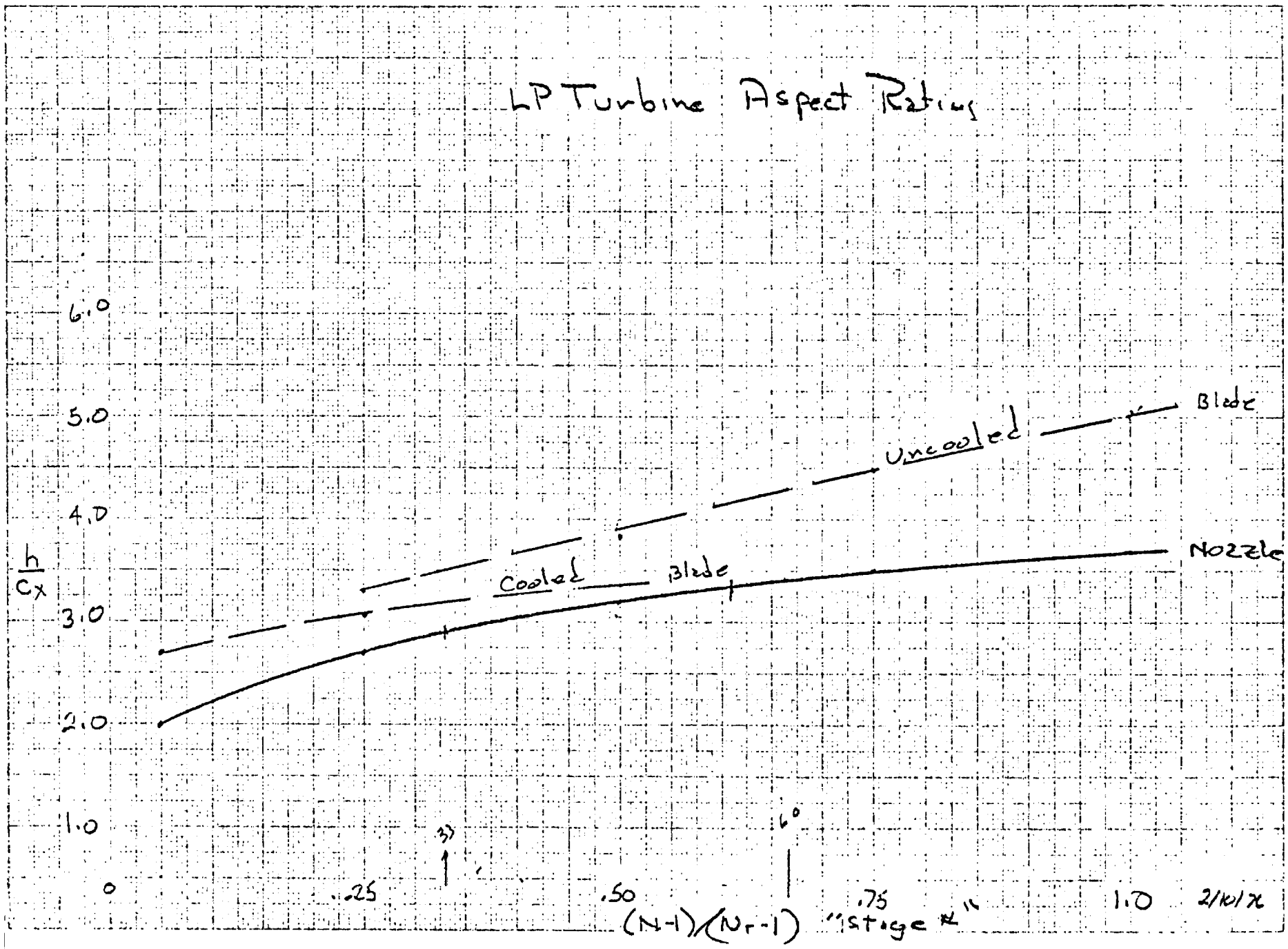
1) Aspect ratio from attached graph

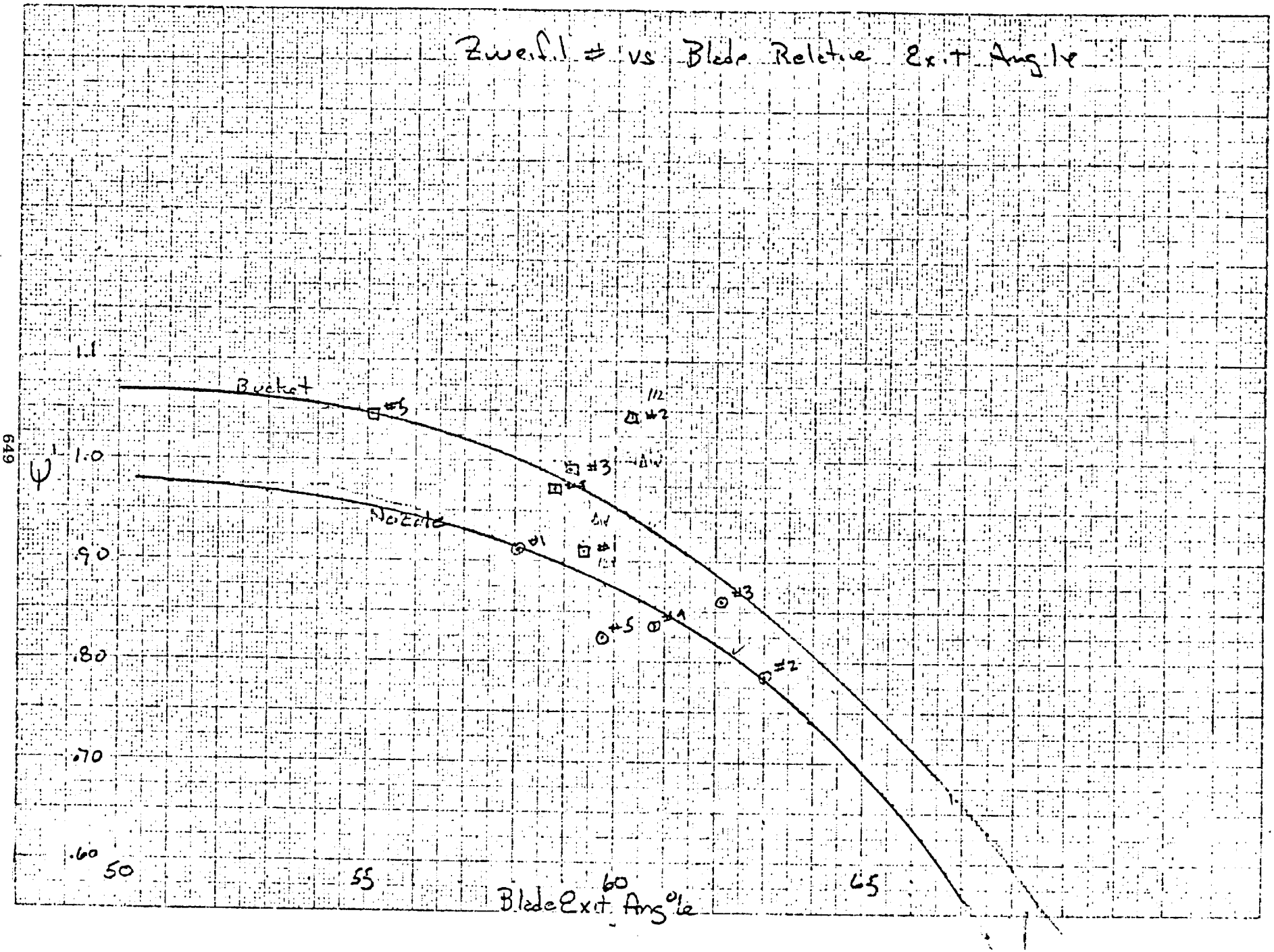
2) $Cx = \frac{\text{Blade Height (h)}}{AR}$

3) Zweifel # From attached graph (ψ)

4) $\text{Pitch (P)} = \frac{Cx\ \psi}{2\omega_i}$

5) $\# = \frac{\pi\ Dp}{P}$


LP Turbine Aspect Ratios
6.0
5.0
4.0
3.0
2.0
1.0
0
h/cx
Blade
Uncooled
Cooled
Blade
Nozzle
.25
.50
.75
1.0
(N-1)/(Nr-1) "Stage #"
3
6
2/10/76


Zweifel # vs Blade Relative Exit Angle
Bucket
Nozzle
Ψ
1.1
1.0
.90
.80
.70
.60
50
55
60
65
Blade Exit Angle
#5
#3
#1
#2
#1
#5
#4
#3
#2

Cooling Analysis Program - Nomenclature

T3 - Compressor discharge temperature, (°R)
F/A RATIO - Fuel to air ratio
T4 - Turbine stage 1 nozzle exit average temperature, (°R)
W4 - " " " " flow, (lb/sec)
PFI - Combustor pattern factor
PDFI - Combustor profile factor
DTADD - Design adder, (°R)
W4/W2 - W4 / Core inlet air flow
TC - bucket or nozzle cooling air temperature, (°R)
TB - allowable airfoil bulk temperature, (°R)
%WC - cooling flow, (% of W_{2c})
C = .0567
HA/WCP - heat transfer coefficient × airfoil area / gas flow × coolant specific heat
N - no. of airfoils
ZI PTCH - Incompressible Zweifel number at pitch
DP - Pitch diameter, (in)
HT-S - Height of airfoil, suction side (in)
HT-P - " " " , pressure side (in)
P - airfoil perimeter
AX-W - axial width
B1 - Inlet gas angle (degrees)
B2 - Exit gas angle (degrees)
K - Gas heat conductivity, [(Btu/hr-ft²)/(°R/ft)]
CPC - Coolant specific heat (Btu/lb°R)
PR NO - Prandl Number
VISC - Gas viscosity, (lb/sec-ft)
RE S - Suction side Reynolds number
RE P - Pressure side Reynolds number
WG - W4

```
ALL TEMPS INPUT & OUTPUT IN DEG R
ENTER NAME OF INPUT FILE
= ZZX
DO YOU WANT OUTPUT FOR ALL  8 CASES?
= YES
ENTER STG 1 BAND COOLING -%
= 0
ENTER T3,F/A RATIO,T4,W4,PF1,PDF1,DTADD,W4/W2
= 1530,.025,2300,59,.25,.1,150,.09
IS COOLANT TEMP TO BE THE SAME FOR ALL BLADE ROWS ?
= YES
ENTER TC
= 1227
IS COOLING TECHNOLOGY TO BE THE SAME FOR ALL BLADES ?
= NO
STAGE  1  NOZZLE

ENTER NO. OF AIRFOILS AND AXIAL WIDTH
IF NO OF AIRFOILS=0, SOLIDITIES WILL BE SET WITH
ZN=.85 AND ZB=1.0
= 57,.85
ENTER T3,%WC
= 2260,0
ENTER PEAK GAS TEMP, IF 0 PROGRAM WILL CALCULATE
= 0
ENTER LEVEL OF COOLING TECHNOLOGY DESIRED
= B

CONSTANT C=0.0567  HA/WCP=0.0214

N= 57  ZI  PTCH =1.142  DP=21.55  HT-S= 2.15  HT-P= 1.25  P= 2.498
 X W= 0.85  B1=  0.   B2= 62.6  K=.050  CPC=.2555  AG=  242.07
 R NO=0.6922  VISC= 0.318E-04
RE S= 0.482E+06  RE P= 0.276E+06
WG=  59.0

COOLING TECHNOLOGY  B   -CURRENT FILM

2WCCP/AGWG= 0.76

AVG GAS  PEAK GAS    BULK      COOLANT     COOLING      COOLING FLOW
TEMP R   TEMP R     TEMP R     TEMP R   EFFECTIVENESS      %W2C
 2310.2   2655.3    2260.0     1227.0      0.277           0.808

STAGE  1  BUCKET

ENTER NO. OF AIRFOILS AND AXIAL WIDTH
= 104,.96
ENTER T3,%WC
= 2280,0
ENTER PEAK GAS TEMP, IF 0 PROGRAM WILL CALCULATE
= 0
ENTER LEVEL OF COOLING TECHNOLOGY DESIRED
= C+

CONSTANT C=0.0567  HA/WCP=0.0463

N=104  ZI  PTCH =0.856  DP=22.20  HT-S= 2.90  HT-P= 2.30  P= 2.530
AX W= 0.96  B1= 46.2  B2= 63.3  K=.047  CPC=.2555  AG=  684.14
PR NO=0.6927  VISC= 0.306E-04
RE S= 0.374E+06  RE P= 0.222E+06
WG=  59.0
```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2 NOZZLE

ER NO. OF AIRFOILS AND AXIAL WIDTH
91,1.23
ENTER TB,%NC
= 2260,0
ENTER PEAK GAS TEMP, IF 0 PROGRAM WILL CALCULATE
= 0
ENTER LEVEL OF COOLING TECHNOLOGY DESIRED
= B

CONSTANT C=0.0567 HA/WCP=0.0534

N= 91 ZI PTCH =0.631 DP=22.80 HT-S= 3.60 HT-P= 3.05 P= 3.397
AX W= 1.23 B1= 37.0 B2= 66.1 X=.045 CPC=.2555 AG= 1027.94
PR NO=0.6931 VISC= 0.297E-04
RE S= 0.451E+06 RE P= 0.195E+06
WG= 59.0

COOLING TECHNOLOGY B -CURRENT FILM

2WCCP/AGHG= 0.18

AVG GAS TEMP R	PEAK GAS TEMP R	BULK TEMP R	COOLANT TEMP R	COOLING EFFECTIVENESS	COOLING FLOW %W2C
2068.5	2353.2	2260.0	1227.0	0.083	0.467

STAGE 2 BUCKET

ENTER NO. OF AIRFOILS AND AXIAL WIDTH
= 81,1.357
ENTER TB,%NC
= 2230,0
ENTER PEAK GAS TEMP, IF 0 PROGRAM WILL CALCULATE
= 0
ENTER LEVEL OF COOLING TECHNOLOGY DESIRED
= C+

CONSTANT C=0.0567 HA/WCP=0.0503

N= 81 ZI PTCH =0.804 DP=23.50 HT-S= 4.40 HT-P= 3.75 P= 3.618
AX W= 1.36 B1= 47.9 B2= 64.3 X=.043 CPC=.2555 AG= 1194.18
PR NO=0.6939 VISC= 0.233E-04
RE S= 0.373E+06 RE P= 0.205E+06
WG= 59.0

COOLING TECHNOLOGY C+ -CONVECTION PLUS

2WCCP/AGHG= 0.

AVG GAS TEMP R	PEAK GAS TEMP R	BULK TEMP R	COOLANT TEMP R	COOLING EFFECTIVENESS	COOLING FLOW %W2C
1925.3	2129.1	2230.0	1227.0	0.	0.

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ENTER NO. OF AIRFOILS AND AXIAL WIDTH
= 4.9
ENTER T3,%WC
= 2260,0
ENTER PEAK GAS TEMP, IF 0 PROGRAM WILL CALCULATE
= 0
ENTER LEVEL OF COOLING TECHNOLOGY DESIRED
= B

CONSTANT C=0.0567 HA/WCP=0.1135

N= 70 ZI PTCH =0.255 DP=24.00 HT-S= 5.20 HT-P= 4.60 P=13.159
AX W= 4.90 B1= 38.7 B2= 62.6 K=.040 CPC=.2555 AG= 4513.47
PR NO=0.6947 VISC= 0.272E-04
RE S= 0.110E+07 RE P= 0.531E+06
WG= 59.0

COOLING TECHNOLOGY B -CURRENT FILM

2WCCP/AGHG= 0.

AVG GAS TEMP R	PEAK GAS TEMP R	BULK TEMP R	COOLANT TEMP R	COOLING EFFECTIVENESS	COOLING FLOW %W2C
1814.4	2035.5	2260.0	1227.0	0.	0.

STAGE 3 BUCKET

ENTER NO. OF AIRFOILS AND AXIAL WIDTH
= 55,5.87
ENTER T3,%WC
= 2165,0
ENTER PEAK GAS TEMP, IF 0 PROGRAM WILL CALCULATE
= 0
ENTER LEVEL OF COOLING TECHNOLOGY DESIRED
= C+

CONSTANT C=0.0567 HA/WCP=0.0950

N= 55 ZI PTCH =0.282 DP=24.70 HT-S= 4.30 HT-P= 5.45 P=14.997
AX W= 5.87 B1= 35.9 B2= 61.4 K=.033 CPC=.2555 AG= 4545.90
PR NO=0.6957 VISC= 0.259E-04
RE S= 0.102E+07 RE P= 0.502E+06
WG= 59.0

COOLING TECHNOLOGY C+ -CONVECTION PLUS

2WCCP/AGHG= 0.

AVG GAS TEMP R	PEAK GAS TEMP R	BULK TEMP R	COOLANT TEMP R	COOLING EFFECTIVENESS	COOLING FLOW %W2C
1689.7	1865.1	2165.0	1227.0	0.	0.

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2RCCP/AGNG= 0.38

AVG GAS TEMP R	PEAK GAS TEMP R	BULK TEMP R	COOLANT TEMP R	COOLING EFFECTIVENESS	COOLING FLOW %W2C
2163.8	2391.8	2250.0	1227.0	0.096	0.891

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Table II

LPT Efficiency Estimate

@ 35K/.8/+.8 MxCL

P/P	9.32
RPM	8490
ψ_p	.98
No. Stages	4
η stage uncooled	.9040
$\Delta\eta$ Reheat	-.018
$\Delta\eta$ RNI	-.011
$\Delta\eta$ Advanced Tech.	+.004
$\Delta\eta$ Air Turbine Test	-.003
$\Sigma\Delta\eta$	+.0075
η uncooled	.9115
$\Delta\eta$ cooling	+.0097
η LPT	.921

Blade + Vane Cooling	2.16%
Shroud + Leakage	.5%

Cooling Flow (% WZC)

1N	.81
1R	.87
2N	.48
2R	0

5.4.3 Installation Aerodynamics

Attached is an estimate of the turboprop installation drag along with a discussion of wing scrubbing drag.

GENERAL ELECTRIC

EVENDALE PLANT

CINCINNATI, OHIO 45215

Ed

For our LOR

• SUBJECT

USTEDLEC TURBOPROP & PROP-FAN
INSTALLATION LOSSES

MAIL DROP E198

DIAL COMM 8•332 4025

COPIES:
S Drabek
J Kutney
R Neitzel

November 17, 1975

R. Hirschkron
Preliminary Design

Calculated nacelle system losses are attached for USTEDLEC turboprop and shrouded propellor installations. With this transmittal, our planned aerodynamic technical effort on Task I studies is complete. However, we will continue to support your efforts in preparation for the Task I final review at NASA in December.

R. C. Ammer, Manager
QCSEE Propulsion Systems

:al

A 14-E

PERFORMANCE SUMMARY
USTEDLEC TASK I TURBOPROP
UNDER-WING INSTALLATIONS
M_o = 0.8, 35K MAX CLIMB
F_N = 5357 LBS

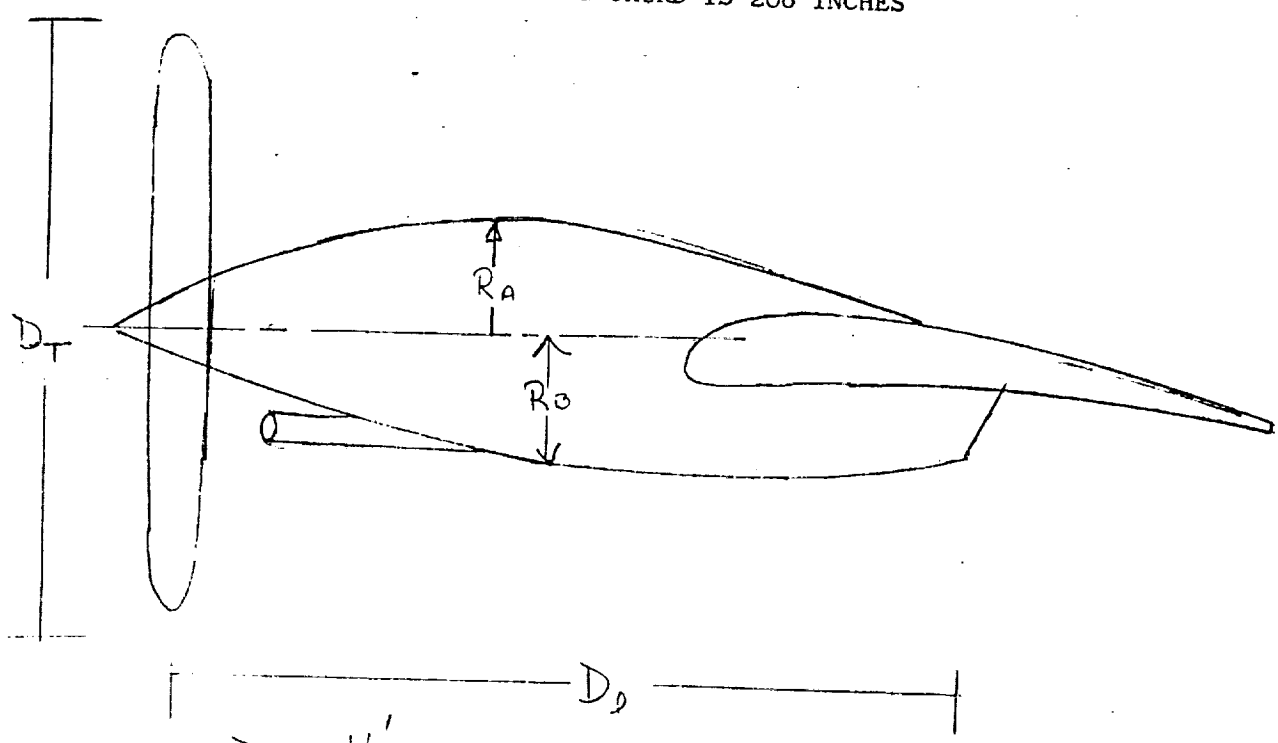
I. INTERNAL PRESSURE LOSSES

	$\% \Delta P_T/P_T$
CORE DUCT FRICTION	0.98

II. EXTERNAL DRAG

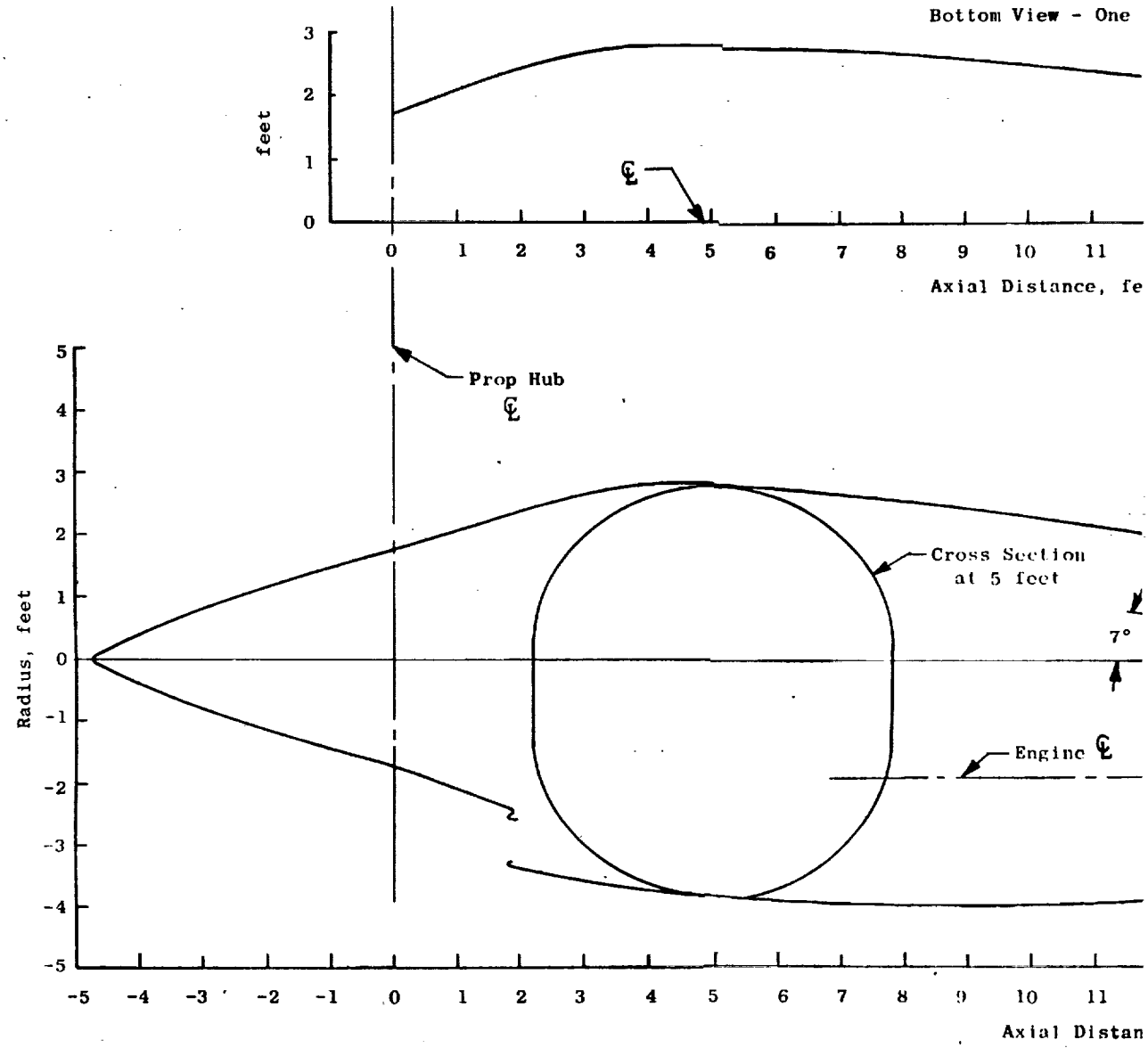
	LBS	% F_N
NACELLE PRESSURE DRAG	111.3	2.08
NACELLE FRICTION DRAG	206.7	3.86
PROP FLOW WING SCRUBBING DRAG INCREMENT (RELATIVE TO FREESTREAM)	28.0 (OUTBRD)*	0.523
	34.0 (INBRD)*	0.635
CORE FLOW WING SCRUBBING DRAG INCREMENT (RELATIVE TO FREESTREAM)	2.8 (OUTBRD)	0.052
	3.4 (INBRD)	0.063

* OUTBOARD NACELLE WING CHORD IS 173.5 INCHES
INBOARD NACELLE WING CHORD IS 208 INCHES



$D_T = 16'$
$D_P = 235.8''$
$R_A = 33.6''$
$R_B = 48.0''$

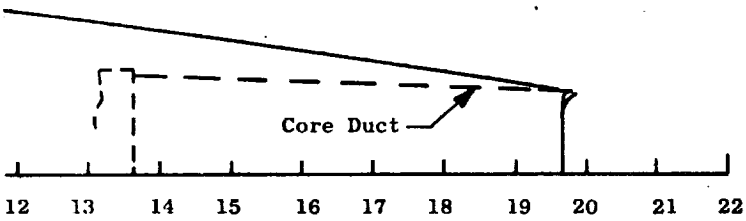
FOLDOUT FRAME



2.

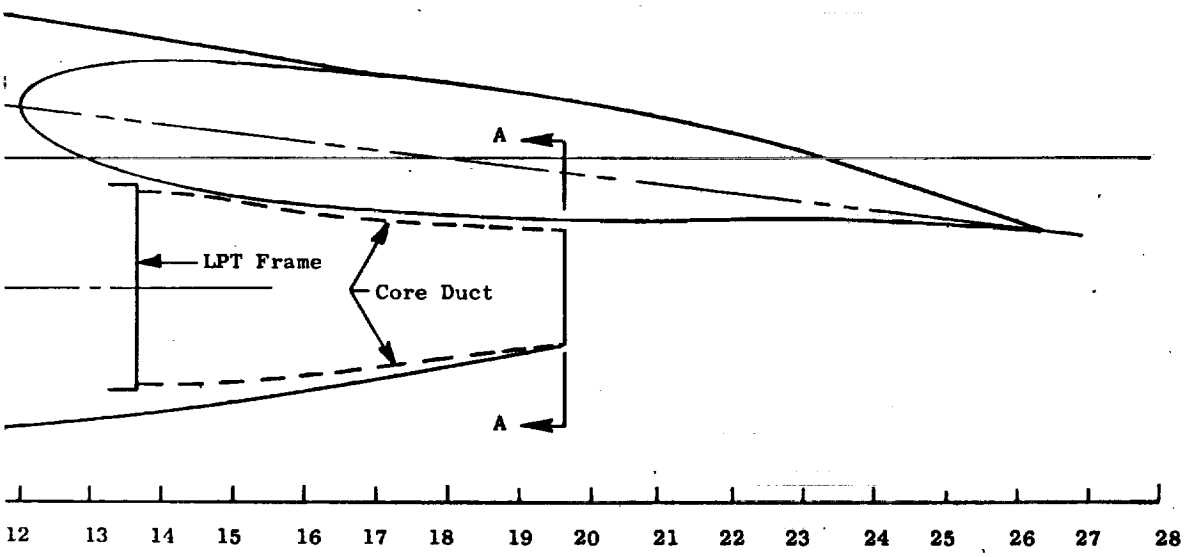
FOLDOUT FRAME

Side

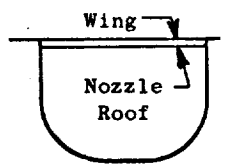


et

- USTEDLEC Turbo-Prop Study
- Scale: 1 in. = 1 ft
- Reduced Offset Between Engine ℄ and Gearbox ℄ per 10/7/75 Preliminary Drawing from E. Riley
- Outboard Nacelle Wing Chord = 173.5 in.
- 16 ft Prop Diameter



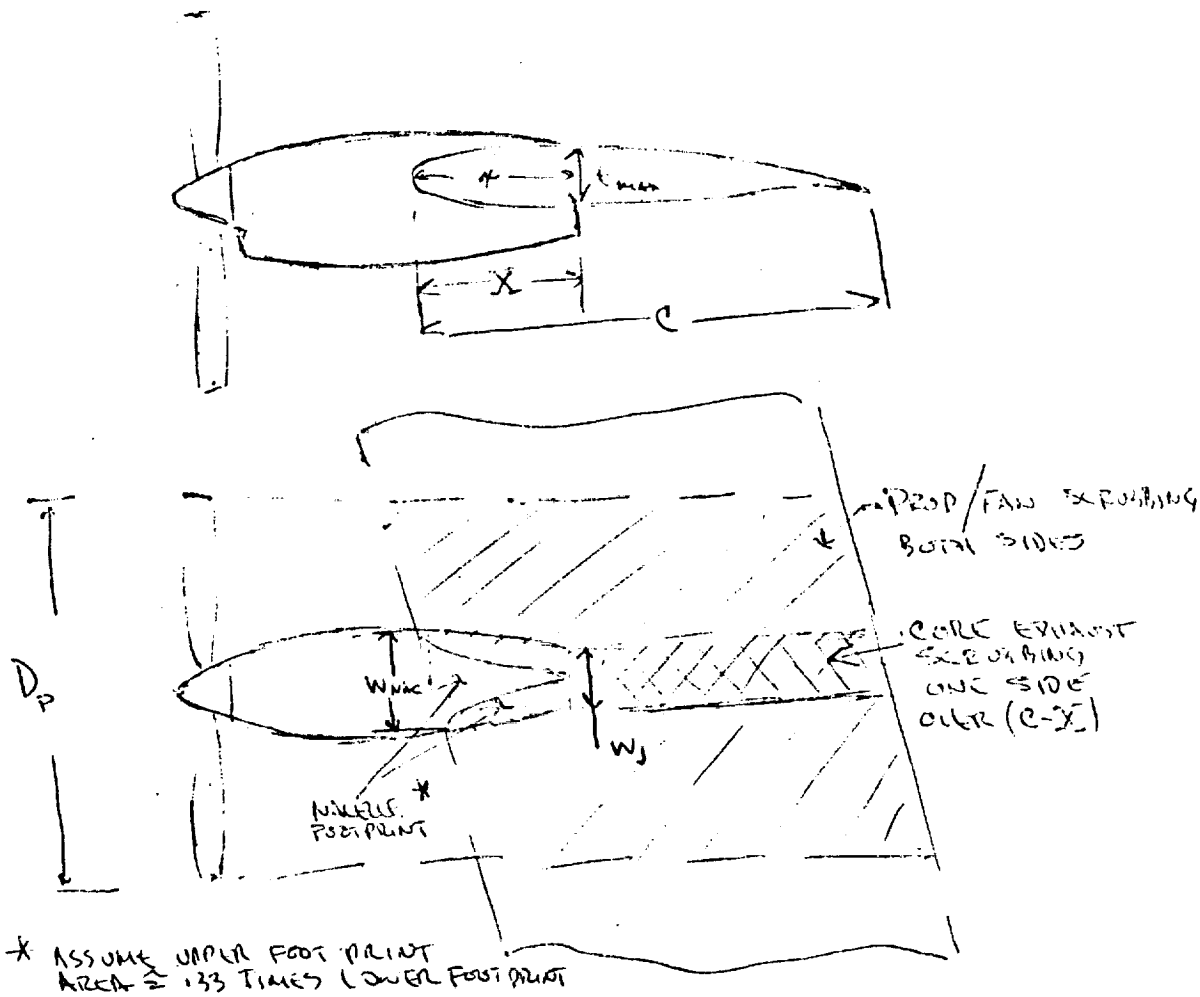
ce, feet



Sect A - A

G. WING SCRUBBING LOSSES

TURBO PROP AND SHROUDED PROPELLOR INSTALLATIONS STUDIED UNDER THE ASTEALL TASKS WERE MOUNTED ON THE WING IN SUCH A WAY THAT BOTH CORE EXHAUST AND PROP/FAN SLIPSTREAMS SCRUBBED THE WING SURFACES. SINCE SCRUBBING VELOCITIES ARE HIGHER THAN WOULD ORDINARILY BE FOUND WITH FREESTREAM FLOW OVER THE WING SURFACES A DRAG (FRICTION) INCREMENT IS CALCULATED AND ASSIGNED AS AN ENGINE INSTALLATION LOSS.



* ASSUME UPPER FOOTPRINT AREA ≅ .33 TIMES LOWER FOOTPRINT

THE METHOD USED TO ESTABLISH THE SCRUBBING DRAG INCREMENT IS TO FIRST ESTABLISH THE WING FREESTREAM DRAG OVER THE SAME SURFACES SCRUBBED BY EXHAUST, THEN DETERMINE THE ABSOLUTE VALUE OF SCRUBBING DRAG RAISED BY FAN & CORE FLOWS. THE DRAG INCREMENT IS THE CALCULATED DIFFERENCE WHICH WE WILL CALL WING SCRUBBING LOSS.

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FRICTION DRAGS ARE DETERMINED FROM THE BASIC EQUATION

$$D_F = C_{f_{AVG}} \left(\frac{C_f}{C_{f_{M=0}}} \right) K_{SV} K_R \, q \, A_{WET}$$

WHERE: $C_{f_{AVG}} = \dfrac{.455}{(\log_{10} R_e)^{2.58}}$ [SCHLICHTING]

R_e = REYNOLDS NO BASED ON WING CHORD, (OR IN THE CASE OF CORE EXHAUST R_e BASED ON, $C-\bar{X}$), AND THE STREAM PROPERTIES OF T_T, P_T, MACH NO REF NACA 1135 CHART #2,5

$$\left[\frac{C_f}{C_{f_{M=0}}} \right] = \frac{1}{\left[1 + \frac{\gamma - 1}{2} M^2 \right]^{.467}}$$ [FRANKL - VOSHEL

K_{SV} = SUPERVELOCITY CORRECTION $= 1 + K_p \, t/c$
WHERE $K_p = f(t/c)$ FROM FIGURE 7, SECT III F ; ASSUME $t/c = .35$

K_R = ROUGHNESS FACTOR $= 1.0$

$q = \frac{\gamma}{2} P_S M^2$ FOR STREAM CONSIDERED

A_{WET} = WING SURFACE CONSIDERED (BOTH SIDES)

- FOR CORE SCRUBBING THE DOUBLE CROSS HATCHED AREA IS CONSIDERED
- FOR FAN OR PROP STREAM SCRUBBING THE TOTAL CROSS HATCHED AREA, MINUS THE CORE (DOUBLE HATCHED) AREA MINUS THE NACELLE FOOT PRINT AREA IS USED

SAMPLE CALCULATION - TURBOPROP INSTALLATION

G WING SCRUBBING LOSSES — PROPELLOR STREAM

INPUT GEOMETRY:

FOR WING OUTBOARD INSTALLATION

c = CHORD = 173.5 IN
t = WING THICKNESS = 23.4 IN } FLOWPATH DRAWING

t_{MAX} IS AT $x/c = .3$

X = 91.8 INCHES = CENTERLINE DISTANCE FROM WING LEADING EDGE TO NOZZLE EXIT

W_{NAC} = NACELLE WIDTH AT WING LEADING EDGE INTERCEPT WITH ENGINE CENTERLINE

W_{NAC} = 53.5 IN

W_J = NOZZLE WIDTH AT EXIT

W_J = 27.6 IN

D_P = PROPELLOR DIAMETER = 192 INCHES.

WING WETTED SURFACE AREA SCRUBBED BY PROP STREAM (CONSIDERING BOTH SIDES, AND IGNORING WING SURFACE CURVATURE)

$$A_{WET} = 2D_P c - 1.33\left(\frac{W_{NAC}+W_J}{2}\right)X - W_J(c-X)$$

$$= 2\times 192\times 173.5 - 1.33\left(\frac{53.5+27.6}{2}\right)91.8 - 27.6(173.5-91.8)$$

$$= 59{,}418\ \text{IN}^2$$

REYNOLDS NUMBER BASED ON WING CHORD, AND MACH NO.

TWO CALCULATIONS MUST BE MADE HERE AND THEN THROUGHOUT THE CALCULATION PROCEDURE TO ARRIVE AT A DRAG INCREMENT BETWEEN FREESTREAM AND SCRUBBING VELOCITY:

$M_0 = 0.8$

$[OM_2]_{PROPELLOR} = .039$ (GIVEN FROM PROPELLOR DESIGN)

$\therefore\ M_{PROP} = 0.839$

SAMPLE CALCULATION – TURBOPROP INSTALLATION (CONT'D)

G WING SCRUBBING LOSSES – PROPELLOR STREAM

FREESTREAM CASE	PROPELLOR STREAM CASE
$M_0 = .8$	$M_{PROP} = 0.839$
$P_0 = 3.458$ (35 000 ft) PSIA	$P_0 = 3.458$ PSIA
$P_{T0} = 5.274$ PSIA	$P_{T_{PROP}} = 1.04 \times P_{T_0} = 5.486$ PSIA
$T_{T0} = 444.7\,°R$ (STANDARD DAY TEMP) $= (-15\,°R)$	$T_{T_{PROP}} \sim 444.7\,°R$
$q_0/P_s = .448 = f(M_0)$	$q_P/P_s = .493 = f(M_{PROP})$
$q_0 = 1.549$	$q_{PROP} = 1.705$
$R/L = .365 \times 10^6$ (chart 25 of NACA 1135)	$R/L = .37 \times 10^6$ (SAME SOURCE)
$R_e = (R/L)(P_T)(c)$ $= .365 \times 10^6 \times 5.274 \times \frac{173.5}{12} = 2.78 \times 10^7$	$R_e = 2.935 \times 10^7$
$C_{f_{AVG}} = \frac{.455}{[\log_{10} R_e]^{2.58}} = .00256$	$C_{f_{AVG}} = .00254$
$\left[\frac{C_f}{C_{f_{M=0}}}\right] = \frac{1}{(1+\frac{\gamma-1}{2}M^2)^{.467}} = .9453$ ($\gamma = 1.4$)	$\left[\frac{C_f}{C_{f_{M=0}}}\right] = .9403$ ($\gamma = 1.4$)
$t/c = 23.4/173.5 = .135$	$t/c = .135$
$t/c = .3$ (WING GEOMETRY INPUT)	$t/c = .3$
$K_p = f(x/c) = 2.0$	$K_p = 2$
$K_{SV} = 1 + K_p(t/c)$ $= 1 + 2 \times .135 = 1.27$	$K_{SV} = 1.27$
$K_R = 1.05$	$K_R = 1.05$
$D_F = C_{f_{AVG}} \left[\frac{C_f}{C_{f_{M=0}}}\right] K_{SV} K_R\, q\, S_{WET}$	$D_F = .00254[.9403]1.27(1)(1.705)(5948)$
$= .00256[.9453]1.27 \times 1 \times 1.549 \times 5948$ $= \cancel{282.9}$ LBS 297.0	$= \cancel{307.3}$ LBS 322.7

SLIPSTREAM SCRUBBING DRAG INCREMENT =

$$D_{SCRUB} = [D_F]_{PROP\ STREAM} - [D_F]_{FREE\ STREAM}$$

$$= \cancel{307.3}\ 322.7\ \text{LBS} - \cancel{282.9}\ 297.0\ \text{LBS} = \cancel{24.4}\ 25.7\ \text{LBS}.$$

ENGINE EVALUATION WAS PERFORMED WITH $D_{SCRUB} = 28.0$ LBS. OBTAINED FROM AN EARLIER SCALING ESTIMATES. DIFFERENCE FROM THE CORRECT VALUE OF 25.7 WAS NEGLECTED

5.4.4 Turboprop Mechanical Design

The turboprop, counter-rotating turboprop and the shrouded fan use the same basic engine (from the mechanical design standpoint). The engine cross-section is shown in Figure 5.4.4-1.

The STEDLEC Task III core is used for this engine as it is for all of the other USTEDLEC engines.

The booster is a straightforward 3 stages without IGV. The first and second stage vanes are variable and the last stage is fixed. Rotor speed is sufficiently low with a U_{rim} of only 900 fps that a rolled ring titanium drum with shallow discs can be used to save costs. Tangential dovetails are used to attach titanium blades.

The booster stator is conventional titanium with split casing. The general arrangement is directed at modular maintenance so that the stator and rotor can be easily removed by unbolting one casing flange and one rotor flange.

The forward sump and shaft has two LP shaft bearings; thrust and radial. In addition the shaft assembly includes a fully-flooded lubricated flexible spline to drive the quill shaft to the propeller gear box. The spline is large diameter and short to give reliable, long life performance. The arrangement assumes the engine will lubricate the aft spline of the quill shaft and the propeller reduction gear system will lubricate the forward end.

The intermediate frame connects booster to compressor; supports the PTO, booster and compressor rotors and the accessory gear box; and will serve as the forward engine

mount. To assure a reliable, cost effective frame the construction is welded and brazed steel. There is not a weight or cost advantage for aluminum or composite because of the relatively small diameter of the frame compared to a full fan frame. Cast aluminum would have a lower first cost but cost of ownership would be higher.

The four stage LPT operates at relatively low speed compared to the other geared fans (U_{pitch} is 920 fps vs. 1000-1070 fps) but has a considerable larger exit area. The latter increases weight and cost. Only the first stage rotor is cooled and the first and second stage vanes are cooled. Rotor cooling air is extracted externally from the compressor and conducted through the first stage vanes to a rim entry diffusor which supplies cooling air to the first stage rotor blades. Second stage vane cooling comes directly through casing passages to the vane tip. This air is also used to block the second stage vane seal.

The rotor has a separate first stage disc because it has cooled blades and is a bit different in construction and build-up from the last three stages. The last three stage disks are a welded assembly for lower cost weight and better reliability/life.

The blades are cast with tip shrouds. First stage blades are Ni76XB, the second stage if R125 and the last 2 stages are R80.

The LPT stator has a split casing since the rotor is a welded assembly and it also offers many advantages for maintenance and inspection.

The LPT can be removed as module for easy maintenance.

The Turbine Frame is a welded IN718 assembly similar to the USTEDLEC fans. The annulus area is larger because of the high turbine work extraction of the turboprop. There are no OGV required in the frame because of the low 0.92 loading, which helps reduce weight and cost.

The rear sump and bearings are also comparable to the other USTEDLEC engines. No carbon oil seals are used in order to reduce maintenance costs.

Two tables of data are available to provide an overall view of all USTEDLEC engines. Table 4.10.1 gives most of the key parameters that define the requirements of the mechanical design. Table 4.10.2 provides a weight breakdown by component of the turboprop and the other USTEDLEC engines. The Task III STEDLEC weights are also shown.

TURBOPROP ENGINE

CYCLE PRESSURE RATIO = 38:1

TURBINE INLET TEMP. = 2600°F

3 STG. LP COMPRESSOR
DRIVEN BY POWER TURBINE

4 STG. POWER TURBINE

BASELINE CORE ENGINE

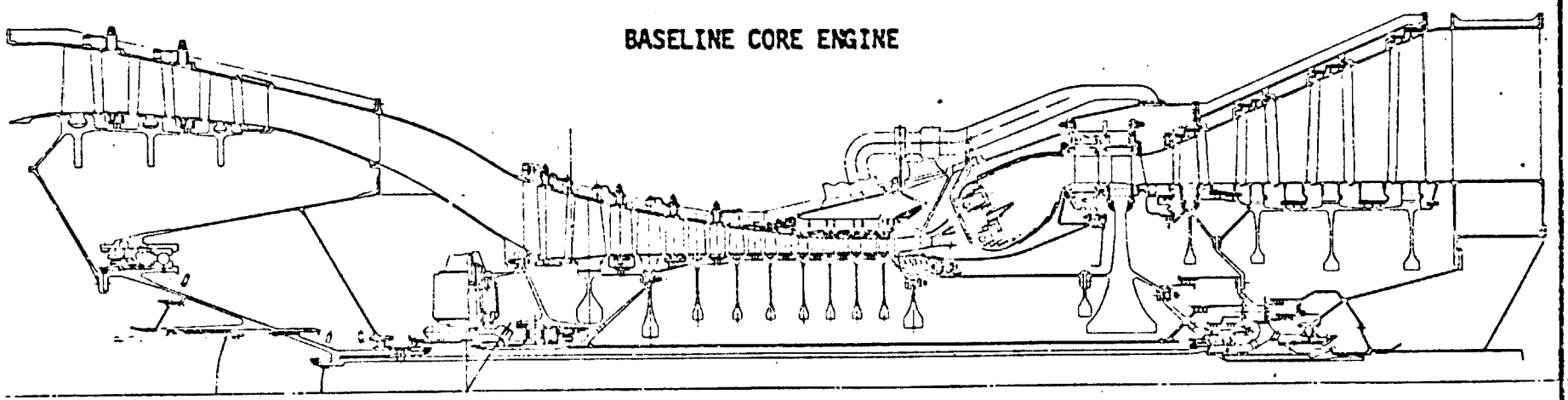

FIGURE 5.4.4-1

5.5 Propeller Systems Studied

The three following propeller systems were evaluated:

1) Basic propeller aerodynamics with basic technology weights. Single rotation.
2) Basic propeller aerodynamics with advanced technology weights. Single rotation.
3) Counter-rotating propeller with advanced technology weights.

All systems studied used the same core engine and cycle.

5.5.1 Engine Evaluation

Attached are the calculations supporting the Task I DOC, ROI and Wf results. The typical calculation is described below.

1) Installed engine weight, cost and performance are determined in the design size i.e., $W_{2C}\sqrt{\theta}/\delta = 68.4$. Table 5.5.1-1 presents the three turboprop engines (three levels of prop/gear technology).

2) For example, consider Table 5.5.1-3, "Basic Prop Transcon". The column titled "Design Size" gives the propulsion system characteristics in the $W_{2C}\sqrt{\theta}/\delta = 68.4$ core size. The prop and gear weights and costs are taken from the HSD supplied curves included in this section.

3) The column titled "Aircraft" presents the propulsion system characteristics used in the mission analysis.

4) The design size engine is then scaled to the same Max. Climb thrust as the aircraft. The propulsion system scale factor is the ratio of the design thrust to mission thrust, for this case SF = .365.

5) The propulsion system weights and costs are scaled to the mission values by the scale factor raised to the exponents shown on Table 5.5.1-2. For example, engine weight $(3554)(.365)^{1.25} = 1008$.

6) The difference in propulsion system weight, cost and SFC from the aircraft mission numbers are computed.

Adjustment of Aircraft Performance

1) The aircraft DOC, ROI and Wf are adjusted from the mission values by use of the Aircraft Influence Coefficients.

2) The propulsion system maintenance is made up of three parts:

   a) Engine maintenance is the initial difference in engine price times the parts replacement factor (PI)

   b) Propeller labor maintenance from HSD curve.

   c) Propeller material maintenance from HSD curves.

3) The adjustments to DOC, ROI and Wf are shown on Tables 5.5.1-3 through 5.5.1-6.

   Consider the DOC adjustment for the basic technology turboprop in the Transcon Aircraft 55% LF.

   ΔInitial Price = -11.6K (Total Propulsion System)

   ΔDOC/$1000 Initial Price = .011 (No effect on maintenance)

   ΔDOC = -.12%

   ΔInitial Price = -8.4 (Engine only)

   ΔDOC/$1000 x PI = .013 (Effect on maintenance only)

   ΔDOC = -.11

   ΔSFC = -.72%

   ΔDOC/Δ % SFC = .411

   ΔDOC = -.3

   ΔWt. = -1.8

   ΔDOC/100# = .205

   ΔDOC = -.37

ORIGINAL PAGE IS
OF POOR QUALITY

ΔProp Labor/hr = .0006

ΔDOC/Δ \$/hr = 1.1

ΔDOC = .0007

ΔProp Material = .0018

ΔDOC/Δ \$/F hour = .368

ΔDOC = .0007

$\Sigma\Delta$DOC = -.9

ΔDOC = 1.3787 -.9% = 1.366

Original Mission Value

The remainder of parameters ~~was~~ were adjusted in similar manner.

Table 5.5.1-1

Final Revision of Aircraft Mission

The following data is in design size core ie $W_{zc}\sqrt{\theta}/\delta = 68.4$

Final Engine + Prop Definition

	Basic Weight Single Rot.	Adv Wt Sing Rot	Counter-Rotation
F_N 35K/.8/418 Mxcl	9947 →		10529
D_{TIP}	21.87 →	→	
SFC_I @ 95% MxCr	.51 →		.483
Wt Engine	3554 →	→	
Wt Prop	4099	3658	3877
Wt Gear	3699	3480	4277
Wt Installation	3608 →		
Engine Price	516.9 →		
Prop + Gear Price	From Curve →	→	
Installation Price	326.9 →	→	

Table 5.5.1-2

Weight and Price Scaling

Weight and price were scaled by flow size to the following exponent

Item	Exponent
F_N	1.0
Engine Weight	1.25
Prop "	1.24
Gear	1.50
Installation	1.1
Engine Price "	.55
Installation "	.80

Note

Intercon. Aircraft corresponds to 1000 units on HSD $ Curve

Transcon Aircraft corresponds to 3200 units. Multiply 2800 unit price by .968

To convert 1975 $ (HSD Data) to 1974 $ divide by 1.141

The following represent the propulsion system scaled into mission size

TABLE 5.5.1-3

Basic Prop Transcon

	Design Size (1)	Mission Size (2)	Aircraft (3)
DT	21.87	13.21	
Engine	9947	3630	
SF	1.0	.365	
SFC 95%	.51	.51	.514
Wt Eng LBS	3554	1008	1010
Wt prop LBS	4099	1175	1168
Wt Gear LBS	3699	816	810
Wt Install LBS	3608	1190	1381
Price Eng 100$		417.1	425.5
Price Prop 100$		135.7	136.
Price Install 100$		205.1	207.5
(Corr Flow) W2.0* LB/sec	68.41	24.96	

(1) Design Size. Engine performance, weight, and cost in W2.0 TO & = 68.4 size

(2) Mission Size. Engine performance, weight, and cost scaled the MWCI thrust of the engine.

(3) Aircraft - Engine performance, weight and cost actually used in the mission analysis

Adv Wt | Transcom

	Design Size	Mission Size	Aircraft
DT	2187	13.21	
EW	9947	3630	
SEF	1.0	.365	
SFC	.51	.51	.514
Wt Eng	3554	1008	
Wt Prop	3658	1048	
Wt Gear	3480	767	
Wt Install	3608	1190	
Price Eng.		417.1	
Price Prop		145.9	
Price Install		205.1	
Wt ac	68.4	24.96	

Counter-Rotating Transcon

	DESIGN SIZE	MISSION SIZE	Aircraft
DT	21.87	12.81	
FN	10529	3630	
SE	1.0	.3947	
SFC	.483	.483	.514
Wt Eng	3554	938	
Wt prop	3877	1035	
Wt Gear	4277	866	
Wt Install	3608	1118	
Price Eng		401.2	
Price Prop		195.97	
Price Install		195.9	
W20*	68.4	23.58	

Basic Wt Interconn.

	DESIGN SIZE	MISSION SIZE	Aircraft
DT	21.87	15.3	
FN	9947	4875	
SFC	1.0	.49	.50798
SFC	.51	.51	.514
Wt Eng	3564	1457	1460
Wt prop	4099	1692	1683
Wt Gear	3699	1269	1260
Wt Install	3608	1646	1908
Price Eng		628.4	641.
Price Prop		245.4	244.6
Price Install		332.6	336.4
W_{ZF}*	68.4	33.52	

Adv Wt Intercom

	DESIGN SIZE	MISSION SIZE	Aircraft
DT	21.82	15.3	
FNT	9947	4875	
SFT	1.0	.49	
SFC	.51	.51	.514
Wt Eng	3554	1457	
Wt Eng SFC	3658	1510	
Wt Gear	3420	1194	
Wt Install	3608	1646	
PRICE Eng		628.4	
Price Prop		262.9	
PRICE Install		332.6	
Wzero	68.4	33.52	

Counter notating Intercon

	DESIGN SIZE	MISSION SIZE	Aircraft
DT	21.87	14.88	
EN	10529	4875	
SF	1.0	.463	
SFC	.483	.483	.514
Wt Eng	3554	1357	
Wt Engp	3877	1492	
Wt Gear	4272	1346	
Wt Install	3608	1547	
Price		609.1	
Eng Price		297.1	
Eng Price Install		317.9	
W2CK	68.4	31.66	

Aircraft Influence Coefficients

DOMESTIC TURBOPROP
3000 N.M. DESIGN CASE 100% PL, 100% RANGE

	TOGW	ΔTOGW%	FUEL BURNED	Δ FUEL BURNED %	DOC	ΔDOC% % CHANGE	ROI	Δ% ROI DIFFERENCE IN ROI
BASE	217930	BASE	40685	BASE	1.089725	BASE	98.15821	BASE
+100#/ENG.	218826	+.402%	40807	+.2977%	1.071702	+1.7796	97.8235	-.3600
+100#/NAC (EACH)	218826	"	40807	"				
+100#/PROP	218826	"	40807	"				
+100#/G.B.	218807	"	40807	"				
300# ACOUSTIC LINING	219917	+.912%	40962	+.6808%	1.075054	+1.4712	97.2357	-.9534
+1% SFC	218837	+.4391%	41163	+1.2363%	1.077795	+1.1337	97.7124	-.4697

DOMESTIC TURBOPROP
3000 N.M.
OFF DESIGN CASE 55% L.F., 700 N.MI.

	FUEL	Δ FUEL % BURNED	DOC	Δ DOC % % CHANGE	ROI	Δ% ROI DIFFERENCE IN ROI
BASE	9737	BASE	1.373721	BASE	17.91318	BASE
+100#/ENG	9769	+.3236%	1.381542	+.2661	17.81153	-.1165
+100#/NAC	9769	"				
+100#/PROP	9769	"		Same		
100#/GB	9769	"				
+200#/COMPOSITE UNINS.	9810	+.7497%	1.389761	+.51062	17.65359	-.25957
+1% SFC	9849	+1.1503%	1.384392	+.41133	17.77082	-.14236
$1000/E INFLUENCE EXPIRATE			1.379082	+.02256	17.9015	-.01168
$1000/E NO INFLUENCE ON MAINT.			1.375574	+.01110	17.90336	-.00982
$1000/E INFLUENCE ON MAINT. ONLY			1.378373	+.01139	17.91131	-.00187
+$1 MM/EFH	= .73¢		1.383797	+.39817	17.85323	-.05795
+.1 MMH/EFH.	.1 MMH		1.389837	+.90625	17.78187	-.13131

INTERCONTINENTAL TURBOPROP
5500 N.MI.
DESIGN CASE

100% PL. , 100% RANGE

	TOGW	ΔTOGW %	FUEL BURNED	Δ FUEL BURNED %	DOC	ΔDOC % CHANGE	ROI %	Δ % ROI DIFFERENCE IN ROIS
BASE	311111	BASE	91536	BASE	1.69094	BASE	45.7697	BASE
+100#/ENG	312220	+.3565%	91821	+.2874%	1.67415	+.2055	45.5973	-.1718
+100#/NAC	312220	"	91820	+.2853%				
+100#/prop	312220	"	91820	"		same		
+100#/G.B.	312221	+.3568%	91821	+.2874%				
+600# ACOUSTIC LINING	313651	+.8261%	92169	+.6695%	1.63408	+.4919	45.346	-.4235
+1% SFC	313608	+.8026%	92955	+1.528%	1.70273	+.7517	45.3755	-.4219

11-25-75

INTERCONTINENTAL TURBOPROP

65000 N.MI.

OFF DESIGN CASE 55% L.F., 2000 N.MI RANGE

	FUEL BURNED	Δ FUEL % BURNED	DOC	Δ DOC % CHANGE	ROI %	Δ % ROI DIFFERENCE IN ROI
BASE	30649	BASE	1.778934	BASE	4.670421	BASE
+100#/ENG	30744	+.3100%	1.782695	+.2114	4.583647	-.03177
+100#/NAC	[illegible]					
+100#/PROP	30744	+.3100%				
+100#/GB	30744	"				
+800# ACOUSTIC LINING	30866	+.7000%	1.783177	+.5796	4.465577	-.20492
+1% SFC	31105	+1.4973%	1.79148	+.7147	4.441337	-.22903
+$1000/ENG. INFLUENCE EVERYWHERE			1.779173	+.0137	4.665314	-.00511
+$1000/E. NO INFLUENCE ON MAINT.			1.779047	+.0064	4.666707	-.00371
+$1000/E. INFLUENCE ON MAINT ONLY			1.779065	+.0074	4.669027	-.00139
+$1 MATL/EFH			1.783761	+.2713	4.619245	-.05113
+.1 MMH/EFH			1.783506	+.5943	4.552249	-.12117

Table 5.5.1-3

Intercontinental

55% LF

2000 NM

45 ¢ Fuel

		DOC BASE	DOC Adv wt	DOC CR	ROI BASE	ROI Adv wt	ROI CR
(1)	Δ$ No maint	-15.5	+2	+2	-15.5	+2	+2
	Δ/Δ$	.0064	.0064	.0064	-.0037	-.0037	-.0037
	Δ	-.099	+.0128	+.0128	.057	-.0074	-.0074
(2)	Δ$ maint	-12.6	-12.6	-31.9	-12.6	-12.6	-31.9
PI*	Δ/Δ maint	.0083	.0083	.0083	-.0017	-.0017	-.0017
	Δ	-.11	-.11	-.28	.021	.021	.054
(3)	ΔSFC	-.72	-.72	-6.1	-.72	-.72	-6.1
	Δ/ΔSFC	.715	.715	.715	-.229	-.229	-.229
	Δ	-.515	-.515	-4.36	.165	.165	1.396
(4)	Δ$ Lab	.0006	.0006	.259	.0006	.0006	.259
	Δ/$Lab	.814	.814	.814	-.154	-.154	-.154
	Δ	.0005	.0005	.21	-.0009	-.0009	-.04
(5)	Δ$ mat	.0024	.032	1.0	.0024	.032	1.0
	Δ/Δ mat	.271	.271	.271	-.051	-.051	-.051
	Δ	.0006	.0086	.271	.001	-.016	-.051
(6)	Δ wt	-2.47	-5.04	-5.69	-2.47	-5.04	-5.69
	Δ/Δwt	.211	.211	.211	-.082	-.082	-.082
	Δ	-.521	-1.06	-1.2	.202	.413	.467
		-1.29	-1.67	-5.35	.45	.59	1.82
		1.757	1.749	1.684	4.691	4.697	4.755
		DOC			ROI		

(1) Difference in initial Price – No maintenance
(2) Difference in spare parts price
(3) ΔSFC
(4) Prop maintenance labor } From HSD Curves
(5) Prop maintenance parts }
(6) system weight

Table 5.5.1-4

Transcontinental
55% LF
700 NM
30¢ Fuel

	DOC BASE	DOC Adv wt	DOC CR	ROI BASE	ROI Adv wt	ROI CR
Δ$ No mod	-11.6	-.9	27.1	-11.6	-.9	27.1
Δ/Δ$	.011	.011	.011	-.0078	-.0078	-.0078
Δ	-.128	-.01	.298	.113	.009	-.266
Δ$ mod	-8.4	-8.4	-21.3	-8.4	-8.4	-21.3
PI * Δ/Δ mod	.013	.013	.013	-.023	-.023	-.023
Δ	-.11	-.11	-.28	.193	.193	.49
ΔSFC	-.72	-.72	-6.1	-.72	-.72	-6.1
Δ/ΔSFC	.411	.411	.411	-.142	-.142	-.142
Δ	-.3	-.3	-2.5	.102	.102	.866
Δ$ Lab	+.0006	.0006	.22	.0006	.0006	.22
Δ/$ Lab	1.1	1.1	1.1	-.18	-.18	-.18
Δ	+.0007	.0007	.24	-.0001	-.0001	-.039
Δ$ mat	+.0018	.0158	.508	+.0018	.0158	.508
Δ/Δ mat	.368	.368	.368	-.06	-.06	-.06
Δ	.0007	.006	.187	-.0001	-.0001	-.03
Δ wt	-1.8	-3.56	-4.12	-1.8	-3.56	-4.12
Δ/Δ wt	.205	.205	.205	-.101	-.101	-.101
Δ	-.37	-.73	-.84	.182	.359	.416
Δ	-.9	-1.14	-2.9	+.59	+.66	+1.43
	1.366	1.363	1.339	18.02	18.03	18.17
	DOC			ROI		

Table 5.5.1-5

Transcontinental

Block Fuel	Design Basic	Design Adv wt	Design CR	Off design Basic	Off design Adv wt	Off design CR	Transcon
Δ% SFC	-.72	-.72	-6.1	-.72	-.72	-6.1	
Δ/Δ SFC	1.236	1.236	1.236	1.15	1.15	1.15	
Δ WF	-.89	-.89	-7.53	-.828	-.828	-7.0	
Δ wt	-1.8	-3.56	-4.12	-1.8	-3.56	-4.12	
Δ/Δ wt	.3	.3	.3	.329	.329	.329	
Δ WF	-.59	-1.07	-1.24	-.59	-1.17	-1.36	
Δ WF	-1.43	-1.96	-8.77	-1.42	-2.0	-8.36	
→ ~~Δ WF~~ WF	40103	39887	37116	9599	9542	8922	

Table 5.5.1-6

Block	Fuel				ODES			
	BASIC	ADV WT	CR		BASIC	ADV	CR	
Δ% SFC	-.72	-.72	-6.1		-.72	-.72	-6.1	
Δ / Δ SFC	1.528	1.528	1.523		1.488	1.488	1.459	
Δ WF	-1.1	-1.1	-9.32		-1.07	-1.07	-9.08	
Δ wt	-2.47	-5.04	-5.69		-2.47	-5.04	-5.69	
Δ / Δ wt	.288	.288	.288		.31	.31	.31	
Δ WF	-.711	-1.45	-1.69		-.76	-1.56	-1.76	
Δ WF	-1.81	-2.55	-10.96		-1.84	-2.63	-10.8	
→ ΔWF	59899	59221	81520		30085	29849	27338	

Interven

5.6 Turboprop Installation

Figure 5.1 shows the installed turboprop with the propeller centerline intersecting the wing chord. The nacelle top and sides are aerodynamically defined to provide a maximum radius of .35 times the propeller tip radius. The engine is mounted below the propeller centerline, structurally supported by the inlet and off-set gear box in front and by long links from the turbine frame to the pylon in the rear.

The pylon, not shown, projects forward from the wing spars to the gear box. The outer sides of the pylon form a portion of both sides of the nacelle. The cowlings, top and bottom, are attached to the pylon. Large access doors are included in the top cowling for servicing the top of the engine, the gear box and aircraft accessories. Large access doors in the bottom cowling permit servicing the bottom of the engine and its accessories, as well as removal and installation of the engine without removal of the propeller and gear box.

The total cowling forward of the wing is light weight advanced composite sandwich configuration consistent with that planned for the baseline turbofan. The turbine exhaust duct and fire walls are steel and the cowling around the exhaust duct is titanium.

The weight and percent price estimate for the 16 ft. turboprop installation with a maximum climb Fn = 5703 lbs and TO Fn = 20,913 lbs is as follows:

	Weight Estimate	% Price Estimate
Propeller Rotor	1888 lbs.	
Gear Box	1449	
Gear Box lube and cooling system	70	
Nacelle:		
Inlet and drive shaft	128	6.0%
Outer cowl and fire wall	493	21.0
Exhaust pipe and centerbody	107	6.0
Wing protection & insulation	96	5.0
Pylon/EBU/Systems	1076	62.0
Subtotal	1900 lbs	100.%

TURBOPROP INSTALLED

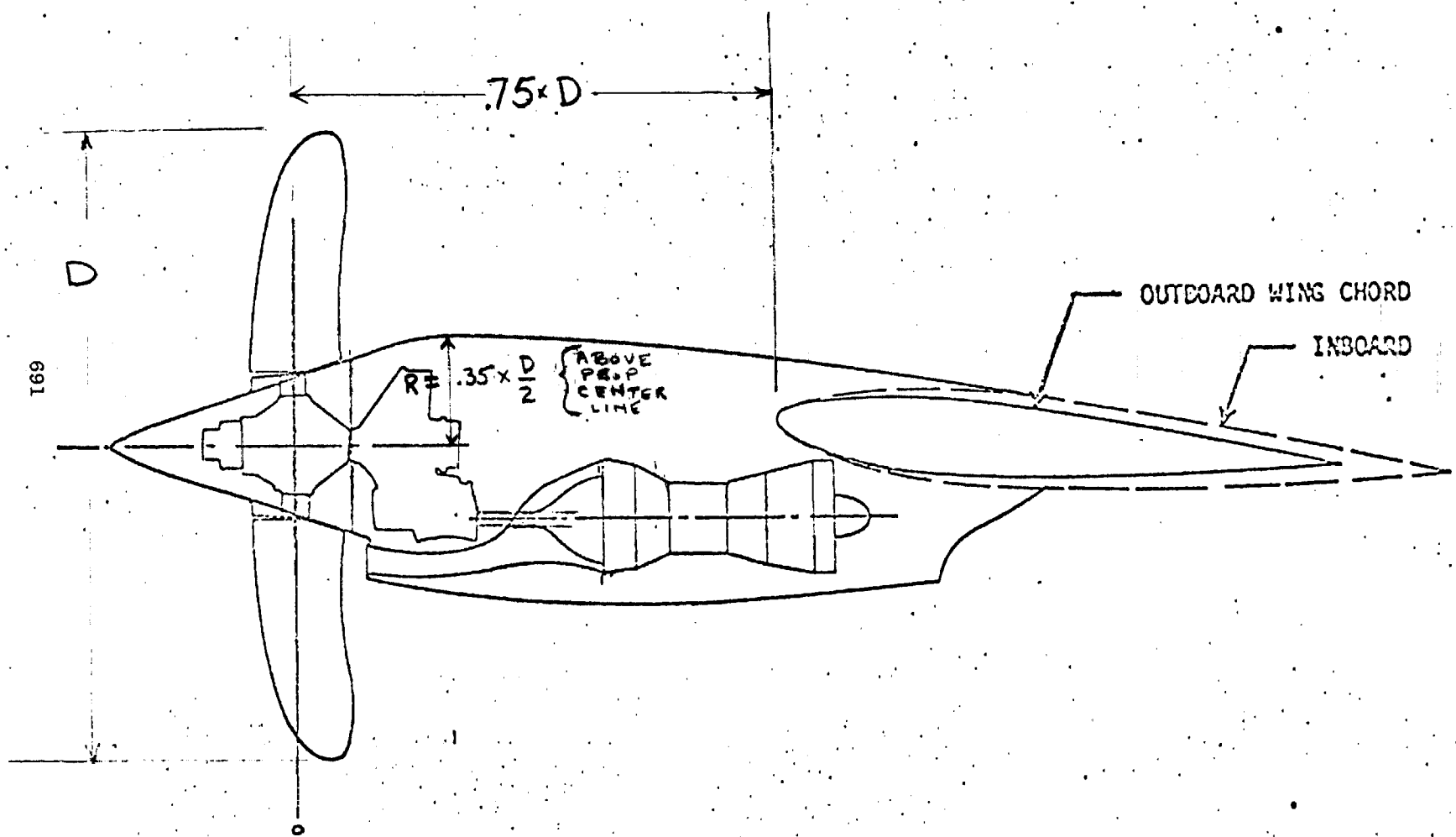

Figure 5.6.1

5.7 Introduction - Shrouded Propeller

The concept of the very high bypass ratio fan ($\beta = 73$) is to provide a propulsion system with propulsive efficiency approaching that of a propeller. The advantage of the high bypass fan ("Shrouded Prop") is expected to be found in a fan efficiency that is superior to that of the propeller. The efficiency improvement is results from the swirl recovery in the stator behind the fan as opposed to the unrecovered swirl in the propeller stream.

The penalties associated with the fan are the cowl weight and drag that are not inherent to the propeller.

5.7.1 Cycle Definition

The core engine cycle (STEDLEC MF12) chosen for shrouded propeller is the same as that for the turboprop, i.e. $P/P_{cycle} = 38$ and $T_4 = 2600^{\circ}F$. (SLS T/O)

The fan pressure ratio was chosen to be 1.08 @ 35K/.8/+18 MxCl.

Attached are cycle points at 35K/.8/+18 and 0/0/+27 T/O. Due to computer program flow size limitations, it was necessary to run at a core size $W_{2C}\sqrt{\theta}/\delta = 6.154$. Written aside of the printed output is the flow related parameters scaled to a $W_{2C}\sqrt{\theta}/\delta = 68.4$.

5.7.2 Component Aero Definition

Attached is the aerodynamic definition of the P/P = 1.08 fan.

The booster and LPT aerodynamic design were assumed to be similar to those of the turboprop defined in sections 5.4.1 and 5.4.2.

Using the cycle point in 5.7.1 the fan D_T is scaled up to 228" with $W_{2C}\sqrt{\theta}/\delta = 68.4$.

Point 1 | MxCl P/P_{fan} = 1.08 | MxCl P/P_{cycle} = 38.1 | MO T_4, °F = 2600

TWIN SPOOL SEPARATED FLOW TURBOFAN

FN	955.6 (10,654.6)	SEC	0.4304	FNW2	2.41
FN8E	83.0	FN8F	875.5 9732		
FG	10785.1	FR	9826.5	FGW2	27.17
WFM	460.5	WFR	0.	WFT	460.5
WFD	0.				

P0	3.458	T0	411.85	WK2	1047.389 1,64
P2	5.273	T2	464.79	W2	397.000 4413
P3F	5.695	T3F	476.31	W3F	391.604 4353
P3A	14.501	T3A	643.74	W3A	5.396 60.0
P2C	14.356	T2C	643.74	WK2C	6.154 61.4
P3C	200.981	T3C	1444.3	W31C	4.920
P4T	190.329	T4T	2960.0	W4T	5.048
P5T	50.127	DHT4T	0.07098	WK4T	1.443
P4V	50.127	T4V	2228.4 > 246.773	W4V	5.310 55.
P5V	5.001	DHT4V	0.11074	WK4V	5.001 55.6
P6E	4.953	T6E	1351.6	W6E	5.524
P6F	5.638	T6F	476.31	W6F	391.604
P72E	4.953				
P72F	5.638				
P8E	4.953	T8E	1351.6	W8E	5.524
P8F	5.638	T8F	476.3	W8F	391.604

P2P0	1.5249	ETAR	1.0000	MO	0.8000
P3P2F	1.0800	ETF	0.9000	BPR	72.5690
P3P2A	2.7500	ETA	0.8720	P2CP3A	0.9900
P3P2C	14.0000	ETC	0.8600	UNHPT	2.741
P3CP2	38.115			P4VP5T	1.0000
P4TP3C	0.9470	ETAHP	0.9875	LHV	18400.
P4P5T	3.7969	ETT	0.8980	WC5TWC	0.0485
P4P5V	10.0235	ETV	0.9116	UNHPV	0.
P6EP5	0.9935			WC5VWC	0.0397
P7271E	1.0000	ETAHE	0.	V8T	1240.9
P7271F	1.0000	ETA8F	0.	V8F	848.2
P872E	1.0000	CFG8E	0.9987	A9A8E	1.0000
P872F	1.0000	CFG8F	0.9970	A9A8F	1.0000
P8EP0	1.4325	CF8E	0.9965	A8E	83.49
P8FP0	1.6448	CF8F	0.9700	A8F	2954.09
ETACYC	0.4597	ETAK	0.9470	V9EXE	1242.6
ETAP	0.9399	ETAOV	0.4126	V9EXF	870.8
				V9EXEF	1.4500

D/F_N	F_N
.132	3237.5
.29	3105.3

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Point 2 P/P_{fan} = 1.08 P/P_{cycle} = 38.1 T_4, °F = 2600

TWIN SPOOL SEPARATED FLOW TURBOFAN

FN	5443.2	SFC	0.1816	FNW2	9.17
FN8E	241.0	FN8F	5207.2		
FG	7561.8	FR	2113.6	FGW2	12.73
WFM	989.1	WFR	0.	WFT	989.1
WFD	0.				

P0	14.696	T0	545.27	WK2	605.199
P2	14.799	T2	546.36	W2	593.813
P3F	16.030	T3F	560.40	W3F	582.295
P3A	37.603	T3A	737.15	W3A	11.518
P2C	37.227	T2C	737.15	WK2C	5.421
P3C	436.227	T3C	1555.9	W31C	10.502
P4T	413.107	T4T	3060.0	W4T	10.777
P5T	108.989	DHT4T	0.07096	WK4T	1.443
P4V	108.989	T4V	2311.7	W4V	11.335
P5V	16.625	DHT4V	0.09492	WK4V	5.001
P6E	16.467	T6E	1539.4	W6E	11.793
P6F	16.010	T6F	560.40	W6F	582.295
P72E	16.467				
P72F	16.010				
P8E	16.467	T8E	1539.4	W8E	11.793
P8F	16.010	T8F	560.4	W8F	582.295

P2P0	1.0070	ETAR	1.0000	MO	0.1000
P3P2F	1.0832	ETF	0.9000	BPR	50.5562
P3P2A	2.5409	ETA	0.8720	P2CP3A	0.9900
P3P2C	11.7182	ETC	0.8600	UNHPT	2.741
P3CP2	29.476			P4VP5T	1.0000
P4TP3C	0.9470	ETABM	0.9875	LHV	18400.
P4P5T	3.7903	ETT	0.8980	WC5TWC	0.0485
P4P5V	6.5558	ETV	0.9118	UNHPV	0.
P6EP5	0.9905			WC5VWC	0.0397
P7271E	1.0000	ETABE	0.	V8E	769.4
P7271F	1.0000	ETABF	0.	V8F	402.2
P872E	1.0000	CFG8E	0.9988	A9A8E	1.0000
P872F	1.0000	CFG8F	0.9969	A9A8F	1.0000
P8EP0	1.1205	CF8E	0.9965	A8E	83.52
P8FP0	1.0894	CF8F	0.9700	A8F	2954.08
ETACYC	0.3722	ETAK	0.9937	V9EXE	770.3
ETAP	0.4298	ETAOV	0.1570	V9EXF	403.4
				V9EXEF	1.9093

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USTEDLEC DUCTED PROP AERO DESIGN

A preliminary aerodynamic design of the high bypass ducted prop was completed including axisymmetric flow calculations at the aerodynamic design point (max climb) and the takeoff point. This fan has several unusual aerodynamic features in addition to the variable stagger rotor blade. The specific flow at the design point is very high at 43.2 lb/sec-ft^2 and the radius ratio is very low at .23 in order to keep the tip diameter to an absolute minimum. The low pressure ratio requirement in conjunction with a relatively high tip speed leads to unusually low solidity requirements for both the rotor and stator.

The extremely large flow modulation required between design point and takeoff conditions presents a severe off-design problem which is only partially solved by the variable stagger rotor. If the fan were to run at its design speed at the takeoff condition, the fan stator vanes would be subjected to very high negative incidence angles. By increasing the corrected tip speed from 750 ft/sec to 1000 ft/sec at the takeoff point, the average swing in stator incidence angle can be reduced from about 13° to about 6°.

Table I summarizes the major design parameters at the design point and the takeoff point. Table II gives a summary of the blade geometries and aero parameters at the design point.

The ducted propellor flowpath is shown in figure 5.7.2-1

TABLE 1 -- DESIGN SUMMARY

	Climb (Design Pt.)	Take-off
Pressure Ratio	1.080	1.056
Corrected Flow, lb/sec	10,313	4594
Specific Flow, lb/sec - ft^2	43.2	19.3
Exit Mach No.	.71	.25
Corrected RPM	799	1066
Corrected Tip Speed, ft/sec	750	1000
Inlet Radius Ratio	.23	----
Tip Diameter, in	215.0	----
Number Rotor Blades	6	----
Number Stator Vanes	10	----
Rotor Blade Closure from design angle, deg	0	30

TABLE 2 -- PRELIMINARY BLADE GEOMETRY
AND DESIGN POINT AERO DATA

	ROTOR			STATOR		
	Hub	Pitch	Tip	Hub	Pitch	Tip
Chord, in	22.4	30.0	30.0	25.0	25.0	25.0
Aspect Ratio	---	2.6	---	---	2.9	---
Solidity	.74	.40	.27	1.14	.55	.37
Max Thickness/Chord	.12	.04	.01	.05	.05	.05
Stagger, deg	-8	27	41	9	3	3
Camber, deg	43	6	15	33	17	20
Inlet Mach No.	.67	.84	.94	.87	.72	.67
Inlet Air Angle, deg	14	33	48	24	10	10
Leaving Air Angle, deg	10	27	39	0	0	0
Diffusion Factor	.08	.27	.25	.29	.12	.31
Lift Coefficient	1.40	.79	.86	.75	.63	.95

5.7.3
~~5.7.2~~ Ducted Propeller Installation Aerodynamics

Attached is a summary of the ducted prop installation drag along with a discussion of the method used in estimating the drag.

The drag presented for 215" D_T is 1218 lbs. Scaling to D_T = 228 yields a drag equal to 1370 lbs which is equal to 12.85% FN

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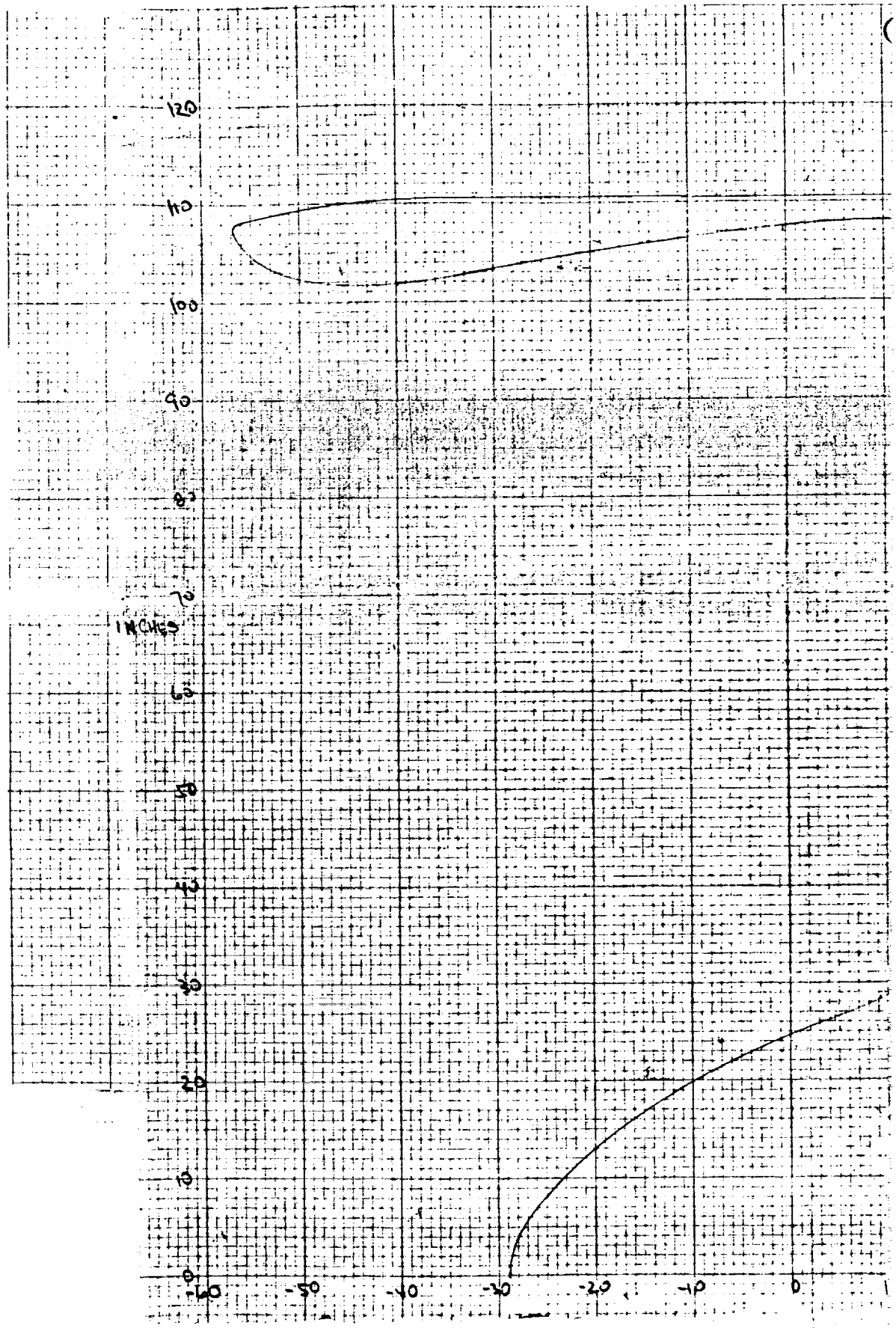

DUCTED PRC

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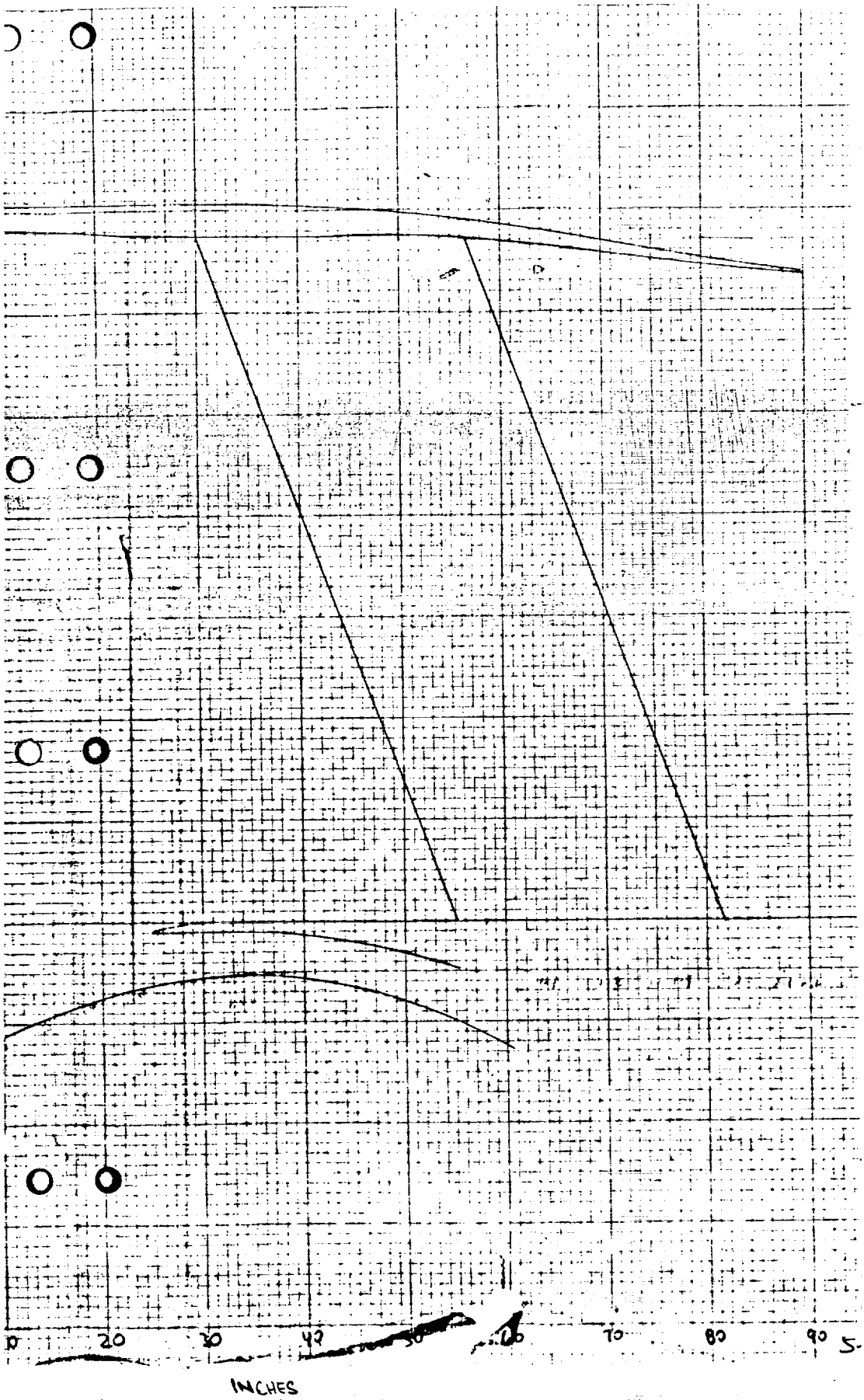

PELLER FLOWPATH

FIG 5.7.2-1

Page 5-160

PERFORMANCE SUMMARY
USTEDLEC TASK I SHROUDED PROPELLOR
UNDER-WING INSTALLATION
$M_o = 0.8$, 35K MAX CLIMB
$F_N = 9160$ LBS

I. INTERNAL PRESSURE LOSSES	$\% \Delta P_T/P_T$
FAN DUCT FRICTION	0.125
CORE DUCT FRICTION	1.00

II. EXTERNAL DRAG	LBS	$\% F_N$
NACELLE PRESSURE DRAG	587*	6.40
FAN SHROUD FRICTION DRAG	370	4.04
CORE COWL FRICTION DRAG (FAN SCRUBBING)	197.7	2.16
FAN FLOW WING SCRUBBING DRAG INCREMENT (RELATIVE TO FREESTREAM)	55.7**	0.61
CORE FLOW WING SCRUBBING DRAG INCREMENT (RELATIVE TO FREESTREAM)	5.8**	0.063
	1216	13.3%

* Based on the assumption (probably optimistic) that the very large fan shroud diameter relative to core cowl diameter makes it possible to treat each body independently and using a "carpet plot" method for determining drag. From this assumption, a fan shroud drag of 507 lbs. was calculated with a core cowl drag value of 80 lbs. For reference, using the standard L/D_{eq} method an overall pressure drag value of 746.5 lbs. (8.15%) was determined.

Technical Brief 72-2, Carpet Plots for Determination of Level I Isolated Nacelle Afterbody Pressure and Friction Drags, by D.J. Lahti et al, March 1972, describes the carpet plot method.

** Calculated for the outboard nacelle with wing chord of 278 inches.

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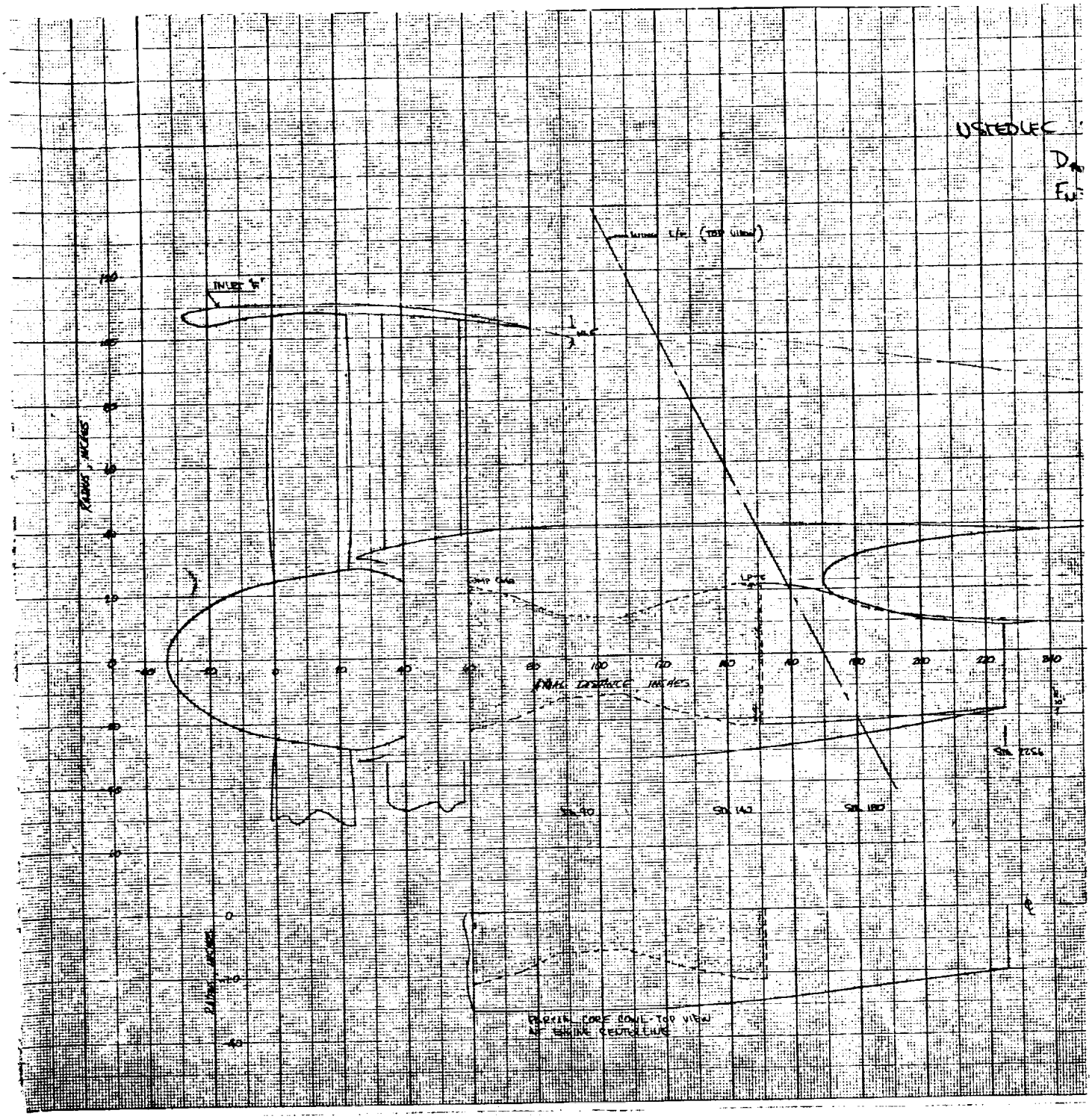

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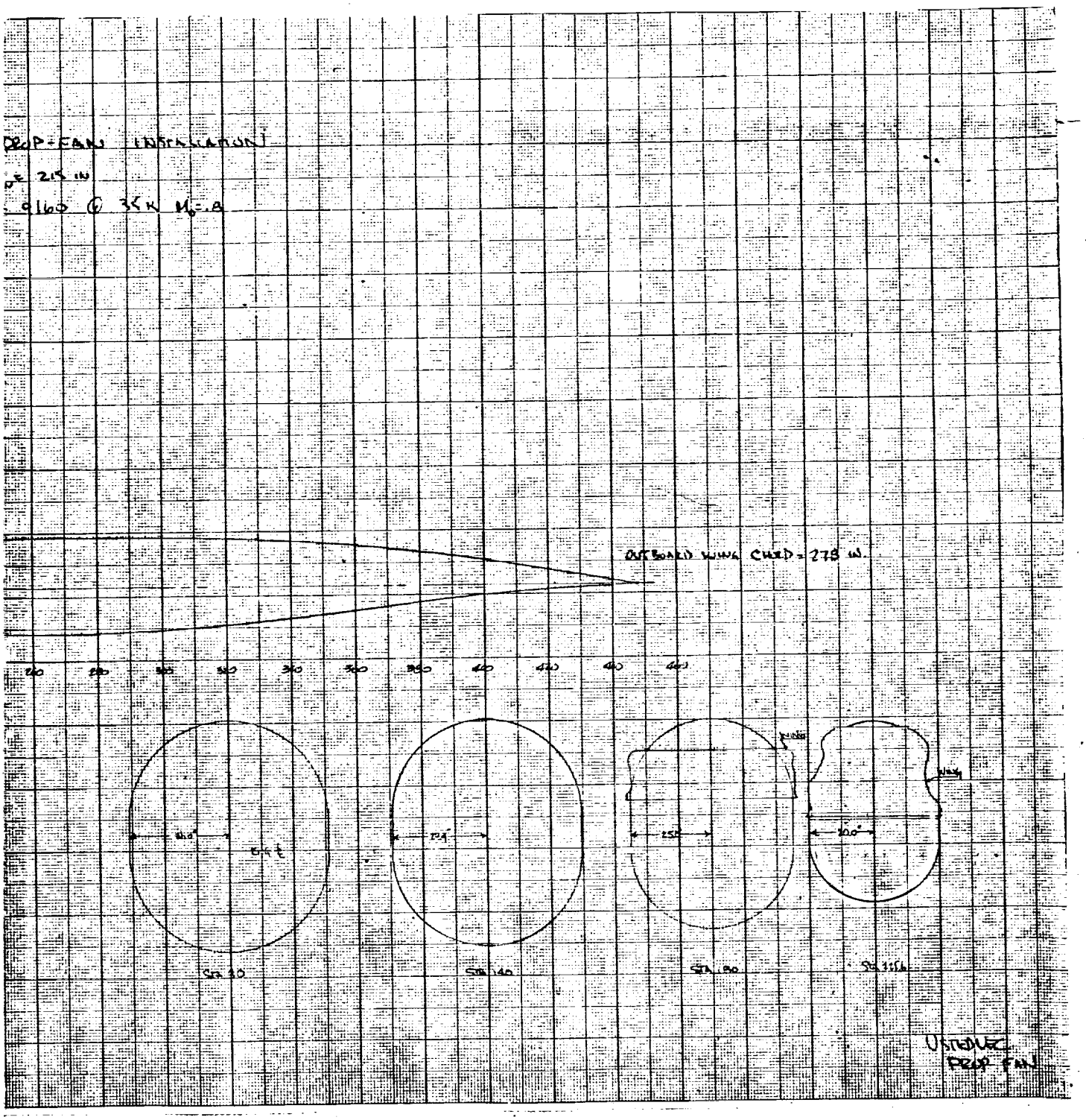

assumptions were based on Bertin Aerotrain data for a single conical nozzle configuration.

10.8.3.2 DYNAMIC EFFECT

The effect of forward flight on all components was accounted for by applying a 40 $\log\left(\frac{1}{1-m\cos\theta}\right)$ correction factor, ~~refined~~ referred to as dynamic effect. This correction term was indicated by theory and supported by analysis of static-to-flight data comparisons for varying flight velocities. Here θ is the angle between the flight path and the observer.

10.8.3.3 DISTANCE CORRECTION FACTORS

Decay rates as a function of distance were calculated assuming a typical spectrum shape, depending on the type of source (i.e. - jet, core, turbine). The results, indicated below, were used to extrapolate the static 200' sideline levels to the appropriate acoustic ranges for both takeoff and approach.

Source	Decay Rate (ΔPNL Basis)
Jet	$24 \log R_1/R_2$
Core	$25 \log R_1/R_2$
Turbine	$30 \log R_1/R_2$

10.8.3.4 CERTIFICATION GROUND

The prediction techniques used to obtain the static engine noise levels were based on data measured over a hard surface, not typical of a ground surface used during flight noise certification testing. To account for the difference between the two types of surfaces, the following corrections, based on data, were applied:

Source	ΔPNL Correction (Static-to-flight)
Jet	-0.5
Core	-0.5
Turbine	-1.5

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THE INLET DESIGN APPROACH USED FOR THE SHROUDED PROPELLOR WAS TO STUDY THROAT MACH NUMBER VS INLET LENGTH TRADES TO ARRIVE AT A SHORT INLET WHICH PROVIDED SATISFACTORY CRUISE PERFORMANCE IN TERMS OF RECOVERY AND SPILLAGE DRAG, YET PROVIDED SUFFICIENT RECOVERY AT TAKE OFF (RECOVERIES AS LOW AS 0.94) AND ALLOWED FOR "SAFE" FAN OPERATION.

THE PARAMETRIC INLET DATA FROM THESE STUDIES IS GIVEN ON TABLES 1 AND 2. INLET DESIGN DATA FROM WHICH THESE INLETS WERE DESIGNED ARE GIVEN ON FIGURES 2 AND 3. INLET DRAWINGS OF THESE STUDY RESULTS ARE GIVEN ON FIGURE 4. CONFIGURATION F WAS SELECTED FOR USE IN NACELLE LOSS STUDIES.

7/18/75

TABLE 1

$R_{MAX} = \frac{221.28}{2} = 110.64''$

$\eta_{R_{CRUISE}} \neq 1$

SELECTED

VERSION 1

		A	B	C	D	E	F	G
	$M_{TH_{CRUISE}}$	.80			.72		.64	.584
(#/sec/ft²)	$(WF/\delta A)_{M_{TH}}$	47.59			45.73		43.15	40.901
	GUESS $\eta_{R_{CRUISE}}$	.9977			.9990		.9998	1.0
(ft²)	A_{TH}	216.186			225.272		238.933	252.118
(INCHES)	R_{TH}	99.545			101.616		104.651	107.500
	GUESS R_{AL}/R_{MAX}	.973	.943	.913	.973	.932	.973	.973
(INCHES)	R_{AL}	107.653	104.337	101.014	107.653	103.116	107.653	107.653
	R_{AL}/R_{TH}	1.0815	1.0481	1.0148	1.0594	1.0148	1.0287	1.00142
	a/b	2.0	2.0	1.0	2.0	1.0	2.0	1.0
(INCHES)	L_{LIP}	16.216	9.578	1.469	12.074	1.500	6.004	0.153
(INCHES)	L_{DIFF} FOR $\theta_{DIV} = 7.5°$ (.1317)	60.402	60.402	60.402	44.677	44.677	21.633	0
(INCHES)	L_{INLET}	76.618	69.980	61.871	56.751	46.177	27.637	0.153
	L_{INLET}/D_F	0.356	0.325	0.288	.264	.215	.1285	.00071
DIFFUSER LOSS COEFF.	$\frac{\Delta P_T/q_{TH}}{(1 - A_{TH}/A_{EX})^2}$	0.3838	.3786	.3725	.3685	.3604	.3461	.3250
	$\Delta P_T/P_T$	.00229	.00226	.00222	.00107	.00105	.00021	0
	η_R ? GUESS	.99771 ✓	.99774 ✓	.99778 ✓	.99893 ✓	.99895	.99979 ✓	1.0 ✓
	A_O/A_{MAX}	.8095	.8095	.8095	.8106	.8106	.8112	.8114
NACA 1 (GEOM.)	$M_{DD_{MAX}}$	.82	>.94	>.94	.82	>.94	.82	.82
	X/D_{MAX}	.102	.175	.235	.102	.198	.102	.102
(INCHES)	X	22.571	38.724	52.001	22.571	43.813	22.571	22.571
(ft²)	A_{AL}	252.836	237.487	227.613	252.836	231.974	252.836	252.836
	A_O/A_{AL}	.8550	.9103	.9711	.8562	.9332	.8568	.8570
(ASSUMED)	$\approx \eta_{R_{TO(SLS)}}$	.983 ~~GUESS~~	.968	.953	.974	.953	.960	.946
	$A_O/A_{MAX})_{MIN}$	.8095	~.69	~.60	.8106	~.65	.8112	.8114
(#/sec)	$(WF/\delta)_{MIN}$ FOR $M_{DD} = .82$	10,312	8,790	7,643	10,312	8,269	10,312	10,312
(INCHES)	$(L_{INLET} - X)$	54.047	31.256	9.870	34.180	3.864	5.066	−22.418

$A_{EX} = A_{TP} = 252.118$ ft² $\quad A_{MAX} = 267.062$ ft²

TABLE 2

INLET GEOMETRY INPUT FOR VERSION 1 PROP FAN (215" D_T)

• LIP/FOREBODIES – ALL "INLET 1" (NACA 1-SERIES)

	A	B	C	D	E	F	G
X	22.571	38.724	52.001	22.571	43.813	22.571	22.571
Y	2.987	6.306	9.626	2.987	7.524	2.987	2.987
XREF	-76.618	-69.980	-61.871	-56.751	-46.177	-27.637	-0.153
YREF	107.653	104.334	101.014	107.653	103.116	107.653	107.653
NN	30	30	30	30	30	30	30
XE	16.216	9.578	1.469	12.074	1.500	6.004	0.153
RTHROT	99.545	99.545	99.545	101.616	101.616	104.651	107.500

• DIFFUSERS – ALL "CUBIC"

	A, B, C	D, E	F	G
X_1	-60.402	-44.677	-21.633	X
Y_1	99.545	101.616	104.651	
θ_1	0°	0°	0°	
X_2	0	0	0	
Y_2	107.5	107.5	107.5	
θ_2	0°	0°	0°	

$M_{M_{CRUISE}}$	.80	.80	.80	.72	.72	.64	.584
R_{IN}/R_{MAX}	.973	.943	.913	.973	.932	.973	.973
X/D_{MAX}	.102	.175	.235	.102	.198	.102	.102
M_{DD}	.82	>.94	>.94	.82	>.94	.82	.82
R_{IN}/R_{TH}	1.0815	1.0481	1.0148	1.0594	1.0148	1.0287	1.0014
$\approx \eta_{R_{SLS}}$	.983	.968	.953	.974	.953	.960	.946
L/D_F	.356	.325	.288	.264	.215	.1285	.00071
$(W/\delta_2)_{HW}$ (#/sec) FOR .22 M_{DD}	10,312	8,790	7,643	10,312	8,269	10,312	10,312

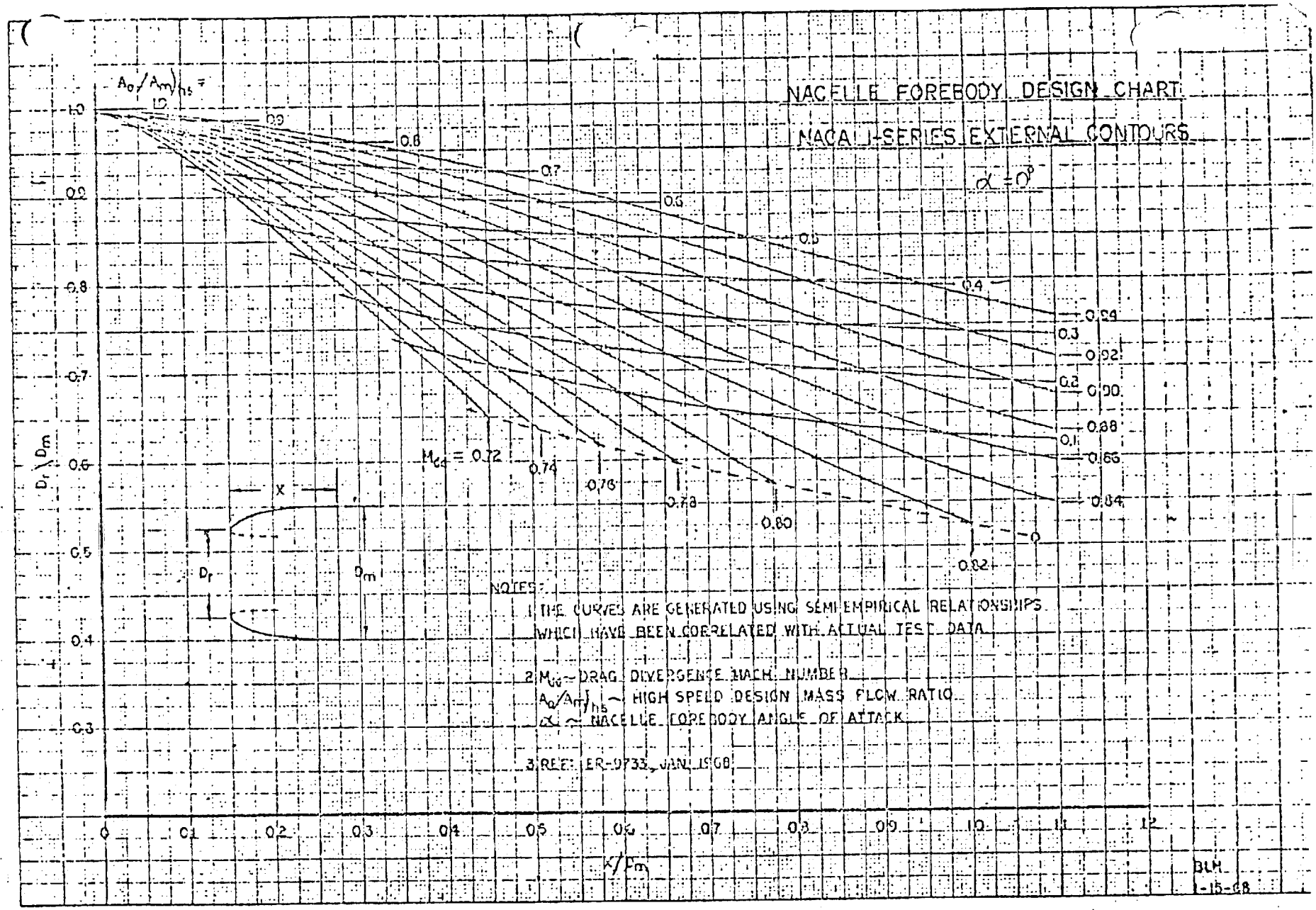

Fig 2 GRAPH OBTAINED FROM LOCKHEED GEORGIA

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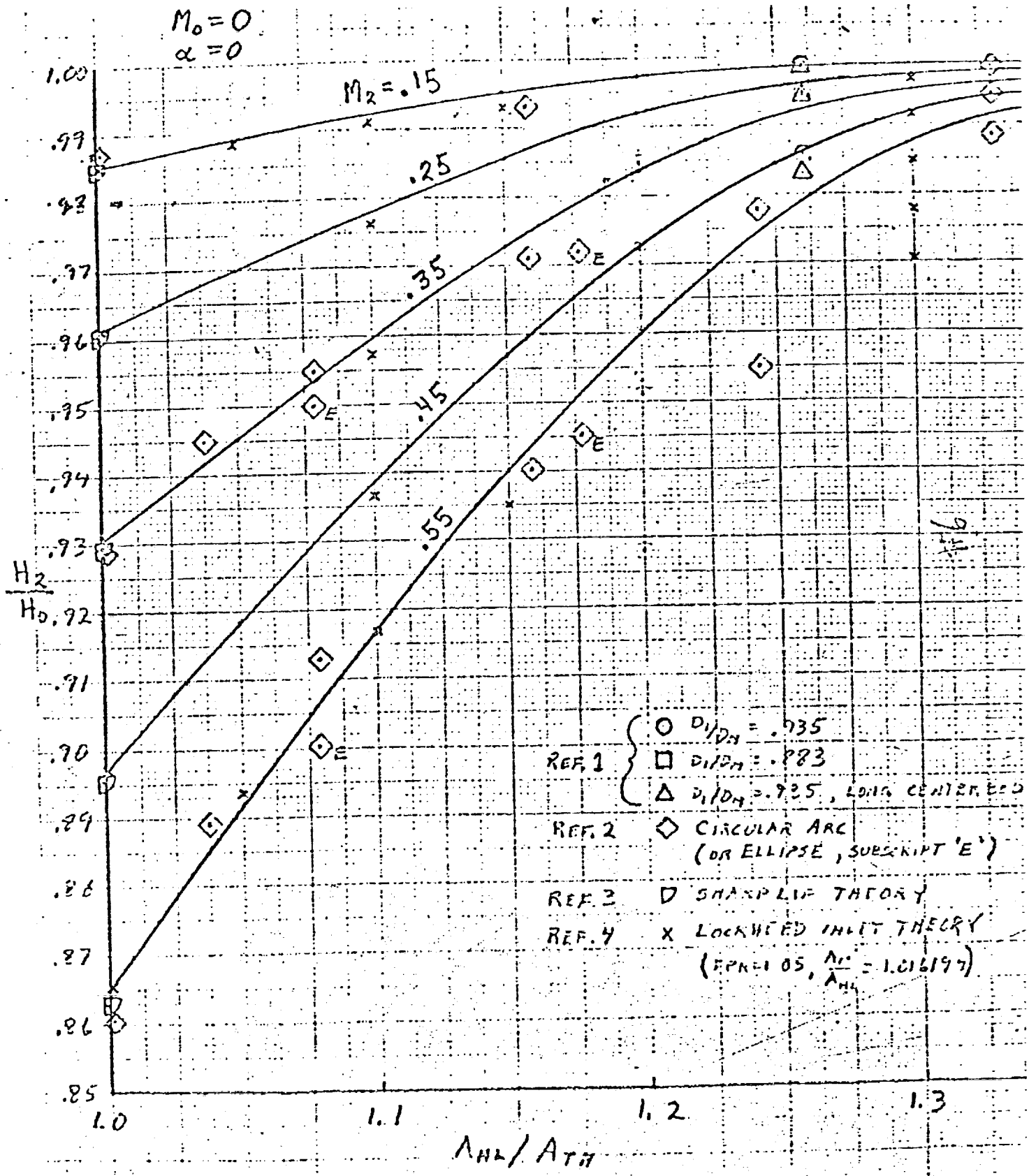

REF. 1, UNPUBLISHED 10" INLET DATA, NASA-LEWIS, HOWARD WESCKY

REF. 2, NACA TN 3170

REF. 3, NACA REPORT 1193

REF. 4, AIAA PAPER No. 69-448

FIG 3 DATA FROM NASA LEWIS (MIKKELSON PRESENTATION)

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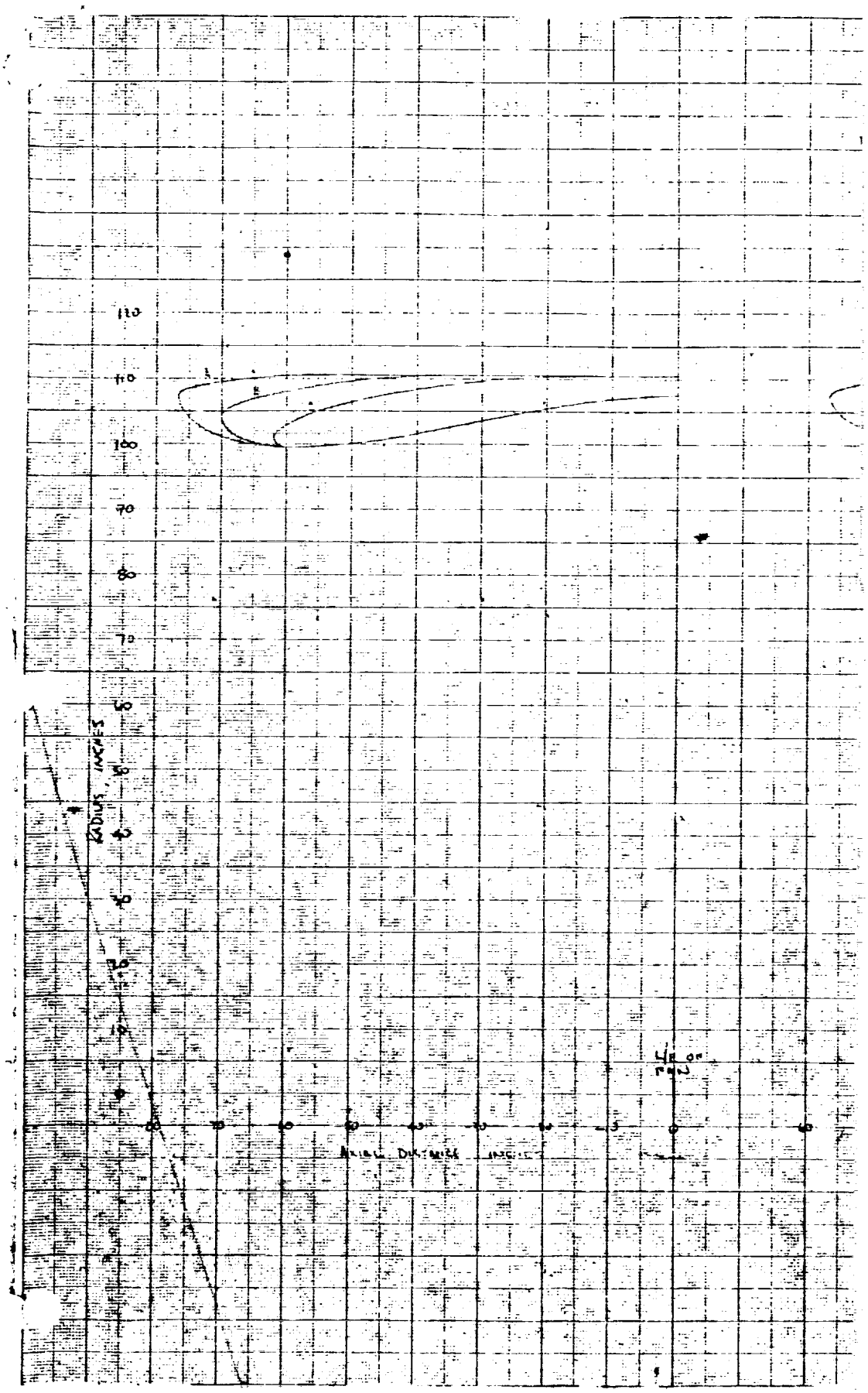

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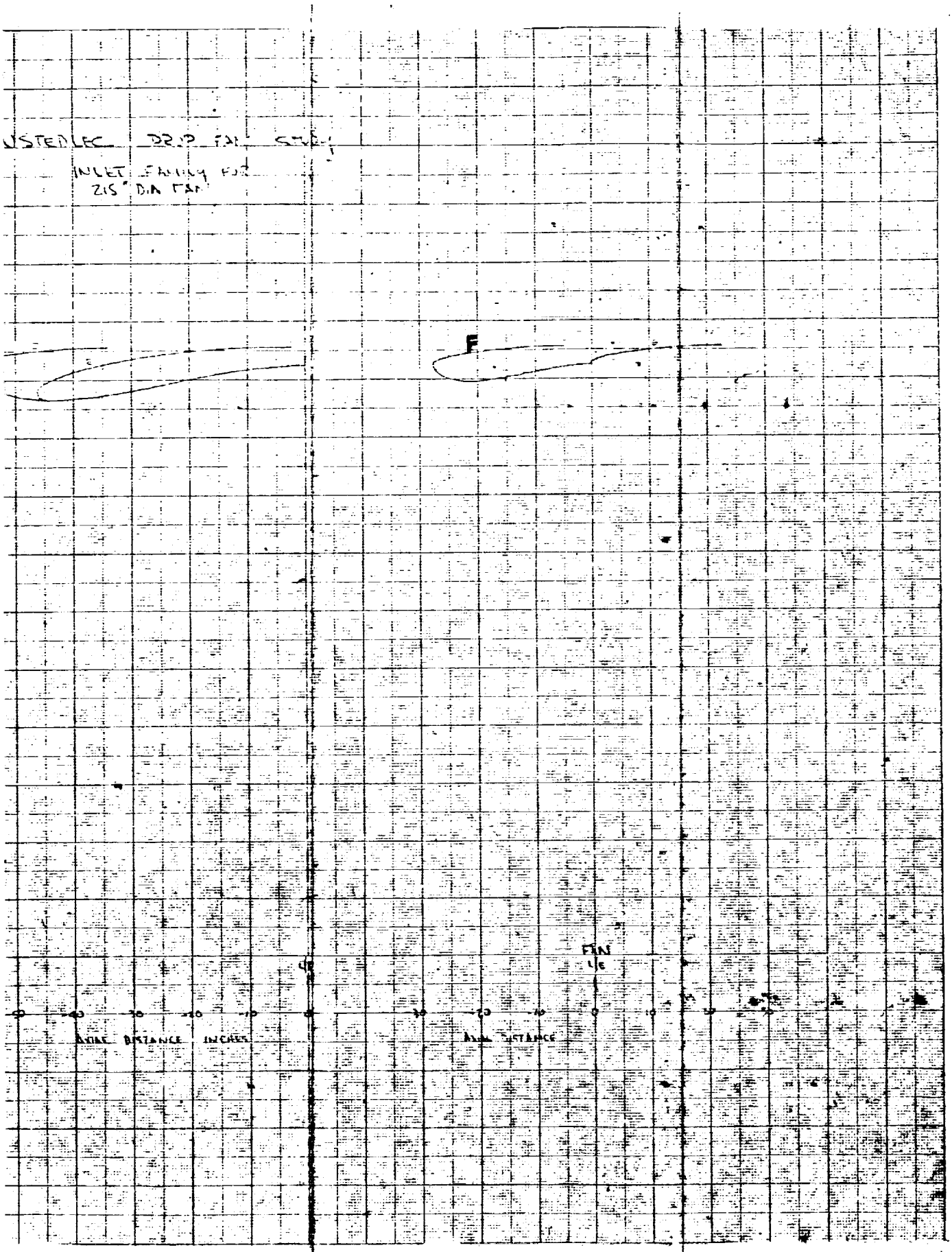

FIGURE 4

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SAMPLE CALCULATION – SHROUDED PROPELLOR

B. FAN DUCT TOTAL PRESSURE LOSS

DUCT FRICTION LOSS – METHOD 2

FROM THE FLOWPATH GEOMETRY, THE FAN SHROUD AND CORE DUCTING BEGINS BEHIND THE FAN EXIT GUIDE VANES (ENGINE STATION 58) AND EXTENDS TO STATION 80. THE LOSS CALCULATION EXAMPLE PRESENTED HERE IS CALCULATED ON THIS 22 INCH SECTION.

– CROSS SECTION GEOMETRY AT THE SECTIONAL MID POINT IS:

- FAN SHROUD INTERNAL FLOWPATH RADIUS, STATION 69 = 104 INCHES
- WETTED SURFACE $A_{SURFACE\ SHROUD} = (2\pi)(104)(22) = 14{,}376\ IN^2$

- CORE COWL CONSISTS OF TWO SEMI CIRCULAR SECTIONS, EACH HAVING A 31 INCH RADIUS & CENTERS DISPLACED 1 INCH BELOW AND 9 INCHES ABOVE ENGINE CENTERLINE, BOTTOM HALF AND TOP HALF RESPECTIVELY.
- WETTED SURFACE IS

$$A_{SURFACE\ CORE\ COWL} = 2\pi(31)(22) + 2(9+1)(22) = 4725\ IN^2$$

∴ TOTAL WETTED SURFACE:

$$A_{SURFACE} = 14376 + 4725 = 19101\ IN^2$$

AVERAGE FLOW AREA AT SECTION MID POINT IS:

$$A_{AVG\ FLOW} = \pi(104^2) - \pi(31)^2 - (9+1)(31+31)$$
$$= 33979\ IN^2 - 3019\ IN^2 - 620$$

∴ $A_{AVG\ FLOW} = 30340\ IN^2$

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SAMPLE CALCULATION ON SHROUDED PROPELLOR
DUCT FRICTION LOSS - METHOD 2, CONTINUED

- CYCLE DATA
  AT 35000 FT, 0.8 MACH NO.
  - $A_{FAN\ EXIT}$ (STATION 80) = 29184 IN^2
  - FAN PRESSURE RATIO 1.08
  - RAM PRESSURE RATIO (0.8 MACH) = $P_{t0}/P_0 = 1.524$
  - NOZZLE PRESSURE RATIO $P_t/P_0 = 1.646$
  - $P_t = 1.646 \times 3.458 (P_0 @ 35000\ FT) = 5.69$ PSIA
  - $T_T = 515\ °R$ - FAN DISCHARGE TOTAL TEMPERATURE

- FLOW PROPERTIES IN THE FAN DUCT FROM MACH NUMBER FLOW TABLES

  AT $P_t/P_0 = 1.646$:

  $M_{FAN\ EXIT} = .8745$

  $A_{FAN\ EXIT}/A^* = 1.0142$

  AND WITH DUCT MID SECTION GEOMETRY (STATION 69)

$$\frac{A_{AVG\ FLOW}}{A^*} = \left[\frac{A_{FAN\ EXIT}}{A^*}\right] \times \left[\frac{A_{AVG\ FLOW}}{A_{FAN\ EXIT}}\right]$$

$$= 1.0142 \times \frac{30340}{29184} = 1.0544$$

THEN, FROM TABLES AT $\frac{A_{AVG\ FLOW}}{A^*} = 1.0544$

$$\left[M_{AVG}\right]_{STA\ 69} = f(1.0544) = .765$$

$$\left[q/P_s\right]_{STA\ 69} = f(1.0544) = .4097$$

$$Re_L = f(M_{AVG}, T_T, P_t \text{ AND SECTION LENGTH})$$

USING CHART #25 OF NACA 1135

SAMPLE CALCULATION - SHROUDED PROPELLOR

DUCT FRICTION LOSS - METHOD 2 CONT'D

$$\left[\frac{R_{eL}}{\mu P_t}\right]_{\substack{M=.765 \\ T_t=55°F\ (515°R)}} = .295 \times 10^6 \quad ; \quad R_{eL} = \left[\frac{R_{eL}}{\mu P_t}\right] \times P_t \times L_{SECTION}$$

$$\therefore \quad R_{eL} = .295 \times 10^6 \times 5.69 \times \frac{22\ IN \times FT}{12\ IN} = 3.08 \times 10^6$$

AND THEN, FRICTION COEFFICIENT IS:

$$C_{f_{AVG}} = \left[\frac{.455}{\log_{10} R_{eL}}\right]^{2.58} = \left[\frac{.455}{\log_{10} 3.08 \times 10^6}\right]^{2.58} = .00365$$

AND COMPRESSIBILITY CORRECTION FACTOR IS

$$\left[\frac{C_f}{C_{f_{M=0}}}\right] = \left[\frac{1}{1+\frac{\gamma-1}{2} M_{AVG}^2}\right]^{.467} = \left[\frac{1}{1+\left(\frac{1.4-1}{2}\right)(.765)^2}\right]^{.467} = .95$$

FINALLY DUCT TOTAL PRESSURE LOSS:

$$\frac{\Delta P_t}{P_t} = 1.05\left(\frac{q}{P_s}\right)\left(C_{f_{AVG}}\right)\left(\frac{C_f}{C_{f_{M=0}}}\right)\left(\frac{A_{SURFACE}}{A_{AIR\ FLOW}}\right)$$

$$= (1.05)(.4097)(.00365)(.95)\left(\frac{19101}{30340}\right) = .0009$$

AND PERCENT $\frac{\Delta P_T}{P_t}$;

Duct $\Delta P/P$ used in shrouded prop includes acoustic treatment. It is assumed that this increases $\Delta P/P$ 37% therefore increasing it from .09% to .125%

$$\% \frac{\Delta P_t}{P_t} = \frac{\Delta P_t}{P_t} \times 100 = .09\%$$ FOR DUCT WITHOUT ACOUSTIC TREATMENT

C. CORE DUCT PRESSURE LOSSES

THE EXAMPLES GIVEN TO ILLUSTRATE THE DUCT FRICTION LOSS CALCULATION BY METHODS 1 AND 2 ARE SIMILAR TO WHAT WOULD BE SHOWN FOR CORE DUCT FRICTION LOSS CALCULATIONS, THEREFORE CORE LOSS CALCULATION EXAMPLES WILL NOT BE GIVEN.

F (CONT'D)

CALCULATION PROCEDURE - CARPET PLOT PRESSURE DRAG

GENERALIZED ISOLATED NACELLE AFTERBODY PRESSURE DRAG CURVES HAVE BEEN GENERATED WHICH ENABLE AN ASSESSMENT OF NACELLE PRESSURE DRAG TO BE MADE FOR PRELIMINARY DESIGN PURPOSES. THESE CURVES, PRESENTED IN THE FORM OF CARPET PLOTS ON FIGURES 1 AND 2, WERE OBTAINED FROM DOUGLAS-NEUMAN AND STRATFORD & BEAVERS TURBULENT BOUNDARY LAYER COMPUTER ANALYSES. FIGURE 3 SHOWS THE NACELLE AERO-DYNAMIC MODEL UPON WHICH THESE ESTIMATES WERE BASED.

THE METHOD WAS USED FOR ESTABLISHING NACELLE (FAN SHROUD AND CORE COWLING) PRESSURE DRAGS FOR THE SHROUDED PROPELLOR INSTALLATION, BECAUSE IT APPEARED THAT THE L/D_{eq} METHOD MAY NOT BE APPLICABLE HERE WITH SHROUD DIAMETER AND LENGTH RELATIONSHIPS SO DIVERSE RELATIVE TO NORMAL HIGH BYPASS RATIO ENGINE GEOMETRIES.

FRICTION DRAGS ON FAN SHROUD EXTERNAL SURFACE AND ON THE CORE COWL WERE MADE AFTER L/D_{eq} FRICTION DRAG PROCEDURE (FAN EXTERNAL SHROUD SURFACE) AND AFTER THE FRICTION DRAG CALCULATIONS FOUND IN SECTION III B METHOD -2 (CORE COWL)

ISOLATED NACELLE MATRIX

INLET AND AFTERBODY

GEOMETRY

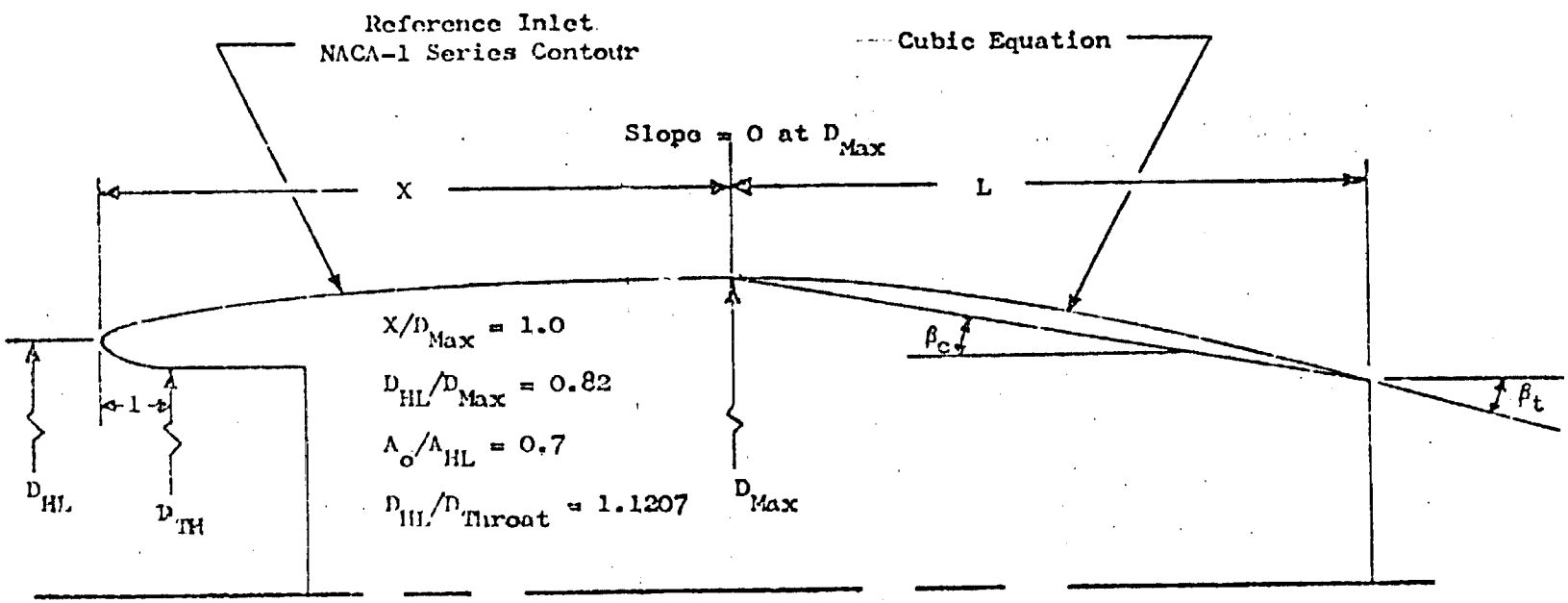

FIGURE 3

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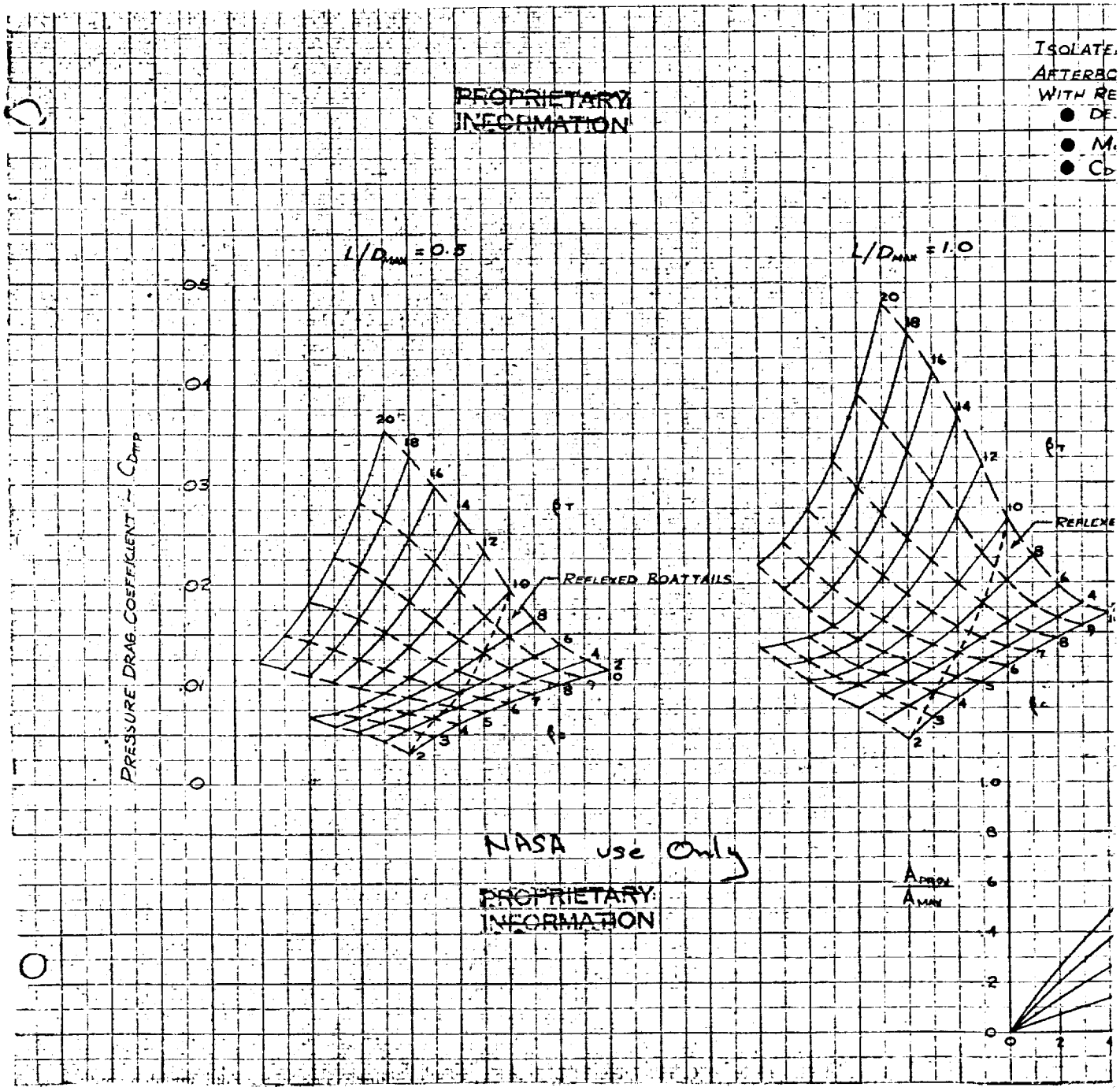
FOLDOUT FRAME



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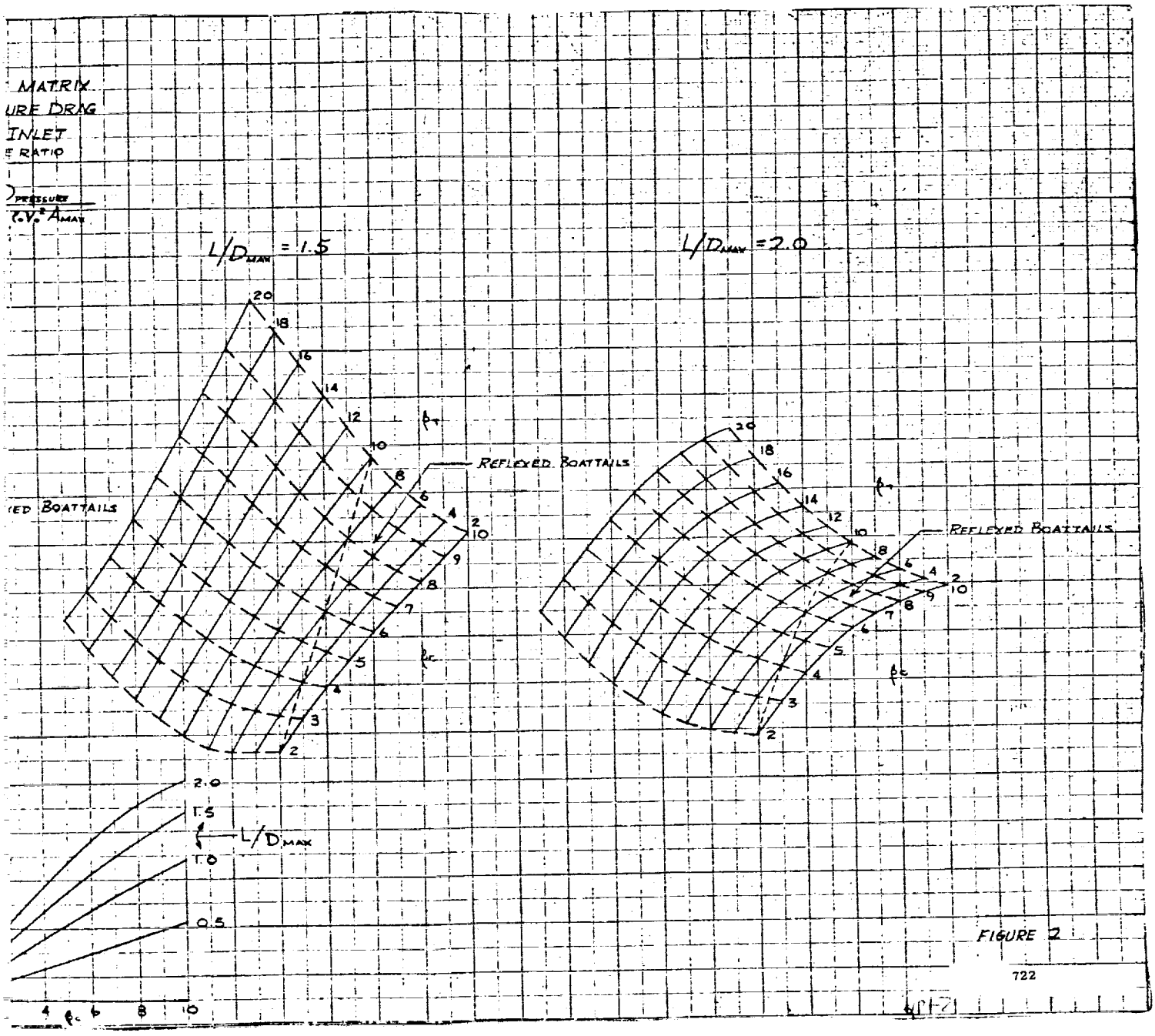


FIGURE 2

2.

FOLDOUT FRAME

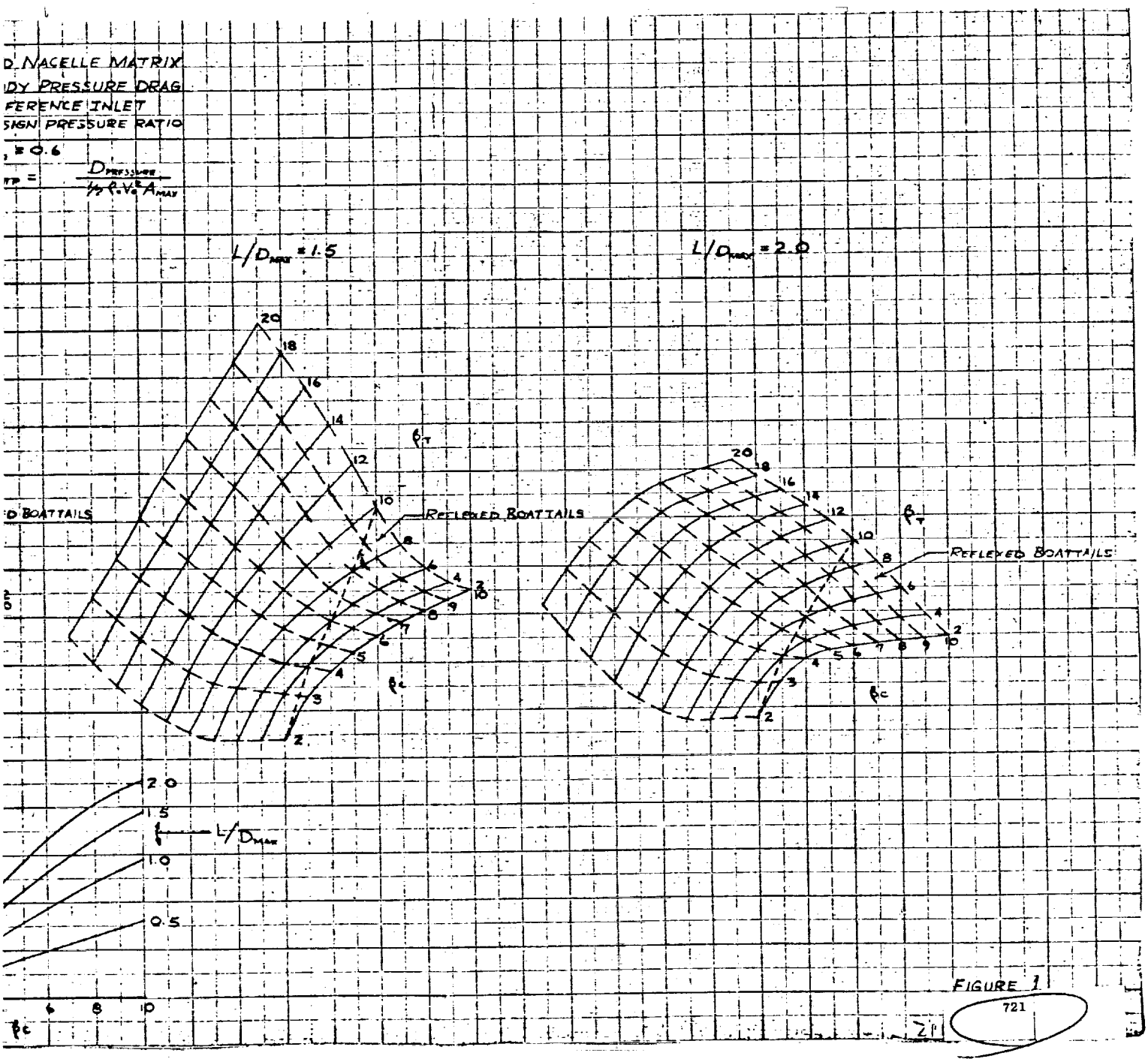
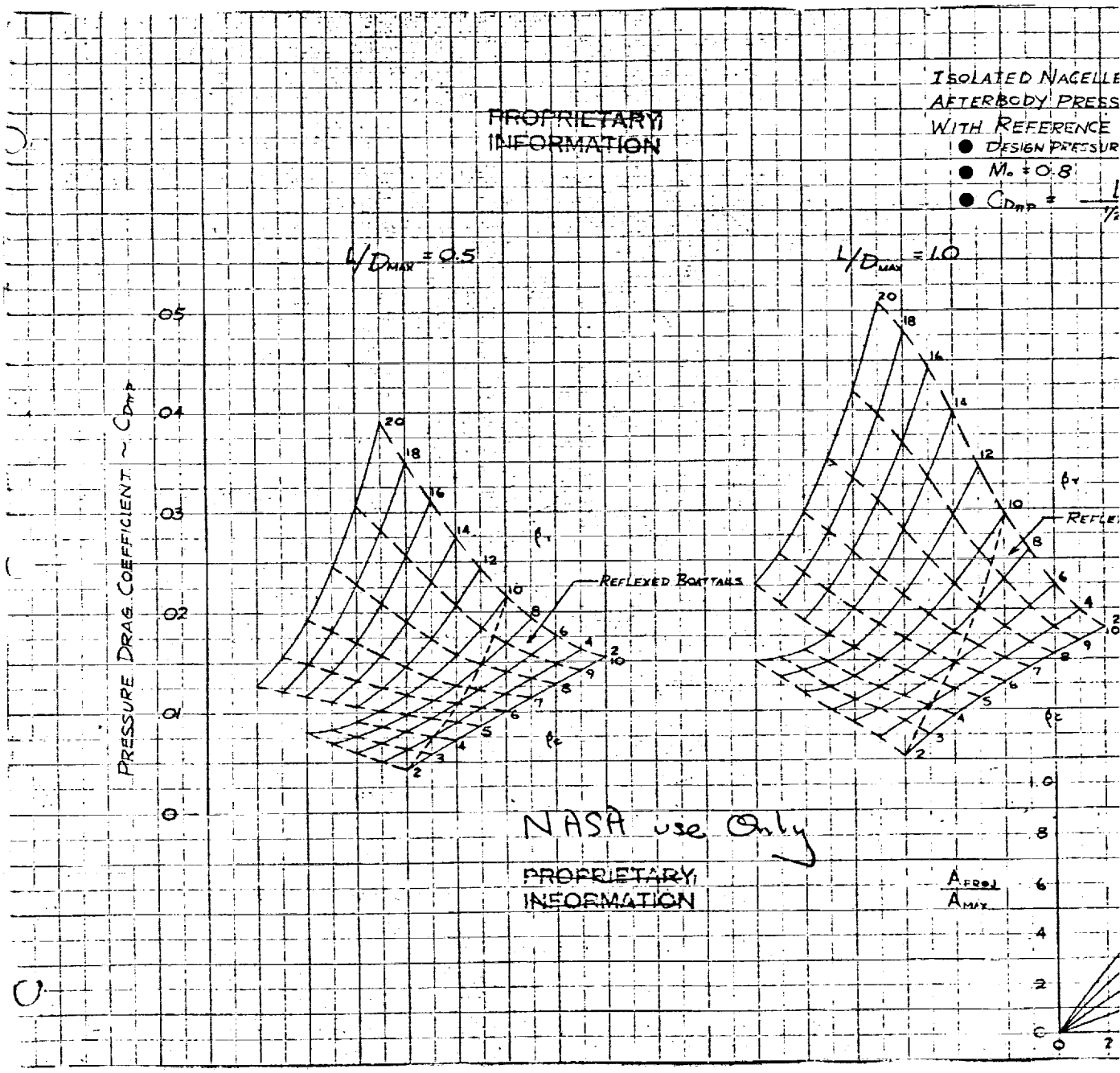


FIGURE 1

1.

FOLDOUT FRAME

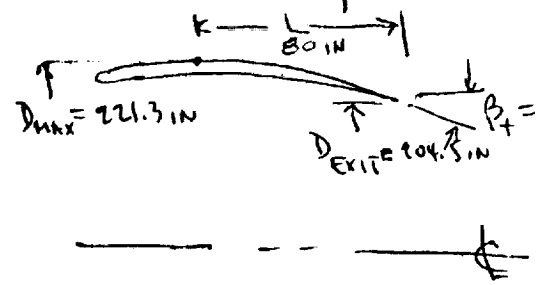


SAMPLE CALCULATION - SHROUDED PROPELLOR

F. EXTERNAL NACELLE DRAG - CARPET PLOT METHOD

NACELLE PRESSURE DRAG WAS DETERMINED FOR BOTH FAN SHROUD AND CORE COOLING USING THIS METHOD. BECAUSE OF SIMILARITY ONLY THE FAN SHROUD PRESSURE DRAG SOLUTION IS EXEMPLIFIED HERE.

- FAN SHROUD GEOMETRY, IN TERMS OF FIGURE 3:



$A_{MAX} = \frac{\pi}{4} \times 221.3^2 = 38464 \text{ IN}^2$

$\beta_e = \tan^{-1}\left(\frac{221.3 - 204.5}{2 \times 80}\right)$

$\beta_e = \tan^{-1}(.105) = 6°$

$L/D_{MAX} = \frac{80}{221.3} = .361$

- CARPET PLOT VALUES FOR C_{DTIP} @ $M_0 = .8$ ARE ESTABLISHED FOR $\beta_t = 14.5$ AND $\beta_e = 6°$ FOR VARIOUS L/D_{MAX} VALUES THEN C_{DTIP} IS DETERMINED FOR $[L/D_{MAX}]_{SHROUD} = .361$ BY EXTRAPOLATION USING $C_{DTIP} \equiv 0$ @ $L/D_{MAX} = 0$.

L/D_{MAX}	C_{DTIP} @ $\beta_t = 14.5$, $\beta_e = 6$
.5	.0135
1.0	.0206
1.5	.0256

$[C_{DTIP}]_{SHROUD} = 0.0085$

WITH $q_0 = f(M_0 = .8)_{35000 FT} = \left(\frac{q}{P_s}\right) P_s = .448 \times 3458 = 1.549$ (GAS TABLES)

$D_{PRESSURE} = C_{DTIP} \times q_0 \times A_{MAX}$

$= .0085 \times 1.549 \times 38464 = 507$ LBS

AND, BY SIMILAR DETERMINATION, THE CORE COOL PRESSURE DRAG WAS CALCULATED TO BE 80 LBS.

6.7.4

~~5.7.3~~ Ducted Prop Installation Design

The ducted prop installation differs from the propeller installation in that the variable pitch fan and its reduction gear is axisymmetric with the gas turbine and a long shroud (or very short duct) of minimum thickness (and high risk) is supported by the engine frame structure. See Figure 5.7.3.1. The pylon structure, not shown, connects to the forward end of the engine in the region of the reduction gear and forward frame. The turbine frame is supported by links to the pylon. Like the other installations, the nacelle is advanced composite sandwich construction except for the titanium cowl around the steel tailpipe. As with the turboprop design, thermal protection for the lower side of the wing is required.

The weight and cost estimates are shown in the following table.

4/19/75

2 - 8.5' Ducted Prop. Installation
Weights + Cost Estimates

Inlet	500 lbs	$42,500.
Fan Duct	260	22,100.
Core Cowl	350	29,800.
Tail pipe	140	16,700
Wing heat + fire shield	120	12,000
Pylon / Exhaust System	2080	219,800
Margin 7%	240	—
Miscellaneous	—	38,100
	3690. lbs	$381,000

S.D.

SHROUDED PROPELLER INSTALLATION

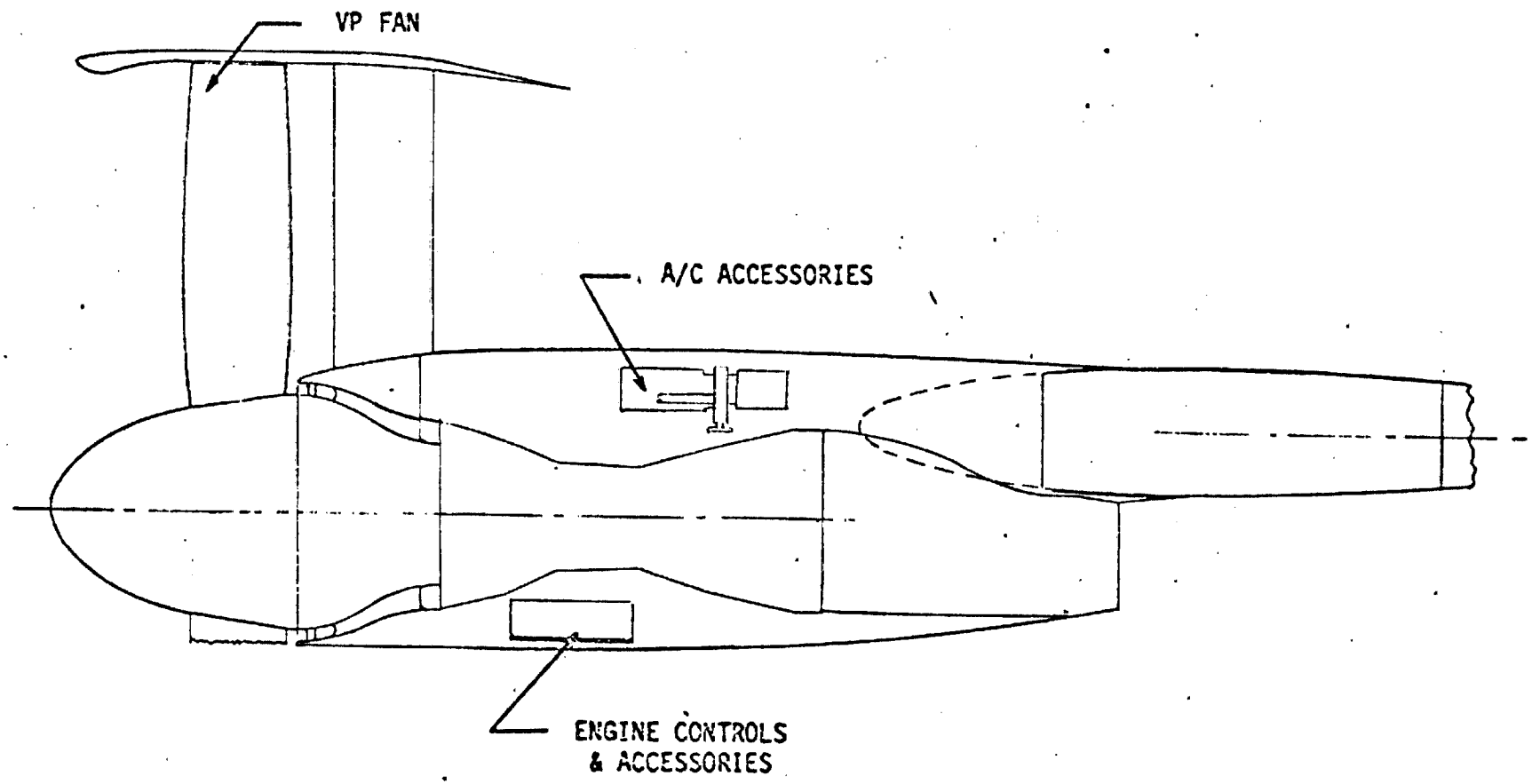


Fig 5.73.1

5.7.5

~~5.7.4~~ Ducted Prop Mechanical Design

The boosters, core and LPT for the ducted prop are the same as the turboprop. The boosters have a slightly lower pressure ratio than the turboprop at 2.55 vs. 2.75 but this is accomplished by blading changes.

The key parameter summary (Table 4.10.1) and the component weight tabulation (Table 4.10.2) illustrate the weight penalty that this engine configuration has.

Figure 5.7.3.1 which shows the ducted prop installation illustrates the very large prop rotor, prop and engine forward frame and the prop duct/nacelle.

The fan rotor weight was determined by assuming the same technology as was used in the turboprop. For comparison:

	Ducted Prop	Turboprop
U_T - fps	1000	800
Number of blades	6	8
Tip radius, in.	114.3	120
Blade AR	2.6	4.0
Rotor weight, lbs.	4334	3500

The combined effect of U_T and AR result in the much heavier rotor weight despite the lower number of blades.

The frame and forward casing are very large compared even to the 6U engine. The advanced QCSEE composite vane/frame technology was used to make a preliminary design. The result was a weight considerable lighter than would have resulted from simple scale-up of the 6U design, but is

nevertheless a heavy component. The sheer physical size is responsible. The frame is 20 ft. in diameter and with 2 ft. chord vane/ struts! The forward prop casing is ~20 ft. diameter and 3.5 ft. long!

The reduction gear weight was obtained using the ft/s gear technology applied to the concentric two-stage gear.

The design size weight of this engine is 14,730 lbs compared to 4,323 lbs for STEDLEC Task III. See Table 4.10.2.

5.7.5 Economic Evaluation

Attached is the chosen shrouded propellor design scaled to the turboprop intercontinental mission size (see fig 5.7.5-1).

In the evaluation of the shrouded prop, propulsion system price was not considered, as a result of the poor fuel burned performance. Figure 5.7.5-2 presents a summary of the benefit analysis.

Fig 5.7.5-1.

SHROUDED PROPELLER DESIGN COMPARISON

35K/.8/+18°F MAX CLIMB INTERCONTINENTAL, 5500 N. MI. RANGE, 55% LF

45¢/GAL FUEL

	BASELINE (P/P 1.7) TURBOFAN	COUNTERROTATING TURBOPROP	UNIDIRECTIONAL TURBOPROP	SHROUDED PROPELLER
FN	5140	5200	5200	5600
Δ % SFC	+18.3	-5.7	BASE	-.4
DRAG	250	325	325	720
FN - DRAG	4890	4875	4875	4875
Δ % SFC INSTALLED	+16.8	-5.5	BASE	+5.2
ENGINE WEIGHT	2160	1357	1460	6275
(CORE, LPT, BOOSTERS ALONE)	1720	-	1210	1320
INSTALLED ENGINE WEIGHT	3900	7260	6066	8090
PROP/FAN DIAMETER, FT	5.0	14.9	15.3	13.7
FAN P/P	1.71	-	1.05	1.08
FAN ADIABATIC EFFICIENCY	.86	-		.90
PROPELLER UNINSTALLED EFF.	-	.846	.797	-

AIRCRAFT ENGINE GROUP

GENERAL ELECTRIC

USTEDLEC - TASK I

DATE 12/11/75

CHART NO. ~~11-12~~

Fig 5.7.5-2

SHROUDED PROPELLER - ECONOMIC ANALYSIS

INTERCONTINENTAL MISSION, 5500 N. MI. RANGE, 45¢/GAL FUEL, 55% LF

35K/.8/+18°F MAX CLIMB

		TURBOPROP		SHROUDED PROP		Δ %	ΔDOC % (1)	ΔW_f %
FAN/PROP DIA., FT		15.3		13.7				
SFC, Δ %		BASE		-.4			(-.3)	(-.6)
FN, LBS		5200		5595				
DRAG, LBS		325		720				
FN - DRAG, LBS		4875		4875				
INSTALLED SFC, Δ%		BASE		+5.2			+3.7	+7.7
WEIGHT BREAKDOWN, LBS								
CORE, LPT, BOOSTERS	1210		1320					
FAN FRAME, STATOR, CASING *	0		1120					
C&A + OTHER	250		370					
ENGINE TOTAL (LESS FAN/PROP), LBS		1460		2810		+1350		
PROP WEIGHT, LBS		1690		2085		+395		
GEAR WEIGHT, LBS		1270		1380		+110		
NACELLE WEIGHT, LBS		959		715		-244		
PYLON WEIGHT, LBS		687		1100		+413		
INSTALLED WEIGHT, LBS		6056		8090		+2024	+4.3	+6.3
					TOTAL		+8.0	+14.0

*FOR SHROUDED PROP, INCLUDES ENGINE FRONT MOUNT

(1) No Price Effects

6.0 EVALUATION PROCEDURE

6.1 AIRCRAFT DESIGN AND SELECTION PROCESS

6.1.1 Aircraft Design

The primary consideration in selecting the host aircraft was the total amount of fuel burned, since the overall purpose of this study was to study ways of reducing the fuel consumption.

A second consideration was to select compatible turboprop and turbofan aircraft -- aircraft that would have as much as possible in common so that the process of comparison would not involve allowances for different capabilities.

At the same time, these aircraft were meant to be the optimum designs within the above constraints that also met all the requirements of the application.

Four base aircraft were needed: domestic and international turbofan and domestic and international turboprop. The domestic aircraft had a 3000 n. mi. range and a payload of 200 passengers at 205 lb/passenger (41,000 lb). The international aircraft had a 5500 n. mi. range with a payload of 200 passengers at 215 lb/passenger (43,000 lb). Since new host turbofan airplanes had to be designed from scratch, it was thought that this was a good time to compare three- and four-engine airplanes, both required to do the same job.

This is the reason why a group of 7 aircraft -- 4 domestic turbofan, 1 domestic turboprop, 1 international turbofan, and 1 international turboprop -- was born and carried throughout this study. These aircraft include supercritical wing technology, advanced composite structure technology, active control systems, and, especially, a very high technology wing flaps system which provides a relatively short takeoff capability.

The tool used in conducting parametric studies leading to the aircraft definition was MASCOT, a commercial mission analysis computer program for use on the GE635. This program calculates the weight breakdown and aerodynamics of the aircraft, given the TOGW, wing loading, thrust loading, and the characteristics of wing sweep, wing thickness, fuselage size, etc.

One of the facts clearly demonstrated during this study was the need to develop and carry numbers to a level of accuracy that would normally be considered excessive. This is necessary in order to produce the desired normal accuracy in the sensitivity factors and also to allow confident, meaningful comparisons.

A set of "System Analysis Ground Rules" was provided by NASA for a previous study conducted by General Electric, "Study of Turbofan Engines Designed for Low Energy Consumption." These ground rules covered the vehicle, the mission, and the economic procedure to be followed. The most pertinent of these rules - the wing sweep, wing thickness, max landing approach speed, TOBFL, takeoff wing loading limits, and structural and aerodynamic efficiencies - were respected in the present study for the turbofan aircraft.

There were no separate ground rules from NASA for the turboprop aircraft. Therefore an effort was made to make these aircraft as consistent as possible with the turbofan aircraft by using the same level technology. Design characteristics peculiar to the turboprop aircraft used in this study are described below.

1. The size of the horizontal tail was increased 5% and that of the vertical tail 3% to compensate for the pitch and yaw destabilizing movements introduced by the propeller. Therefore the weight and drag of these components was increased by about these percentages.

2. A fixed weight of 800 lb was added to the body contents of the turboprop for extra acoustical shielding estimated to be required in the plane of the propellers.

3. Landing Gear: While not an exception since the same rules and inputs were used for the turboprop and turbofan, this point needs emphasis. The landing gear type, length, and weight were considered the same for both the TP and the TF. The evidence available indicated that there would be no problem with propeller tip clearance with the propeller loading selected (approx. ~~40~~ 30 SHP/D^2 at M = .8 @ 35 K) even with the low wing design selected for both the TP and TF.

4. The nacelle weight used for the turboprop was much heavier than that of the turbofan and was defined differently. While the TF had the strut and nacelle wrap separately, the TP had the engine supporting structure, the nacelle wrap, and other miscellaneous weights such as the oil cooler, wing protection, exhaust, etc. all lumped together and called the nacelle installation. This was used with one scaling exponent which was the weighted average of the individual components.

5. The nacelle drag of the TP is influenced by the propwash. Since this is a function of the power setting, it was most practical to bookkeep the nacelle drag, and the slipstream drag of the portion of the wing

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in the propwash, against the engine performance - not the aircraft. This differs from the TF where the nacelle drag is calculated as part of the aircraft drag. The assumptions and inputs used for calculating nacelle drag were consistent for both the TF and the TP.

While this was the best way to handle the aerodynamic calculation, it does introduce some confusion which must be recognized. A quick look at the aircraft aerodynamic printout results in the impression that the TP is more efficient (appears to have a higher L/D) whereas it is really the same; it just doesn't have the nacelle drag included in it. Conversely, it must be remembered that the nacelle drag and the scrubbing drag on the wing are included when converting the TP horsepower performance to thrust and, therefore, the engine performance makes the TP appear less efficient than it actually is. (Note: A small drag (f = .10) was included as part of the aircraft drag of the TP as the penalty for a cooler for the gearbox oil.)

The aircraft mission performance was calculated in the same way for both the TP and TF. The climb and descent paths were the same and the cruise and loiter were done at the same MN and altitude.

The engine installation factors for bleed air and HP extraction were slightly different. These factors were:

At takeoff:

TP Fn x .957
TF Fn x .985

These were only used to determine TOBFL, since the takeoff fuel burned was an input to MASCOT.

All other mission legs*:

TP Fn x .896; SFC x 1.057
TF Fn x .912; SFC x 1.035

*Except for the loiter at M = .4 @ 1500 feet where the engine performance was supplied on an installed basis.

The descents for both the TP and TF were done using an estimated net thrust of one pound with the fuel flow at flight idle used as the SFC. This was done because the flight idle thrust level was not known and the desire was to avoid introducing any artificial difference between the TP and the TF. At the SF = 1.0 size, the fuel flow was taken as the same for the TP and the TF since the gas generators are very similar.

The takeoff fuel was found using 345 lb/engine for both the TP and the TF in their scale factor one size, and the landing fuel by using 160 lb/engine. This was done also because the actual engine performance was not known well enough to warrant introducing differences. The fuels used are small and it was more straightforward to handle them as described.

6.1.2 Powerplant Performance

Since MASCOT can handle only turbofan aircraft, all the turboprop characteristics were translated into equivalent turbofan characteristics and used as such in the study.

The engine performance used is shown and compared in Figs. 6.1.1 through 6.1.7. These are labeled noting that the performance includes the estimated propeller supercharging and inlet losses, and also the installation loss factors to be used to account for bleed and HP extraction (except for loiter at M = .4 @ 1500 ft.).

Also noted is the fact that the TP thrust has the nacelle drag plus the nacelle and wing propwash scrubbing drag subtracted from it. This was done, as explained previously, because the propwash is a function of the power setting and, therefore, it was most practical to incorporate it into the engine performance.

The TP shaft HP data was converted into thrust using the generalized propeller efficiency data supplied by Hamilton Standard. The propeller selected was an eight-bladed, single-plane, M = .8 design with a loading of SHP/D^2 = 39.95 at maximum climb power @ M = .8, 35,000 ft, standard + 18° F day. The engines were flat rated to this temperature. The SHP/D^2 is the loading at the propeller and, therefore, includes the gearbox losses.

The weights corresponding to the base engine thrust size @ SLS standard day (33,153 lb for TF and 46,500 lb for TP) and the exponents applied to the thrust scale factors were as follows:

	Turbofan		Turboprop	
	Exponent	Weight lb	Exponent	Weight lb
Bare engine	1.25	4344	1.25	3404
Reverser	1.10	772	-	-
Nacelle Wrap	1.10	1338	-	-
Nacelle Installation	-	-	1.1	4020
Prop	-	-	1.24	3897
Gearbox	-	-	1.5	3480

6.1.3 Base Aircraft Selection

The inputs used for the base aircraft are as follows:

a)	Body	
	Overall length	164 ft
	Maximum diameter	18 ft
	Wetted area	8000 sq ft
b)	Wing	
	Aspect ratio	12
	Taper ratio	34%
	Average T/C	10%
c)	Horizontal Tail	
	Aspect ratio	6
	Taper ratio	35%
	Average T/C	10%
	Area/wing area	28%
d)	Vertical Tail	
	Aspect ratio	4
	Taper ratio	30%
	Average T/C	10%
	Area/wing area	16.5%

After all the above characteristics are inputed, MASCOT performs all the steps involved in designing and flying a commercial transport as follows:

a) Determines the weight of each aircraft component.
b) Finds the drag.
c) Flies the mission.
d) Repeats these steps for a number of tentative TOGW's and finds the TOGW that satisfies the mission.

The output is summarized in parametric form in the carpet plots of Figs. 6.1.8 - 6.1.17. The parameters were the wing loading, the thrust to weight ratio, and TOGW. The ability to use T/W as a parameter is a new feature for MASCOT.

In addition to meeting the design range, the optimum aircraft also had to satisfy the following requirements:

a) Maximum TOBFL = 8000 ft for the domestic aircraft and 10,500 ft for the international aircraft at SL 86° F.

The TOBFL limiting line was obtained by using a correlation between the TOBFL and a takeoff parameter. This parameter includes the wing loading, total installed engine thrust at M = .15, the maximum available takeoff lift coefficient, $C_{L\,max} = 2.75$ (C_L useable = $2.75/1.2^2 = 1.910$) and the ambient conditions ($\sigma = .954$ for SL 86° F).

b) Maximum landing approach speed of 135 kts for the domestic aircraft and of 140 kts for the international aircraft. The landing approach speed limiting line was found by expressing the landing approach wing loading as a function of takeoff wing loading, available useable landing lift coefficient, $C_L = 2.019$ ($C_L = C_{L\,max} / 1.3^2 = 3.4/1.69$) and ambient conditions (SL 86° F).

The landing W/S to be used was not specified by NASA and was selected as that corresponding to OWE plus 100% payload plus reserve fuel. It should be recognized that the landing W/S could be as high as the takeoff W/S if so specified and that this would move the limiting line on the carpet plots enough to influence the decision on the aircraft to be selected.

c) 5 ft/sec ROC capability at initial cruise condition at maximum climb.

d) Capability of cruising at maximum cruise power setting at initial cruise condition.

The ROC and cruise capabilities are part of the computer output. Limiting lines can be obtained by cross-plotting the results for the nine parametric aircraft designs. In every case, the ROC requirement was more severe than the cruise one and, therefore, only the ROC limit line is shown on the carpet plots.

All the above limiting lines are shown on the carpet plots. Two sets of carpet plots are presented, - one with the TOGW as a parameter and the other with the fuel burned as a parameter.

For purposes of uniformity, it was decided to select aircraft with an ROC capability of exactly 5 ft/sec. With this requirement respected, the international aircraft were chosen to have the same wing loading and were designed as follows:

	Turbofan	Turboprop
Wing loading	150	150
T/W SLS uninstalled	.2430	.3037
TOGW	317,404	311,111
Fuel burned	103,994	91,556
TOBFL	8684	7168
ROC capability	5	5

With the 5 ft/sec ROC capability requirement respected, it was found that the optimum domestic turboprop and 4-engine turbofan aircraft had a wing loading of 140, but the domestic 3-engine turbofan aircraft could not meet the TOBFL requirement. It was decided to hold W/S at 140 for the domestic trifan and to accept the resulting higher ROC capability. These three aircraft were designed as follows:

	Domestic Trifan	Domestic Quadfan	Domestic Quadprop
Wing loading	140	140	140
T/W SLS uninstalled	.2910	.2598	.3230
TOGW	224,081	217,104	217,930
Fuel burned	47,688	46,186	40,685
TOBFL	8005	7593	6300
ROC capability	10.8	5.0	5.0

To keep the exact 5 ft/sec ROC capability requirement for the domestic trifan and also meet the TOBFL limit, the wing loading had to be dropped to 120. For comparison purposes, it was decided to allow the domestic quadfan to go to the same wing loading. These two aircraft were designed as follows:

	Domestic Trifan	Domestic Quadfan
Wing loading	120	120
T/W SLS uninstalled	.2519	.2525
TOGW	226,261	224,218
Fuel burned	47,329	47,024
TOBFL	7934	6706
ROC capability	5.0	5.0

These lower-wing-loading aircraft are heavier and use more fuel. Their only advantage is that they require slightly smaller engines.

Tables 6.1.1 - 6.1.4 present the results of the technical effort described in this section. By comparing the four domestic turbofan aircraft considered in this study, one observes that the quadfan with W/S = 140 has the lowest TOGW and the lowest fuel burned; these facts qualify it as the best turbofan design. Thus, this aircraft was used as the representative domestic turbofan in the comparison with the optimal domestic turboprop design.

The compared turbofan and turboprop aircraft, both domestic and international, had the following in common:

Number of engines	4
Wing loading	140 lb/sq ft domestic 150 lb/sq ft international
ROC capability at the start of cruise alt.	5 ft/sec
Range	3000 n. mi. domestic 5500 n. mi. international
Passengers	200

Figs. 6.1.18 and 6.1.19 show the payload vs. range capabilities of the four aircraft selected for further study.

Table 6.1.1

2.2.1 Aircraft Characteristics

	Domestic Fan	Domestic Fan	Domestic Fan	Domestic Fan	Domestic Prop	Intern'l Fan	Intern'l Prop
Number of Engines	3	3	4	4	4	4	4
Wing loading, lb/sq ft	120	140	120	140	140	150	150
TOGW, lb	226,261	224,081	222,218	217,104	217,930	317,404	311,111
Thrust/weight, lb/lb	.2519	.291	.2525	.2598	.323	.243	.3037
Design range, n. mi.	3,000	3,000	3,000	3,000	3,000	5,500	5,500
Cruise alt. /MN	35 K/.8	35 K/.8	35 K/.8	35 K/.8	35 K/.8	35 K/.8	35 K/.8
Passengers	200	200	200	200	200	200	200
Max Payload, lb	75,000	75,000	75,000	75,000	75,000	75,000	75,000
ROC capability, ft/sec	5.0	10.8	5.0	5.0	5.0	5.0	5.0
TOBFL, ft	7,934	8,005	6,706	7,593	6,300	8,684	7,168
Wing aspect ratio	12	12	12	12	12	12	12
Wing area, sq ft	1,886	1,601	1,868	1,551	1,557	2,116	2,074
Wing sweep (1/4 chord), degrees	25	25	25	25	25	25	25
Wing T/C - average, %	10	10	10	10	10	10	10
Total structural weight, lb	93,401	88,894	92,258	86,365	86,919	112,238	110,921
Total powerplant weight, lb	11,679	13,635	11,152	11,104	17,476	15,836	25,244
Operating equipment weight, lb	22,500	22,500	22,500	22,500	23,300	25,500	26,300
Fuel burned, lb	47,329	47,688	47,024	46,186	40,685	103,994	91,556
Reserve fuel, lb	10,352	10,364	10,284	9,949	8,550	16,836	14,090
Design payload, lb	41,000	41,000	41,000	41,000	41,000	43,000	43,000
[illegible] S.F.	.5730	.6556	.4231	.4253	.3484	.5612	.5250
Core Design Corrected Flow, lb/sec	39.2	44.8	28.9	29.1	25.9	39.8	34.7

Table 6.1.2

Aircraft Weight Breakdown

	Domestic Fan	Domestic Fan	Domestic Fan	Domestic Fan	Domestic Prop	Intern'l Fan	Intern'l Prop
Number of Engines	3 W/S = 120	3 W/S = 140	4 W/S = 120	4 W/S=140	4 W/S=140	4 W/S=150	4 W/S=150
Tail	4,523	3,661	4,470	3,514	3,727	5,249	5,399
Landing gear	8,598	8,515	8,520	8,250	8,281	12,061	11,822
Hydraulic, electric, pneumatic	3,895	3,871	3,873	3,794	3,803	4,829	4,768
Communications equipment	2,500	2,500	2,500	2,500	2,500	2,500	2,500
Surface controls	3,959	3,921	3,923	3,800	3,807	5,533	5,414
Air conditioning, anti-ice	3,620	3,585	3,588	3,474	3,487	5,079	4,978
Body	32,520	32,484	31,968	31,812	31,956	32,770	32,880
Wing	32,794	29,547	32,439	28,444	28,575	43,078	42,053
Fuel system	992	810	977	777	783	1,139	1,107
Total structural	93,401	88,894	92,258	86,365	86,919	112,238	110,921
Total powerplant	11,679	13,635	11,152	11,104	17,476	15,836	25,244
Operating equipment	22,500	22,500	22,500	22,500	23,300	25,500	26,300
Operating weight empty	127,580	125,029	125,910	119,969	127,695	153,574	162,465
OWE/TOGW	.564	.558	.562	.553	.586	.484	.522

Table 6.1.3

Powerplant Weight Breakdown

	Domestic Fan	Domestic Fan	Domestic Fan	Domestic Fan	Domestic Prop	Intern'l Fan	Intern'l Prop
Number of Engines	3 W/S=120	3 W/S=140	4 W/S=120	4 W/S=140	4 W/S=140	4 W/S=150	4 W/S=150
Bare engine	2,166	2,563	1,499	1,492	1,010	2,206	1,460
Thrust reverser	418	485	303	301	-	425	-
Nacelle wrap	725	841	525	523	-	737	-
Prop	-	-	-	-	1,168	-	1,683
Nacelle installation*	-	-	-	-	1,381	-	1,908
Gearbox	-	-	-	-	810	-	1,260
Total nacelle	3,309	3,889	2,327	2,316	4,369	3,368	6,311
Strut	584	656	461	460	-	591	-
Nacelle and strut	3,893	4,545	2,788	2,776	4,369	3,959	6.311
Total powerplant	11,679	13,635	11,152	11,104	17,476	15,836	25,244

*Nacelle installation for TP includes: Engine supporting structure, engine accessories, oil cooler, other A/F accessories.

Table 6.1.4

Aircraft Fuel Breakdown

	Domestic Fan	Domestic Fan	Domestic Fan	Domestic Fan	Domestic Prop	Intern'l Fan	Intern'l Prop
Number of Engines	3 W/S=120	3 W/S=140	4 W/S=120	4 W/S=140	4 W/S=140	4 W/S=150	4 W/S=150
Total mission fuel, lb	47,329	47,688	47,024	46,186	40,685	103,994	91,556
takeoff, lb	593	679	589	587	522	803	701
climb, lb	7,009	5,637	6,957	6,526	4,737	8,897	6,401
cruise, lb	38,915	40,445	38,674	38,272	34,654	93,156	83,366
descent, lb	537	612	531	529	530	766	763
landing, lb	275	315	273	272	242	372	325
Total reserve fuel, lb	10,352	10,364	10,284	9,949	8,550	16,836	14,090
climb, lb	2,215	1,988	2,194	2,060	1,490	2,351	1,724
cruise, lb	1,387	1,565	1,384	1,377	1,236	1,723	1,510
descent, lb	442	504	439	434	436	629	628
loiter, lb	6,308	6,307	6,267	6,078	5,388	12,133	10,228

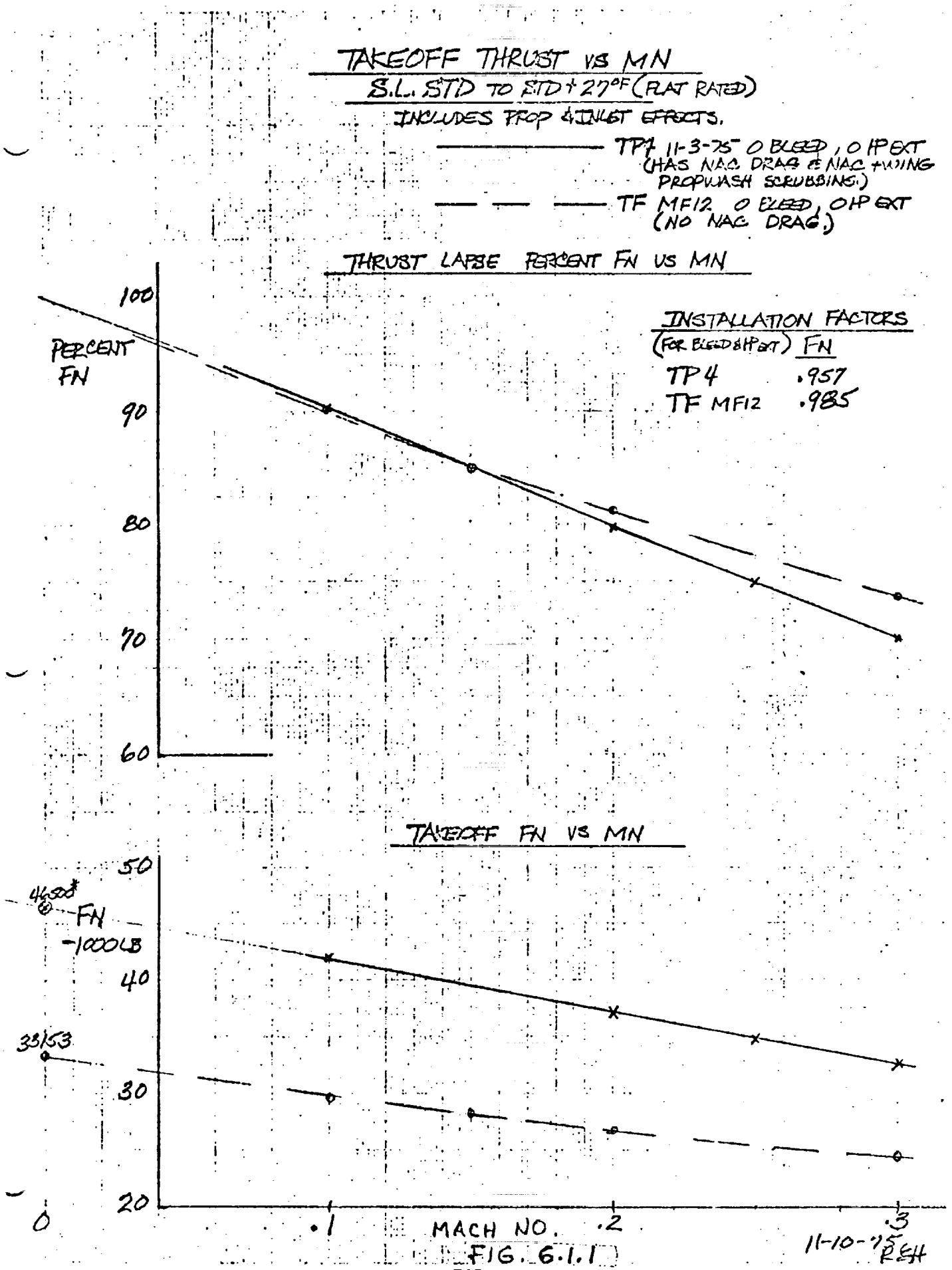

TAKEOFF THRUST VS MN
S.L. STD TO STD + 27°F (FLAT RATED)
INCLUDES PROP & INLET EFFECTS.
TP4 11-3-75 0 BLEED, 0 HP EXT (HAS NAC DRAG & NAC + WING PROPWASH SCRUBBING.)
TF MF12 0 BLEED, 0 HP EXT (NO NAC DRAG.)
THRUST LAPSE PERCENT FN VS MN
PERCENT FN
100
90
80
70
60
INSTALLATION FACTORS
(FOR BLEED & HP EXT) FN
TP4 .957
TF MF12 .985
TAKEOFF FN VS MN
FN -1000LB
50
40
30
20
46508
33153
0
.1
.2
.3
MACH NO.
11-10-75 RSH

FIG. 6.1.1

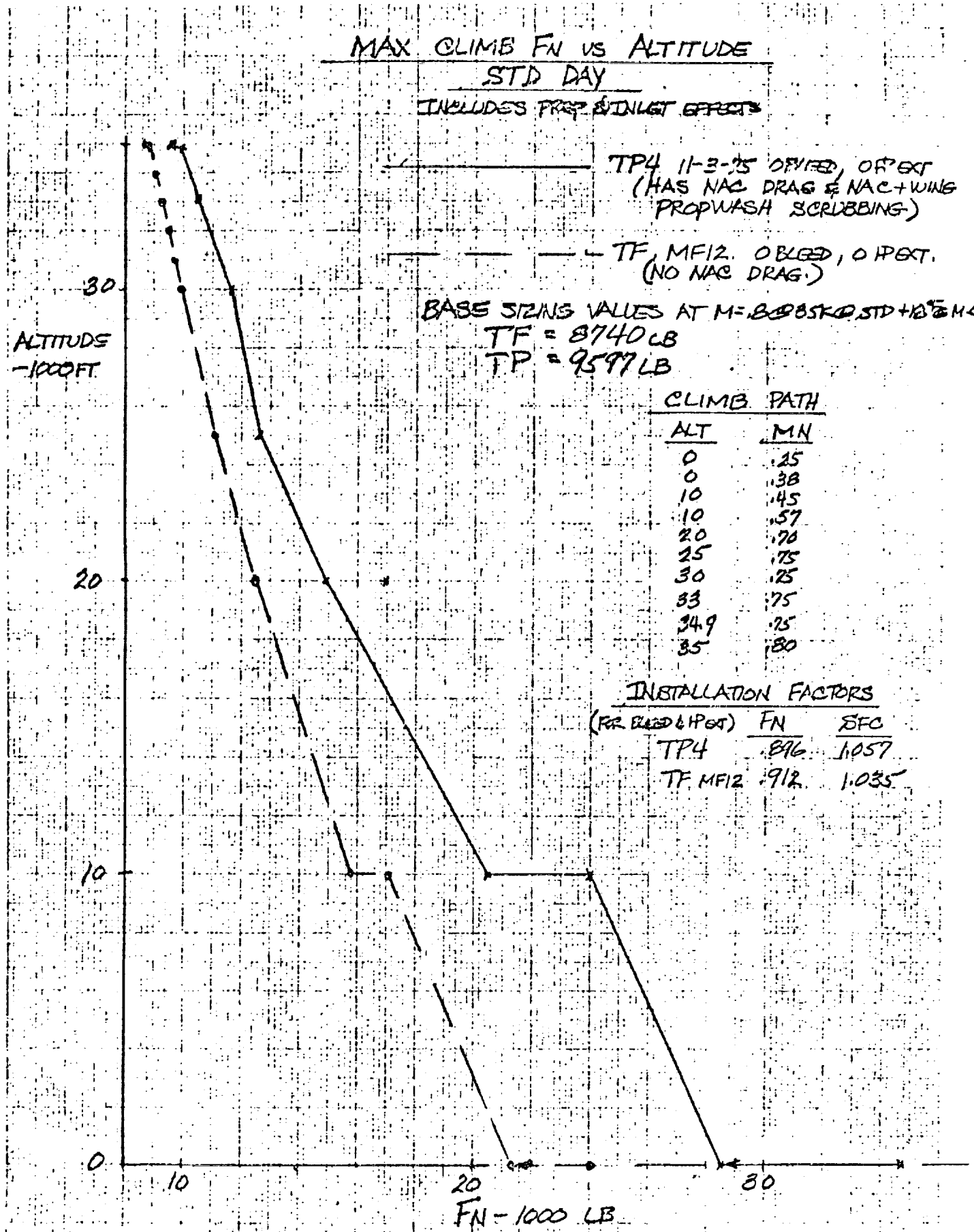
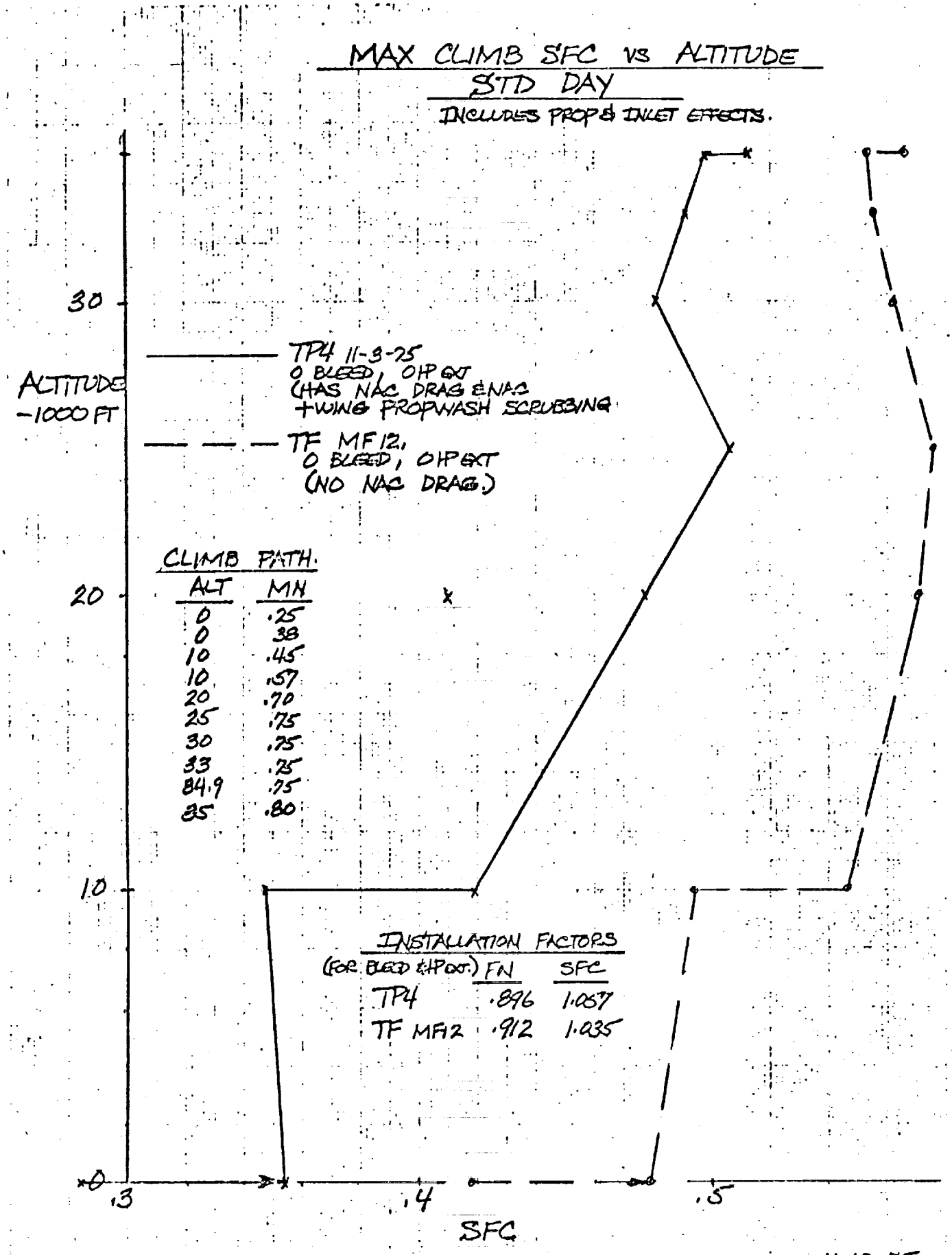


FIG. 6.1.2.

11-10-75
RSH



11-10-75
R.E.H.

FIG. 6.1.3.

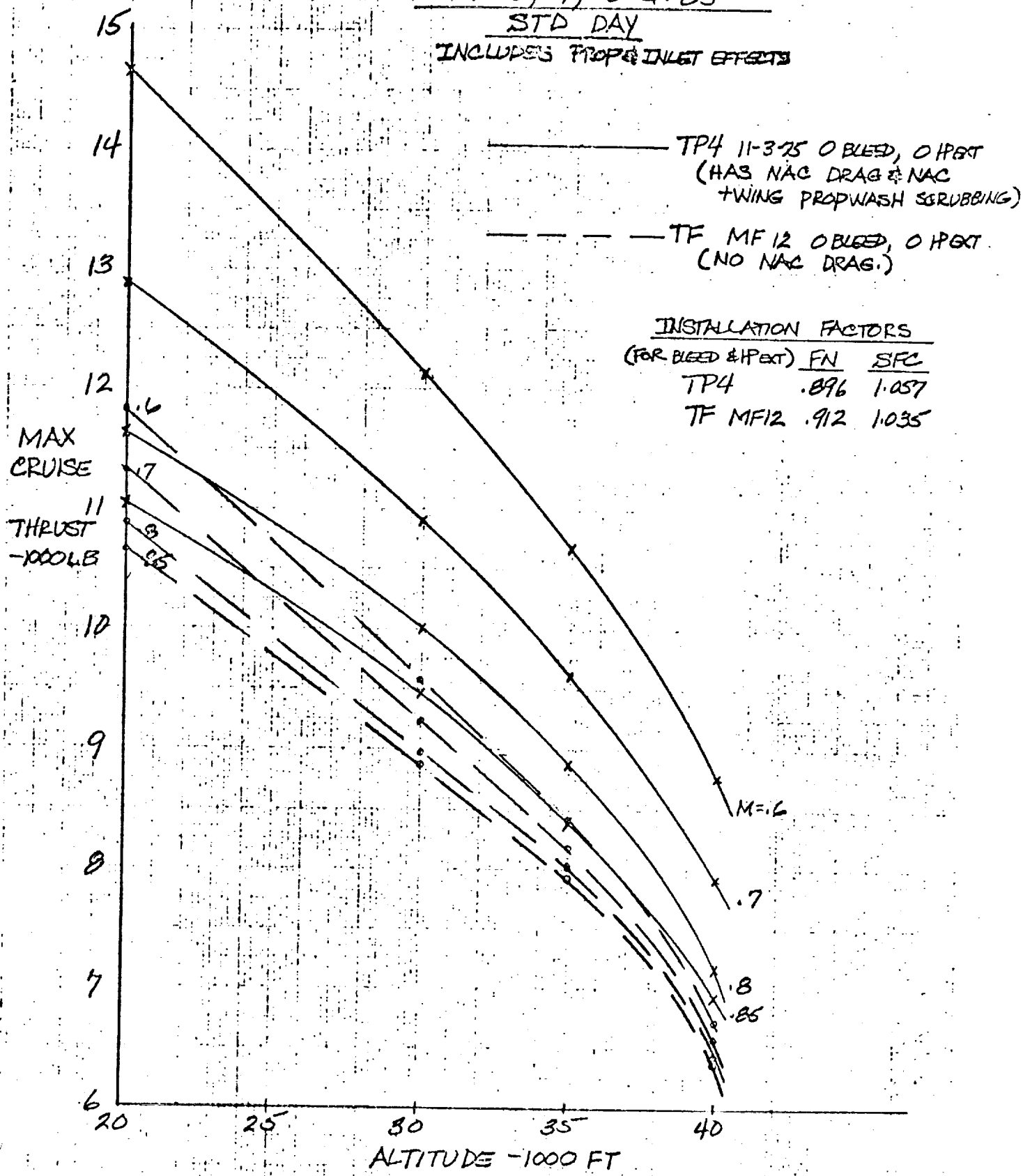
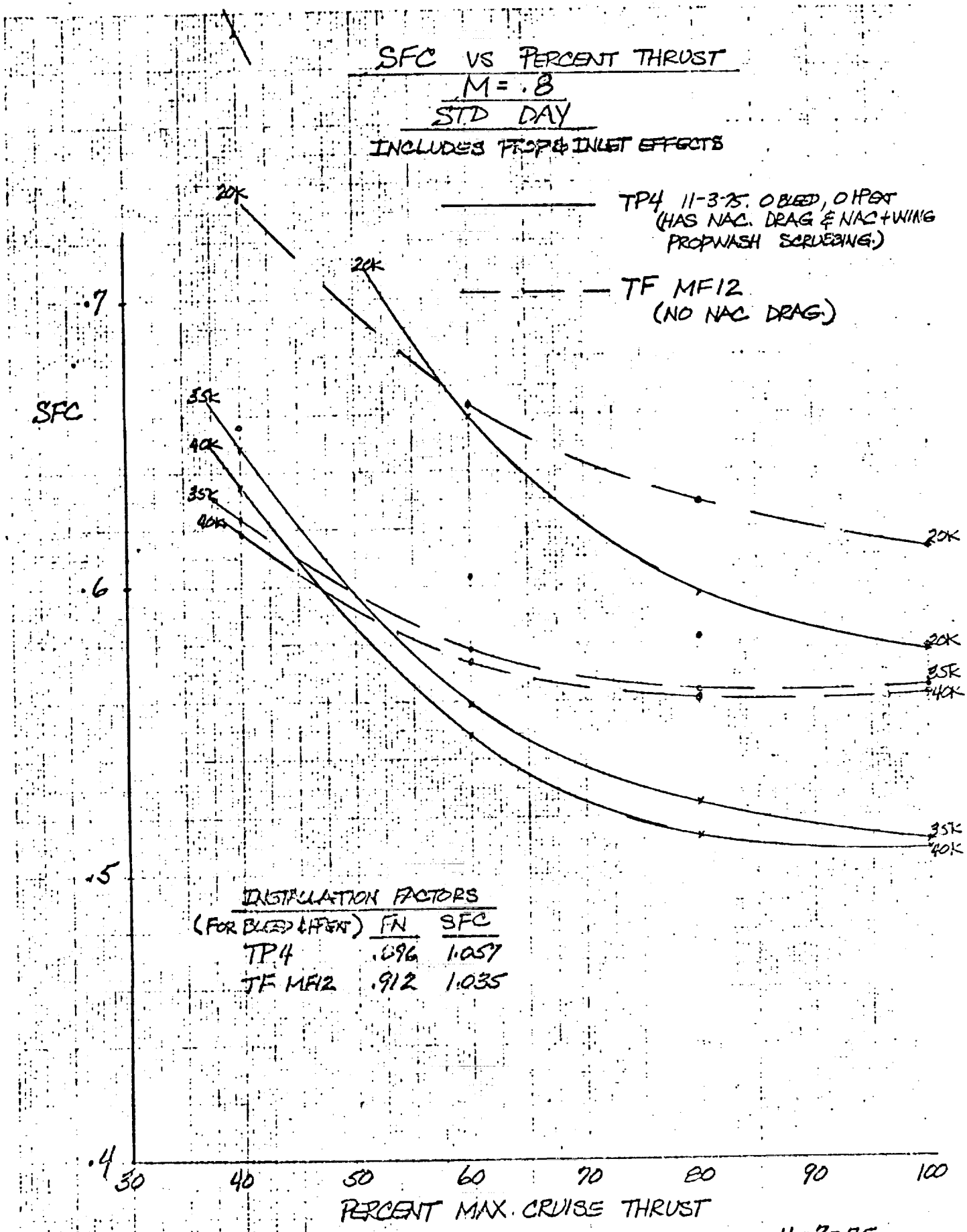


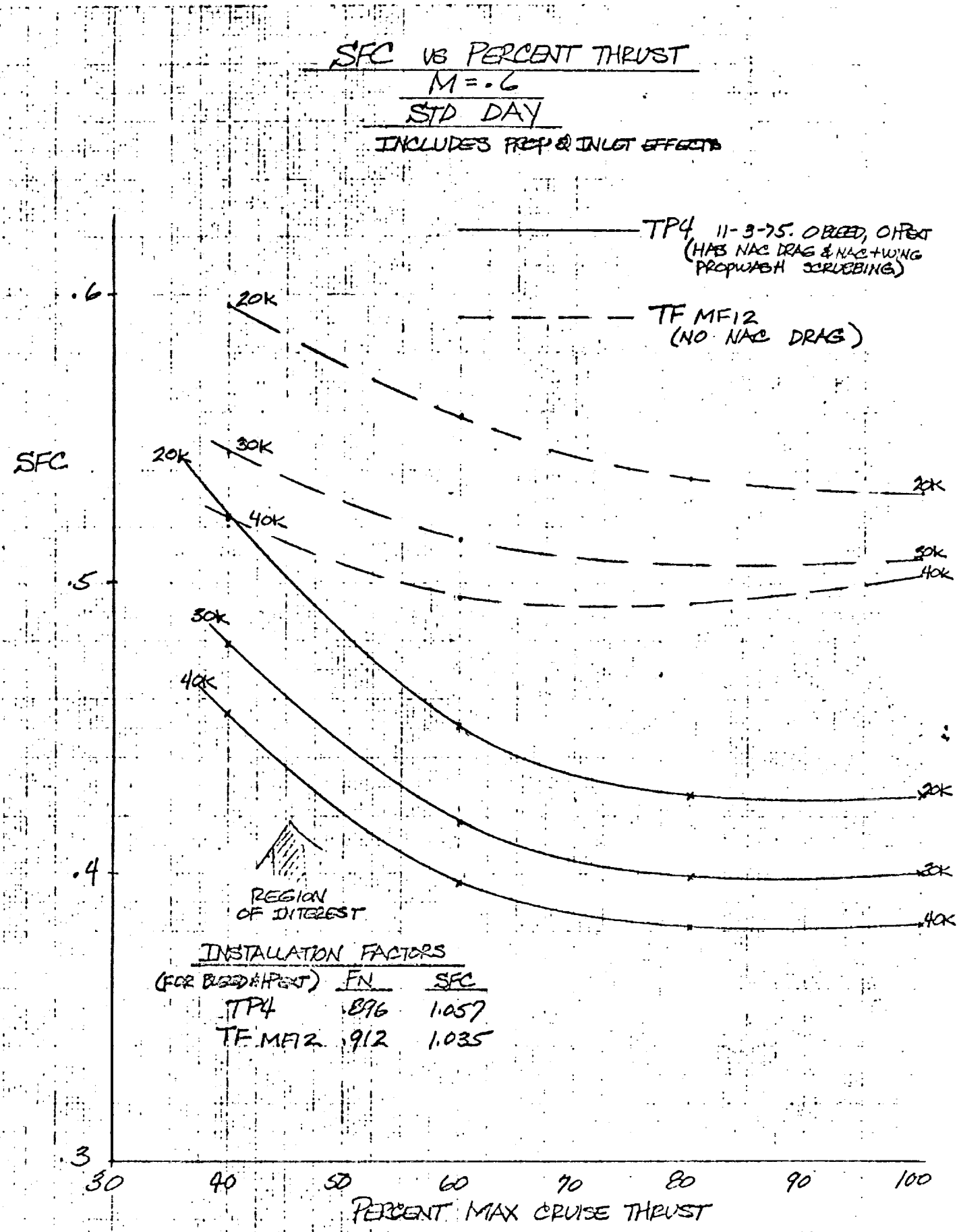
FIG. 6.1.4.

11-10-75
REH



11-7-75
REH

FIG. 6.1.5



INSTALLATION FACTORS

(FOR BLEED & HPEXT)	FN	SFC
TP4	.896	1.057
TF MF12	.912	1.035

FIG. 6.1.6

11-7-75
RSH

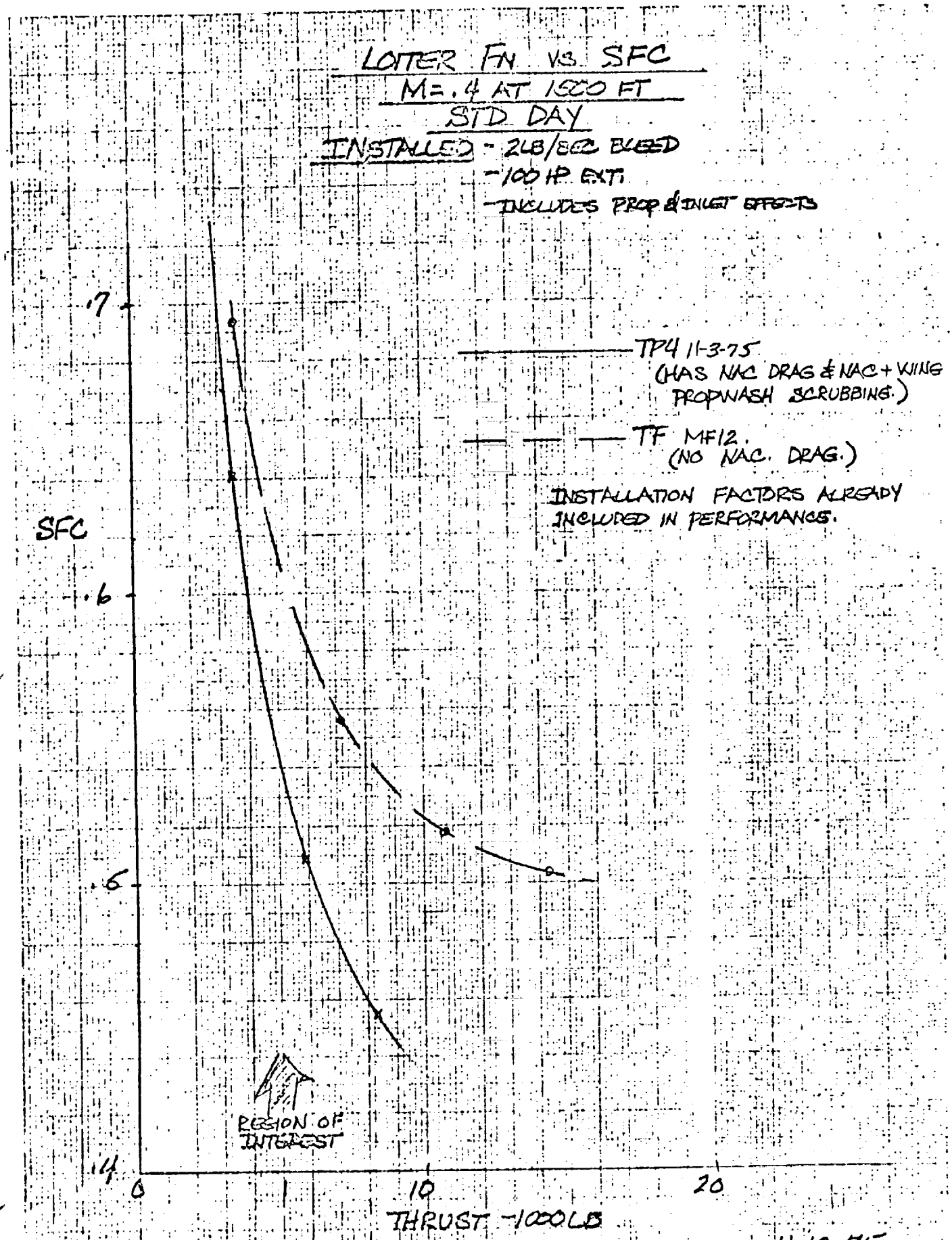

LOITER FN VS SFC
M=.4 AT 1500 FT
STD DAY
INSTALLED - 2LB/SEC BLEED
-100 HP EXT.
-INCLUDES PROP & INLET EFFECTS
TP4 11-3-75
(HAS NAC DRAG & NAC + WING PROPWASH SCRUBBING.)
TF MF12.
(NO NAC. DRAG.)
INSTALLATION FACTORS ALREADY INCLUDED IN PERFORMANCE.
SFC
.7
.6
.5
.4
REGION OF INTEREST
0
10
20
THRUST -1000LB
11-10-75
RSH

FIG. 6.1.7

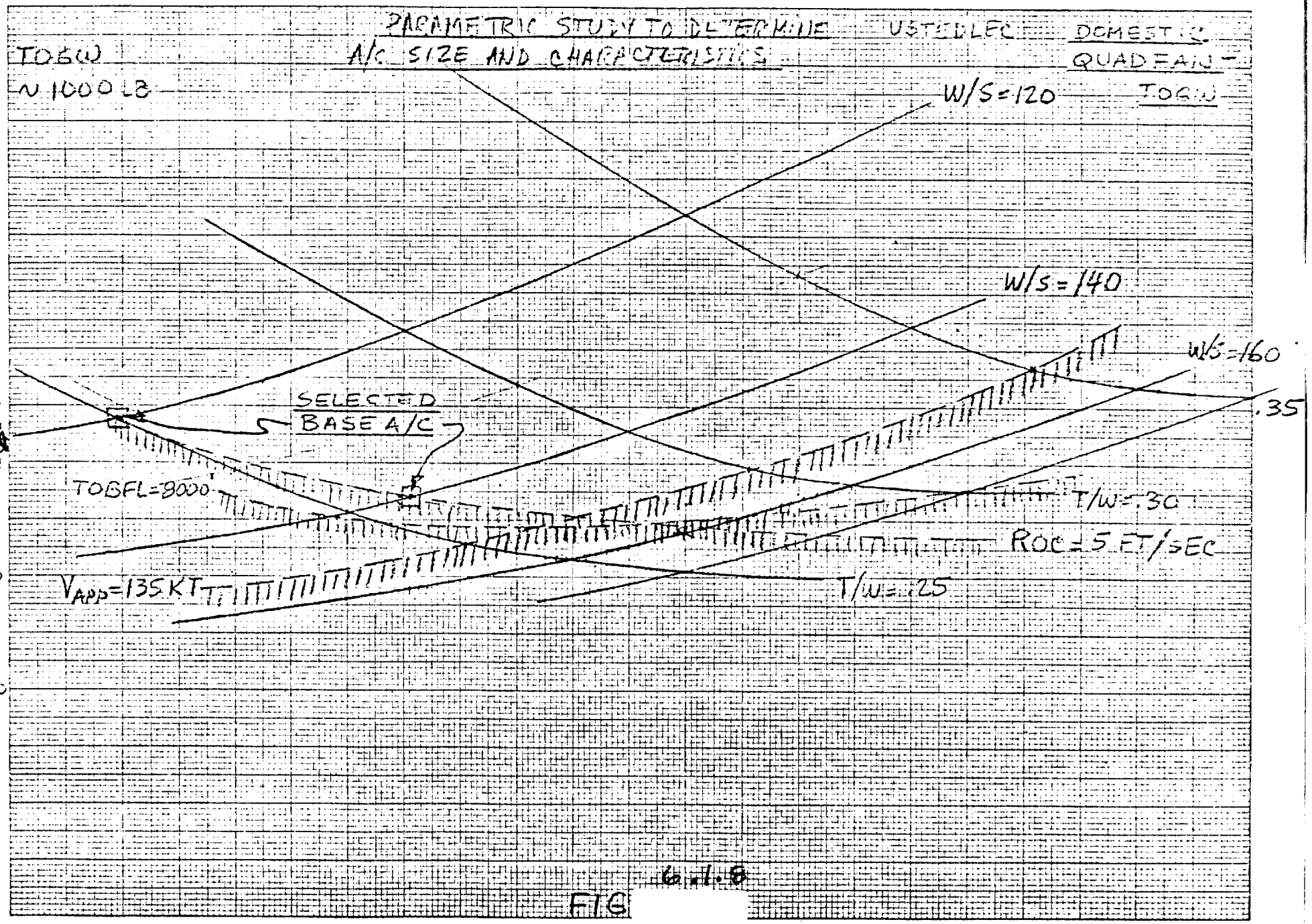

PARAMETRIC STUDY TO DETERMINE A/C SIZE AND CHARACTERISTICS
USTOLFC
DOMESTIC QUAD FAN - TOGW
TOGW ~ 1000 LB
250
240
230
220
210
200
W/S=120
W/S=140
W/S=160
.35
SELECTED BASE A/C
TOBFL=8000
T/W=.30
ROC=5 FT/SEC
VAPP=135 KT
T/W=.25

FIG 6.1.8

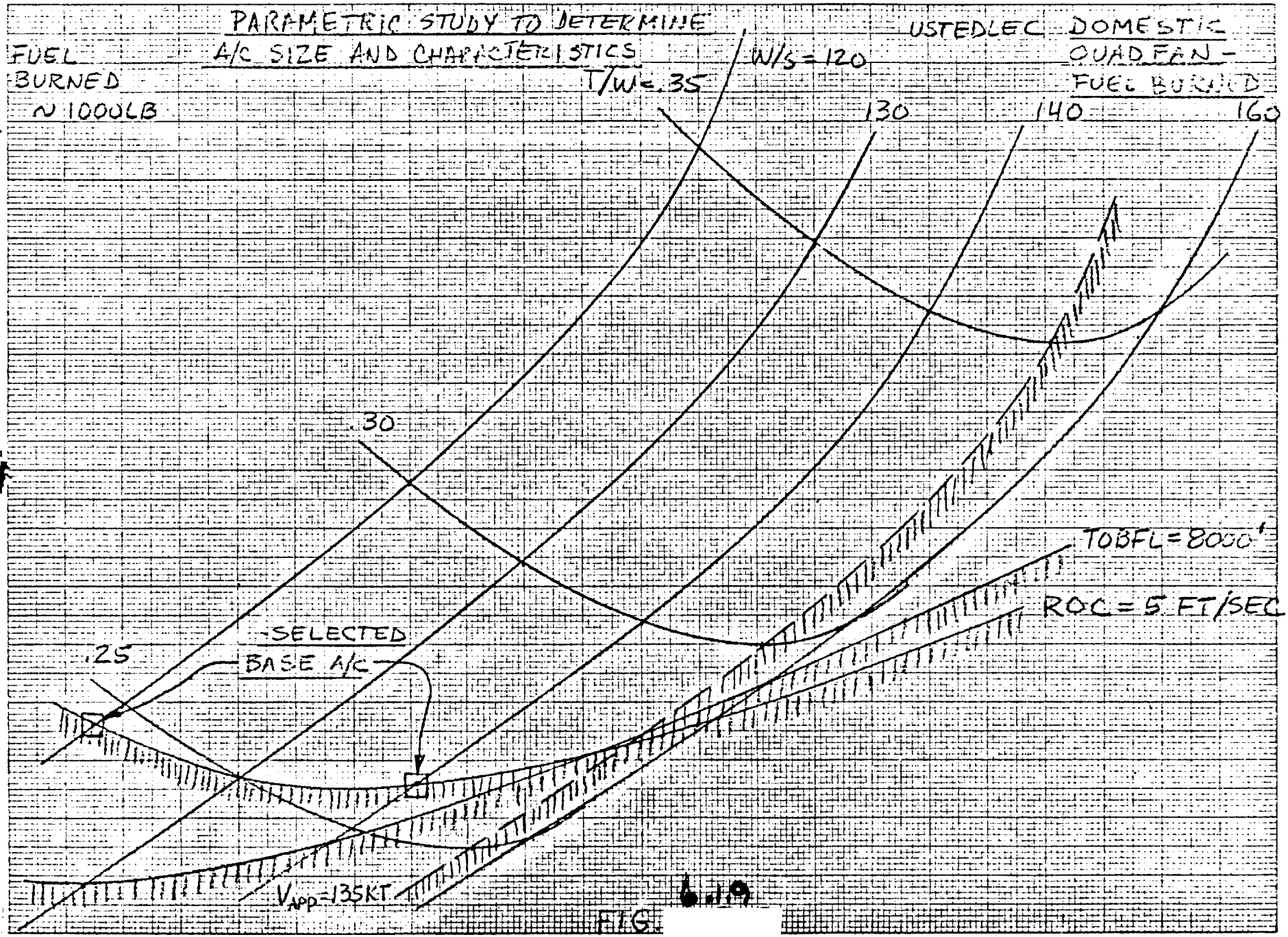

PARAMETRIC STUDY TO DETERMINE
A/C SIZE AND CHARACTERISTICS
USTEDLEC DOMESTIC
QUAD FAN -
FUEL BURNED
FUEL
BURNED
~1000LB
52
51
50
49
48
47
46
W/S = 120
130
140
160
T/W = .35
.30
.25
TOBFL = 8000'
ROC = 5 FT/SEC
SELECTED
BASE A/C
VAPP = 135KT

FIG. 6.1.9

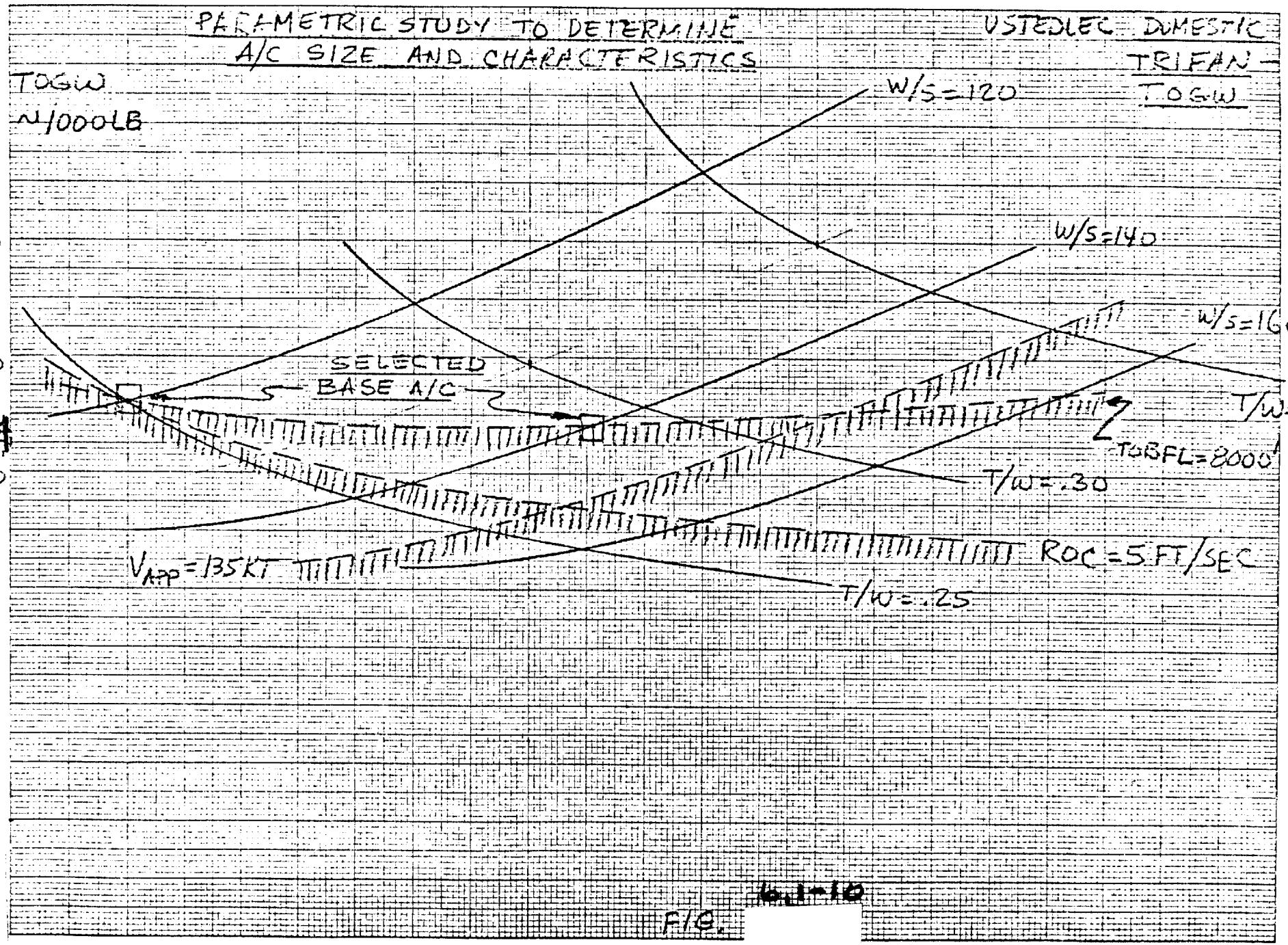

PARAMETRIC STUDY TO DETERMINE
A/C SIZE AND CHARACTERISTICS
USTEDLEC DOMESTIC
TRIFAN
TOGW
TOGW
~1000LB
250
240
230
220
210
200
W/S=120
W/S=140
W/S=160
SELECTED
BASE A/C
T/W=.35
TOBFL=8000'
T/W=.30
ROC=5 FT/SEC
VAPP=135KT
T/W=.25

FIG. 6.1-10

754

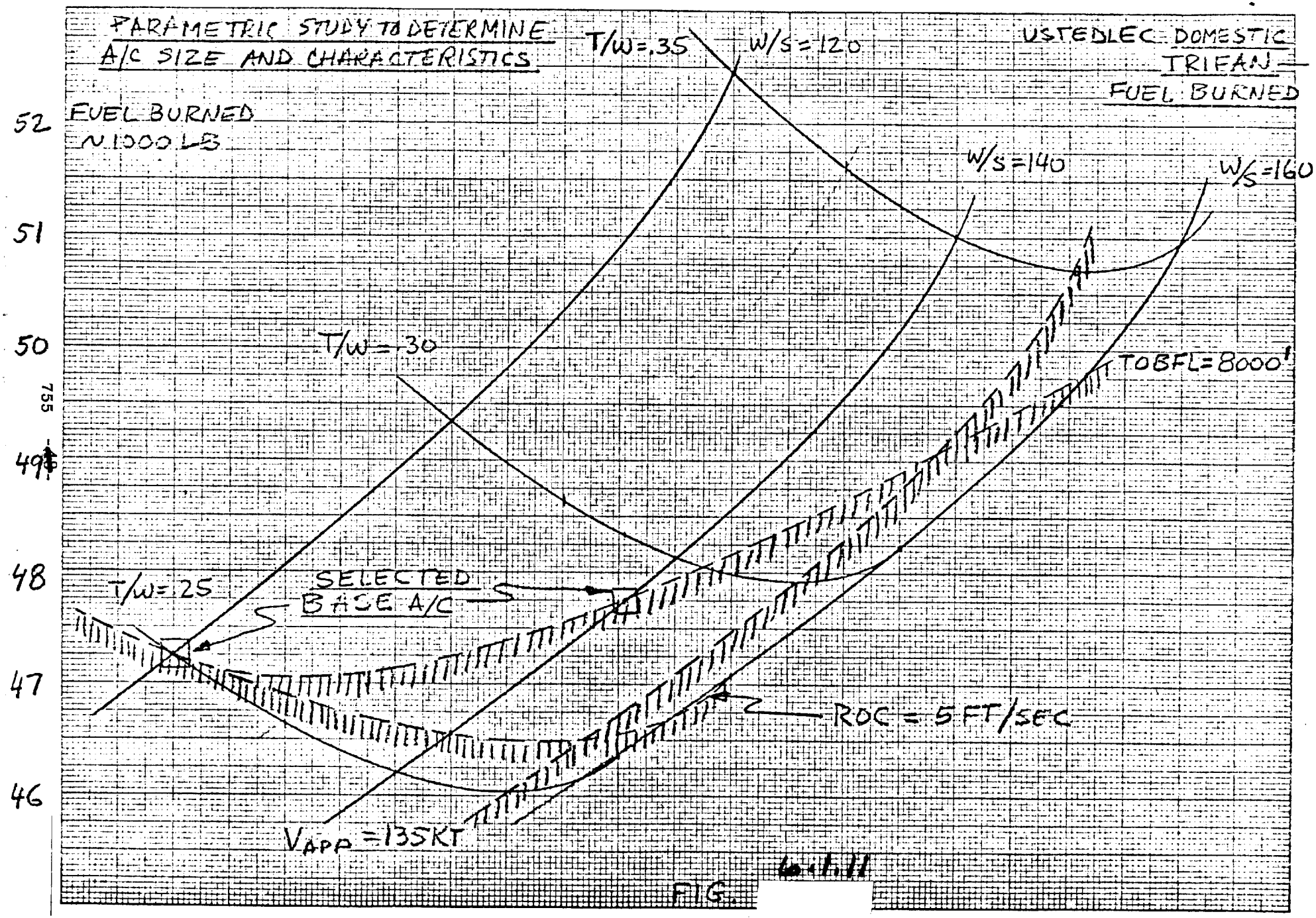

PARAMETRIC STUDY TO DETERMINE
A/C SIZE AND CHARACTERISTICS
USTEDLEC DOMESTIC
TRIFAN
FUEL BURNED
FUEL BURNED
~1000 LB
52
51
50
49
48
47
46
T/W=.35
W/S=120
W/S=140
W/S=160
T/W=.30
TOBFL=8000'
T/W=.25
SELECTED
BASE A/C
ROC = 5 FT/SEC
VAPP =135KT

FIG. 6.1.11

755

PARAMETRIC STUDY TO DETERMINE A/C SIZE AND CHARACTERISTICS

USTEDLEC DOMESTIC QUADPROP. - TOGW

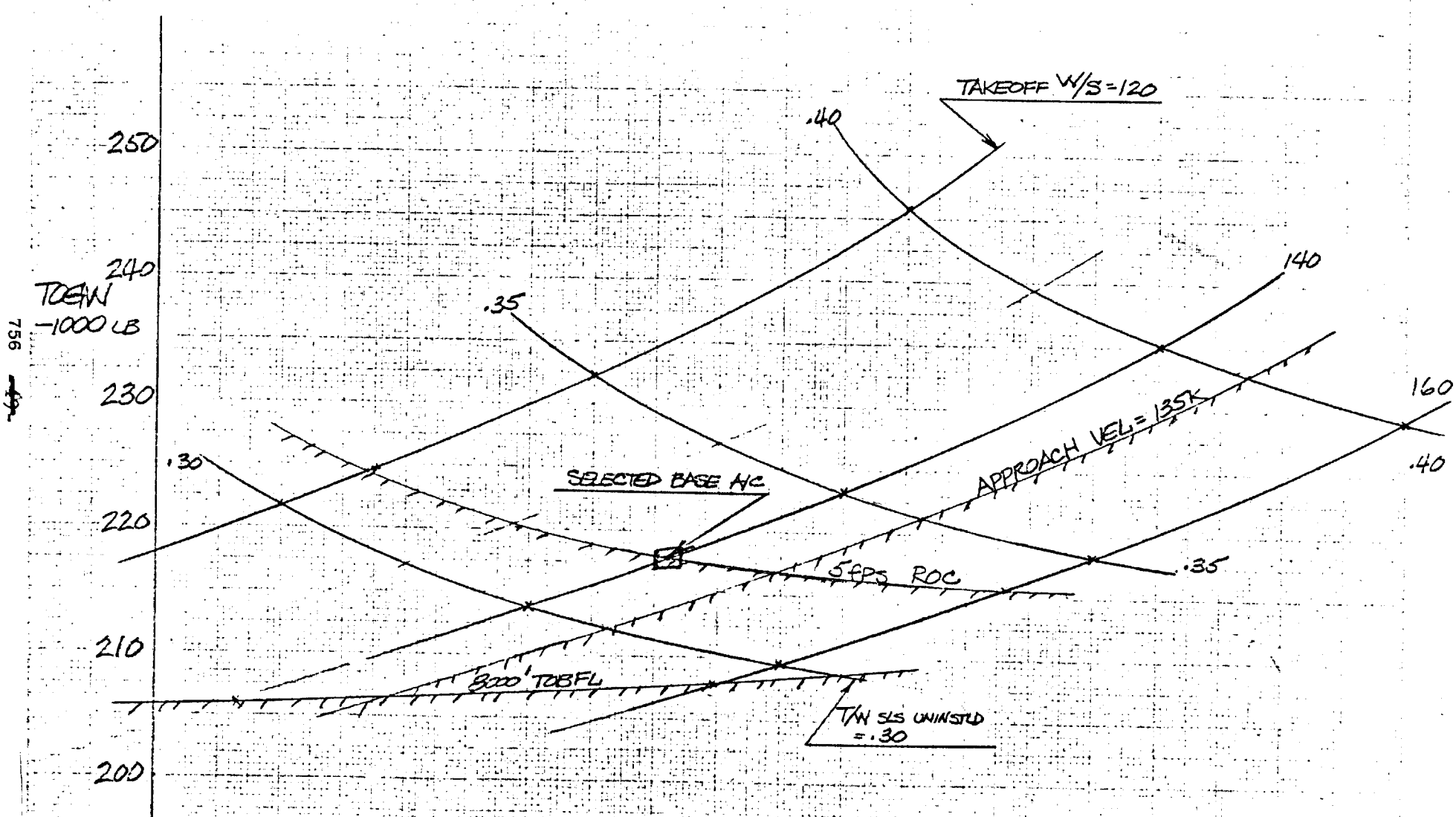


FIG. 6.1.12

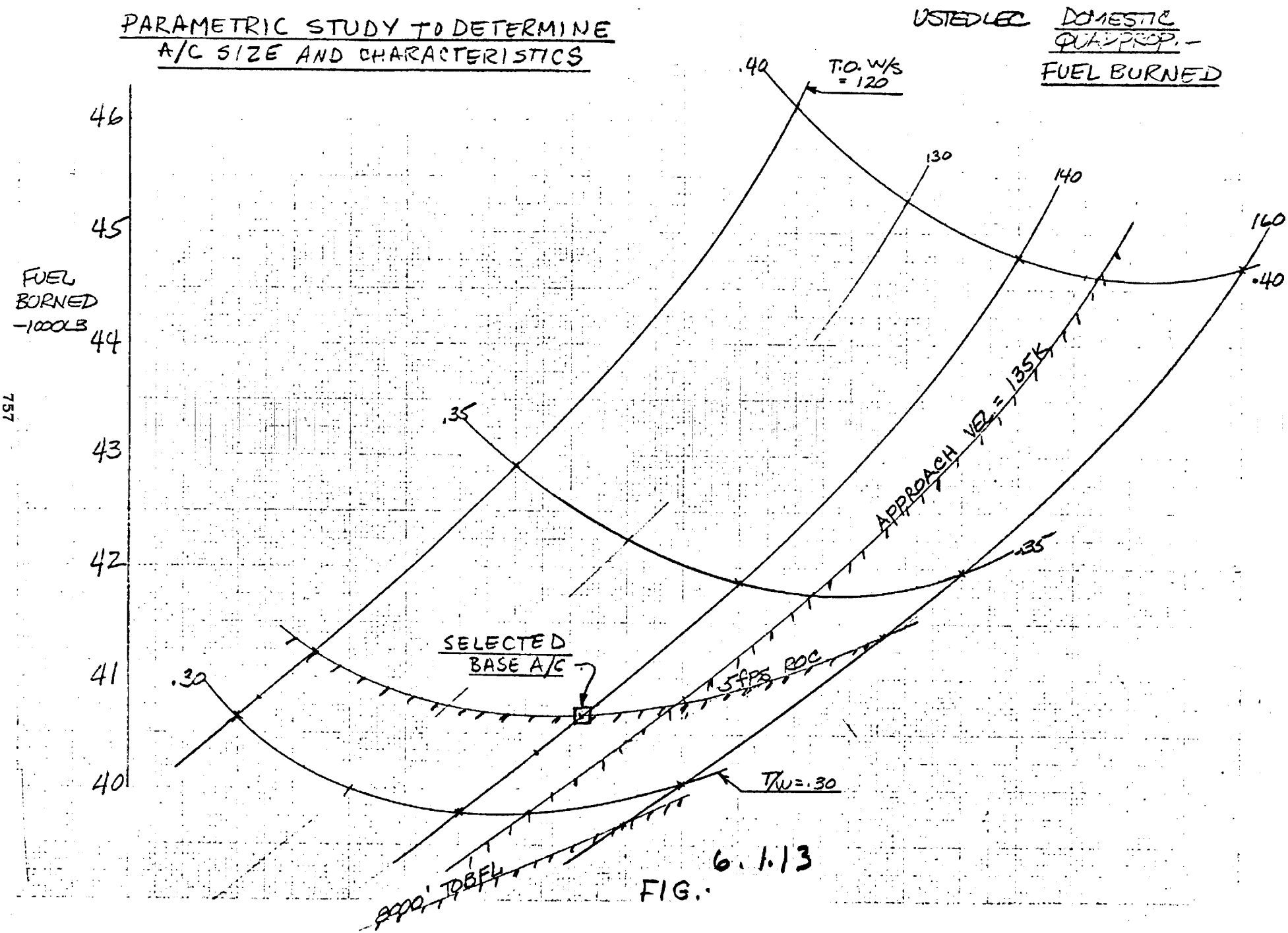

PARAMETRIC STUDY TO DETERMINE
A/C SIZE AND CHARACTERISTICS
USTED LEC
DOMESTIC
QUAD PROP. -
FUEL BURNED
FUEL BURNED -1000LB
46
45
44
43
42
41
40
.40
T.O. W/S = 120
130
140
160
.40
.35
.35
APPROACH VEL = 135K
SELECTED BASE A/C
.30
5 FPS ROC
T/W = .30
8000' TOBFL

FIG. 6.1.13

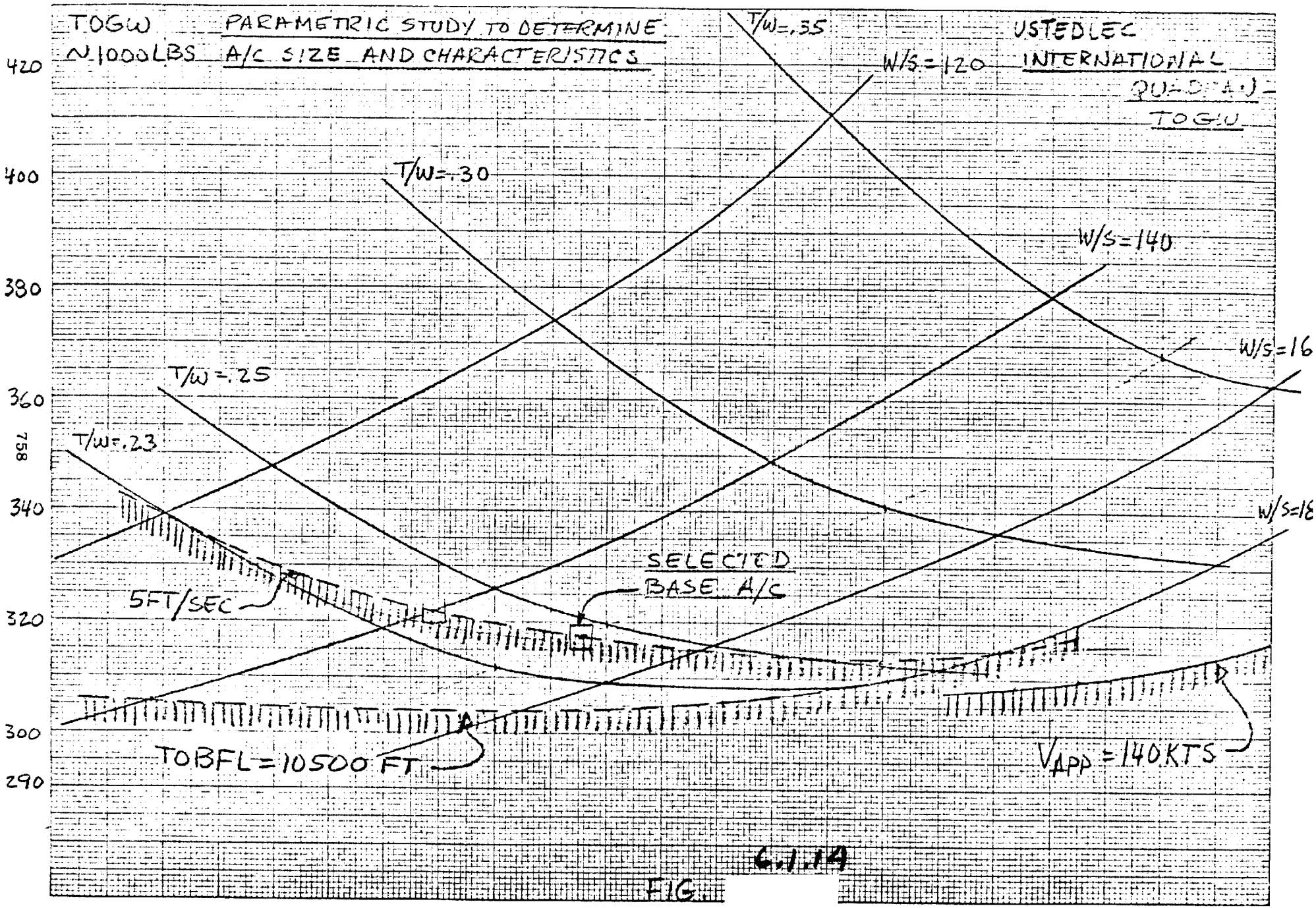

TOGW
~1000LBS
PARAMETRIC STUDY TO DETERMINE
A/C SIZE AND CHARACTERISTICS
USTEDLEC
INTERNATIONAL
QUADRAJET
TOGW
T/W=.35
W/S=120
T/W=.30
W/S=140
W/S=16
T/W=.25
T/W=.23
W/S=18
SELECTED
BASE A/C
5FT/SEC
TOBFL=10500 FT
VAPP=140KTS
420
400
380
360
340
320
300
290

FIG. 6.1.14

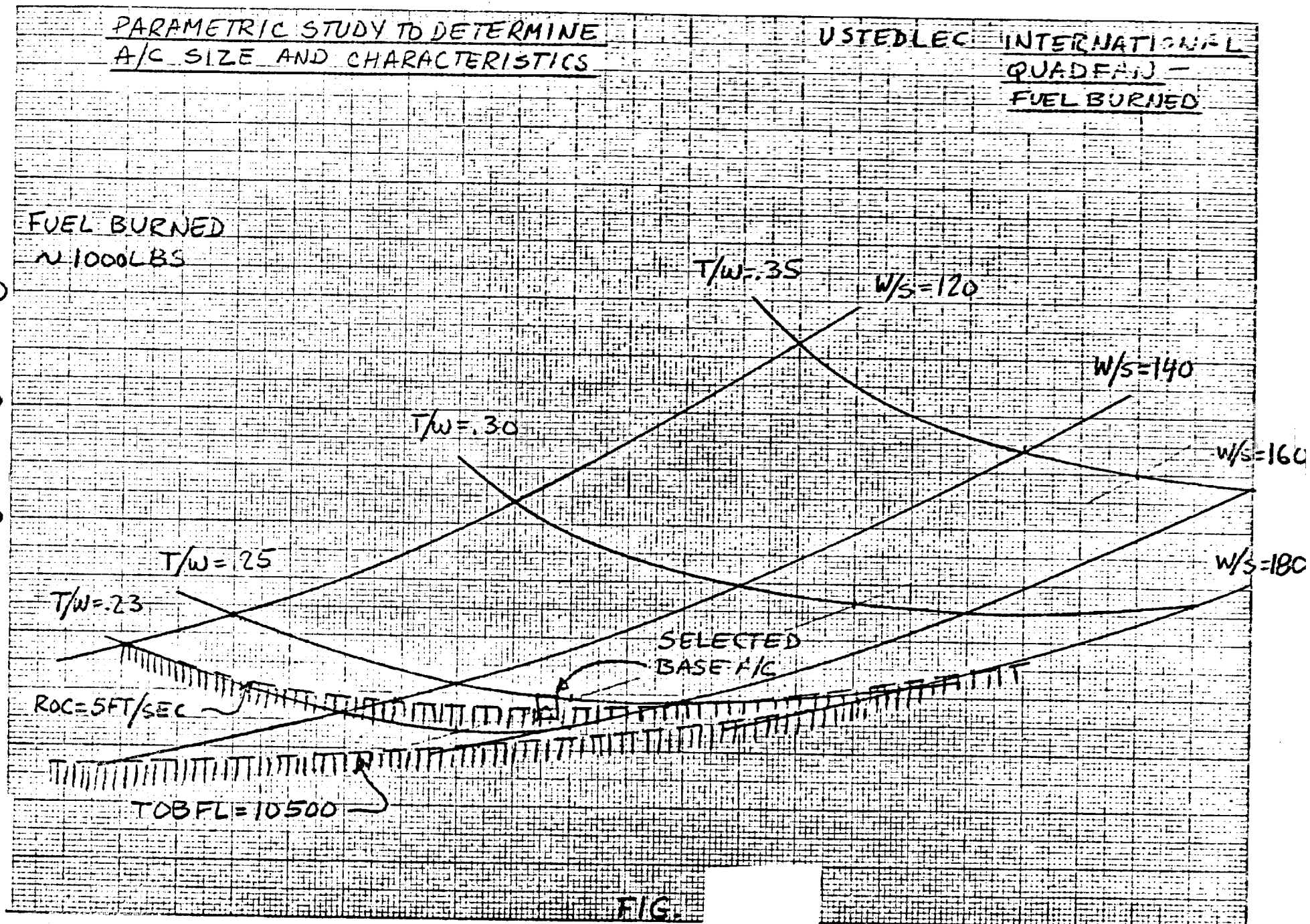

PARAMETRIC STUDY TO DETERMINE
A/C SIZE AND CHARACTERISTICS
USTEDLEC INTERNATIONAL
QUADFAN –
FUEL BURNED
FUEL BURNED
~1000LBS
140
130
120
110
100
T/W=.35
W/S=120
W/S=140
T/W=.30
W/S=160
T/W=.25
W/S=180
T/W=.23
SELECTED
BASE A/C
ROC=5FT/SEC
TOBFL=10500

FIG. 6.1.15

PARAMETRIC STUDY TO DETERMINE A/C SIZE AND CHARACTERISTICS

USTEDLEC INTERNATIONAL QUAD PROP - TOGW

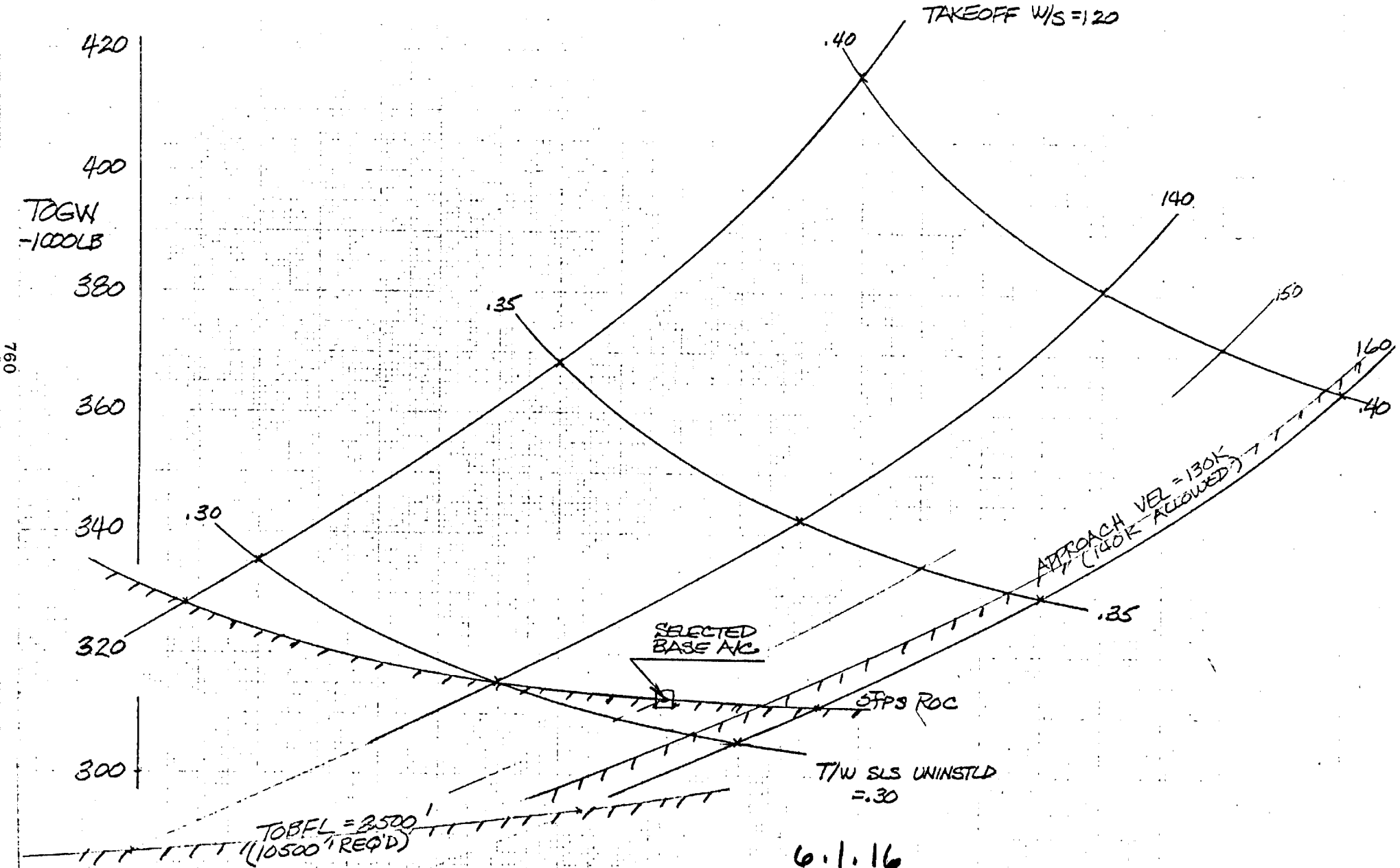
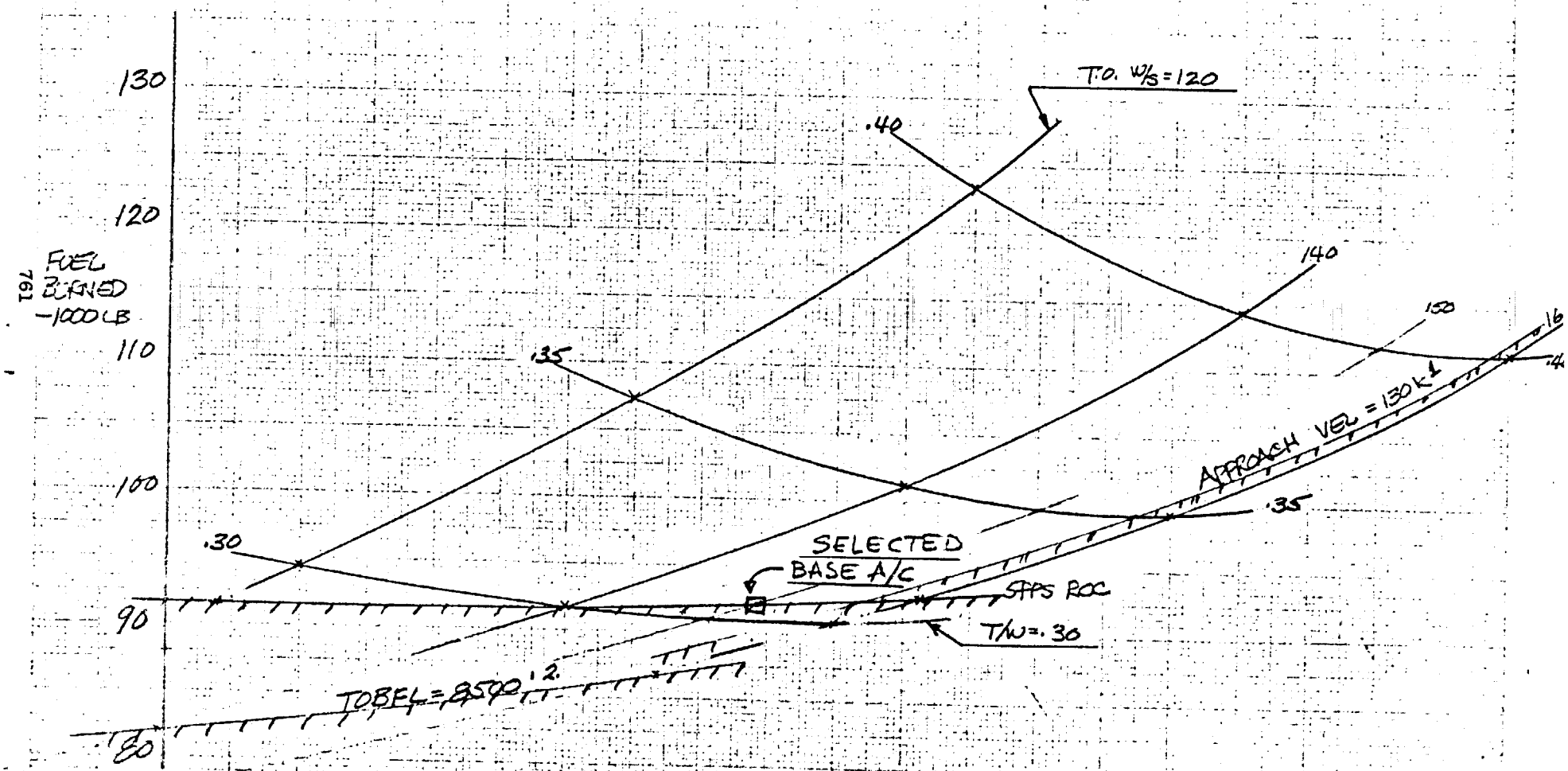


FIG. 6.1.16

PARAMETRIC STUDY TO DETERMINE A/C SIZE AND CHARACTERISTICS

USTEDLEC INTERNATIONAL QUADPROP. — FUEL BURNED



1. 140K ALLOWED.
2. 10500' ALLOWED.

FIG. 6.1.17

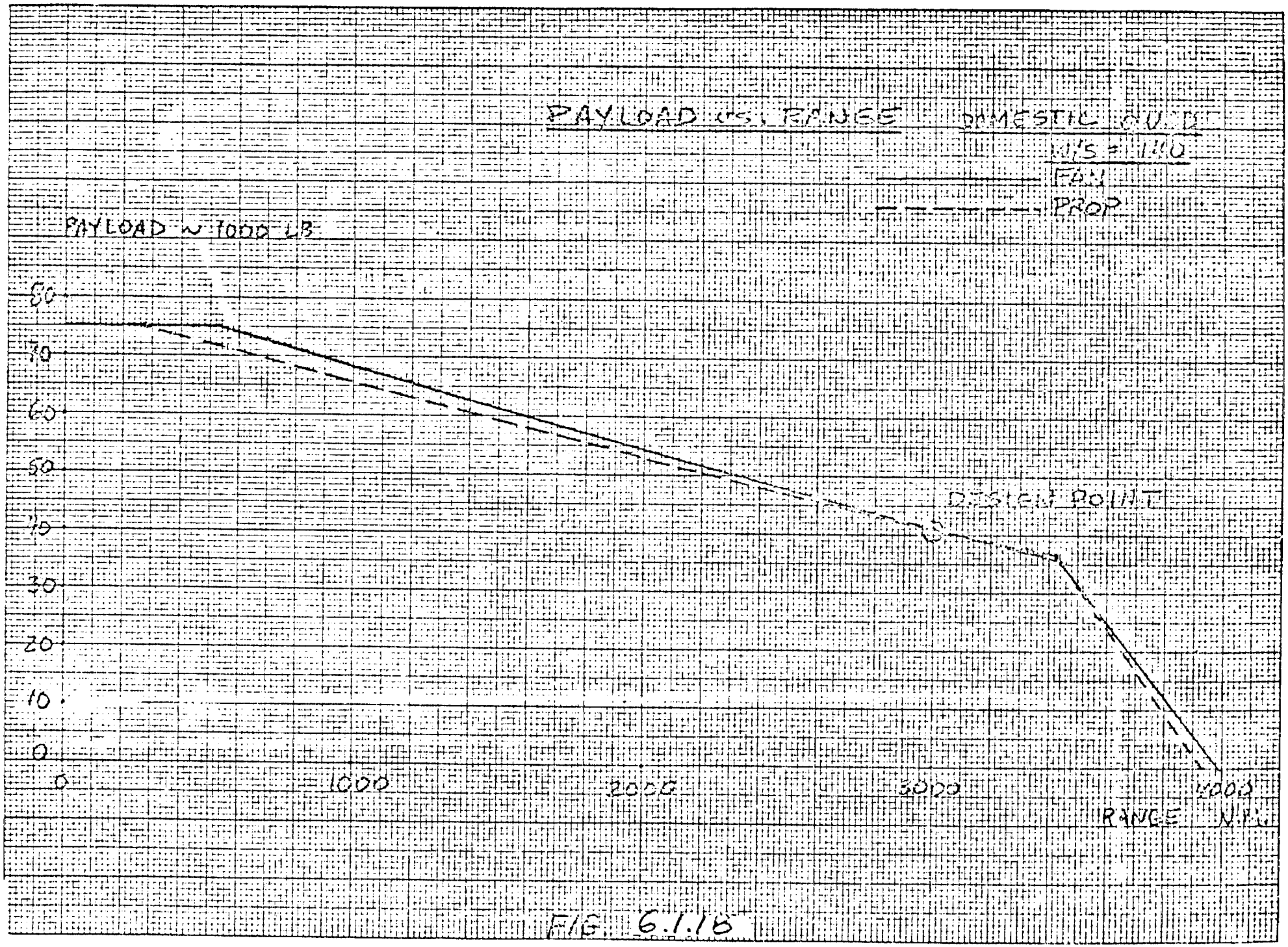


FIG. 6.1.18

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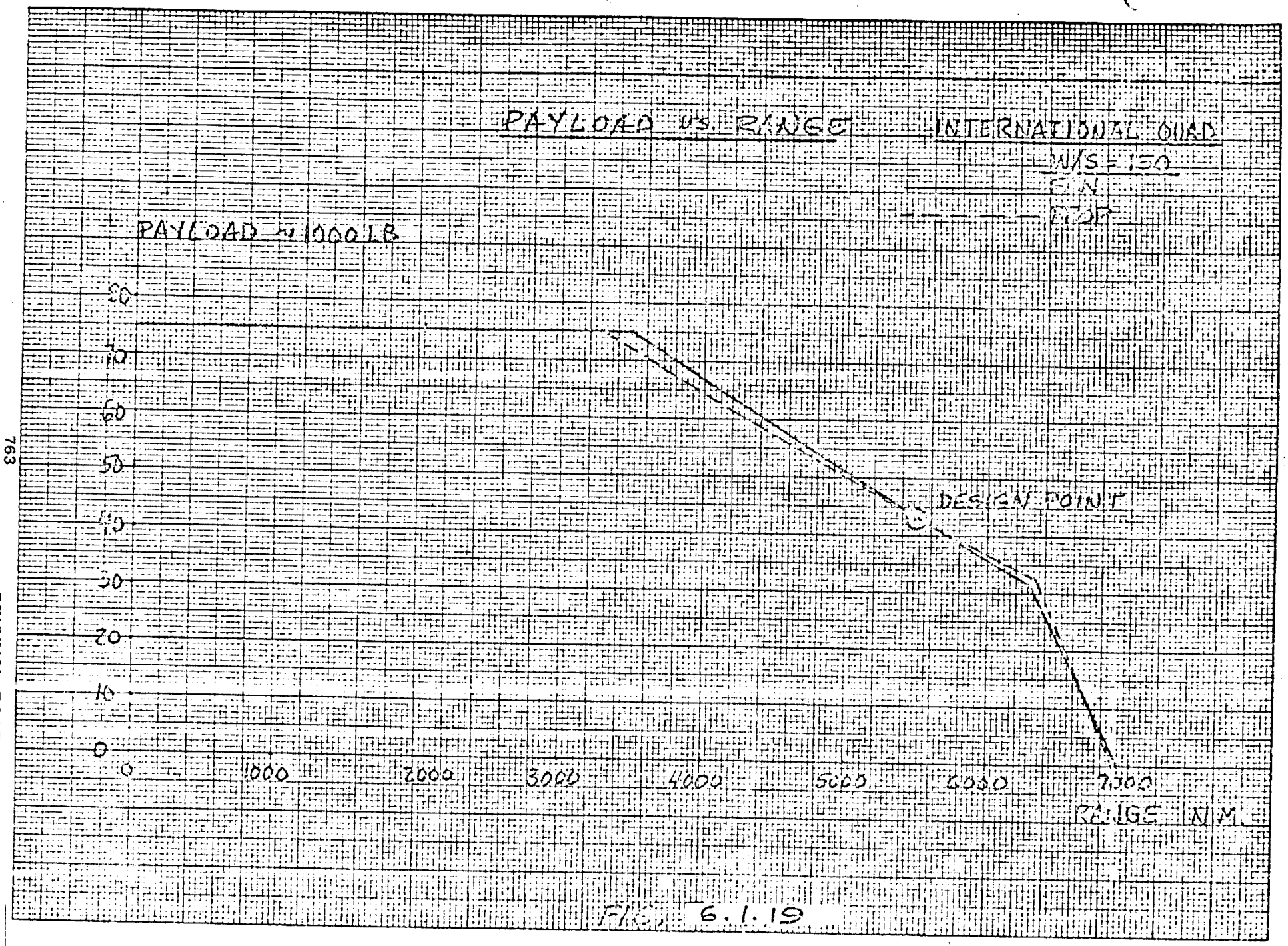

FIG. 6.1.19

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6.2 AIRCRAFT SENSITIVITY FACTORS

The concept of completely rubberized aircraft was used in obtaining the aircraft sensitivity factors. This concept basically allows the physical characteristics of the aircraft (such as gross weight, wing area, engine thrust size, etc.) to change as necessary to accommodate small changes in chosen parameters. The aircraft sensitivity factors are not normally used by themselves, but rather they are a step toward obtaining the economic sensitivity factors.

Again, the computer program MASCOT was used to define new aircraft (all with the same W/S and T/W as the respective base aircraft) that met all the mission requirements when the basic parameters were changed slightly.

Following are the small weight changes considered at mission size:

Turbofan:	+ 100 lb/engine
	+ 100 lb/nacelle wrap
Turboprop:	+ 100 lb/engine
	+ 100 lb/nacelle installation
	+ 100 lb/prop
	+ 100 lb/gearbox

For the turboprop aircraft, a small change of + 800 lb in the weight of the acoustic lining was considered. Since the acoustic lining base weight was set at 800 lb, the above small change provides the sensitivity to doubling this weight. It was further assumed that the same sensitivity would apply to any equivalent change in any kind of fixed weight for the turboprop aircraft. Another small change considered for all aircraft was a 1% increase in SFC during climb, cruise, and descent, with the SFC remaining constant for takeoff and loiter.

In running the program MASCOT, the wing loading and the thrust loading for the sensitivity aircraft were kept constant at the values determined for the base aircraft.

The aircraft sensitivity factors which were obtained in this section and were used further in obtaining economic sensitivity factors were:

- block fuel changes, shown in Table 6.2.1
- block time changes
- aircraft weight changes, shown in Table 6.2.2

Aircraft component weight changes were also obtained here and were used in the economic analysis.

Table 6.2.1
Mission Fuel Sensitivity, Δ Fuel Burned, %

	Domestic Fan	Domestic Fan	Domestic Fan	Domestic Fan	Domestic Prop	Intern'l Fan	Intern'l Prop
Number of Engines	3 W/S=120	3 W/S=140	4 W/S=120	4 W/S=140	4 W/S=140	4 W/S=150	4 W/S=150
Design Range, 100% Load Factor							
+ 100 lb/engine*	.247	.258	.315	.316	.300	.315	.289
+ 800 lb/aircraft body weight**	-	-	-	-	.681	-	.670
+ 1% SFC	1.274	1.273	1.272	1.243	1.236	1.547	1.528
Off-Design Range, 55% Load Factor							
+ 100 lb/engine*	.270	.280	.339	.346	.329	.335	.310
+ 800 lb/aircraft body weight**	-	-	-	-	.750	-	.708
+ 1% SFC	1.188	1.172	1.180	1.155	1.150	1.506	1.488

* The sensitivities to weight changes of the engine, propeller, gearbox, and nacelle installation for the turboprop, and to weight changes of the engine and nacelle wrap for the turbofan were found to be the same, respectively.

**This sensitivity was calculated for a change in A/F acoustic lining, but it applies to any equal change in aircraft body weight.

Table 6.2.2

Design Takeoff Gross Weight Sensitivity, Δ TOGW, %

	Domestic Fan	Domestic Fan	Domestic Fan	Domestic Fan	Domestic Prop	Intern'l Fan	Intern'l Prop
Number of Engines	3	3	4	4	4	4	4
	W/S=120	W/S=140	W/S=120	W/S=140	W/S=140	W/S=150	W/S=150
+ 100 lb/engine*	.342	.345	.435	.433	.402	.394	.357
+ 800 lb/aircraft body weight**	-	-	-	-	.912	-	.826
+ 1% SFC	.500	.499	.495	.473	.439	.859	.803

* The sensitivities to weight changes of the engine, propeller, gearbox, and nacelle installation for the turboprop, and to weight changes of the engine and nacelle wrap for the turbofan were found to be the same, respectively.

** This sensitivity was calculated for a change in A/F acoustic lining, but it applies to any equal change in aircraft body weight.

6.3 ECONOMIC SENSITIVITY FACTORS

The concept of rubberized engine and rubberized aircraft was applied. The airplane performance factors used were those described in Section 6.2.

The airframe pricing, described below, was done according to the economic ground rules suggested by NASA for STEDLEC. It was desired to make the price of the aircraft consistent with the price of the engine, and therefore the number of aircraft used was determined as follows:

a) For domestic trifans - 2400 engines, 550 aircraft, 45.5% spare parts

b) For domestic quadfans and quadprops - 3200 engines, 550 aircraft, 45.5% spare parts

c) For international quadfan and quadprop - 1000 engines, 175 aircraft, 42.9% spare parts

The total aircraft selling price (in 1974 $) as defined in this study is made up of:

Airframe structure
Furnishings
Electronics
Total powerplant

The first three are found using the following expression provided by NASA in their study ground rules.

$$\text{Price (in M\$)} = .207 \left(\frac{\text{AMPR}}{1000}\right)^{.87} \times \left(\frac{Q}{250}\right)^{-.42} + \frac{8.6}{Q} \left(\frac{\text{AMPR}}{1000}\right)^{.89}$$

$$+ .003(\text{seats}) + .60$$

AMPR Weight = TOGW - Fuel - Payload - Operating Equipment - Powerplant - Electronics

Q = Number of Aircraft in Production Run

The AMPR Weight and Q define the airframe structure price.
The furnishings are priced at $3000/seat.
The electronics are priced at $600, 000.

The powerplant price is the total of the engine plus reverser plus nacelle wrap plus pylon in the case of the turbofan, and the engine plus propeller plus gearbox plus total nacelle installation for the turboprop.

For the turboprop, a small cost was added for the 800 lb of acoustic shielding installed in the cabin to shield against propeller noise.

The above represent the total selling price. There was no additional amound for the amortization of research and development costs. These were considered to be in the above prices.

Table 6.3.1 shows the selling prices used for the engine and associated parts in the scale factor one size. The procedure used for scaling the selling prices is also shown.

In general, the economic ground rules recommended by NASA for turbofan aircraft were followed in performing the airline economic analysis. Following are the exceptions:

A. Direct Operating Costs

- For the engine maintenance costs, the text of NASA CR134645 was not followed. Instead, a method which is more representative of GE experience was employed. The formulas used were:

Material per engine per 1000 flight hours	2.5% of engine price
Material per engine per 1000 flight cycles	1.0% of engine price
Labor manhours per engine per flight hour	0.55 + 0.002 x SL thrust/1000
Labor manhours per flight cycle	0.45 + 0.002 x SL thrust/1000
Material per reverser per 1000 flight hours	0.5% of reverser price
Material per reverser per 100 flight cycles	0.5% of reverser price
Labor manhours per reverser per flight hour	0.6%
Labor manhours per reverser per flight cycle	0.6%

- The airframe maintenance costs were allowed to vary with the aircraft weight and price.

- It was assumed that the burden was related to labor costs only (rather than to labor and material costs). The accepted industry standard of 200% of labor was used.

B. Indirect Operating Costs

- The equations used were based on a study entitled "A Proposed Standard Method for Estimating Airline Indirect Operating Expense", Report No. LW700-500R, May 1970, by R. F. Stoessel. Inspection shows that this method is very similar to that used in the ground rules.

- Those costs which are functions of aircraft size and price were allowed to change, rather than varying landing fees only.

There were no ground rules relating to the maintenance of the prop and gearbox. Following is a description of the method used in handling these.

The turboprop powerplant maintenance was divided into three elements; the engine, the propeller plus gearbox, and the nacelle installation. This is comparable to the turbofan which was divided into the engine, the reverser, and the nacelle wrap.

The turboprop engine maintenance was calculated using the same formulae as used for the turbofan except:

- The labor and material costs were both increased by 8% from what is used for a turbofan, since what is called "the engine" in the case of the turboprop is actually just the core portion of a turbofan engine without the fan which is a low maintenance item.

- The maintenance labor is a function of SLS thrust in the formula used. Rather than use the high static thrust of the prop (46,500 lb) combined with the turboprop scale factor, the decision was made to use the static thrust of the fan (33,153 lb) times the turboprop scale factor as more representative of the engine maintenance labor.

The turboprop propeller plus gearbox maintenance was found using expressions supplied by Hamilton Standard.

$$\text{Labor \$/flt hr} = (.51)(\text{S. F.})^{.48} \quad \text{for domestic and international}$$

$$\text{Material \$/flt hr} = (1.32)(\text{S. F.})^{.71} \quad \text{for domestic}$$

$$= (1.79)(\text{S. F.})^{.71} \quad \text{for international}$$

(Note: S. F. = scale factor)

The nacelle installation maintenance was found as part of the airframe maintenance, as was the turbofan nacelle wrap maintenance.

The tool used to perform the economic sensitivity analysis was COSTBC74 - a time-sharing program for calculating DOC, IOC, cash flow and ROI. COSTBC74 was run repeatedly with the various aircraft sensitivity factors incorporated and new economic results were obtained. By comparing these factors with those for the base aircraft, the economic sensitivity factors were derived.

The economic analysis was performed for a representative average range of 700 n. mi. for the domestic aircraft and 2000 n. mi. for the international aircraft, and for an average passenger load factor of 55% for all aircraft studied.

Tables 6.3.2 and 6.3.3 present lists of inputs used in COSTBC74 to determine the airline economics associated with the base aircraft.

Fig. 6.3.1 contains plots of DOC vs. range for the base aircraft.

The DOC breakdown for the base aircraft is shown in Table 6.3.4.

The economic sensitivity factors obtained in this section are shown in Tables 6.3.5 and 6.3.6.

Table 6.3.7 shows the effects of doubling the domestic fuel prices on the DOC and ROI.

As expected, the turboprop aircraft shows a considerable amount of fuel saved, which, in turn, causes a relatively not so large a reduction of DOC. However, the DOC effect is not enough to significantly influence ROI because of the increased investment necessary with the turboprop. It should be noted that, if the fuel prices increase, then the DOC influence on ROI will be larger, and the beneficiary will be the turboprop aircraft.

Table 6.3.1

AVERAGE SELLING PRICES

	Domestic Trifan	Domestic Quadfan	Domestic Prop	Intern'l Fan	Intern'l Prop
Engine	798,300	750,700	726,175	962,500	930,330
Reverser	119,300	112,200	-	143,800	-
Nacelle Wrap & Pylon	373,000	350,800	-	449,800	-
Prop & Gearbox	-	-	264,760	-	384,910
Nacelle Installation	-	-	451,410	-	578,320

The above prices are for a 33,153 lb SL standard day engine size for the turbofan, and 46,500 lb SL standard day engine size for the turboprop. These were the base engines used which were scaled to find the actual size needed to satisfy the payload-range requirements. The expressions used for selling price were:

Engine	$(\text{Base Price})(\text{S. F.})^{.55}$
Reverser	$(\text{Base Price})(\text{S. F.})^{.8}$
TF Nacelle Wrap & Pylon	$(\text{Base Price})(\text{S. F.})^{.8}$
Prop & Gearbox	$(\text{Base Price})(\text{S. F.})^{.5}$ - 69735 for domestic $(\text{Base Price})(\text{S. F.})^{.5}$ - 103420 for international
TP Nacelle Installation	$(\text{Base Price})(\text{S. F.})^{.8}$

Table 6.3.2

INPUTS FOR ECONOMIC SENSITIVITY FACTORS

BASE AIRCRAFT
COMMON TO ALL AIRCRAFT

Depreciation period	15 years
Residual value	0
Airframe spares	6%
Engine spares*	30%
Service life	15 years
Depreciation schedule	Double declining to straight line
Borrowed investment	50%
Interest rate on above	15%
Additional investment	0
Investment tax credit	0
Tax rate	50%
Insurance rate	1%
Average passenger load factor	55%
Labor rate	$7.30/hr
Burden factor (times labor)	2
Cargo	0
Total number of seats	200
Number of first class seats	30
Number of tourist seats	170
Year for economic calculations	1974
Enplaned ratio	.9
Ground maneuver time	.25 hr
Flight Mach number	.8
Cargo revenue	0

*Same percentage used for reverser spares for TF and prop and gearbox spares for TP

Table 6.3.3

INPUTS FOR ECONOMIC SENSITIVITY FACTORS

BASE AIRCRAFT

NOT COMMON TO ALL AIRCRAFT

	Domestic Fan	Domestic Prop	Intern'l Fan	Intern'l Prop
	4-engine W/S=140	4-engine W/S=140	4-engine W/S=150	4-engine W/S=150
Fuel cost, $/lb	.0458	.0458	.0687	.0687
(¢/gal)	30	30	45	45
Total aircraft cost, $M	11.824	12.138	23.142	23.454
Cost of one engine, $	469,082	425,544	714,404	640,993
OWE-Engine Wt.-Op. Equip., lb	102,795	108,181	133,047	139,093
Design TOGW, lb	217,104	217,930	317,404	311,111
Thrust/engine @ SLS, lb	14,101	12,547	19,282	16,842
Number of engines	4	4	4	4
Cost of one reverser, $	56,617	-	93,209	-
Cost of one prop & gearbox, $	-	136,039	-	244,626
Block time, hrs	1.90	1.895	4.72	4.72
Block fuel, lb	11,259	9,737	34,600	30,649
Stage length, n. mi.	700	700	2000	2000
Passenger revenue, ¢/pass.-n.mi.	8.997	8.997	8.248	8.248

Table 6.3.4

BASE AIRCRAFT DOC BREAKDOWN
OFF-DESIGN RANGE, 55% L. F.

	Domestic Fan	Domestic Prop	Intern'l Fan	Intern'l Prop
	4-engine W/S=140	4-engine W/S=140	4-engine W/S=150	4-engine W/S=150
DOC, ¢/seat-n.mi.	1.413	1.379	1.835	1.779
Fuel, %	26.64	23.62	33.07	30.22
Crew, %	19.24	19.67	16.87	17.32
Depreciation, %	24.46	25.71	26.86	28.15
Insurance, %	3.33	3.49	3.68	3.85
Airframe labor, %	3.81	4.05	2.49	2.63
Airframe material, %	2.84	2.96	3.07	3.16
Engine labor, %	2.11	2.32	1.24	1.37
Engine material, %	4.86	4.87	4.74	4.74
Reverser labor, %	.24	-	.13	-
Reverser material, %	.15	-	.14	-
Prop and gearbox labor, %	-	.11	-	.09
Prop and gearbox material, %	-	.23	-	.28
Burden, %	12.32	12.97	7.71	8.19

Table 6.3.5

DOC SENSITIVITY, Δ DOC, %

OFF-DESIGN RANGE, 55% LOAD FACTOR

	Domestic Fan	Domestic Prop	Intern'l Fan	Intern'l Prop
Number of Engines	4 W/S=140	4 W/S=140	4 W/S=150	4 W/S=150
+ 100 lb/engine*	.228	.205	.237	.211
+ 100 lb/nacelle wrap	.263	-	.250	-
+ 800 lb/aircraft body weight	-	.511	-	.520
+ 1% SFC	.446	.411	.971	.715
+ $1000/engine	.0212	.0226	.0128	.0137
+ $1000/engine (w/o spares)	.0108	.0111	.00616	.00640
+ $1000/engine (spares only)	.0103	.0114	.00665	.00740
+ $1 mat'l/flt hr/engine	.334	.368	.244	.271
+ .1 man-hr/flt hr/engine	.731	.806	.534	.594

*For the turboprop, it was decided to apply the DOC sensitivity due to engine weight change to equal weight changes in propeller, gearbox, and nacelle installation.

Table 6.3.6

ROI SENSITIVITY, Δ ROI, POINTS

OFF-DESIGN RANGE, 55% LOAD FACTOR

	Domestic Fan	Domestic Prop	Intern'l Fan	Intern'l Prop
Number of Engines	4 W/S=140	4 W/S=140	4 W/S=150	4 W/S=150
+ 100 lb/engine*	-.114	-.102	-.0933	-.0818
+ 100 lb. nacelle wrap	-.120	-	-.0960	-
+ 800 lb/aircraft body weight	-	-.260	-	-.205
+ 1% SFC	-.155	-.142	-.364	-.229
+ $1000/engine	-.0119	-.0117	-.00505	-.00511
+ $1000/engine (w/o spares)	-.0101	-.00982	-.00372	-.00371
+ $1000/engine (spares only)	-.00177	-.00187	-.00132	-.00139
+ $1 mat'l/flt hr/engine	-.0569	-.0600	-.0486	-.0512
+ .1 man-hr/flt hr/engine	-.125	-.131	-.107	-.112

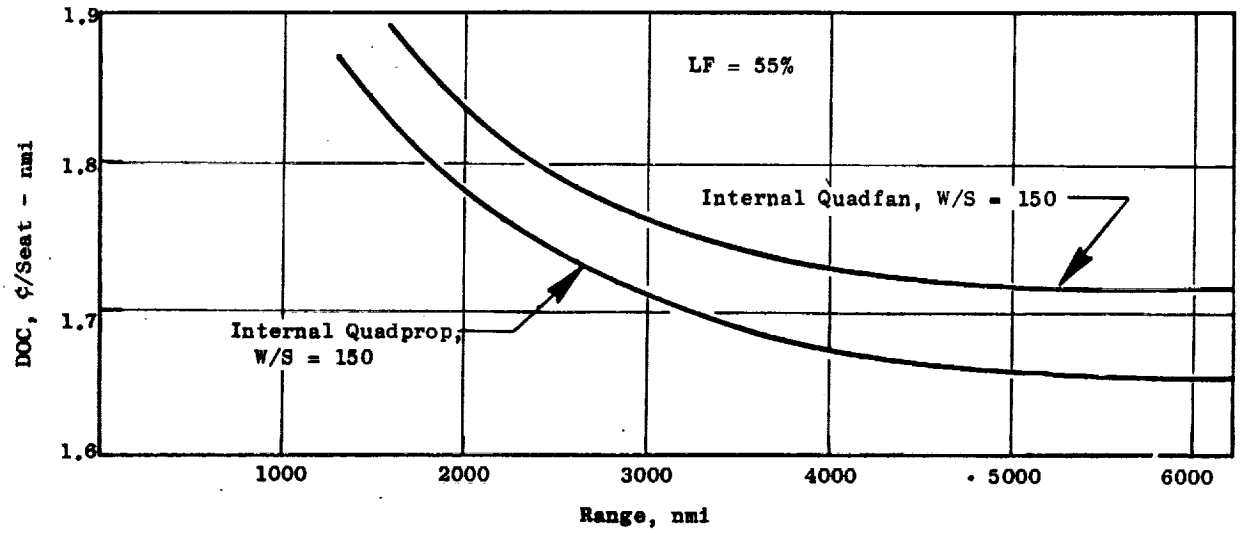
*For the turboprop, it was decided to apply the ROI sensitivity due to engine weight change to equal weight changes in propeller, gearbox, and nacelle installation.

Table 6.3.7

FUEL PRICE INFLUENCE ON AIRLINE ECONOMICS
DOMESTIC AIRCRAFT

Range = 700 n. mi., L. F. = 55%

	QUADFAN W/S=140		QUADPROP W/S=140	
	Fuel @ 30¢/gal	Fuel @ 60¢/gal	Fuel @ 30¢/gal	Fuel @ 60¢/gal
• DOC, ¢/seat-n. mi.	1.4126	1.7883	1.3787	1.7036
• ROI, %	18.0507	13.4351	17.9132	14.0211
• Δ DOC, % due to				
+100 lb/engine	+.228	+.253	+.205	+.228
+100 lb/nacelle wrap	+.263	+.281	-	-
+800 lb/body acoustic lining	-	-	+.511	+.556
+1% SFC	+.446	+.595	+.411	+.552
+$1000/engine	+.0212	+.0168	+.0226	+.0183
+$1000/engine (w/o spares)	+.0108	+.00856	+.0111	+.00898
+$1000/engine (spares only)	+.0103	+.00816	+.0114	+.00922
+$1 mat'l/flt hr/engine	+.334	+.264	+.368	+.298
+.1 man-hr/flt hr/engine	+.731	+.577	+.806	+.653


LF = 55%
Internal Quadfan, W/S = 150
Internal Quadprop, W/S = 150
DOC, ¢/Seat - nmi
1.9
1.8
1.7
1.6
1000
2000
3000
4000
5000
6000
Range, nmi

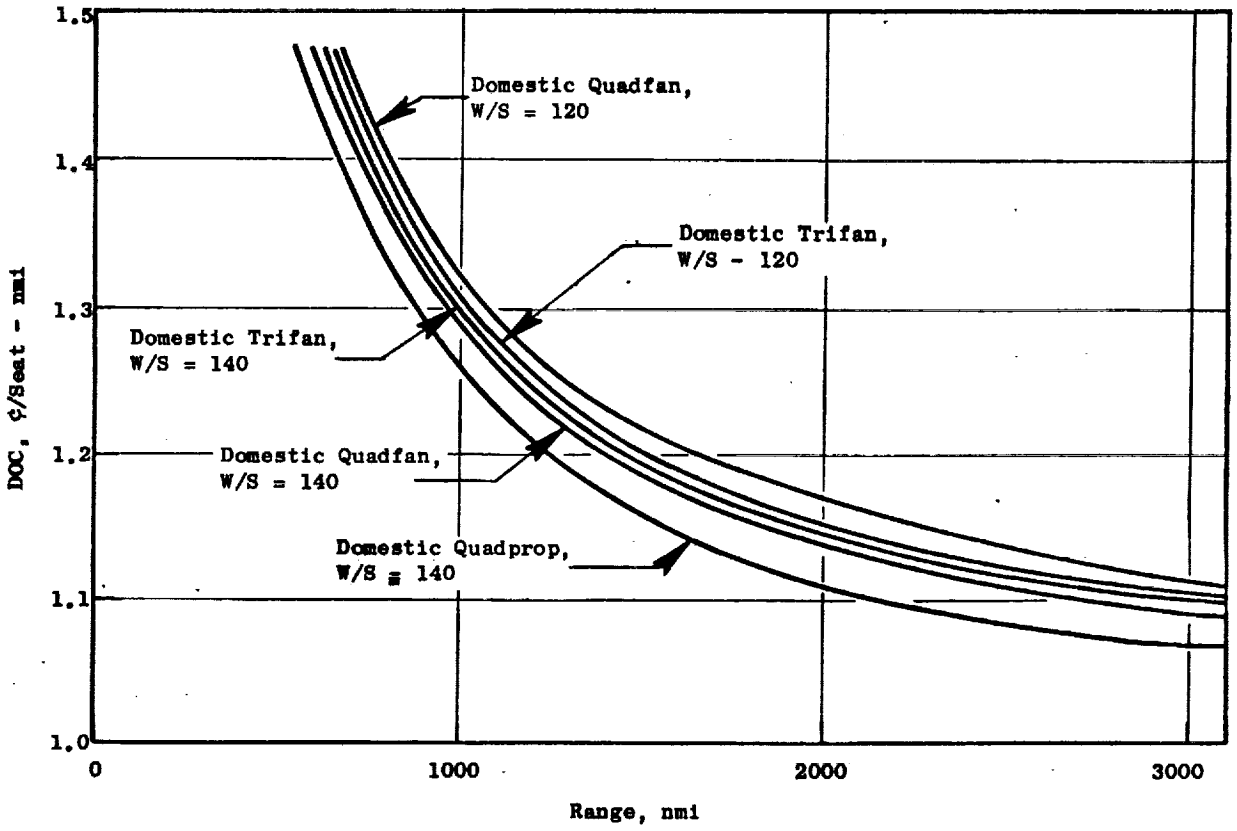

Domestic Quadfan, W/S = 120
Domestic Trifan, W/S - 120
Domestic Trifan, W/S = 140
Domestic Quadfan, W/S = 140
Domestic Quadprop, W/S = 140
DOC, ¢/Seat - nmi
1.5
1.4
1.3
1.2
1.1
1.0
0
1000
2000
3000
Range, nmi

FIGURE 6.3.1

7.0 TASK II REVIEW OF INTERTURBINE REGENERATOR

7.1 Introduction

This heat exchanger engine showed promise as the best of the engines of its type during Task I. The results showed though that with optimistic assumptions it was worse than a geared fan at the same fan pressure ratio. This configuration was not recommended for further study. Nevertheless, NASA requested that the engine be subjected to thorough review to ensure that the recommendation was supportable.

7.2 Cycle and Aerodynamic

A review of the aerodynamic inputs to the regenerator cycles was conducted. The following four areas were updated.

1) HPT cooling increased by 1.4%.
2) Regenerator duct pressure drop increased by 4.5% (Section 7.2.2)
3) Booster efficiency adjusted (Section 7.2.3).

Section 7.2.1 presents the final cycle definition. The influence of the above changes was permitted to appear in core exhaust velocity with no change in bypass ratio.

7.2.0 Final Cycle Performance

The following defines the final installed performance for the regenerative engines compared with the P/P=1.7 conventional turbofan cycle* @ 35K/.8/+18°/Mx CL

	BASE	REG →	
P/P	1.7	1.7	1.55
W_2 B/S, lb/sec	1252	925	1092
DT FEW	78.8"	67.7"	73.6"
FN Mx Climb, lb	8737	5030	5282
Drag, lb	430	344	387
FN Installed, lb	8307	4686	4895
SFC BARE	.582	.544	.518
SFC Installed	.612	.584	.559

Cycle data is attached

* STEDLEC MF12

35K/.8/+18/MxCC

Point 1 P/P_{fan} (MxCl) = 1.70 P/P_{cycle} (MxCl) = 32.2 T_4, °F (r/O) = 2800 ε = .90

TWIN SPOOL SEPARATED FLOW TURBOFAN

FN	5029.3	SFC	0.5438	FNW2	14.35
FN8E	850.2	FN8F	4179.1		
FG	13704.7	FR	8675.4	FGW2	39.10
WFM	2734.9	WFR	0.	WFT	2734.9
WFD	0.	WFI	0.		
P0	3.458	T0	411.85	WK2	924.691
P2	5.273	T2	464.79	W2	350.493
P3F	8.964	T3F	553.64	W3F	298.658
P35F	8.964				
P3A	12.233	T3A	612.21	W3A	51.834
P35A	12.233			EFCOOL	0.
P2C	12.111	T2C	612.21	WK2C	68.333
P3C	169.555	T3C	1378.9	W31C	44.266
P35C	147.936	T35C	2210.1		
P4T	140.096	T4T	3160.0	W4T	45.026
P5T	40.503	DHT4T	0.06580	WK4T	18.067
P55T	40.503	T5T	2299.1	EFRGNT	0.9000
P4V	40.503	T4V	1627.3	W4V	52.594
P5V	5.818	DHT4V	0.09558	WK4V	52.333
P55V	5.818	T5V	1039.5	EFRGNV	0.
P6E	5.768	T6E	1039.5	W6E	52.594
P6F	8.818	T6F	553.64	W6F	298.658
P72E	5.768				
P72F	8.818				
P8E	5.768	T8E	1039.5	W8E	52.594
P8F	8.818	T8F	553.6	W8F	298.658
P2P0	1.5249	ETAR	1.0000	M0	0.8000
P3P2F	1.7000	ETF	0.8590	BPR	5.7618
P3P2A	2.3200	ETA	0.8590	P2CP3A	0.9900
P3P2C	14.0000	ETC	0.8600	UNHPT	0.
P3CP2	32.155			P4VP5T	1.0000
P4TP3C	0.9470	ETABK	0.9874	LHV	18400.
P4P5T	3.4509	ETT	0.9275	WC5THC	0.1460
P4P5V	6.9619	ETV	0.9120	UNHPV	0.
P6EP5	0.9915			WC5VHC	0.
P7271E	1.0000	ETA3E	0.	V8E	1304.8
P7271F	1.0000	ETA3F	0.	V8F	1053.2
P872E	1.0000	CFG3E	0.9990	A9A3E	1.0000
P872F	1.0000	CFG3F	0.9976	A9A3F	1.0000
P8EP0	1.6651	CF3E	0.9965	A3E	563.86
P8FP0	2.5500	CF3F	1.0000	A3F	1495.69
ETACYC	0.4778	ETAK	0.9933	V9EXE	1306.1
ETAP	0.7777	ETADV	0.3645	V9EXF	1249.2
				V9EXEF	1.0456

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J: SL/Static/+.27/T10

Point 2 P/P_{fan} (Hxcl) = 1.70 P/P_{cycle} (Hxcl) = 32.2 T_4, °F (T10) = 2800 ε = .78

TWIN SPOOL SEPARATED FLOW TURBOFAN

FN	17160.5	SFC	0.3856	FNW2	21.79
FN8E	2215.3	FN8F	14945.2		
FG	22768.5	FR	5606.1	FGW2	28.91
WFM	6617.3	WFR	0.	WFT	6617.3
WFD	0.	WFI	0.		
P0	14.696	T0	545.60	WK2	788.633
P2	15.112	T2	549.96	W2	787.546
P3F	23.099	T3F	632.05	W3F	676.325
P35F	23.099				
P3A	31.522	T3A	698.21	W3A	111.222
P35A	31.522			EFCOOL	0.
P2C	31.207	T2C	698.21	WK2C	60.769
P3C	357.318	T3C	1464.1	W31C	94.983
P35C	323.109	T35C	2196.6		
P4T	305.985	T4T	3260.0	W4T	96.821
P5T	91.991	DHT4T	0.06711	WK4T	18.067
P55T	91.991	T5T	2400.6	EFRGNT	0.7760
P4V	91.991	T4V	1816.5	W4V	113.060
P5V	17.655	DHT4V	0.05413	WK4V	52.383
P55V	17.655	T5V	1254.6	EFRGNV	0.
P6E	17.505	T6E	1254.6	W6E	113.060
P6F	22.722	T6F	632.05	W6F	676.325
P72E	17.505				
P72F	22.722				
P8E	17.505	T8E	1254.6	W8E	113.060
P8F	22.722	T8F	632.0	W8F	676.325
P2P0	1.0263	ETAR	1.0000	BO	0.2000
P3P2F	1.5285	ETF	0.8640	BPR	6.0609
P3P2A	2.0359	ETA	0.8660	P2CP3A	0.9900
P3P2C	11.4661	ETC	0.8665	UNHPT	0.
P3CP2	23.575			P4VP5T	1.0000
P4TP3C	0.9470	ETABH	0.9874	LHV	18400.
P4P5T	3.3263	ETT	0.9290	WC5TWC	0.1460
P4P5V	5.2103	ETV	0.9070	UNHPV	0.
P6EP5	0.9915			WC5VWC	0.
P7271E	1.0000	ETABE	0.	V8E	855.7
P7271F	1.0000	ETABF	0.	V8F	940.0
P872E	1.0000	CFG3E	0.9965	A9A8E	1.0000
P872F	1.0000	CFG3F	0.9969	A9A8F	1.0000
P8EP0	1.1912	CFBE	1.0165	A8E	563.96
P8FP0	1.5462	CFBF	0.9699	A8F	1498.93
ETACYC	0.3809	ETAK	0.9934	V9EXE	858.4
ETAP	0.3958	ETAGV	0.1479	V9EXF	942.9
				V9EXEF	0.9104

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Point 3 P/P_{fan} = 1.55 P/P_{cycle} = 32.2 T_4, °F = 2800 ε = .90

P/P FAN = 1.55

TWIN SPOOL SEPARATED FLOW TURBOFAN

FN	5262.3	SFC	0.5177	FNN2	12.76
FN8E	1029.4	FN8F	4252.8		
FG	15528.8	FR	10246.6	FGN2	37.51
WFM	2734.4	WrR	0.	WFT	2734.4
WFD	0.	WHI	0.		
P0	3.458	T0	411.65	WK2	1092.160
P2	5.273	T2	464.79	W2	413.970
P3F	8.173	T3F	535.55	W3F	362.137
P35F	8.173				
P3A	12.233	T3A	611.87	W3A	51.833
P35A	12.233			EFCOOL	0.
P2C	12.111	T2C	611.87	WK2C	68.312
P3C	169.555	T3C	1378.2	W31C	44.265
P35C	147.936	T35C	2210.3		
P4T	142.759	T4T	3160.0	W4T	45.025
P5T	41.305	DHT4T	0.06677	WK4T	17.729
P55T	41.305	T5T	2299.3	EFRONT	0.9000
P4V	41.305	T4V	1626.9	W4V	52.593
P5V	6.349	DHT4V	0.09299	WK4V	51.357
P55V	6.349	T5V	1055.7	EFRONV	0.
P6E	6.295	T6E	1055.7	W6E	52.593
P6F	8.040	T6F	535.55	W6F	362.137
P72E	6.295				
P72F	8.040				
P8E	6.295	T8E	1055.7	W8E	52.593
P8F	8.040	T8F	535.6	W8F	362.137
P2P0	1.5249	ETAR	1.0000	B0	0.8000
P3P2F	1.5500	ETF	0.8790	BPR	6.9866
P3P2A	2.3200	ETA	0.6610	P2CP3A	0.9900
P3P2C	14.0000	ETC	0.8600	UNHPT	0.
P3CP2	32.155			P4VP5T	1.0000
P4TP3C	0.9650	ETABM	0.9874	LHV	18400.
P4P5T	3.4562	ETT	0.9275	WC5TWC	0.1460
P4P5V	6.5054	ETV	0.9120	UNHPV	0.
P6EP5	0.9915			WC5VWC	0.
P7271E	1.0000	ETABE	0.	V8E	1414.4
P7271F	1.0000	ETABF	0.	V8F	1035.2
P872E	1.0000	CFG8E	0.9966	A9A8E	1.0000
P872F	1.0000	CFG8F	1.0002	A9A8F	1.0000
P8EP0	1.8205	CF8E	0.9965	A8E	515.64
P8FP0	2.3250	CF8F	0.9863	A8F	1986.71
ETACYC	0.4900	ETAK	0.9999	V9EXE	1416.1
ETAP	0.7915	ETAUV	0.3829	V9EXF	1173.8
				V9EXEF	1.2064

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SL/Static/+27/T/O

Point 4 P/P_{fan} = 1.55 (1xCl) P/P_{cycle} = 32.2 (1xCl) T_4, °F = 2800 (T/O) ε = .78

TWIN SPOOL SEPARATED FLOW TURBOFAN

FN	18664.9	SFC	0.3569	FNW2	19.95
FN8E	2530.6	FN8F	16154.2		
FG	25354.5	FR	6669.0	FGW2	27.07
WFM	6669.1	WFR	0.	WFT	6669.1
WFD	0.	WFI	0.		
P0	14.696	T0	545.60	WK2	937.905
P2	15.112	T2	549.98	W2	936.613
P3F	21.623	T3F	617.09	W3F	824.321
P35F	21.623				
P3A	32.365	T3A	704.11	W3A	112.292
P35A	32.365			EFCOOL	0.
P2C	32.042	T2C	704.11	WK2C	60.006
P3C	361.258	T3C	1468.5	W31C	95.897
P35C	326.216	T35C	2198.8		
P4T	314.798	T4T	3260.0	W4T	97.750
P5T	94.810	DHT4T	0.06702	WK4T	17.729
P55T	94.810	T5T	2402.0	EFRGNT	0.7760
P4V	94.810	T4V	1819.7	W4V	114.144
P5V	18.300	DHT4V	0.08390	WK4V	51.358
P55V	18.300	T5V	1258.5	EFRGNV	0.
P6E	18.145	T6E	1258.5	W6E	114.144
P6F	21.271	T6F	617.09	W6F	824.321
P72E	18.145				
P72F	21.271				
P8E	18.145	T8E	1258.5	W8E	114.144
P8F	21.271	T8F	617.1	W8F	824.321
P2P0	1.0283	ETAR	1.0000	M0	0.2000
P3P2F	1.4309	ETF	0.8840	BPR	7.3409
P3P2A	2.1417	ETA	0.8660	P2CP3A	0.9900
P3P2C	11.2746	ETC	0.8685	UNHPT	0.
P3CP2	23.906			P4VP5T	1.0000
P4TP3C	0.9650	ETABM	0.9874	LHV	18400.
P4P5T	3.3203	ETT	0.9290	WC5TWC	0.1460
P4P5V	5.1808	ETV	0.9070	UNHPV	0.
P6EP5	0.9915			WC5VWC	0.
P7271E	1.0000	ETABE	0.	V8E	938.6
P7271F	1.0000	ETABF	0.	V8F	859.5
P872E	1.0000	CFG8E	0.9968	A9A8E	1.0000
P872F	1.0000	CFG8F	0.9969	A9A8F	1.0000
P8EP0	1.2347	CF8E	1.0165	A8E	515.79
P8FP0	1.4474	CF8F	0.9699	A8F	1985.68
ETACYC	0.3906	ETAK	0.9934	V9EXE	941.6
ETAP	0.4170	ETAOV	0.1598	V9EXF	862.2
				V9EXEF	1.0921

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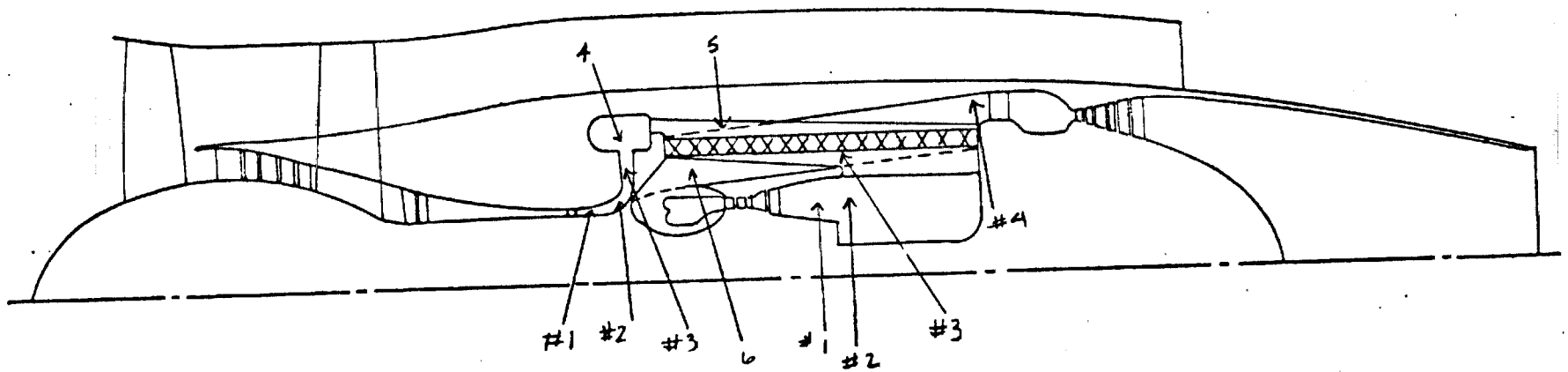
7.2.2 Regenerator Ducting Losses

The following losses were estimated in the evaluation of the rotary regenerator. Loss stations refer to accompanying diagram

#	Description	Loss % P_T	Sizing M
	Cold Side		
1	Compressor Exit Diffuser	.9	.3
2	90° Turn	.34	.14
3	Radial Diffusion	.30	.14
4	Dump to Scroll	.50	.08
5	Loss over core	.70	.1
6	180° Turn to Combustor	2.15	.1
		4.89%	
	Hot Side		
1	HPT Exit Diffuser	1.0	.28
2	Dump to Plenum	.8	.16
3	Loss Over core	.7	.1
4	Acceleration to LPT	.1	.1
		2.6	

Total Loss 7.5%

Regenerator Duct Pressure Loss



7.2.3 Booster Aerodynamic Definition

The following represents the buildup of efficiency for the two regenerative engines @ 35K/.8/+18/MxCl.

P/P_{Fan}	1.7	1.55
Booster		
No. Stages	2	3
$U_T/\sqrt{\theta}$	890	760
P/P_{Boost}	1.42	1.57
P/P_{Stage}	1.19	1.16
r/r	.79	.83
η Stage	.917	.914
$\Delta\eta$ Location	-.005	-.005
$\Delta\eta$ Variable Stator	-.01	-.01
$\Delta\eta$ Advanced Tech.	+.03	+.03
$\Delta\eta$ Reheat	-.003	-.0065
$\Delta\eta$ Radius Ratio	-.012	-.0145
η Boost	.891	.8825
$P/P_{Fan\ Hub}$	1.63	1.48
η Fan Hub	.812	.805
η Overall	.859	.861

The above efficiency is derived from a correlation of single stage efficiency then corrected for reheat, test correlation and geometry. In generation of cycle data the fan hub and booster are lumped to provide an overall pressure ratio and efficiency into the core.

7.3 Engine Mechanical Design Review Weight, Cost and Maintenance

For Task II, the interturbine regenerator engine design was re-evaluated for weight, cost and maintenance effects.

Since there were no changes in the Task II base regenerator engine in terms of size, cycle or operating parameters, the previously estimated base engine weight of 3635 lbs in the design size was retained. A breakdown of the engine weight is given in the Task I design discussion of the regenerative engine.

However, there was a small change in the size of the interturbine regenerator and a corresponding change in the estimated weight. The overall diameter of the regenerator remained unchanged as shown on Fig. 7.3.1, but the regenerator length was decreased to 34 inches. This affected the weight of the distribution and collector duct but not the ~~MPC~~ HPC headers or the LPT plenum and the bearing support or rotator.

Starting with the original Task I weight estimate in all Nickel alloy shown in Table 7.3.1, a new regenerator weight estimate was made shown in Table 7.3.2 in all nickel alloy construction. Ti-Alum. alloys were then applied where possible and a new regenerator weight estimate was made of 683# as shown in Table 7.3.3.

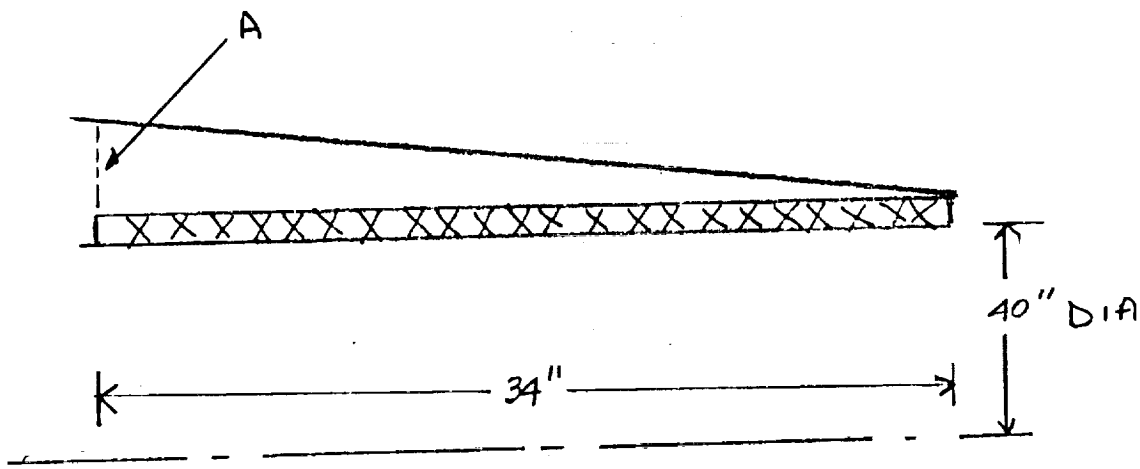
In the above weight estimating procedure a minimum cast wall thickness of .060 nominal was assumed for all distributors, headers and collectors.

Maintenance Costs were estimated by breaking down the engine into components and estimating the average number of times each component would be replaced over a 36000 hour engine life. This number was called the replacement factor. For the regenerator engine, 30 components were estimated in this way. A list of the components and the replacement factors assigned is given in Table 7.3.3.

Replacement factors were estimated by using current commercial experience and making an adjustment for differences in operating environment and for materials used in the components. A replacement factor equal to one indicates just one replacement in the engine lifetime or a part life of 18000 hours. A replacement factor of less than one indicates that only a partial replacement of that component would occur in 36000 hours or that only one replacement of a large item (such as a fan frame) would be expected in a group of several engines over their lifetime. The ceramic exchanger replacement factor was based on manufacturer's supplied estimates.

Engine maintenance costs per hour are calculated using the replacement factor to generate parts costs per hour and then adding a labor cost as a fraction of the parts cost. It is believed that the above procedure reflects more accurately the maintenance cost variations between engine configuration and technology levels.

Revised Regenerator Casing Dimensions



(1) $A_{cold\ in} = 105\ in^2$ $\quad$ $A_{Hot\ in} = 683\ in^2$

$A_{cold\ out} = 133\ in^2$ $\quad$ $A_{Hot\ out} = 605\ in^2$

2) Two 90° Sectors for each area

℄ ℞

Fig 7.3.1

Table 9.3.1

cc KH
6/20/75

To: E. Reilly
From: R. Tobiasz

Subject: Installation Wt for the Rotary Regenerator in the Inter-Turbine Location

Item		Wt Est.	(Al-Ti)
HPC	Exit Collector + Scroll	- 93#	
HPC	Distributor (Cold Side)	- 280#	140#
HPC	Collector (Hot Side)	- 93#	
HPT	Exit Collector, Diffuser + Duct	- 207#	
LPT	Collector (Cold Side)	- 81#	40
LPT	Plenum	- 65#	32
Regenerator Support, Bearings, Rotor		- 122#	
Est. Total		- 941#	

VGT

Table 7.3.2

		Ni Alloy	Ti Al
HPC	Collector Scroll	93	
HPC	Distributor	238	119*
HPC	Collector (Hot Side)	93	
HPT	Exit Collector Diff + Dist	191	
LPT	Collector	69	35
LPT	Plenum	65#	32
Rotor Support, Bearings, Rotor		120#	
		869#	683

Table 7.3.3

To: E. D. Riley

From: R. P. Johnston

Subject: Re-estimate of the Regenerative Engine Weight for USTEDLEC

Reviewing the engine weight shows no changes in cycle, flow, etc. to necessitate any change in the previously estimated engine weight.

Regen. Eng. #2	(P/P = 1.55)
Engine Weight	3397
Regenerator	683*
	4080#
7% Margin	286
Total	4366#

*Assumes extensive use of (Ti-Al) alloys wherever possible in the distribution and collectors. A more conventional alloy system in Ni Alloys would weigh 869#.

cc RH

2/27/76

TABLE 7-3-3

To: F.D.R.
From: R.J

Subject: Replacement Factors Estimates for the Regenerative Engine.

Component	Recommended Factor (2 engines)		
Fan Blades	1.38		
Fan Disk	.1		
Fan Frame	.2		
Booster R. Blades	.4		
Booster R. Disks	.05		
Booster S. Vanes	.2		
Booster S. Case	.05		
HPC. Blades	3.1		
HPC Rotor	.15		
HPC Vanes	.3		
HPC Stator Case	.1		
Combustor	2.2		
HPT Blades	~~4.0~~ 3.0		
HPT Rotor	.6		
HPT Vanes	6.1		
HPT Case	.4		
LPT Vanes	.2		
LPT Case	.2		
LPT Blades	.4		
LPT Disks	.05		
Turbine Frame	.1		
C+A + misc	.3		
Minor Parts	2		
Special Stuff: HPC Collector (Cold)	.2	.21	88.0
Special Stuff: HPC Return (Hot)	.25		
Special Stuff: HPT Collector (Hot	.5		
Special Stuff: LPT Return (Cold)	.2		
Special Stuff: LPT Plenum (Cold)	.05		
Envelope Frame + Rotary Equip	.25		
Engine	33.0		10.0

7.4 Regenerator Installation

The installation of the 1.55 and 1.7 P/P regenerator engines were based on the design used for the STEDLEC baseline engine installation. The inlets had the same ratios of L/D for aerodynamic characteristics and acoustic treatment. The same type of fan reverser was used scaled to the bypass air flow. Because of the increase in total length required by the regenerator, both the outer duct and core cowl lengths were adjusted to suit. The use of separate exhaust flow were accounted for.

The weight and cost breakdown are as follows:

11/25/75

Regenerator Engine Installations + Pylon Weight + Cost Estimates

	#1		#2	
P/P	1.7		1.55	
F_n T.O. SLS, lb	20,293		22,366	
F_n Max Climb, lb	5125		5336	
Fan D_T, in	67.8		73.66	
D_m, lb	77.1		83.7	
AE 25, in^2	2216		2610	
	lbs	% Price	lbs	% Price
INLET	220	9.	265	10.
FAN REVERSER + DUCT	590	27	665	28
CORE COWL	175	8	170	6
TAIL CONE + CENTER BODY	75	4	160	8
ENGINE BUILDUP	310	23	320	21.
PYLON Δ	30	1	30	1.
WEIGHT MARGIN 7%	100	–	110	
~~Amplification~~	–	–	–	
Subtotals	1500	72.	1720	74.
PYLON Subtotals	720	28.0	750	26.
	2220	100.0	2470	100.
		353.4 K		395.6 K

7.5 Economic Evaluation

Based on the installed SFC of the two regenerator engines, it was decided to perform a detailed benefit analysis on only the P/P = 1.55 engine.

Attached is the benefit analysis output for the Transcontinental and Intercontinental aircraft.

BENEFIT ANALYSIS RESULTS FORMAT

FEATURE STUDIED

DESIGN INPUT

BENEFIT RESULTS

/HLECMCBX
INPUT NAME OF DATA FILE
=ROTREG

ER
3-15-96

ENGINE	P/P=1.55 REGENERATOR
MISSION	INTERCON
MATERIAL SUBSTITUTION	NONE FOR MF12 BASE
FUEL PRICE	$0.45
HOST COMPONENT	REGENERATOR

PARAMETERS AFFECTED	CHANGE
0	0

	DESIGN SIZE BASE	DESIGN SIZE REPLACE	DESIGN SIZE DELTA	MISSION SIZE BASE	MISSION SIZE REPLACE	MISSION SIZE DELTA
FN, LBS	33156.	31708.		21000.	20083.	
DEL DIRECT WT, LB			4623.0			
DEL DIRECT PR, K$			432.2			
DEL MMH, MMH/FL HR			0.			
DEL MMA, $MMA/FL HR			8.54			
TOTAL WEIGHT, LB	4442.	9065.	4623.	2510.	5122.	2612.
TOT INIT PRICE, K$	962.	1395.	432.	747.	1083.	335.6
NAC WEIGHT, LB	3090.	4509.	1419.	1870.	2728.	858.6
NAC PRICE, K$	594.	766.	173.	412.	532.	119.8
SFC	0.5790	0.5160	-0.0630			
SFC INSTALL	0.6138	0.5635	-0.0503			

	MISSION SIZE	DEL %DOC	DEL %ROI	DEL %TOGW	DEL %WF
TOT DEL WEIGHT, 100#	26.12	5.8513	-2.4084	10.0569	8.1761
DEL WT DIR	26.12	5.8512	-2.4084	10.0568	8.1760
DEL WT CYCLE	0.00	0.0000	-0.0000	0.0001	0.0001
TOT DEL PRICE, K$		2.0202	-1.2550		
DEL PRICE DIR INIT	335.57	2.0201	-1.2550		
DEL PRICE DIR REP	0.	0.	0.		
DEL PRICE DIR TOT		2.0201	-1.2550		
DEL PRICE CYCLE	0.00	0.0000	-0.0000		
DEL MMH, MMH/FL HR	0.	0.	0.		
DEL MMA, $MMA/FL HR	8.54	2.0411	-0.4543		
DEL %SFC	-8.19	-5.7820	2.0229	-7.1087	11.7687
DEL %RK2C	0.				
NAC WEIGHT, 100#	8.59	1.9234	-0.7917	3.3058	2.6876
NAC PRICE, K$	119.79	0.7211	-0.4480		
TOTAL		6.7750	-3.3346	6.2539	-0.9050

*

INPUT NAME OF DATA FILE
=ROTREG

ENGINE	P/P=1.55 ROTARY REGN
MISSION	TRANSCONTINENTAL
MATERIAL SUBSTITUTION	NONE FOR MF12 BASE
FUEL PRICE	$0.30
HOST COMPONENT	REGENERATOR

PARAMETERS AFFECTED	CHANGE
0	0

	DESIGN SIZE BASE	DESIGN SIZE REPLACE	DESIGN SIZE DELTA	MISSION SIZE BASE	MISSION SIZE REPLACE	MISSION SIZE DELTA
FN, LBS	33156.	31708.		20000.	19126.	
DEL DIRECT WT, LB			4623.0			
DEL DIRECT PR, KS			358.5			
DEL MMH, MMH/FL HR			0.			
DEL MMA, SMMA/FL HR			8.54			
TOTAL WEIGHT, LB	4442.	9065.	4623.	2362.	4819.	2457.
TOT INIT PRICE, KS	798.	1157.	358.	603.	874.	270.9
AC WEIGHT, LB	3090.	4509.	1419.	1772.	2586.	813.7
NAC PRICE, KS	492.	636.	143.	329.	424.	95.5
SFC	0.5790	0.5160	-0.0630			
SFC INSTALL	0.6138	0.5635	-0.0503			

	MISSION SIZE	DEL %DOC	DEL %ROI	DEL %TCGW	DEL %WF
TOT DEL WEIGHT, 100#	24.57	4.1039	-1.4916	7.7654	6.2910
DEL WT DIR	24.57	4.1040	-1.4917	7.7657	6.2912
DEL WT CYCLE	-0.00	-0.0001	0.0001	-0.0003	-0.0002
TOT DEL PRICE, KS		1.9883	-1.2190		
DEL PRICE DIR INIT	270.91	1.9885	-1.2191		
DEL PRICE DIR REP	0.	0.	0.		
DEL PRICE DIR TOT		1.9885	-1.2191		
DEL PRICE CYCLE	-0.01	-0.0001	0.0001		
DEL MMH, MMH/FL HR	0.	0.	0.		
DEL MMA, SMMA/FL HR	8.54	1.9557	-0.3126		
DEL %SFC	-8.19	-3.2186	0.9091	-3.6656	-8.9350
DEL %MR2C	0.				
AC WEIGHT, 100#	8.14	1.3588	-0.4939	2.5712	2.0505
NAC PRICE, KS	95.55	0.7013	-0.4300		
TOTAL		6.8894	-3.0380	6.4711	-0.5936

*

8.1 Introduction

Geared Fans

The geared fan selected for further study in Task II is the P/P 1.55 fan with booster stages located aft of the fan blade and driven off the high speed LP turbine through a gear with a gear ratio of 2.6. The emphasis in the detail study was to select efficient booster and LP turbine stages in a compact arrangement. The core was identical to the 14:1/2600°F takeoff turbine inlet temperature core used throughout this study.

8.2 Tabulation of Component Efficiency Levels

7-U Geared Fan

35K/.8/+18 Mx Climb

Efficiencies	
Fan Tip	.880
Fan Hub + Booster	.8732
Compressor	.860
HP Turbine	.898
LP Turbine	.9195
Mixing	.750
Combustor	.9875
Gear	.990
Pressure Ratios	
Inter Compressor	.984
Inter Turbine	1.0
Fan Duct	.9956
Core Duct	.9940
Combustor	.947

Cooling & Leakage, %/Energy Charge		Sink
Sump Purge	0.5/.25	Post LPT
LP Turbine	2.22/.612	Post LPT
HP Turbine & Leakage	4.9/1.0	Post HPT

8.3.1 Cycle and Aero Design

The cycle was defined with component efficiencies based on a flowpath layout which is attached. Then detail aerodynamic and mechanical design evaluations proceeded and the final cycle was not actually recomputed in full. Instead, the effect on SFC and sizing parameters of the component changes were obtained by the use of engine sensitivity factors.

All component aero design calculations are carried out at the Mach .8/35,000 ft max. climb sizing point. This corresponds to Point #1 of the attached data.

Cycle Data for 7-U

All components correct and final except for booster efficiency too high by 1.6 points. LPT efficiency too high by 0.1 points (trivial).

All cycle data are presented in the 68.4 lb/sec core airflow size and then scaled to the size needed for mission analysis.

The corrected component inlet flow tabulated at W_{2C}^{*} = 68.74 lb/sec includes 0.34 lb/sec 1.5% which does not actually enter the compressor inlet and is bypassed to perform sump purging functions. The compressor is sized at 68.4 lb/sec.

ENG. 7-0 CYCLE DATA

CASE	h	M_p	ΔT_0 °F	RATING
1	35K	.8	+18	Mx CL
2				" "
3				Mx Cruise
4			0	My Cruise
5				Operating Line
6				
7				
8				
9				
10	0	0	+27	TO
11	0	.25	+27	TO

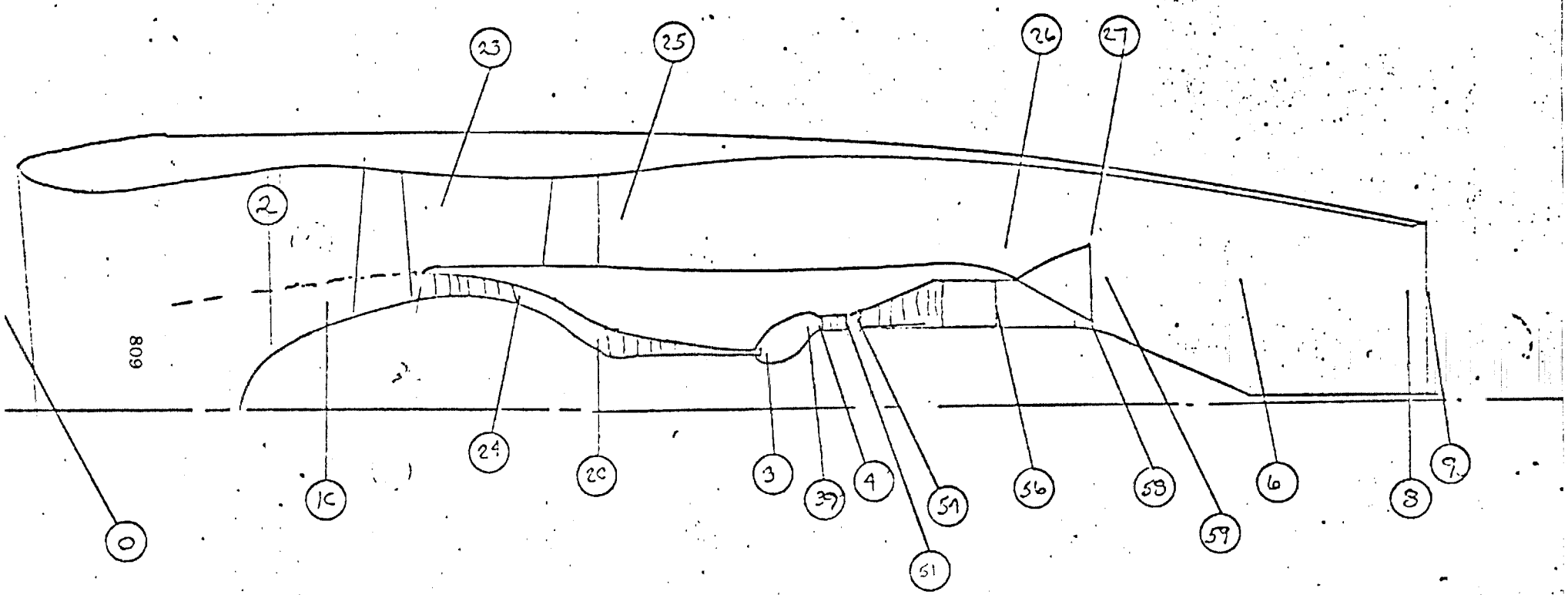
Turboprop Simulation
Batch ~~MP12~~ CYCLE NOMENCLATURE

Alt	Altitude, ft
M	Mach Number
P	Pressure, Psia
W	Flow, lb/sec
T	Temperature, ^{o}R
DELTO	To-Tstd day
ETAR	Ram Recovery
B, β	Bypass Ratio
~~FNG-MX~~	~~Fully Mixed Net Thrust, lbs~~
~~SPC-MX~~	~~Specific Fuel Consumption Based on FNG-MX lbm/hr/lb~~
~~FNG-PM~~	~~Partially Mixed Net Thrust, lbs~~
~~SPC-PM~~	~~Specific Fuel Consumption Based on FNG-PM~~
~~PCNF~~	~~Fan Physical Speed, %~~
~~NF~~	~~Fan Physical Speed, RPM~~
ECNF*	~~Fan Corrected Speed~~
~~ETAF~~	~~Fan Tip Adiabatic Efficiency~~
Q	Dynamic Pressure
ETAIC	Fan Hub + Booster Adiabatic Efficiency
PCNG	Core Physical Speed, %
NG	Core Physical Speed, RPM
PCNG*	Core Corrected Speed, %
WFM	Fuel Flow, lb/hr
ETABM	Burner Efficiency
TFFC	HP Turbine Flow Function
NRT4	HP Turbine Corrected Speed

*Indicates a corrected flow

MF12 CYCLE NOMENCLATURE (Cont.)

DH/T4	HP Turbine Energy Function
TFF2TC	LP Turbine Flow Function
N/RT54	LP Turbine Corrected Speed
DH/T54	LP Turbine Energy Function
V	Velocity, ft/sec
CF	Flow Coefficient
AE	Effective Area, in^2
CV	Velocity Coefficient
FGG-MX	Mixed Gross Thrust, lb
FD	Ram Drag
~~FGG-PM~~	~~Partial Mixed Gross Thrust, lb~~
~~PC-MX~~	~~Mixing Effectiveness~~



Station Designations

NASA-USTED(EC/70 CYCLE (TASK 2)
DUAL-SPOOL, LOW FAN P/P, AND FORWARD COUNTERROTATING BOOSTER
NOTE - W2C* = PRINTOUT VALUE * .995
NOTE - FOR THIS CYCLE, LPT RPM = GEAR RATIO * FAN RPM

CASE	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00
ALT	35000.	35000.	35000.	35000.	35000.	35000.	35000.	35000.
MO	0.800	0.800	0.800	0.800	0.800	0.800	0.800	0.800
PC	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
RC	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
FNG-MX	9695.4	9692.6	8802.7	8887.7	8442.3	7996.3	7100.1	5313.2
SFCGMX	0.5355	0.5355	0.5343	0.5200	0.5202	0.5206	0.5229	0.5445
FNG-CF	0.	0.	0.	0.	0.	0.	0.	0.
SFCGCF	0.	0.	0.	0.	0.	0.	0.	0.
FNG-PM	9599.4	9596.8	8809.9	8808.3	8369.8	7930.7	7048.1	5286.2
SFCGPM	0.5408	0.5409	0.5394	0.5247	0.5247	0.5249	0.5268	0.5473
	MAX CLIMB		MAX CRUISE					
DELTO	18.00	18.00	18.00	0.	0.	0.	0.	0.
TO	411.85	411.85	411.85	393.85	393.85	393.85	393.85	393.85
PO	3.4580	3.4580	3.4580	3.4580	3.4580	3.4580	3.4580	3.4580
T2	464.80	464.80	464.80	444.49	444.49	444.49	444.49	444.49
ETAR	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
P2	5.274	5.274	5.274	5.272	5.272	5.272	5.272	5.272
P22/P2	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996
M21	0.7000	0.6995	0.6718	0.6740	0.6588	0.6443	0.6165	0.5628
P22	5.272	5.272	5.272	5.270	5.270	5.270	5.270	5.270
B	9.8505	9.8504	10.1216	10.1059	10.2636	10.4349	10.8364	11.8254
PATH	PMIX	PMIX	PMIX	PMIX	PMIX	PMIX	PMIX	PMIX
WB/W2C	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
WB	0.	0.	0.	0.	0.	0.	0.	0.
PBD	194.42	194.38	183.27	183.98	177.82	171.61	158.86	133.56
TBD	1437.7	1437.6	1410.7	1355.4	1340.9	1326.2	1295.4	1230.7
WBI	0.120	0.120	0.115	0.118	0.115	0.112	0.105	0.092
PBI	76.89	76.87	73.02	73.26	71.12	68.95	64.43	55.15
TBI	1137.1	1137.0	1117.7	1072.5	1062.2	1051.7	1029.8	982.6
HPE	0.	0.	0.	0.	0.	0.	0.	0.
PCNF	94.664	94.648	92.524	90.327	89.056	87.807	85.206	79.304
NF	3053.7	3053.1	2975.0	2913.8	2872.8	2832.5	2748.6	2558.2
PCNF*	100.000	99.982	97.422	97.574	96.201	94.852	92.042	85.666
W2*	1719.28	1718.87	1685.50	1668.32	1668.84	1649.20	1609.19	1522.18
W2	651.54	651.39	638.74	653.97	646.42	638.81	623.32	589.61
P23/22	1.5500	1.5501	1.5075	1.5086	1.4845	1.4605	1.4119	1.3118
Z22	0.6627	0.6634	0.6245	0.6231	0.6013	0.5791	0.5325	0.4353
ETAF	0.8800	0.8800	0.8823	0.8823	0.8819	0.8815	0.8797	0.8457
HPFAN	14159.	14157.	12946.	12685.	12042.	11402.	10134.	7816.
RNI22	0.4132	0.4132	0.4132	0.4378	0.4378	0.4378	0.4378	0.4378
SMF	39.44	39.40	40.61	40.74	41.40	42.08	43.50	46.64
M23	0.5500	0.5497	0.5527	0.5535	0.5551	0.5567	0.5601	0.5670
P25P23	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
M25P	0.5500	0.5497	0.5548	0.5555	0.5583	0.5612	0.5675	0.5811
AE25P	3952.4	3952.4	3952.4	3952.4	3952.4	3952.4	3952.4	3952.4

NASA-USTED(EC/7U CYCLE (TASK 2)
DUAL-SPOOL, LOW FAN P/P, AND FORWARD COUNTERROTATING BOOSTER
NOTE - W2C* = PRINTOUT VALUE * .995
NOTE - FOR THIS CYCLE, LPT RPM = GEAR RATIO * FAN RPM

CASE	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00
P25P	8.172	8.172	7.948	7.950	7.823	7.696	7.440	6.913
P2525P	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
P25	8.172	8.172	7.947	7.949	7.823	7.696	7.440	6.912
Q25	1.4094	1.4086	1.3904	1.3938	1.3826	1.3715	1.3496	1.3014
T25	535.5	535.5	530.6	507.5	504.9	502.3	497.0	487.0
M25	0.5500	0.5498	0.5549	0.5556	0.5584	0.5613	0.5676	0.5812
W25	591.50	591.35	581.31	595.08	589.03	582.95	570.66	543.64
P26/25	0.9956	0.9956	0.9955	0.9955	0.9955	0.9955	0.9954	0.9952
P26	8.136	8.136	7.912	7.914	7.788	7.661	7.406	6.879
M26	0.4000	0.3999	0.4029	0.4033	0.4049	0.4066	0.4103	0.4181
P27/26	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
P27	8.136	8.136	7.912	7.914	7.788	7.661	7.406	6.879
M27	0.4800	0.4798	0.4838	0.4843	0.4865	0.4888	0.4937	0.5042
PS27	6.948	6.950	6.741	6.740	6.623	6.505	6.268	5.782
W27	591.50	591.35	581.31	595.08	589.03	582.95	570.66	543.64
T27	535.5	535.5	530.6	507.5	504.9	502.3	497.0	487.0
Z1C	0.6616	0.6612	0.6839	0.6830	0.6973	0.7135	0.7451	0.7903
P24/1C	2.7500	2.7490	2.6711	2.6761	2.6343	2.5929	2.4990	2.2706
W1C*	158.45	158.42	151.55	152.02	148.16	144.21	135.95	118.68
W1C	60.05	60.04	57.43	58.88	57.39	55.86	52.66	45.97
ETA1C	0.8880	0.8880	0.8894	0.8897	0.8899	0.8899	0.8888	0.8834
SFF1C	0.56862	0.56862	0.56862	0.56862	0.56862	0.56862	0.56862	0.56862
HP1C	3578.	3576.	3304.	3245.	3104.	2965.	2675.	2074.
P24	14.498	14.493	14.082	14.102	13.882	13.664	13.169	11.966
T24	640.5	640.5	634.5	607.1	604.1	601.2	594.5	577.7
M24	0.4500	0.4500	0.4383	0.4390	0.4321	0.4246	0.4101	0.3837
Q24	1.7866	1.7861	1.6584	1.6662	1.5951	1.5232	1.3808	1.1141
P2C/24	0.9840	0.9840	0.9847	0.9847	0.9851	0.9855	0.9864	0.9879
AE2D	0.	0.	0.	0.	0.	0.	0.	0.
WB/W24	0.	0.	0.	0.	0.	0.	0.	0.
PS242D	0.	0.	0.	0.	0.	0.	0.	0.
DP/Q2D	0.	0.	0.	0.	0.	0.	0.	0.
P2D/24	0.	0.	0.	0.	0.	0.	0.	0.
W2D	0.	0.	0.	0.	0.	0.	0.	0.
M2D	0.	0.	0.	0.	0.	0.	0.	0.
PS2D	0.	0.	0.	0.	0.	0.	0.	0.
PS25P	6.653	6.654	6.447	6.445	6.330	6.214	5.979	5.498
P2C	14.266	14.261	13.867	13.886	13.675	13.466	12.990	11.821
T2C	640.5	640.5	634.5	607.1	604.1	601.2	594.5	577.7
PCNG	98.706	98.703	97.501	95.420	94.773	94.119	92.776	89.981
PCNG*	88.821	88.824	88.154	88.195	87.815	87.424	86.661	85.260
NG	14385.	14385.	14210.	13906.	13812.	13717.	13521.	13124.
PCNG*M	100.000	100.003	99.248	99.294	98.867	98.426	97.567	95.991
WARC2C	0.	0.	0.	0.	0.	0.	0.	0.
W2C	60.05	60.03	57.43	58.88	57.39	55.87	52.66	45.97
W2C*	68.74	68.74	67.32	67.43	66.56	65.64	63.78	60.32

NASA-USTEDIEC/7U CYCLE (TASK 2)
DUAL-SPOOL, LOW FAN P/P, AND FORWARD COUNTERROTATING BOOSTER
NOTE - W2C* = PRINTOUT VALUE * .995
NOTE - FOR THIS CYCLE, LPT RPM = GEAR RATIO * FAN RPM

CASE	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00
P3/P2C	14.0018	14.0033	13.5827	13.6173	13.3669	13.1016	12.5784	11.6281
SMC	4.56	4.56	5.41	5.32	5.80	6.29	7.39	9.45
Z2C	0.5870	0.5870	0.5798	0.5816	0.5772	0.5725	0.5618	0.5377
ETAC	0.8600	0.8600	0.8627	0.8627	0.8640	0.8653	0.8677	0.8710
HPC	16572.	16568.	15404.	15155.	14530.	13904.	12645.	10238.
RNI2C	0.7446	0.7445	0.7323	0.7746	0.7676	0.7605	0.7439	0.7017
P3/P2	37.8885	37.8798	35.7257	35.8817	34.6868	33.4800	31.0051	26.0842
P3	199.75	199.71	188.35	189.09	182.79	176.43	163.39	137.46
PS3	188.85	188.81	177.96	178.64	172.63	166.56	154.13	129.48
T3	1437.7	1437.6	1410.7	1355.4	1340.9	1326.2	1295.4	1230.7
WARC3	0.	0.	0.	0.	0.	0.	0.	0.
WAR3	0.	0.	0.	0.	0.	0.	0.	0.
W3	58.01	57.99	55.48	56.88	55.44	53.97	50.87	44.41
W31	51.68	51.67	49.43	50.68	49.40	48.08	45.33	39.57
M3	0.2890	0.2890	0.2904	0.2903	0.2911	0.2920	0.2937	0.2970
P4/P3	0.9470	0.9470	0.9465	0.9464	0.9461	0.9458	0.9451	0.9439
WFM	5191.4	5190.5	4751.8	4621.8	4391.7	4163.2	3712.8	2893.0
ETABM	0.9875	0.9875	0.9875	0.9875	0.9875	0.9875	0.9875	0.9875
FAR339	0.02790	0.02790	0.02670	0.02533	0.02470	0.02405	0.02275	0.02031
T39	3054.2	3054.2	2971.5	2855.8	2810.9	2764.6	2670.6	2484.1
T4	2960.0	2960.0	2880.0	2767.4	2724.1	2679.7	2588.9	2408.5
WAR4	0.	0.	0.	0.	0.	0.	0.	0.
FAR4	0.02604	0.02605	0.02492	0.02364	0.02305	0.02245	0.02124	0.01896
P4	189.17	189.12	178.27	178.95	172.93	166.86	154.42	129.74
W4	56.81	56.80	54.28	55.58	54.14	52.67	49.59	43.19
TFFC	16.34	16.34	16.34	16.34	16.34	16.34	16.34	16.34
N/RT4	264.41	264.40	264.78	264.35	264.64	264.98	265.74	267.21
DH/T4	0.06976	0.06976	0.06976	0.06974	0.06974	0.06974	0.06972	0.06967
ETAT	0.8980	0.8980	0.8980	0.8980	0.8980	0.8980	0.8981	0.8981
HPT	16597.	16593.	15428.	15178.	14552.	13925.	12664.	10255.
HPAUX	25.10	25.09	23.61	22.76	22.01	21.26	19.80	17.10
P4/P51	3.6968	3.6967	3.7010	3.7072	3.7098	3.7120	3.7167	3.7255
P51	51.169	51.160	48.169	48.270	46.616	44.952	41.548	34.826
T51	2237.5	2237.5	2172.6	2081.2	2046.3	2010.6	1937.7	1794.3
FAR51	0.02474	0.02474	0.02308	0.02246	0.02190	0.02133	0.02018	0.01801
WAR51	0.	0.	0.	0.	0.	0.	0.	0.
W51	59.72	59.71	57.06	58.44	56.92	55.38	52.14	45.42
M51	0.4800	0.4800	0.4796	0.4789	0.4786	0.4783	0.4776	0.4761

NASA-USTED/EC/7U CYCLE (TASK 2)
DUAL-SPOOL, LOW FAN P/P, AND FORWARD COUNTERROTATING BOOSTER
NOTE - W2C* = PRINTOUT VALUE * .995
NOTE - FOR THIS CYCLE, LPT RPM = GEAR RATIO * FAN RPM

CASE	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00
P54/51	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
P54	51.169	51.160	48.169	48.270	46.616	44.952	41.548	34.826
T54	2237.5	2237.5	2172.6	2081.2	2046.3	2010.6	1937.7	1794.3
FAR54	0.02474	0.02474	0.02368	0.02246	0.02190	0.02133	0.02018	0.01801
WAR54	0.	0.	0.	0.	0.	0.	0.	0.
W54	59.72	59.71	57.06	58.44	56.92	55.38	52.14	45.42
TFF2TC	55.21	55.21	55.22	55.23	55.24	55.24	55.25	55.25
N/RT54	64.56	64.55	63.83	63.87	63.51	63.17	62.44	60.39
DH/T54	0.09382	0.09382	0.09264	0.09258	0.09190	0.09119	0.08960	0.08576
ETA2T	0.9110	0.9110	0.9098	0.9100	0.9094	0.9088	0.9076	0.9034
HP2T	17737.	17733.	16250.	15930.	15146.	14367.	12809.	9890.
RNT54	0.6942	0.6941	0.6750	0.7092	0.6978	0.6860	0.6603	0.6023
P54/56	6.4092	6.4095	6.2651	6.2805	6.1962	6.1081	5.9116	5.4693
P56	7.984	7.982	7.689	7.686	7.523	7.359	7.028	6.368
T56	1492.2	1492.2	1453.3	1386.0	1365.2	1344.0	1301.5	1221.4
W56	61.37	61.36	58.64	60.05	58.50	56.91	53.59	46.68
M56	0.4500	0.4500	0.4374	0.4368	0.4297	0.4223	0.4062	0.3718
P58/56	0.9940	0.9940	0.9943	0.9943	0.9945	0.9946	0.9950	0.9957
P58	7.936	7.934	7.645	7.642	7.482	7.320	6.993	6.340
PS58	6.948	6.947	6.741	6.738	6.622	6.505	6.268	5.782
M58	0.4500	0.4500	0.4373	0.4367	0.4295	0.4220	0.4057	0.3710
P59	8.048	8.047	7.819	7.821	7.693	7.564	7.304	6.772
M59	0.4928	0.4926	0.4927	0.4926	0.4926	0.4926	0.4926	0.4925
T59	631.9	631.9	620.9	593.0	587.3	581.5	569.7	547.7
W59	652.87	652.71	639.95	655.13	647.53	639.86	624.24	590.33
P6/P59	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
FAR8MX	0.00221	0.00221	0.00207	0.00196	0.00189	0.00181	0.00165	0.00136
WAR8MX	0.	0.	0.	0.	0.	0.	0.	0.
W8-MX	652.87	652.71	639.95	655.13	647.53	639.86	624.24	590.33
T8-MX	631.9	631.9	620.9	593.0	587.3	581.5	569.7	547.7
P8-MX	8.048	8.047	7.819	7.821	7.693	7.564	7.304	6.772
P8P0MX	2.3273	2.3272	2.2611	2.2618	2.2247	2.1874	2.1123	1.9582
M8-MX	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
V8-MX	1125.0	1125.0	1115.1	1089.8	1084.6	1079.2	1068.3	1047.4
CF8-MX	0.9965	0.9965	0.9965	0.9965	0.9965	0.9965	0.9965	0.9965
A8-MX	3849.7	3849.0	3849.7	3849.7	3849.7	3849.6	3849.7	3849.9
V9-MX	1125.0	1125.0	1115.1	1089.8	1084.6	1079.2	1068.3	1047.4
CV9-MX	0.9978	0.9978	0.9974	0.9974	0.9971	0.9969	0.9964	0.9954
CFG-MX	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
FGG-MX	25823.	25816.	24704.	24718.	24090.	23460.	22188.	19586.
FD	16128.	16124.	15811.	15830.	15648.	15463.	15088.	14272.
FGG-PM	25727.	25721.	24621.	24638.	24017.	23394.	22136.	19569.
PC-MX	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750

NASA-USTED FC/7U CYCLE (TASK 2)
DUAL-SPOOL, LOW FAN P/P, AND FORWARD COUNTERROTATING BOOSTER
NOTE - W2C* = PRINTOUT VALUE * .995
NOTE - FOR THIS CYCLE, LPT RPM = GEAR RATIO * FAN RPM

CASE	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00
CASE	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00
FAR8CF	0.02406	0.02406	0.02303	0.02185	0.02130	0.02074	0.01962	0.01752
W28-CF	591.5	591.4	581.3	595.1	589.0	583.0	570.7	543.6
T28-CF	535.5	535.5	530.6	507.5	504.9	502.3	497.0	487.0
P28-CF	8.1358	8.1360	7.9118	7.9138	7.7875	7.6611	7.4056	6.8793
P28POC	2.3527	2.3528	2.2880	2.2885	2.2520	2.2155	2.1416	1.9894
AE28CF	3163.0	3162.2	3181.8	3184.6	3195.2	3206.1	3229.4	3278.5
M28-CF	0.	0.	0.	0.	0.	0.	0.	0.
V28-CF	1035.7	1035.7	1030.9	1008.2	1005.7	1003.1	997.7	987.7
W8-CF	61.37	61.36	58.64	60.05	58.50	56.91	53.59	46.68
T8-CF	1492.2	1492.2	1453.3	1386.0	1365.2	1344.0	1301.5	1221.4
P8-CF	7.936	7.934	7.645	7.642	7.482	7.320	6.993	6.340
P8POCF	2.2949	2.2944	2.2107	2.2099	2.1636	2.1168	2.0222	1.8335
M8-CF	0.	0.	0.	0.	0.	0.	0.	0.
V8-CF	1713.2	1713.2	1691.5	1653.1	1641.0	1628.7	1603.5	1532.6
AE8-CF	570.5	570.5	558.0	557.6	550.4	542.8	526.1	489.1
CF8-CF	0.	0.	0.	0.	0.	0.	0.	0.
V9-CF	1713.2	1713.2	1691.5	1653.1	1641.0	1628.7	1603.5	1532.6
CV9-CF	0.9978	0.9978	0.9974	0.9974	0.9971	0.9969	0.9964	0.9954
CV29CF	0.	0.	0.	0.	0.	0.	0.	0.
V29-CF	1180.9	1181.0	1158.4	1133.2	1120.6	1107.6	1080.5	1021.6
CFG-CF	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
FGD-CF	21713.5	21708.7	20932.3	20962.6	20517.4	20070.4	19166.3	17264.0
FGM-CF	3726.5	3725.2	3440.8	3438.7	3283.3	3127.7	2814.6	2213.8
CFGDCF	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
FGG-CF	0.	0.	0.	0.	0.	0.	0.	0.
FN-CF	0.	0.	0.	0.	0.	0.	0.	0.
SFCGCF	0.	0.	0.	0.	0.	0.	0.	0.
FNU/W2	14.73	14.73	13.79	13.47	12.95	12.41	11.31	8.97
D/F-PC	5.1	5.1	5.5	5.5	5.7	5.9	6.5	8.2
CD	0.1843	0.1843	0.1843	0.1843	0.1843	0.1843	0.1843	0.1843
FDI	490.9	490.8	481.3	482.1	476.5	470.9	459.5	434.7
SWFMG	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
SFNG	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
WC3/2C	0.0759	0.0759	0.0759	0.0759	0.0759	0.0759	0.0759	0.0759
WC4/2C	0.0614	0.0614	0.0614	0.0614	0.0614	0.0614	0.0614	0.0614
WC5I2C	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360
WC5D2C	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125
WC542C	0.	0.	0.	0.	0.	0.	0.	0.
WC5S1I	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050
WC5S1I2	0.0224	0.0224	0.0224	0.0224	0.0224	0.0224	0.0224	0.0224
WC552C	0.0274	0.0274	0.0274	0.0274	0.0274	0.0274	0.0274	0.0274
WCI/2C	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320
FIBAH	0.3880	0.3880	0.3880	0.3880	0.3880	0.3880	0.3880	0.3880
FCAH51	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850
FCAH54	0.7500	0.7500	0.7500	0.7500	0.7500	0.7500	0.7500	0.7500
FCH551	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
FCH552	0.2770	0.2770	0.2770	0.2770	0.2770	0.2770	0.2770	0.2770

NASA-USTEDLEC/7U CYCLE (TASK 2)
DUAL-SPOOL, LOW FAN P/P, AND FORWARD COUNTERROTATING BOOSTER
NOTE - W2C* = PRINTOUT VALUE * .995
NOTE - FOR THIS CYCLE, LPT RPM = GEAR RATIO * FAN RPM

CASE	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00
AE21	5479.3	5479.3	5479.3	5479.3	5479.3	5479.3	5479.3	5479.3
AE25P	3952.4	3952.4	3952.4	3952.4	3952.4	3952.4	3952.4	3952.4
AE25	3952.4	3952.4	3952.4	3952.4	3952.4	3952.4	3952.4	3952.4
AE26	5030.1	5030.1	5030.1	5030.1	5030.1	5030.1	5030.1	5030.1
AE27	4365.7	4365.7	4365.7	4365.7	4365.7	4365.7	4365.7	4365.7
AE24	285.7	285.7	285.7	285.7	285.7	285.7	285.7	285.7
AE3	44.3	44.3	44.3	44.3	44.3	44.3	44.3	44.3
AE51	147.86	147.86	147.86	147.86	147.86	147.86	147.86	147.86
AE56	826.5	826.5	826.5	826.5	826.5	826.5	826.5	826.5
AE58	831.5	831.5	831.5	831.5	831.5	831.5	831.5	831.5
AE59	5197.2	5197.2	5197.2	5197.2	5197.2	5197.2	5197.2	5197.2
PCNFRM	100.00	99.98	97.42	97.57	96.20	94.85	92.04	85.67
P2322M	1.8750	1.8751	1.8074	1.8091	1.7709	1.7326	1.6553	1.4960
FFFMB	1406.26	1405.93	1378.63	1380.93	1365.00	1348.93	1316.21	1245.04
ETAFMB	0.8503	0.8503	0.8525	0.8525	0.8521	0.8518	0.8500	0.8171
PCN1RM	100.00	99.98	97.42	97.57	96.20	94.85	92.04	85.67
P241CM	2.5440	2.5432	2.4744	2.4788	2.4419	2.4055	2.3225	2.1211
FF1CMB	279.91	279.86	267.79	268.50	261.71	254.77	240.24	209.85
SFF1CR	0.9955	0.9955	0.9953	0.9957	0.9956	0.9955	0.9952	0.9946
ET1CMB	0.8558	0.8558	0.8575	0.8574	0.8579	0.8580	0.8573	0.8530
SET1CR	0.9952	0.9952	0.9947	0.9951	0.9949	0.9947	0.9943	0.9932
PCNRTM	100.00	100.00	99.25	99.29	98.87	98.43	97.57	95.99
P302CM	11.9998	12.0011	11.6453	11.6746	11.4627	11.2383	10.7956	9.9917
CFFMB	130.060	130.068	127.488	127.647	126.074	124.383	120.979	114.583
SCFFR	0.9994	0.9994	0.9992	0.9995	0.9994	0.9993	0.9990	0.9983
ETACMB	0.8530	0.8530	0.8561	0.8559	0.8575	0.8590	0.8617	0.8656
SETACR	1.0001	1.0001	1.0001	1.0002	1.0002	1.0002	1.0001	1.0000
DHQT4M	0.07290	0.07290	0.07289	0.07288	0.07288	0.07287	0.07286	0.07280
XNQR4M	184.24	184.24	184.50	184.20	184.40	184.64	185.17	186.19
TFFMB	33.42	33.42	33.42	33.42	33.42	33.42	33.42	33.42
STFFR	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
ETATMB	0.8878	0.8878	0.8878	0.8878	0.8878	0.8878	0.8879	0.8880
SETATR	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999
DHQ54M	0.07260	0.07260	0.07169	0.07164	0.07112	0.07057	0.06934	0.06637
XNR54M	98.97	98.95	97.85	97.92	97.36	96.84	95.72	92.58
TFF2MB	125.04	125.04	125.08	125.08	125.10	125.12	125.16	125.25
SF2TR	0.9995	0.9995	0.9993	0.9995	0.9995	0.9994	0.9992	0.9985
ETA2MB	0.9175	0.9175	0.9164	0.9164	0.9159	0.9154	0.9143	0.9105
SET2TR	0.9975	0.9975	0.9974	0.9975	0.9975	0.9974	0.9973	0.9967
NSI1	0	0	0	0	0	0	0	0
NSI2	0	0	0	0	0	0	0	0
NSI3	0	0	0	0	0	0	0	0
NSI4	0	0	0	0	0	0	0	0
NSI5	0	0	0	0	0	0	0	0
ICASE	2	3	4	5	6	7	8	9

NASA-USTED LEC/7U CYCLE (TASK 2)
DUAL-SPOOL, LOW FAN P/P, AND FORWARD COUNTERROTATING BOOSTER
NOTE - W2C* = PRINTOUT VALUE * .995
NOTE - FOR THIS CYCLE, LPT RPM = GEAR RATIO * FAN RPM

CASE	9.00	10.00	11.00
ALT	35000.	0.	0.
HO	0.800	0.	0.250
PC	50.00	50.00	50.00
RC	40.00	40.00	40.00
FNG-MX	3520.4	39258.7	29303.2
SFCGMX	0.6041	0.2834	0.3844
FNG-CF	0.	0.	0.
SFCGCF	0.	0.	0.
FNG-PM	3524.1	39177.3	29307.5
SFCGPM	0.6050	0.2840	0.3855
		TO	TO
DELTO	0.	27.00	27.00
TO	393.85	545.67	545.67
PO	3.4580	14.6960	14.6960
T2	444.49	545.67	552.51
ETAR	1.0000	1.0000	1.0000
P2	5.272	14.696	15.350
P22/P2	0.9996	0.9996	0.9996
M21	0.5116	0.5464	0.5558
P22	5.270	14.690	15.344
B	13.1984	10.4861	10.8285
PATH	PMIX	PMIX	PMIX
WB/W2C	0.0020	0.0020	0.0020
WB	0.	0.	0.
PBD	106.13	417.37	425.42
TBD	1159.4	1533.7	1540.1
WBI	0.078	0.253	0.258
PBI	45.82	169.49	173.38
TBI	931.4	1225.7	1232.4
HPE	0.	0.	0.
PCNF	72.685	91.185	91.038
NF	2344.7	2941.4	2936.7
PCNF*	78.517	88.900	88.207
W2*	1427.56	1492.53	1509.27
W2	552.97	1454.56	1526.76
P23/22	1.2091	1.4079	1.3905
Z22	0.3342	0.6646	0.6064
ETAF	0.7676	0.8770	0.8840
HPFAN	5628.	28794.	29288.
RNI22	0.4378	0.9371	0.9635
SMF	50.21	34.22	37.27
M23	0.5731	0.5036	0.5191
P25P23	1.0000	1.0000	1.0000
M25P	0.5955	0.5076	0.5254
AE25P	3952.4	3952.4	3952.4

NASA-USTED/FC/7U CYCLE (TASK 2)
DUAL-SPOOL, LOW FAN P/P, AND FORWARD COUNTERROTATING BOOSTER
NOTE - W2C* = PRINTOUT VALUE * .995
NOTE - FOR THIS CYCLE, LPT RPM = GEAR RATIO * FAN RPM

CASE	9.00	10.00	11.00
P25P	6.371	20.682	21.335
P2525P	1.0000	1.0000	1.0000
P25	6.371	20.682	21.334
Q25	1.2459	3.1283	3.4151
T25	476.8	609.6	614.3
M25	0.5957	0.5077	0.5255
W25	514.02	1327.92	1397.69
P26/25	0.9950	0.9961	0.9959
P26	6.339	20.602	21.247
M26	0.4262	0.3741	0.3852
P27/26	1.0000	1.0000	1.0000
P27	6.339	20.602	21.247
M27	0.5153	0.4461	0.4605
PS27	5.288	17.973	18.374
W27	514.02	1327.92	1397.69
T27	476.8	609.6	614.3
ZIC	0.8569	0.7258	0.7410
P24/IC	2.0445	2.3720	2.3512
W1C*	100.54	129.94	127.59
W1C	38.95	126.64	129.07
ETA1C	0.8687	0.8958	0.8949
SFF1C	0.56862	0.56862	0.56862
HP1C	1534.	7329.	7485.
P24	10.774	34.845	36.076
T24	560.8	715.8	722.9
M24	0.3507	0.4094	0.4041
Q24	0.8520	3.6331	3.6739
P2C/24	0.9897	0.9865	0.9868
AE2D	0.	0.	0.
WB/W24	0.	0.	0.
PS242D	0.	0.	0.
DP/Q2D	0.	0.	0.
P2D/24	0.	0.	0.
W2D	0.	0.	0.
M2D	0.	0.	0.
PS2D	0.	0.	0.
PS25P	5.012	17.348	17.678
P2C	10.663	34.373	35.599
T2C	560.8	715.8	722.9
PCNG	86.585	101.684	101.849
PCNG*	83.268	86.556	86.269
NG	12619.	14819.	14843.
PCNG*H	93.747	97.449	97.126
WARC2C	0.	0.	0.
W2C	38.95	126.64	129.08
W2C*	55.81	63.61	62.91

NASA-USTEDLEC/7U CYCLE (TASK 2)
DUAL-SPOOL, LOW FAN P/P, AND FORWARD COUNTERROTATING BOOSTER
NOTE - W2C* = PRINTOUT VALUE * .995
NOTE - FOR THIS CYCLE, LPT RPM = GEAR RATIO * FAN RPM

CASE	9.00	10.00	11.00
P3/P2C	10.4466	12.4854	12.2894
SMC	11.88	7.88	8.32
Z2C	0.5136	0.5565	0.5517
ETAC	0.8722	0.8688	0.8697
HPC	7913.	36203.	36897.
RNI2C	0.6571	1.5654	1.6019
P3/P2	21.1385	29.2142	28.5128
P3	111.39	429.16	437.49
PS3	104.72	405.03	412.79
T3	1159.4	1533.7	1540.1
WARC3	0.	0.	0.
WAR3	0.	0.	0.
W3	37.62	122.33	124.69
W31	33.52	109.00	111.09
M3	0.3014	0.2940	0.2947
P4/P3	0.9423	0.9456	0.9453
WFM	2132.1	11126.7	11297.4
ETABM	0.9875	0.9875	0.9875
FAR339	0.01767	0.02836	0.02825
T39	2274.7	3154.5	3154.2
T4	2206.9	3060.1	3060.2
WAR4	0.	0.	0.
FAR4	0.01649	0.02647	0.02637
P4	104.96	405.79	413.58
W4	36.50	119.86	122.16
TFFC	16.34	16.34	16.34
N/RT4	268.61	267.89	268.32
DH/T4	0.06955	0.06985	0.06985
ETAT	0.8981	0.8982	0.8982
HPT	7928.	36250.	36944.
HPAUX	14.49	46.78	47.62
P4/P51	3.7329	3.6989	3.6988
P51	28.118	109.707	111.815
T51	1636.3	2319.7	2319.9
FAR51	0.01567	0.02515	0.02505
WAR51	0.	0.	0.
W51	38.39	126.00	128.42
M51	0.4740	0.4819	0.4818

NASA-USTED FC/7U CYCLE (TASK 2)
DUAL-SPOOL, LOW FAN P/P, AND FORWARD COUNTERROTATING BOOSTER
NOTE - W2C* = PRINTOUT VALUE * .995
NOTE - FOR THIS CYCLE, LPT RPM = GEAR RATIO * FAN RPM

CASE	9.00	10.00	11.00
P54/51	1.0000	1.0000	1.0000
P54	28.118	109.707	111.815
T54	1636.3	2319.7	2319.9
FAR54	0.01567	0.02515	0.02505
WAR54	0.	0.	0.
W54	38.39	126.00	128.42
TFF2TC	55.23	55.32	55.32
N/RT54	57.96	61.07	60.97
DH/T54	0.08058	0.08735	0.08724
ETA2T	0.8971	0.9059	0.9057
HP2T	7162.	36123.	36773.
RNI54	0.5382	1.4305	1.4579
P54/56	4.9215	5.5169	5.5053
P56	5.713	19.885	20.311
T56	1136.4	1606.3	1607.4
W56	39.46	129.47	131.96
M56	0.3316	0.3842	0.3834
P58/56	0.9965	0.9955	0.9955
P58	5.693	19.796	20.220
PS58	5.289	17.975	18.367
M58	0.3306	0.3835	0.3827
P59	6.230	20.375	20.984
M59	0.4913	0.4485	0.4605
T59	525.7	705.3	706.9
W59	553.48	1457.39	1529.65
P67/P59	1.0000	1.0000	1.0000
FAR8MX	0.00107	0.00213	0.00206
WAR8MX	0.	0.	0.
W8-MX	553.48	1457.39	1529.65
T8-MX	525.7	705.3	706.9
P8-MX	6.230	20.375	20.984
P8P0MX	1.8015	1.3864	1.4279
M8-MX	0.9566	0.7001	0.7325
V8-MX	988.7	869.2	906.7
CF8-MX	0.9965	1.0165	1.0165
A8-MX	3849.6	3849.6	3849.8
V9-MX	988.7	869.2	906.7
CV9-MX	0.9944	0.9970	0.9970
CFG-MX	1.0000	1.0000	1.0000
FGG-MX	16915.	39259.	42982.
FD	13385.	0.	13588.
FGG-PM	16909.	39177.	42896.
PC-MX	0.750	0.750	0.750

NASA-USTDLFC/7U CYCLE (TASK 2)
DUAL-SPOOL, LOW FAN P/P, AND FORWARD COUNTERROTATING BOOSTER
NOTE - W2C* = PRINTOUT VALUE * .995
NOTE - FOR THIS CYCLE, LPT RPM = GEAR RATIO * FAN RPM

CASE	9.00	10.00	11.00
CASE	9.00	10.00	11.00
FAR8CF	0.01524	0.02446	0.02436
W28-CF	514.0	1327.9	1397.7
T28-CF	476.8	609.6	614.3
P28-CF	6.3393	20.6017	21.2472
P28P0C	1.8332	1.4019	1.4458
AE28CF	3330.9	3250.7	3265.9
M28-CF	0.	0.	0.
V28-CF	954.3	820.8	858.9
W8-CF	39.46	129.47	131.96
T8-CF	1136.4	1606.3	1607.4
P8-CF	5.693	19.796	20.220
P8P0CF	1.6464	1.3470	1.3759
M8-CF	0.	0.	0.
V8-CF	1349.5	1258.7	1301.4
AE8-CF	448.7	557.4	546.9
CF8-CF	0.	0.	0.
V9-CF	1349.5	1258.7	1301.4
CV9-CF	0.9944	0.9970	0.9970
CV29CF	0.	0.	0.
V29-CF	954.3	820.8	858.9
CFG-CF	1.0000	1.0000	1.0000
FGD-CF	15247.5	33883.2	37317.9
FGH-CF	1646.1	5050.6	5322.0
CFGDCF	1.0000	1.0000	1.0000
FGG-CF	0.	0.	0.
FN-CF	0.	0.	0.
SFCGCF	0.	0.	0.
FNU/W2	6.37	26.93	19.20
D/F-PC	11.6	0.	0.6
CD	0.1843	0.1843	0.1843
FDI	407.6	0.	178.9
SWFMG	1.00000	1.00000	1.00000
SFNG	1.0000	1.0000	1.0000
WC3/2C	0.0759	0.0759	0.0759
WC4/2C	0.0614	0.0614	0.0614
WC5I2C	0.0360	0.0360	0.0360
WC5D2C	0.0125	0.0125	0.0125
WC542C	0.	0.	0.
WC55I1	0.0050	0.0050	0.0050
WC55I2	0.0224	0.0224	0.0224
WC552C	0.0274	0.0274	0.0274
WCI/2C	0.0320	0.0320	0.0320
FIDAH	0.3880	0.3880	0.3880
FCAH51	0.2850	0.2850	0.2850
FCAH54	0.7500	0.7500	0.7500
FCH551	1.0000	1.0000	1.0000
FCH552	0.2770	0.2770	0.2770

NASA-USTED LFC/7U CYCLE (TASK 2)
DUAL-SPOOL, LOW FAN P/P, AND FORWARD COUNTERROTATING BOOSTER
NOTE - W2C* = PRINTOUT VALUE * .995
NOTE - FOR THIS CYCLE, LPT RPM = GEAR RATIO * FAN RPM

CASE	9.00	10.00	11.00
AE21	5479.3	5479.3	5479.3
AE25P	3952.4	3952.4	3952.4
AE25	3952.4	3952.4	3952.4
AE26	5030.1	5030.1	5030.1
AE27	4365.7	4365.7	4365.7
AE24	285.7	285.7	285.7
AE3	44.3	44.3	44.3
AE51	147.86	147.86	147.86
AE56	826.5	826.5	826.5
AE58	831.5	831.5	831.5
AE59	5197.2	5197.2	5197.2
PCNFRM	78.52	88.90	88.21
P2322M	1.3326	1.6489	1.6212
FFFMB	1167.65	1220.79	1234.49
ETAFMB	0.7417	0.8474	0.8542
PCN1RM	78.52	88.90	88.21
P241CM	1.9215	2.2105	2.1922
FF1CMB	177.88	228.58	224.43
SFF1CR	0.9940	0.9997	0.9998
ET1CMB	0.8396	0.8594	0.8583
SET1CR	0.9923	0.9997	0.9999
PCNRTM	93.75	97.45	97.13
P302CM	8.9920	10.7169	10.5511
CFFMB	106.212	120.531	119.231
SCFFR	0.9973	1.0000	1.0000
ETACMB	0.8674	0.8621	0.8630
SETACR	0.9999	1.0011	1.0011
DHQT4M	0.07268	0.07300	0.07299
XNQR4M	187.17	186.67	186.97
TFFMB	33.42	33.42	33.42
STFFR	0.9999	1.0000	1.0000
ETATMB	0.8880	0.8880	0.8880
SETATR	0.9998	1.0000	1.0000
DHQ54M	0.06235	0.06760	0.06751
XNR54M	88.86	93.63	93.47
TFF2MB	125.34	125.22	125.23
SF2TR	0.9975	1.0000	1.0000
ETA2MB	0.9050	0.9119	0.9116
SET2TR	0.9958	0.9980	0.9980
NSI1	0	0	0
NSI2	0	0	0
NSI3	0	0	0
NSI4	0	0	0
NSI5	0	0	0
ICASE	10	11	12

C-4

8.3.2 Fan Design

P/P Tip	1.55
$U_T/\sqrt{\theta_2}$ ft/sec	1300
$W_2\sqrt{\theta_2}/\delta_{2AA}$	43.25
r_H/r_T Inlet	.35
D_T, inch	91.13
η_{Tip}	.880
N_F RPM	3095
P/P Hub	1.30
η_{Hub}	.830

Composite unshrouded blades N_B = 36

Vane Frame with integrated struts/OGV N_V = 40

The tip speed is selected as the lowest speed possible for at least 20% stall margin. Fan efficiency is estimated as a function of the design details.

8.3.3 Booster (Low Pressure Compressor) Aero Design

The booster stages are designed to supply the difference between the fan hub pressure ratio of 1.30:1, the core compressor pressure ratio of 14:1 and the overall desired pressure ratio of 38:1, matching the baseline turbofan. Thus the required P/P is

$$P/P \text{ booster} = \frac{38.115}{1.30 \times 14.0 \times .99} = 2.115$$

The boosters are directly driven at high speed from the low pressure turbine. The turbine design will be discussed separately, but the turbine RPM selection and the booster design represent a compromise. The turbine RPM chosen was 8030 at the match point. Two booster stages were selected on a flowpath placing the first booster rotor tip at a diameter of 37.6".

Booster Data

D_T 1R, in.	37.6
$U_T/\sqrt{\theta_{24}}$ ft/sec	1330
r_H/r_T inlet	.74
$U_H/\sqrt{\theta_{24}}$	984

From correlation of pressure ratio capability @

N_S	2
$U_H/\sqrt{\theta_{24}}$	984
P/P	2.12

Required P/P=2.11 - hence flowpath OK.

Efficiency estimated using P/P, U_T/θ_{24}, No stages. r_H/r_T, var. stators and booster location 87.3%, including 83.0% for the fan hub alone.

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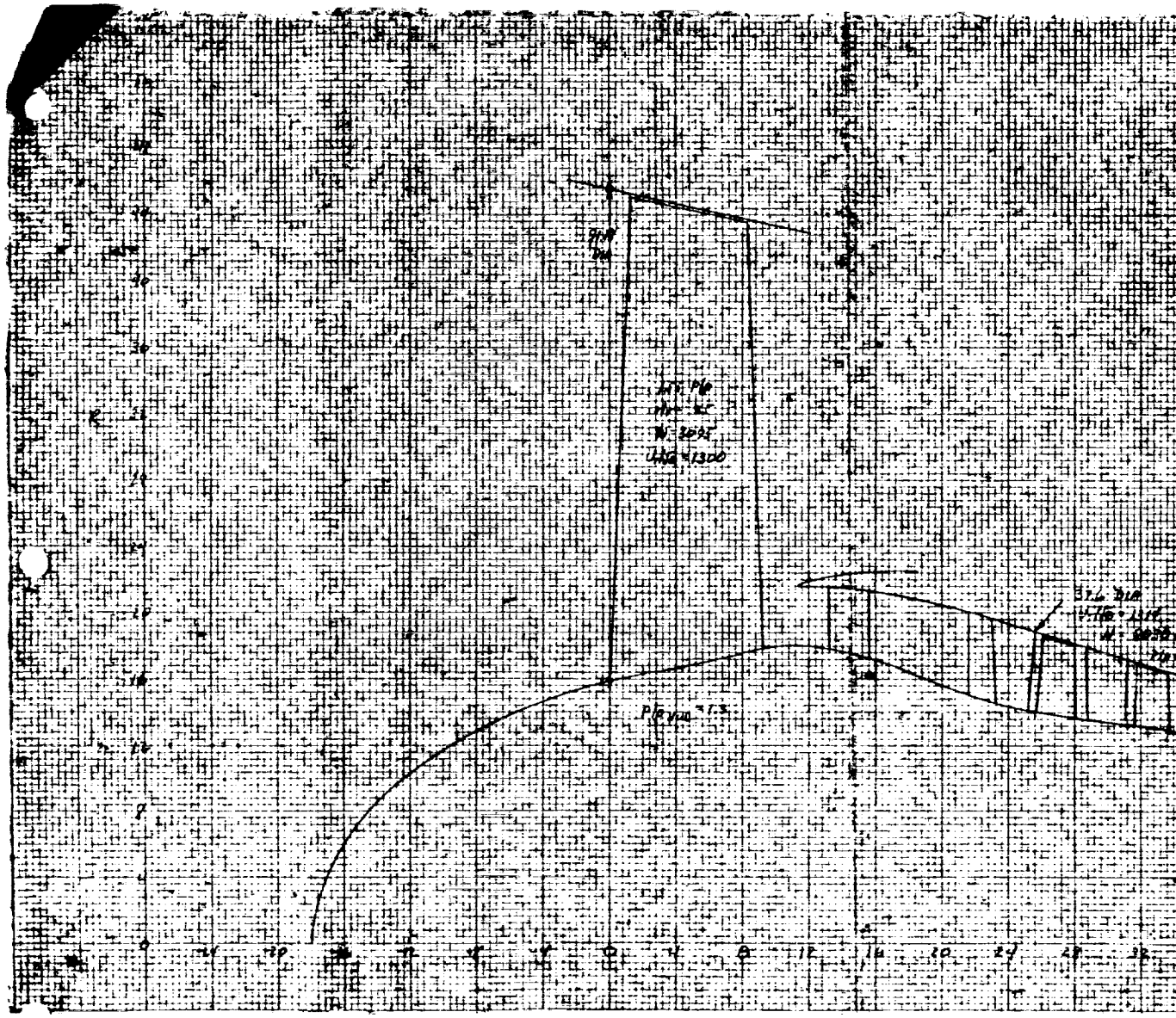

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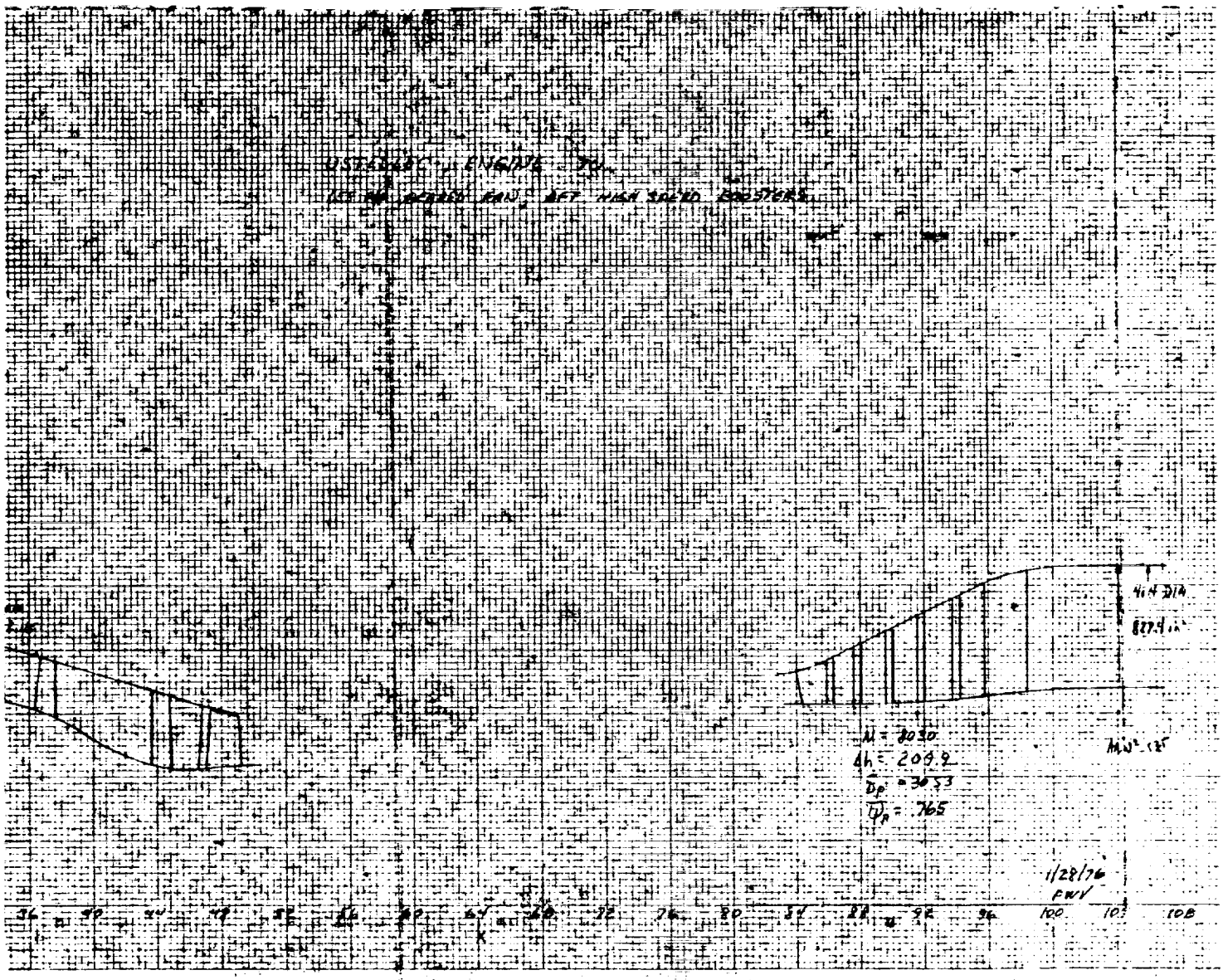

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8.3.4 LP Turbine

The geared three stage turbine detail design completed in Task I and described in section 4.5 was used as a basis for the necessary turbine design data such as efficiency, cooling flow levels and dimensional data for weight, cost and maintenance estimates.

The flowpath is shown on the engine layout in this section, compatible with the 7-U geared fan. Key design parameters are:

No. Stages	3
N	8030 RPM
Δh, BTU/lb	209.9
$\bar{D}_P$, in	30.53
$\bar{\psi}_P$	.765
η	.9195

Row	Width, in.	No.	Blade/Vane Cool. W/W_{2C}%	Shroud/Lkg.
1V	1.44	46	.69	-
1B	1.33	88	.63	.50
2V	1.60	83	.40	-
2B	1.42	82	-	-
3V	1.80	68	-	-
3B	1.56	64	-	-
			Total	2.23

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8.3.5 Maintenance Calculation

The procedure consisted of establishing the replacement cost/initial cost = parts index for every part and the price for every part. The parts index based on replacement experience for similar parts in the CF6-6 engine, adjusted for differences in design. The cost system which follows then computes the maintenance $/flight hour in the design size and mission size for both the transcon and intercontinental missions. The results are adjusted by 1.25 to allow for the actual in service life of approximately 45,000 hrs. vs. the design life of 36,000 on which the parts index is based.

MAINTENANCE COST CALCULATION PAGE 1

DESIGN SIZE (Base line Engine)

ENGINE DESIGNATION: MF12 BASE-TASK III
NO. OF ENGINES: 3 TYPE: TRANSCOM TURBOFAN RANGE: 700 MILES

	PART INDEX
FAN ROT BLADES-	1.380
FAN ROT DISC---	0.100
FAN FRAME/STAT-	0.200
BOOS ROT BLADES	0.400
BOOS ROT DISC--	0.050
BOOS STAT VANES	0.200
BOOS STAT CASE-	0.050
HPT BLADES-----	4.000
HPT VANES------	6.100
HPT DISC-------	0.600
HPT CASE-------	0.400
COMBUSTOR------	2.000
HPC BLADES-----	3.100
HPC VANES------	0.300
HPC DISC-------	0.150
HPC CASING-----	0.100
GEAR SET-------	0.300
GEAR LUBE & COOLING SYSTEM-	0.500
LPT STAT VANES-	0.250
LPT STAT CASE--	0.300
LPT ROT BLADES-	0.500
LPT ROT DISC---	0.050
TURB FRAME-----	0.100
CRASHISC-------	0.300
~~MISC PARTS~~---	2.000
----------	0.
----------	0.
----------	0.
----------	0.

TOTAL---------- 749135

TOTAL COST PER FLIGHT HOUR, $ ~~28.63~~

+1.25 = 29.53

Misc Adjust

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MAINTENANCE COST CALCULATION

MISSION SIZE

ENGINE DESIGNATION: MF12 BASE-TASK III
NO. OF ENGINES: 3 TYPE: TRANSCON TURBOFAN RANGE: 700 MILES

	MAT CST /FL HR	LAB CST /FL HR	TOT CST /FL HR
FAN ROT BLADES-	0.37	0.16	0.53
FAN ROT DISC---	0.02	0.01	0.03
FAN FRAME&STA--	0.15	0.07	0.22
BOOS ROT BLADES	0.02	0.01	0.04
BOOS ROT DISC--	0.01	0.00	0.01
BOOS STAT&VANES	0.05	0.02	0.08
BOOS STAT CASE-	0.01	0.00	0.01
HPT BLADES-----	2.62	1.12	3.74
HPT VANES------	4.27	1.83	6.10
HPT DISC-------	0.33	0.14	0.48
HPT CASE-------	0.15	0.07	0.22
COMBUSTOR------	2.04	0.88	2.92
HPC BLADES-----	0.45	0.19	0.64
HPC VANES------	0.05	0.02	0.07
HPC DISC-------	0.10	0.04	0.14
HPC CASING-----	0.06	0.02	0.08
GEAR SET-------	0.	0.	0.
GEAR LUBE ?			
COOLING SYSTEM-	0.	0.	0.
LPT STAT VANES-	0.14	0.06	0.20
LPT STAT CASE--	0.10	0.04	0.14
LPT ROT BLADES-	0.33	0.14	0.47
LPT ROT DISC---	0.03	0.01	0.05
TURB FRAME-----	0.05	0.02	0.07
CRASHISO-------	0.66	0.28	0.94
----------	0.50	0.22	0.72
----------	0.	0.	0.
----------	0.	0.	0.
----------	0.	0.	0.
----------	0.	0.	0.
TOTAL----------	12.52	5.37	17.90

TOTAL COST PER FLIGHT HOUR, $ ~~17.90~~

x1.25 = 22.38

Mission Adjust.

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DESIGN SIZE (Base line Engine)

ENGINE DESIGNATION: MF12
NO. OF ENGINES: 4 TYPE: INTERCON TURBOFAN RANGE: 2000 MILES

	PART INDEX
FAN ROT BLADES-	1.380
FAN ROT DISC--	0.100
FAN FRAME&STAT-	0.200
BOOS ROT BLADES	0.400
BOOS ROT DISC--	0.050
BOOS STAT VANES	0.200
BOOS STAT CASE-	0.050
HPT BLADES----	4.000
HPT VANES-----	6.100
HPT DISC------	0.600
HPT CASE-------	0.400
COMBUSTOR-----	2.000
HPC BLADES-----	3.100
HPC VANES-----	0.300
HPC DISC-------	0.150
HPC CASING----	0.100
GEAR SET------	0.300
GEAR LUBE & COOLING SYSTEM-	0.500
LPT STAT VANES-	0.250
LPT STAT CASE--	0.200
LPT ROT BLADES-	0.500
LPT ROT DISC--	0.050
TURB FRAME----	0.100
C&A&MISC------	0.300
[illegible]	2.000
----------	0.
----------	0.
----------	0.
----------	0.

TOTAL---------- 901972

TOTAL COST PER FLIGHT HOUR, $ ~~22.38~~

1.25 = 27.97

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MAINTENANCE COST CALCULATION

MISSION SIZE

ENGINE DESIGNATION: MF12
NO. OF ENGINES: 4 TYPE: INTERCON TURBOFAN RANGE: 2000 MILES

	MAT CST /FL HR	LAB CST /FL HR	TOT CST /FL HR
FAN ROT BLADES-	0.36	0.16	0.52
FAN ROT DISC---	0.02	0.01	0.03
FAN FRAME&STA--	0.15	0.06	0.21
BOOS ROT BLADES	0.02	0.01	0.03
BOOS ROT DISC--	0.01	0.00	0.01
BOOS STAT&VANES	0.05	0.02	0.07
BOOS STAT CASE-	0.01	0.00	0.01
HPT BLADES-----	2.55	1.09	3.64
HPT VANES------	4.15	1.78	5.93
HPT DISC-------	0.33	0.14	0.46
HPT CASE-------	0.15	0.06	0.21
COMBUSTOR------	1.99	0.85	2.84
HPC BLADES-----	0.44	0.19	0.62
HPC VANES------	0.05	0.02	0.07
HPC DISC-------	0.09	0.04	0.13
HPC CASING-----	0.05	0.02	0.08
GEAR SET-------	0.	0.	0.
GEAR LUBE & COOLING SYSTEM-	0.	0.	0.
LPT STAT VANES-	0.14	0.06	0.19
LPT STAT CASE--	0.10	0.04	0.14
LPT ROT BLADES-	0.32	0.14	0.46
LPT ROT DISC---	0.03	0.01	0.05
TURB FRAME-----	0.05	0.02	0.07
C&A&MISC-------	0.64	0.27	0.92
[illegible]	0.49	0.21	0.70
----------	0.	0.	0.
----------	0.	0.	0.
----------	0.	0.	0.
----------	0.	0.	0.
TOTAL---------	12.18	5.23	17.41

TOTAL COST PER FLIGHT HOUR, $ ~~17.41~~ 21.76

MAINTENANCE COST CALCULATION 318 PAGE 1

DESIGN SIZE (7U Configuration)

ENGINE DESIGNATION: 7U
NO. OF ENGINES: 3 TYPE: TRANSCON TURBOFAN RANGE: 700 MILES

	SHOP COST	PART INDEX	MATERIAL COST	LABOR COST
FAN ROT BLADES-		1.100		
FAN ROT DISC---		0.100		
FAN FRAME&STAT-		0.200		
BOOS ROT BLADES		1.200		
BOOS ROT DISC--		0.050		
BOOS STAT VANES		0.200		
BOOS STAT CASE-		0.050		
HPT BLADES-----		4.000		
HPT VANES------		6.100		
HPT DISC-------		0.600		
HPT CASE-------		0.400		
COMBUSTOR------		2.000		
HPC BLADES-----		3.100		
HPC VANES------		0.300		
HPC DISC-------		0.150		
HPC CASING-----		0.100		
GEAR SET-------		0.300		
GEAR LUBE & COOLING SYSTEM-		0.500		
LPT STAT VANES-		0.250		
LPT STAT CASE--		0.200		
LPT ROT BLADES-		0.700		
LPT ROT DISC---		0.100		
TURB FRAME-----		0.100		
C&A&MISC-------		0.300		
Access Gearbox---		2.000		
Exhaust Frame---		0.100		
----------	0.	0.		
----------	0	0.		
----------	0	0.		
TOTAL----------			803394	

TOTAL COST PER FLIGHT HOUR, $ 25.34 ×1.25 = 31.68

MISSION SIZE

ENGINE DESIGNATION: 7U
NO. OF ENGINES: 3 TYPE: TRANSCON TURBOFAN RANGE: 700 MILES

	SHOP COST* SCALE FACT	MATERIAL COST	LABOR COST	MAT CST /FL HR	LAB CST /FL HR	TOT CST /FL HR
FAN ROT BLADES-				0.35	0.15	0.50
FAN ROT DISC---				0.03	0.01	0.04
FAN FRAME&STA--				0.17	0.07	0.25
BOOS ROT BLADES				0.07	0.03	0.10
BOOS ROT DISC--				0.01	0.00	0.01
BOOS STAT&VANES				0.05	0.02	0.07
BOOS STAT CASE-				0.01	0.00	0.01
HPT BLADES-----				2.50	1.07	3.58
HPT VANES------				4.08	1.75	5.83
HPT DISC-------				0.32	0.14	0.46
HPT CASE-------				0.15	0.06	0.21
COMBUSTOR------				1.95	0.84	2.79
HPC BLADES-----				0.43	0.18	0.61
HPC VANES------				0.05	0.02	0.07
HPC DISC-------				0.09	0.04	0.13
HPC CASING-----				0.05	0.02	0.08
GEAR SET-------				0.25	0.11	0.36
GEAR LUBE & COOLING SYSTEM-				0.08	0.04	0.12
LPT STAT VANES-				0.10	0.04	0.14
LPT STAT CASE--				0.07	0.03	0.10
LPT ROT BLADES-				0.31	0.13	0.44
LPT ROT DISC---				0.04	0.02	0.06
TURB FRAME-----				0.04	0.02	0.06
C&A&MISC-------				0.68	0.29	0.98
Wood Lodge				0.94	0.40	1.34
Lostadream				0.01	0.01	0.02
----------				0.	0.	0.
----------				0.	0.	0.
----------				0.	0.	0.
TOTAL----------				12.83	5.50	18.33

TOTAL COST PER FLIGHT HOUR, $ 18.33

×1.25 = 22.91

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MAINTENANCE COST CALCULATION

DESIGN SIZE 3/8

ENGINE DESIGNATION: 7U
NO. OF ENGINES: 4 TYPE: INTERCON TURBOFAN RANGE: 2000 MILES

	SHOP CUST	PART INDEX	MATERIAL COST	LABOR COST
FAN ROT BLADES-		1.100		
FAN ROT DISC---		0.100		
FAN FRAME&STAT-		0.200		
BOOS ROT BLADES		1.200		
BOOS ROT DISC--,		0.050		
BOOS STAT VANES		0.200		
BOOS STAT CASE-		0.050		
HPT BLADES-----		4.000		
HPT VANES------		6.100		
HPT DISC-------		0.600		
HPT CASE-------		0.400		
COMBUSTOR------		2.000		
HPC BLADES-----		3.100		
HPC VANES------		0.300		
HPC DISC-------		0.150		
HPC CASING-----		0.100		
GEAR SET-------		0.300		
GEAR LUBE & COOLING SYSTEM-		0.500		
LPT STAT VANES-		0.250		
LPT STAT CASE--		0.200		
LPT ROT BLADES-		0.700		
LPT ROT DISC---		0.100		
TURB FRAME-----		0.100		
C&A&MISC-------		0.300		
Misc Parts		2.000		
Instrument		0.100		
----------		0.		
----------		0.		
----------		0.		
TOTAL----------			967303	

TOTAL COST PER FLIGHT HOUR, $ 24.00

x 1.25 = 30.00

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MISSION SIZE

ENGINE DESIGNATION: 70
NO. OF ENGINES: 4 TYPE: INTERCON TURBOFAN RANGE: 2000 MILES

	SHOP COST* SCALE FACT	MATERIAL COST	LABOR COST	MAT CST /FL HR	LAB CST /FL HR	TOT CST /FL HR
FAN ROT BLADES-				0.34	0.15	0.49
FAN ROT DISC---				0.03	0.01	0.04
FAN FRAME&STA--				0.17	0.07	0.24
BOOS ROT BLADES				0.07	0.03	0.10
BOOS ROT DISC--				0.01	0.00	0.01
BOOS STAT&VANES				0.05	0.02	0.06
BOOS STAT CASE-				0.01	0.00	0.01
HPT BLADES-----				2.43	1.04	3.48
HPT VANES------				3.97	1.70	5.67
HPT DISC-------				0.31	0.13	0.44
HPT CASE-------				0.14	0.06	0.20
COMBUSTOR------				1.90	0.81	2.71
HPC BLADES-----				0.42	0.18	0.60
HPC VANES------				0.05	0.02	0.07
HPC DISC-------				0.09	0.04	0.13
HPC CASING-----				0.05	0.02	0.07
GEAR SET-------				0.25	0.11	0.35
GEAR LUBE & COOLING SYSTEM-				0.08	0.03	0.12
LPT STAT VANES-				0.09	0.04	0.13
LPT STAT CASE--				0.07	0.03	0.09
LPT ROT BLADES-				0.30	0.13	0.43
LPT ROT DISC---				0.04	0.02	0.06
TURB FRAME-----				0.04	0.02	0.06
C&A&MISC-------				0.67	0.29	0.95
Misc Parts				0.91	0.39	1.30
Entire Trans				0.01	0.01	0.02
----------				0.	0.	0.
----------				0.	0.	0.
----------				0.	0.	0.
TOTAL----------				12.48	5.35	17.83

TOTAL COST PER FLIGHT HOUR, $ 17.83

x 1.25 = 22.29

8.3.6 Installation Aero

Drag calculations for the geared fans were done by defining the nacelle dimensions sufficient to estimate surface areas and then using the DRAG program which treats the nacelle as an equivalent solid body of revolution. The baseline nacelle (MF12) was recalculated using this method and checked the more detailed calculation reported in STEDLEC Task III within a .1%.

The preparation of input data, the drag calculations and the correlation of pylon drag with engine airflow follow. The results for the variable boost (8-U) engine are covered at the same time.

Drag Calculation Procedure - Task II

1. Estimate surface area by simple geometry for MF12, 7-U, 8-U.
2. Run drag for each.
3. Establish ratio by MF12 drag estimated in detail.

	MF12	7U	8U
W_2^*, lb/sec	1253	1719	1934
Fan D_T, in	78.8	91.13	96.66
D_{Max}, in	89.7	105.1	111.4
D_{H2}/D_{Max}	.88	.88	.88
Nac. Length, in	227.0	248.0	265.2
Inlet Length, in	53.7	62.9	66.7
Engine " , in	103.9	101.6	110.0
Exhaust " , in	69.4	83.5	88.5
A_8, in^2	3005	3850	4320
A_0, in^2	3524	4835	5440
D_{Nac}, lbs	359	481	537.3
D_{Press}, lbs	113	169	187.8
$D_{Friction}$, lbs	248	313	349.5
D_{Pylon}, lbs	72	85	91
D_{Total}, lbs	431	566	629

Installation Surface Areas & Dimensions

	MF12	7-U	8-U	8-U Scaled
D_T, in	78.8	91.13	96.66	91.13
D_{HL}, in	78.94	92.49	98.0	
D_{Max}, in	89.7	105.1	111.4	105.1
L_{Inlet}, in	53.7	62.9	66.7	62.9
A_{Inlet}, in^2	14228	19522	21939	
Length, in		248.0	264.0	248.9
D_{Max}, in	89.7	105.1	111.4	105.0
Length, in	103.9	101.6	110.0	103.7
A_{Eng}, in^2	29279	33706	38497	
D_{Max}, in	89.7	105.1	111.4	
D_8, in	61.9	70.03	74.2	
L_{Exh}, in	69.4	83.5	87.5	82.5
A_{Exh}, in^2	16526	22970	25509	
A_{Total}, in^2	60025	76198	85946	
Drag, lbs	360.9	481.2	537.8	478.0

```
=DRINMF12

LINLET/DHL     =  0.68

D PRESS        = 112.7
D FAN COWL     = 248.2
D WAIST COWL   =   0.
D PLUG         =   0.

D TOTAL        = 300.9
SFC IN         = 0.6089

*LIST DRINMF12

501 1,7612,.580,103.9,227.0,53.7,34.7
502 35,89.7,78.94,3524,3005,0,497.95
503 .60,227.0,60025,1,0,0,1,0,0

ready

*
```

DRAG CALCULATION

MF12 - BASELINE

DRAG - CALCULATION

7-U

```
/HDRAG
INPUT NAME OF DATA FILE
=DRIN7U

LINLET/DHL      =  0.68

D PRESS         = 168.5
D FAN COWL      = 312.6
D WAIST COWL    =   0.
D PLUG          =   0.

D TOTAL         = 481.2
SFC IN          = 0.5706

*LIST DRIN7U

501 1,8810,.5394,101.6,248.0,62.9,40.6
502 35,105.1,92.49,4835,3850,0,497.95
503 .80,248.0,76198,1,0,0,1,0,0

ready

*
```

8-U

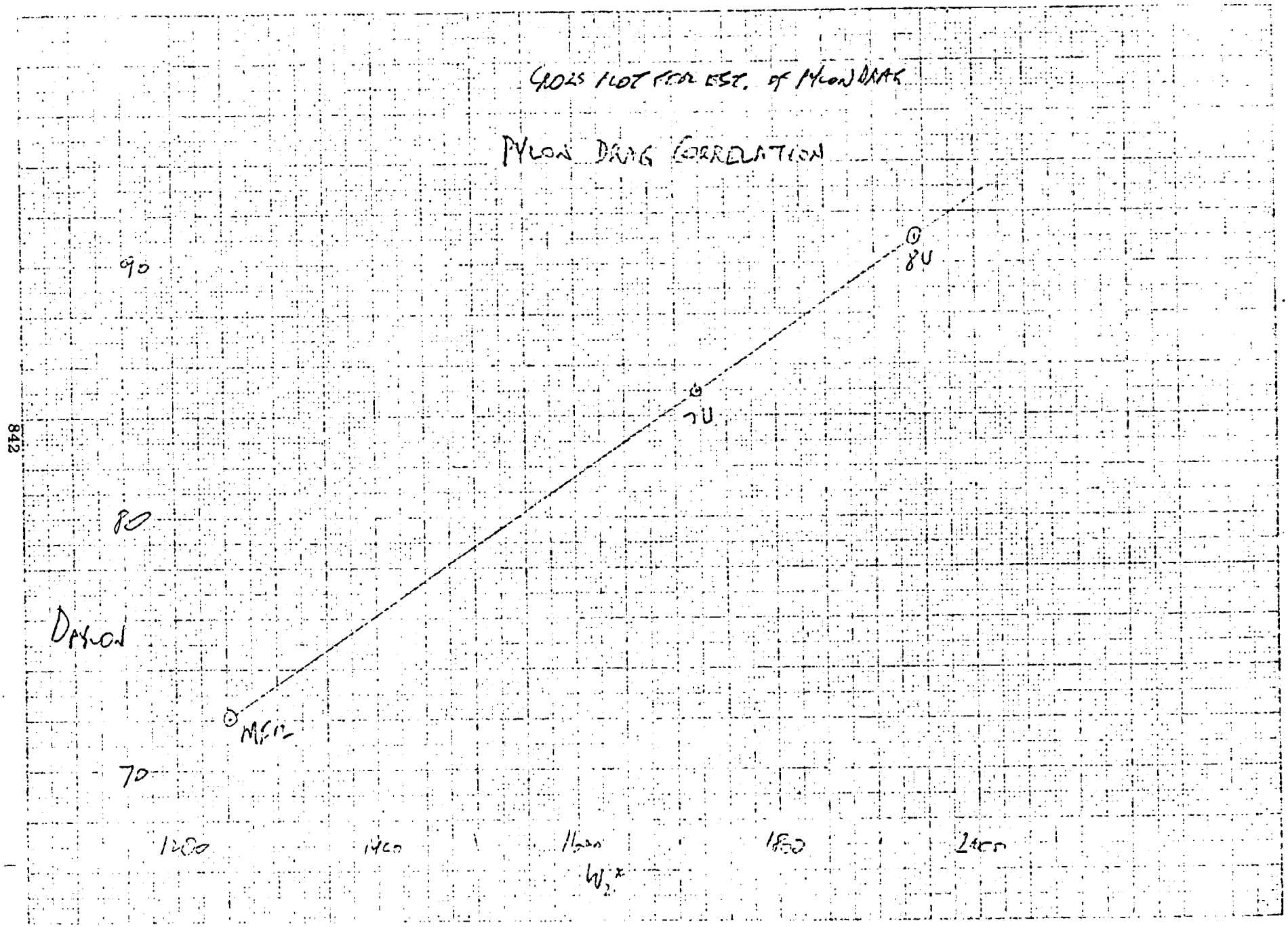
```
/HDRAG
INPUT NAME OF DATA FILE
=DRIN8U

LINLET/DHL      =  0.68

D PRESS         = 187.8
D FAN COWL      = 350.2   349.5
D WAIST COWL    =   0.
D PLUG          =   0.

D TOTAL         = 538.0   537.5
SFC IN          = 0.5064

*LIST DRIN8U
                          264.2
501 1,9350,.5338,110.0,265.2,66.7,43.1
502 35,111.4,98.0,5440,4320,0,497.95
503 .80,265.2,86237,1,0,0,1,0,0   85945
```


GROSS PLOT FOR EST. OF PYLON DRAG
PYLON DRAG CORRELATION
90
80
70
Drag
8U
7U
MFR
1200
1400
1600
1800
2000
W_2^*

Weight Est. for 7U Engine

Weight est. for the 7U engine as compared to the baseline Tech III engine.

Item	Baseline (78.8)	7U (91.15 D_F)
Design Corrected Air Flow, lb/sec	1253	1719
Fan Rotor	532	548
Fan Frame	475	583
Fwd Casing	140	130
Fan Blade Contain.	96	60
LP Shaft + Cones	160	129
Booster Rotor	105	105
Booster Stator	122	145
LPT Rotor	263	272
LPT Stator	293	274
Turbine Frame	176	152
Intermediate Frame	0	61
LP System	2367	2459
HP System	1129	1129
Misc		
Reduction Gear + Cooler	0	420
Sumps	104	104
Engine Drop + Sump	0	30
Drives	130	130
C&A Conf.	310	310
Misc Total	544	994
Weight	4040	4532
7% Margin	404	458
Total Wt + Margin	4444	5040

OC CRW
REW

2/27/76

To: R. H

From: R. J.

Subject: Replacement Factors (Maintenance) Survey

The following are recommended replacement factors for a 36000 hr. engine life.

Item	Recommended Gerald	Recommended Dent
Fan Blades	1.1	1.38
Fan Disk	.1	
Fan Frame	.2	
Booster R. Blades	1.2	.4
Booster R. Disks	.05	
Booster S. Vanes	.2	
Booster Case	.05	
HPC Blades	3.1	
HPC Rotor	.15	
HPC Vanes	.3	
HPC Stator Case	.1	
Combustor	2.0	
HPT Blades	4.0	
HPT Rotor	.6	
HPT Vanes	6.1	
HPT Case	.4	
LPT Vanes	.25	
LPT Case	.2	
LPT Blades	.7	.5
LPT Rotor	.1	.05
Turbine Frame	.1	
C+A + Main	.3	
Main Part	2	
Gear Set	.3	
Gear Lube + Cooler	.5	

8.4 Geared Fan Detail Design

Figure 8.4.1 illustrates the geared turbofan layout. A large 1.55 P/P composite fan is driven at 1300 fps tip speed by a high speed 3 stage LPT through a 2.63:1 gear ratio star epicyclic gear. The two stage aft booster stages are directly driven at the high LPT rpm to accomplish the needed core supercharging.

The same core engine as in the baseline was used and is the same as that in the STEDLEC Task III study previously reported.

The material technology exercised in the geared engine was essentially the same as in the baseline direct drive. The gear design was based on the advanced gear technology described earlier. For the most compact engine, the gear box was mounted forward of the fan rotor and the entire box-rotor assembly was suspended by a tail shaft mounted from the composite frame.

Weights were estimated from similar engine components and through some point designs on components that were different. One such component was the high speed booster rotor.

A Boron Aluminum booster blade design was done as well as a titanium blade design. Although the titanium blade design was retained due to the uncertainty of the B/Al technology, there is some weight benefit to be gained through the use of B/Al. Not enough is known of the cost implications however, to know if a net advantage results in using B/Al. Table 8.4.1 shows the two comparative weights for the 1st booster stage of the 7U while Figure 8.4.2 is a drawing of both disk designs.

Table 8.4.2 is a stress analysis run of the titanium blade design. Stress levels were set according to accepted General Electric design practices.

The fan rotor and stator weight designs were scaled from previous designs after taking into account differences in speed and size. Table 8.4.3 is a list of the component weights for the 7U and the baseline (Task III STEDLEC) comparison engine. These weights are in the design size with the core corrected flow at 68.4#/sec.

Maintenance factors for the base engine were developed from prior commercial engine experiences with modifications due to differing operating conditions and material properties. Table 8.4.4 is a complete listing of replacement factors over a 36,000 hour engine life for both direct and geared designs. The gear expected maintenance factors were developed by doing a worst-best case analysis and then choosing a likely case to develop the maintenance factors. A typical component cost estimate was used to develop the overall replacement factor of .3 for the gear set. Table 8.4.5 is a listing of the process and the results.

The gear design for the 7U engine was based on the advanced gear technology discussed earlier in the CDR. The next 3 pages are the sizing work to design a 29,000 HP design-size gear set. Figure 8.4.3 is a cut-away front view cross section of the gear set used in 7U and the variable boost version 8U.

7U Design

29000 HP @ 3056 rpm for N_1

$$T = \frac{(29000)(33000)}{(3056)(2\pi)} \approx 50000 \text{ ft-lb.}$$ output Torque

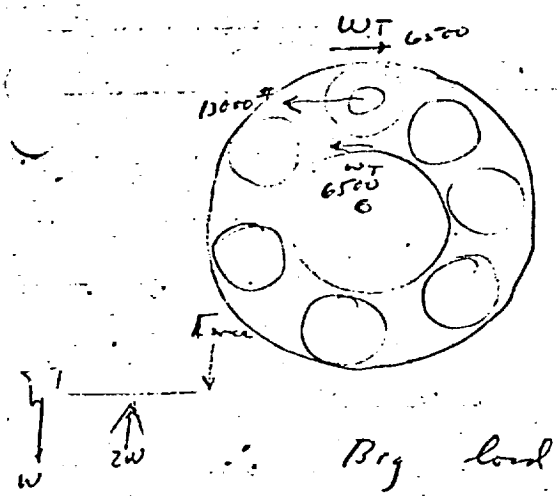
$$\left[\left[\frac{OD_{ring}}{7.65}\right]^{1.85} = \frac{L_{ring}}{14300}\right]$$ $P_{10\,sym} = 36000$ lb for 12 bmp

7 Star Design with $m_g \sim 2.36$

Rig gear $P_D \cong 26.4''$

Sun gear $P_D \cong 11.2$

Star gear $P_D \cong 7.6''$



$$\frac{7 W_T \cdot 13.2}{12} = 50000$$

$$W_T = \frac{(50000)(12)}{(13.2)(7)} = 6494\#$$

Use 6500#

$\therefore$ Rig load = 6500# at SLTO rpm star = 10615 rpm

$$\left[\frac{OD_{ring}}{7.65}\right]^{1.85} = \frac{6500}{14300} = .4545 \qquad \frac{1}{1.85} = .5405$$

$$\frac{OD_{ring}}{7.65} = (.4545)^{.5405} =$$

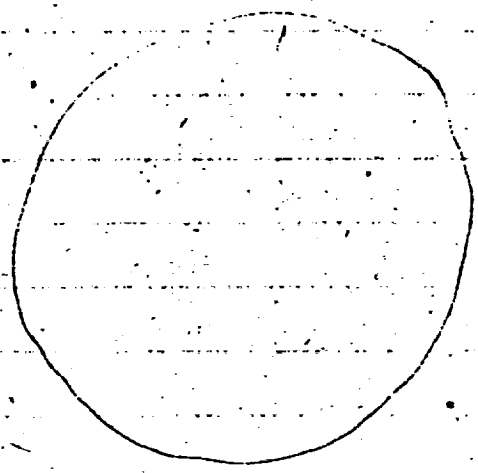
$OD_{ring} = (7.65)(\quad) = 4.995 = \underline{5.0 \text{ inches}}$ min face OD

Accepted MSO bmp

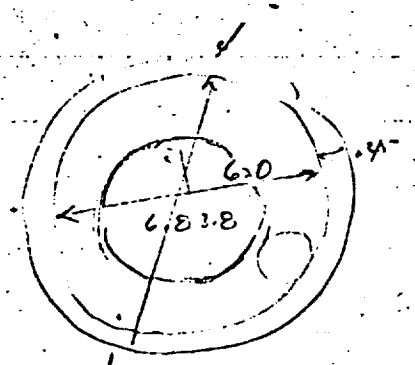
$\left[\frac{6.8 - 5.42}{2}\right] = .7$ avail for roll libber

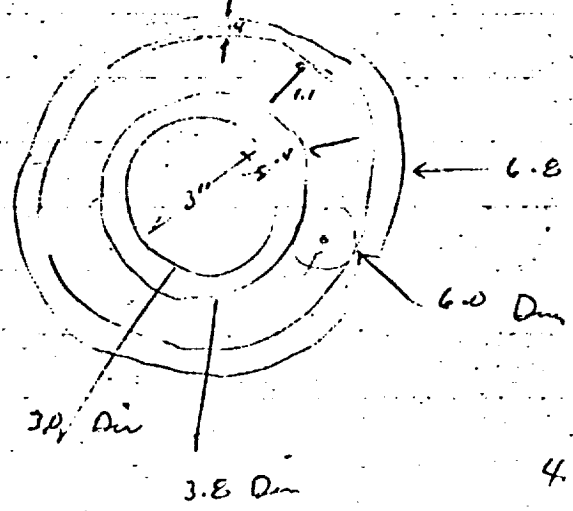
Assume .40 roll thickness

∴ 1.1" roller diameter (11)



15850# load





4.6 P.D of bar = N.A. = $\frac{12.1}{2.3}$

$\left[\frac{6}{7.65}\right]^{1.85}\left[14500\right]$ = Capacity for B_{10} = 36000 hr

= 9125#

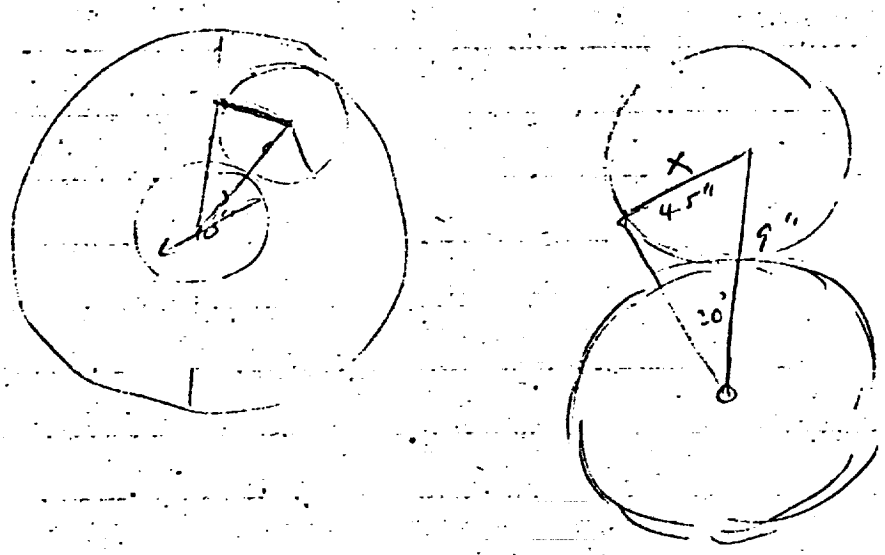
[~.2" for spacer (cage between each roller

Not clear $\frac{\text{Lon}}{e \times}$

X ≤ 5 y

3095 rpm @ 29000 HP

$$T = \frac{(29000)(33000)}{(3095)(6.28)} = 49200 \text{ ft-lbs}$$



8.4" OD of ctr
9.0" Avail
∴ 6 stns

$$\frac{(49200)(12)}{13.6} = W_{1\,stn} = 7570 \text{ \#/stn} = \text{load/bearing}$$

2 brg/stn

Min ID of stn = 6.8" = [OD of bearing]

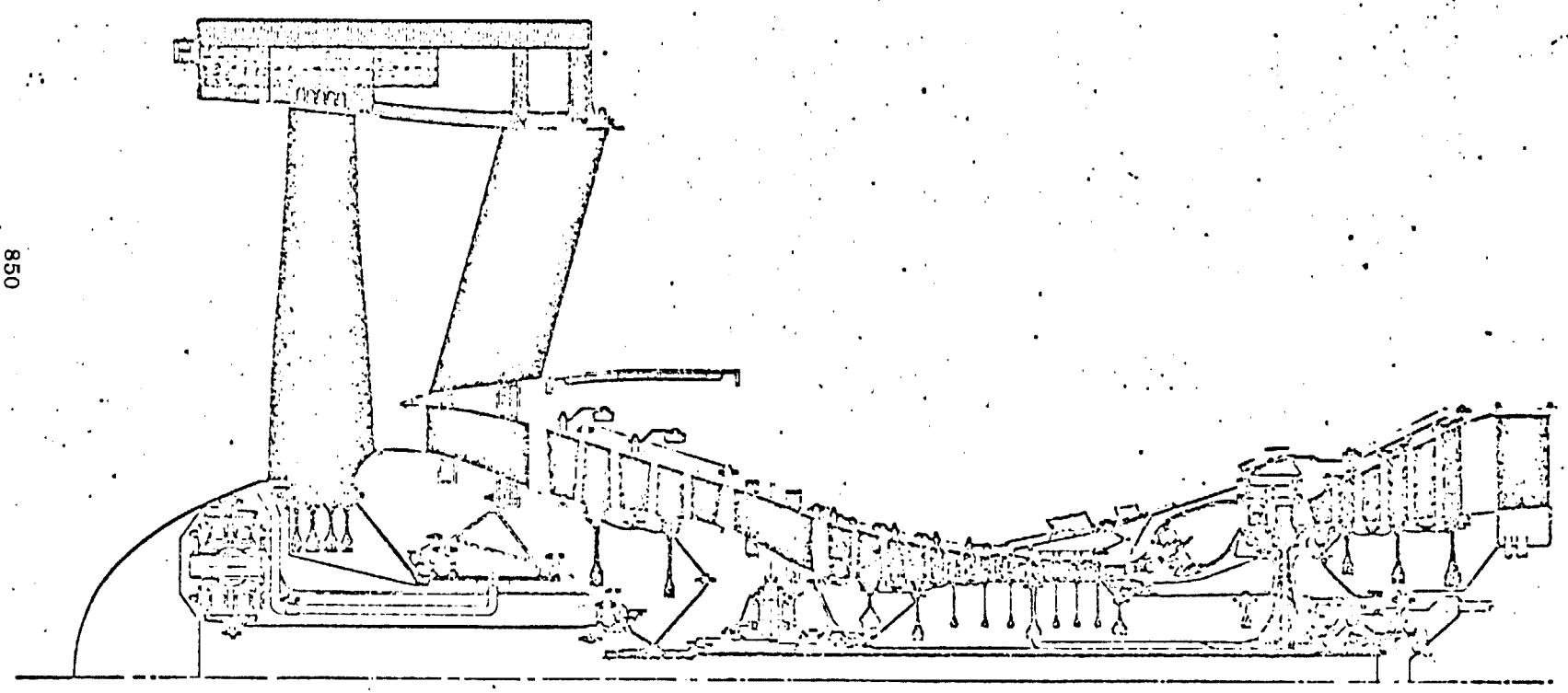
$$\left[\frac{OD}{7.65}\right]^{1.85} = \frac{7570}{14300} = .5294$$

$$OD^{1.85} = (43.129)(.5294)$$

$$OD = \left(\left[43.129\right]\left[.5294\right]\right)^{.5405} = 5.42 \text{ inches needed}$$

Figure 8.4.1

GEARED TURBOFAN



Title [illegible]

Booster - Stg 1

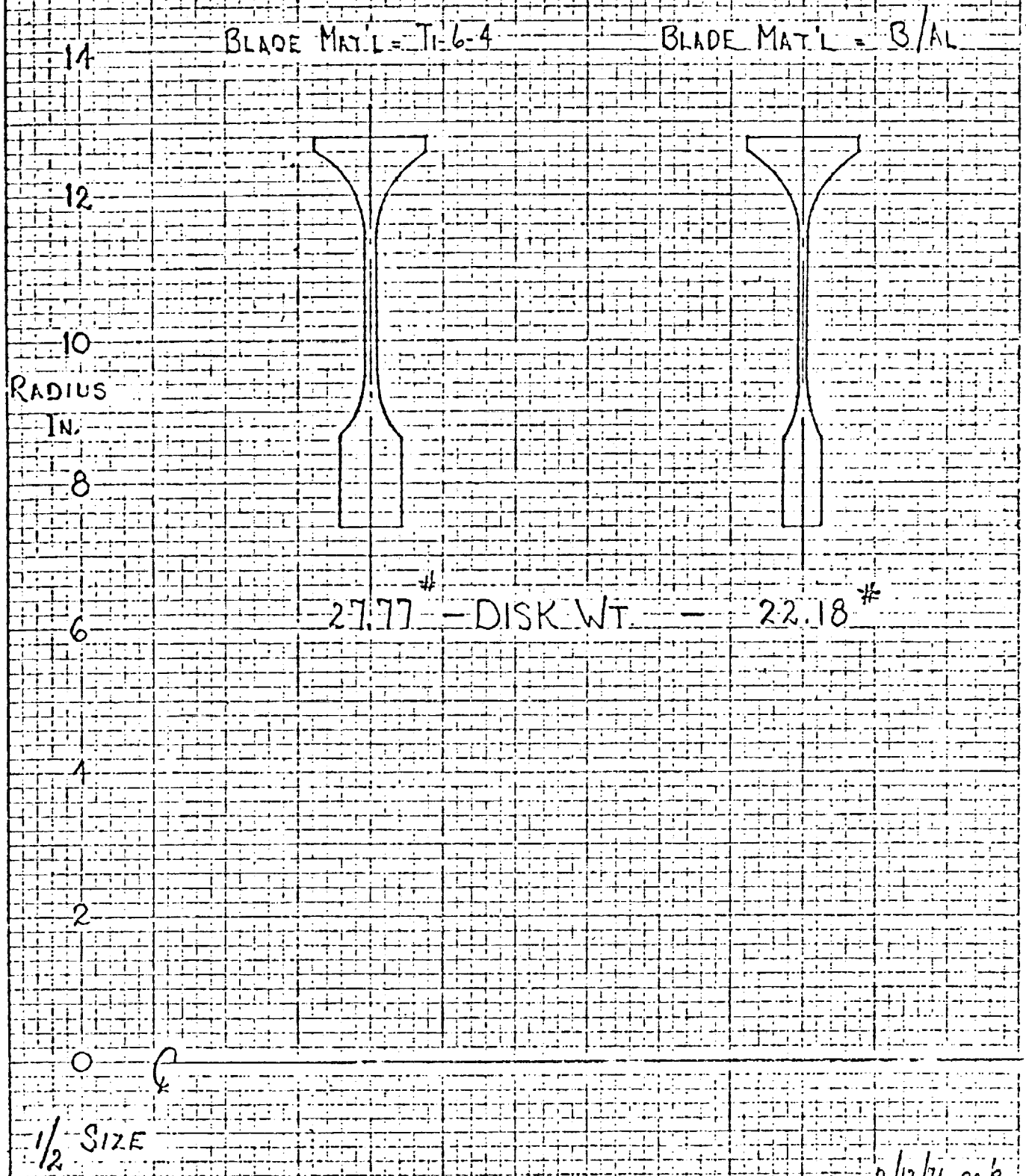
gals

7.0

	Blade Mat'l = Ti-6-4	Blade Mat'l = B/al
Blade Wt - #	13.0	8.075
Dead Wt - #	5.694	5.694
Disk Wt - #	27.77	22.18
TOTAL WT - #	46.464	35.949

46.5 1st stg.
40.5 2nd stg. wt
15. stage wt
2# misc.
105 #

7-U BOOSTER – 1ST STG. DISK



2/17/76 gak

Table 8.4.2

BOOSTER
1ST STG DISK

```
LIST 770-860

770 DATA 108900, .56
780 DATA 14, 7940, 8.047, .312, .161, 64
790 DATA 225, 0, 0, 0, 0, 0, 0
800 DATA 0, 0, 0, 0, 0, 0, 225
810 DATA 7.4, 8.0, 8.65, 9.0, 9.2, 9.5, 10.5
820 DATA 11.5, 12.0, 12.25, 12.43, 12.45, 12.6, 12.8
830 DATA .85, .85, .85, .34, .255, .17, .17
840 DATA .17, .43, .7, 1.05, 1.35, 1.55, 1.55
```

(BLADE MAT'L = TI-6-4)

```
ready

*RUN
```

TI:6-4 MATERIAL DATA RANGE IS :

TEMPERATURE	MODULUS	ALFA
0	163.00e 05	48.000e-07
1200	104.80e 05	51.500e-07

MASS DEN. = .161 #/IN^3
NOTCH SEN. = .56
POISSON'S = .312

SPD = 8047 RPM RAD.LOAD = 7940 #/IN ULT.STR = 108900 #/IN^2

RADIUS (IN)	THICK. (IN)	TEMP. (F.)	RAD.STR. (KSI)	TAN.STR. (KSI)	EFF.STR. (KSI)	RAD.DISP. (IN.)
7.40	.850	225	.0	83.5	83.5	.0462
8.00	.850	225	4.7	77.0	74.8	.0457
8.65	.850	225	8.4	71.3	67.5	.0455
9.00	.340	225	23.4	72.9	64.5	.0455
9.20	.255	225	31.7	74.2	64.5	.0457
9.50	.170	225	48.0	77.7	67.9	.0463
10.50	.170	225	47.9	74.0	65.0	.0486
11.50	.170	225	46.9	70.7	62.3	.0510
12.00	.430	225	18.4	59.8	53.0	.0516
12.25	.700	225	11.3	56.4	51.7	.0517
12.43	1.050	225	7.6	54.3	51.0	.0517
12.45	1.350	225	5.9	53.7	51.0	.0517
12.60	1.550	225	5.1	52.7	50.3	.0517
12.80	1.550	225	5.1	51.7	49.4	.0517

AVG.TAN.STRESS= 68.43615 KSI

CROSS SECT.AREA= 2.73425 SQ.IN.

WHEEL WEIGHT = 27.76951 LBS.

BURST SPEED = 9727.067 RPM = 120.8782 PER CENT OF 8047

```
ready
*
```

cc S.T.
RCN
3/4/76
3/3/76
Rennie

To: R. Hirschkorn

From: R. Johnston

Subject: Weight Est. for 70 [illegible]

Items	Baseline (78.8 D_T)	70 (91.15 D_T)
Fan Rotor	532	548
Fan Frame	475	583
Fan Casing	140	130
Fan Blade Contain	96	60
LP Shaft + Core	160	129
Booster Rotor	105	105 *
Booster Stator	122	145
LPT Rotor	263	272
LPT Stator	298	274
Turbine Frame	176	152
Intermediate Frame	0	61
LP System	2367	2459
HP System	1129	1129
Reduction Gear/Cooler	0	370/50
Sumpes	104	104
Extra Pumps + Sumpes	0	30
Drive	130	130
C+A, Coupling	310	310
Total	544	994
Σ Weight	4040	4582
Note → 10% Margin	404	458
	854	
Total Wt + Margin	4444	5040

OK

Table 8.7.4

2/27/76

To: R. H

From: R. J.

Subject: Replacement Factors (Maintenance) Survey

The following are recommended replacement factors for a 36000 hr engine life.

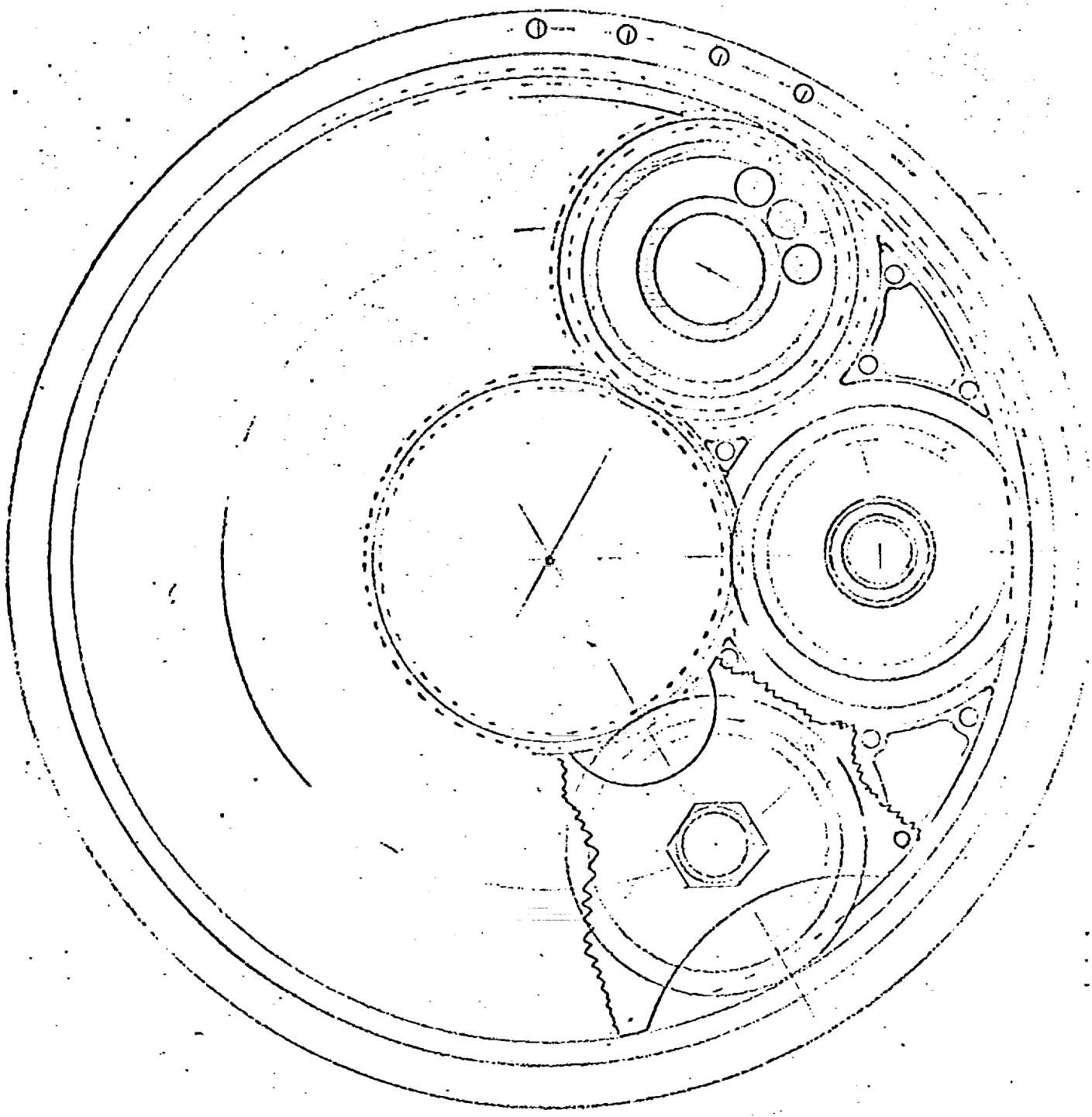
Item	Recommended Good	Recommended Dust
Fan Blades	1.1	1.38
Fan Disk	.1	
Fan Frame	.2	
Booster R. Blades	1.2	.4
Booster R. Disks	.05	
Booster S. Vanes	.2	
Booster Case	.05	
HPC Blades	3.1	
HPC Rotor	.15	
HPC Vanes	.3	
HPC Stator Case	.1	
Combustor	2.0	
HPT Blades	4.0	
HPT Rotor	.6	
HPT Vanes	6.1	
HPT Case	.14	
LPT Vanes	.25	
LPT Case	.2	
LPT Blades	.7	.5
LPT Rotor	.1	.05
Turbine Frame	.1	
CRA + Hose	.3	
Minor Parts	2	
Gear Set	.3	
Gear Lube + Cooler	.5	

Table 8.4.5

Gear Box Maintenance [Based on 2U Gear Set] Typical of 70 & 80

Item	Nr Used	Σ Cost Est.	36000 hr Repl. Factor 9000 TBO Intent	Expected	Funded Design	Replacement Cost Intent	Expected	Funded Design
~~Stat Gear Bearings~~	~~12~~	~~$11400~~						
Star Gear Brgs	12	9600	.1	.25	3	960	2400	28800
Ring Gear	1	3600	0	.2	3	0	720	10800
Sun Gear	1	1600	0	.3	3	0	480	4800
Star Gears	6	10200	0	.3	3	0	3060	30600
Output Shaft	1	2000	0	.2	1	0	400	2000
Input Shaft	1	1800	0	.2	1	0	360	1800
Covers	2	800	0	.2	3	0	160	2400
Stator	1	5000	0	.25	3	0	1250	15000
Misc Hdwe	—	600	3	3	3	1800	1800	1800
Totals		$35200	—	—	—	2760	10630	98000
Overall Replacement Factor			.078	.30	2.78	.077/hr	.30/hr	2.72/hr

Figure 8.4.3



70/80 Gear Set Frontal Cut-Away Section

8.5 Installation Design

The installation design parallels that of the baseline installation in all respects, aerodynamically, acoustically, materials and construction. This permits a direct comparison of component by component in both weight and price as indicated in the following table.

INSTALLATION	BASELINE MF12	7L	
Fan P/P Max Climb	1.7	1.55	
W2 corrected	1253	1718.9	
Fan DT	78.8	91.13	
Fn SLS +27 T.O.	33,248	39,177	
Fn Max Cl. 35K/.9M	8838	9597	
AE 25 (Mxcl)	(2558)	(3952)	
FF 25 (T.O.)	1076	1585	
AE 59	3594	5197	
Nacelle - overall size			
Dmax, Engine Casing/Nacelle	89.7	105.1	
Engine length	103.9	101.6	
Inlet length (aero)	53.7	62.9	
Exhaust length (aero)	69.4	83.5	
Nacelle length	227.0	248.0	
Nacelle Weight Estimates:			
Inlet	310	440	
Fan Rev/Duct	720	100	
Core Cowl	100	~~130~~ 110	
Tail cone	150	225	
Mixer + Plug	200	300	
Engine Build up	450	475	
Pylon Delta	40	50	
Margin 7%	140	190	
Totals	2110	~~2910~~	2590
Nacelle Cost Estimates:			
Inlet	26,300	33,900	
Fan Rev./Duct	72,000	98,200	
Core Cowl	9,000	~~11,100~~	9700
Tail cone	17,900	24,000	
Mixer + Plug	19,000	25,500	
Engine Build up	68,000	71,400	
Pylon Δ	3,700	4,200	
Air + Cables	23,900	29,800	
Totals	239,800	~~298,100~~	296.5
Pylon Weight, Est.	980	1280	
Pylon Cost Est.	90,000	109,000	

(OK)

8.~~8~~ 6 Engine Evaluation

Summary of input data for LECMB, the evaluation system and the pertinent evaluation cases follow.

3-2-96

FINAL 7-U INPUT FOR LECMB

	MF 12	7-U		
SLS TO FN	33150	39177		
Mx CL FN	8737	9597		
95% Mx CL FN	7612	8370	7701	
SFC	.579	.5394		
NAC DRAG	359	481		
PYLON DRAG	72	85		
TOTAL DRAG	431	566	520	+89.8
Mx CL FN - D	8306	9027	8306	
ENG WT	4444	5040	4541	+98
ENG COST	534.7	585.6	559.4	+24.7
NAC WT	3090	4170	3805	+715
NAC COST	329.8	407.1	380.9	+51.5
MHA R/FT @ TRI/TRANSCON	22.38	22.91		+.53
MHA R/FT @ QUAD/INTICON	21.76	22.29		+.53

Gear Maintenance Sensitivity 7-U

This effect was simple enough so that only a hand calculation was made to estimate the effect.

Transcon Mission

	Base Case	Sensitivity Case	Δ
Gear Maint. $/FH	.48	1.05	+.57
Total Maint., $/FH	22.91	23.48	
Δ from Baseline, $/FH	+.53	1.10	1
ΔDOC, %	-.59	-.46	+.13
ΔROI, %	-.07	-.09	-.021

BENEFIT ANALYSIS RESULTS FORMAT

FEATURE STUDIED

DESIGN INPUT

BENEFIT RESULTS

8-62A

INPUT NAME OF DATA FILE
=TR13004

ENGINE	7U STAR GEAR
MISSION	TRIJET 10.5 FL
MATERIAL SUBSTITUTION	1.55 STARG FOR MF12 TF
FUEL PRICE	$0.30
HOST COMPONENT	USTEDLEC TURB-FAN WITH PYLON EFFECTS

PARAMETERS AFFECTED	CHANGE
ETAB....	-1.6000
ETALPT..	-0.0010

	DESIGN SIZE BASE	DESIGN SIZE REPLACE	DESIGN SIZE DELTA	MISSION SIZE BASE	MISSION SIZE REPLACE	MISSION SIZE DELTA
FN, LBS	33156.	36047.		20000.	21744.	
DEL DIRECT WT, LB			98.0			
DEL DIRECT PR, K$			36.9			
DEL MMH, MMH/FL HR			0.			
DEL MMA, $MMA/FL HR			0.53			
TOTAL WEIGHT, LB	4444.	4561.	118.	2362.	2425.	63.
TOT INIT PRICE, K$	798	838	39.	603	633	29.9
NAC WEIGHT, LB	3090.	3792.	702.	1772.	2174.	402.4
NAC PRICE, K$	492	567	75.	329	379	49.9
SFC	0.5790	0.5419	-0.0371	-6.4		
SFC INSTALL	0.6138	0.5811	-0.0327			

	MISSION SIZE	DEL %DOC	DEL %ROI	DEL %TUGW	DEL %NF
TOT DEL WEIGHT, 100#	0.63	0.1046	-0.0380	0.1978	0.1603
DEL WT DIR	0.52	0.0870	-0.0316	0.1646	0.1334
DEL WT CYCLE	0.11	0.0176	-0.0064	0.0332	0.0269
TOT DEL PRICE, K$	29.75	0.2331	-0.1365		
DEL PRICE DIR INIT	27.87	0.2046	-0.1254		
DEL PRICE DIR REP	0.	0.	0.		
DEL PRICE DIR TOT		0.2046	-0.1254		
DEL PRICE CYCLE	1.98	0.0265	-0.0111		
DEL MMH, MMH/FL HR	0.	0.	0.		
DEL MMA, $MMA/FL HR	0.53	0.1214	-0.0194		
DEL %SFC	-5.32	-2.0915	0.5907	-2.5120	-5.8063
DEL %K2C	0.7668				
NAC WEIGHT, 100#	4.02	0.0719	-0.2442	1.2714	1.0139
NAC PRICE, K$	49.94	0.3666	-0.2247		
TOTAL		-0.5940	-0.0722	-1.0427	-4.6321

INPUT NAME OF DATA FILE
QUINTER

2/12/74

ENGINE	/U STAR GEAR
MISSION	QUADJET 10.5 FL
MATERIAL SUBSTITUTION	1.55 STARG FOR MF12 TF
FUEL PRICE	$0.45
HOST COMPONENT	USTEDLEC -- INTERCON.

PARAMETERS AFFECTED	CHANGE
ETAB....	-1.6000
BETALPT.	-0.0010

	DESIGN SIZE BASE	DESIGN SIZE REPLACE	DELTA	MISSION SIZE BASE	MISSION SIZE REPLACE	DELTA
FN, LBS	33156.	36047.		21000.	22830.	
DEL DIRECT WT, LB			98.0			
DEL DIRECT PR, K$			44.5			
DEL MMH, MMH/FL HR			0.			
DEL MMA, $MMA/FL HR			0.53			
TOTAL WEIGHT, LB	4444.	4561.	118.	2511.	2577.	66.
TOT INIT PRICE, K$	692	1010	48.	747	784	37.0
NAC WEIGHT, LB	3090.	3792.	702.	1870.	2294.	424.4
NAC PRICE, K$	594	684	90.	412	475	62.6
SFC	0.5790	0.5419	-0.0371			
SFC INSTALL	0.6138	0.5811	-0.0327			

	MISSION SIZE	DEL %DOC	DEL %ROI	DEL %TOGW	DEL %RF
TOT DEL WEIGHT, 100#	0.66	0.1487	-0.0612	0.2555	0.2073
DEL WT DIR	0.55	0.1240	-0.0511	0.2132	0.1733
DEL WT CYCLE	0.11	0.0247	-0.0101	0.0424	0.0345
TOT DEL PRICE, K$		0.2383	-0.0091		
DEL PRICE DIR INIT	34.52	0.2078	0.		
DEL PRICE DIR REP	0.	0.	0.		
DEL PRICE DIR TOT		0.2078	0.		
DEL PRICE CYCLE	2.43	0.0304	-0.0091		
DEL MMH, MMH/FL HR	0.	0.	0.		
DEL MMA, $MMA/FL HR	0.53	0.1267	-0.0620		
DEL %SFC	-5.32	-3.7573	1.3145	-4.6195	-7.6477
DEL %K2C	0.7088				
NAC WEIGHT, 100#	4.24	0.9507	-0.3913	1.6340	1.3284
NAC PRICE, K$	62.59	0.3768	-0.2341		
TOTAL		-1.9162	0.5568	-2.7300	-6.1115

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FUEL PRICE SENSITIVITY

ENGINE 70 STAR GEAR

MISSION TRIJET 10.5 FL
MATERIAL SUBSTITUTION 1.55 STARG FOR MF12 TF
FUEL PRICE $0.40
HOST COMPONENT USTEDLEC TURB-FAN WITH PYLON EFFECTS

PARAMETERS AFFECTED	CHANGE
ETAB....	-1.6000
ETALPT..	-0.0010

	DESIGN SIZE BASE	DESIGN SIZE REPLACE	DESIGN SIZE DELTA	MISSION SIZE BASE	MISSION SIZE REPLACE	MISSION SIZE DELTA
FN, LBS	33156.	36047.		20000.	21744.	
DEL DIRECT WT, LB			98.0			
DEL DIRECT PR, K$			36.9			
DEL MMH, MMH/FL HR			0.			
DEL MMA, $MMA/FL HR			0.53			
TOTAL WEIGHT, LB	4444.	4561.	118.	2362.	2425.	63.
TOT INIT PRICE, K$	797	838	39.	603	633	29.9
NAC WEIGHT, LB	3090.	3792.	702.	1772.	2174.	402.4
NAC PRICE, K$	492	567	75.	329	379	49.9
SFC	0.5790	0.5419	-0.0371			
SFC INSTALL	0.6138	0.5811	-0.0327			

	MISSION SIZE	DEL %DOC	DEL %ROI	DEL %TOGW	DEL %WF
TOT DEL WEIGHT, 100#	0.63	0.1089	-0.0397	0.1978	0.1603
DEL WT DIR	0.52	0.0906	-0.0330	0.1646	0.1334
DEL WT CYCLE	0.11	0.0183	-0.0067	0.0332	0.0269
TOT DEL PRICE, K$		0.2159	-0.1324		
DEL PRICE DIR INIT	27.67	0.1895	-0.1215		
DEL PRICE DIR REP	0.	0.	0.		
DEL PRICE DIR TOT		0.1895	-0.1215		
DEL PRICE CYCLE	1.98	0.0264	-0.0109		
DEL MMH, MMH/FL HR	0.	0.	0.		
DEL MMA, $MMA/FL HR	0.53	0.1124	-0.0199		
DEL %SFC	-5.32	-2.3630	0.6652	-2.5120	-5.8063
DEL %WK2C	0.7688				
NAC WEIGHT, 100#	4.02	0.7001	-0.2551	1.2714	1.0300
NAC PRICE, K$	49.94	0.3396	-0.2178		
TAL		-0.8860	0.0004	-1.0427	-4.6160

The Noise section covers analyses performed for all Task I engine turbofans as well as Task II turbofans.

8.7 NOISE

8.7.1 GENERAL

Noise estimates were made for two geared fan configurations, 3U and 7U. The two engine configurations were identical, for noise calculation purposes, except for location of the booster with 3U having the booster located forward of the fan and 7U being a conventional design with aft boosters. ~~a conventional design with aft boosters.~~ Both designs were evaluated for a long duct mixed flow nacelle configuration employed to reduce jet noise at takeoff.

The component noise levels, including fan inlet, fan exhaust, core, jet, booster and turbine, were estimated using semi-empirical prediction techniques described in the following section.

8.7.2 COMPONENT NOISE PREDICTION TECHNIQUES

8.7.2.1 JET NOISE

The static jet noise estimates were based on a semi-empirical prediction technique derived from scale model test data on a partial mixer nozzle. The correlation used for the power level is shown in Figure 8.7.A while the directivity patterns are given in Figure 8.7.B.

8.7.2.2 CORE NOISE

Static core noise levels were estimated using a prediction technique based on measured engine data. The correlation used for power level is shown in Figure 8.7.1

8.7.2.3 FAN INLET AND FAN EXHAUST NOISE

The fan noise component noise levels, both inlet and exhaust, were based on measured engine data. Fan inlet radiated noise was estimated using Figure 8.7.2 which correlates maximum inlet radiated PNL with fan tip speed. The normalized level obtained from this correlation was corrected for weight flow and blade passing frequency. A similar correlation (Figure 8.7.3) was used for fan exhaust noise with fan pressure ratio being the correlating parameter. Corrections were

Figure 8.7.1

$\dot{W}$ = core weight flow, LB/sec
T_4 = Total temperature at combustor exit, °R
T_3 = " " " combustor inlet, °R
ρ_3 = density at combustor inlet, LB/ft^3
ρ_0 = density at standard day (SSA) conditions, LB/ft^3
OAPWL = Overall sound power level

Figure 8.7.2

BPF = fan fundamental tone frequency, Hz
W = inlet weight flow, LB/sec
V_T = fan tip speed, ft/sec

Figure 8.7.3

IGV - inlet guide vane
B/V - blade/vane
Fan P/P = fan pressure ratio

Figure 8.7.4

OASPL = Overall sound pressure level re: .0002 microbar
A = cross sectional area at exit of last turbine stage, ft^2
U_{TIP} = tip speed of dominant turbine stage, ft/sec

P_R = total pressure ratio across low pressure turbine
γ = 1.4

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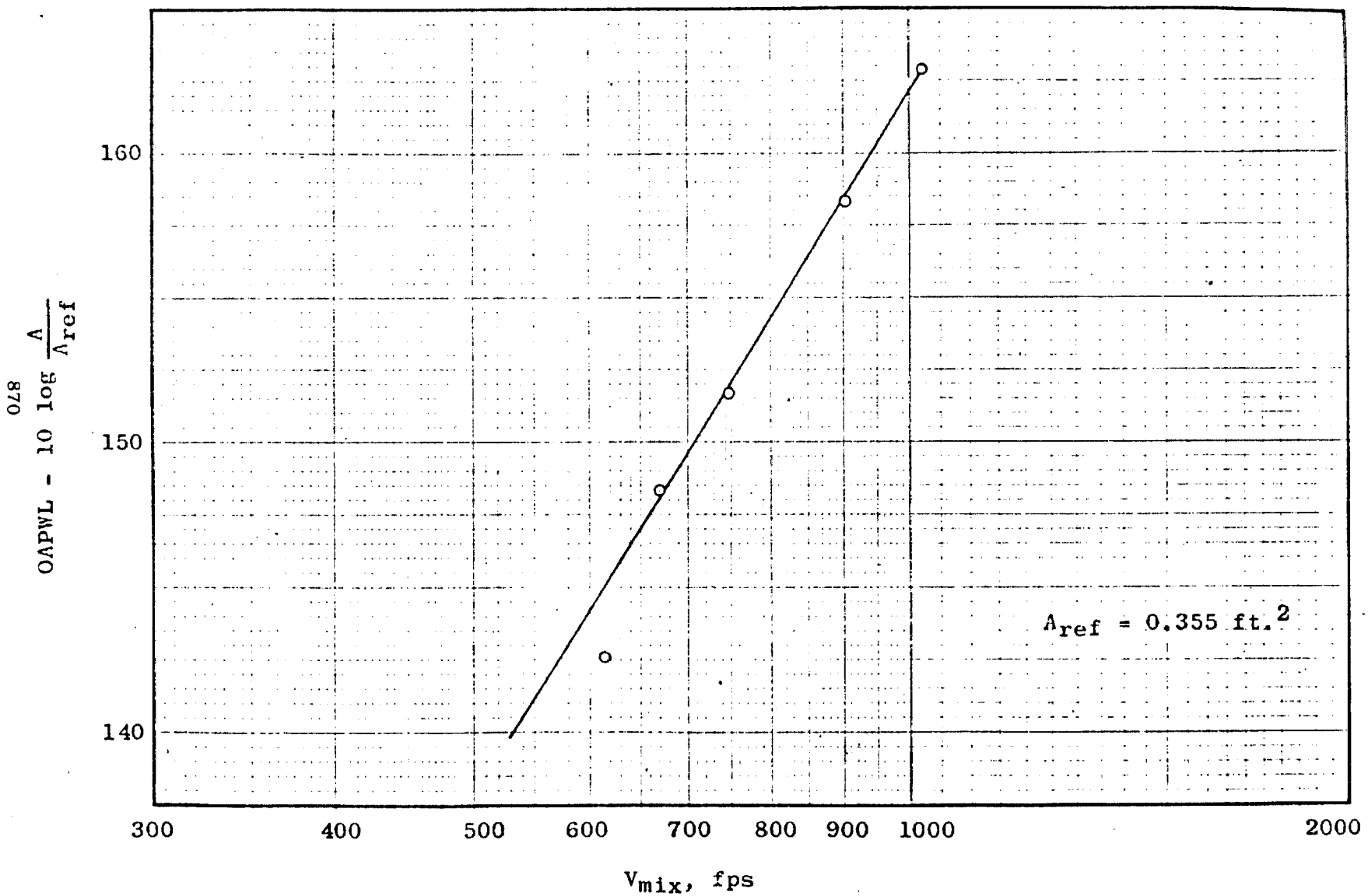
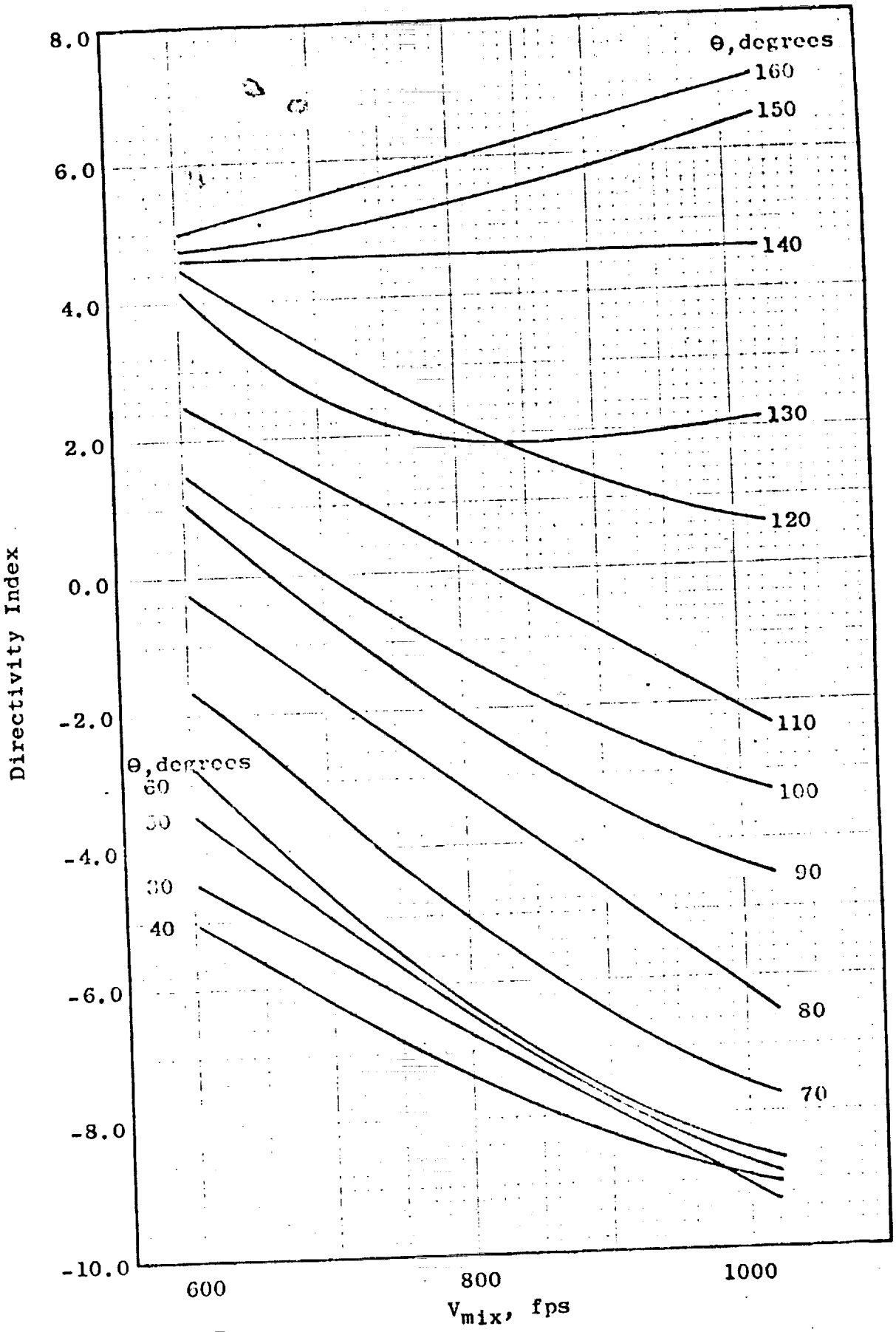


8.7.A

~~Figure 8.7~~ Normalized Overall Power Level vs. V_{mix}.



8.7.B.

~~Figure 2.~~ Directivity Index vs. V_{mix} for Values of Angle θ from the Inlet Axis of 30° through 160°.

applied for weight flow and blade passing frequency to obtain the static far field levels.

8.7.2.4 TURBINE NOISE

Turbine noise levels were estimated using the semi-empirical prediction technique shown in Figure 8.7.4. The levels obtained were corrected for blade passing frequency of the dominant stage.

8.7.2.5 BOOSTER NOISE

Booster noise was estimated using measured engine data. The estimates were scaled to the proper engine size accounting for weight flow and blade passing frequency.

8.7.3 CYCLE DATA

The pertinent cycle data used for the acoustic analysis is shown in Table 8.7-I. The cycle data are presented at approach and takeoff flight conditions.

8.7.4 STATIC ENGINE NOISE LEVELS

Utilizing the various component noise prediction techniques the 200' sideline static untreated engine noise levels at the max forward and aft angles were estimated and are shown in Figures 8.7.5 and 8.7.6 for configuration 3U. The dominant components are the fan inlet, booster and fan exhaust radiated noise for the untreated nacelle statically.

8.7.5 STATIC-TO-FLIGHT EXTRAPOLATION PROCEDURE

The various flight effects accounted for in extrapolating the static 200' sideline untreated engine levels to flight, including inlet clean-up, jet relative velocity effects and dynamic effects are explained below.

8.7.5.1 INLET CLEAN-UP EFFECTS

Analysis of static-to-flight data comparisons for high bypass turbofan engines has indicated a reduction in fan noise due to forward

flight. This reduction, believed to be caused by reduced turbulence levels in flight relative to static conditions, was accounted for by reducing the untreated fan inlet noise component by 2 PNdB at takeoff and 4 PNdB at approach. The amount of reduction was based on CF6-50 static-to-flight noise ~~components~~ comparisons.

8.7.5.2 JET RELATIVE VELOCITY EFFECTS

The source reduction due to forward flight on the jet component was accounted for assuming no reduction in the forward quadrant and a 60 log V_{REL}/V_{JET} relationship in the aft quadrant. The particular assumptions were based on static-to-flight comparisons for single jet engines and ~~A~~ Bertin Aerotrain data, believed to be representative of flight effects for a mixed flow system.

8.7.5.3 DYNAMIC EFFECT

The effect of forward flight on all component levels was accounted for by applying a 40 log$\left(\frac{1}{1-M\cos\theta}\right)$ correction factor, referred to as ~~is~~ dynamic effect. This correction term, based upon theoretical analysis, has been substantiated by static-to-flight data comparisons for varying flight velocities.

8.7.5.4 DISTANCE CORRECTION FACTORS

Decay rates as a function of distance were calculated assuming a typical spectrum shape, depending on the type of source (i.e. - jet, core, fan, turbine). The results, indicated below, were used to extrapolate the static 200' sideline levels to the appropriate acoustic ranges for both takeoff and approach.

Source	Decay Rate (on a ΔPNL Basis)
Jet	24 Log R_1/R_2
Core	25 Log R_1/R_2
Fan	27 Log R_1/R_2
Turbine	30 Log R_1/R_2
Booster	30 Log R_1/R_2

8.7.5.5 CERTIFICATION GROUND

The prediction techniques used to obtain the static engine noise levels were based on data measured over a hard surface, not typical of a ground surface used during flight noise certification testing. To account for the difference between the two types of surfaces the following corrections, based on data, were applied:

Source	ΔPNL Correction (Static-to-flight)
Jet	-0.5
Core	-0.5
Fan	-1.5
Turbine	-1.5
Booster	-1.5

8.7.6 ACOUSTIC TREATMENT BENEFITS

The noise reduction on turbomachinery noise components was estimated based on current achievable suppression levels with a 50% improvement assumed for advanced technology. The total assumed suppression is shown below for each component at takeoff and approach.

	ΔPNL Reduction	
Source	Takeoff	Approach
Fan Inlet	-8	-12
Fan Exhaust	-15	-15

No turbine noise suppression was required since the basic design provided for a high number of turbine blades causing the dominant stage blade passing frequency to be above 10 KHz, out of the frequency range of interest.

For configuration 3U no reduction in booster noise was assumed. Since the source was located in the center of the inlet, inlet wall treatment would be virtually ineffective in reducing booster noise.

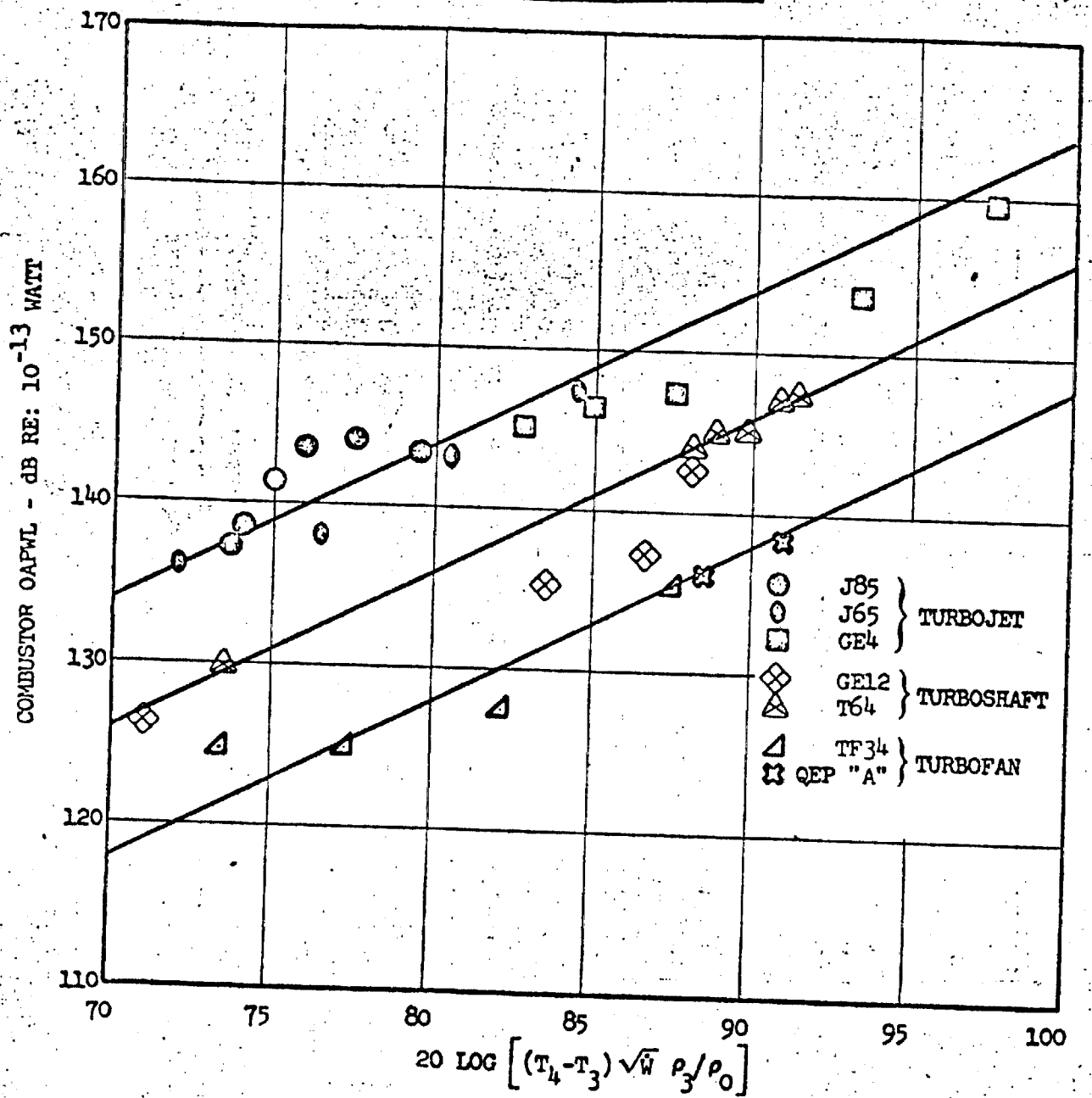
8.7.7 FLIGHT NOISE ESTIMATES

The 200' sideline static untreated engine noise levels were extrapolated to flight conditions using the procedure detailed in 8.7.5. The turbomachinery suppression delta's were then applied to produce treated engine noise levels in flight. The resultant component levels for a typical trijet at takeoff and approach are shown in Figures 8.7.7 and 8.7.8 for configuration 3U. Similar charts for configuration 7U are shown in Figures 8.7.9 and 8.7.10. The levels for configuration 7U were derived from 3U by removing the booster component. Since 7U has the boosters located aft of the fan no measurable contribution from the boosters in anticipated due to attenuation through the fan rotor.

Figures 8.7.7 and 8.7.8 show the booster component to be the dominant source at takeoff and approach for configuration 3U. The dominance of this component is due to the high source levels and lack of suppression. Figures 8.7.9 and 8.7.10 indicate that the dominant sources for configuration 7U are the fan inlet, fan exhaust, core and jet at takeoff and approach, indicating a balanced design.

Relative to the direct drive baseline engine defined in the STEDLEC program, the front booster configuration (3U) is approximately 3 EPNdB higher at takeoff and 3.5 EPNdB higher at approach (Figure 8.7.11) The higher levels for the 3U configuration are directly attributable to the booster component, both at takeoff and approach. The geared fan configuration using aft boosters (7U) is nearly identical to the baseline in terms of overall noise level. This was anticipated since the parameters controlling overall noise were very similar for both engines. The overall levels shown in Figure 8.7.11 indicate the forward booster configuration to be substantially noisier at all conditions compared to more conventional designs. Further, the possibility of achieving noise reduction on forward radiated booster noise is doubtful, making this configuration (3U) unattractive from an acoustic point of view.

CORE NOISE PREDICTION METHOD



~~FIGURE 3.2.4 POWER LEVEL CORRELATION~~

Figure 8.7.1

FORWARD RADIATED K[illegible] NOISE

- BPF 3150 Hz
- HARD GROUND
- INCLUDES EXTRA GROUND ATTENUATION
- 200 FT. SIDELINE
- MAX FORWARD ANGLE
- SINGLE ENGINE

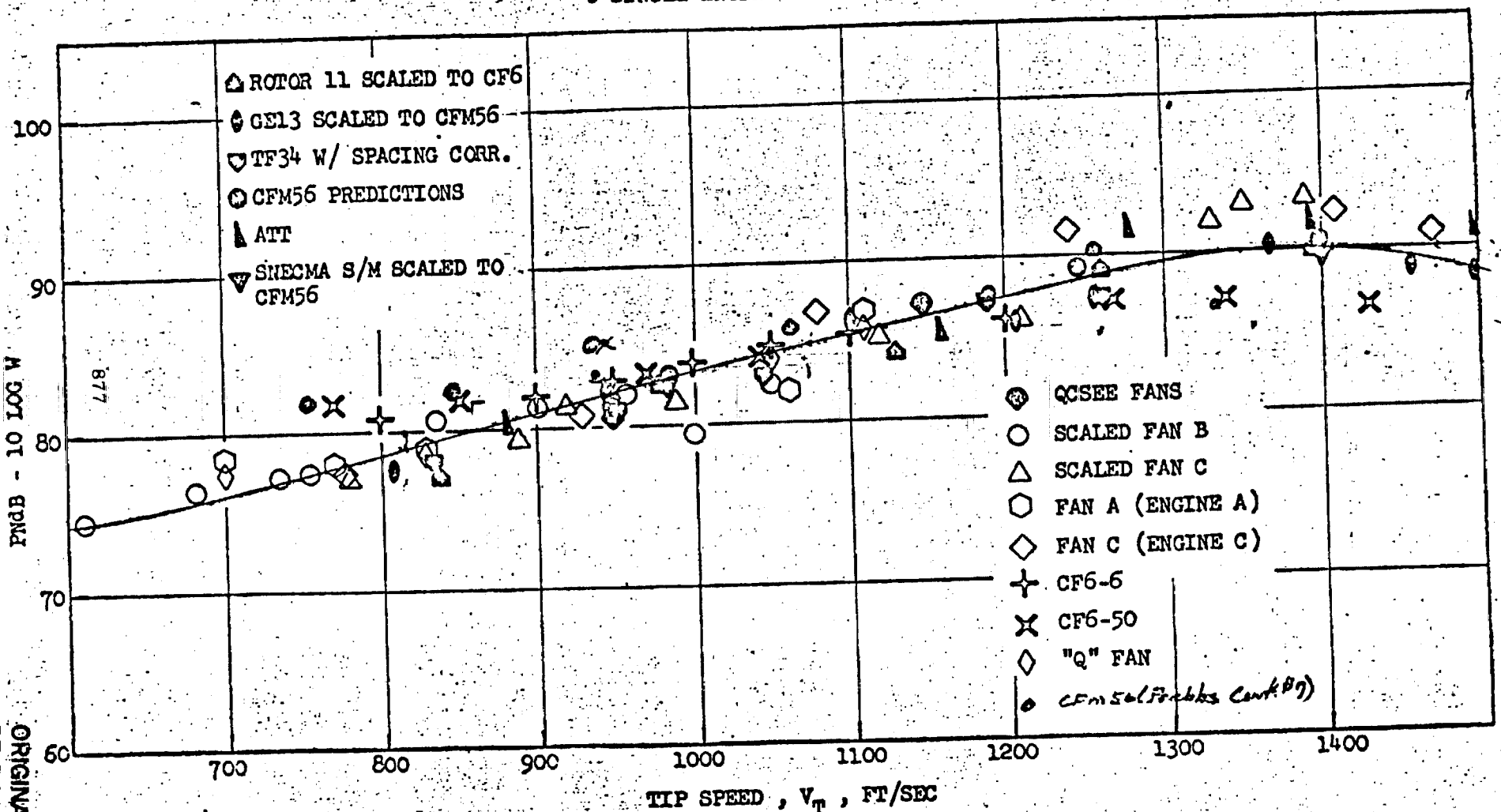


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FIGURE 1

Figure 8.7.2

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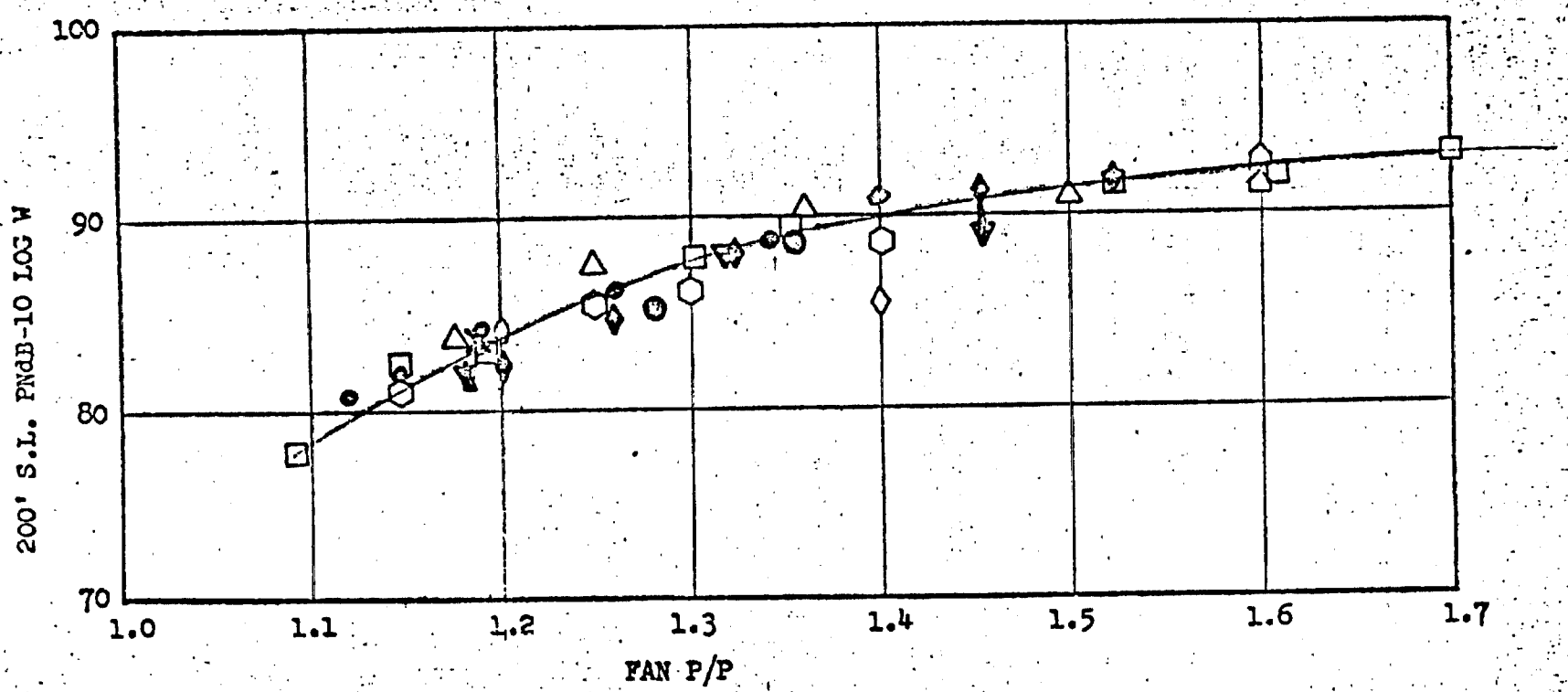
AFT RADIATED FAN NOISE

- 200 FT. SIDELINE, MAX AFT ANGLE
- SINGLE STAGE FAN
- NO IGV
- 2 - CHORD B/V SPACING
- BPF ~ 3200 Hz
- HARD GROUND
- AFT CONTRIBUTION OF INLET RADIATED NOISE NOT INCLUDED
- JET NOISE AND CORE INTERNAL NOISE EXCLUDED
- INCLUDES EXTRA GROUND ATTENUATION



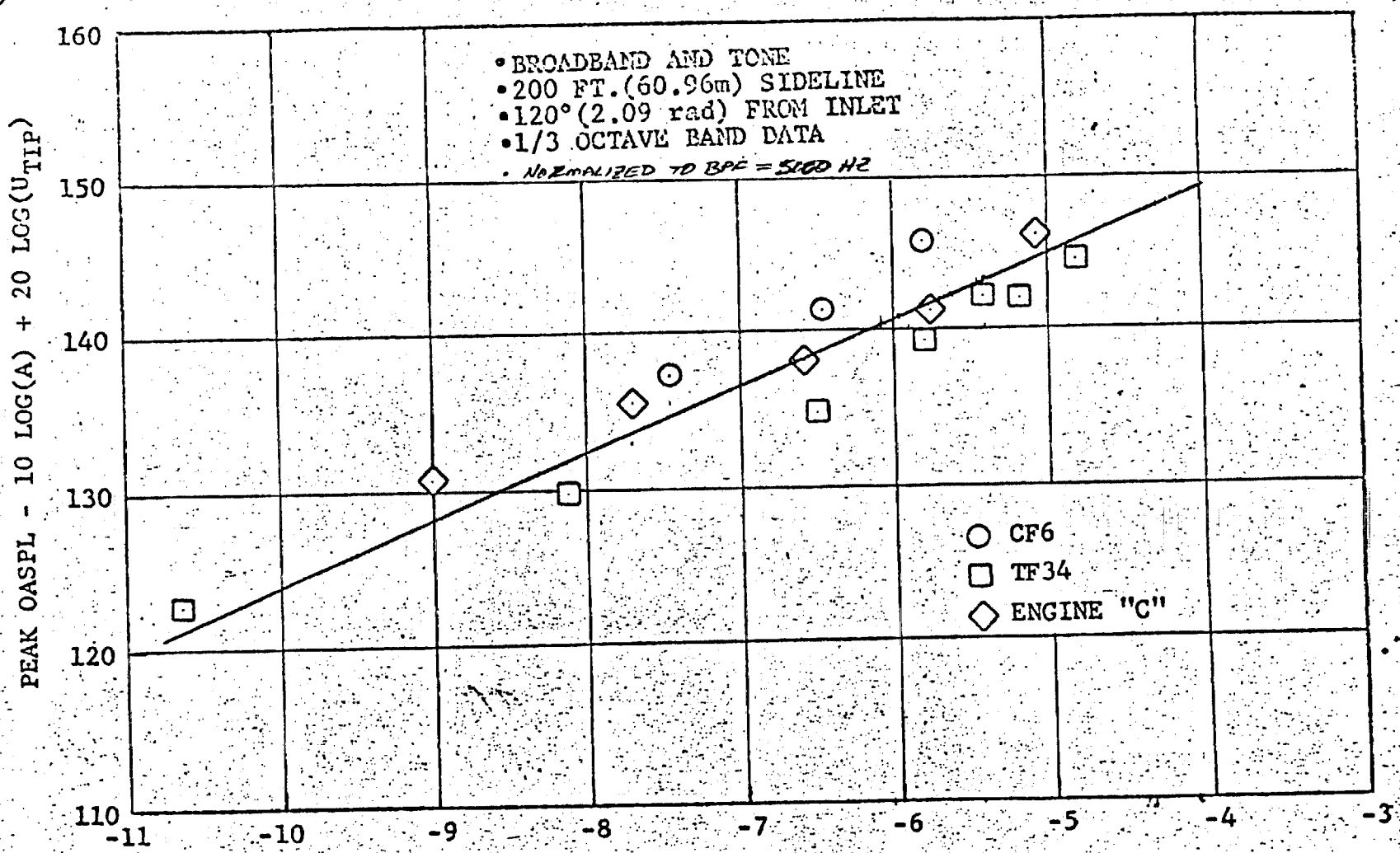
TF34 WITH SPACING CORR.
CFM56 PREDICTION
CFM56 S/M (SNECMA)

QCSEE ENGINES
NASA QEP ENGINE "C"
NASA QEP ENGINE "A"
NASA QF3
NASA QF9
NASA QF5
NASA QF6
CF6-50
CFM56 (Peebles Cont. #7)

FIGURE 2

Figure 5

8.7.3



$$\frac{\Delta T}{T} = \left[1-\left(\frac{1}{P_R}\right)^{\frac{\gamma-1}{\gamma}}\right] \qquad P_R = (P_{T_0}/P_{S_2})$$

Figure 8.7.4 ~~FIGURE 8.2.8-5~~ TURBINE NOISE CORRELATION. THIS CORRELATION INCLUDES BOTH BROADBAND AND DISCRETE FREQUENCY NOISE. ~~TO BE USED FOR QUICK (APPROXIMATE) ESTIMATES.~~

8.7-I

TABLE ~~8~~

CYCLE DATA.

FOR GEARED FAN STUDY

	TAKEOFF	APPROACH.
ALTITUDE - FT	1325	370
M_N	0.24	0.206
ΔT_0 - °F	+18	+18
F_N/δ_0 - LB.	16144	6785
% F_N/δ_0	100	40
β	10.4	12.6
$N1/\sqrt{\theta}$ - RPM	3750	2726
FAN DIAMETER - in	68.75	68.75
TIP SPEED - FT/SEC	1125	818
W2# - LB/SEC	844	598
FAN P/P	1.4	1.17
A8 - sq. ft.	14.8	14.8
W8 - LB/SEC	853	596
V8 - FT/SEC	905	602
T3 - °R	1530	1270
T4 - °R	3015	2315
P3 - LB/in²	427	227
W3 - LB/SEC	69.6	42.4

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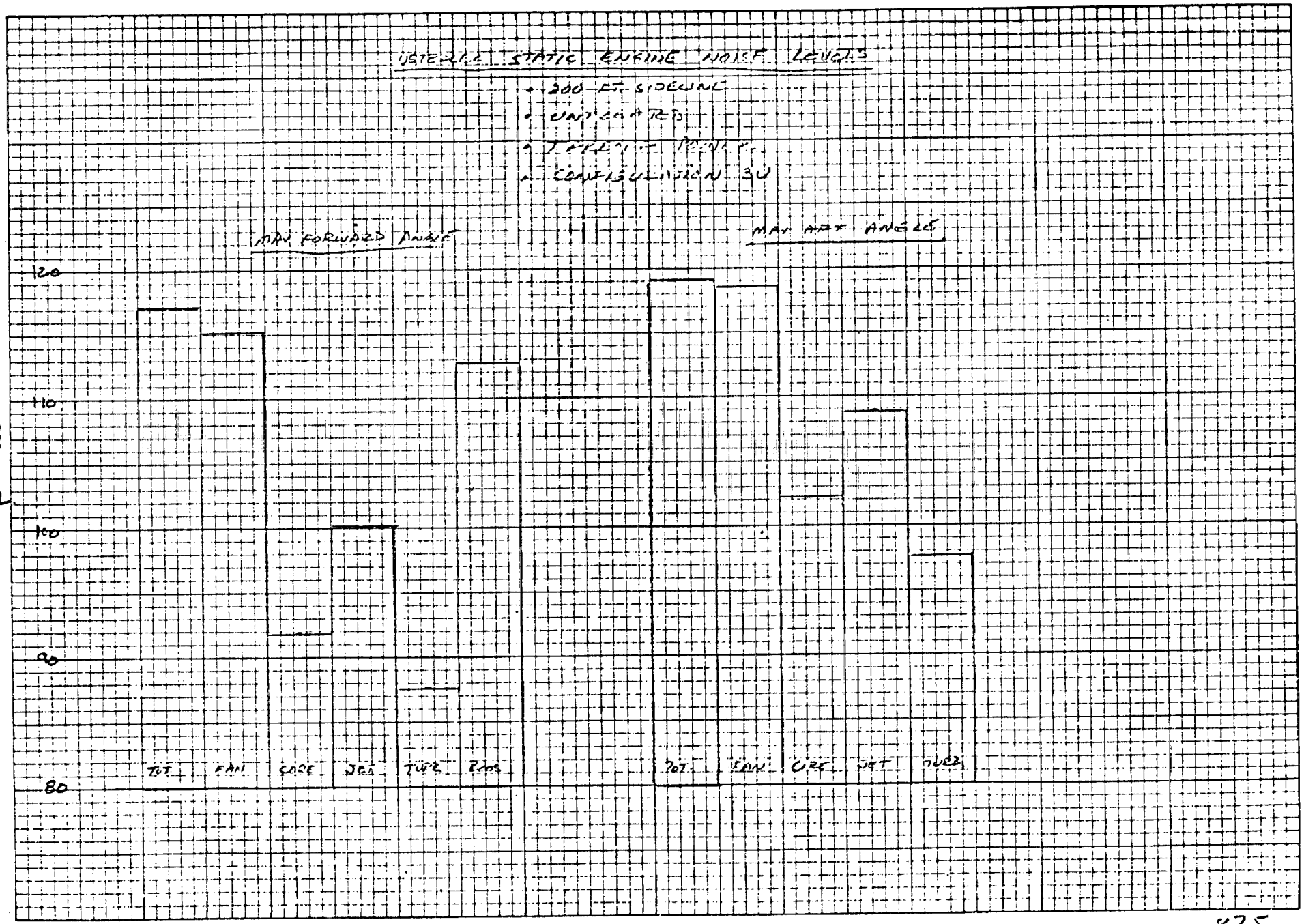

Figure E7.5

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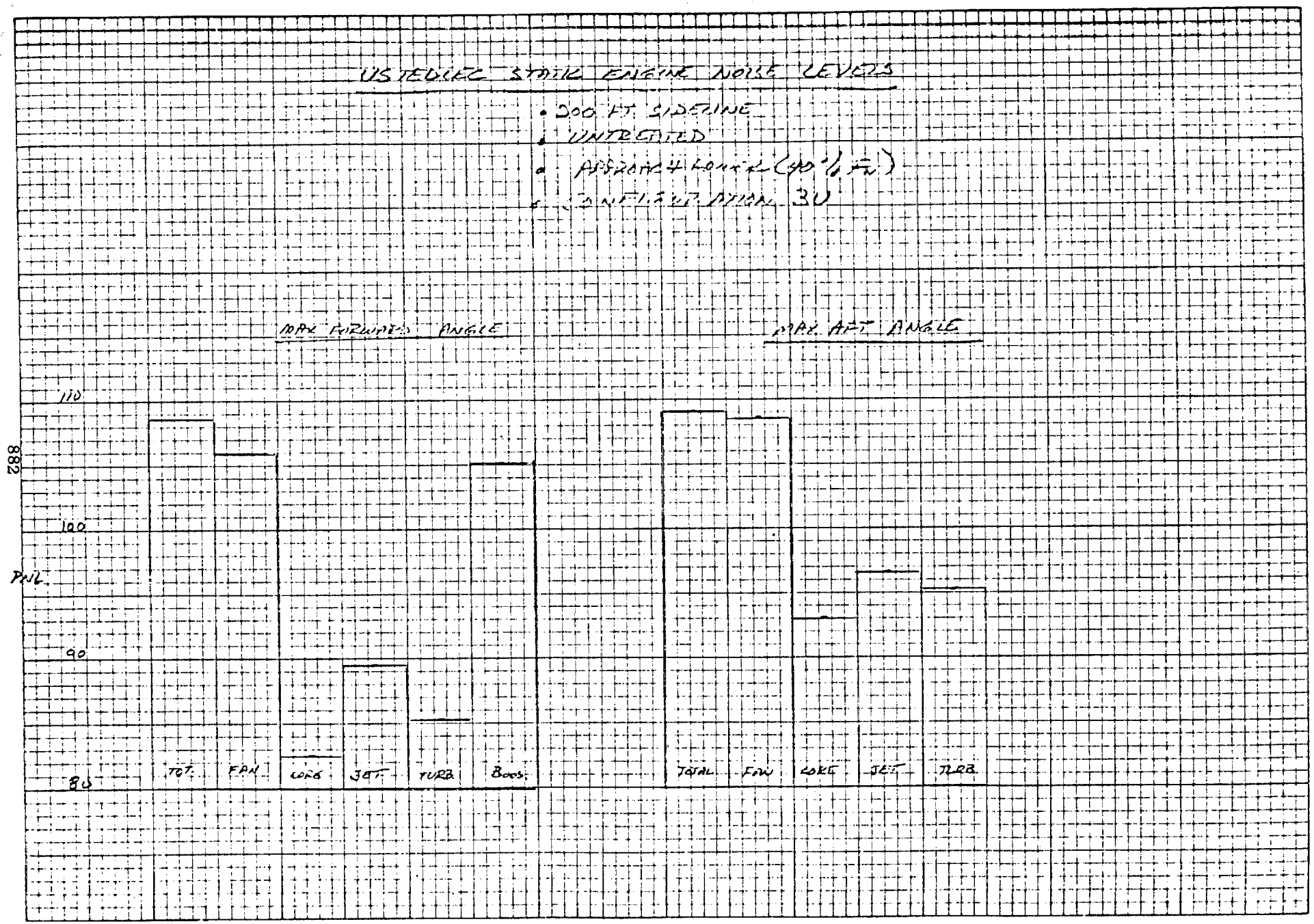

Figure 8.7.6

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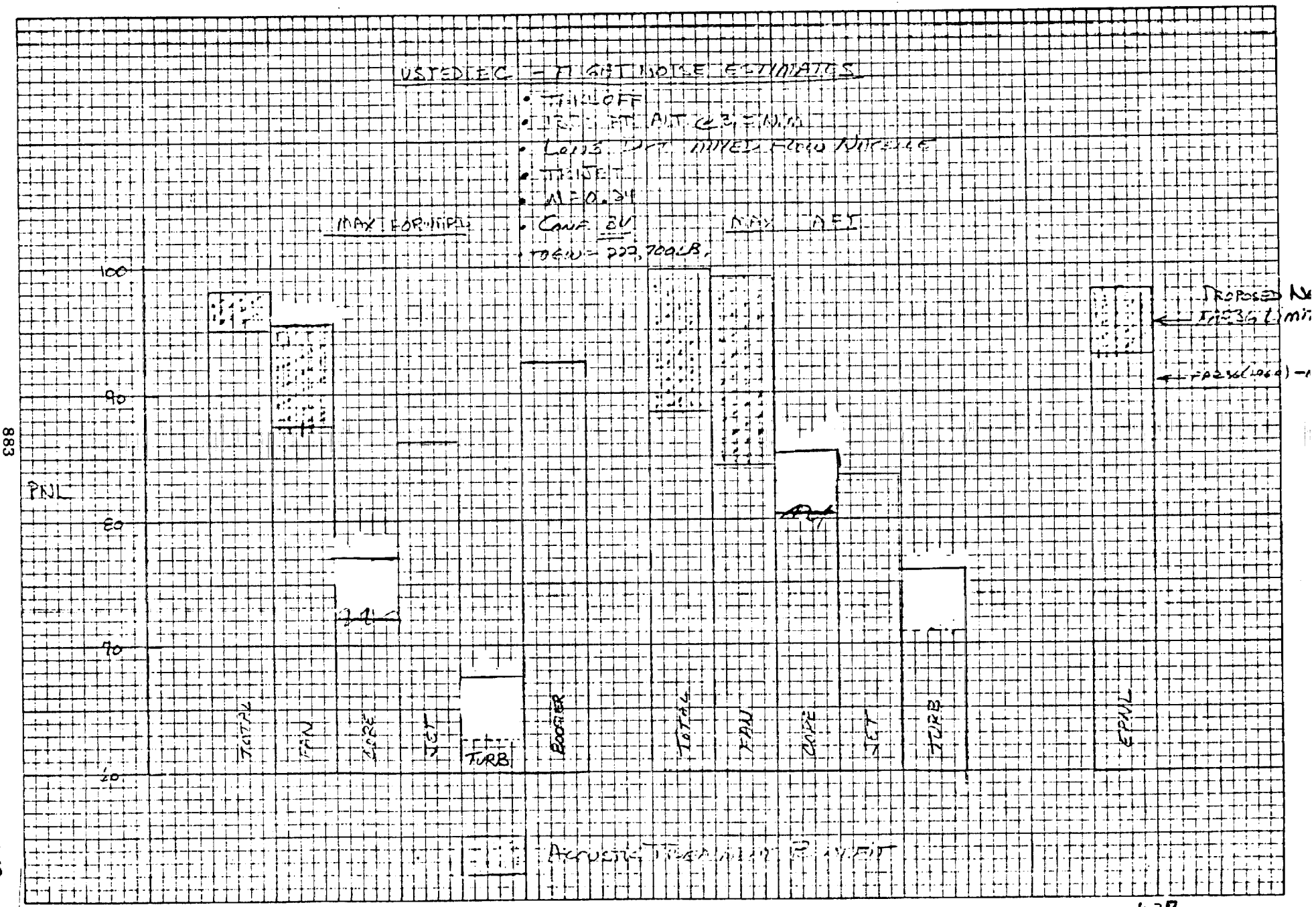

Fig 8.27

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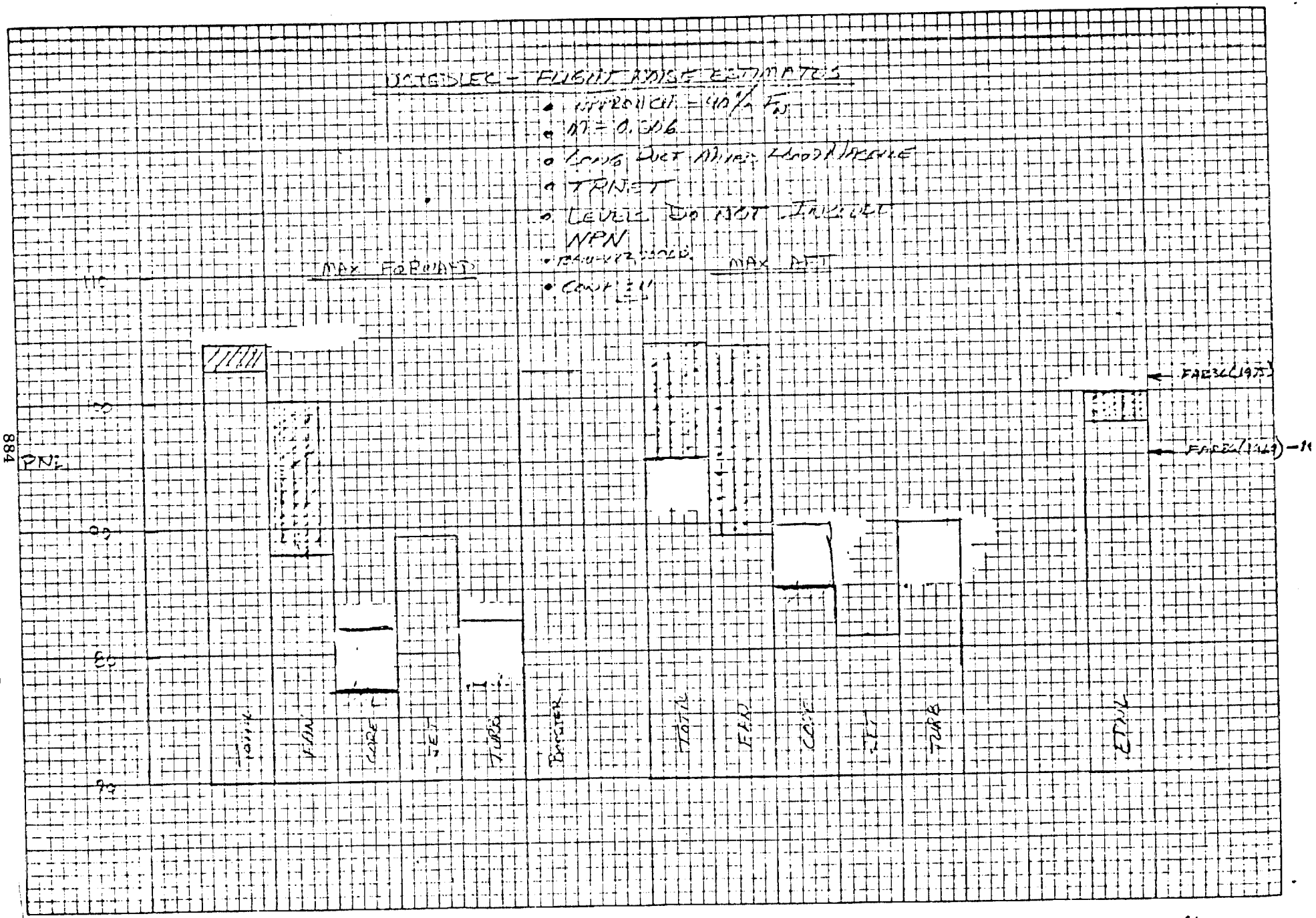

Fig. 3.7.8

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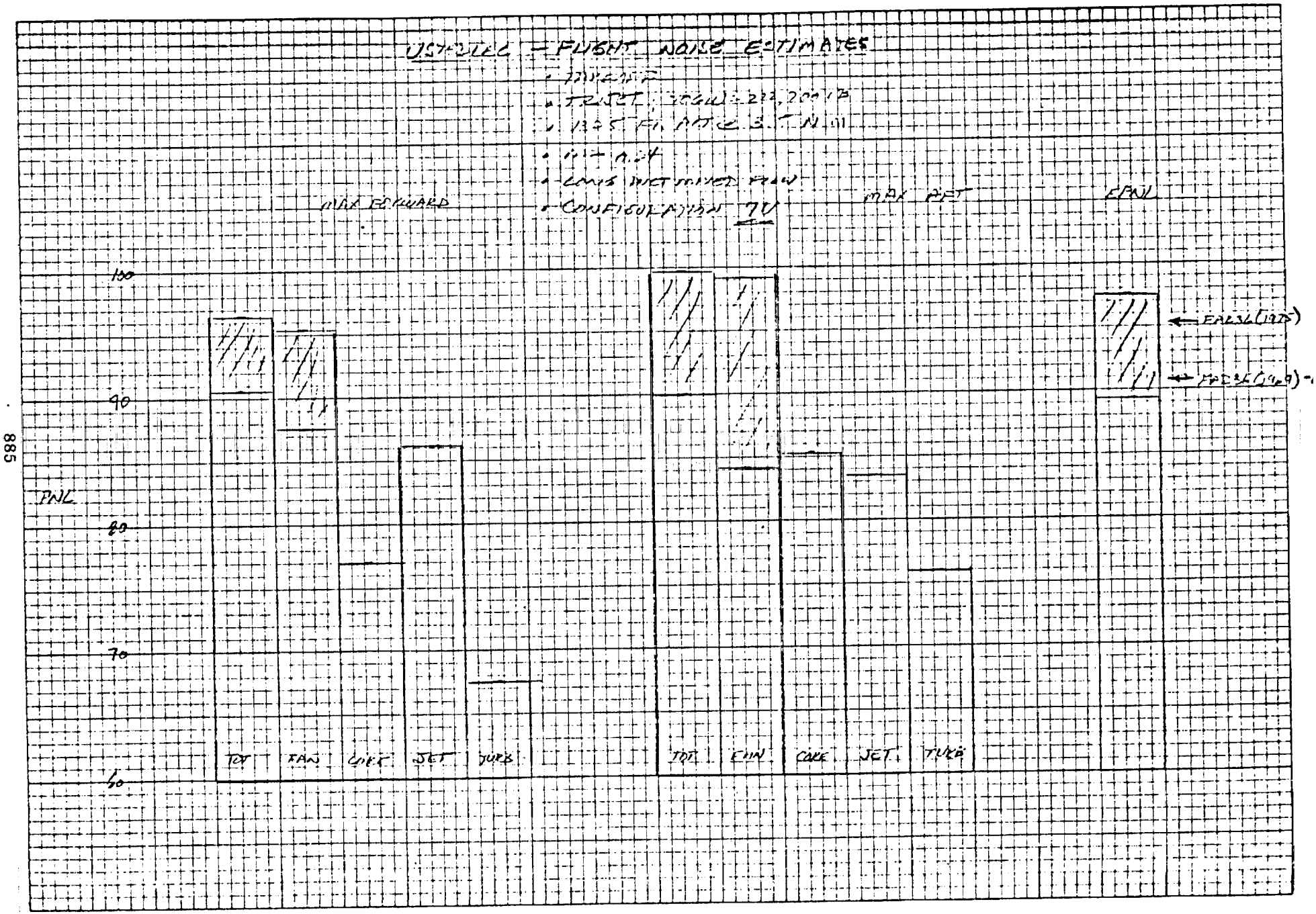

Fig. 8.7.9

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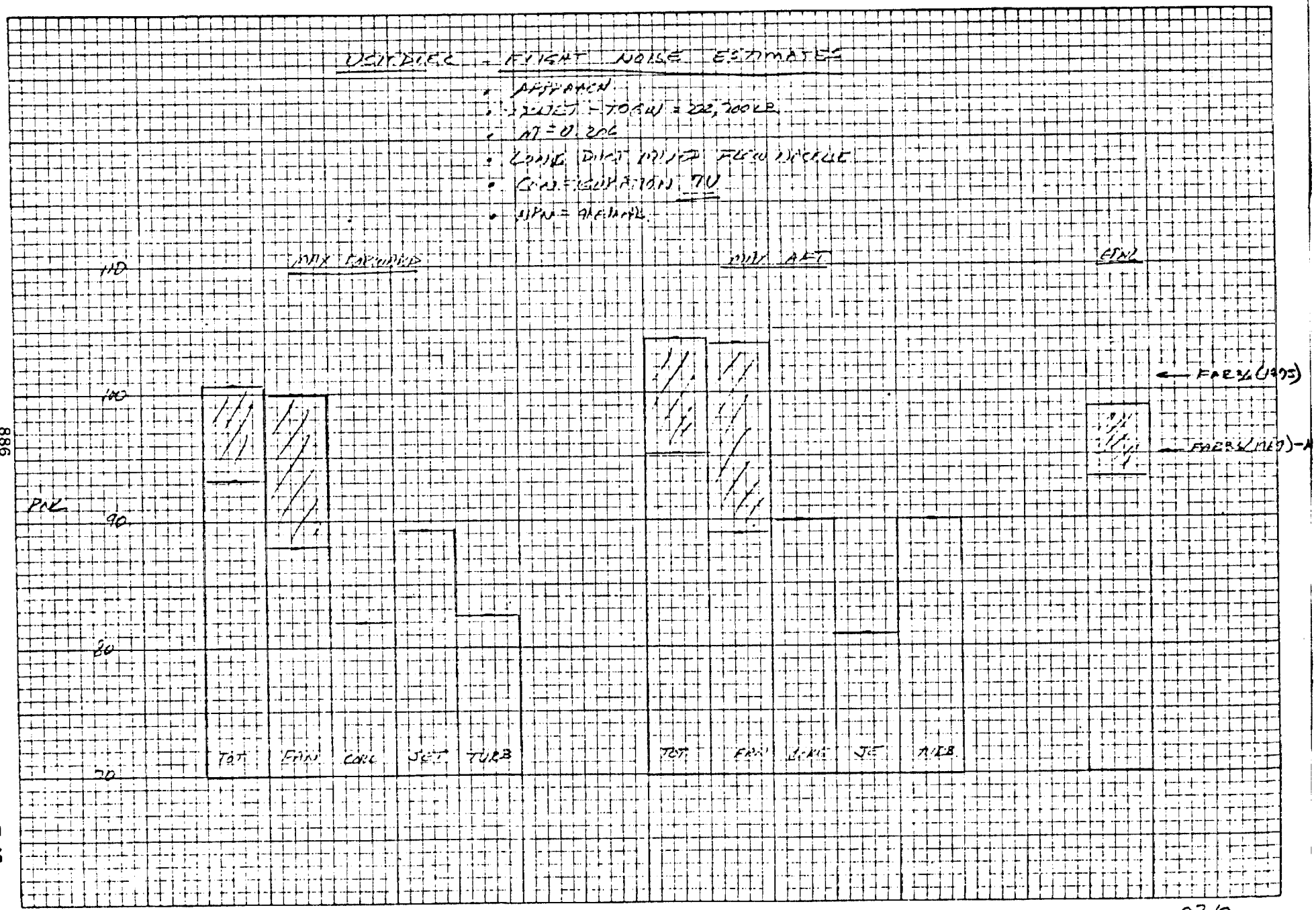

Fig. 8.7.10

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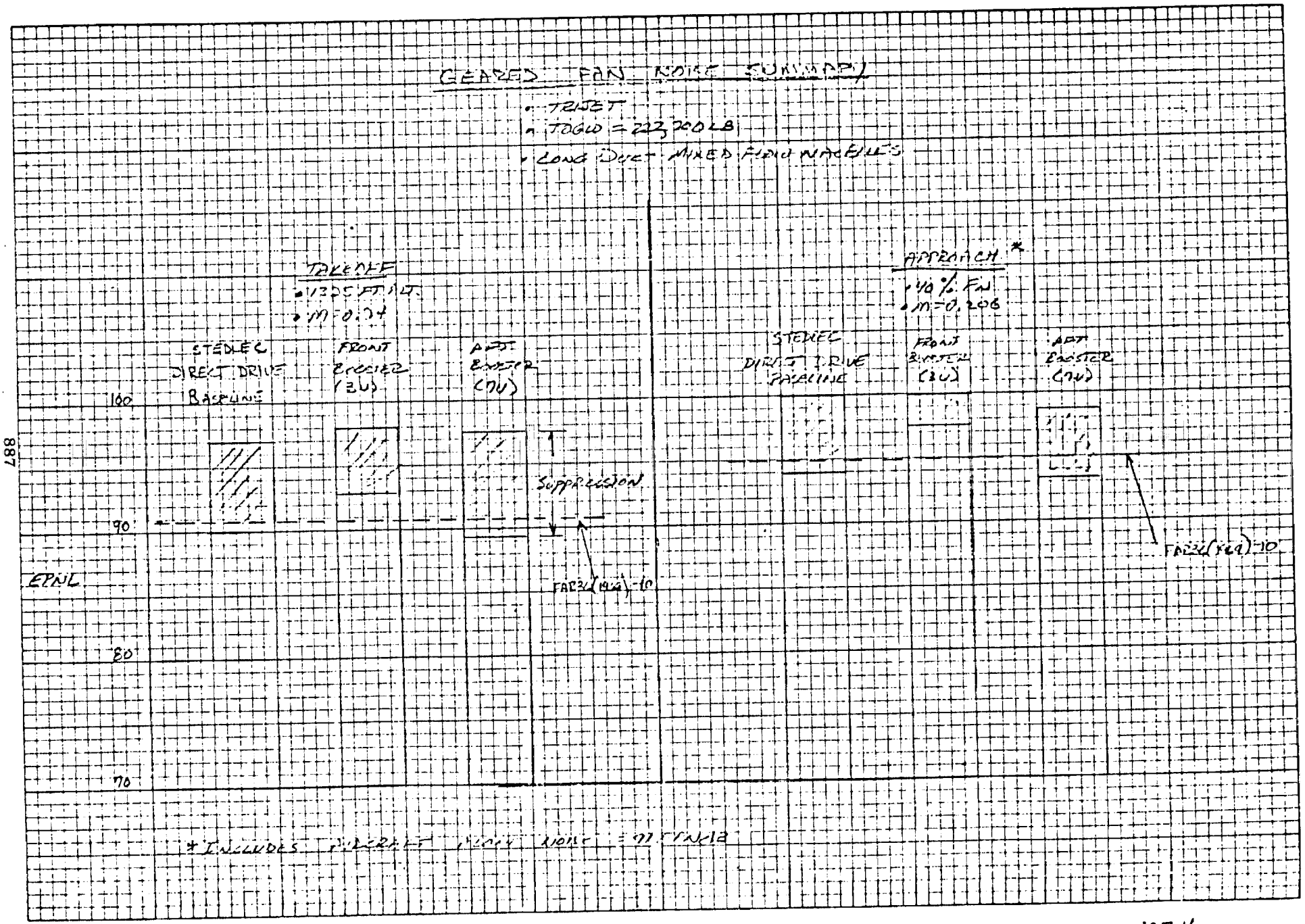

Fig. 7.8.7.11

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Task II - Variable Boost Geared Fan Detail Design

Task II - Variable Boost Geared Fan Detail Design

9.1 Introduction

The performance of turbofans at high turbine inlet temperatures can be improved by increasing the cycle pressure ratio and therefore thermal efficiency. Previous studies had shown that the benefits of improved SFC tend to be offset by the various design penalties necessary to allow engine operation at higher cycle pressure ratios. These limiting design conditions are critical only at takeoff power and at sea level and low altitudes. Therefore, the concept was evolved to design an engine which would have high cycle pressure (in this study 45:1) at altitude cruise, but by the use of low pressure compressor (booster) variable stators which are closed to produce a lower pressure ratio at the sea level takeoff critical design condition.

The engine studied employs the same fan design as the pressure ratio 1.55 geared fan described in Section 8. Also a three stage geared turbine, a nine stage - 14:1 core compressor driven by a single stage turbine are used. The booster required three stages rather than two for the fixed geometry geared fan.

9.2 Cycle Definition and Performance

9.2 Tabulation of Component Efficiency Levels

8-U P/P 1.55 Variable Boost Geared Fan

35K/.8/+18°F Max. Climb

Efficiencies	
Fan Tip	.880
Fan Hub & Booster	.8710 **
Compressor	.860
HP Turbine	.898
LP Turbine	.9195
Mixing	.75
Combustor	.9875
Gear	.99
Pressure Ratios	
Inter Compressor, P_{2c}/P_{24}	.984
Inter Turbine, P_{54}/P_{51}	1.0
Fan Duct, P_{27}/P_{25}	.9956
Core Duct, P_{59}/P_{56}	.9940
Combustor, P_4/P_3	.947

Cooling & Leakage, % of W_{2c} Energy Charge*		Sink
Sump Purge	0.5/.25	Post LPT
LP Turbine	2.22/.612	
HP Turb ine & Leakage	4.9/1.0	Post HPT

$$* \ \% \text{ ENERGY CHARGE} = \frac{h_{ex}-h_{2c}}{h_3-h_{2c}} = \frac{\text{enthalpy rise to cooling flow extraction}}{\text{Compressor enthalpy rise}}$$

** CYCLE DATA RUN WITH ETA IC = .8775

ENGINE EVALUATION, pg. 9-54 — 9-57 CONTAINS ADJUSTMENTS OF ETA B = −0.65 (EQUIVALENT TO ETA IC = .8710 - .8775)

TABLE - CYCLE DATA
ENGINE P-U

CASE	ALT	M	ΔTo °F	RATING
1	35000	.8	+18.1	MCC
2	↓	↓		↓
3				MCL
4	0	0	+27	TO

CYCLE NOMENCLATURE

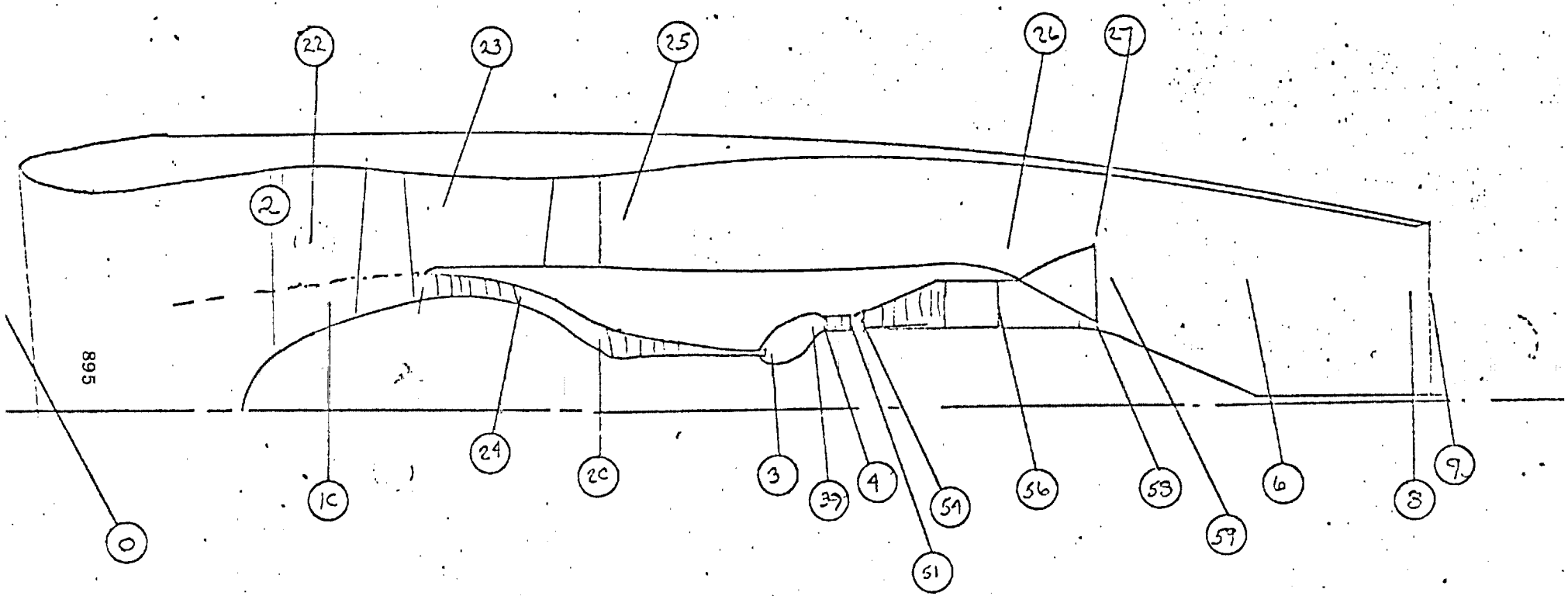
Alt	Altitude, ft
M	Mach Number
P	Pressure, Psia
W	Flow, lb/sec
T	Temperature, ^{o}R
DELTO	To-Tstd day
ETAR	Ram Recovery
B, β	Bypass Ratio
FNG MX	~~Fully Mixed Net Thrust, lbs~~
SFC MX	Specific Fuel Consumption Based on FNG MX lbm/hr/lb
FNG-PM	Partially Mixed Net Thrust, lbs
SFC-PM	Specific Fuel Consumption Based on FNG PM
PCNF	Fan Physical Speed, %
NF	Fan Physical Speed, RPM
ECNF*	Fan Corrected Speed
ETAF	Fan Tip Adiabatic Efficiency
Q	Dynamic Pressure
ETAIC	Fan Hub + Booster Adiabatic Efficiency
PCNG	Core Physical Speed, %
NG	Core Physical Speed, RPM
PCNG*	Core Corrected Speed, %
WFM	Fuel Flow, lb/hr
ETABM	Burner Efficiency
TFFC	HP Turbine Flow Function
NRT4	HP Turbine Corrected Speed

*Indicates a corrected flow

CYCLE NOMENCLATURE (Cont.)

DH/T4	HP Turbine Energy Function
TFF2TC	LP Turbine Flow Function
N/RT54	LP Turbine Corrected Speed
DH/T54	LP Turbine Energy Function
V	Velocity, ft/sec
CF	Flow Coefficient
AE	Effective Area, in^2
CV	Velocity Coefficient
FGG-MX	Mixed Gross Thrust, lb
FD	Ram Drag
~~FGG-PM~~	~~Partial Mixed Gross Thrust, lb~~
~~PC-MX~~	~~Mixing Effectiveness~~
FGG-PM	Partial Mixed Gross Thrust, lb
PC-MX	Mixing Effectiveness

$$= \frac{F_G - F_{G\ SEPARATE}}{F_{G\ MIX\ IDEAL} - F_{G\ SEPARATE}}$$



Station Designations

NASA-USTEDLEC/BU CYCLE (TASK 2)
DUAL-SPOOL, LOW FAN P/P, AND FORWARD COUNTERROTATING BOOSTER
NOTE - W2C* = PRINTOUT VALUE * .995
NOTE - FOR THIS CYCLE, LPT RPM = GEAR RATIO * FAN RPM

CASE	1.00	2.00	3.00	4.00
ALT	35000.	35000.	35000.	0.
MO	0.800	0.800	0.800	0.
PC	50.00	50.00	50.00	50.00
RC	40.00	40.00	40.00	40.00
FNG-MX	10856.5	10855.6	9928.5	39018.8
SFCGMX	0.5301	0.5302	0.5292	0.2741
FNG-CF	0.	0.	0.	0.
SFCGCF	0.	0.	0.	0.
FNG-PM	10756.4	10755.6	9842.6	38953.3
SFCGPM	0.5350	0.5351	0.5338	0.2746
		MX CLIMB	MX CRUISE	TO
DELTO	18.00	16.00	18.00	27.00
TO	411.85	411.85	411.85	545.67
PO	3.4580	3.4580	3.4580	14.6960
T2	464.80	464.80	464.80	545.67
ETAR	1.0000	1.0000	1.0000	1.0000
P2	5.274	5.274	5.274	14.696
P22/P2	0.9996	0.9996	0.9996	0.9996
M21	0.7000	0.6998	0.6706	0.5028
P22	5.272	5.272	5.272	14.690
B	9.4568	9.4566	9.7306	11.5417
PATH	PMIX	PMIX	PMIX	PMIX
WB/W2C	0.0020	0.0020	0.0020	0.0020
WB	0.	0.	0.	0.
PBD	233.56	233.56	219.73	417.91
TBD	1519.5	1519.5	1490.4	1553.4
WBI	0.140	0.140	0.134	0.246
PBI	92.46	92.45	87.58	162.94
TBI	1204.1	1204.1	1183.0	1227.3
HPE	0.	0.	0.	0.
PCNF	94.664	94.661	92.132	86.740
NF	2917.0	2916.9	2839.0	2672.8
PCNF*	100.000	99.996	97.325	84.567
W2*	1934.16	1934.07	1894.49	1585.81
W2	732.98	732.94	717.94	1545.46
P23/22	1.5500	1.5500	1.5061	1.3602
Z22	0.6627	0.6629	0.6237	0.6664
ETAF	0.8800	0.8800	0.8823	0.8754
HPFAN	15868.	15868.	14465.	27637.
RNI22	0.4132	0.4132	0.4132	0.9371
SMF	39.44	39.43	40.62	32.05
M23	0.5500	0.5499	0.5526	0.4843
P25P23	1.0000	1.0000	1.0000	1.0000
M25P	0.5500	0.5499	0.5549	0.4961
AE25P	4429.4	4429.4	4429.4	4429.4

NASA-USTFDLEC/8U CYCLE (TASK 2)
DUAL-SPOOL, LOW FAN P/P, AND FORWARD COUNTERROTATING BOOSTER
NOTE - W2C* = PRINTOUT VALUE * .995
NOTE - FOR THIS CYCLE, LPT RPM = GEAR RATIO * FAN RPM

CASE	1.00	2.00	3.00	4.00
P25P	8.172	8.172	7.940	19.981
P2525P	1.0000	1.0000	1.0000	1.0000
P25	8.172	8.172	7.940	19.980
Q25	1.4094	1.4093	1.3895	2.9092
T25	535.5	535.5	530.4	603.0
M25	0.5500	0.5500	0.5550	0.4962
W25	662.88	662.85	651.04	1422.23
P26/25	0.9956	0.9956	0.9955	0.9963
P26	8.136	8.136	7.905	19.906
M26	0.4000	0.4000	0.4029	0.3669
P27/26	1.0000	1.0000	1.0000	1.0000
P27	8.136	8.136	7.905	19.906
M27	0.4800	0.4799	0.4839	0.4367
PS27	6.948	6.949	6.734	17.463
W27	662.88	662.85	651.04	1422.23
T27	535.5	535.5	530.4	603.0
Z1C	0.6616	0.6615	0.6860	0.1921
P24/1C	3.3180	3.3177	3.2105	2.0451
W1C*	184.97	184.96	176.55	126.45
W1C	70.10	70.09	66.91	123.23
ETA1C	0.8775	0.8775	0.8788	0.8820
SFF1C	0.66378	0.66378	0.66378	0.52417
HP1C	5155.	5154.	4754.	5870.
P24	17.493	17.491	16.926	30.043
T24	681.5	681.5	674.2	685.8
M24	0.4500	0.4500	0.4390	0.4660
Q24	2.1539	2.1534	1.9967	3.9275
P2C/24	0.9840	0.9840	0.9847	0.9830
AE2D	0.	0.	0.	0.
WB/W24	0.	0.	0.	0.
PS242D	0.	0.	0.	0.
DP/Q2D	0.	0.	0.	0.
P2D/24	0.	0.	0.	0.
W2D	0.	0.	0.	0.
M2D	0.	0.	0.	0.
PS2D	0.	0.	0.	0.
PS25P	6.653	6.653	6.441	16.889
P2C	17.213	17.211	16.666	29.532
T2C	681.5	681.5	674.2	685.8
PCNG	101.717	101.717	100.459	103.455
PCNG*	88.738	88.739	88.113	89.968
NG	14824.	14824.	14641.	15078.
PCNG*M	99.906	99.907	99.202	101.291
WARC2C	0.	0.	0.	0.
W2C	70.10	70.09	66.91	123.23
W2C*	68.60	68.60	67.26	70.51

NASA-USTEDLEC/8U CYCLE (TASK 2)
DUAL-SPOOL, LOW FAN P/P, AND FORWARD COUNTERROTATING BOOSTER
NOTE - W2C* = PRINTOUT VALUE * .995
NOTE - FOR THIS CYCLE, LPT RPM = GEAR RATIO * FAN RPM

CASE	1.00	2.00	3.00	4.00
P3/P2C	13.9400	13.9406	13.5475	14.5324
SMC	4.80	4.79	5.59	3.55
Z2C	0.5843	0.5843	0.5779	0.5886
ETAC	0.8605	0.8604	0.8630	0.8530
HPC	20480.	20480.	18999.	37355.
RNI2C	0.8324	0.8324	0.8167	1.4171
P3/P2	45.5123	45.5108	42.8269	29.2153
P3	239.95	239.94	225.79	429.18
PS3	226.89	226.88	213.38	406.13
T3	1519.5	1519.5	1490.4	1553.4
WARC3	0.	0.	0.	0.
WAR3	0.	0.	0.	0.
W3	67.71	67.71	64.63	119.04
W31	60.33	60.33	57.59	106.06
M3	0.2890	0.2890	0.2903	0.2872
P4/P3	0.9470	0.9470	0.9465	0.9477
WFM	5755.2	5755.2	5253.9	10695.1
ETABM	0.9875	0.9875	0.9875	0.9875
FAR339	0.02650	0.02650	0.02534	0.02801
T39	3049.8	3049.8	2967.2	3153.3
T4	2960.0	2960.0	2880.0	3060.0
WAR4	0.	0.	0.	0.
FAR4	0.02473	0.02473	0.02366	0.02615
P4	227.23	227.22	213.71	406.71
W4	66.23	66.23	63.15	116.60
TFFC	15.86	15.86	15.86	15.86
N/RT4	272.47	272.47	272.82	272.57
DH/T4	0.07394	0.07394	0.07393	0.07409
ETAT	0.8980	0.8980	0.8980	0.8980
HPT	20509.	20509.	19026.	37403.
HPAUX	28.99	28.99	27.16	47.14
P4/P51	4.0570	4.0570	4.0623	4.0638
P51	56.009	56.008	52.609	100.082
T51	2199.0	2199.0	2134.9	2277.9
FAR51	0.02350	0.02350	0.02247	0.02484
WAR51	0.	0.	0.	0.
W51	69.63	69.63	66.40	122.57
M51	0.4800	0.4800	0.4796	0.4824

NASA-USTEDLEC/8U CYCLE (TASK 2)
DUAL-SPOOL, LOW FAN P/P, AND FORWARD COUNTERROTATING BOOSTER
NOTE - W2C* = PRINTOUT VALUE * .995
NOTE - FOR THIS CYCLE, LPT RPM = GEAR RATIO * FAN RPM

CASE	1.00	2.00	3.00	4.00
P54/51	1.0000	1.0000	1.0000	1.0000
P54	56.009	56.008	52.609	100.082
T54	2199.0	2199.0	2134.9	2277.9
FAR54	0.02350	0.02350	0.02247	0.02484
WAR54	0.	0.	0.	0.
W54	69.63	69.63	66.40	122.57
TEF2TC	58.30	58.30	58.32	58.45
N/R154	62.21	62.20	61.44	56.00
DH/T54	0.09704	0.09704	0.09583	0.08482
ETA2T	0.9090	0.9090	0.9077	0.8970
HP2T	21023.	21022.	19219.	33507.
RNI54	0.7746	0.7745	0.7516	1.3314
P54/56	7.0129	7.0124	6.8486	5.3046
P56	7.986	7.987	7.682	18.867
T56	1439.5	1439.5	1402.1	1595.6
W56	71.55	71.55	68.23	125.95
M56	0.4500	0.4500	0.4370	0.3366
P58/56	0.9940	0.9940	0.9943	0.9965
P58	7.939	7.939	7.638	18.801
PS58	6.948	6.949	6.734	17.456
M58	0.4500	0.4500	0.4369	0.3357
P59	8.051	8.051	7.814	19.656
M59	0.4915	0.4915	0.4915	0.4305
T59	629.5	629.5	618.4	690.2
W59	734.44	734.40	719.27	1548.18
P6/P59	1.0000	1.0000	1.0000	1.0000
FAR8MX	0.00218	0.00218	0.00203	0.00192
WAR8MX	0.	0.	0.	0.
W8-MX	734.44	734.40	719.27	1548.18
T8-MX	629.5	629.5	618.4	690.2
P8-MX	8.051	8.051	7.814	19.656
P8P0MX	2.3283	2.3282	2.2598	1.3375
M8-MX	1.0000	1.0000	1.0000	0.6587
V8-MX	1122.8	1122.8	1112.9	813.2
CF8-MX	0.9965	0.9965	0.9965	1.0165
A8-MX	4320.3	4320.3	4320.3	4320.8
V9-MX	1122.8	1122.8	1112.9	813.2
CV9-MX	0.9978	0.9978	0.9974	0.9970
CFG-MX	1.0000	1.0000	1.0000	1.0000
FGG-MX	29000.	28998.	27700.	39019.
FD	18143.	18142.	17771.	0.
FGG-PM	28900.	28898.	27614.	38953.
PC-MX	0.750	0.750	0.750	0.750

NASA-USTEDLEC/BU CYCLE (TASK 2)
DUAL-SPOOL, LOW FAN P/P, AND FORWARD COUNTERROTATING BOOSTER
NOTE - W2C* = PRINTOUT VALUE * .995
NOTE - FOR THIS CYCLE, LPT RPM = GEAR RATIO * FAN RPM

CASE	1.00	2.00	3.00	4.00
CASE	1.00	2.00	3.00	4.00
FARBCF	0.02285	0.02285	0.02186	0.02416
W28-CF	662.9	662.8	651.0	1422.2
T28-CF	535.5	535.5	530.4	603.0
P28-CF	8.1358	8.1356	7.9046	19.9062
P28POC	2.3527	2.3527	2.2859	1.3545
AE28CF	3544.7	3544.6	3566.2	3680.3
M28-CF	0.	0.	0.	0.
V28-CF	1035.7	1035.7	1030.8	775.6
W8-CF	71.55	71.55	68.23	125.95
T8-CF	1439.5	1439.5	1402.1	1595.6
P8-CF	7.939	7.939	7.638	18.801
P8POCF	2.2957	2.2959	2.2088	1.2793
M8-CF	0.	0.	0.	0.
V8-CF	1683.7	1683.7	1662.4	1144.3
AE8-CF	652.5	652.4	637.8	600.1
CF8-CF	0.	0.	0.	0.
V9-CF	1683.7	1683.7	1662.4	1144.3
CV9-CF	0.9978	0.9978	0.9974	0.9970
CV29CF	0.	0.	0.	0.
V29-CF	1180.9	1180.9	1157.7	775.6
CFG-CF	1.0000	1.0000	1.0000	1.0000
FGD-CF	24334.0	24332.5	23428.3	34290.8
FGM-CF	4266.6	4266.7	3929.0	4466.8
CFGDCF	1.0000	1.0000	1.0000	1.0000
FGG-CF	0.	0.	0.	0.
FN-CF	0.	0.	0.	0.
SFCGCF	0.	0.	0.	0.
FNU/W2	14.67	14.67	13.71	25.20
D/F-PC	5.1	5.1	5.5	0.
CD	0.1843	0.1843	0.1843	0.1843
FDI	552.3	552.3	541.0	0.
SWFMG	1.00000	1.00000	1.00000	1.00000
SFNG	1.0000	1.0000	1.0000	1.0000
WC3/2C	0.0759	0.0759	0.0759	0.0759
WC4/2C	0.0614	0.0614	0.0614	0.0614
WC5I2C	0.0360	0.0360	0.0360	0.0360
WC5D2C	0.0125	0.0125	0.0125	0.0125
WC5A2C	0.	0.	0.	0.
WC5S11	0.0050	0.0050	0.0050	0.0050
WC5S12	0.0224	0.0224	0.0224	0.0224
WC5S2C	0.0274	0.0274	0.0274	0.0274
WCI/2C	0.0320	0.0320	0.0320	0.0320
FIBAH	0.3880	0.3880	0.3880	0.3880
FCAH51	0.2850	0.2850	0.2850	0.2850
FCAH54	0.7500	0.7500	0.7500	0.7500
FCH551	1.0000	1.0000	1.0000	1.0000
FCH552	0.2770	0.2770	0.2770	0.2770

NASA-USTEDLEC/BU CYCLE (TASK 2)
DUAL-SPOOL, LOW FAN P/P, AND FORWARD COUNTERROTATING BOOSTER
NOTE - W2C* = PRINTOUT VALUE * .995
NOTE - FOR THIS CYCLE, LPT RPM = GEAR RATIO * FAN RPM

CASE	1.00	2.00	3.00	4.00
AE21	6164.1	6164.1	6164.1	6164.1
AE25P	4429.4	4429.4	4429.4	4429.4
AE25	4429.4	4429.4	4429.4	4429.4
AE26	5637.2	5637.2	5637.2	5637.2
AE27	4892.6	4892.6	4892.6	4892.6
AE24	285.3	285.3	285.3	285.3
AE3	44.3	44.3	44.3	44.3
AE51	156.04	156.04	156.04	156.04
AE56	945.0	945.0	945.0	945.0
AE58	950.7	950.7	950.7	950.7
AE59	5843.3	5843.3	5843.3	5843.3
PCNFRM	100.00	100.00	97.32	84.57
P2322M	1.8750	1.8750	1.8052	1.5730
FFFMB	1406.26	1406.19	1377.41	1152.98
ETAFMB	0.8503	0.8503	0.8525	0.8458
PCN1RM	100.00	100.00	97.32	84.57
P241CM	2.5440	2.5438	2.4724	1.6961
FF1CMB	279.91	279.90	267.25	241.31
SFF1CR	0.9955	0.9955	0.9953	0.9997
ET1CMB	0.8558	0.8558	0.8575	0.7214
SET1CR	0.9952	0.9952	0.9947	0.9997
PCNRTM	99.91	99.91	99.20	101.29
P302CM	11.9475	11.9480	11.6155	12.4487
CFFMB	129.763	129.767	127.327	133.337
SCFFR	0.9998	0.9998	0.9997	1.0000
ETACMB	0.8534	0.8534	0.8562	0.8453
SETACR	1.0003	1.0003	1.0003	1.0010
DHQT4M	0.07290	0.07290	0.07289	0.07305
XNQR4M	184.24	184.24	184.47	184.30
TFFMB	33.42	33.42	33.42	33.42
STFFR	1.0000	1.0000	1.0000	1.0000
ETATMB	0.8878	0.8878	0.8878	0.8878
SETATR	1.0000	1.0000	1.0000	1.0000
DHQ54M	0.07260	0.07260	0.07169	0.06346
XNR54M	98.97	98.97	97.76	89.10
TFF2MB	125.04	125.04	125.09	125.33
SF2TR	0.9997	0.9997	0.9997	1.0000
ETA2MB	0.9175	0.9175	0.9162	0.9052
SET2TR	0.9978	0.9978	0.9977	0.9980
NSI1	0	0	0	0
NSI2	0	0	0	0
NSI3	0	0	0	0
NSI4	0	0	0	0
NSI5	0	0	0	0
ICASE	2	3	4	5

9.3 Engine Aero and Installation Design

Fan

P/P	1.55
$U_T/\sqrt{\theta_2}$	1300
r_H/r_T	.35
$W_2\sqrt{\theta}/\delta_{AA}$	43.25
P/P Hub	1.30

This fan is identical to the design described in Section 8.3 for the geared fan without variable boost.

9.4 Booster (LP Compressor) Stages

At the altitude match point, the booster requirements are without the fan hub:

P/P 2.552

The flowpath attached places the 1st rotor tip diameter at 39.4". At that diameter the corrected tip speed is 1311 ft/sec, which requires three stages. The blading details are provided in Table II attached. Table I gives the design conditions at the design point and at the takeoff condition when the booster vanes are closed.

Table I -- Design Summary (booster only)

	Max Climb (Design Pt.)	Take off
Pressure Ratio	2.552	1.794
Corrected Flow, lb/sec	149.49	109.81
Corrected Flow/An, lb/sec ft^2	35.7	26.2
Corrected Tip Speed, ft/sec	1311.0	1112.8
Exit Mach Number	.39	.38
RPM	8012	6696
Inlet Pt	19.105	17.503
Inlet Tt	572.5	555.1
Inlet Radius Ratio	.711	--
Tip Diameter, in	39.4	--
IGV $\Delta\alpha$	0	+13°
STATOR #1 $\Delta\alpha$	0	+7°
STATOR #2 + 3 $\Delta\alpha$	0	0
BOOSTER EFFICIENCY	86.9	85.4

TABLE I (CONTD

PRELIMINARY STAGE DATA

STAGE	1	2	3
Max Climb (Design Point)			
Pressure Ratio	1.46	1.36	1.28
Fraction of Work	.38	.33	.29
Exit Mach No.	.48	.45	.39
Take - Off			
Pressure Ratio	1.27	1.22	1.17
Fraction of Work	.38	.33	.29
Exit Mach No.	.39	.40	.38

TABLE I CONTD

PRELIMINARY BLADE AERO DATA

(DESIGN POINT)

Blade Row	Radial Location	Diffusion Factor	Inlet Mach No.	Inlet Angle	Leaving Angle
Rotor 1	T	.34	1.20	67	59
	P	.41	1.05	62	51
	H	.49	.89	57	37
Stator 1	T	.39	.58	41	12
	P	.41	.61	44	12
	H	.45	.65	48	12
Rotor 2	T	.35	1.07	65	58
	P	.40	.96	61	51
	H	.47	.84	56	40
Stator 2	T	.41	.54	40	6
	P	.42	.56	43	6
	H	.45	.59	46	6
Rotor 3	T	.32	1.02	65	60
	P	.37	.93	61	54
	H	.44	.84	58	46
Stator 3	T	.42	.48	35	0
	P	.43	.49	37	0
	H	.44	.51	40	0

TABLE I CONTD

PRELIMINARY BLADE AERO DATA

(TAKE-OFF POINT) (CLOSED STATORS)

Blade Row	* Radial Location	Diffusion Factor	Inlet Mach No.	Inlet Angle	Leaving Angle
Rotor 1	T	.32	.91	70	60
	P	.39	.78	65	52
	H	.46	.65	60	37
Stator 1	T	.45	.50	47	19
	P	.46	.52	50	19
	H	.48	.56	53	19
Rotor 2	T	.30	.87	66	58
	P	.35	.77	62	51
	H	.41	.68	57	41
Stator 2	T	.42	.48	41	6
	P	.43	.49	43	6
	H	.44	.51	46	6
Rotor 3	T	.26	.91	65	59
	P	.30	.83	62	54
	H	.36	.75	58	48
Stator 3	T	.30	.43	28	0
	P	.31	.43	30	0
	H	.32	.45	33	0

* T - Tip
P - Pitch
H - Hub

TABLE II CONCLUDED

CHANGES IN BLADE INCIDENCE ANGLES
BETWEEN DESIGN POINT AND TAKE-OFF AT PITCH RADIUS

Blade Row	Δi (des)
Rotor 1	+ 3
Stator 1	- 1
Rotor 2	+ 1
Stator 2	- 0
Rotor 3	+ 1
Stator 3	- 7

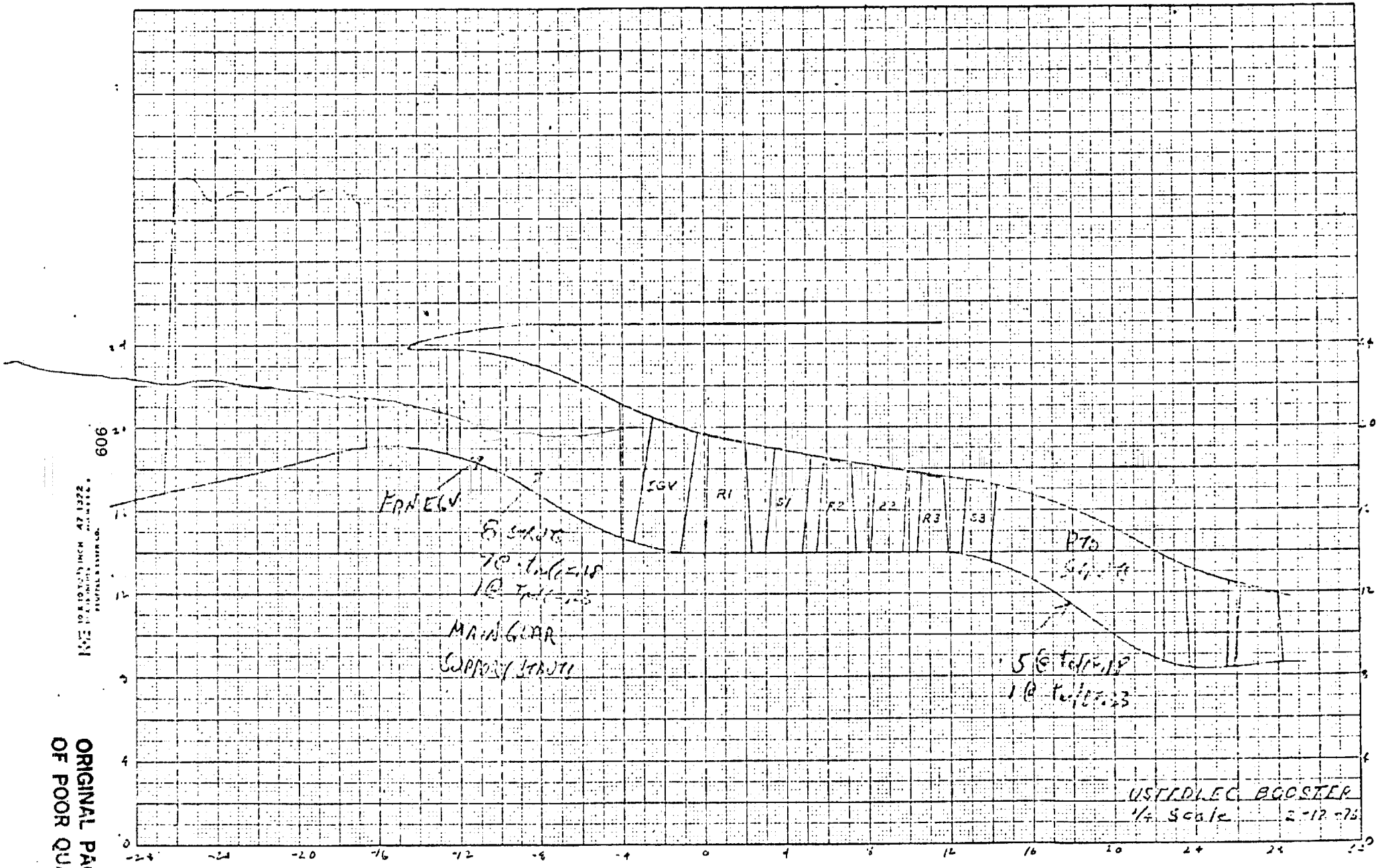


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Table II -- Preliminary Blade Geometry

	No.	Chord	Rad.	Solidity	Tm/C	Stagger*	Camber
Rotor 1	52	3.03	T	1.29	.03	61	9
			P	1.50	.05	53	13
			H	1.79	.08	40	25
Stator 1	69	1.96	T	1.13	.08	22	50
			P	1.30	.06	25	44
			H	1.53	.04	24	53
Rotor 2	56	2.47	T	1.19	.03	59	9
			P	1.35	.05	52	11
			H	1.57	.08	41	21
Stator 2	81	1.62	T	1.15	.08	18	57
			P	1.30	.06	21	51
			H	1.49	.04	20	58
Rotor 3	63	2.07	T	1.16	.03	60	7
			P	1.30	.05	54	9
			H	1.47	.08	46	15
Stator 3	91	1.45	T	1.21	.08	12	55
			P	1.35	.06	16	49
			H	1.53	.04	14	57

* Design point values. IGV and Stator 1 are variable.

9.4.1 Low Pressure Turbine Aero Design

The LPT RPM was limited by the last stage AA_2N^2 limit as a stress indicated. The energy extraction for the 8-U turbine is greater than 7-U, because a larger fan is driven. For comparison the overall conditions for the two turbines are listed below:

	7-U	8-U
	P/P 1.55	Var. Boost/P/P 1.55
D_T Fan	91.1	96.6
Δh	209.9	213.4
M_5	.45	.45
AA_5	827	945
N	8030	7650
$AA \times N^2 \times 10^{-9}$	53.3	55
Ψ_P	.76	.85

The turbine flowpath is shown on the attached engine flowpath. At these light loadings, no turbine efficiency difference is predicted.

9.5 ~~Base~~ Engine Mechanical Design

The mechanical design features for the variable boost geared fan are very similar to the previously described geared fan engine. Fig. 9.5.1 is a cross section view of the geared layout and configuration of this engine.

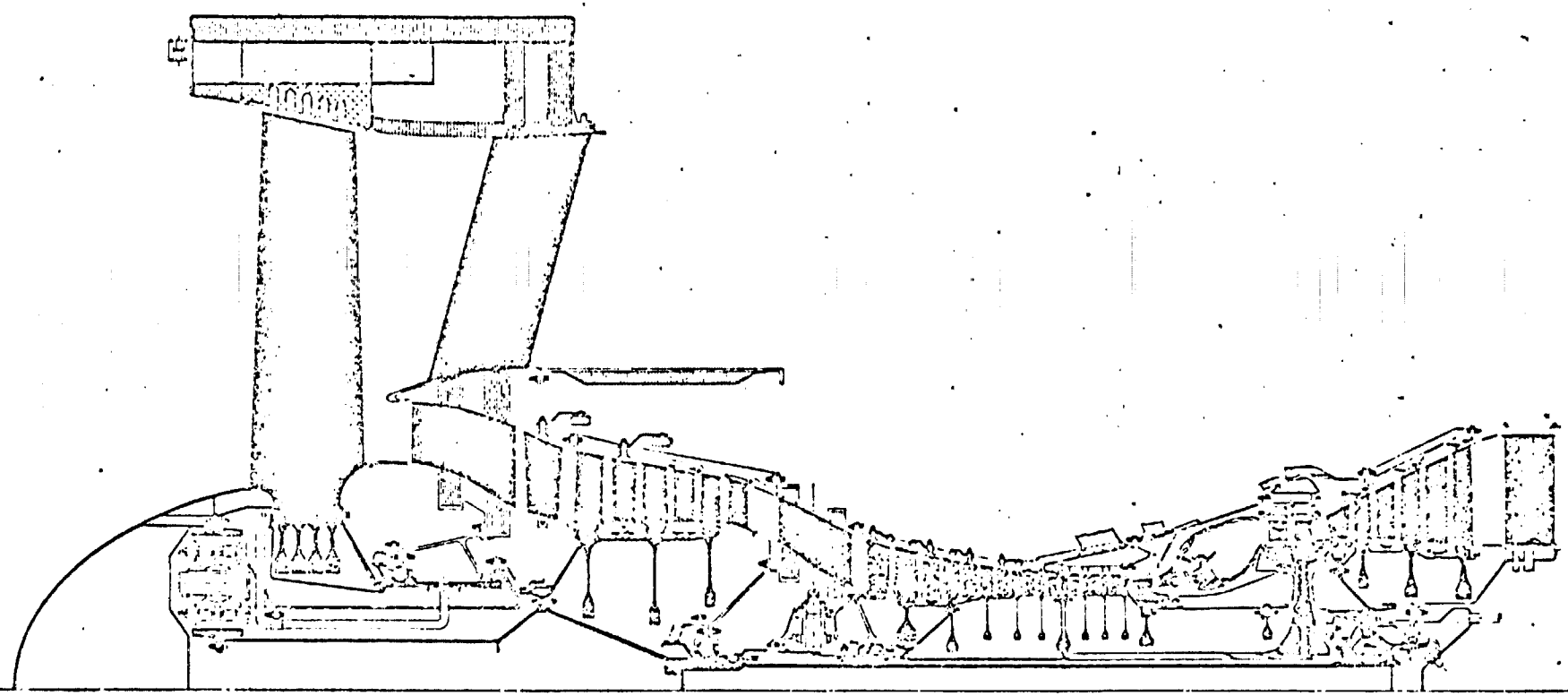
As before, a high speed LPT gear drives a low speed composite fan through a front mounted main transmission gear. The major difference between the 8U (variable boost) and the previously described 7U (geared fan) is an extra high speed aft booster stage. This was required to achieve the higher supercharge boost pressure needed for the ~45:1 overall engine pressure at cruise.

Since the LPT was slowed somewhat due to the larger exit annulus (and resulting higher blade root stresses) the gear ratio remained constant even though the larger fan turned at a lower rpm (but same tip speed) than the 7U. The booster hub radius ratio was altered somewhat so another stress analysis was performed on the most highly loaded first stage booster rotor disk to aid in the weight estimating process. Table 9.5.1 shows the results of both a Ti and B/Al blade disk analysis. The all Titanium design weight has been used for this report. Figure 9.5.2 illustrates the relative size of both live disks for comparative design criteria while Table 9.5.2 is the time share computer output stress and deflection information for the all titanium design.

Since the engine is de-rated at take-off, and the gear box weight is proportional to the maximum T/O H.P. and torque, the gear box weight was not increased as much in the design size as the cruise thrust ratio between 8U and 7U would have indicated. Table 9.5.3 is a list of the major engine component weights in design size as used in the economic evaluation.

Fig 9.5.1

GEARED VARIABLE BOOST FAN.



8U - BOOSTER - STG 1

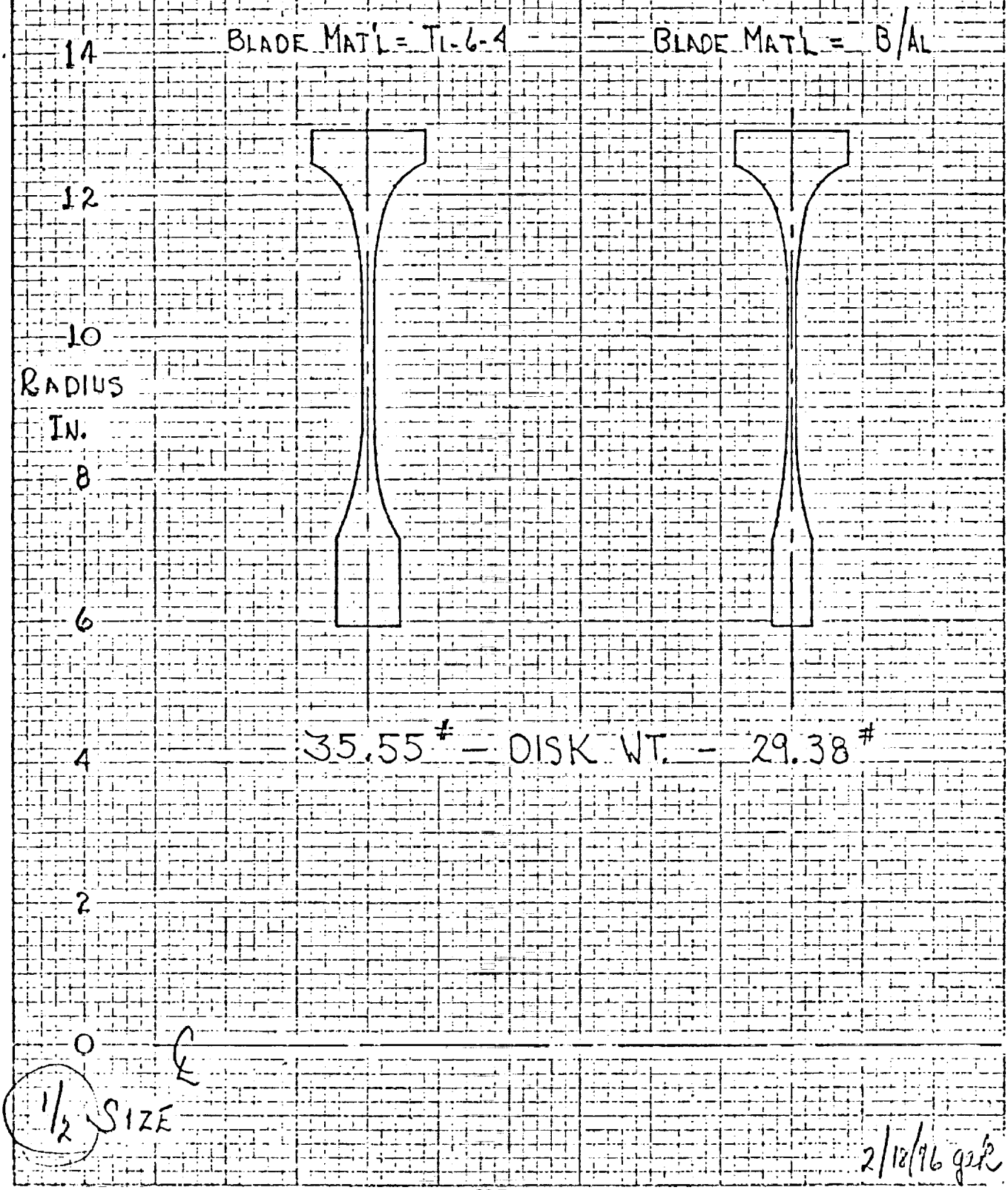
Table 9.4.1

2/10/76
gak

	Blade Mat'l = Ti-6-4		Blade Mat'l = B/Al
Blade wt. #	22.1		13.73
Dead wt. #	6.96		6.96
Disk wt. #	35.55		29.38
Total stage wt. #	64.61	Δwt ~ 14.5#/stage → ~10#/stage	50.07
	56.3	2nd stage (est)	
	49	3rd stg (est)	(45.5# est for 2U's 1st stage)
AN^2 =	4,710,465		
	15"	Shaft	
	3#	Min	

Figure 9.5.2

8-U BOOSTER — 1ST STG. DISK



2/12/96 gzk

Tab 9.4.2

8 U. BOOSTER

1 ST STG. DISK

2/10/76

```
DATA SAVED-8UDSK-1
*LIST 770-860

770 DATA 108900, .56
780 DATA 14, 12178, 7.587, .312, .161, 64
790 DATA 225, 0, 0, 0, 0, 0, 0
800 DATA 0, 0, 0, 0, 0, 0, 225
810 DATA 5.94, 6.5, 7.15, 7.5, 8.0, 8.35, 8.7
820 DATA 9.8, 10.75,11.2, 11.8, 12.15, 12.45, 12.9
830 DATA .9, .9, .9, .6, .3, .22, .18
840 DATA .18, .18, .25, .48, .7, 1.6, 1.6

ready

*RUN
```

(BLADE MAT'L = TI-6-4)

TI:6-4 MATERIAL DATA RANGE IS :

TEMPERATURE	MODULUS	ALFA
0	163.00e 05	48.000e-07
1200	104.80e 05	51.500e-07

MASS DEN. = .161 #/IN^3
NOTCH-SEN. = .56
POISSON'S = .312

SPD = 7587 RPM RAD.LOAD = 12178 #/IN ULT.STR = 108900 #/IN^2

RADIUS (IN)	THICK. (IN)	TEMP. (F.)	RAD.STR. (KSI)	TAN.STR. (KSI)	EFF.STR. (KSI)	RAD.DISP. (IN.)
5.94	.900	225	.0	86.4	86.4	.0382
6.50	.900	225	6.2	79.0	76.1	.0378
7.15	.900	225	11.4	72.3	67.3	.0376
7.50	.600	225	19.7	71.3	63.8	.0377
8.00	.300	225	42.1	74.5	64.7	.0382
8.35	.220	225	57.9	77.9	70.1	.0391
8.70	.180	225	70.6	81.0	76.4	.0402
9.80	.180	225	69.1	79.0	74.6	.0443
10.75	.180	225	67.5	77.3	72.9	.0478
11.20	.250	225	48.1	70.3	62.3	.0491
11.80	.480	225	24.9	60.9	53.1	.0500
12.15	.700	225	17.1	57.0	50.7	.0503
12.45	1.600	225	7.5	52.6	49.3	.0504
12.90	1.600	225	7.6	50.6	47.3	.0505

AVG.TAN.STRESS= 68.4014 KSI

CROSS SECT.AREA= 3.69375 SQ.IN.

WHEEL WEIGHT = 35.55459 LBS.

BURST SPEED = 9108.342 RPM = 120.052 PER CENT OF 7587

ready
*

C-5

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Table 9.3

8U Component Weight

Component	Base Line (78.8 D_T)	8U (96.66 D_T)
Fan Rotor	532	649
Fan Frame	475	680
Fuel Cooling	140	160
Fan Blade Containment	96	91
LP Shaft and Cone	160	145
Booster Rotor	105	190
Booster Stator	122	200
LPT Rotor	263	320
LPT Stator	298	320
Turbine Frame	176	175
Intermediate Frame	0	70
LP System	2367	2880
HP System	1129	1136
Reducing Gear/Cooler	0	405/50
Sumps	104	130
Fuel Pump + Sumps	0	34
Drives	130	150
C + A, Carpenter	310	330
Total	544	1099
Σ Weight	4040	5255
10% Margin	404	521
Total Wt.	4444	5736

9.6 Economic Factors - Variable Boost Geared Fan

The evaluation of the economic factors for the variable boost engine were accomplished in exactly the same way as for 7U previously discussed.

Replacement factors for the various components over an engine design life of 36,000 hours were developed and used with the replacement costs to determine an operating cost per hour. The same replacement factors as used in 7U were used in 8U.

Table 9.6.1 is a repeat of that list. No changes were made in the gear maintenance factors since an identical design and nearly identical load capability was needed.

Comments Page 9 - 34

Section 8 titles have been altered to clarify the engine configuration and this should take care of the confusion between the replacement factors used for 7U and 8U. They were the same and the recommended values were utilized for both.

The difference in column between the previously used values (Pre-USTEDLEC) and the recommended values derive from more and better parts usage data and the better correlation with design features. For example, the large difference between the HPC blade factor (14.6 vs. 3.1) derives from the HPC low aspect ratio blading resistance to erosion as used in the USTEDLEC design versus the base CF6 low aspect ratio commercial experience.

REW

Table 9.6.1

2/27/76

To: R. H

From: R. J

Subject: Replacement Factors (Maintenance) Survey

The following are recommended replacement factors for a 36000 hr. engine life.

Item	Prev. Value	Recommended Good	Recommended Bad
Fan Blades	1.38	1.1	1.38
Fan Disk	.15	.1	
Fan Frame	0	.2	
Booster R. Blades	.65	1.2	.4
Booster R. Disks	.15	.05	
Booster S. Vanes	.2	.2	
Booster Case	.15	.05	
HPC Blades	14.6	3.1	
HPC Rotor	.15	.15	
HPC Vanes	.3	.3	
HPC Stator Case	.15	.1	
Combustor	1.83	2.0	
HPT Blades	4.0	4.0	
HPT Rotor	1.1	.6	
HPT Vanes	6.1	6.1	
HPT Case	1.0	.4	
LPT Vanes	1.17	.25	
LPT Case	.3	.2	
LPT Blades	1.55	.7	.5
LPT Rotor	.15	.1	.05
Turbine Frame	.3	.1	
CHA + Hse	.4	.3	
Mount Parts	.5	2	
Gear Set	[illegible]	.3	
Gear Lub + Cooler	[illegible]	.5	

9.7 Engine Evaluation (8-U)

The evaluation of the variable boost geared fan was conducted by comparing the engine on a cruise sized basis to the baseline pressure ratio 1.71 fan. Also the comparison was made on a takeoff sized basis, but compared to the pressure ratio 1.55 geared fan (7-U) and scaling to match this takeoff thrust.

9.7.1 Nacelle Weight and Price Estimates

The parallel design of the nacelles for the variable boost geared fan, the geared fan and the baseline turbofan permits the direct comparison in weight and costs shown in the following table 9.7.1. Note that the fan reverser is slightly lighter because of the reduced amount of fan air available at landing conditions.

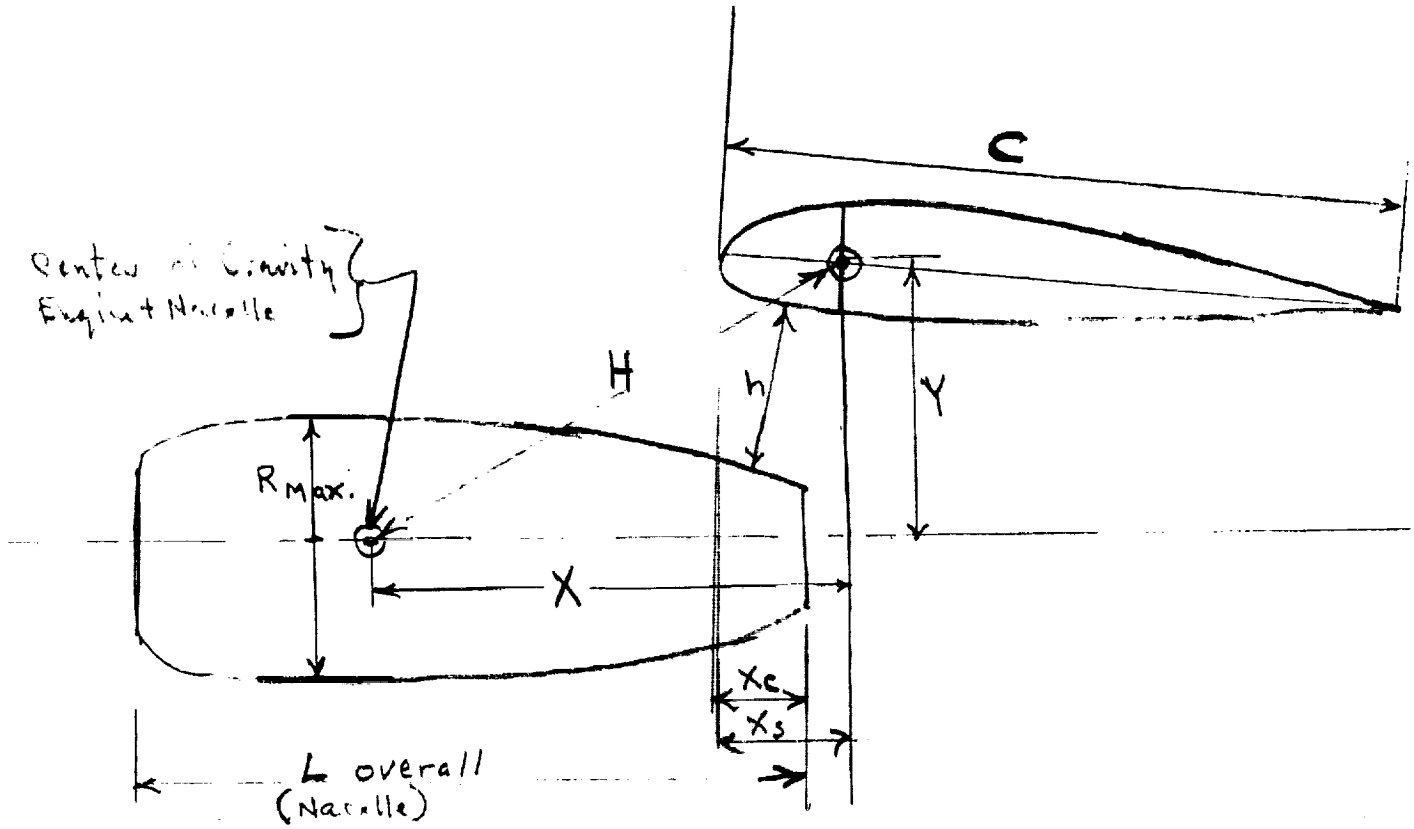
TABLE 9.7.1 NACELLE WEIGHT AND COST ESTIMATES	STEULLER BASELINE MF12	7U	8U	8U SCALED DOWN TO 7U
Fan P/P Max Climb	1.7	1.55	1.55	1.55
W2 corrected	1253	1718.9	1934	1718.9
Fan Dr	78.8	91.13	96.66	91.13
Fn SLS +27 T.O.	32,248	39177	38950	34,618
Fn Max Cl. 35K/.8M	8838	9597	10,756	9560
AE 25 (Max cl)	(2558)	(3952)	(4429)	(3950)
FF 25 (T.O)	1076	1595	1734	1541
AE 59	3594	5197	5843	5193
Nacelle - overall size				
Dmax, Engine Casing/Nacelle	89.7	105.1	111.5	105.1
Engine length	103.9	104.	110	103.7
Inlet length (aero)	53.7	62.9	66.7	62.9
Exhaust length (aero)	69.4 67.	83.5	88.5	83.4
Nacelle length	227.0	250.4	265.2	250.0
Nacelle Weight Estimates:				
Inlet	310	440.	503.	440.
Fan Rev/Duct	720.	1102.	1216.	1068
Core Cowl	100	111.	115.	101.
Tail cone	150	225	256	225
Mixer + Plug	200	300	341	300
Engine Build up	450	477	517	476
Pylon Delta	40	44 2617	50 2998	44 2657
Margin, 7%	140	189	210	186
Totals - lbs	2110	2888	3208	2840
			Δ=-48	
Nacelle Cost Estimates:				
Inlet	26,300	32,500	37,400	33,900
Fan Rev./Duct	72,000	98,100	105,400	95,900
Core Cowl	9,000	9,700	10,000	9,100
Tail cone	17,900	24,000	26400	24,000
Mixer + Plug	19,000	25,500	28000	25,500
Engine Build up	68,000	71,400	76500	71,300
Pylon Δ	3,700	4,000 2660.00	4310 2580	3,900 2600
Air + Cables	23,900	29600	32,000	29,300
Totals $	239,800	296,200	320,000	292,900
Pylon Weight, Est., lbs,	980	1287	1366 Δ=-89	1198
Pylon Cost, Est. $	90,000 925	109,900	114,800	104,300
TOTAL NACELLE + PYLON	3090.	4175	4574	4038

3/12

TABLE 9.7.1. (CONTINUED)

Pylon Wgt & Cost Estimates

T	Baseline	76	86	84 scaled to 70
Fn SLS/TO	33,248	39,177	38,950	34,618
Rmax	44.55	52.55	55.75	52.55
L overall	227.0	250.4	265.2	250.0
L beyond Engine Zero	173.3	187.5	198.5	187.1
C	264	286.6	285.7	269.4
h .12 c	31.7	34.4	34.3	32.3
X_c .217 c	57.3	62.2	62.0	58.5
y .110 yc	29.1	31.6	31.5	29.7
Y Rmax + y	74.0	84.2	87.3	82.3
X_s .167 c	44.1	47.9	47.7	45.0
Engine CG	37.1	33.0/5040	35.0/5563	33.0/4925
Nacelle CG	43.4	61.0/2888	65.0/3208	61.0/2340
Installed CG	52.4	43.2	46.0	43.4
Inst. CG from Tip Cut	120.9	144.3	152.5	143.7
	-13.2	-14.3	-14.3	-13.5
$X = CG(TP) - X_c + X_s$	107.7	130.0	138.2	130.2
$H = (X^2 + Y^2)^{1/2}$	130.7	154.9	163.5	154.0
$Z = T \times H \times D_{max} \times 10^{-6}$	389.8	637.8	710.1	560.3
$Wgt = 36.43 \times Z^{.552}$	981.	1287	1366.	1178
Cost Baseline Wgt (1.0) $\left(\frac{Wgt}{Wgt}\right)^{.8/1.1}$	90,200	109,800	114,800	104,300



C - Wing Chord at engine center line
X = horizontal distance (engine center line)
Y = vertical distance
H = hypotenuse $= \sqrt{X^2 + Y^2}$
} Forward wing spar center to C.G. of engine and nacelle.
h = minimum clearance - wing to nacelle.
X_c = overlap; tailpipe behind wing leading edge.
X_s = wing leading edge to wing spar.

All dimensions in inches

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9.7.2 Maintenance Data Preparation

DESIGN SIZE

3/12/76

ENGINE DESIGNATION: 8U - CRUISE SIZED
NO. OF ENGINES: 4 TYPE: INTERCON TURBOFAN RANGE: 2000 MILES

FINAL

	SHOP COST	PART INDEX	MATERIAL COST	LABOR COST
FAN ROT BLADES-		1.100		
FAN ROT DISC---		0.100		
FAN FRAME&STAT-		0.200		
BOOS ROT BLADES		1.200		
BOOS ROT DISC--		0.050		
BOOS STAT VANES		0.200		
BOOS STAT CASE-		0.050		
HPT BLADES-----		4.000		
HPT VANES------		6.100		
HPT DISC-------		0.600		
HPT CASE-------		0.400		
COMBUSTOR------		2.000		
HPC BLADES-----		3.100		
HPC VANES------		0.300		
HPC DISC-------		0.150		
HPC CASING-----		0.100		
GEAR SET-------		0.300		
GEAR LUBE & COOLING SYSTEM-		0.500		
LPT STAT VANES-		0.250		
LPT STAT CASE--		0.200		
LPT ROT BLADES-		0.700		
LPT ROT DISC---		0.100		
TURB FRAME-----		0.100		
C&A&MISC-------		0.300		
----------		~~0.200~~ 2.0		
----------		0.100		
----------		0.		
----------		0.		
----------		0.		
TOTAL----------				

TOTAL COST PER FLIGHT HOUR, $

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MISSION SIZE

ENGINE DESIGNATION: 8U - CRUISE SIZED
NO. OF ENGINES: 4 TYPE: INTERCON TURBOFAN RANGE: 2000 MILES

	SHOP COST* SCALE FACT	MATERIAL COST	LABOR COST	MAT CST /FL HR	LAB CST /FL HR	TOT CST /FL HR
FAN ROT BLADES-				0.34	0.15	0.49
FAN ROT DISC---				0.03	0.01	0.04
FAN FRAME&STA--				0.17	0.07	0.24
BOOS ROT BLADES				0.09	0.04	0.13
BOOS ROT DISC--				0.01	0.01	0.02
BOOS STAT&VANES				0.06	0.03	0.09
BOOS STAT CASE-				0.01	0.00	0.01
HPT BLADES-----				2.28	0.98	3.26
HPT VANES------				3.72	1.60	5.32
HPT DISC-------				0.29	0.13	0.42
HPT CASE-------				0.13	0.06	0.19
COMBUSTOR------				1.78	0.76	2.55
HPC BLADES-----				0.39	0.17	0.56
HPC VANES------				0.04	0.02	0.06
HPC DISC-------				0.08	0.04	0.12
HPC CASING-----				0.05	0.02	0.07
GEAR SET-------				0.23	0.10	0.33
GEAR LUBE & COOLING SYSTEM-				0.08	0.04	0.12 +
LPT STAT VANES-				0.10	0.04	0.14
LPT STAT CASE--				0.07	0.03	0.10
LPT ROT BLADES-				0.31	0.13	0.44
LPT ROT DISC---				0.04	0.02	0.06
TURB FRAME-----				0.04	0.02	0.06
C&A&MISC-------				0.67	0.29	0.95 r
----------				~~0.09~~	~~0.04~~	~~0.13~~ 1.3a
----------				0.02	0.01	0.02
----------				0.	0.	0.
----------				0.	0.	0.
----------				0.	0.	0.
TOTAL----------				11.14	4.78	~~15.92~~ 17.09

TOTAL COST PER FLIGHT HOUR, $

~~17.25 = 19.90~~ 21.36

```
*OLD C8UINTER
READY
*110 8U - CRUISE SIZED    ,INTERCON TURBOFAN
*114 1.80,.429,38950,20230,.55
*RESAVE C8UINTER
DATA SAVED-C8UINTER
*LIST

110 8U - CRUISE SIZED    ,INTERCON TURBOFAN
112 2000,4
114 1.80,.429,38950,20230,.55
116 3840,15
118 14240,1.1
119 11660,.1
120 38600,.2
121 3600,1.2
122 10800,.05
123 13800,.2
124 7500,.05
125 26200,4.0
126 28000,6.1
127 22300,.6
128 15200,.4
129 40900,3.0
130 5800,3.1
131 6800,.3
132 25500,.15
133 22600,.1
134 35500,.3
135 7500,.5
136 17600,.25
137 15800,.2
138 20250,.7
139 20150,.1
140 19200,.1
141 101900,.3
142 20910,(2) 2
143 7600,.1
144 0,0
145 0,0
146 0,0

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MAINTENANCE COST CALCULATION

DESIGN SIZE

rev 3/12 FWAL

ENGINE DESIGNATION: 8U - CRUISE SIZED
NO. OF ENGINES: 3 TYPE: TRANSCON TURBOFAN RANGE: 700 MILES

	SHOP COST	PART INDEX	MATERIAL COST	LABOR COST
FAN ROT BLADES-		1.100		
FAN ROT DISC---		0.100		
FAN FRAME&STAT-		0.200		
BOOS ROT BLADES		1.200		
BOOS ROT DISC--		0.050		
BOOS STAT VANES		0.200		
BOOS STAT CASE-		0.050		
HPT BLADES-----		4.000		
HPT VANES------		6.100		
HPT DISC-------		0.600		
HPT CASE-------		0.400		
COMBUSTOR------		2.000		
HPC BLADES-----		3.100		
HPC VANES------		0.300		
HPC DISC-------		0.150		
HPC CASING-----		0.100		
GEAR SET-------		0.300		
GEAR LUBE & COOLING SYSTEM-		0.500		
LPT STAT VANES-		0.250		
LPT STAT CASE--		0.200		
LPT ROT BLADES-		0.700		
LPT ROT DISC---		0.100		
TURB FRAME-----		0.100		
CAA&MISC-------		0.300		
----------		2.000		
----------		0.100		
----------		0.		
----------		0.		
----------		0.		
TOTAL----------				

TOTAL COST PER FLIGHT HOUR, $

MISSION SIZE

ENGINE DESIGNATION: 8U - CRUISE SIZED
NO. OF ENGINES: 3 TYPE: TRANSCON TURBOFAN RANGE: 700 MILES

	SHOP COST* SCALE FACT	MATERIAL COST	LABOR COST	MAT CST /FL HR	LAB CST /FL HR	TOT CST /FL HR
FAN ROT BLADES-				0.35	0.15	0.50
FAN ROT DISC---				0.03	0.01	0.04
FAN FRAME&STA--				0.17	0.07	0.25
BOOS ROT BLADES				0.10	0.04	0.14
BOOS ROT DISC--				0.01	0.01	0.02
BOOS STAT&VANES				0.06	0.03	0.09
BOOS STAT CASE-				0.01	0.00	0.01
HPT BLADES-----				2.35	1.01	3.36
HPT VANES------				3.83	1.64	5.47
HPT DISC-------				0.30	0.13	0.43
HPT CASE-------				0.14	0.06	0.19
COMBUSTOR------				1.83	0.79	2.62
HPC BLADES-----				0.40	0.17	0.58
HPC VANES------				0.05	0.02	0.07
HPC DISC-------				0.09	0.04	0.12
HPC CASING-----				0.05	0.02	0.07
GEAR SET-------				0.24	0.10	0.34
GEAR LUBE & COOLING SYSTEM-				0.08	0.04	0.12
LPT STAT VANES-				0.10	0.04	0.14
LPT STAT CASE--				0.07	0.03	0.10
LPT ROT BLADES-				0.32	0.14	0.45
LPT ROT DISC---				0.05	0.02	0.06
TURB FRAME-----				0.04	0.02	0.06
C&A&MISC-------				0.69	0.29	0.98
----------				0.94	0.40	1.34
----------				0.02	0.01	0.02
----------				0.	0.	0.
----------				0.	0.	0.
----------				0.	0.	0.
TOTAL----------				12.30	5.28	17.57

TOTAL COST PER FLIGHT HOUR, $

x1.25 = 21.96

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MAINTENANCE COST CALCULATION

REV. 3/12
FINAL

DESIGN SIZE.

ENGINE DESIGNATION: 8U - TAKEOFF SIZED
NO. OF ENGINES: 3 TYPE: TRANSCON TURBOFAN RANGE: 700 MILES

	SHOP COST	PART INDEX	MATERIAL COST	LABOR COST
FAN ROT BLADES-		1.100		
FAN ROT DISC---		0.100		
FAN FRAME&STAT-		0.200		
BOOS ROT BLADES		1.200		
BOOS ROT DISC--		0.050		
BOOS STAT VANES		0.200		
BOOS STAT CASE-		0.050		
HPT BLADES-----		4.000		
HPT VANES------		6.100		
HPT DISC-------		0.600		
HPT CASE-------		0.400		
COMBUSTOR------		2.000		
HPC BLADES-----		3.100		
HPC VANES------		0.300		
HPC DISC-------		0.150		
HPC CASING-----		0.100		
GEAR SET-------		0.300		
GEAR LUBE & COOLING SYSTEM-		0.500		
LPT STAT VANES-		0.250		
LPT STAT CASE--		0.200		
LPT ROT BLADES-		0.700		
LPT ROT DISC---		0.100		
TURB FRAME-----		0.100		
C&A&MISC-------		0.300		
----------		2.000		
----------		0.100		
----------		0.		
----------		0.		
----------		0.		
TOTAL----------				

TOTAL COST, PER FLIGHT HOUR, $

MISSION SIZE

ENGINE DESIGNATION: 8U - TAKEOFF SIZED
NO. OF ENGINES: 3 TYPE: TRANSCON TURBOFAN RANGE: 700 MILES

	SHOP COST* SCALE FACT	MATERIAL COST	LABOR COST	MAT CST /FL HR	LAB CST /FL HR	TOT CST /FL HR
FAN ROT BLADES-				0.36	0.16	0.52
FAN ROT DISC---				0.03	0.01	0.04
FAN FRAME&STA--				0.18	0.08	0.26
BOOS ROT BLADES				0.10	0.04	0.14
BOOS ROT DISC--				0.01	0.01	0.02
BOOS STAT&VANES				0.06	0.03	0.09
BOOS STAT CASE-				0.01	0.00	0.01
HPT BLADES-----				2.44	1.05	3.48
HPT VANES------				3.97	1.70	5.68
HPT DISC-------				0.31	0.13	0.44
HPT CASE-------				0.14	0.06	0.20
COMBUSTOR------				1.90	0.82	2.72
HPC BLADES-----				0.42	0.18	0.60
HPC VANES------				0.05	0.02	0.07
HPC DISC-------				0.09	0.04	0.13
HPC CASING-----				0.05	0.02	0.08
GEAR SET-------				0.25	0.11	0.35
GEAR LUBE & COOLING SYSTEM-				0.09	0.04	0.12
LPT STAT VANES-				0.10	0.04	0.15
LPT STAT CASE--				0.07	0.03	0.11
LPT ROT BLADES-				0.33	0.14	0.47
LPT ROT DISC---				0.05	0.02	0.07
TURB FRAME-----				0.04	0.02	0.06
C&A&MISC-------				0.71	0.30	1.02
[illegible]				0.97	0.42	1.39
[illegible]				0.02	0.01	0.03
----------				0.	0.	0.
----------				0.	0.	0.
----------				0.	0.	0.
TOTAL----------				12.76	5.47	18.23

TOTAL COST PER FLIGHT HOUR, $

22.81 x 1.25 =

DESIGN SIZE

3/12/76

ENGINE DESIGNATION: 8U - TAKEOFF SIZED
NO. OF ENGINES: 4 TYPE: INTERCON TURBOFAN RANGE: 2000 MILES

FINAL

	SHOP COST	PART INDEX	MATERIAL COST	LABOR COST
FAN ROT BLADES-		1.100		
FAN ROT DISC---		0.100		
FAN FRAME&STAT-		0.200		
BOOS ROT BLADES		1.200		
BOOS ROT DISC--		0.050		
BOOS STAT VANES		0.200		
BOOS STAT CASE-		0.050		
HPT BLADES-----		4.000		
HPT VANES------		6.100		
HPT DISC-------		0.600		
HPT CASE-------		0.400		
COMBUSTOR------		2.000		
HPC BLADES-----		3.100		
HPC VANES------		0.300		
HPC DISC-------		0.150		
HPC CASING-----		0.100		
GEAR SET-------		0.300		
GEAR LUBE & COOLING SYSTEM-		0.500		
LPT STAT VANES-		0.250		
LPT STAT CASE--		0.200		
LPT ROT BLADES-		0.700		
LPT ROT DISC---		0.100		
TURB FRAME-----		0.100		
C&A&MISC-------		0.300		
----------		~~0.200~~ 2.0		
----------		0.100		
----------		0.		
----------		0.		
----------		0.		
TOTAL----------				

TOTAL COST PER FLIGHT HOUR, $

MISSION SIZE

ENGINE DESIGNATION: 8U - TAKEOFF SIZED
NO. OF ENGINES: 4 TYPE: INTERCON TURBOFAN RANGE: 2000 MILES

	SHOP COST* SCALE FACT	MATERIAL COST	LABOR COST	MAT CST /FL HR	LAB CST /FL HR	TOT CST /FL HR
FAN ROT BLADES-				0.35	0.15	0.51
FAN ROT DISC---				0.03	0.01	0.04
FAN FRAME&STA--				0.17	0.07	0.25
BOOS ROT BLADES				0.10	0.04	0.14
BOOS ROT DISC--				0.01	0.01	0.02
BOOS STAT&VANES				0.06	0.03	0.09
BOOS STAT CASE-				0.01	0.00	0.01
HPT BLADES-----				2.37	1.02	3.39
HPT VANES------				3.86	1.66	5.52
HPT DISC-------				0.30	0.13	0.43
HPT CASE-------				0.14	0.06	0.20
COMBUSTOR------				1.85	0.79	2.64
HPC BLADES-----				0.41	0.17	0.58
HPC VANES------				0.05	0.02	0.07
HPC DISC-------				0.09	0.04	0.12
HPC CASING-----				0.05	0.02	0.07
GEAR SET-------				0.24	0.10	0.34
GEAR LUBE & COOLING SYSTEM-				0.08	0.04	0.12
LPT STAT VANES-				0.10	0.04	0.14
LPT STAT CASE--				0.07	0.03	0.10
LPT ROT BLADES-				0.32	0.14	0.46
LPT ROT DISC---				0.05	0.02	0.07
TURB FRAME-----				0.04	0.02	0.06
C&A&MISC-------				0.69	0.30	0.99
----------				~~0.09~~	~~0.04~~	~~0.14~~ 1.40
----------				0.02	0.01	0.02
----------				0.	0.	0.
----------				0.	0.	0.
----------				0.	0.	0.
TOTAL----------				11.56	4.96	~~16.52~~ 17.78

TOTAL COST PER FLIGHT HOUR, $ 17.78

×1.25 = 22.23

9.7.3 Preparation of Evaluation Input Data

	MF12 P/P 1.71 Baseline	Var. Boost Cruise	Sized	Δ	8-U P/P 1.55 Var. Boos To Sized-Match 7-U	Δ
SLS TO Fn, lbs	33150	38950	31950		36047	
Eng. Wt., lbs	4444	5732	4475	+31	5202	+758
Cost, 1000 $	534.7	622.5	558.2	+23.5	596.5	+61.8
Nac. Wt., lbs	3090	4574	3678	+588	4200	+1110
Nac. Cost, 1000 $	329.8	434.8	371.1	+41.3	408.7	+78.9
Fn-D, lbs	8306	10127	8306	0	9372	
SL .25 TO Fn lbs	25553	29137	23900		26905*	
Drag lbs	431	629			582	
95% MxCr Fn lbs		9350			8653	
Tri SLS TO Fn lbs	20000		19276		21747	
Quad SLS TO Fn lbs	21000		20240		22834	
Maint. $/FH Tri	22.38		21.96	-.42	23.60	+1.22
" " Quad	21.76		21.36	-.40	22.90	+1.14

*Same as 7-U TO Fn/.25M

BENEFIT ANALYSIS RESULTS FORMAT

FEATURE STUDIED

DESIGN INPUT

BENEFIT RESULTS

MW 8/12

FINAL

ENGINE	8U STAR GEAR
MISSION	TRIJT 10.5FL CR SIZE
MATERIAL SUBSTITUTION	1.55VARBST FOR MF12 TF
FUEL PRICE	$0.30
HOST COMPONENT	USTEDLEC TURB-FAN WITH PYLON EFFECTS

PARAMETERS AFFECTED	CHANGE
ETAB....	-0.6500

	DESIGN SIZE BASE	DESIGN SIZE REPLACE	DESIGN SIZE DELTA	MISSION SIZE BASE	MISSION SIZE REPLACE	MISSION SIZE DELTA
FN, LBS	33156.	31950.		20000.	19269.	
DEL DIRECT WT, LB			31.0			
DEL DIRECT PR, K$			35.1			
DEL MMH, MMH/FL HR			0.			
DEL MMA, $MMA/FL HR			-0.42			
TOTAL WEIGHT, LB	4444.	4483.	39.	2362.	2382.	20.
TOT INIT PRICE, K$	768	934	36.	602	631	27.3
NAC WEIGHT, LB	3090.	3673.	583.	1772.	2106.	333.8
NAC PRICE, K$	492	553	61.	329	369	40.7
SFC	0.5790	0.5348	-0.0442			
SFC INSTALL	0.6138	0.5733	-0.0404			

	MISSION SIZE	DEL %DOC	DEL %RDI	DEL %TOGW	DEL %WF
TOT DEL WEIGHT, 100#	0.20	0.0337	-0.0123	0.0638	0.0517
DEL WT DIR	0.16	0.0275	-0.0100	0.0521	0.0422
DEL WT CYCLE	0.04	0.0062	-0.0023	0.0117	0.0095
TOT DEL PRICE, K$	27.25	0.2053	-0.1235		
DEL PRICE DIR INIT	26.51	0.1946	-0.1193		
DEL PRICE DIR REP	0.	0.	0.		
DEL PRICE DIR TOT		0.1946	-0.1193		
DEL PRICE CYCLE	0.74	0.0107	-0.0042		
DEL MMH, MMH/FL HR	0.	0.	0.		
DEL MMA, $MMA/FL HR	-0.42	-0.0962	0.0154		
DEL %SFC	-6.59	-2.5881	0.7310	-3.1083	-7.1847
DEL %WK2C	0.3120				
NAC WEIGHT, 100#	3.34	0.5574	-0.2026	1.0547	0.8411
NAC PRICE, K$	40.71	0.2988	-0.1632		
TOTAL		-1.5890	0.2248	-1.9898	-6.2919

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ENGINE 8U STAR GEAR

MISSION OUDJT 10.5FL CR SIZE
MATERIAL SUBSTITUTION 1.55VARBST FOR MF12 TF
FUEL PRICE $0.45
HOST COMPONENT USTEDLEC TURB FAN WITH PYLON EFFECTS

PARAMETERS AFFECTED	CHANGE
ETAB....	-0.6500

	DESIGN SIZE BASE	DESIGN SIZE REPLACE	DESIGN SIZE DELTA	MISSION SIZE BASE	MISSION SIZE REPLACE	MISSION SIZE DELTA
FN, LBS	33156.	31950.		21000.	20230.	
DEL DIRECT WT, LB			31.0			
DEL DIRECT PR, K$			42.3			
DEL MMH, MMH/FL HR			0.			
DEL MMA, $MMA/FL HR			-0.40			
TOTAL WEIGHT, LB	4444.	4483.	39.	2511.	2532.	21.
TOT INIT PRICE, K$	962	1006	44.	747	781	33.7
NAC WEIGHT, LB	3090.	3673.	583.	1870.	2222.	351.9
NAC PRICE, K$	594	667	74.	412	463	51.0
SFC	0.5790	0.5348	-0.0442			
SFC INSTALL	0.6138	0.5733	-0.0404			

	MISSION SIZE	DEL %DOC	DEL %ROI	DEL %TOGW	DEL %WF
TOT DEL WEIGHT, 100#	0.21	0.0472	-0.0194	0.0811	0.0660
DEL WT DIR	0.18	0.0392	-0.0161	0.0674	0.0548
DEL WT CYCLE	0.04	0.0080	-0.0033	0.0137	0.0112
TOT DEL PRICE, K$		0.2086	-0.0033		
DEL PRICE DIR INIT	32.84	0.1977	0.		
DEL PRICE DIR REP	0.	0.	0.		
DEL PRICE DIR TOT		0.1977	0.		
DEL PRICE CYCLE	0.87	0.0109	-0.0033		
DEL MMH, MMH/FL HR	0.	0.	0.		
DEL MMA, $MMA/FL HR	-0.40	-0.0956	0.0468		
DEL %SFC	-6.59	-4.6493	1.6266	-5.7161	-9.4633
DEL %WK2C	0.3120				
NAC WEIGHT, 100#	3.52	0.7882	-0.3244	1.3547	1.1014
NAC PRICE, K$	50.99	0.3070	-0.1907		
TOTAL		-3.3940	1.1356	-4.2803	-8.2959

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8/14

ENGINE GU STARGEAR
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MISSION QUDJT 70 TO FN SIZE
MATERIAL SUBSTITUTION 1.55VARBST FOR MF12 TF
FUEL PRICE $0.45
HOST COMPONENT USTEDLEC TURB FAN WITH PYLON EFFECTS

PARAMETERS AFFECTED CHANGE
ETAB.... -0.6500

	DESIGN SIZE BASE	DESIGN SIZE REPLACE	DESIGN SIZE DELTA	MISSION SIZE BASE	MISSION SIZE REPLACE	MISSION SIZE DELTA
FN, LBS	33150.	36047.		21000.	22834.	
DEL DIRECT WT, LB			758.0			
DEL DIRECT PR, K$			111.2			
DEL MMH, MMH/FL HR			0.			
DEL MMA, $MMA/FL HR			1.14			
TOTAL WEIGHT, LB	4444.	5210.	766.	2511.	2944.	433.
TOT INIT PRICE, K$	962	1075	113.	747	835	87.4
NAC WEIGHT, LB	3090.	4194.	1104.	1870.	2538.	668.4
NAC PRICE, K$	594	735	141.	412	510	98.1
SFC	0.5790	0.5348	-0.0442			
SFC INSTALL	0.6136	0.5733	-0.0404			

	MISSION SIZE	DEL %DOC	DEL %ROI	DEL %TOGW	DEL %UF
TOT DEL WEIGHT, 100#	4.33	0.9706	-0.3995	1.6682	1.3562
DEL WT DIR	4.28	0.9595	-0.3949	1.6492	1.3408
DEL WT CYCLE	0.05	0.0110	-0.0045	0.0190	0.0154
TOT DEL PRICE, K$		0.5331	-0.0039		
DEL PRICE DIR INIT	86.36	0.5200	0.		
DEL PRICE DIR REP	0.	0.	0.		
DEL PRICE DIR TOT		0.5200	0.		
DEL PRICE CYCLE	1.05	0.0131	-0.0039		
DEL MMH, MMH/FL HR	0.	0.	0.		
DEL MMA, $MMA/FL HR	1.14	0.2725	-0.1334		
DEL %SFC	-6.59	-4.6507	1.6271	-5.7179	-9.4661
DEL %R2C	0.3120				
NAC WEIGHT, 100#	6.68	1.4972	-0.6162	2.5733	2.0920
NAC PRICE, K$	98.08	0.5904	-0.3668		
TOTAL		-0.7870	0.1072	-1.4764	-6.0179

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ENGINE 8U STAR GEAR

MISSION TRIJT 7U TO FN SIZE
MATERIAL SUBSTITUTION 1.55VARBST FOR MF12 TF
FUEL PRICE $0.30
HOST COMPONENT USTEDLEC TURB-FAN WITH PYLON EFFECTS

PARAMETERS AFFECTED CHANGE
ETAB.... -0.6500

	DESIGN SIZE BASE	DESIGN SIZE REPLACE	DESIGN SIZE DELTA	MISSION SIZE BASE	MISSION SIZE REPLACE	MISSION SIZE DELTA
FN, LBS	33156.	36047.		20000.	21747.	
DEL DIRECT WT, LB			758.0			
DEL DIRECT PR, K$			92.3			
DEL MMH, MMH/FL HR			0.			
DEL MMA, $MMA/FL HR			1.22			
TOTAL WEIGHT, LB	4444.	5210.	766.	2362.	2770.	408.
TOT INIT PRICE, K$	799	892	93.	603	674	70.6
NAC WEIGHT, LB	3090.	4194.	1104.	1772.	2406.	633.5
NAC PRICE, K$	492	610	117.	329	407	78.2
SFC	0.5790	0.5348	-0.0442			
SFC INSTALL	0.6138	0.5733	-0.0404			

	MISSION SIZE	DEL %DOC	DEL %ROI	DEL %TOGW	DEL %WF
TOT DEL WEIGHT, 100#	4.08	0.6809	-0.2475	1.2883	1.0437
DEL WT DIR	4.03	0.6731	-0.2446	1.2736	1.0317
DEL WT CYCLE	0.05	0.0078	-0.0028	0.0148	0.0120
TOT DEL PRICE, K$		0.5241	-0.3186		
DEL PRICE DIR INIT	69.74	0.5119	-0.3138		
DEL PRICE DIR REP	0.	0.	0.		
DEL PRICE DIR TOT		0.5119	-0.3138		
DEL PRICE CYCLE	0.85	0.0123	-0.0048		
DEL MMH, MMH/FL HR	0.	0.	0.		
DEL MMA, $MMA/FL HR	1.22	0.2794	-0.0447		
DEL %SFC	-6.59	-2.5888	0.7312	-3.1093	-7.1868
DEL %WK2C	0.3120				
NAC WEIGHT, 100#	6.33	1.0579	-0.3845	2.0018	1.5964
NAC PRICE, K$	78.24	0.5743	-0.3521		
TOTAL		0.5277	-0.6161	0.1809	-4.5467

*

10.1 Turboprop - Introduction

A review of the turboprop engine was conducted in Task II in an attempt to further optimize the system. The following items were investigated:

1) 3 Stage LPT - page 10-14
2) Variable boost cycle - page 10-15
3) Review booster efficiency - page 10-26
4) Increased LP turbine speed for 4 stage LPT - page 10-27
5) "Installation Sized" engines - page 10-93

In addition to the engine review, the basic aerodynamics with advanced technology weights was chosen as the baseline configuration.

10.2.1 Turboprop Cycle and Performance

Attached is the cycle data defining the Task II turboprop cycle along with the 35K/.8/0 operating line. Table 10.2.1-1 presents the calculation leading to installed performance.

The use of the attached cycle data is the same as that discussed in 5.2.3.

Baseline Turboprop Performance

Table 10.2.1-1

Pt #	1	3	4	5	6	7	2	
Alt	35K →						0	
ΔT	+18	+18	0 →				+27	
M_0	.8 →						.2	
P_s	$M_x C_L$	$M_x C_r$	$M_x C_r$	$.8 M_x C_r$	$.6 M_x C_r$	$.4 M_x C_r$	T/O	
HPF	17205	15767	15493	12463	9467	6414	31887	Fan HP
SHPP	17033	15609	15338	12338	9372	6449	31568	Propellor HP
SHP/D^2	36.95	32.95	32.37	26.09	19.98	13.61	66.62	
D	21.77 →							Propellor Dia, ft
$W_2 \sqrt{\theta}/\delta$	68.4							
F_D	15600	15186	15195	14277	13266	12146	9851	Turbofan Ram Drag, lb
β	9.271	9.5169	9.506	10.058	10.883	12.107	9.893	Bypass Ratio
F_R	1519	1444	1446	1291	1116	926	904	Turboprop Ram Drag, lb
W_8	62.37	59.25	60.62	53.99	46.58	38.55	129.19	Nozzle Exit flow, lb/sec
V_8	1378	1285	1250	1066	878	688	821	" " Velocity, f/s
F_{N8}	1142	913	900	491	150	-107	2380	Engine Net Thrust, lb
V_p	796.6 →		778 →					Flight Speed f/s
PROP U_T	800	800	800					Prop Tip Speed f/s
η_p	.797	.812	.815	.824	.834	.833	$\boxed{1.24}$	$\frac{F}{SHP}$ Prop efficiency
F_{NP}	9372	8751	8837	7187	5525	3798	39144	Propellor Thrust, lb
WF	5210	4739	4602	3688	2812	1988	11001	Engine fuel flow, lb/hr
F_D'	625	621	621	613	603	592	410	Nacelle Drag, lb
F_{NI}	9889	9043	9116	7065	5072	3099	41114	Installed Thrust, lb
SFC_I	.527	.524	.505	.522	.554	.6415	.268	" SFC lb/hr/lb

SHPP = .99 x HPF (Gear efficiency = .99)

F_R = Ram Drag

F_D' = Installation Drag

F_{NP} = Prop Thrust

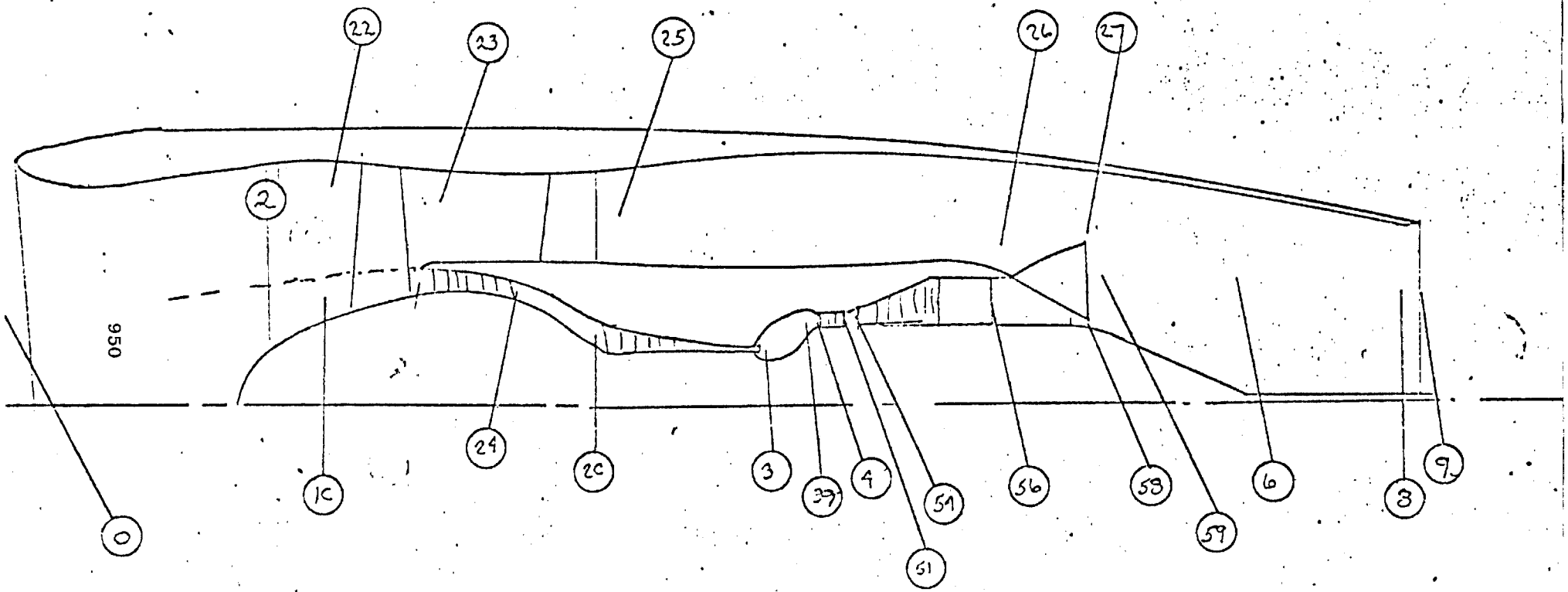
Turboprop Simulation
Batch ~~MF12~~ CYCLE NOMENCLATURE

Alt	Altitude, ft
M	Mach Number
P	Pressure, Psia
W	Flow, lb/sec
T	Temperature, ^{o}R
DELTO	To-Tstd day
ETAR	Ram Recovery
B, β	Bypass Ratio
FNG MX	~~Fully Mixed Net Thrust, lbs~~
SFC MX	Specific ~~Fuel Consumption Based on~~ FNG MX lbm/hr/lb
FNG-PM	~~Partially Mixed Net Thrust, lbs~~
SFC-PM	~~Specific Fuel Consumption Based on FNG PM~~
PCNF	~~Fan Physical Speed, %~~
NF	Fan Physical Speed, RPM
ECNF*	Fan Corrected Speed
ETAF	~~Fan Tip Adiabatic Efficiency~~
Q	Dynamic Pressure
ETAIC	Fan Hub + Booster Adiabatic Efficiency
PCNG	Core Physical Speed, %
NG	Core Physical Speed, RPM
PCNG*	Core Corrected Speed, %
WFM	Fuel Flow, lb/hr
ETABM	Burner Efficiency
TFFC	HP Turbine Flow Function
NRT4	HP Turbine Corrected Speed

*Indicates a corrected flow

MF12 CYCLE NOMENCLATURE (Cont.)

DH/T4	HP Turbine Energy Function
TFF2TC	LP Turbine Flow Function
N/RT54	LP Turbine Corrected Speed
DH/T54	LP Turbine Energy Function
V	Velocity, ft/sec
CF	Flow Coefficient
AE	Effective Area, in^2
CV	Velocity Coefficient
FGG-MX	Mixed Gross Thrust, lb
FD	Ram Drag
~~FGG-PM~~	~~Partial Mixed Gross Thrust, lb~~
~~PC-MX~~	~~Mixing Effectiveness~~



Station Designations

NASA-USTEDLEC/TPS CYCLE (TURBOPROP CORE CYCLE)
REVISED 2/18/76 TO CORRECT BOOSTER AND LPT EFFICIENCIES
BOOSTER INLET CONDITIONS REFLECT THE EFFECTS OF A PROP
BOOSTER AND LPT ETAS HAVE BEEN HAND INPUT ON EACH CASE

Base Turbop
2/19/76

CASE	1.00	2.00	3.00	4.00	5.00	6.00	7.00
	Match Pt			35K/.8/0 operating line			
ALT	35000.	0.	35000.	35000.	35000.	35000.	35000.
MO	0.800	0.200	0.800	0.800	0.800	0.800	0.800
PC	50.00	50.00	50.00	50.00	50.00	50.00	50.00
RC	40.00	40.00	40.00	40.00	40.00	40.00	40.00
FNG	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SFCG	[illegible]	[illegible]	[illegible]	0.5396	0.5400	[illegible]	0.5819
DELTO	22.15	32.50	22.10	3.90	3.90	3.90	3.90
TO	416.00	551.17	415.95	397.75	397.75	397.75	397.75
PO	3.4580	14.6960	3.4580	3.4580	3.4580	3.4580	3.4580
T2	469.43	555.59	469.43	448.89	448.89	448.89	448.89
ETAR	1.0180	1.0160	1.0180	1.0180	1.0180	1.0180	1.0180
P2	5.369	15.384	5.369	5.367	5.367	5.367	5.367
P22/P2	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996
M21	0.6393	0.4829	0.6097	0.6108	0.5524	0.4964	0.4409
P22	5.367	15.378	5.367	5.365	5.365	5.365	5.365
B	9.2714	9.8934	9.5169	9.5058	10.0583	10.8833	12.1071
PATH	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR	SEPR
HB/H2C	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
HB	0.	0.	0.	0.	0.	0.	0.
PBD	199.15	419.67	186.63	187.13	161.24	133.65	105.24
TBD	1857.7	1587.7	1830.3	1837.8	1311.2	1234.8	1151.1
HBI	0.122	0.253	0.116	0.119	0.106	0.092	0.076
PBI	78.76	169.67	74.35	74.53	65.34	56.15	44.70
TBI	1137.5	1235.5	1133.7	1087.5	1042.4	985.8	925.2
HPE	0.	0.	0.	0.	0.	0.	0.
PCNF	95.101	88.628	92.301	90.753	85.016	78.353	70.638
NF	4[illegible].1	4169.6	4348.3	4256.5	4005.1	3691.2	3327.8
PCNFR	100.001	85.035	97.022	97.123	91.385	[illegible]	75.930
N2R	1633.41	1361.71	[illegible]	1591.77	1[illegible].59	1389.69	1271.78
N2	627.03	1376.70	610.[illegible]	624.65	500.00	545.35	499.06
P23/22	1.7000	1.4[illegible]	1.6511	1.6528	1.5440	1.4[illegible]	1.3026
Z22	0.6622	0.6522	0.6462	0.6466	0.6030	0.5880	0.[illegible]02
ETAF	[illegible]	0.6511	0.6[illegible]	0.6[illegible]	0.6627	0.6809	0.[illegible]
NPFAN	17205.	31867.	15767.	15493.	12463.	9867.	6514.
RNI22	[illegible]	[illegible]	0.4153	0.4[illegible]	0.4[illegible]	0.4[illegible]	0.4[illegible]
N23	0.4[illegible]	0.4175	0.4484	0.4484	0.4452	0.4[illegible]	0.4343
P25P23	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
N25P	0.4409	0.4206	0.4499	0.4498	0.4497	0.4[illegible]	0.4474
AG25P	3996.2	3996.2	3996.2	3996.2	3996.2	3996.2	3996.2

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OF POOR QUALITY

NASA-USTDLEC/TPS CYCLE (TURBOPROP CORE CYCLE)
REVISED 2/10/76 TO CORRECT BOOSTER AND LPT EFFICIENCIES
BOOSTER INLET CONDITIONS REFLECT THE EFFECTS OF A PROP
BOOSTER AND LPT ETAS HAVE BEEN HAND INPUT ON EACH CASE

CASE	1.00	2.00	3.00	4.00	5.00	6.00	7.00
P25P	9.125	22.570	8.862	8.868	8.283	7.660	6.989
P2525P	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
P25	9.124	22.570	8.862	8.867	8.283	7.660	6.989
Q25	1.1258	2.0746	1.0933	1.0940	1.0214	0.9425	0.8545
T25	559.2	630.7	553.7	529.6	517.9	504.9	490.6
H25	0.4500	0.4208	0.4499	0.4499	0.4497	0.4491	0.4475
H25	565.98	1250.35	552.42	565.18	533.83	499.46	460.98
P28/25	0.9930	0.9938	0.9930	0.9930	0.9930	0.9930	0.9931
P28	9.061	22.430	8.800	8.805	8.225	7.606	6.940
T28	559.2	630.7	553.7	529.6	517.9	504.9	490.6
H28	565.98	1250.35	552.42	565.18	533.83	499.46	460.98
CV29	0.9993	0.9970	0.9989	0.9989	0.9979	0.9975	0.9970
CF28	0.9863	0.9702	0.9862	0.9862	0.9860	0.9850	0.9822
AE28	2777.3	2732.2	2777.1	2777.1	2776.5	2773.7	2765.9
A28	2815.9	2816.1	2816.0	2816.0	2816.0	2816.0	2816.0
V20	1058.4	928.6	1053.2	1030.0	1018.5	1005.7	991.4
H28	1.0000	0.8012	1.0000	1.0000	1.0000	1.0000	1.0000
Z1C	0.6617	0.6666	0.6827	0.6821	0.7366	0.7695	0.8329
P24/1C	2.7501	2.2235	2.6557	2.6591	2.4705	2.2153	1.9639
H1C*	159.03	125.01	151.20	151.53	135.25	116.94	97.03
H1C	61.05	126.39	58.05	59.46	53.07	45.89	38.08
BFF1C	0.57067	0.57067	0.57067	0.57067	0.57067	0.57067	0.57067
ETA1C	0.8720	0.8740	0.8670	0.8670	0.8690	0.8810	0.8770
HP1C	3742.	6995.	3437.	3371.	2745.	2026.	1408.
P24	14.761	34.194	14.254	14.266	13.254	11.885	10.537
T24	650.2	718.3	644.0	616.2	601.6	579.2	558.1
H24	0.4499	0.4158	0.4382	0.4387	0.4107	0.3838	0.3470
Q24	1.8181	3.6640	1.6776	1.6832	1.3932	1.1069	0.8173
P2C/24	0.9900	0.9913	0.9904	0.9904	0.9915	0.9924	0.9937
AE20	0.	0.	0.	0.	0.	0.	0.
HB/H24	0.	0.	0.	0.	0.	0.	0.
P2C	14.613	33.896	14.118	14.130	13.141	11.796	10.470
T2C	650.2	718.3	644.0	616.2	601.6	579.2	558.1
PCNG	99.448	102.284	98.234	98.116	93.392	90.149	86.182
PCNG*	88.821	86.919	88.158	88.185	86.718	85.305	83.084
NG	14494.	14907.	14317.	14008.	13611.	13138.	12560.
PCNGAH	99.999	97.858	99.253	99.284	97.632	96.041	93.541
WARC2C	0.	0.	0.	0.	0.	0.	0.
W2C	61.05	126.38	58.05	59.46	53.07	45.89	38.08
W2C*	60.74	64.48	67.33	67.40	63.92	60.42	55.43

NASA-USTOLEC/TPS CYCLE (TURBOPROP CORE CYCLE)
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CASE	1.00	2.00	3.00	4.00	5.00	6.00	7.00
P3/P2C	14.0915	12.7288	13.9850	13.6112	12.6182	11.6605	10.3552
Z2C	0.5070	0.5615	0.5798	0.5815	0.5628	0.5390	0.5133
ETAC	0.8600	0.8677	0.8627	0.8627	0.8675	0.8709	0.8721
HPC	17091.	36674.	15798.	15516.	12915.	10262.	7660.
RNI2C	0.7487	1.5373	0.7320	0.7738	0.7415	0.6979	0.6492
P3/P2	38.1202	28.0569	35.7337	35.8470	30.9075	25.6365	20.2090
P3	204.60	431.46	191.79	192.32	165.82	137.54	108.42
P83	193.40	407.33	181.23	181.70	156.44	129.57	101.92
T3	1457.7	1547.7	1430.3	1373.8	1311.2	1234.8	1151.1
HAR3	0.	0.	0.	0.	0.	0.	0.
H3	58.97	122.09	56.07	57.44	51.27	44.33	36.78
H31	52.51	108.70	49.93	51.14	45.65	39.47	32.75
K3	0.2890	0.2933	0.2904	0.2904	0.2936	0.2969	0.3017
P4/P3	0.9470	0.9458	0.9465	0.9464	0.9452	0.9439	0.9421
HFH	5209.8	11001.5	4739.3	4602.0	3688.4	2812.5	1987.9
ETADH	0.9875	0.9875	0.9875	0.9875	0.9875	0.9875	0.9875
FAR339	0.02796	0.02611	0.02637	0.02500	0.02244	0.01979	0.01686
T39	3053.2	3153.8	2970.4	2853.5	2667.1	2450.9	2221.2
T4	2960.0	3060.1	2880.0	2766.1	2586.4	2384.9	2156.0
HAR4	0.	0.	0.	0.	0.	0.	0.
FAR4	0.02573	0.02624	0.02461	0.02333	0.02095	0.01847	0.01574
P4	193.76	408.07	181.53	182.01	156.73	129.83	102.14
H4	57.70	119.52	54.81	56.07	49.93	43.07	35.68
TEFC	16.20	16.20	16.20	16.20	16.20	16.20	16.20
N/RT4	266.40	269.48	266.70	266.34	267.64	269.03	270.51
DH/T4	0.07083	0.07098	0.07083	0.07082	0.07079	0.07073	0.07059
ETAT	0.8980	0.8982	0.8980	0.8980	0.8981	0.8981	0.8981
HPT	17117.	36721.	15818.	15540.	12935.	10279.	7674.
HPAUX	25.55	47.04	24.04	23.15	20.10	17.09	14.17
P4/P51	3.7850	3.7905	3.7903	3.7966	3.8066	3.8167	3.8258
P51	51.186	107.656	47.895	47.940	41.173	34.015	26.699
T51	2227.5	2308.9	2162.8	2070.8	1926.8	1767.3	1588.7
FAR51	0.02444	0.02493	0.02338	0.02216	0.01990	0.01755	0.01495
HAR51	0.	0.	0.	0.	0.	0.	0.
H51	60.66	125.65	57.62	58.95	52.51	45.30	37.49
K51	0.4800	0.4823	0.4796	0.4789	0.4777	0.4760	0.4736
P54/51	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
P54	51.186	107.656	47.895	47.940	41.173	34.015	26.699
T54	2227.5	2308.9	2162.8	2070.8	1926.8	1767.3	1588.7
FAR54	0.02444	0.02493	0.02338	0.02216	0.01990	0.01755	0.01495
HAR54	0.	0.	0.	0.	0.	0.	0.
H54	60.66	125.65	57.62	58.95	52.51	45.30	37.49
TEFZTC	55.93	56.08	55.95	55.96	55.98	55.98	55.96
N/RT54	94.97	86.69	93.50	93.54	91.24	87.80	83.49
DH/T54	0.10957	0.09473	0.10891	0.10898	0.10625	0.10147	0.09402

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CASE	1.00	2.00	3.00	4.00	5.00	6.00	7.00
ETA2T	0.9170	0.9190	0.9190	0.9210	0.9210	0.9180	0.9120
HP2T	20947.	38882.	19204.	18823.	15208.	11993.	7922.
RNIS4	0.6979	1.4110	0.6745	0.7083	0.6585	0.5982	0.5280
P54/56	9.5366	6.4049	9.3558	9.3823	8.8134	7.9174	6.6961
P56	5.367	16.808	5.119	5.110	4.672	4.296	3.987
T56	1359.2	1538.3	1319.2	1254.6	1175.0	1097.3	1019.5
H56	62.37	129.19	59.25	60.62	53.99	46.58	38.55
M56	0.5002	0.3254	0.4866	0.4853	0.4476	0.3947	0.3294
P0/56	0.9900	0.9950	0.9904	0.9904	0.9916	0.9933	0.9952
FAR8	0.02375	0.02423	0.02273	0.02154	0.01934	0.01706	0.01453
WAR8	0.	0.	0.	0.	0.	0.	0.
H8	62.37	129.19	59.25	60.62	53.99	46.58	38.55
T8	1359.2	1538.3	1319.2	1254.6	1175.0	1097.3	1019.5
P8	5.314	16.731	5.070	5.061	4.633	4.267	3.968
P8OP0	1.5366	1.1385	1.4662	1.4635	1.3397	1.2341	1.1475
M8	0.8200	0.4444	0.7711	0.7680	0.6681	0.5626	0.4520
V8	1377.9	821.1	1284.9	1249.7	1065.6	877.9	687.5
CF8	1.0165	1.0165	1.0165	1.0165	1.0165	1.0165	1.0165
CV9	0.9970	0.9970	0.9970	0.9970	0.9970	0.9970	0.9970
AEB	850.41	851.25	850.52	850.45	850.68	849.62	850.11
A8	836.6	837.4	836.7	836.6	836.9	835.8	836.3
FD	15599.	9851.	15186.	15195.	10277.	13266.	12140.
FGG	24956.	39270.	23725.	23732.	21107.	18390.	15556.
FNU/W2	10.92	21.37	13.99	13.67	11.64	9.40	6.84
D/F-PC	5.0	0.4	5.3	5.3	6.3	7.7	10.6
CO	0.1843	0.1843	0.1843	0.1843	0.1843	0.1843	0.1843
FDI	466.4	103.3	454.1	454.5	427.1	396.8	363.1
SWEMG	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
BONG	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
HC3/2C	0.0765	0.0765	0.0765	0.0765	0.0765	0.0765	0.0765
HC4/2C	0.0614	0.0614	0.0614	0.0614	0.0614	0.0614	0.0614
HCS12C	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360	0.0360
HCS02C	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125	0.0125
HCS42C	0.	0.	0.	0.	0.	0.	0.
HCS11	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050
HCS12	0.0230	0.0230	0.0230	0.0230	0.0230	0.0230	0.0230
HCS52C	0.0280	0.0280	0.0280	0.0280	0.0280	0.0280	0.0280
HCI/2C	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320
FIBAN	0.3880	0.3880	0.3880	0.3880	0.3880	0.3880	0.3880
FCAN51	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850	0.2850
FCAN54	0.7500	0.7500	0.7500	0.7500	0.7500	0.7500	0.7500
FCH551	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
FCH552	0.2770	0.2770	0.2770	0.2770	0.2770	0.2770	0.2770

NASA-USTEDLEC/TPS CYCLE (TURBOPROP CORE CYCLE)
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CASE	1.00	2.00	3.00	4.00	5.00	6.00	7.00
CASE	1.00	2.00	3.00	4.00	5.00	6.00	7.00
AE21	5449.7	5449.7	5449.7	5449.7	5449.7	5449.7	5449.7
AE25P	3996.2	3996.2	3996.2	3996.2	3996.2	3996.2	3996.2
AE25	3996.2	3996.2	3996.2	3996.2	3996.2	3996.2	3996.2
AE26	4417.4	4417.4	4417.4	4417.4	4417.4	4417.4	4417.4
AE27	3833.9	3833.9	3833.9	3833.9	3833.9	3833.9	3833.9
AE24	287.5	287.5	287.5	287.5	287.5	287.5	287.5
AE3	44.3	44.3	44.3	44.3	44.3	44.3	44.3
AE51	149.78	149.78	149.78	149.78	149.78	149.78	149.78
AE56	1099.3	1099.3	1099.3	1099.3	1099.3	1099.3	1099.3
AE58	1192.8	1192.8	1192.8	1192.8	1192.8	1192.8	1192.8
AE59	1192.8	1192.8	1192.8	1192.8	1192.8	1192.8	1192.8
PCHPRH	100.00	85.48	97.02	97.12	91.39	84.22	75.93
P2322H	1.8751	1.5887	1.8139	1.8160	1.6600	1.5346	1.3783
FFFHB	1406.26	1172.35	1369.03	1370.41	1287.61	1196.43	1094.88
ETAFHB	0.8503	0.8484	0.8521	0.8521	0.8540	0.8521	0.8371
PCN1RH	100.00	85.48	97.02	97.12	91.39	84.22	75.93
P241CH	2.5441	2.0795	2.4609	2.4638	2.2974	2.0723	1.8505
FF1CHB	279.91	219.10	266.21	266.67	238.14	206.06	171.03
BFF1CR	0.9956	0.9998	0.9953	0.9957	0.9952	0.9945	0.9941
ET1CHB	0.8558	0.8631	0.8579	0.8578	0.8581	0.8551	0.8415
BET1CR	0.9952	0.9999	0.9947	0.9951	0.9942	0.9930	0.9923
PCNRTH	100.00	97.86	99.25	99.28	97.63	96.00	93.54
P302CH	11.9995	10.9228	11.6472	11.6694	10.8293	10.0190	8.9187
CFFHB	130.058	122.164	127.505	127.609	121.237	114.784	105.515
BCFFR	0.9990	1.0000	0.9992	0.9995	0.9990	0.9983	0.9971
ETACHB	0.8530	0.8608	0.8560	0.8560	0.8615	0.8655	0.8673
BETACR	1.0001	1.0011	1.0001	1.0002	1.0001	1.0000	0.9998
DHOTAH	0.07290	0.07303	0.07290	0.07288	0.07286	0.07279	0.07265
XNORAH	184.24	186.37	184.50	184.20	185.10	186.06	187.09
TFFHB	33.42	33.42	33.42	33.42	33.42	33.42	33.42
BTFFR	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999
ETATHB	0.8878	0.8879	0.8878	0.8878	0.8879	0.8880	0.8880
BETATR	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9998
DHOS4H	0.07261	0.06277	0.07217	0.07222	0.07041	0.06724	0.06230
XNRS4H	98.97	90.35	97.44	97.48	95.09	91.51	87.01
TFF2HB	125.04	125.31	125.10	125.10	125.18	125.28	125.37
BF2TR	0.9995	1.0000	0.9993	0.9995	0.9992	0.9985	0.9973
ETA2HB	0.9175	0.9076	0.9158	0.9158	0.9134	0.9086	0.9014
BET2TR	0.9975	0.9980	0.9973	0.9975	0.9973	0.9967	0.9956
NS11	0	0	0	0	0	0	0
NS12	0	0	0	0	0	0	0
NS13	0	0	0	0	0	0	0
NS14	0	0	0	0	0	0	0
NS15	0	0	0	0	0	0	0

Baseline Turboprop

10.2.2 Cycle Influence Coefficients

The following influence coefficients were derived to determine the effects of various cycle variables on core size and installed SFC holding engine thrust constant and exhaust nozzle pressure ratio constant

	Δ% W2C lb/s	Δ% SHP	Δ% SFC_I
1% η_{Boost}	-.7	.02	-.13
1% η_{LPT}	-1.09	.2	-1.06
1% W/W_{LPT}	1.88	-.18	.76
1 #/sec Customer Bleed	2.63		1.4
100 HP Extract	.50	.	.57

10.2.3 Revised Baseline Cycle

After component aerodynamic definition, it was found that adjustments were required for cooling flow and LPT efficiency.

	Cycle value	Required	Δ
W/W_{cool}	2.3%	2.55%	+.25%
η_{LPT} @80% MxC	.921	.919	-.2%
η_{Boost}	.872	.881	+.9%

Using Influence Coefficients

$$\Delta W2C\sqrt{\theta_\delta} = (.25)(1.88) + (-.2)(-1.09) + (.9)(.7) = +.058\ \%$$

$$\Delta SP = (.25)(-.18) + (-.2)(.2) + (.9)(.02) = -.067\ \%$$

$$\Delta SFC_I = (.25)(.76) + (-.2)(-1.06) + (.9)(-.13) = +.285\ \%$$

Adjustment of D_{TIP} when scaled to $W2C\sqrt{\theta/\delta}$

$$\Delta SP = (-.058 + .067) = -.125\%$$

$\Delta SFC_I = +.246$ (Assumed at all conditions)

@ 35K/1.8/0 80% MxC $SFC_I = .523$

$FN_{Installed}$ @ MxC = 9883

9/67

10.2.4 3 Stage LPT Turboprop Cycle

The basic cycle for the 3 stage LPT is the same as the baseline. The following modifications from the cycle printout are required.

	Cycle	Aero design	Δ
η_{boost}	.972	.882	+1%
η_{LPt}	.921	.905	-1.6%

Using influence coefficients as before

$W2CV\theta/\delta = 68.4$

80% MxCr	Δ%SFC = +1.56%	⇒	$SFC_{I_{80\% MxCr}} = .531$
MxCr	Δ%FNI = -1.01%	⇒	$FNI_{MxCr} = 9791.$
	$D_T =$		

A correction is also applied for the fact that the installed drag is 620# rather than 625# used in original calculation

$FN_I = 9796$

$SFC_I = .531$

Evaluation of this engine can be found in the "Engine Evaluation Section". The results indicate this engine has inferior installed performance as compared with the 4 stage LPT

10.2.5 Variable Boost Cycle

Attached is the cycle printout for the Variable boost. Below is the calculation to arrive at the 35K/.8/+18 MX CL

HPFAN	.19521
SHP	19325
SHP/D²	35.85
D	23.2
FD	17761
β	8.954
FR	1784
W_8	73.19
V_8	1350
F_{N8}	1275
V_P	796.6
η_P	.797
F_{NP}	10633
WF	5802
F_U	714
F_{NT}	11194
SFC	.5183

This cycle is run to a $P_{3c}/P_2 = 46$ @ 35K/.8/+18/MXCL. The boost is adjusted at SLS to set $P_3/P_2 = 29$

The following adjustments are required from the base cycle.

	Cycle	Aero design	Δ
η_{Boost}	.862	.8655	+.35 %
η_{LPT}	.921	.916	−.5 %
ω/ω_{LPT}	2.3	2.0	−.3 %

The above changes result in the following installed performance $W_2\sqrt{\theta}/\delta = 68.4$

@ 35K/.8/+18 MxCL

$F_{NI} = 1/227$

$SFC_I = .52$

The assumption is made that the ratio $\frac{SFC \text{ @ } 80\% \text{ MxCL}}{SFC \text{ MxCL}}$ is the same as the baseline engine

$$\therefore \quad SFC_I = .52\left(\frac{.522}{.527}\right) = .515$$

Turboprop Simulation
Batch ~~MF14~~ CYCLE NOMENCLATURE

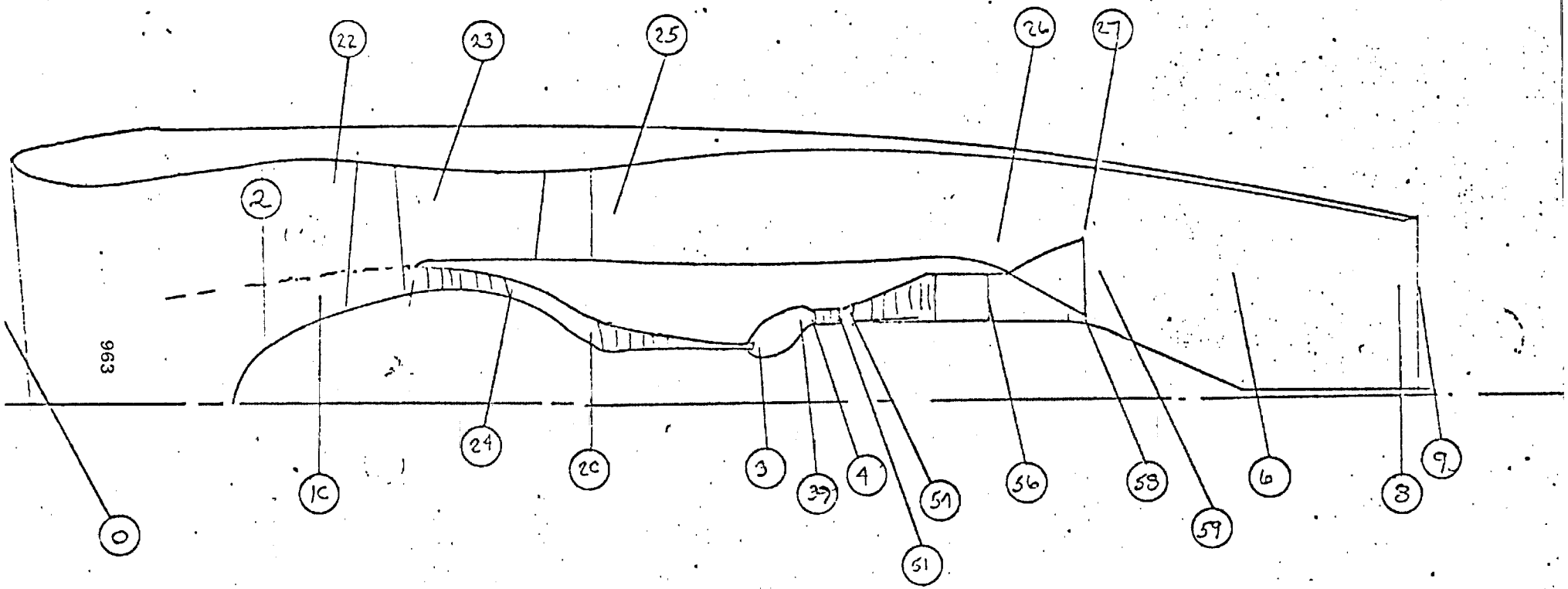
Alt	Altitude, ft
M	Mach Number
P	Pressure, Psia
W	Flow, lb/sec
T	Temperature, ^{o}R
DELTO	To-Tstd day
ETAR	Ram Recovery
B, β	Bypass Ratio
FNG MX	~~Fully Mixed Net Thrust, lbs~~
SFC MX	Specific Fuel Consumption Based on FNG MX lbm/hr/lb
FNG-PM	Partially Mixed Net Thrust, lbs
SFC-PM	Specific Fuel Consumption Based on FNG PM
PCNF	~~Fan Physical Speed, %~~
NF	Fan Physical Speed, RPM
ECNF*	Fan Corrected Speed
ETAF	~~Fan Tip Adiabatic Efficiency~~
Q	Dynamic Pressure
ETAIC	Fan Hub + Booster Adiabatic Efficiency
PCNG	Core Physical Speed, %
NG	Core Physical Speed, RPM
PCNG*	Core Corrected Speed, %
WFM	Fuel Flow, lb/hr
ETABM	Burner Efficiency
TFFC	HP Turbine Flow Function
NRT4	HP Turbine Corrected Speed

*Indicates a corrected flow

TURBOPROP SIMULATION BATCH

CYCLE NOMENCLATURE (Cont.)

DH/T4	HP Turbine Energy Function
TFF2TC	LP Turbine Flow Function
N/RT54	LP Turbine Corrected Speed
DH/T54	LP Turbine Energy Function
V	Velocity, ft/sec
CF	Flow Coefficient
AE	Effective Area, in^2
CV	Velocity Coefficient
FGG-MX	Mixed Gross Thrust, lb
FD	Ram Drag
~~FGG-PM~~	~~Partial Mixed Gross Thrust, lb~~
PC-MX	~~Mixing Effectiveness~~



Station Designations

Turboprop-Variable Boost Cycle /TP6

PT#	Alt	M_0	ΔT_0	Description
1	35K	.8	+18°F	Mx CL
2	↓	↓	↓	↓
3				Mx Cr
4	0	0	+27	T/O

NASA-USTEDLEC/TP6 CYCLE (TURBOPROP CORE CYCLE)
THIS CYCLE IS THE VARIABLE BOOST VERSION OF THE TP5
BOOSTER INLET CONDITIONS REFLECT THE EFFECTS OF A PROP

CASE	1.00	2.00	3.00	4.00
ALT	35000.	35000.	35000.	0.
MO	0.800	0.800	0.800	0.
PC	50.00	50.00	50.00	50.00
RC	40.00	40.00	40.00	40.00
FNG	10595.5	10595.1	9631.3	37071.5
SFCG	0.5476	0.5476	0.5476	0.2852
DELTO	22.15	22.15	22.15	32.50
TO	416.00	416.00	416.00	551.17
PO	3.4580	3.4580	3.4580	14.6960
T2	469.48	469.48	469.48	551.17
ETAR	1.0180	1.0180	1.0180	1.0180
P2	5.369	5.369	5.369	14.961
P22/P2	0.9996	0.9996	0.9996	0.9996
M21	0.6395	0.6393	0.6081	0.4387
P22	5.367	5.367	5.367	14.955
B	8.9539	8.9538	9.1904	10.6122
PATH	SEPR	SEPR	SEPR	SEPR
WB/W2C	0.0020	0.0020	0.0020	0.0020
WB	0.	0.	0.	0.
PBD	240.34	240.33	224.90	418.04
TBD	1541.3	1541.3	1509.9	1562.4
WBI	0.143	0.143	0.136	0.245
PBI	95.76	95.76	90.12	162.74
TBI	1224.5	1224.5	1201.0	1234.2
HPE	0.	0.	0.	0.
PCNF	95.140	95.138	92.155	83.442
NF	4482.1	4481.9	4341.4	3930.9
PCNF*	100.000	99.998	96.862	80.944
W2*	1859.82	1859.77	1807.78	1441.93
W2	713.95	713.93	693.97	1423.38
P23/22	1.7000	1.7000	1.6483	1.4161
Z22	0.6627	0.6628	0.6452	0.6893
ETAF	0.8590	0.8590	0.8607	0.8501
HPFAN	19521.	19521.	17803.	29923.
RNI22	0.4152	0.4152	0.4152	0.9419
M23	0.4500	0.4499	0.4483	0.3962
P25P23	1.0000	1.0000	1.0000	1.0000
M25P	0.4500	0.4499	0.4499	0.4040
AE25P	4534.3	4534.3	4534.3	4534.3

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NASA-USTEDLEC/TP6 CYCLE (TURBOPROP CORE CYCLE)
THIS CYCLE IS THE VARIABLE BOOST VERSION OF THE TP5
BOOSTER INLET CONDITIONS REFLECT THE EFFECTS OF A PROP

CASE	1.00	2.00	3.00	4.00
P25P	9.124	9.124	8.847	21.177
P25/P	1.0000	1.0000	1.0000	1.0000
P25	9.124	9.124	8.847	21.177
Q25	1.1258	1.1258	1.0914	2.1614
T25	559.2	559.2	553.5	619.0
M25	0.4500	0.4500	0.4499	0.4040
W25	642.22	642.20	625.87	1300.81
P28/25	0.9930	0.9930	0.9930	0.9942
P28	9.061	9.060	8.785	21.055
T28	559.2	559.2	553.5	619.0
W28	642.22	642.20	625.87	1300.81
CV29	0.9993	0.9993	0.9988	0.9970
CF28	0.9863	0.9863	0.9862	0.9688
AE28	3151.4	3151.4	3151.1	3095.4
A28	3195.2	3195.1	3195.2	3195.2
V28	1058.4	1058.4	1053.0	852.0
M28	1.0000	1.0000	1.0000	0.7354
Z1C	0.6616	0.6616	0.6783	0.2018
P24/1C	3.4266	3.4264	3.2842	1.9881
W1C*	186.85	186.84	177.40	124.17
W1C	71.73	71.72	68.10	122.58
SFF1C	0.67050	0.67050	0.67050	0.54057
ETA1C	0.8620	0.8620	0.8639	0.8665
HP1C	5596.	5596.	5086.	5742.
P24	18.392	18.391	17.627	29.731
T24	699.3	699.3	689.5	689.0
M24	0.4500	0.4500	0.4404	0.4797
Q24	2.2638	2.2633	2.0906	4.0825
P2C/24	0.9900	0.9900	0.9904	0.9888
AE2D	0.	0.	0.	0.
WB/W24	0.	0.	0.	0.
P2C	18.206	18.207	17.458	29.400
T2C	699.3	699.3	689.5	689.0
PCNG	102.290	102.290	101.014	103.797
PCNG*	88.096	88.096	87.610	90.058
NG	14908.	14908.	14722.	15127.
PCNG*M	99.183	99.184	98.637	101.392
WARC2C	0.	0.	0.	0.
W2C	71.73	71.72	68.10	122.58
W2C*	67.22	67.22	66.10	70.62

THIS CYCLE IS THE VARIABLE BOOST VERSION OF THE TP5
BOOSTER INLET CONDITIONS REFLECT THE EFFECTS OF A PROP

CASE	1.00	2.00	3.00	4.00
P3/P2C	13.5600	13.5603	13.2376	14.5988
Z2C	0.5816	0.5816	0.5762	0.5935
ETAC	0.8632	0.8632	0.8649	0.8524
HPC	21099.	21098.	19471.	37430.
RNI2C	0.8532	0.8532	0.8322	1.4028
P3/P2	46.0000	45.9988	43.0560	28.7004
P3	246.90	246.89	231.10	429.20
PS3	233.47	233.47	218.42	406.37
T3	1541.3	1541.3	1509.9	1562.4
WAR3	0.	0.	0.	0.
W3	69.29	69.29	65.78	118.41
W31	61.69	61.69	58.57	105.43
M3	0.2890	0.2890	0.2901	0.2859
P4/P3	0.9470	0.9470	0.9466	0.9481
WFM	5801.9	5801.7	5274.0	10572.1
ETABM	0.9875	0.9875	0.9875	0.9875
FAR339	0.02612	0.02612	0.02501	0.02786
T39	3048.7	3048.7	2966.2	3152.8
T4	2960.0	2960.0	2880.1	3060.0
WAR4	0.	0.	0.	0.
FAR4	0.02438	0.02438	0.02335	0.02600
P4	233.81	233.81	218.75	406.91
W4	67.71	67.71	64.22	115.89
TFFC	15.75	15.75	15.75	15.75
N/RT4	274.01	274.01	274.32	273.47
DH/T4	0.07451	0.07451	0.07451	0.07470
ETAT	0.8980	0.8980	0.8980	0.8979
HPT	21128.	21128.	19499.	37477.
HPAUX	29.65	29.64	27.68	47.13
P4/P51	4.1105	4.1105	4.1164	4.1196
P51	56.881	56.880	53.141	98.775
T51	2193.9	2193.9	2129.9	2272.1
FAR51	0.02316	0.02316	0.02218	0.02470
WAR51	0.	0.	0.	0.
W51	71.19	71.18	67.52	121.84
M51	0.4800	0.4800	0.4797	0.4827
P54/51	1.0000	1.0000	1.0000	1.0000
P54	56.881	56.880	53.141	98.775
T54	2193.9	2193.9	2129.9	2272.1
FAR54	0.02316	0.02316	0.02218	0.02470
WAR54	0.	0.	0.	0.
W54	71.19	71.18	67.52	121.84
TFF2TC	58.62	58.62	58.64	58.79
N/RT54	95.69	95.69	94.07	82.47
DH/T54	0.11368	0.11367	0.11249	0.09106

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NASA-USTEDLEC/TP6 CYCLE (TURBOPROP CORE CYCLE)
THIS CYCLE IS THE VARIABLE BOOST VERSION OF THE TP5
BOOSTER INLET CONDITIONS REFLECT THE EFFECTS OF A PROP

CASE	1.00	2.00	3.00	4.00
ETA2T	0.9210	0.9210	0.9191	0.9031
HP2T	25117.	25116.	22889.	35665.
RNI54	0.7886	0.7886	0.7612	1.3177
P54/56	10.5950	10.5945	10.3755	6.0966
P56	5.369	5.369	5.122	16.202
T56	1303.9	1304.0	1269.4	1541.2
W56	73.19	73.19	69.43	125.27
M56	0.5000	0.5000	0.4864	0.2811
P8/56	0.9900	0.9900	0.9904	0.9965
FAR8	0.02251	0.02251	0.02156	0.02401
WAR8	0.	0.	0.	0.
W8	73.19	73.19	69.43	125.27
T8	1303.9	1304.0	1269.4	1541.2
P8	5.315	5.315	5.073	16.145
P8QP0	1.5370	1.5370	1.4670	1.0986
M8	0.8192	0.8193	0.7707	0.3777
V8	1349.7	1349.7	1261.0	701.4
CF8	1.0165	1.0165	1.0165	1.0165
CV9	0.9970	0.9970	0.9970	0.9970
AE8	976.41	976.36	976.37	976.77
A8	960.6	960.5	960.5	960.9
FD	17761.	17760.	17264.	0.
FGG	28357.	28356.	26895.	37072.
FNU/W2	14.84	14.84	13.88	26.04
D/F-PC	5.0	5.0	5.4	0.
CD	0.1843	0.1843	0.1843	0.1843
FDI	531.1	531.1	516.2	0.
SWFMG	1.00000	1.00000	1.00000	1.00000
SFNG	1.0000	1.0000	1.0000	1.0000
WC3/2C	0.0765	0.0765	0.0765	0.0765
WC4/2C	0.0614	0.0614	0.0614	0.0614
WC5I2C	0.0360	0.0360	0.0360	0.0360
WC5D2C	0.0125	0.0125	0.0125	0.0125
WC542C	0.	0.	0.	0.
WC5511	0.0050	0.0050	0.0050	0.0050
WC5512	0.0230	0.0230	0.0230	0.0230
WC552C	0.0280	0.0280	0.0280	0.0280
WC1/2C	0.0320	0.0320	0.0320	0.0320
FIBAH	0.3880	0.3880	0.3880	0.3880
FCAH51	0.2850	0.2850	0.2850	0.2850
FCAH54	0.7500	0.7500	0.7500	0.7500
FCH551	1.0000	1.0000	1.0000	1.0000
FCH552	0.2770	0.2770	0.2770	0.2770

NASA/JSTEDLEC/TP6 CYCLE (TURBOPROP CORE CYCLE)
THIS CYCLE IS THE VARIABLE BOOST VERSION OF THE TP5
BOOSTER INLET CONDITIONS REFLECT THE EFFECTS OF A PROP

CASE	1.00	2.00	3.00	4.00
CASE	1.00	2.00	3.00	4.00
AE21	6205.1	6205.1	6205.1	6205.1
AE25P	4534.3	4534.3	4534.3	4534.3
AE25	4534.3	4534.3	4534.3	4534.3
AE26	5012.2	5012.2	5012.2	5012.2
AE27	4350.1	4350.1	4350.1	4350.1
AE24	281.3	281.3	281.3	281.3
AE3	44.4	44.4	44.4	44.4
AE51	156.87	156.87	156.87	156.87
AE56	1261.9	1261.9	1261.9	1261.9
AE58	1192.8	1192.8	1192.8	1192.8
AE59	1192.8	1192.8	1192.8	1192.8
PCNFRM	100.00	100.00	96.86	80.94
P2322M	1.8750	1.8750	1.8104	1.5202
FFFMB	1406.26	1406.22	1366.90	1090.28
ETAFMB	0.8503	0.8503	0.8520	0.8415
PCN1RM	100.00	100.00	96.86	80.94
P241CM	2.5440	2.5439	2.4534	1.6287
FF1CMB	279.91	279.90	265.85	229.78
SFF1CR	0.9956	0.9956	0.9953	0.9997
ET1CMB	0.8558	0.8558	0.8582	0.7168
SET1CR	0.9952	0.9952	0.9947	0.9997
PCNRTM	99.18	99.18	98.64	101.39
P302CM	11.6261	11.6263	11.3533	12.5049
CFFMB	127.239	127.241	125.189	133.539
SCFFR	0.9997	0.9997	0.9996	1.0000
ETACMB	0.8564	0.8564	0.8583	0.8447
SETACR	1.0003	1.0003	1.0003	1.0010
DHQT4M	0.07290	0.07290	0.07290	0.07308
XNQR4M	184.24	184.24	184.45	183.87
TFFMB	33.42	33.42	33.42	33.42
STFFR	1.0000	1.0000	1.0000	1.0000
ETATMB	0.8878	0.8878	0.8878	0.8877
SETATR	1.0000	1.0000	1.0000	1.0000
DHQ54M	0.07260	0.07260	0.07184	0.05816
XNR54M	98.97	98.97	97.29	85.29
TFF2MB	125.04	125.04	125.10	125.39
SF2TR	0.9998	0.9998	0.9997	1.0000
ETA2MB	0.9175	0.9175	0.9157	0.8995
SET2TR	0.9979	0.9979	0.9977	0.9980
NSI1	0	0	0	0
NSI2	0	0	0	0
NSI3	0	0	0	0
NSI4	0	0	0	0
NSI5	0	0	0	0
ICASE	2	3	4	5

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Task II

10.3.1 Booster Aerodynamic Design

The following is the aerodynamic definition and efficiency buildup of the boosters @ 35K/.8/+18/MxCL

	Baseline	3 Stage LPT	Variable Boost
No Stages	3	3	4
$U_T/\sqrt{\theta}$	1195	1190	1205
r_{hub}/r_{tip}	.72	.711	.717
P/Pover-all	2.75	2.75	3.43
P/Pstage	1.4	1.4	1.34
Efficiency			
η stage	.884	.884	.875
$\Delta\eta$ Variable Stator	-.01	-.01	-.01
$\Delta\eta$ Advanced Tech.	+.03	+.03	+.03
$\Delta\eta$ Reload	-.014	-.014	-.021
$\Delta\eta$ Radius Ratio	-.0085	-.008	-.0085
$\Sigma\Delta\eta$	-.0025	-.002	-.0095
η Boost	.881	.882	.8655

10.3.2 LP Turbine Aerodynamic Definition

Attached is the aerodynamic design computer output, blade No. calculations and heat transfer analysis output for the three LP turbines. Efficiency buildup is also attached.

In the final design of the baseline 4 stage turbine the rpm was increased from 6150 to 7130 @ 35K/.8/+18°F MxCl with a reduction of pitch diameter. The LPT efficiency was held the same as the buildup but the LP cooling flow increased to 2.55%.

TURBINE AERO PROGRAM NOMENCLATURE

TTØ - total temperature
PTØ - total pressure
MØ - Mach number
} At station Ø (Nozzle inlet)

PS1 - static pressure
PTS1 = PTØ/PS1
TS1 - static temperature
ALFA - angle of flow from axial
V1 - velocity of flow
M1 - mach number of flow
CZ1 - axial component of flow velocity
CU1 - tangential component of flow velocity
ZIN - incompressible Zweifel nbr. (tangential force coefficient)
FNA - axial force per unit nozzle height
FNT - tangential force per unit nozzle height
} At station 1R (Nozzle exit)

PTB - Total pressure relative to the bucket
TTB - Total temperature relative to the bucket
BET1 - angle of flow from axial relative to bucket
R1 - velocity of flow relative to bucket
MR1 - mach number of flow relative to bucket
W1 - wheel speed
} at station 1 (Bucket inlet)

PT2 - Total pressure
PS2 - Static pressure
PTS2 = PTØ/PS2
TT2 - Total temperature
TF - Test factor
TS2 - static temperature
BET2 - angle of flow leaving bucket relative to bucket
DLBA - Turning angle
RX - Reaction
V2 - velocity of flow
R2 - velocity of flow relative to bucket
MR2 - Mach number of flow relative to bucket
W2 - wheel speed
} at station 2 (Bucket exit)

TURBINE AERO PROGRAM NOMENCLATURE (CONT'D)

CZ2 - axial component of flow velocity
CU2 - tangential component of flow velocity
SWRL - swirl angle.
MF - Axial velocity Mach number
ZIB - Incompressible Zweifel nbr.
FBA - axial force per unit bucket height
FBT - tangential force per unit bucket height.
PSI - loading parameter
W/NO - velocity ratio.

} at station 2 (Bucket exit

ETATT - total efficiency
ETATS - static efficiency

TP5..4-STAGE.LPT

Pass II
1/27/76

Beseline 4 Stage

STAGE 1

	ROOT	PITCH	TIP
STA 0 NOZZLE INLET		WG= 51.90	
DIAMETER	25.650	27.475	29.300
ANNULUS AREA		157.53	
TTO		1922.0	
PTO		40.48	
MO		0.449	
STA 1PR NOZZLE EXIT		WG= 51.90	
DIAMETER	25.650	28.375	31.100
ANNULUS AREA		242.91	
FF (FLOW FUNCTION)		56.21	
PS1	24.08	26.13	27.76
PTS1	1.6812	1.5490	1.4565
TS1	1701.3	1734.3	1759.0
ALPHA	64.66	62.35	60.13
V1	1768.1	1630.7	1519.7
M1	0.900	0.822	0.761
CZ1		756.8	
CU1	1597.9	1444.5	1317.9
ZIN	0.774	0.822	0.864
FNA	1029.8	959.4	895.7
FNT	1045.7	1074.5	1096.9
NOZZLE AXIAL FORCE= 2614.3		TANG FORCE= 2928.0	
STA 1 BUCKET INLET		WG= 51.90	
DIAMETER	25.650	28.525	31.400
ANNULUS AREA		257.64	
PTB	30.69	31.29	31.92
TTB	1804.2	1811.4	1819.4
BET1	53.20	45.09	35.43
R1	1174.7	996.7	863.6
MR1	0.597	0.502	0.431
W1	657.4	731.0	804.7
STA 2 BUCKET EXIT		WG= 51.90	
DIAMETER	25.650	29.025	32.400
ANNULUS AREA		307.75	
PT2		25.49	
PS2	22.79	22.98	23.12
PTS2	1.7758	1.7612	1.7511
TT2		1738.0	
TF		0.960	
TS2	1684.1	1687.5	1689.9
BET2	59.55	60.25	61.15
DLBA	112.75	105.34	96.58
RX	0.100	0.244	0.351
V2	809.4	779.3	757.4
R2	1304.3	1332.2	1370.1
MR2	0.667	0.681	0.700
W2	657.4	743.9	830.4
CZ2		661.0	
CU2	467.0	412.7	369.7
SWRL	35.24	31.98	29.22
MF	0.338	0.338	0.338
ZIB	1.560	1.356	1.176
FBA	149.2	350.8	551.5
FBT	920.1	967.8	1005.5
BUCKET AXIAL FORCE= 1184.0		TANG FORCE= 3266.2	
PSI	1.508	1.193	0.975
W/VO	0.352	0.395	0.437

GENERAL STAGE RESULTS

WORK= 52.05 ETATT=0.902 ETATS=0.746

STAGE 2

	ROOT	PITCH	TIP
STA 0 NOZZLE INLET		WG= 51.90	
DIAMETER	25.650	29.225	32.800
ANNULUS AREA		328.23	
TTO		1738.0	
PTO		25.49	
MO		0.368	
STA 1PR NOZZLE EXIT		WG= 51.90	
DIAMETER	25.650	29.925	34.200
ANNULUS AREA		401.90	
FF (FLOW FUNCTION)		84.89	
PS1	13.01	15.34	17.01
PTS1	1.9596	1.6617	1.4982
TS1	1479.3	1538.8	1577.4
ALPHA	68.59	65.42	62.40
V1	1894.4	1662.4	1492.6
M1	1.031	0.887	0.787
CZ1		691.5	
CU1	1764.1	1512.1	1323.1
ZIN	0.868	0.973	1.061
FNA	804.3	717.5	638.9
FNT	769.9	815.4	847.8
NOZZLE AXIAL FORCE= 3067.3		TANG FORCE= 3485.8	
STA 1 BUCKET INLET		WG= 51.90	
DIAMETER	25.650	30.125	34.600
ANNULUS AREA		423.52	
PTB	17.95	18.60	19.31
TTB	1602.0	1613.8	1627.5
BET1	59.65	48.41	33.01
R1	1282.5	976.1	772.7
MR1	0.697	0.520	0.406
W1	657.4	772.1	886.7
STA 2 BUCKET EXIT		WG= 51.90	
DIAMETER	25.650	30.725	35.800
ANNULUS AREA		489.87	
PT2		14.00	
PS2	11.86	12.14	12.31
PTS2	2.1483	2.0996	2.0708
TT2		1521.5	
TF		0.960	
TS2	1451.8	1460.1	1465.1
BET2	61.87	62.39	63.39
DLBA	121.52	110.80	96.41
RX	0.100	0.318	0.457
V2	917.1	852.3	810.6
R2	1442.9	1463.1	1519.0
MR2	0.793	0.804	0.831
W2	657.4	787.4	917.5
CZ2		680.3	
CU2	615.1	513.5	440.7
SWRL	42.12	37.05	32.94
MF	0.374	0.373	0.372
ZIB	1.591	1.305	1.061
FBA	95.7	323.3	561.4
FBT	631.7	692.6	735.3
BUCKET AXIAL FORCE= 1640.7		TANG FORCE= 3514.8	
PSI	1.737	1.235	0.922
W/VO	0.327	0.388	0.449

GENERAL STAGE RESULTS

WORK= 59.97 ETATT=0.903 ETATS=0.742

STAGE 3

	ROOT	PITCH	TIP
STA 0 NOZZLE INLET		WG= 51.90	
DIAMETER	25.650	30.875	36.100
ANNULUS AREA		506.31	
TTO		1521.5	
PTO		14.00	
MO		0.446	
STA 1PR NOZZLE EXIT		WG= 51.90	
DIAMETER	25.650	31.825	38.000
ANNULUS AREA		617.33	
FF (FLOW FUNCTION)		144.64	
PS1	6.85	8.59	9.69
PTS1	2.0436	1.6289	1.4445
TS1	1276.5	1349.5	1389.9
ALPHA	67.22	62.43	58.11
V1	1820.3	1525.3	1334.2
M1	1.062	0.865	0.746
CZ1		704.8	
CU1	1678.3	1353.1	1133.2
ZIN	0.985	1.142	1.259
FNA	426.4	353.8	290.8
FNT	501.7	543.5	569.7
NOZZLE AXIAL FORCE= 2184.8		TANG FORCE= 3356.2	
STA 1 BUCKET INLET		WG= 51.90	
DIAMETER	25.650	32.025	38.400
ANNULUS AREA		641.39	
PTB	9.59	10.16	10.84
TTB	1390.2	1408.1	1429.9
BET1	56.69	37.98	11.56
R1	1222.2	851.4	685.0
MR1	0.712	0.482	0.382
W1	657.4	820.7	984.1
STA 2 BUCKET EXIT		WG= 51.90	
DIAMETER	25.650	32.825	40.000
ANNULUS AREA		739.91	
PT2		7.45	
PS2	6.20	6.35	6.42
PTS2	2.2558	2.2050	2.1796
TT2		1318.0	
TF		0.960	
TS2	1250.2	1257.4	1261.1
BET2	57.38	58.97	61.15
DLBA	114.08	96.95	72.72
RX	0.100	0.378	0.530
V2	895.6	839.1	808.6
R2	1376.2	1439.2	1537.6
MR2	0.811	0.846	0.902
W2	657.4	841.2	1025.1
CZ2		741.8	
CU2	501.7	392.1	321.7
SWRL	34.07	27.86	23.45
MF	0.437	0.436	0.435
ZIB	1.793	1.293	0.940
FBA	45.6	227.8	407.6
FBT	374.8	423.1	453.0
BUCKET AXIAL FORCE= 1634.6		TANG FORCE= 3035.9	
PSI	1.592	0.996	0.682
W/VO	0.340	0.429	0.519

GENERAL STAGE RESULTS

WORK= 54.96 ETATT=0.903 ETATS=0.735

..4-STAGE.LPT

STAGE 4

	ROOT	PITCH	TIP
STA 0 NOZZLE INLET		WG= 51.90	
DIAMETER	25.650	32.975	40.300
ANNULUS AREA		758.83	
TTO		1318.0	
PTO		7.45	
MO		0.477	
STA 1PR NOZZLE EXIT		WG= 51.90	
DIAMETER	25.650	33.875	42.100
ANNULUS AREA		875.32	
FF (FLOW FUNCTION)		253.03	
PS1	4.46	5.30	5.73
PTS1	1.6690	1.4055	1.2990
TS1	1158.3	1209.8	1234.0
ALPHA	60.12	52.81	46.68
V1	1451.4	1196.2	1053.9
M1	0.885	0.714	0.623
CZ1		723.1	
CU1	1258.4	952.9	766.7
ZIN	1.200	1.349	1.407
FNA	156.6	117.9	89.0
FNT	265.8	284.1	293.8
NOZZLE AXIAL FORCE= 969.3		TANG FORCE= 2336.8	
STA 1 BUCKET INLET		WG= 51.90	
DIAMETER	25.650	33.575	41.500
ANNULUS AREA		835.92	
PTB	5.53	5.98	6.56
TTB	1225.6	1248.9	1278.4
BET1	38.02	7.48	-20.39
R1	975.9	775.4	820.2
MR1	0.597	0.464	0.486
W1	657.4	860.5	1063.6
STA 2 BUCKET EXIT		WG= 51.90	
DIAMETER	25.650	35.175	44.700
ANNULUS AREA		1052.56	
PT2		4.71	
PS2	4.10	4.11	4.12
PTS2	1.8144	1.8107	1.8091
TT2		1185.5	
TF		0.960	
TS2	1138.5	1139.1	1139.4
BET2	47.22	53.81	59.15
DLBA	85.24	61.29	38.75
RX	0.100	0.373	0.505
V2	740.7	735.3	732.9
R2	1073.4	1234.8	1421.6
MR2	0.660	0.760	0.874
W2	657.4	901.5	1145.6
CZ2		729.1	
CU2	130.5	95.1	74.9
SWRL	10.15	7.43	5.86
MF	0.449	0.449	0.448
ZIB	1.718	1.045	0.685
FBA	27.6	126.4	220.3
FBT	180.7	201.6	213.7
BUCKET AXIAL FORCE= 1203.6		TANG FORCE= 1920.4	
PSI	1.014	0.565	0.359
W/VO	0.417	0.558	0.700

GENERAL STAGE RESULTS

WORK= 35.01 ETATT=0.897 ETATS=0.704

CUT HERE

OVERALL TURBINE RESULTS

TTIN/TTEXIT= 1.621 PTIN/PTEXIT= 8.594 PTIN/PSEXIT= 9.843
WORK= 201.99 ETATT=0.918 ETATS=0.877 PSI= 0.966

```
*LIST FVTDIN

5 TP5..4-STAGE.LPT
10 0,.021,53.3,4.1922,40.48
20 1,0,51.9,5874,0,0,0
30 52,.96,.1,.97,.95,1,1,90,90,1.0
40 25.65,29.3,25.65,31,1,25.65,31.4,25.65,32.4
50 2,0,51.9,5874,0,0,0
60 60,.96,.1,.97,.95,1,1,90,90,1.0
70 25.65,32.8,25.65,34.2,25.65,34.6,25.65,35.8
80 3,0,51.9,5874,0,0,0
90 55,.96,.1,.97,.95,1,1,90,90,1
100 25.65,36.1,25.65,38.0,25.65,38.4,25.65,40.0
110 4,0,51.9,5874,0,0,0
120 35,.96,.1,.97,.95,1,1,90,90,1.0
130 25.65,40.3,25.65,42.1,25.65,41.5,25.65,44.7

ready

*
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GENERAL STAGE RESULTS

WORK= 52.05 ETATT=0.902 ETATS=0.746

Baseline LPT

	h	AR	C_x	β	ψ	Zw_i	P	D_p	#	r/v
1N	2.275	2.0	1.138	62.35	.81	.822	1.121	27.925	60	
1R	3.125	2.7	1.157	60.25	.948	1.356	.809	28.775	112	.792
2N	3.925	2.12	1.85	65.42	.67	.973	.785	29.575	73	
2R	4.775	3.5	1.36	62.4	.875	1.305	.917	30.425	98	.716
3N	5.20	2.85	2.0	62.48	.80	1.142	1.136	31.35	72	
3R	6.775	4.3	1.576	58.97	.98	1.298	1.19	32.425	86	.641
4N	7.775	3.46	2.25	52.81	.97	1.349	1.574	33.425	65	
4R	8.725	5.0	1.745	53.81	1.058	1.045	1.314	34.375	61	.574

LPT Designed @ 80% Mx Cr 35K/.8/0

Cooling flow summary included in "LPT Efficiency Estimate"

Cooling Analysis Program - Nomenclature

T3 - Compressor discharge temperature, (°R)
F/A RATIO - Fuel to air ratio
T4 - Turbine stage 1 nozzle exit average temperature, (°R)
W4 - " " " " flow, (lb/sec)
PF1 - Combuster pattern factor
PDF1 - Combuster profile factor
DTADD - Design adder, (°R)
W4/W2 - W4/Core inlet air flow
TC - bucket or nozzle cooling air temperature, (°R)
TB - allowable airfoil bulk temperature, (°R)
%WC - cooling flow, (% of W_{2c})
C = .0567
HA/WCP - heat transfer coefficient × airfoil area/gas flow × coolant specific heat
N - no. of airfoils
Z1 PTCH - Incompressible Zweifel number at pitch
DP - Pitch diameter, (in)
HT-S - Height of airfoil, suction side (in)
HT-P - " " " , pressure side (in)
P - airfoil perimeter
AX-W - axial width
B1 - Inlet gas angle (degrees)
B2 - Exit gas angle (degrees)
K - Gas heat conductivity, [(Btu/hr-ft²)/(°R/ft)]
CPC - Coolant specific heat (Btu/lb°R)
PR NO - Prandl Number
VISC - Gas viscosity, (lb/sec-ft)
RE S - Suction side Reynolds number
RE P - Pressure side Reynolds number
WG - W4

```
DO YOU WANT OUTPUT FOR ALL  8 CASES?
=YES
ENTER STG 1 BAND COOLING -%
=0
ENTER T3,F/A RATIO,T4,W4,PR1,PDF1,DTADD,W4/W2
=.048,.025,2296,123.8,.25,.1,15930,.985
IS COOLANT TEMP TO BE THE SAME FOR ALL BLADE ROWS ?
=YES
ENTER TC
=1245
IS COOLING TECHNOLOGY TO BE THE SAME FOR ALL BLADES ?
=NO
STAGE  1  NOZZLE

ENTER NO. OF AIRFOILS AND AXIAL WIDTH
IF NO OF AIRFOILS=0, SOLIDITIES WILL BE SET WITH
ZN=.85 AND Z3=1.0
=60,1.138
ENTER TB,%WC
=2260,0
ENTER PEAK GAS TEMP, IF 0 PROGRAM WILL CALCULATE
=0
ENTER LEVEL OF COOLING TECHNOLOGY DESIRED
=B

CONSTANT C=0.0567  HA/WCP=0.0207

N= 60  ZI PTCH  =1.073  DP=28.38  HT-S= 2.72  HT-P= 1.82  P= 3.334
AX W= 1.14  B1=  0.   B2= 62.3  K= 0.050  CPC= 0.2561  AG=  454.14
PR NU=0.6922  VISC= 0.318E-04
RE S= 0.803E 06  RE P= 0.403E 06
WG= 123.8

COOLING TECHNOLOGY  B   -CURRENT FILM

2WCCP/AGHG= 0.76

AVG GAS   PEAK GAS    BULK      COOLANT     COOLING      COOLING FLOW
TEMP R    TEMP R    TEMP R     TEMP R   EFFECTIVENESS      %W2C
 2307.7    2647.6    2260.0     1245.0      0.276           0.774


STAGE  1  BUCKET

ENTER NO. OF AIRFOILS AND AXIAL WIDTH
=112,1.157
ENTER TB,%WC
=2299,0
ENTER PEAK GAS TEMP, IF 0 PROGRAM WILL CALCULATE
=0
ENTER LEVEL OF COOLING TECHNOLOGY DESIRED
=C+

CONSTANT C=0.0567  HA/WCP=0.0394

N=112  ZI PTCH  =0.954  DP=29.03  HT-S= 3.38  HT-P= 2.88  P= 2.982
AX W= 1.16  B1= 45.1  B2= 60.3  K= 0.047  CPC= 0.2561  AG= 1045.35
PR NU=0.6927  VISC= 0.306E-04
RE S= 0.549E 06  RE P= 0.328E 06
WG= 123.8

COOLING TECHNOLOGY  C+  -CONVECTION  PLUS
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Turboprop Tess II
SL/.2/M0
using TP4
Baseline 4 stage LPT

1795
460
2255

```
GE  2  NOZZLE

NTER NO. OF AIRFOILS AND AXIAL WIDTH
=93,1.453
ENTER TB,%WC
=2260,0
NTER PEAK GAS TEMP, IF 0 PROGRAM WILL CALCULATE
0
ENTER LEVEL OF COOLING TECHNOLOGY DESIRED
=B

CONSTANT C=0.0567  HA/WCP=0.0430

N= 93  ZI PTCH  =0.677  DP=29.92  HT-S= 4.27  HT-P= 3.58  P= 3.978
AX W= 1.45  B1= 32.0  B2= 65.4  K= 0.046  CPC= 0.2561  AG= 1452.21
PR NU=0.6931  VISC= 0.297E-04
RE S= 0.690E 06  RE P= 0.292E 06
WG= 123.8

COOLING TECHNOLOGY  B   -CURRENT FILM

2WCCP/AGHG= 0.19

AVG GAS   PEAK GAS   BULK      COOLANT    COOLING      COOLING FLOW
TEMP R    TEMP R    TEMP R    TEMP R   EFFECTIVENESS     %W2C
 2078.0    2360.5    2260.0    1245.0     0.090          0.412


STAGE  2  BUCKET

ENTER NO. OF AIRFOILS AND AXIAL WIDTH
90,1.592
ENTER TB,%WC
=2248,0
ENTER PEAK GAS TEMP, IF 0 PROGRAM WILL CALCULATE
=0
ENTER LEVEL OF COOLING TECHNOLOGY DESIRED
=C+

CONSTANT C=0.0567  HA/WCP=0.0439

N= 90  ZI PTCH  =0.879  DP=30.73  HT-S= 5.08  HT-P= 4.47  P= 4.198
AX W= 1.59  B1= 48.4  B2= 62.4  K= 0.043  CPC= 0.2561  AG= 1804.13
PR NU=0.6939  VISC= 0.284E-04
RE S= 0.561E 06  RE P= 0.322E 06
WG= 123.8

COOLING TECHNOLOGY  C+  -CONVECTION  PLUS

2WCCP/AGHG= 0.

AVG GAS   PEAK GAS   BULK      COOLANT    COOLING      COOLING FLOW
TEMP R    TEMP R    TEMP R    TEMP R   EFFECTIVENESS     %W2C
 1929.5    2132.5    2248.0    1245.0     0.             0.
```

TPS TURBOPROP 3 STAGE TURBINE

STAGE 1

AA N^2 h_x = 55

N = 6897

N = L/2 = 7150

	ROOT	PITCH	TIP
STA 0 NOZZLE INLET		WG= 51.90	
DIAMETER	25.500	27.425	29.350
ANNULUS AREA		165.85	
TTO		1922.0	
PTO		40.48	
MO		0.420	
STA 1PR NOZZLE EXIT		WG= 51.90	
DIAMETER	24.700	27.875	31.050
ANNULUS AREA		278.04	
FF (FLOW FUNCTION)		56.21	
PS1	19.33	22.44	24.86
PTS1	2.0944	1.8043	1.6284
TS1	1614.9	1672.4	1713.3
ALPHA	69.09	66.68	64.35
V1	2081.6	1876.3	1715.9
M1	1.067	0.963	0.870
CZ1		742.8	
CU1	1944.9	1723.4	1547.2
ZIN	0.067	0.727	0.780
FNA	1369.7	1277.2	1189.4
FNT	1105.0	1156.1	1194.7
NOZZLE AXIAL FORCE= 4055.1		TANG FORCE= 3670.5	
STA 1 BUCKET INLET		WG= 51.90	
DIAMETER	24.600	27.950	31.300
ANNULUS AREA		294.15	
PTB	27.27	28.15	29.10
TTB	1755.9	1767.2	1779.9
BETI	60.21	51.66	40.50
R1	1397.2	1119.1	913.0
MR1	0.729	0.573	0.462
W1	740.3	841.1	941.9
STA 2 BUCKET EXIT		WG= 51.90	
DIAMETER	23.900	28.225	32.550
ANNULUS AREA		383.50	
PT2		20.46	
PS2	17.33	17.79	18.08
PTS2	2.3360	2.2758	2.2390
TT2		1655.9	
TF		0.960	
TS2	1579.6	1589.7	1596.0
BET2	65.07	65.99	66.71
DLBA	125.68	117.65	107.21
RX	0.100	0.280	0.405
V2	958.8	881.5	829.3
R2	1567.2	1586.6	1633.0
MR2	0.628	0.835	0.858
W2	719.2	849.3	979.5
CZ2		645.7	
CU2	708.8	600.2	520.4
SWRL	47.07	42.91	38.87
MF	0.341	0.340	0.339
ZIB	1.344	1.162	0.993
FBA	476.6	463.4	766.5
FBT	896.5	992.9	1057.6
BUCKET AXIAL FORCE= 2004.3		TANG FORCE= 4294.5	
PSI	1.763	1.314	1.017
W/VJ	0.329	0.381	0.433

GENERAL STAGE RESULTS

WORK= 74.98 ETATT=0.904 ETATS=0.763

STAGE 2

	ROOT	PITCH	TIP
STA 0 NOZZLE INLET		WG= 51.90	
DIAMETER	23.750	28.300	32.850
ANNULUS AREA		404.53	
TTO		1655.9	
PTO		20.46	
RO		0.433	
STA 1PR NOZZLE EXIT		WG= 51.90	
DIAMETER	22.650	28.700	34.750
ANNULUS AREA		545.49	
FF (FLOW FUNCTION)		103.23	
PS1	8.47	11.73	13.77
PTS1	2.4149	1.7446	1.4857
TS1	1337.1	1446.5	1504.0
ALPHA	72.56	68.30	64.27
V1	2089.0	1692.9	1442.0
M1	1.193	0.930	0.776
CZ1		626.0	
CU1	1993.0	1572.9	1299.0
ZIN	0.769	0.941	1.086
FNA	680.3	568.1	464.4
FNT	607.9	681.8	728.7
NOZZLE AXIAL FORCE= 3436.8		TANG FORCE= 4125.1	
STA 1 BUCKET INLET		WG= 51.90	
DIAMETER	22.400	28.750	35.100
ANNULUS AREA		573.54	
PTB	13.06	14.00	15.10
TTB	1490.6	1512.1	1538.9
BET1	66.21	50.01	21.24
R1	1465.8	920.2	634.4
MR1	0.838	0.505	0.341
W1	674.1	865.1	1058.2
STA 2 BUCKET EXIT		WG= 51.90	
DIAMETER	21.450	29.225	37.000
ANNULUS AREA		713.85	
PT2		9.14	
PS2	6.85	7.49	7.78
PTS2	2.9852	2.7318	2.6290
TT2		1381.8	
TF		0.960	
TS2	1274.8	1303.5	1316.1
BET2	66.70	66.54	67.71
DLBA	132.91	116.56	88.96
RX	0.100	0.426	0.591
V2	1143.7	956.7	801.8
R2	1707.7	1697.1	1781.5
MR2	0.999	0.982	1.025
W2	645.5	879.4	1113.4
CZ2		675.6	
CU2	922.9	677.4	535.0
SWRL	53.80	45.08	38.38
MF	0.395	0.391	0.389
ZIB	1.437	1.108	0.814
FBA	90.8	380.7	693.0
FBT	425.7	529.6	592.3
BUCKET AXIAL FORCE= 2959.7		TANG FORCE= 4117.3	
PSI	2.155	1.233	0.797
W/VO	0.294	0.388	0.483

GENERAL STAGE RESULTS

T WORK= 74.93 ETATT=0.904 ETATS=0.743

STAGE 3

	ROOT	PITCH	TIP
STA 0 NOZZLE INLET		WG= 51.90	
DIAMETER	21.250	29.275	37.300
ANNULUS AREA		738.06	
TTO		1381.8	
PTO		9.14	
MO		0.527	
STA 1PR NOZZLE EXIT		WG= 51.90	
DIAMETER	20.500	29.825	39.150
ANNULUS AREA		873.73	
FF (FLOW FUNCTION)		211.06	
PS1	4.60	6.39	7.18
PTS1	1.9886	1.4315	1.2739
TS1	1163.6	1263.1	1300.5
ALPHA	68.40	60.05	52.90
V1	1702.9	1256.0	1039.4
M1	1.037	0.734	0.599
CZ1		627.0	
CU1	1583.3	1088.3	829.1
ZIN	1.055	1.365	1.538
FNA	197.0	119.5	59.9
FNT	291.8	333.1	352.2
NOZZLE AXIAL FORCE= 1113.9		TANG FORCE= 3106.0	
STA 1 BUCKET INLET		WG= 51.90	
DIAMETER	20.050	29.775	39.500
ANNULUS AREA		909.68	
PTB	6.29	7.04	8.08
TTB	1262.2	1295.2	1341.1
BET1	59.43	17.93	-31.45
R1	1179.5	630.5	703.2
MR1	0.720	0.368	0.405
W1	603.3	896.0	1188.6
STA 2 BUCKET EXIT		WG= 51.90	
DIAMETER	19.000	30.145	41.290
ANNULUS AREA		1055.47	
PT2		4.86	
PS2	3.92	4.12	4.19
PTS2	2.3313	2.2161	2.1821
TT2		1193.6	
TF		0.960	
TS2	1121.8	1136.6	1141.2
BET2	57.67	60.28	64.33
DLBA	117.10	78.21	32.88
RX	0.100	0.533	0.687
V2	921.7	808.0	769.6
R2	1352.6	1459.1	1670.1
MR2	0.839	0.899	1.027
W2	571.7	907.1	1242.5
CZ2		723.4	
CU2	571.2	360.0	262.8
SWRL	38.30	26.46	19.97
MF	0.449	0.446	0.445
ZIB	1.872	1.020	0.551
FBA	24.2	198.7	368.7
FBT	185.9	230.4	250.1
BUCKET AXIAL FORCE= 2214.5		TANG FORCE= 2567.8	
PSI	1.812	0.770	0.423
W/VO	0.318	0.488	0.658

GENERAL STAGE RESULTS

WORK= 49.97 ETATT=0.904 ETATS=0.733

----CUT HERE----

```
usage:  2.4 cpu-sec,   3.1 i/o-sec,   26.7 l*sec,   0.50 con-hrs.
off lynn-a at  8.303 on 02/02/76.  0.0068 nbu  $   1.66


CP DISCONNECTSx;rw~()oo_o~o?ow)^~(ogC~)c~

1302400

lynn tss  02/02/76 at  8.351 line 2531

user id -17601LU;17601
password--
[illegible]

SYSTEM ?FORT
**LYNN TSS WILL BE GOING DOWN IN 5 MIN FIOR 5 MIN

OLD OR NEW-PLD  DEL
LD STAGE3
READY
*LIST

5   TP5 TURBOPROP  3 STAGE TURBINE
10 0,.021,53.3,3,1922,40.46
20 1,0,51.9,6897,0,0,0
30 75,.96,.1,.97,.95,1,1,90,90,1
40 25.5,29.35,24.7,31.05,24.6,31.3,23.9,32.55
50 2,0,51.9,6897,0,0,0
60 75,.96,.1,.97,.95,1,1,90.,90,1
70 23.75,32.85,22.65,34.75,22.4,35.1,21.45,37
80 3,0,51.9,6897,0,0,0
90 50,.96,.1,.97,.95,1,1,90,90,1
100 21.25,37.3,20.5,39.15,20.05,39.5,19.,41.29

ready
```

750

3 Stage LPT

	h	AR	Cx	β	ψ	Zwi	P	Dp	#	r/v
1N	2.66	2.0	1.331	66.7	.59	.727	1.08	27.6	62	
1R	3.84	2.7	1.421	66	.715	1.162	.874	28.09	101	.734
2N	5.30	2.12	2.5	68.3	.475	.941	.785	28.5	71	
2R	7.06	3.9	1.81	66.5	.690	1.11	1.12	28.99	80	.58
3N	8.68	2.59	3.35	60.5	.86	1.365	1.424	29.55	14	
3R	10.44	5.0	2.09	60.3	.95	1.02	1.94	29.96	48	.46

3 Stage LPT designed @ 80% MxCr 35K/.810

3STage Turboprop
4/30/76
SL/.2/ TP9

```
DO YOU WANT OUTPUT FOR ALL  6 CASES?
=YES
ENTER STG 1 BAND COOLING -%
=0
ENTER T3,F/A RATIO,T4,W4,PR1,PDF1,DTADD,W4/W2
=1546,.025,2298,123.8,.25,.1,150,.985
IS COOLANT TEMP TO BE THE SAME FOR ALL BLADE ROWS ?
=NO DEL
YES
ENTER TC
=1245
IS COOLING TECHNOLOGY TO BE THE SAME FOR ALL BLADES ?
=NO
STAGE  1  NOZZLE

ENTER NO. OF AIRFOILS AND AXIAL WIDTH
IF NO OF AIRFOILS=0, SOLIDITIES WILL BE SET WITH.
ZN=.85 AND ZB=1.0
=62,1.331
ENTER TB,%WC
=2269,0.0
ENTER PEAK GAS TEMP, IF 0 PROGRAM WILL CALCULATE
=0
ENTER LEVEL OF COOLING TECHNOLOGY DESIRED
=B

CONSTANT C=0.0567  HA/WCP=0.0283

N= 62  ZI PTCH  =0.773  DP=27.68  HT-S= 3.17  HT-P= 1.92  P= 4.108
AX W= 1.33  B1=  0.   B2= 66.6  K= 0.050  CPC= 0.2561  AG=  646.21
PR NU=0.6922  VISC= 0.318E-04
RE S= 0.101E 07  RE P= 0.479E 06
WG= 123.8

COOLING TECHNOLOGY  B   -CURRENT FILM

2WCCP/AGWG= 0.77

AVG GAS   PEAK GAS    BULK      COOLANT     COOLING      COOLING FLOW
TEMP R    TEMP R    TEMP R     TEMP R    EFFECTIVENESS     %W2C
 2311.5    2652.3    2200.0     1245.0      0.279           1.075

STAGE  1  BUCKET

ENTER NO. OF AIRFOILS AND AXIAL WIDTH
=112,1.157
ENTER TB,%WC
=2236,0
ENTER PEAK GAS TEMP, IF 0 PROGRAM WILL CALCULATE
=0
ENTER LEVEL OF COOLING TECHNOLOGY DESIRED
=C+

CONSTANT C=0.0567  HA/WCP=0.0466

N=112  ZI PTCH  =0.779  DP=28.23  HT-S= 4.33  HT-P= 3.35  P= 3.092
AX W= 1.16  B1= 46.6  B2= 65.1  K= 0.046  CPC= 0.2561  AG= 1329.68
PR NU=0.6930  VISC= 0.300E-04
RE S= 0.550E 06  RE P= 0.315E 06
WG= 123.8
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```
NOZZLE

NO. OF AIRFOILS AND AXIAL WIDTH
=63
TB,%WC
=0
PEAK GAS TEMP, IF 0 PROGRAM WILL CALCULATE

ENTER LEVEL OF COOLING TECHNOLOGY DESIRED
=B

CONSTANT C=0.0567  HA/WCP=0.0615

N= 90  ZI PTCH  =0.435  DP=28.70  HT-S= 6.05  HT-P= 4.55  P= 5.524
AX W= 1.96  B1= 31.2  B2= 68.3  K= 0.044  CPG= 0.2561  AG= 2635.18
PR NU=0.6936  VISC= 0.288E-04
RE S= 0.819E 06  RE P= 0.341E 06
WG= 123.8

COOLING TECHNOLOGY  B  -CURRENT FILM

2WCCP/AGHG= 0.

AVG GAS   PEAK GAS    BULK      COOLANT     COOLING      COOLING FLOW
TEMP R    TEMP R    TEMP R     TEMP R   EFFECTIVENESS      %W2C
 1979.8    2237.8    2260.0     1245.0      0.              0.


STAGE 2  BUCKET

ENTER NO. OF AIRFOILS AND AXIAL WIDTH
=62,2.353
ENTER TB,%WC
=2135,0
ENTER PEAK GAS TEMP, IF 0 PROGRAM WILL CALCULATE
=0
ENTER LEVEL OF COOLING TECHNOLOGY DESIRED
=C+

CONSTANT C=0.0567  HA/WCP=0.0460

N= 62  ZI PTCH  =0.650  DP=29.23  HT-S= 7.77  HT-P= 6.35  P= 6.301
AX W= 2.35  B1= 43.3  B2= 66.4  K= 0.040  CPG= 0.2561  AG= 2756.14
PR NU=0.6948  VISC= 0.271E-04
RE S= 0.702E 06  RE P= 0.341E 06
WG= 123.8

COOLING TECHNOLOGY  C+  -CONVECTION  PLUS

2WCCP/AGHG= 0.

AVG GAS   PEAK GAS    BULK      COOLANT     COOLING      COOLING FLOW
TEMP R    TEMP R    TEMP R     TEMP R   EFFECTIVENESS      %W2C
 1803.2    1996.4    2135.0     1245.0      0.              0.
```


ORIGINAL PAGE IS
OF POOR QUALITY

STAGE 1

	ROOT	PITCH	TIP
STA 0 NOZZLE INLET		WG= 71.19	
DIAMETER	25.600	27.400	29.200
ANNULUS AREA		154.94	
TTO		2194.0	
PTO		56.88	
MO		0.487	
STA 1PR NOZZLE EXIT		WG= 71.19	
DIAMETER	25.300	27.850	30.400
ANNULUS AREA		223.11	
FF (FLOW FUNCTION)		58.62	
PS1	31.88	34.61	36.80
PTS1	1.7844	1.6435	1.5457
TS1	1921.0	1957.5	1985.3
ALPHA	61.05	58.66	56.39
V1	1988.9	1851.1	1739.2
M1	0.956	0.882	0.823
CZ1		962.7	
CU1	1740.4	1581.0	1448.4
ZIN	0.847	0.888	0.922
FNA	1440.5	1349.4	1266.2
FNT	1618.2	1662.5	1697.4
NOZZLE AXIAL FORCE= 3441.0		TANG FORCE= 4239.4	
STA 1 BUCKET INLET		WG= 71.19	
DIAMETER	25.260	27.980	30.700
ANNULUS AREA		239.09	
PTB	42.20	43.09	44.04
TTB	2052.7	2061.5	2071.1
BET1	48.52	40.26	30.84
R1	1329.0	1153.7	1025.4
MR1	0.637	0.548	0.483
W1	747.6	828.0	908.5
STA 2 BUCKET EXIT		WG= 71.19	
DIAMETER	24.850	28.250	31.650
ANNULUS AREA		301.75	
PT2		34.46	
PS2	30.23	30.49	30.67
PTS2	1.8815	1.8654	1.8543
TT2		1972.7	
TF		0.960	
TS2	1903.5	1907.4	1910.1
BET2	57.45	58.28	59.33
DLBA	105.97	98.55	90.17
RX	0.100	0.233	0.332
V2	932.5	901.8	879.8
R2	1464.3	1498.6	1544.4
MR2	0.707	0.723	0.745
W2	735.4	836.0	936.7
CZ2		787.9	
CU2	498.8	438.8	391.7
SWRL	32.34	29.12	26.43
MF	0.381	0.380	0.380
ZIB	1.562	1.363	1.188
FBA	241.9	516.8	795.3
FBT	1392.3	1476.0	1543.6
BUCKET AXIAL FORCE= 1757.0		TANG FORCE= 5018.5	
PSI	1.458	1.158	0.942
W/VO	0.355	0.398	0.441

GENERAL STAGE RESULTS

WORK= 64.03 ETATT=0.900 ETATS=0.734

STAGE 2

	ROOT	PITCH	TIP
STA 0 NOZZLE INLET		WG= 71.19	
DIAMETER	24.650	28.375	32.100
ANNULUS AREA		332.06	
TTO		1972.7	
PTO		34.46	
MO		0.387	
STA 1PR NOZZLE EXIT		WG= 71.19	
DIAMETER	24.300	29.150	34.000
ANNULUS AREA		444.15	
FF (FLOW FUNCTION)		91.76	
PS1	16.69	20.54	23.16
PTS1	2.0641	1.6780	1.4881
TS1	1664.7	1747.3	1797.1
ALPHA	69.62	65.98	62.53
V1	2090.2	1788.3	1578.3
M1	1.076	0.899	0.782
CZ1		728.0	
CU1	1959.6	1633.6	1400.6
ZIN	0.807	0.928	1.030
FNA	1102.7	970.2	851.1
FNT	1028.2	1108.0	1162.9
NOZZLE AXIAL FORCE= 4705.7		TANG FORCE= 5373.7	
STA 1 BUCKET INLET		WG= 71.19	
DIAMETER	24.150	29.225	34.300
ANNULUS AREA		465.95	
PTB	23.59	24.69	25.92
TTB	1810.0	1826.8	1846.7
BET1	61.30	48.01	28.47
R1	1433.1	1028.6	782.8
MR1	0.733	0.516	0.387
W1	714.7	864.9	1015.1
STA 2 BUCKET EXIT		WG= 71.19	
DIAMETER	23.800	29.650	35.500
ANNULUS AREA		544.92	
PT2		17.92	
PS2	14.78	15.30	15.59
PTS2	2.3317	2.2527	2.2108
TT2		1711.7	
TF		0.960	
TS2	1623.3	1636.9	1644.4
BET2	62.62	63.07	64.21
DLBA	123.93	111.08	92.69
RX	0.100	0.354	0.505
V2	1048.8	952.3	895.0
R2	1623.0	1647.7	1715.5
MR2	0.846	0.855	0.889
W2	704.3	877.5	1050.6
CZ2		746.3	
CU2	736.9	591.5	494.0
SWRL	44.64	38.40	33.50
MF	0.389	0.387	0.387
ZIB	1.589	1.263	0.989
FBA	127.6	487.0	853.0
FBT	809.5	915.9	986.8
BUCKET AXIAL FORCE= 2848.8		TANG FORCE= 5358.3	
PSI	1.839	1.220	0.868
W/VO	0.317	0.390	0.462

GENERAL STAGE RESULTS

WORK= 73.94 ETATT=0.903 ETATS=0.741

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STAGE 3

	ROOT	PITCH	TIP
STA 0 NOZZLE INLET		WG= 71.19	
DIAMETER	23.650	29.825	36.000
ANNULUS AREA		578.58	
TTO		1711.7	
PTO		17.92	
MO		0.456	
STA 1PR NOZZLE EXIT		WG= 71.19	
DIAMETER	23.200	30.600	38.000
ANNULUS AREA		711.38	
FF (FLOW FUNCTION)		164.37	
PS1	8.11	11.07	12.73
PTS1	2.2084	1.6182	1.4072
TS1	1414.6	1524.3	1576.4
ALPHA	68.71	62.80	57.45
V1	2025.1	1608.5	1366.7
M1	1.126	0.862	0.720
CZ1		735.3	
CU1	1887.3	1430.9	1152.2
ZIN	0.937	1.144	1.290
FNA	539.2	425.5	329.3
FNT	604.8	676.7	717.3
NOZZLE AXIAL FORCE= 3148.6		TANG FORCE= 5007.4	
STA 1 BUCKET INLET		WG= 71.19	
DIAMETER	23.000	30.700	38.400
ANNULUS AREA		742.64	
PTB	11.94	12.92	14.13
TTB	1557.5	1583.7	1617.5
BET1	60.30	36.58	0.31
R1	1408.0	868.8	697.7
MR1	0.783	0.465	0.367
W1	680.7	908.5	1136.4
STA 2 BUCKET EXIT		WG= 71.19	
DIAMETER	22.500	31.250	40.000
ANNULUS AREA		859.03	
PT2		8.93	
PS2	6.97	7.34	7.49
PTS2	2.5707	2.4427	2.3915
TT2		1465.9	
TF		0.960	
TS2	1368.6	1386.1	1393.5
BET2	58.68	59.77	62.15
DLBA	118.93	96.35	62.46
RX	0.100	0.448	0.609
V2	1095.6	979.2	926.1
R2	1608.4	1660.5	1789.4
MR2	0.909	0.933	1.002
W2	665.9	924.8	1183.8
CZ2		836.0	
CU2	708.2	509.9	398.4
SWRL	40.27	31.38	25.48
MF	0.473	0.470	0.468
ZIB	1.835	1.246	0.829
FBA	56.0	343.0	630.9
FBT	445.9	535.9	584.8
BUCKET AXIAL FORCE= 3001.2		TANG FORCE= 4689.0	
PSI	1.872	1.010	0.630
W/VO	0.310	0.422	0.535

GENERAL STAGE RESULTS

WORK= 67.77 ETATT=0.902 ETATS=0.721

STAGE 4

	ROOT	PITCH	TIP
STA 0 NOZZLE INLET		WG= 71.19	
DIAMETER	22.400	31.425	40.450
ANNULUS AREA		890.99	
TTO		1465.9	
PTO		8.93	
MO		0.521	
STA 1PR NOZZLE EXIT		WG= 71.19	
DIAMETER	22.000	32.250	42.500
ANNULUS AREA		1038.49	
FF (FLOW FUNCTION)		305.28	
PS1	4.84	6.33	6.95
PTS1	1.8435	1.4113	1.2844
TS1	1260.4	1346.2	1377.9
ALPHA	62.11	52.20	44.37
V1	1663.2	1269.2	1088.2
M1	0.976	0.720	0.611
CZ1		778.0	
CU1	1470.0	1002.8	760.9
ZIN	1.198	1.427	1.487
FNA	184.7	121.0	76.2
FNT	317.3	353.2	369.0
NOZZLE AXIAL FORCE= 1239.8		TANG FORCE= 3619.9	
STA 1 BUCKET INLET		WG= 71.19	
DIAMETER	21.800	32.275	42.750
ANNULUS AREA		1062.11	
PTB	6.42	7.20	8.32
TTB	1354.6	1391.5	1442.6
BET1	47.92	3.54	-33.90
R1	1129.5	758.4	912.0
MR1	0.663	0.430	0.511
W1	645.2	955.2	1265.2
STA 2 BUCKET EXIT		WG= 71.19	
DIAMETER	21.150	32.925	44.700
ANNULUS AREA		1217.97	
PT2		5.36	
PS2	4.44	4.49	4.50
PTS2	2.0094	1.9896	1.9833
TT2		1305.5	
TF		0.960	
TS2	1238.1	1241.2	1242.3
BET2	46.00	53.03	59.23
DLBA	93.93	56.57	25.33
RX	0.100	0.483	0.628
V2	903.7	880.1	872.4
R2	1242.6	1435.1	1687.1
MR2	0.735	0.848	0.997
W2	625.9	974.4	1322.9
CZ2		863.1	
CU2	268.0	172.2	126.8
SWRL	17.25	11.28	8.36
MF	0.511	0.510	0.510
ZIB	2.068	1.006	0.527
FBA	13.6	173.6	321.8
FBT	203.8	238.9	254.5
BUCKET AXIAL FORCE= 2044.0		TANG FORCE= 2812.9	
PSI	1.337	0.580	0.322
W/VO	0.357	0.541	0.726

GENERAL STAGE RESULTS

WORK= 43.13 ETATT=0.896 ETATS=0.680

----CUT HERE----

Variable Boost LPT

Designed @ M x C_L

2/16/76

	h	AR	C_x	β	Z_{wi} (.707)	ψ	P	D_p	#	M/r	AAN^2 (10^9)	TTB
1N	2.175	1.67	1.3	58.7	.888	.901	1.66	22.63	52			
1R	3.06	2.7	1.133	58.3	1.363	.976	.828	28.12	107	.785	13.88	2278
2N	4.29	2.26	1.9	65.98	.928	.64	1.31	28.76	69			
2R	5.46	3.5	1.56	63.07	1.263	.847	1.046	29.44	88	.67	25.1	2208
3N	6.79	3.77	1.8	62.8	1.144	.79	1.243	30.21	76			
3R	8.23	4.3	1.91	59.77	1.246	.96	1.474	30.98	66	.562	39.5	
4N	9.64	4.7	2.05	52.2	1.427	.975	1.4	31.84	71			
4R	11.12	5.0	2.22	53.03	1.006	1.06	2.343	32.6	44	.473	56	

Flowpath Determined Overall Length (slopes)

Aspect Ratios for Rotor Set ⇒ C_x Nozzle Falls Out

1N Z_{wi} correction $\left(\frac{1581-323}{1581}\right)(.888) = .707$

Cooling Done with $U_T = 800$ @ SLS

Variable DOOSI LPT

```
=0
ENTER T3,F/A RATIO,T4,W4,PF1,PDF1,DTADD,W4/W2
=1562,.025,2272,121.8,.25,.1,150,.994
IS COOLANT TEMP TO BE THE SAME FOR ALL BLADE ROWS ?
=YES
ENTER TC
=1221,931
IS COOLING TECHNOLOGY TO BE THE SAME FOR ALL BLADES ?
=NO
STAGE  1  NOZZLE

ENTER NO. OF AIRFOILS AND AXIAL WIDTH
IF NO OF AIRFOILS=0, SOLIDITIES WILL BE SET WITH
ZN=.85 AND ZB=1.0
=52,1.3
ENTER TB,%WC
=2260,0
ENTER PEAK GAS TEMP, IF 0 PROGRAM WILL CALCULATE
=0
ENTER LEVEL OF COOLING TECHNOLOGY DESIRED
=B

CONSTANT C=0.0567  HA/WCP=0.0184

N= 52  ZI PTCH  =1.149  DP=27.85  HT-S= 2.55  HT-P= 1.80  P= 3.651
AX W= 1.30  B1=  0.   B2= 58.7  K= 0.049  CPC= 0.2557  AG=  412.97
PR NO=0.6923  VISC= 0.316E-04
RE S= 0.845E 06  RE P= 0.451E 06
WG= 121.8

COOLING TECHNOLOGY  B   -CURRENT FILM

2WCCP/AGHG= 0.07

AVG GAS   PEAK GAS    BULK      COOLANT     COOLING      COOLING FLOW
TEMP R    TEMP R    TEMP R     TEMP R   EFFECTIVENESS      %W2C
 2279.5    2608.9    2260.0     1231.0      0.253          0.613

STAGE  1  BUCKET

ENTER NO. OF AIRFOILS AND AXIAL WIDTH
=107,1.133
ENTER TB,%WC
=2278,0
ENTER PEAK GAS TEMP, IF 0 PROGRAM WILL CALCULATE
=0
ENTER LEVEL OF COOLING TECHNOLOGY DESIRED
=C+

CONSTANT C=0.0567  HA/WCP=0.0350

N=107  ZI PTCH  =0.998  DP=28.25  HT-S= 3.40  HT-P= 2.72  P= 2.852
AX W= 1.13  B1= 40.3  B2= 58.3  K= 0.047  CPC= 0.2557  AG=  933.78
PR NO=0.6928  VISC= 0.303E-04
RE S= 0.503E 06  RE P= 0.314E 06
WG= 121.8

COOLING TECHNOLOGY  C+  -CONVECTION  PLUS

2WCCP/AGHG= 0.28

AVG GAS   PEAK GAS    BULK      COOLANT     COOLING      COOLING FLOW
TEMP R    TEMP R    TEMP R     TEMP R   EFFECTIVENESS      %W2C
 2134.8    2356.5    2278.0     1231.0      0.070          0.485
```

10°

995

```
 /TER NO. OF AIRFOILS AND AXIAL WIDTH
=69,1.9
ENTER TB,%WC
=2260,0
ENTER PEAK GAS TEMP, IF 0 PROGRAM WILL CALCULATE
=0
ENTER LEVEL OF COOLING TECHNOLOGY DESIRED
=B

CONSTANT C=0.0567  HA/WCP=0.0411

N= 69  ZI PTCH  =0.648  DP=29.15  HT-S= 4.85  HT-P= 3.72  P= 5.235
AX W= 1.90  B1= 29.1  B2= 66.0  K= 0.045  CPC= 0.2557  AG= 1547.74
PR NU=0.6933  VISC= 0.294E-04
RE S= 0.835E 06  RE P= 0.367E 06
WG= 121.8

COOLING TECHNOLOGY  B   -CURRENT FILM

2WCCP/AGHG= 0.10

AVG GAS   PEAK GAS    BULK      COOLANT     COOLING      COOLING FLOW
TEMP R    TEMP R    TEMP R     TEMP R   EFFECTIVENESS      %W2C
 2042.8    2313.0    2260.0     1231.0      0.049           0.400


STAGE  2  BUCKET

ENTER NO. OF AIRFOILS AND AXIAL WIDTH
=88,1.56
ENTER TB,%WC
=2208,0
ENTER PEAK GAS TEMP, IF 0 PROGRAM WILL CALCULATE
=0
ENTER LEVEL OF COOLING TECHNOLOGY DESIRED
=C+

CONSTANT C=0.0567  HA/WCP=0.0450

N= 88  ZI PTCH  =0.857  DP=29.65  HT-S= 5.85  HT-P= 5.08  P= 4.127
AX W= 1.56  B1= 48.0  B2= 63.1  K= 0.042  CPC= 0.2557  AG= 1984.67
PR NU=0.6941  VISC= 0.280E-04
RE S= 0.506E 06  RE P= 0.286E 06
WG= 121.8

COOLING TECHNOLOGY  C+  -CONVECTION  PLUS

2WCCP/AGHG= 0.

AVG GAS   PEAK GAS    BULK      COOLANT     COOLING      COOLING FLOW
TEMP R    TEMP R    TEMP R     TEMP R   EFFECTIVENESS      %W2C
 1891.7    2089.8    2208.0     1231.0      0.              0.
```

```
 /E  3  NOZZLE

 /TER NO. OF AIRFOILS AND AXIAL WIDTH
 100,1
ENTER TB,%WC
=2300,0
 NTER PEAK GAS TEMP, IF 0 PROGRAM WILL CALCULATE
 0
ENTER LEVEL OF COOLING TECHNOLOGY DESIRED
=B

CONSTANT C=0.0567  HA/WCP=0.0343

N=100  ZI PTCH  =1.100  DP=30.60  HT-S= 7.40  HT-P= 6.17  P= 2.689
AX W= 1.00  B1= 38.4  B2= 62.8  K= 0.040  CPC= 0.2557  AG= 1824.47
PR NO=0.6950  VISC= 0.268E-04
RE S= 0.261E 06  RE P= 0.132E 06
WG= 121.8

COOLING TECHNOLOGY  B   -CURRENT FILM

2WCCP/AGHG= 0.

AVG GAS   PEAK GAS    BULK      COOLANT     COOLING      COOLING FLOW
TEMP R    TEMP R    TEMP R     TEMP R   EFFECTIVENESS      %W2C
 1772.6    1975.2    2300.0     1231.0      0.              0.


STAGE  3  BUCKET

ENTER NO. OF AIRFOILS AND AXIAL WIDTH
 100,1
 NTER TB,%WC
=2300,0
ENTER PEAK GAS TEMP, IF 0 PROGRAM WILL CALCULATE
=0
ENTER LEVEL OF COOLING TECHNOLOGY DESIRED
=C+

CONSTANT C=0.0567  HA/WCP=0.0308

N=100  ZI PTCH  =1.223  DP=31.25  HT-S= 8.75  HT-P= 7.70  P= 2.527
AX W= 1.00  B1= 36.6  B2= 59.8  K= 0.037  CPC= 0.2557  AG= 2078.59
PR NO=0.6962  VISC= 0.254E-04
RE S= 0.195E 06  RE P= 0.101E 06
WG= 121.8

COOLING TECHNOLOGY  C+  -CONVECTION  PLUS

2WCCP/AGHG= 0.

AVG GAS   PEAK GAS    BULK      COOLANT     COOLING      COOLING FLOW
TEMP R    TEMP R    TEMP R     TEMP R   EFFECTIVENESS      %W2C
 1640.0    1811.1    2300.0     1231.0      0.              0.
```

```
STAGE  4  NOZZLE

ENTER NO. OF AIRFOILS AND AXIAL WIDTH
=100,1
ENTER TB,%WC
=2300,0
ENTER PEAK GAS TEMP, IF 0 PROGRAM WILL CALCULATE
=0
ENTER LEVEL OF COOLING TECHNOLOGY DESIRED
=B

CONSTANT C=0.0567  HA/WCP=0.0263

N=100  ZI PTCH  =1.446  DP=32.25  HT-S=10.25  HT-P= 9.02  P= 2.459
AX W= 1.00  B1= 31.4  B2= 52.2  K= 0.034  CPC= 0.2557  AG= 2369.38
PR NO=0.6974  VISC= 0.240E-04
RE S= 0.136E 06  RE P= 0.805E 05
WG= 121.8

COOLING TECHNOLOGY  B  -CURRENT FILM

2WCCP/AGHG= 0.

AVG GAS   PEAK GAS    BULK      COOLANT     COOLING      COOLING FLOW
TEMP R    TEMP R     TEMP R     TEMP R   EFFECTIVENESS      %W2C
 1518.0    1657.0    2300.0     1231.0      0.               0.


STAGE  4  BUCKET

ENTER NO. OF AIRFOILS AND AXIAL WIDTH
=100,1
ENTER TB,%WC
=2300,0
ENTER PEAK GAS TEMP, IF 0 PROGRAM WILL CALCULATE
=0
ENTER LEVEL OF COOLING TECHNOLOGY DESIRED
=C+

CONSTANT C=0.0567  HA/WCP=0.0256

N=100  ZI PTCH  =1.041  DP=32.93  HT-S=11.77  HT-P=10.47  P= 2.511
AX W= 1.00  B1=  3.5  B2= 53.0  K= 0.033  CPC= 0.2557  AG= 2792.06
PR NO=0.6984  VISC= 0.232E-04
RE S= 0.126E 06  RE P= 0.616E 05
WG= 121.8

COOLING TECHNOLOGY  C+  -CONVECTION  PLUS

2WCCP/AGHG= 0.

AVG GAS   PEAK GAS    BULK      COOLANT     COOLING      COOLING FLOW
TEMP R    TEMP R     TEMP R     TEMP R   EFFECTIVENESS      %W2C
 1441.0    1586.6    2300.0     1231.0      0.               0.
```

LPTurbine Efficiency Estimate

	Baseline (1)	3 Stage (1)	Variable Boost (2)
P/P	8.6	8.6	10.6
RPM	5874	6897	6783
ψ	.97	1.094	.969
No Stage	4	3	4
η uncooled	.904	.895	.903
$\Delta\eta$ Reheat	+.0175	+.016	+.0181
$\Delta\eta$ RNI	−.011	−.011	−.011
$\Delta\eta$ OGV	0	−.0028	0
$\Delta\eta$ Air-turbine-Engine	−.003	−.003	−.003
$\Delta\eta$ Advanced Tech	+.004	+.004	+.004
$\Sigma\Delta\eta$	+.0075	+.0032	+.0081
η uncooled	.912	.90	.9107
$\Delta\eta$ cooling	+.0071	+.0065	+.0054
η cycle	.919	+.905	+.916
W/W_{2c} cool+leak	2.31%	2.3%	2.0%

(1) 80% Mx Cr 35K/.8/0

(2) Mx CL 35K/.8/+18

Cooling Flows (% W_{2c})

1N	.774	1.08	.613
1R	.628	.71	.485
2N	.412		.40
2R			

10.4.1 Installation Drag - Revisions

Attached is an estimate of installation drag for the Task I turboprop nacelle. The characteristic dimensions are shown at the bottom of the "Performance Summary" Section 5.4.3

For Task II the Nacelle dimensions were revised as follows

	Task I Base	Task II 4 Stage LPT	3 Stage	Variable Point
D_T	16'	21.73	21.62'	23.22'
R_A	33.6	45.6	45.4	48.7
R_B	48	63.2	63	67.53
D_L	235.8	298.2	296.3	318.6

The Task I drags were corrected as follows

Wing scrubbing $\propto D_T$

Nacelle Friction $\propto D_L(3R_A + R_B)$

Nacelle Pressure $\propto (R_A^2 + R_B^2)$

The resulting total Drags are as follows

	4 Stage	3 Stage	Variable Point
F_{Drag}	625	620	714

10.4.2 Turboprop Installation Design Weight and Cost Estimates

The turboprop installation follows the design defined in Task I, section 5.6. The aerodynamic flow lines from the propeller move in a curved path over and under the wing and the engine exhaust is discharged below the wing. The pylon supports the propeller at the reduction gear box and the nacelle is supported by and integrated with the pylon. Figure 5.6.1 shows the basic layout.

The various propeller-engine combinations studied maintain the basic ratio of the distance between propeller and wing at .75 x propeller diameter. Maximum pylon radius at the top and sides is equal to .35 x propeller radius. At the bottom the pylon covers the engine and its accessories and is thus influenced by these radial dimensions and the radial offset for the reduction gear box. A tabulation of the significant installation dimensions for the various Task II turboprop installations studied are listed in Table 10.4.2.1. The weight and price estimates are listed in Table 10.4.2.2.

Table 10.4.2.1

Turboprop Nacelle Dimentions

Turboprop No.	Task I Base design	5A 45t LPT	5B 38t LPT	6 Variable Cycle
Prop. Diam ft.	16.0	21.73	21.62	23.22
? Gear Box Centerlines Δ (a)	22.8"	31.0"	30.8"	31.3"
Top Radius, max	33.6"	45.6"	45.4"	48.7"
? Bottom Radius, max.,	48.0"	63.2" ?	63.0" ?	63.5" ?
Lengths from Prop. centerline to:				
✓ Spinner / Nacelle L.E.(b)	16.8"	22.8"	22.7"	24.4"
✓ Inlet L.E.	21.2"	28.8"	28.6"	30.8"
Wing forward spar C.L.(c)	173.0"	235."	234."	251."
Tailpipe Trailing Edge	236.0"	321."	319."	342."

Notes (a) Vertical between propeller and engine shaft centerlines
(b) L.E. = leading edge
(c) C.L. = Centerline.

Table 10.4.2.2

Turboprop Nacelle Weight and Price Estimates.

Turboprop No.	5a 4 Stage L.P.T.	5b 3 Stage L.P.T.	6 Variable Cycle
Weight Estimates			
Inlet + Drive Shaft	210 lbs	218	265
Composite Cowl + Firewalls	697	690	790
Exhaust pipe, centerbody Ti Cowl, + wing protection	329	325	379
Pylon / EBU Systems	1817	1801	1954
Margin 7%	214	212	237
Totals	3267 lbs	3246	3625
Price Estimates			
Inlet + Drive shaft	5.2%	5.4%	5.7%
Composite Cowl + Firewalls	16.3	16.3	16.6
Exhaust pipe, centerbody, Ti Cowl + wing protection	10.9	10.8	11.2
Pylon / EBU Systems	67.6	67.5	66.5
Total Cost	$472 K	470 K	$509 K

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P 10-59A – What is EBU?

E.B.U. – Engine Build Up Units

= Accessories, devices, cabling, hose etc., added by the aircraft manufacturer to "complete" the engine-installation assembly.
Examples: Fire detection + extinguishing; anti-icing piping + valves; customer compressor bleed piping and valves; bleed air cooler, power supply and controls for fan reverser; instrumentation lines and control cable to cockpit; Alternator; etc.

10.4.3 ~~Basic~~ Engine Mechanical Design

The Task II turboprop mechanical design effort was principally to evaluate the direction to take in refining the Task I engine and to design the variable boost engine.

For the fixed boost engine, the engine arrangement was the same as the Task I engine. The Task II engine cross-section is shown in Figure 10.4.3-1. This engine arrangement is described in more detail in section 5.4.4 for the Task I engine. No engine cross-section drawing was done for the variable boost engine.

The turboprop engines are briefly defined by the following table:

Turboprop Definition - W_{2C}^* - 68.4

Identification	TP5A	TP5B	TP6
LPT - Stages	4	3½	4
LPT exit area - in^2	1052	1052	1223
LP shaft max. RPM	6150	7220	6783
$AN^2 \times 10^{-9}$	.97	1.09	.97
Booster - Stages	3	3	4 (var'ble boost)
Tip Speed, fps	1260	1260	1205
Booster r/r_*	.81	.734	.717
Booster W_2^*	159	159	186.9
Booster P/P	2.75	2.75	3.43
Weight w/10% adder - lbs	3394	3434	3733
Cost - %	100.	98.	106.

Weights - See Table 10.4.3-1.

Core weights are the same as baseline except for the variable boost engine (TP6) which used the USTEDLEC Task I 4-U core weight. 4-U was also a variable boost engine that operates at higher rpm.

The LPT weights were from the two new (rotor and stator) computer programs just completed. These programs are based on correlation with actual hardware weights for TP34, CF6-6D, F101, J101 and T64.

The booster weights came from the weight analyses done during the USTEDLEC Task I weight review. These were based on inlet/outlet flow area average, a r/r correlation, and stage number. A small correction was made to account for different rim speeds.

All other weights were based on Task I techniques of calculation.

Costs

The manufacturing cost of each of the engines used the same formulas as used in Task I and further refined for Task II.

Maintenance Costs

The cost of replacement parts were based on the same cost ratios as were used in the baseline turbofans. That is, where a component such as an LPT rotor had to be broken down into blading costs and rotor costs, the baseline turbofan ratio of blading cost relative to total rotor cost was used to obtain the turboprop blading cost.

The replacement factors recommended are for turbofans, except for booster rotor blading. Booster rotor blading replacement factor was adjusted for $U_{tip}^{2.5}$ from a G.E. erosion correlation.

Originally it was hoped to show more differences due to erosion between turbofans and turboprops based on the smaller

physical size and the potentially cleaner air because of the higher inlet. But as is illustrated in Table 10.4.3-2, there are too many unquantifiable factors so no meaningful difference is logical, at least without considerable more data and study.

Figure 10.4.3-2 was generated to try to evaluate the cleaner (because higher) inlet air available to a turboprop. The figure is based on a turbofan tip-to-ground clearance of 50" which is the DC10 wing engine value. Actually, in the size engine used here, 50" is probably a high value, because our mission aircraft is smaller than a DC10.

Then the turboprop and turbofan installations are superimposed in Figure 10.4.3-2 using the same wing height. The results are:

- TP inlet is 10 inches higher than the TF
- Prop clearance is 35" (Hamilton Standard wants 60")
- A top inlet in the turboprop is ~72 in. higher than a TF
- To obtain 60 in. propeller clearance requires ~25 in. longer landing gear or some other aircraft change.

Table 10.4.3-3 simply illustrates the differing quantity of blades and vanes in the LPT of the three turboprops.

TURBOPROP ENGINE

CYCLE PRESSURE RATIO = 38:1

TURBINE INLET TEMP. = 2600°F

3 STG. LP COMPRESSOR
DRIVEN BY POWER TURBINE

4 STG. POWER TURBINE

BASELINE CORE ENGINE

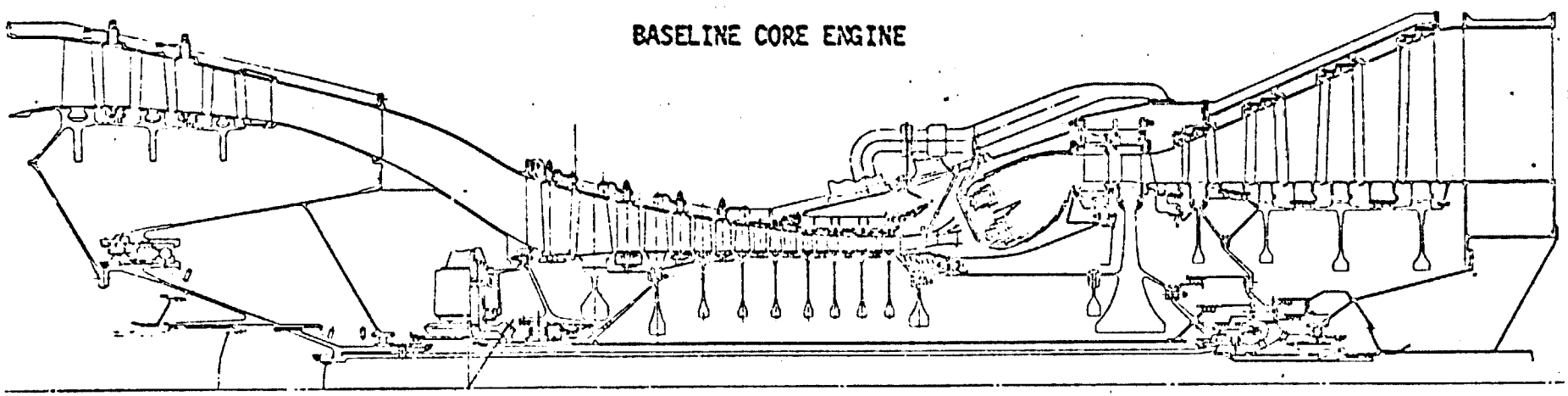

Figure 10.4.3-7

FIGURE 10.4.3-2

TURBOPROP VS. TURBOFAN
INSTALLATION COMPARISON

MISSION SIZE - TRANSCON/4 ENGINE

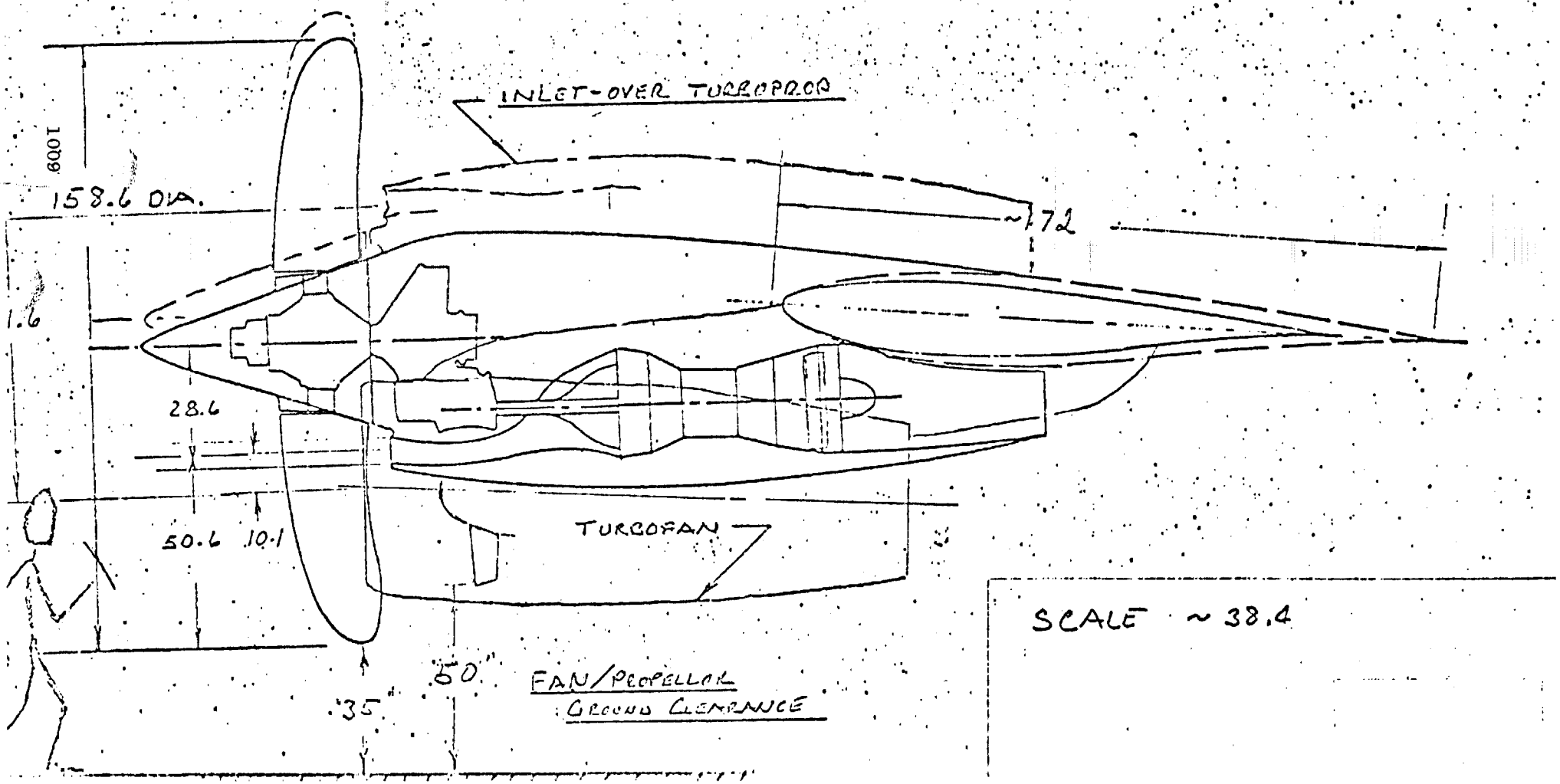

TABLE 10.4.3-1

TURBOPROP WEIGHTS - COLE - 68.6 pps

Components	12-2-75 Base	12-2-75 TP	3 stg	4 stg	4 stg Vanville C.
LP SYSTEM					
1. FWD FRAME	–	0 ?			
2. Booster Rotor	105	163	168	163.	269
3. Booster Stator	122	102	105.	102.	177
4. Frame-intermediate	–	130	130.	130.	130
5. LP shaft cones	110	145	139.	145	145
6. LPT ROTOR	263	460	351 341	366. 377	456
7. LPT STATOR	298	440	310	312	325.
8. TURBINE FRAME	170	194	231	179	197
		1634	1434	1397	1699
HP SYSTEM		1129	1129	1129	1136
MISCELLANEOUS					
1. Sumps		104	SAME AS BASELINE		→
2. Extra Brgs + Supp		0			
3. Drives		130			
4. C+A - Configuration		325			
		559	559	559	55
TOTAL		3322	3122.	3085	339
TOTAL w/margin 10%		3654.	3434.	3394.	373.

TABLE 10.4.3-2

TURBOPROP vs TURBOFAN

EROSION/FOD COMPARISON

Erosion/FOD Factor	Better		Worse
Physical Size			~7%
Inlet height above ground	50-80%		
Fan hub separation effect			✓ ?
Turbulence of ground air induced by prop or fan			✓ ?
Ground vortex	✓ ?		
Reverse thrust effect		?	

TABLE 10.4.8-3

VANE + BLADE NUMBER		TP5A 3stg	TP5B 4stg	TP6 Variable Cycle
LPT				
STATOR	1V	48	40	40
	2V	71	73	69
	3V	44	72	76
	4V	0	65	71
TOTAL		163	250	256
ROTOR	1R	101	112	107
	2R	80	98	88
	3R	48	86	66
	4R	0	61	44
		229	357	305
TOTAL BLADES + VANES		392	607	561

10.6.1 Engine Evaluation

Attached are the calculations supporting the final DOC, ROI and Fuel Burned results for the single rotation/advanced weight turboprop. The typical method of evaluation of an engine is as follows.

1) Installed engine weight, cost and performance are determined in the design size ie. $W_{2c}\sqrt{\theta}/\delta = 68.4$ lb/sec. For example, see the first column on sheet titled "Basic Propellor/Advanced (etc) 4 Stage LPT" TABLE 10.6.1-1 ~~TABLE 6.10~~

2) The engine is then scaled to the the thrust size required by the aircraft at 35K/.8/+18 M/CL ie. $F_{NI} = 3630$. The column titled "Mission Analysis" provides the propulsion system characteristics used in the mission study

3) The engine scale factor is the ratio of the design size installed thrust to the mission size i.e. .3689.

4) Each of the design weights and costs is scaled down by the engine scale factor raised to the indicated exponent (exponents shown on page 10-72) i.e. engine weight $(3539)(.3689)^{1.25} = 1017$ #

5) Propellor and gear price is determined from the curve provided by HSD and found in 5.3.2.

6) The engine maintenance calculation procedure is given in section 8.6. The computer output for the engines shown is attached. For baseline engine Engine maintenance = #1563 hour in transition helicopter

7) Propellor + gearbox maintenance is found from the attached curve (FIG. 10.6.1-1) which is based on HSD data. For the 13.2' dia. this value $1.06/Flight hour.

The above procedure defines the method used in establishing the ~~replacement aircraft~~ replacement propulsion system.

The following describes the procedure used in correcting the aircraft fuel and economics when the replacement propulsion system is "installed".

1) Table 10.6.1-10 presents the differences between the replacement propulsion system and that used in the aircraft mission.
2) The influence of these differences on the aircraft fuel and economics is attached in 5.5.1

3) As an example of the procedure (page 10-87) the adjustment to fuel burned is presented below. For the baseline engine Transcon/Off design mission (333 [illegible])

$\Delta SFC_I = -.2$

$\Delta WF/\Delta SFC = 1.15$

$\Delta WF = -.23\%$

$\Delta wt = 4.71$ (TOTAL PROPULSION WEIGHT/ENGINE)

$\Delta WF/100\# = .3286$

$\Delta WF = -1.55$

$\Delta WF = -1.78\%$ from original aircraft value

Base aircraft value $WF = 9737\#$

-1.78%

$\Longrightarrow WF = 9563\#$

The same procedure was used for DOC + ROI

TABLE 10.6.1-1

Basic Propeller / Advanced Weight / 4 Stage LPT

Transcon Mission

	Design Size Wac Max=63	Scaling Exponent	Scaled to Aircraft		Mission Analysis
D_T	21.73	.5	13.20		
F_N Max C_L	9840		3630		3630
Scale Factor	1.0		.3689		
SFC @ 80% MC	.524		.524		.525
Wt. Engine	3539	1.25	1017		1010
Wt Prop	3694	1.24	1072		1168
Wt Gear	3114	1.5	698		810
Wt Installed	3267	1.1	1090		1381
Price Eng Cost	694.1	.55	401.1		425.5
Price Prop + G	342		145.9		136
Price Install	472.3	.8	212.7		207.5
Prop Maintenance $/Flight h			1.06		
Engine Maintenance $/Flight Hour			15.62		
Wt oil Cool			21		

TABLE 10.6.1-2

Basic Propeller / Advanced Weight / Variable Boost

Transcon Aircraft

	Design Size W2c Vx=68.4	Scaling Exponent	Scaled to Aircraft		Mission Analysis
D_T	23.22		13.2		
F_N Max C_L	11241		3630		3630
Scale Factor	1.0		.3229		
SFC @ 80% MC	.5167		.5167		.525
Wt. Engine	3941	1.25	960		1010
Wt Prop	4316	1.24	1062		1168
Wt Gear	3261	1.5	598		810
Wt Installed	3625	1.1	1045		1381
Price Eng Cost	755	.55	405.3		425.5
Price Prop + G	370		145.9		136
Price Install	509	.8	206		207.5
Prop Maintenance $/Flight h			1.27		
Engine Maintenance $/Flight Hour			14.76		
Wt 0.1 Cooler			21		

TABLE 10.6.1-3

Basic Propellor / Basic Weight / 4st LPT

- TransCon Mission

	Design Size Wac 0% = 68.4	Scaling Exponent	Scaled to Aircraft		Mission Analysis
DT	21.73		13.2		
FN Max CL	9840		3630		3630
Scale Factor	1.0		.3689		
SFC @ 80% inc	.524		.524		.525
Wt. Engine	3639	1.25	1017		1010
Wt Prop	4150	1.24	1205		1168
Wt Gear	3313	1.5	743		810
Wt Installn	3267	1.1	1090		1381
Price Eng Cost	694	.55	401.1		425.5
Price Prop + G			135.7		136
Price Install	4723	.80	212.7		207.5
Prop Maintenance $/Flight h			1.02		
Engine maintenance $/Flight Hour			15.62		
Wt. Oil Cooler			21		

TABLE 10.6.1-4

Basic Propulsion /Advanced Weight /3 Stage LPT

- Transcon Mission

	Design Size Wgt = 68.4	Scaling Exponent	Scaled to Aircraft		Mission Analysis
DT	21.62		13.18		
FN Max CL	9769		3060		3630
Scale Factor	1.0		.3716		
SFC @ 80% Max	.532		.532		.525
Wt. Engine	3434	1.25	997		1010
Wt Prop	3649	1.24	1069		1168
Wt Gear	3059	1.5	693		810
Wt Installn	3246	1.1	1092		1381
Price Eng Cost	687.8	.55	399.		425.5
Price Prop Cost	340		144.2		136
Price Install	469.8	.8	212.8		207.5
Prop Maintenance $/Flight h			1.07		
Engine maintenance $/Fl Hour			15.55		
Wt Oil cooler			21		

TABLE 10.61-5

Basic Prop/Adv Weight/Variable Speed

Intercon Mission

	Design Size Wac W/S=68.4	Scaling Exponent	Scaled to Aircraft		Mission Analysis	
DT			15.29			
FN Max CL			4875		4875	
Scale Factor						
SFC @ 80% inc.			.5167		.525	
Wt Engine			1387		1460	
Wt Prop			1532		1683	
Wt Gear			931		1260	
Wt Installed			1446		1908	
Price Eq Cost			611.3		641	
Prop+G			262.9		244.6	
Install			334.4		336.4	
Prop Maintenance $/Flight h			1.39			
Engine maintenance $/Flight Hour			17.51			
Oil Cooler Wt			28			

TABLE 10.6.1-6

Basic Prop/Basic Weight 145t LPT

- Intercon Mission

	Design Size Wgt 184-68-1	Scaling Exponent	Scaled to Aircraft		Mission Analysis	
D_T			15.29			
F_N Max Cl			4875		4875	
Scale Factor			.495			
SFC @ 80% MC			.524		.525	
Wt. Engine			1470		1460	
Wt Prop			1737		1683	
Wt Gear			1155		1260	
Wt Installed			1509		1908	
Price Eq Cost			604.7		641	
Prop Cost			245.4		244.6	
Install			345.2		336.4	
Prop Maintenance $/Flight h			1.33			
Engine maintenance $/Flight Hour			18.53			
Wt 0.1 Cooler			28			

TABLE 10.6.1-7

Basic Prop/Advanced Weight/AST LPT

Intercon Mission

	Design Size Wac Max=684	Scaling Exponent	Scaled to Aircraft		Mission Analysis
DT			15.29		
FN Max Cl			4875		4875
Scale Factor			.495		
SFC @ 80% MC			.524		.525
Wt. Engine			1490		1460
Wt Prop			1546		1683
Wt Gear			1086		1260
Wt Installed			1509		1908
Price Eng Cost			604.7		641
Prop+G			262.9		244.6
Install			345.2		336.4
Prop Maintenance $/Flight h			1.39		
Engine maintenance $/Fl Hour			18.53		
Wt Oil Cooler			28.		

TABLE 10.6.1-8

Basic Prop/Alu Wt/Sized for Blade + Power

Transcon Mission

	Design Size W2.c W2=684	Scaling Exponent	Scaled to Aircraft		Mission Analysis	
Dr						
FN Max Cl	8841		3630		3630	
Scale Factor	1					
SFC @ 80% MC	.564		.564		.525	
Wt. Engine	3398		1115		1010	
Wt. Prop	3217		1067		1168	
Wt Gear	2650		697		810	
Wt Installn	2990		1123		1381	
Price Eq Cost	708.6		433.9		425.5	
Propt Co	320		145		136	
Install	412.8		202.5		207.5	
Prop Maintenance $/Flight h						
Engine maintenance $/Fl Hour						

TABLE 10.6.1-9

Turbofan

- Transcon Mission

	Design Size W2c 80% = 68.4	Scaling Exponent	Scaled to Aircraft		Mission Analysis	
DT						
FN Max Cl	7516		3530		3530	
Scale Factor						
SFC @ 80%	.65		.65		.614	
Wt. Engine	4136		1609		1485	
Wt Prop						
Wt Gear						
Wt Installed	2830		1233		1206	
Price Eq Cost	744.5		491.5		468.6	
Prop + G						
Install	433.4		236.7		233.4	
Prop Maintenance $/Flight h						
Engine maintenance $/Flight Hour						

DESIGN SIZE

ENGINE DESIGNATION: TP5B
NO. OF ENGINES: 4 TYPE: DOMESTIC RANGE: 700 MILES

	PART INDEX
FAN ROT BLADES-	0.
FAN ROT DISC---	0.
FAN FRAME&STAT-	0.
BOOS ROT BLADES	1.100
BOOS ROT DISC--	0.050
BOOS STAT VANES	0.200
BOOS STAT CASE-	0.050
HPT BLADES-----	4.000
HPT VANES------	6.100
HPT DISC-------	0.600
HPT CASE-------	0.400
COMBUSTOR------	2.000
HPC BLADES-----	3.100
HPC VANES------	0.300
HPC DISC-------	0.150
HPC CASING-----	0.100
GEAR SET-------	0.
GEAR LUBE & COOLING SYSTEM-	0.
LPT STAT VANES-	0.250
LPT STAT CASE--	0.200
LPT ROT BLADES-	0.700
LPT ROT DISC---	0.050
TURB FRAME-----	0.100
C&A&MISC-------	0.300
----------	2.000
----------	0.200
----------	0.
----------	0.
----------	0.
TOTAL----------	

0 MISSION SIZE

ENGINE DESIGNATION:TP5B
NO. OF ENGINES: 4 TYPE:DOMESTIC RANGE: 700 MILES

	MAT CST /FL HR	LAB CST /FL HR	TOT CST /FL HR
FAN ROT BLADES-	0.	0.	0.
FAN ROT DISC---	0.	0.	0.
FAN FRAME&STA--	0.	0.	0.
BOOS ROT BLADES	0.07	0.03	0.09
BOOS ROT DISC--	0.01	0.00	0.01
BOOS STAT&VANES	0.02	0.01	0.03
BOOS STAT CASE-	0.01	0.00	0.02
HPT BLADES-----	1.88	0.81	2.68
HPT VANES------	3.06	1.31	4.37
HPT DISC-------	0.24	0.10	0.34
HPT CASE-------	0.11	0.05	0.16
COMBUSTOR------	1.47	0.63	2.10
HPC BLADES-----	0.32	0.14	0.46
HPC VANES------	0.04	0.02	0.05
HPC DISC-------	0.07	0.03	0.10
HPC CASING-----	0.04	0.02	0.06
GEAR SET-------	0.	0.	0.
GEAR LUBE & COOLING SYSTEM-	0.	0.	0.
LPT STAT VANES-	0.09	0.04	0.13
LPT STAT CASE--	0.06	0.03	0.09
LPT ROT BLADES-	0.29	0.12	0.41
LPT ROT DISC---	0.02	0.01	0.03
TURB FRAME-----	0.04	0.02	0.06
C&A&MISC-------	0.47	0.20	0.67
----------	0.36	0.16	0.52
----------	0.03	0.01	0.04
----------	0.	0.	0.
----------	0.	0.	0.
----------	0.	0.	0.
TOTAL----------	8.70	3.73	12.44

TOTAL COST PER FLIGHT HOUR, $: 12.44

x 1.25 = 15.55

DESIGN SIZE

ENGINE DESIGNATION: TP6
NO. OF ENGINES: 4 TYPE: DOMESTIC RANGE: 700 MILES

	PART INDEX
FAN ROT BLADES-	0.
FAN ROT DISC---	0.
FAN FRAME&STAT-	0.
BOOS ROT BLADES	1.100
BOOS ROT DISC--	0.050
BOOS STAT VANES	0.200
BOOS STAT CASE-	0.050
HPT BLADES-----	4.000
HPT VANES------	6.100
HPT DISC-------	0.600
HPT CASE-------	0.400
COMBUSTOR------	2.000
HPC BLADES-----	3.100
HPC VANES------	0.300
HPC DISC-------	0.150
HPC CASING-----	0.100
GEAR SET-------	0.
GEAR LUBE & COOLING SYSTEM-	0.
LPT STAT VANES-	0.250
LPT STAT CASE--	0.200
LPT ROT BLADES-	0.700
LPT ROT DISC---	0.050
TURB FRAME-----	0.100
C&A&MISC-------	0.300
----------	2.000
----------	0.200
----------	0.
----------	0.
----------	0.
TOTAL----------	

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MISSION SIZE

ENGINE DESIGNATION: TP6
NO. OF ENGINES: 4 TYPE: DOMESTIC RANGE: 700 MILES

	MAT CST /FL HR	LAB CST /FL HR	TOT CST /FL HR
FAN ROT BLADES-	0.	0.	0.
FAN ROT DISC---	0.	0.	0.
FAN FRAME&STA--	0.	0.	0.
BOOS ROT BLADES	0.08	0.04	0.12
BOOS ROT DISC--	0.01	0.00	0.02
BOOS STAT&VANES	0.03	0.01	0.04
BOOS STAT CASE-	0.01	0.01	0.02
HPT BLADES-----	1.74	0.75	2.49
HPT VANES------	2.83	1.22	4.05
HPT DISC-------	0.22	0.10	0.32
HPT CASE-------	0.10	0.04	0.14
COMBUSTOR------	1.36	0.58	1.94
HPC BLADES-----	0.30	0.13	0.43
HPC VANES------	0.03	0.01	0.05
HPC DISC-------	0.06	0.03	0.09
HPC CASING-----	0.04	0.02	0.05
GEAR SET-------	0.	0.	0.
GEAR LUBE & COOLING SYSTEM-	0.	0.	0.
LPT STAT VANES-	0.11	0.05	0.15
LPT STAT CASE--	0.08	0.03	0.11
LPT ROT BLADES-	0.35	0.15	0.50
LPT ROT DISC---	0.03	0.01	0.04
TURB FRAME-----	0.04	0.02	0.06
C&A&MISC-------	0.44	0.19	0.62
----------	0.34	0.14	0.48
----------	0.03	0.01	0.04
----------	0.	0.	0.
----------	0.	0.	0.
----------	0.	0.	0.
TOTAL----------	8.23	3.53	11.76

TOTAL COST PER FLIGHT HOUR, $ ~~11.76~~ 11.81

X1.25 = 14.76

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FIG. 10.6.1-1

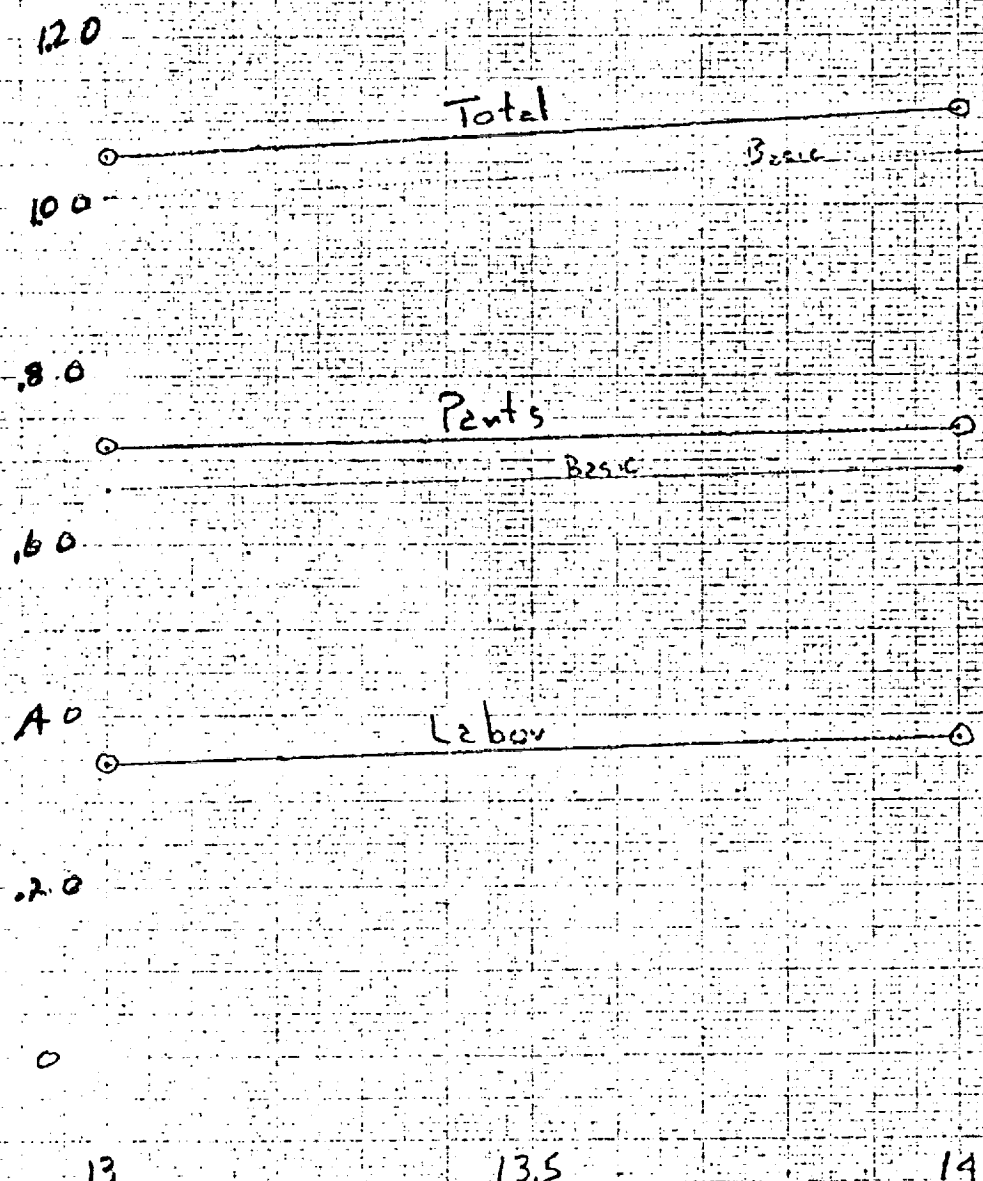
Advanced Weight Prop+Gearbox

Maintenance Cost

Data from HSD in 1979 $ @ 3200 units

DT	13'	16'	
# Parts/1000 hrs	840.58	1148.38	Quantity 2800 units
Man hrs/1000 hrs	47.56	57.8	

used Labor = $7.30/hr



3/2/76

Table 10.6.1-10

Turboprop Performance Summary

Transcon

	Aircraft Propulsion System	Basic Prop Adv Wt	Basic Prop Basic Wt	Basic Prop Adv. Wt 3st LPT	Basic Prop Adv Wt Variable Beam
SFC	.525	.524	.524	.532	.5167
Δ%		-.2	-.2	+1.33	-1.58
Wt	4369	3898	4076	3872	3685
ΔWt		-471	-293	-497	-684
Price	769	759.7	749.5	756	757.2
ΔPrice		-9.3	-19.5	-13	-11.8
Maintance	22.02	16.68	16.64	16.62	15.83
ΔMaintn		-5.34	-5.38	-5.4	-6.19

Intercon

SFC	.525	.524	.524		.5167
Δ%		-.2	-.2		-1.58
Wt	6311	5640	5900		5324
ΔWt		-671	-411		-987
Price	1222.0	1212.8	1195.3		1208.5
ΔPrice		-9.2	-26.7		-13.45
Maintance	25.79	19.92	19.86		18.90
ΔMaintn		-5.87	-5.93		-6.89

TABLE 10.6.1-11

Transocean Mission

573 LP

Block Fuel

3/8/76

	A'	B	6	Basic
ΔSFC	-.2	1.33	-1.58	-.2
ΔWF/ΔSFC	1.15	1.15	1.15	1.15
ΔWF	-.23	1.53	-1.817	-.23
Δwt	-4.71	-4.97	-6.84	-2.93
ΔWF/Δwt	.3286	.3286	.3286	.3286
ΔWF	-1.55	-1.63	-2.25	-.96
ΔWF	-1.78	-1.-	-4.07	-1.19
WF 9737	9563	9727	9340	9621

TOGW

ΔSFC	-.2	1.33	-1.58	-.2
Δw/ΔSFC	.4391	.4391	.4391	.4391
Δwt	-.088	+.58	+.69	-.088
Δwt	-4.71	-4.97	-6.84	-2.93
Δwt/ΔwT	.402	.402	.402	.402
ΔwT	-1.89	+2	-2.75	-1.17
ΔwT	-2.09	+3.33	-3.44	-1.37
TOGW 217930	213375	225187	210433	214944

Basic - Basic Wt Prop

A' Advanced weight Prop

B " " 3 stage LPT

6 Variable Boost

TABLE 10.6.1-12

Transcon Mission

3/11/76

Economic Analysis

~~3/8/76~~

	DOC				ROI			
	Basic	A'	B	6	A'	B	6	Basic
ΔSFC	-.2	-.2	+1.33	-1.53	-.2	+1.33	-1.53	-.2
Δ$/ΔSFC	.4113	.4113	.4113	.4113	-.1424	-.1424	-.1424	-.1424
Δ$	-.082	-.082	.547	-.65	.028	-.189	+.224	.028
Δwt	-2.93	-4.71	-4.97	-6.84	-4.71	-4.97	-6.84	-2.93
Δ$/Δwt	.2046	.2046	.2046	.2046	-.1017	-.1017	-.1017	-.1017
Δ$	-.599	-.964	-1.017	-1.4	.479	.505	.7	.298
Δ$	-19.5	-9.3	-13	-11.8	-9.3	-13	-11.8	-19.5
Δ$/Δ$	.0111	.0111	.0111	.0111	-.0098	-.0098	-.0098	-.0098
Δ$	-.216	-.103	-.144	-.132	.091	.127	.115	.191
ΔM	-5.38	-5.34	-5.40	-6.19	-5.34	-5.40	-6.19	-5.38
Δ$/ΔM	.3682	.3682	.3682	.3682	-.06	-.06	-.06	-.06
Δ$	-1.98	-1.966	-1.99	-2.28	+.32	+.32	+.37	.32
Δ$	-2.88	-3.11	-2.6	-4.46	.92	.763	1.4	.84
$ 1.3187	1.339	1.336	1.342	1.317	18.833	18.676	19.313	18.753

17.9318

Basic – Basic Weight Prop
A' – Advanced Wt Prop
B " " 3 stage LPS
6 Variable Boost

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TABLE 10.6.1-13

Intercon. Mission

		Doc Adv	Doc BAS	ROI Adv	ROI BAS	
ΔSFC	-1.58	-.2	-.2	-.2	-.2	-1.58
Δ$ / ΔSF	.7147	.7147	.7147	-.229	-.229	-.229
Δ$	-1.129	-.143	-.143	.046	.046	.361
Δwt	-9.87	-6.71	-4.11	-6.71	-4.11	-9.87
Δ$ / Δwt	.2114	.2114	.2114	-.0818	-.0818	-.0818
Δ$	-2.09	-1.418	-.869	.549	.336	.81
Δ$	-13.45	-9.2	-26.7	-9.2	-26.7	-13.45
Δ$ / Δ$	.0064	.0064	.0064	-.0037	-.0037	-.0037
Δ$	-.086	-.059	-.171	.034	.099	.05
Δm	-6.89	-5.87	-5.93	-5.87	-5.93	-6.89
Δ$ / Δm	.2713	.2713	.2713	-.05118	-.05118	-.05118
Δ$	-1.87	-1.513	-1.609	.300	.303	.352
Δ$	-5.18	-3.21	-2.79	.93	.72	+1.57
	1.687	1.7217	1.7293	5.600	5.45	6.24

Variable Boost

Basic Wt

BASIC

Advanced Wt

Variable Boost

ADVANCED WEIGHT

TABLE 10.6.1-14

Intercon Mission

	Adv	Bas	TPG
ΔSFC	-.12	-.12	-1.58
ΔWF/ΔSFC	1.4878	1.4878	1.4878
ΔWF	-.296	-.292	-2.35
Δwt	-6.71	-4.11	-9.87
ΔWF/Δwt	-.31	-.31	.31
ΔWF	-2.080	-1.274	-3.06
ΔWF	-2.38	-1.57	-5.41
30649	29919	30168	28990

	TOGW		
ΔSFC	-.12	-.12	-1.58
ΔW/ΔSFC	.8026	.8026	.8026
ΔW	-.161	-.161	
Δwt	-6.71	-4.11	-9.87
ΔW/Δwt	.3565	.3565	.3565
Δwt	-2.392	-1.465	
ΔW	-2.55	-1.63	
311111	303177	306040	307504

Variable Boost

Basic Weight

Advanced Wt.

TABLE 10.6.1-15

Design Summary
OFF Design

Intercan Mission 3/11/76

	Turbofan	Advwt TP	Basic Wt TP	Vem. Pro
WF	34672	29919 -13.7 %	30168 -13.0 %	2899
DOC	1.8156	1.7217 -5.2%	1.7293 -4.8 %	1.68
ROI	4.3711	5.6 +1.23	5.45 +1.08	6.29
TOGW	318175	303177 -4.7%	306040 -3.8%	

Transcan Mission

WF	11257	9563 -15%	9621 -14.5	9339
DOC	1.3918	1.336 -4.0	1.339 -3.8	1.3766
ROI	18.271	18.833 +.56	18.753 +.48	19.34
TOGW	217495	213375 -1.9%	214944 -1.17	

10.6.2 Final Adjustments

In calculation of final installed engine performance for the CDR a small difference in Max. Climb thrust and 80% Mx. Cruise was found relative to the values used in the mission corrections. It was that the final installed thrust was ~.3% higher and the SFC ~.2% better than used. This shift is essentially the same for all the turboprops.

This difference in performance does not affect the comparison between turboprops but increases the advantage of the turboprop over the turbofan.

10.7 Effect of Aircraft Accessory Power and Air Bleed Extraction on Turboprop Evaluation

This study was performed to determine if the advantage of the turboprop relative to the turbofan would be affected by sizing both engines for continuous aircraft accessory power and bleed. The engine cycles were determined by adjusting the base turbofan and turboprop cycles with influence coefficients to account for power and bleed extraction.

The base turbofan cycle is attached along with the influence coefficients used. The data presented in the "Basic Turboprop" section is applicable.

For a four engine, 200 passenger domestic aircraft the following average requirements were assumed at cruise.

WB/Engine = 1.28#/sec interstage compressor air bleed

HP/Engine = 160 SHP extraction

Scaling these requirements into the 68.4 #/sec engine size results in the following:

	Turbofan	Turboprop
WB	3.01 #/s	3.46 #/s
HP	376	432

Applying the influence coefficients the following performance is found:

$$W_{2C}\sqrt{\theta}/\delta = 68.4 \text{ lb/sec}$$

Fn_I 35K/.8/+18 MxCl	7516	8841
SFC_I 35K/.8/0	.65 (.612)	.564 (.524)

(No aircraft accessories)

Evaluation of these engines was made in the manner presented in the "Engine Evaluation Section". The results (Fig. 16.7-1) are attached and show that the turboprop advantage is reduced by a small amount.

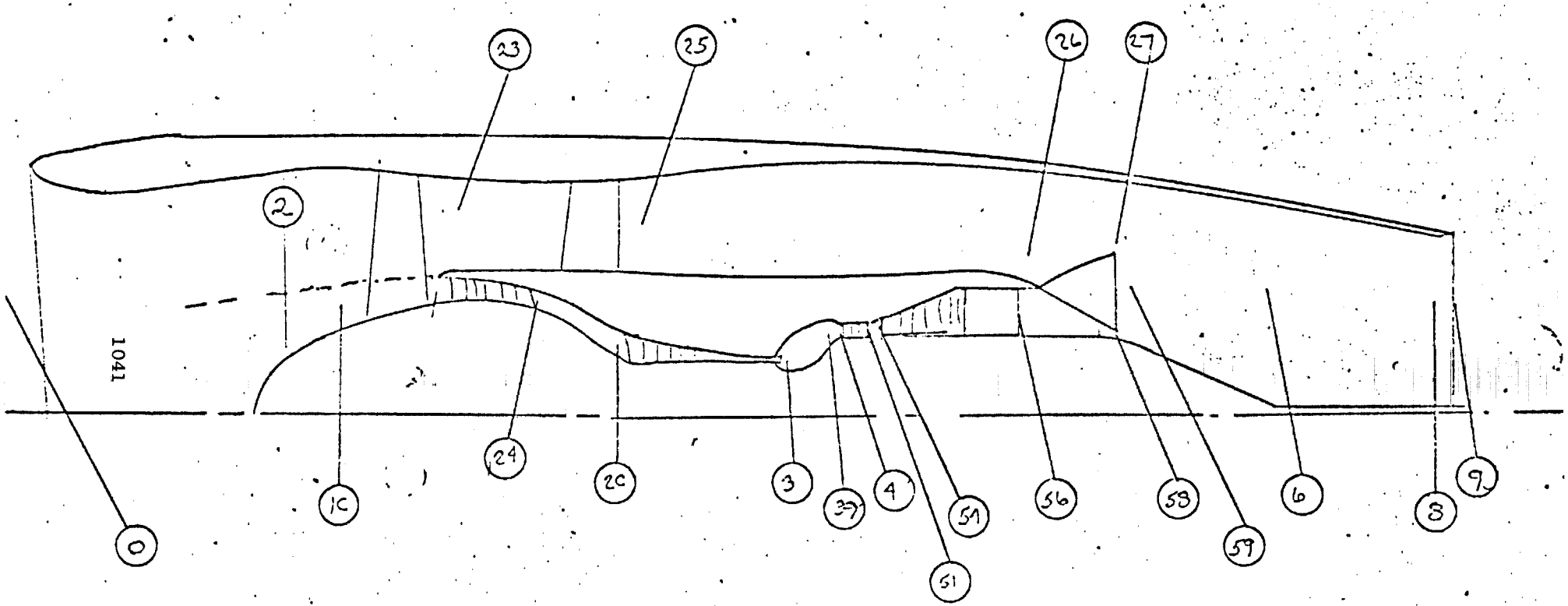
Turboprop Simulation
Batch ~~MP12~~ CYCLE NOMENCLATURE

Alt	Altitude, ft
M	Mach Number
P	Pressure, Psia
W	Flow, lb/sec
T	Temperature, ^{o}R
DELTO	To-Tstd day
ETAR	Ram Recovery
B, β	Bypass Ratio
FNG MX	~~Fully Mixed Net Thrust, lbs~~
SFC MX	Specific Fuel Consumption Based on FNG MX lbm/hr/lb
FNG-PM	Partially Mixed Net Thrust, lbs
SFC-PM	Specific Fuel Consumption Based on FNG PM
PCNF	~~Fan Physical Speed, %~~
NF	Fan Physical Speed, RPM
ECNF*	Fan Corrected Speed
ETAF	~~Fan Tip Adiabatic Efficiency~~
Q	Dynamic Pressure
ETAIC	Fan Hub + Booster Adiabatic Efficiency
PCNG	Core Physical Speed, %
NG	Core Physical Speed, RPM
PCNG*	Core Corrected Speed, %
WFM	Fuel Flow, lb/hr
ETABM	Burner Efficiency
TFFC	HP Turbine Flow Function
NRT4	HP Turbine Corrected Speed

*Indicates a corrected flow

MF12 CYCLE NOMENCLATURE (Cont.)

DH/T4	HP Turbine Energy Function
TFF2TC	LP Turbine Flow Function
N/RT54	LP Turbine Corrected Speed
DH/T54	LP Turbine Energy Function
V	Velocity, ft/sec
CF	Flow Coefficient
AE	Effective Area, in^2
CV	Velocity Coefficient
FGG-MX	Mixed Gross Thrust, lb
FD	Ram Drag
~~FGG-PM~~	~~Partial Mixed Gross Thrust, lb~~
PC-MX	~~Mixing Effectiveness~~



Station Designations

NASA SUBSONIC TURB ENGINE DESIGN FOR LOW ENERGY CONSUMPTION
STEDLEC/MF12 (TASK III REFERENCE) CYCLE
NOTE - W2C* = PRINTOUT VALUE * .995
RATING POINTS

Mx CL

Influence Coefficients

CASE	1.00	2.00
ALT	35000.	35000.
MO	0.800	0.800
PC	50.00	50.00
RC	40.00	40.00
ENG-MX	8837.5	8835.9
SFCGMX	0.5756	0.5756
ENG-CF	0.	0.
SFCGCF	0.	0.
ENG-PM	8738.8	8737.3
SFCGPM	0.5821	0.5821
DELTO	18.00	18.00
TO	411.85	411.85
PO	3.4580	3.4580
T2	464.80	464.80
ETAR	1.0000	1.0000
P2	5.274	5.274
P22/P2	0.9996	0.9996
M21	0.6395	0.6391
P22	5.272	5.272
B	6.8922	6.8920
PATH	PMIX	PMIX
WB/W2C	0.0020	0.0020
WB	0.	0.
PBD	195.61	195.58
TBD	1448.6	1448.6
WBI	0.120	0.120
PBI	77.36	77.35
TBI	1145.9	1145.9
HPE	0.	0.
PCNF	94.664	94.654
NF	4459.6	4459.2
PCNF*	100.000	99.989
W2*	1253.00	1252.79
W2	474.84	474.76
P23/22	1.7097	1.7099
Z22	0.6627	0.6633
ETAF	0.8561	0.8561
HPFAN	12666.	12667.
RNI22	0.4132	0.4132
SMF	26.42	26.38
M23	0.5500	0.5497
P25P23	1.0000	1.0000
M25P	0.5500	0.5497
AE25P	2557.6	2557.6

	$\Delta\%$ W2C	Δ SFCE
1 #/sec Bleed	2.81	1.33
100 HP	.55	.52

Points 1 + 2
35K/.8/+18 /Mx CL
Sizing Point

NASA SUBSONIC TURB ENGINE DESIGN FOR LOW ENERGY CONSUMPTION
STEDLEC/MF12 (TASK III REFERENCE) CYCLE
NOTE - W2C* = PRINTOUT VALUE * .995
RATING POINTS

CASE	0.
ALT	40000.
MO	0.960
PC	50.00
RC	40.00
FNG-MX	9919.4
SFCGMX	0.7181
FNG-CF	0.
SFCGCF	0.
FNG-PM	9678.4
SFCGPM	0.7360
DELTO	18.00
TO	407.97
PO	2.7200
T2	483.49
ETAR	0.9943
P2	4.893
P22/P2	1.0000
M21	0.6395
P22	4.893
B	-4.0805
PATH	PMIX
WB/W2C	0.0208
WB	0.
PBD	142.98
TBD	1416.2
WBI	2.000
PBI	56.67
TBI	1129.6
HPE	100.0
PCNF	96.546
NF	4489.9
PCNF*	99.996
W2*	1414.25
W2	487.66
P23/22	1.8260
Z22	0.5948
ETAF	0.8470
HPLAN	14256.
RN122	0.3643
SMF	19.02
M23	0.4499
P25P23	1.0000
M25P	0.5649
AE25P	2472.0

NASA SUBSONIC TURB ENGINE DESIGN FOR LOW ENERGY CONSUMPTION
STEDLEC/MF12 (TASK III REFERENCE) CYCLE
NOTE - W2C* = PRINTOUT VALUE * .995
RATING POINTS

CASE	0.
P25P	8.934
P2525P	1.0000
P25	8.934
Q25	1.6073
T25	590.9
M25	0.5650
W25	391.67
P26/25	0.9853
P26	8.803
M26	0.4499
P27/26	0.9976
P27	8.782
M27	0.4499
PS27	7.643
W27	391.67
T27	590.9
Z1C	0.6616
P24/1C	2.5439
W1C*	278.38
W1C	95.99
ETA1C	0.8510
SMB	18.26
HP1C	5664.
P24	12.446
T24	657.4
M24	0.5000
Q24	1.8335
P2C/24	0.9827
AE2D	0.
WB/W24	0.
PS242D	0.
DP/Q2D	0.
P2D/24	0.
W2D	0.
M2D	0.
PS2D	0.
PS25P	7.195
P2C	12.231
T2C	657.4
PCNG	99.999
PCNG*	88.821
NG	9714.
PCNG*M	100.000
WARC2C	0.
W2C	95.99
W2C*	129.85

NASA SUBSONIC TURB ENGINE DESIGN FOR LOW ENERGY CONSUMPTION
STFDLEC/MF12 (TASK III REFERENCE) CYCLE
NOTE = W2C* = PRINTOUT VALUE * .995
RATING POINTS

CASE	0.
P3/P2C	11.9999
SMC	20.33
Z2C	0.5870
ETAC	0.8526
HPC	25191.
RN12C	0.6182
P3/P2	29.9983
P3	146.77
PS3	139.02
T3	1416.2
WARC3	0.
WAR3	0.
W3	90.91
W31	76.47
M3	0.2840
P4/P3	0.9490
WFM	7123.4
ETABM	0.9875
FAR339	0.02588
T39	2933.6
T4	2779.9
WAR4	0.
FAR4	0.02293
P4	139.28
W4	88.29
TFFC	33.42
N/RT4	184.24
DH/T4	0.07291
ETAT	0.8865
HPT	25316.
RNT4	0.4128
P4/P51	4.0620
P51	34.290
T51	2070.1
FAR51	0.02176
WAR51	0.
W51	92.89
M51	0.4800

NASA SUBSONIC TURB ENGINE DESIGN FOR LOW ENERGY CONSUMPTION
STEDLEC/MF12 (TASK III REFERENCE) CYCLE
NOTE - W2C* = PRINTOUT VALUE * .995
RATING POINTS

CASE 0.

P54/51	1.0000
P54	34.290
T54	2057.7
FAR54	0.02145
WAR54	0.
W54	94.24
TFE2TC	124.67
N/RT54	98.98
DH/T54	0.07261
ETA2T	0.9132
HP2T	19920.
RNI54	0.5101
P54/56	3.8944
P56	8.805
T56	1519.4
W56	95.96
M56	0.4400
P58/56	0.9912
P58	8.727
PS58	7.641
M58	0.4500
P59	8.689
M59	0.4719
T59	785.4
W59	487.63
P6/P59	1.0000
FAR8MX	0.00407
WAR8MX	0.
W8-MX	487.63
T8-MX	785.4
P8-MX	8.689
P8P0MX	3.1945
M8-MX	1.0000
V8-MX	1253.7
CF8-MX	0.9860
A8-MX	3005.0
V9-MX	1633.9
CV9-MX	1.0000
CFG-MX	0.9950
FGG-MX	24336.
FD	14417.
FGG-PM	24095.
PC-MX	0.600

EFFECT ON ENGINE EVALUATION

OF DESIGNING FOR AIRCRAFT BLEED & HP

SINGLE ROTATION/ADVANCED WEIGHT

35K/.8/+18 - TRANSCON MISSION

	Engine Sized without Accessory HP and Bleed		Engine Sized with Accessory HP and Bleed	
	TURBOFAN	TURBOPROP	TURBOFAN	TURBOPROP
D_{TIP}, FT	4.28	13.2	4.25	13.2
$W_{2C}\sqrt{\theta}/\delta$, LB/SEC	29.0	25.2	32.1	28
FN INSTALLED, LBS	3530	3610	3530	3610
WB_I, LB/SEC	0	0	1.28	1.28
HP A/C	0	0	160	160
$\Delta SFC_{INSTALLED}$ %	BASE	-13	BASE	-11.7
ΔPRICE, 1000 $	BASE	+57.7	BASE	+53.2
ΔINSTALLED WEIGHT, LBS	BASE	+1200	BASE	+1160
ΔBLOCK WF, %	BASE	-15	BASE	-13.5
ΔDOC, %	BASE	-4	BASE	-3.8

10.8 NOISE

10.8.1 GENERAL

Noise estimates for the turbo-prop configuration were made for the core engine only. The prop noise component in flight was supplied by Hamilton-Standard Co. The overall system noise levels were estimated for two aircraft applications; a domestic transcontinental aircraft and an intercontinental aircraft.

The component noise levels, including core, jet and turbine, were estimated using semi-empirical prediction techniques explained in the following section.

10.8.2 COMPONENT NOISE PREDICTION TECHNIQUES

10.8.2.1 JET NOISE

Static jet noise estimates were based on scale model conical nozzle data scaled to the appropriate size.

10.8.2.2 CORE NOISE

The static core noise was estimated using a semi-empirical prediction technique base on measured engine data. The correlation used in shown in Figure 10.8.1.

10.8.2.3 TURBINE NOISE

Turbine noise levels were estimated using the prediction technique shown in Figure 10.8.2. The levels were corrected for blade passing frequency of the dominant stage.

10.8.3 STATIC-TO-FLIGHT EXTRAPOLATION PROCEDURES

10.8.3.1 JET RELATIVE VELOCITY EFFECTS

The source reduction due to forward flight on the jet component was accounted for assuming no reduction in the forward quadrant and a 60 $\log V_{REL}/V_{JET}$ relationship in the aft quadrant. The particular

assumptions were based on Bertin Aerotrain data for a single conical nozzle configuration.

10.8.3.2 DYNAMIC EFFECT

The effect of forward flight on all components was accounted for by applying a $40 \log\left(\frac{1}{1-M\cos\theta}\right)$ correction factor, ~~refined~~ referred to as dynamic effect. This correction term was indicated by theory and supported by analysis of static-to-flight data comparisons for varying flight velocities. Here θ is the angle between the flight path and the observer.

10.8.3.3 DISTANCE CORRECTION FACTORS

Decay rates as a function of distance were calculated assuming a typical spectrum shape, depending on the type of source (i.e. - jet, core, turbine). The results, indicated below, were used to extrapolate the static 200' sideline levels to the appropriate acoustic ranges for both takeoff and approach.

Source	Decay Rate (ΔPNL Basis)
Jet	$24 \log R_1/R_2$
Core	$25 \log R_1/R_2$
Turbine	$30 \log R_1/R_2$

10.8.3.4 CERTIFICATION GROUND

The prediction techniques used to obtain the static engine noise levels were based on data measured over a hard surface, not typical of a ground surface used during flight noise certification testing. To account for the difference between the two types of surfaces, the following corrections, based on data, were applied:

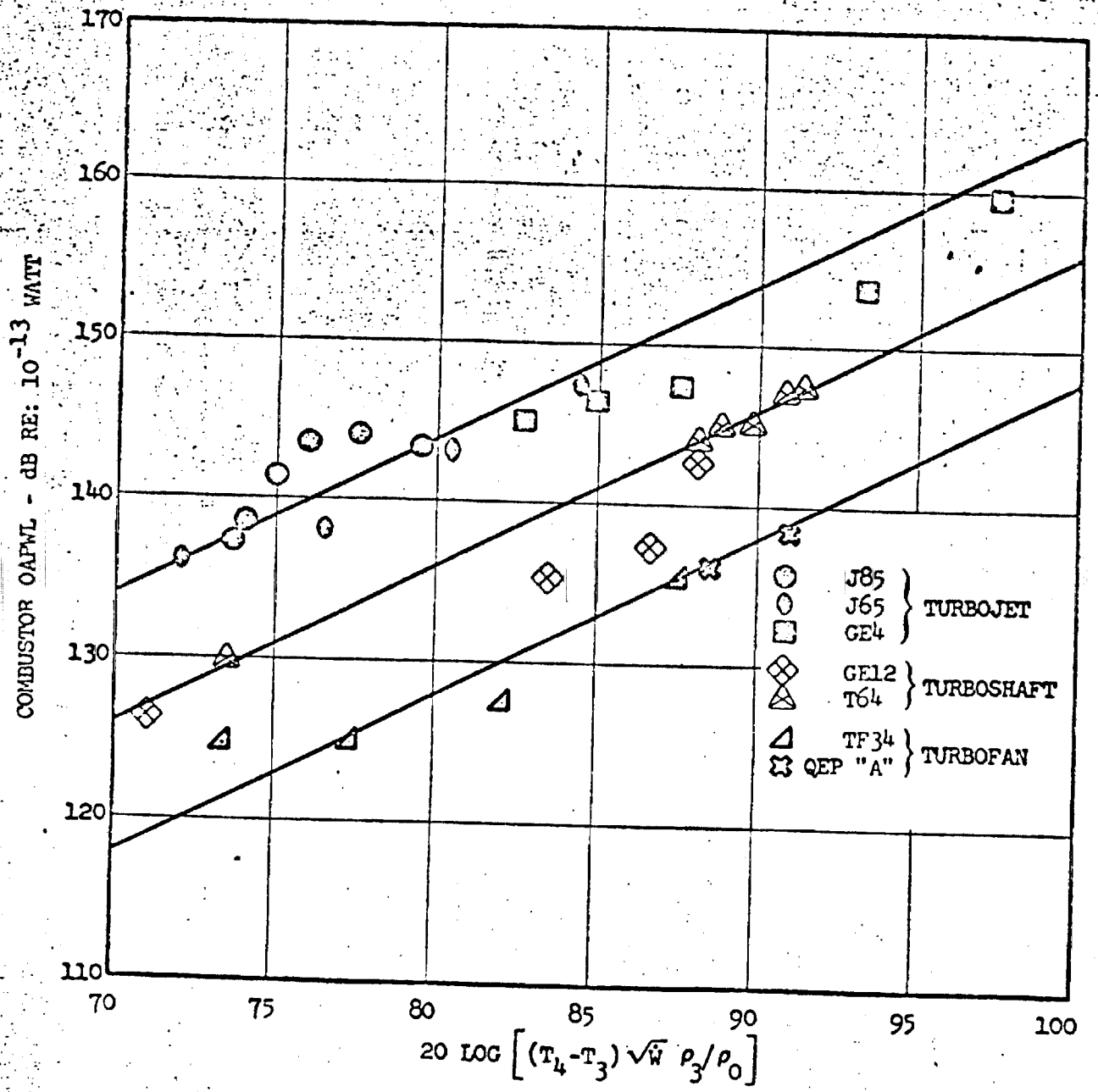
Source	ΔPNL Correction (Static-to-flight)
Jet	-0.5
Core	-0.5
Turbine	-1.5

10.8.4 FLIGHT NOISE ESTIMATES

Flight noise level estimates were obtained using the procedure detailed in $ 10.8.3. The in flight noise prop noise component was supplied by Hamilton-Standard. The resultant component levels for the domestic transcontinental aircraft, at takeoff and approach, are shown in Figures 10.8.3 and 10.8.4. No acoustic treatment was incorporated into the design since the overall system levels were below FAR36 (1969)-10 at approach. The takeoff overall level is controlled by prop noise, thus making reduction of core component noise levels ineffective. A summary chart for both aircraft is shown in Table 10.8 - I.

Figure 10.8.5 shows a comparison of the turbo prop powered aircraft and the STEDLEC baseline overall noise levels at takeoff and approach. The turbo prop is significantly noisier at takeoff, due to the prop noise component while the level at approach is comparable to the STEDLEC baseline. The high level of the turbo prop at takeoff would be extremely difficult to reduce due to the prop noise component, thus making the turbo prop less attractive than the turbofan from an acoustic point of view.

CORE NOISE PREDICTION METHOD

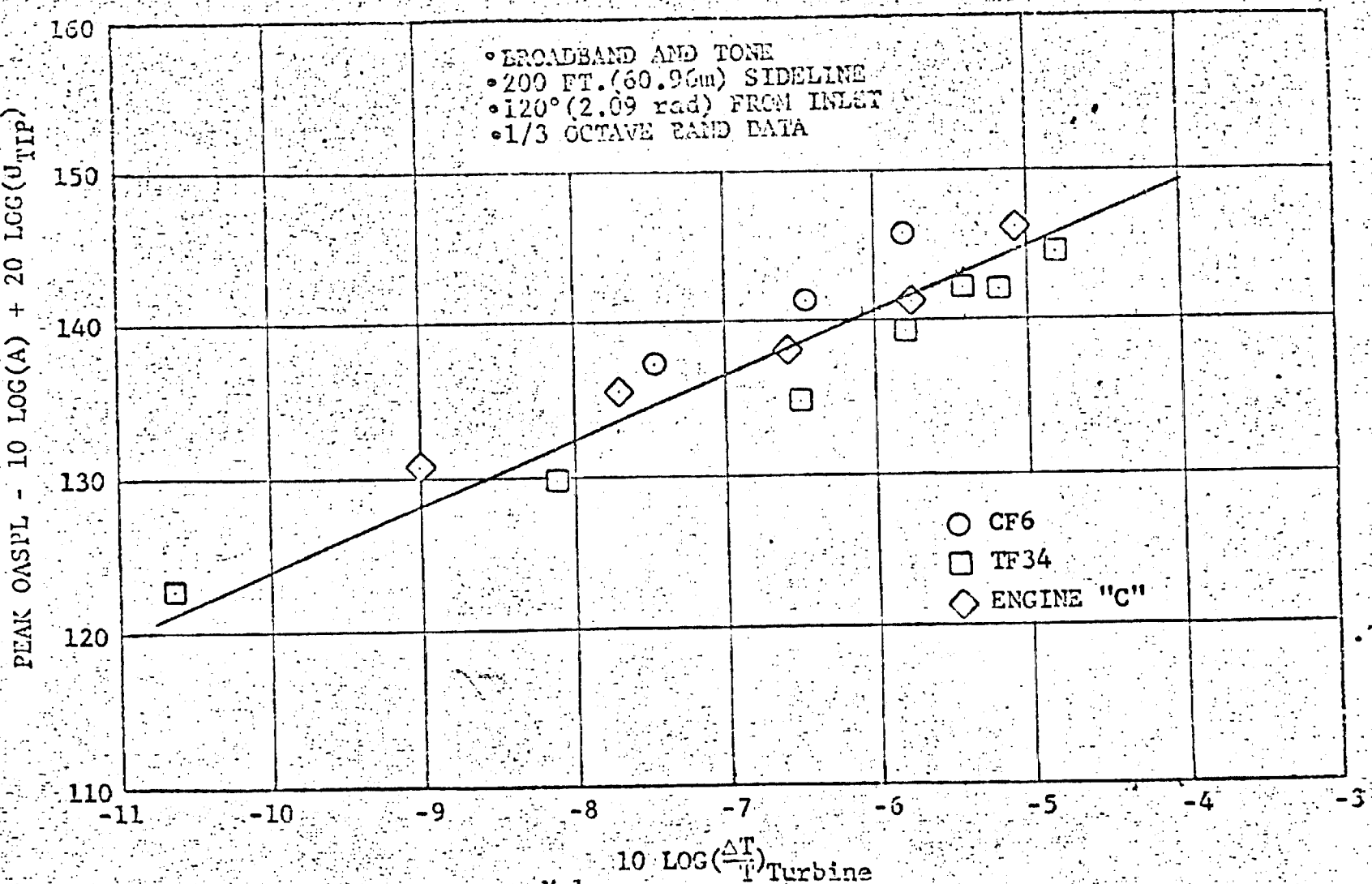


~~FIGURE 3.2-4 POWER LEVEL CORRELATION~~

108.1

Figure 5

1061



$$\frac{\Delta T}{T} = \left[1-\left(\frac{1}{P_R}\right)^{\frac{\gamma-1}{\gamma}}\right] \qquad P_R = (P_{T_0}/P_{S_2})$$

Figure 4 10.8.2

~~FIGURE 9.5~~ TURBINE NOISE CORRELATION. THIS CORRELATION INCLUDES BOTH BROADBAND AND DISCRETE FREQUENCY NOISE. ~~TO BE USED FOR (APPROXIMATE) ESTIMATES.~~

- Approach
- Transcontinental
- M = 0.22

- TOGW = 225,000 lb
- 32% F_N

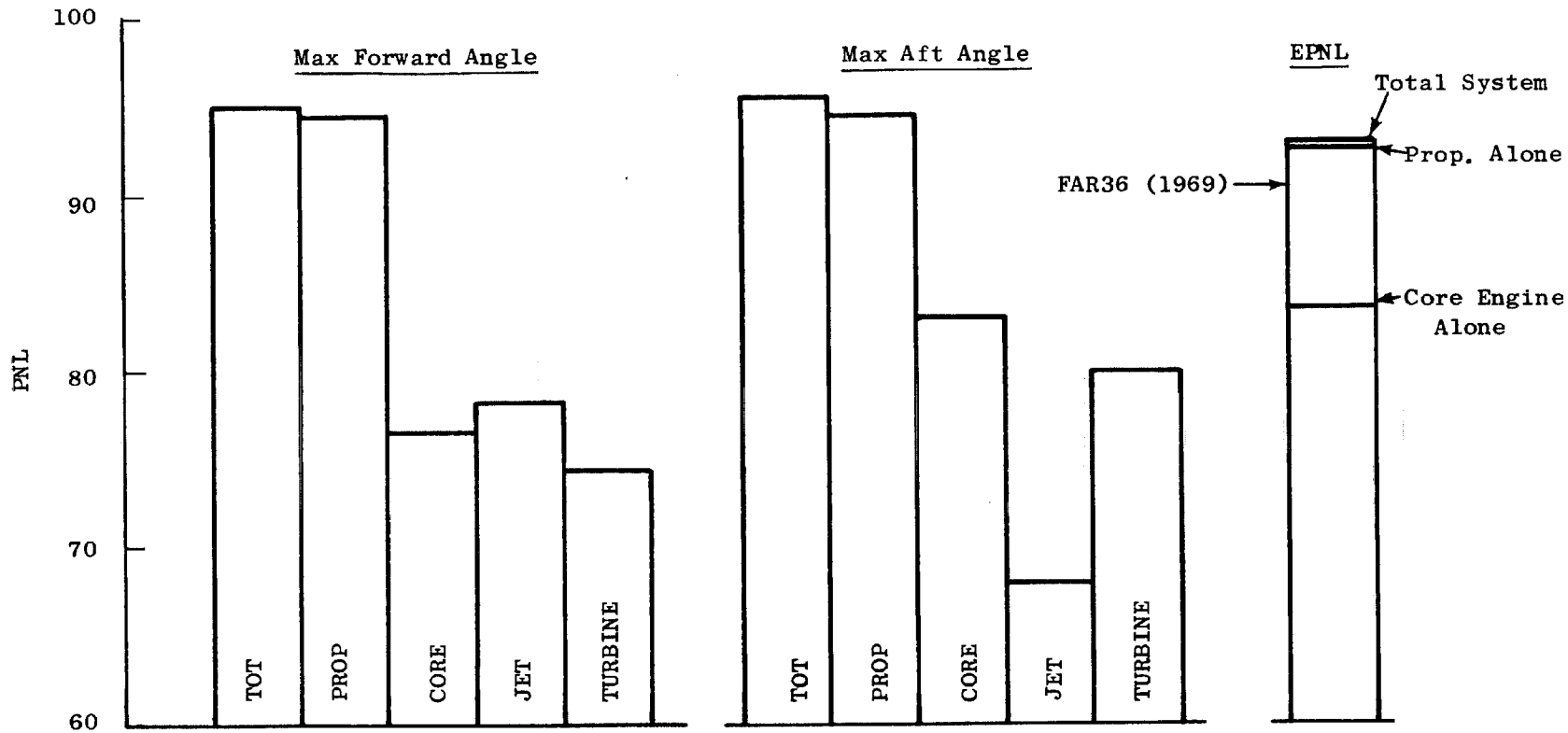


FIGURE 10.8.3

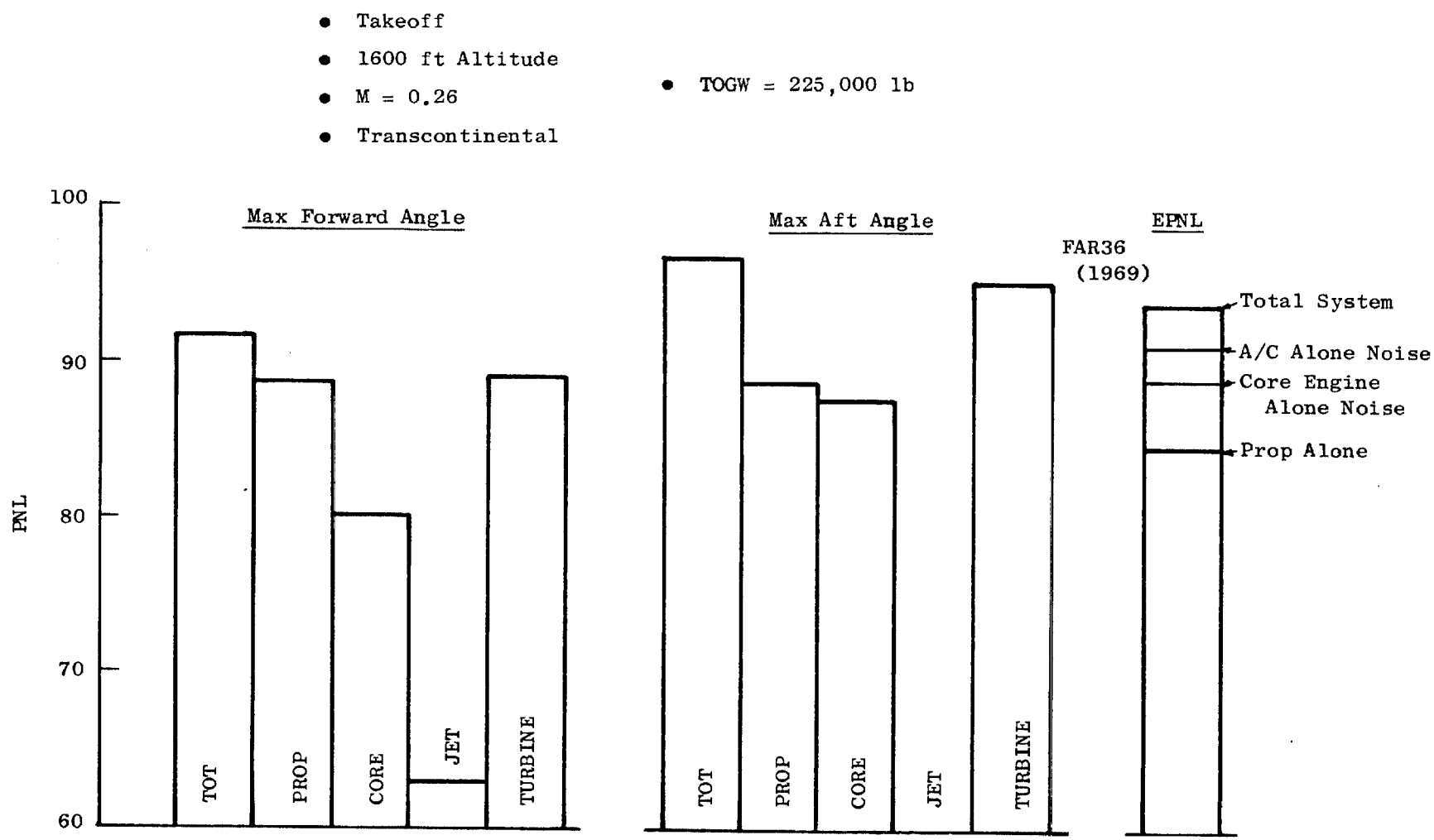

Takeoff
1600 ft Altitude
M = 0.26
Transcontinental
TOGW = 225,000 lb
100
90
80
70
60
PNL
Max Forward Angle
TOT
PROP
CORE
JET
TURBINE
Max Aft Angle
TOT
PROP
CORE
JET
TURBINE
FAR36
(1969)
EPNL
Total System
A/C Alone Noise
Core Engine
Alone Noise
Prop Alone

FIGURE 10.8.4

TABLE 10.8 - I

SUMMARY OF TURBO-PROP NOISE LEVELS (EPNL)

	TAKEOFF	FAR36(1969)-10	APPROACH	FAR36(1969)-10
TRANS. CONTINENTAL (TOGW = 225,000 LB)	93	91	93.7	95.2
INTER. CONTINENTAL (TOGW = 325,000 LB)	95.5	93.6	94.8	96.2

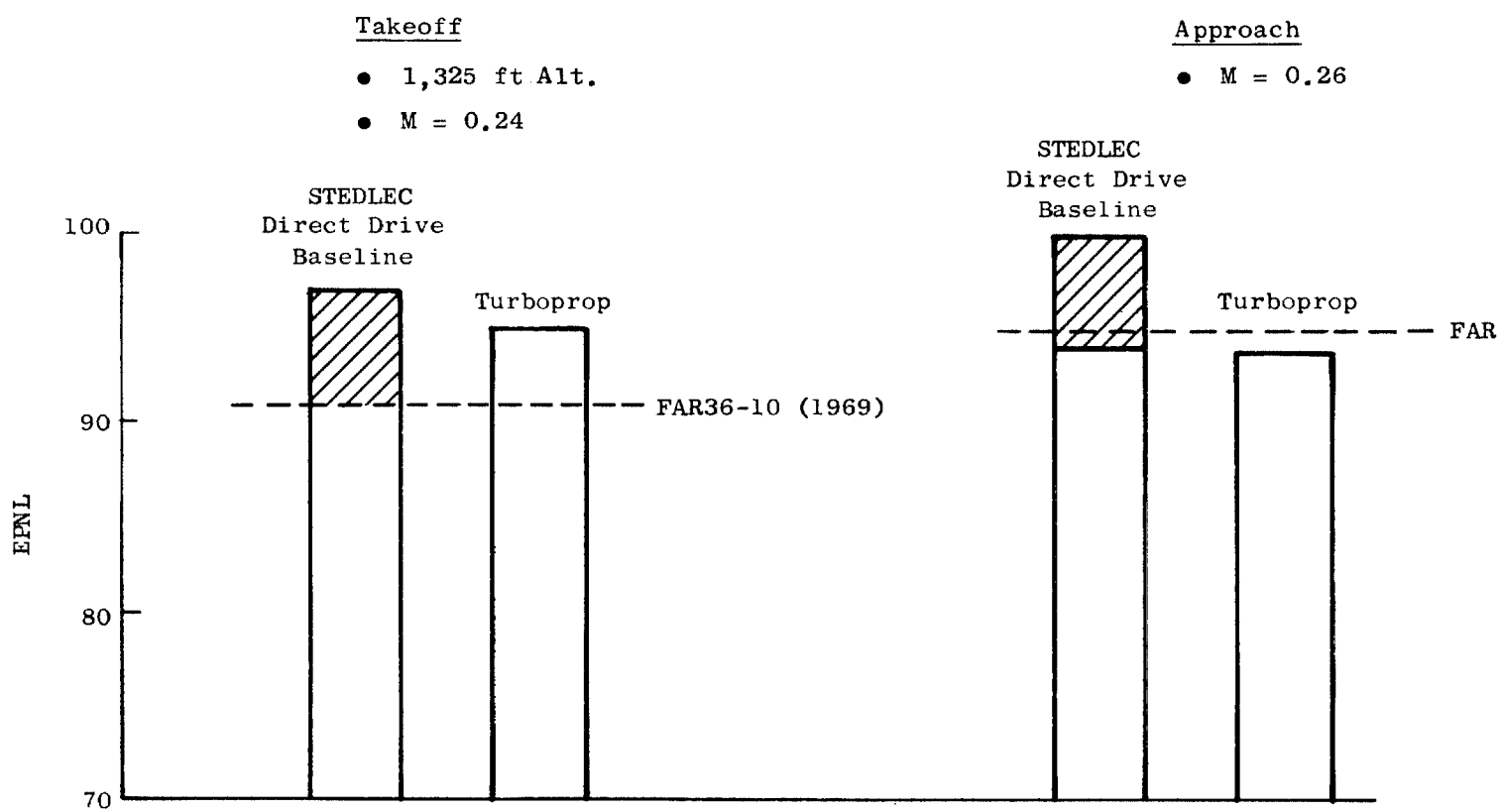

Takeoff
• 1,325 ft Alt.
• M = 0.24
Approach
• M = 0.26
STEDLEC
Direct Drive
Baseline
Turboprop
FAR36-10 (1969)
STEDLEC
Direct Drive
Baseline
Turboprop
FAR
EPNL
100
90
80
70

FIGURE 10.8.5

11.0 Nomenclature

5

NOMENCLATURE USED IN CYCLE ANALYSIS PROGRAM

FN - Net thrust (lbs)
FG - Gross thrust (lbs)
WFM - Fuel flow to combustor (lbs/hr)
SFC - Specific Fuel Consumption ([lbs/hr]/lb of thrust)
FR - Fuel flow to afterburner (lbs/hr) [no afterburner on this engine]
WFR = FG − FN ram drag (lbs)
FNW2 = FN/W2 Net thrust per lb of airflow (lbs of thrust/[lb/sec])
FGW2 = FG/W2 Gross thrust per lb of airflow "
WFT = Total fuel flow

PHYSICAL QUANTITIES

P - Total pressure (psia)
PS - Static pressure (psia)
T - temperature (°R)
M - mach number
W - flow (lbs/sec)

VARIABLES ARE MADE UP OF A PHYSICAL QUATITY SYMBOL FOLLOWED BY A LOCATION SYMBOL, AND IN SOME CASES A SUFFIX, FOR EXAMPLE:

PS6F = PRESSURE IN BYPASS STREAM IN MIXING PLANE
T4T = TOTAL TEMPERATURE AT HPT INLET, °R.
ETC.

LOCATIONS [SEE ALSO FIGURE 1]

0 - Ambient outside engine
2 - At engine intake
3F - fan tip exit
3A - booster hub exit
2C - HP compressor inlet
3C - HP compressor exit
4T - HP turbine inlet
5T - HP turbine exit
4V - LP turbine inlet
5V - LP turbine exit
6 - Mixing plane
7 - Tailpipe entrance
72 - Tailpipe exit
8 - Nozzle throat
9 - Aft of engine

SUFFIXES

F - fan
E - core

NOMENCLATURE USED IN CYCLE ANALYSIS PROGRAM (CONT'D)

OTHER FLOWS

WK2 - corrected flow at engine inlet (lbs/sec)
WK2C - corrected flow at HP compressor inlet (lbs/sec)
W31C - flow at HP compressor exit. (lbs/sec)
WK4T - flow function at HP turbine inlet ([lbs/sec]$\sqrt{°R}$/psia)
WK4V - flow function at LP turbine inlet. ([lbs/sec]$\sqrt{°R}$/psia)

PRESSURE RATIOS

P2PO = P2/PO
P3P2F = P3F/P2 fan tip pressure ratio
P3P2A = P3A/P2 fan hub + booster pressure ratio
P3P2C = P3C/P2C compressor pressure ratio
P3CP2 = P3C/P2 overall pressure ratio
P4P5T = P4T/P5T HPT pressure ratio ← P4T P3C - combustor pressure ratio
P4P5V = P4V/P5V LPT pressure ratio
P6EP5 = P6E/P5V
P7271E = P72E/P7E
P872E = P8E/P72E
P8EPO = P8E/PO

EFFICIENCIES

ETACYC - Overall engine efficiency
ETAP - Propulsive efficiency
ETAR - Ram recovery efficiency
ETF - Fan efficiency
ETA - Fan + booster efficiency
ETC - HP Compressor efficiency
ETABM - Main combustor efficiency
ETT - HPT efficiency
ETV - LPT efficiency
ETABE - Afterburner efficiency

ENTHALPIES

DHT4T - change in enthalpy across HPT / T4T (Btu/°R)
DHT4V - change in enthalpy across LPT / T4T (Btu/°R)

NOMENCLATURE USED IN CYCLE ANALYSIS PROGRAM (CONT'D)

OTHER

CFG8E - Gross thrust coefficient
CF8E - Exhaust Nozzle flow coefficient
ETAK - conversion efficiency
ETAOV - overall efficiency
BPR - Bypass ratio
P2CP3A = P2C/P3A
UNHPT - unbalanced shaft horsepower of HPT (HP)
P4VP5T = P4V/P5T
LHV - Lower heating value of fuel (Btu/lb)
WC5TNC - fraction cooling & parasitic flow reentering at post-HPT (% WK2)
V8E - Velocity at nozzle throat (ft/sec.)
A9A8E - Area ratio for CD nozzle
A8E - Area at engine nozzle throat (in^2)
V9EXE - externally expanded jet velocity (ft/sec.)
UNHPV - unbalanced shaft horsepower of LPT (HP)
WC5VWC - fraction cooling & parasitic flow reentering at post-LPT (% WK2)

TURBINE AERO PROGRAM NOMENCLATURE

TTØ – total temperature
PTØ – total pressure
MØ – Mach number
} At station Ø (Nozzle inlet)

PS1 – static pressure
PTS1 = PTØ/PS1
TS1 – static temperature
ALFA – angle of flow from axial
V1 – velocity of flow
M1 – mach number of flow
CZ1 – axial component of flow velocity
CU1 – tangential component of flow velocity
ZIN – incompressible Zweifel nbr. (tangential force coefficient)
FNA – axial force per unit nozzle height
FNT – tangential force per unit nozzle height
} At station 1R (Nozzle exit)

PTB – Total pressure relative to the bucket
TTB – Total temperature relative to the bucket
BET1 – angle of flow from axial relative to bucket
R1 – velocity of flow relative to bucket
MR1 – mach number of flow relative to bucket
W1 – wheel speed
} at station 1 (Bucket inlet)

PT2 – Total pressure
PS2 – Static pressure
PTS2 = PTØ/PS2
TT2 – Total temperature
TF – Test factor
TS2 – static temperature
BET2 – angle of flow leaving bucket relative to bucket
DLBA – Turning angle
RX – Reaction
V2 – velocity of flow
R2 – velocity of flow relative to bucket
MR2 – Mach number of flow relative to bucket
W2 – wheel speed
} at station 2 (Bucket exit)

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TURBINE AERO PROGRAM NOMENCLATURE (CONT'D)

CZ2 - axial component of flow velocity
CU2 - tangential component of flow velocity
SWFL - swirl angle.
MF - Axial velocity Mach number
ZIB - Incompressible Zweifel nbr.
FBA - axial force per unit bucket height
FBT - tangential force per unit bucket height.
PSI - loading parameter
W/U0 - velocity ratio.

} at station 2 (Bucket exit

ETATT - total efficiency
ETATS - static efficiency

Cooling Analysis Program - Nomenclature

T3 - Compressor discharge temperature, (°R)
F/A RATIO - Fuel to air ratio
T4 - Turbine stage 1 nozzle exit average temperature, (°R)
W4 - " " " " flow, (lb/sec)
PFI - Combustor pattern factor
PDFI - Combustor profile factor
DTADD - Design adder, (°R)
W4/W2 - W4 / Core inlet air flow
TC - bucket or nozzle cooling air temperature, (°R)
TB - allowable airfoil bulk temperature, (°R)
%WC - cooling flow, (% of W_{2c})
C = .0567
HA/WCP - heat transfer coefficient × airfoil area / gas flow × coolant specific heat
N - no. of airfoils
ZI PTCH - Incompressible Zweifel number at pitch
DP - Pitch diameter, (in)
HT-S - Height of airfoil, suction side (in)
HT-P - " " " , pressure side (in)
P - airfoil perimeter
AX-W - axial width
B1 - Inlet gas angle (degrees)
B2 - Exit gas angle (degrees)
K - Gas heat conductivity, [(Btu/hr-ft²) / (°R/ft)]
CPC - Coolant specific heat (Btu/lb°R)
PR NO - Prandl Number
VISC - Gas viscosity, (lb/sec-ft)
RE S - Suction side Reynolds number
RE P - Pressure side Reynolds number
WG - W4

Nomenclature - Weight & Cost & Drag programs

T_{41} = T_4 at T/O

P_3/P_2 = Overall pressure ratio at Max CI.

W_{12R} = W_2^* = Total corrected engine flow

W_{25R} = W_{2c}^* = Corrected core flow

AITES & CLAES -

LINLET - AXIAL LENGTH FROM NACELLE INLET TO FAN

DHL - NACELLE INLET DIAM.

D - DRAG

COMP RF - COMPRESSOR REAR FRAME

C+A - CONTROLS & ACCESSORIES

Nomenclature - Profit Analysis Program

DEL = Δ

MMH - MAINTENANCE MAN HOURS

MMA - MAINTENANCE MATERIALS

FL HR - FLIGHT HOURS

NAC - NACELLE

SFC - SPECIFIC FUEL CONSUMPTION

INIT - INITIAL

REP - REPLACEMENT

WR2C - CORRECTED TOTAL ENGINE AIRFLOW

DOC - DIRECT OPERATING COST

ROI - RETURN ON INVESTMENT

TOGW - TAKE OFF GROSS WEIGHT

WF - FUEL FLOW

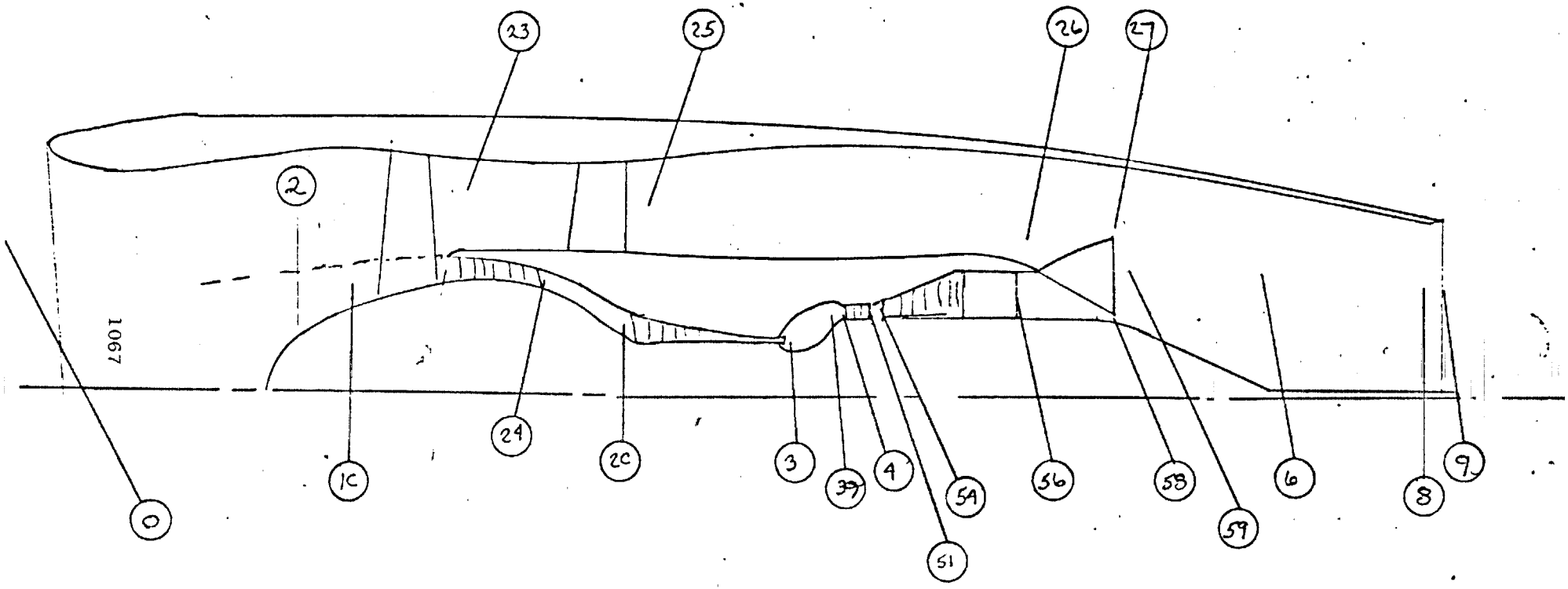
Batch ~~MF12~~ CYCLE NOMENCLATURE

Alt	Altitude, ft
M	Mach Number
P	Pressure, Psia
W	Flow, lb/sec
T	Temperature, ^{o}R
DELTO	To-Tstd day
ETAR	Ram Recovery
B	Bypass Ratio
FNG MX	Fully Mixed Net Thrust, lbs
SFC MX	Specific Fuel Consumption Based on FNG MX lbm/hr/lb
FNG-PM	Partially Mixed Net Thrust, lbs
SFC-PM	Specific Fuel Consumption Based on FNG PM
PCNF	Fan Physical Speed, %
NF	Fan Physical Speed, RPM
ECNF*	Fan Corrected Speed
ETAF	Fan Tip Adiabatic Efficiency
Q	Dynamic Pressure
ETAIC	Fan Hub + Booster Adiabatic Efficiency
PCNG	Core Physical Speed, %
NG	Core Physical Speed, RPM
PCNG*	Core Corrected Speed, %
WFM	Fuel Flow, lb/hr
ETABM	Burner Efficiency
TFFC	HP Turbine Flow Function
NRT4	HP Turbine Corrected Speed

*Indicates a corrected flow

MF12 CYCLE NOMENCLATURE (Cont.)

DH/T4	HP Turbine Energy Function
TFF2TC	LP Turbine Flow Function
N/RT54	LP Turbine Corrected Speed
DH/T54	LP Turbine Energy Function
V	Velocity, ft/sec
CF	Flow Coefficient
AE	Effective Area, in^2
CV	Velocity Coefficient
FGG-MX	Mixed Gross Thrust, lb
FD	Ram Drag
FGG-PM	Partial Mixed Gross Thrust, lb
PC-MX	Mixing Effectiveness



Station Designations

Figure 5.5.15-1

NOMENCLATURE

Covers additional symbols in text, curves and tables of Tasks I, II and III Sections.

DHL	Inlet highlight diameter, meters (feet)
D_{Max}	Nacelle Maximum diameter, meters (feet)
D_T	Fan tip diameter, meters (feet)
ϵ	Regenerator effectiveness
Fn	Net Thrust, newtons (lbs)
Fm	Installed net thrust (net thrust-drag), newtons (lbs)
HEX	Heat Exchanger
L	Inlet Length, meters (feet)
MxCl	Maximum climb rating
MxCr	Maximum cruise rating
η	Efficiency
N_B	No. of fan blades
P/P	Pressure ratio
T_4	Turbine rotor inlet temperature, ^oC (^oF) or ^oK (^oR) absolute
W_c	Turbine cooling flow, kg/sec (lb/sec)
W_{2C}	Core compressor flow, kg/sec (lb/sec)
V_9	Primary jet velocity, meters/sec (ft/sec)
V_{29}	Fan jet velocity, meters/sec (ft/sec)
PAX	Passenger
W_{EI}	Weight of installed engine, kg (lbs)
SFC_I	Installed Specific Fuel Consumption, kg/newton-hr (lb/lb-hr)
PI	$\frac{\text{Replacement Parts}}{\text{New Parts}}$ Cost Ratio
Ni76XB	Advanced Directional Solidified Nickel alloy
T/O	Take-off
W_f	Fuel Flow, Kg/sec (lb/hr)
U_T	Tip Speed
$U_T/\sqrt{\theta 2}$	Corrected Tip Speed, meters/sec (feet/sec)

NOMENCLATURE (Cont.)

r_H	Hub Radius, meters (feet)
r_T	Tip Radius, meters (feet)
r/r	Radius Ratio
U_H	Corrected hub speed - corrected to booster rotor
$\sqrt{\theta_2}B$	inlet conditions, meters/sec (ft/sec)
C_L/L	Clearance / Blade Height
$\bar{U}_p$	Pitch speed
$\bar{\Psi}_P$	Mean loading of turbine stage
MA754	Dispersion Strengthened Alloy
MARM509	High Temperature Nickel alloy
W^*/AA	Corrected flow per unit Annulus area
W_f^*	Corrected fuel flow
η_{mix}	Mixing effectiveness

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