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Aircraft High Bypass Fan Engine Performance

Robert Salmon

March 1994

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16. Abstract

The purpose of this Technical Note is to discuss the performance characteristics of high bypass fan engines. The performance of a CF6-6 type fan engine is compared to two types of modified engines based on the CF6-6 type design. The fully modified engine has an increased bypass ratio (5.8:1 to 9.0:1) and a variable fan pressure ratio. At takeoff power the modified engine produces the rated takeoff thrust of the standard CF6-6 engine with a 32 percent improvement in thrust specific fuel consumption (TSFC) and a turbine inlet temperature 460 °F lower than the standard. At maximum continuous cruise power at 35000 feet and Mn 0.8 the improvement in TSFC would be 18.8 percent and the turbine inlet temperature would be 270 °F lower than the standard CF6-6 engine. The advantage in performance obtained by the increased bypass ratio and variable geometry fan more than offset the increase in the engine weight that would result from these changes.

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EXECUTIVE SUMMARY

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INTRODUCTION

Over the last 40 years the gas turbine engine for aircraft applications has experienced remarkable advances. The earliest engines were heavy and inefficient. A typical aircraft engine thrust-to-weight ratio was in the 0.8 to 0.9 range with a specific fuel consumption in the 1.2 to 1.3 (pounds fuel per hour per pound of thrust) range. Today, with the high bypass fan engines, the thrust-to-weight ratio is in the 5.5 to 7.0 range with specific fuel consumptions at sea level static (SLS) takeoff power ranging from 0.32 to 0.45 pounds fuel per hour per pounds of thrust.

These advances can be credited to improvements in component efficiencies, combustor design, development of high temperature alloys, and the development of the high bypass fan. The biggest advance resulted from the incorporation of the high bypass fan in the engine cycle.

This technical note discusses the bypass fan engine cycle. The primary point of the discussion is the investigation of the potential improvement in energy efficiency of an engine with a rematch of the engine components. A rematch, in this instance, would imply varying the bypass ratio (BPR), the fan pressure ratio (FPR), and the turbine inlet temperature.

DESCRIPTION OF PROCEDURE

The basic engine (called Standard) for the analysis was a CF6-6 type high bypass gas turbine. The engines were assigned the specifications shown in table 1.

TABLE 1. ENGINE DATA

Engine Type	Altitude	Mach. No.	Compressor Pressure Ratio (CPR)	Fan Pressure Ratio (FPR)	Bypass Ratio (BPR)	Core Air Flow (lbs./sec.)
Standard	Sea level	0	24.7	1.58:1	5.8:1	188.84
Partially Modified Engine	Sea level	0	24.7	1.58:1	9.0:1	167.2
Fully Modified Engine	Sea level	0	24.7	1.32:1	9.0:1	188.84
Standard	35,000'	0.8	29.3	1.58:1	5.8:1	55.37
Partially Modified Engine	35,000'	0.8	29.3	1.58:1	9.0:1	49.02
Fully Modified Engine	35,000'	0.8	29.3	1.58:1	9.0:1	55.37

The assumed component efficiencies were 0.87 for compressors and fans, 0.9 for turbines, and 0.97 for nozzles. In calculating the thrust, the nozzles were always considered to be full expansion types. In order to simplify the cycle calculations, the value of the specific heat ratio (γ) was assumed to be 1.4 in all cases. This compromise does not have a major effect on the results inasmuch as the 1.4 value is applicable to the fan calculations which comprise approximately 75 percent of the gross thrust produced by the engine and the impact of this compromise is felt equally by the standard and the modified engines. All of the calculations are based on the values tabulated in the Keenan & Kaye Gas Tables (reference 1).

RESULTS AND DISCUSSION

A summary of the significant results obtained from the calculations are shown in tables 2 and 3, and a more complete tabulation of the results is in the appendix. Comparing the TSFC values of the standard and modified engines at the same level of thrust, i.e., run numbers 1, P/M3, and F/M3, the TSFC improvements for P/M3 and F/M3 are 16 percent and 32 percent respectively. The turbine inlet temperatures are 60°F and 460°F lower at the rated power conditions for the partially modified and fully modified engines respectively at this condition.

TABLE 2. SEA LEVEL STATIC DATA

Run No.	Engine Type	Compressor Pressure Ratio (CPR)	Fan Pressure Ratio (FPR)	Bypass Ratio (BPR)	Turbine Inlet Temp T_4 (°R)	Net Thrust (lbs.)	Thrust Specific Fuel Consumption (TSFC)
1	Standard	24.7:1	1.58:1	5.8:1	2940	43303	0.399
2	Standard	24.7:1	1.58:1	5.8:1	2800	41610	0.366
3	Standard	24.7:1	1.58:1	5.8:1	2750	40828	0.361
4	Standard	24.7:1	1.58:1	5.8:1	2700	40126	0.351
P/M1	Part. Mod. Eng.	24.7:1	1.58:1	9.0:1	3100	50276	0.339
P/M2	Part. Mod. Eng.	24.7:1	1.58:1	9.0:1	2940	47224	0.3237
P/M3	Part. Mod. Eng	24.7:1	1.58:1	9.0:1	2880	43302	0.335
F/M1	Fully Mod. Eng.	24.7:1	1.32:1	9.0:1	2940	50438	0.342
F/M2	Fully Mod. Eng.	24.7:1	1.32:1	9.0:1	2800	45451	0.320
F/M3	Fully Mod. Eng.	24.7:1	1.32:1	9.0:1	2500	43734	0.2705

The partially modified engine runs into a lower limit for the turbine inlet temperature (T_4) at 2880 °R. This is because the high bypass ratio and the standard engine rated fan pressure ratio extracts all the core engine pressure energy at that temperature. If the engine went to a lower T_4 it could not operate due to a negative core exhaust pressure. In order for the partially modified engine to produce at the rated thrust of the standard engine (43303 pounds), the core airflow would have to be reduced to 167.2 pounds per second, an 11.47 percent reduction. Figures 1 and 2 illustrate this feature of the partially modified engine.

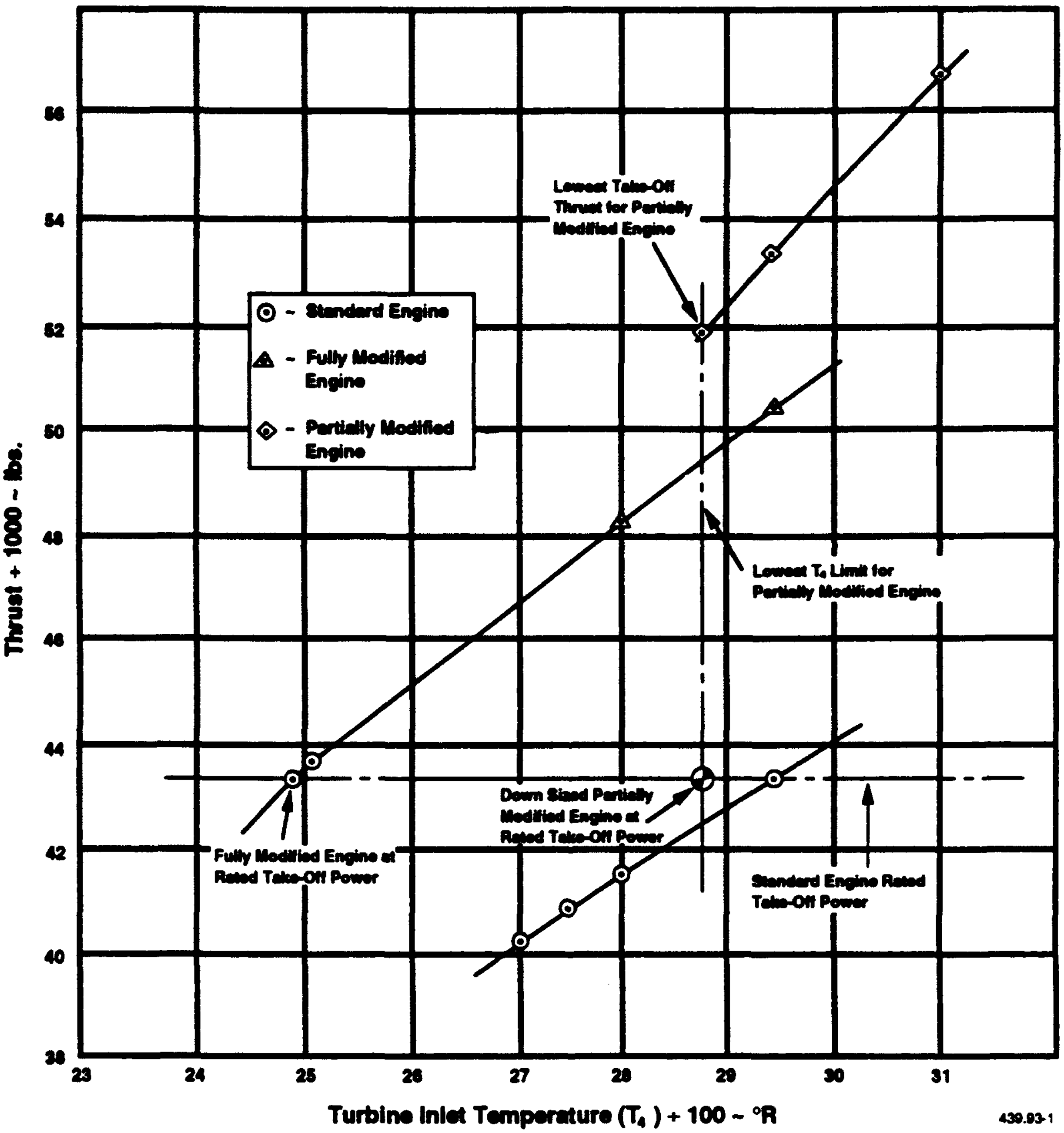

FIGURE 1. TAKEOFF POWER THRUST VERSUS TURBINE INLET TEMPERATURE

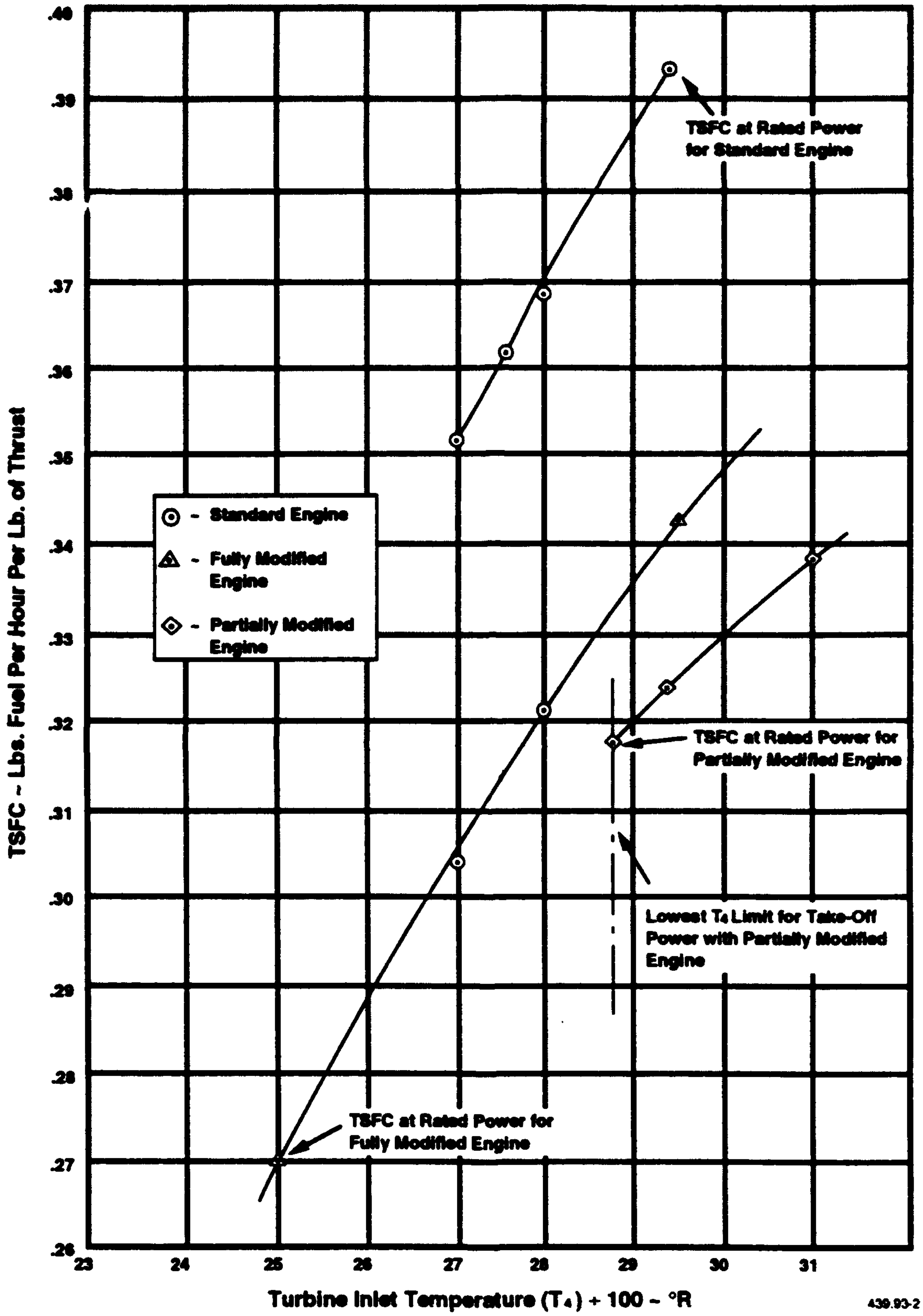

FIGURE 2. SEA LEVEL STATIC TAKEOFF POWER TURBINE INLET TEMPERATURE VERSUS TSFC

ALTITUDE PERFORMANCE.

The comparative performance of the three types of engines at altitude are as shown in table 3. The flight conditions are 35,000 feet, Mn 0.8, and maximum continuous cruise power. Comparing the TSFC values of the standard and modified engines at the same level of thrust, for example, run numbers 101, P/M 105, and F/M 111, the TSFC improvements for P/M 105 and F/M 111 are 13.4 percent and 18.8 percent respectively. The turbine inlet temperatures are 40°F and 270°F lower at the rated power conditions for the partially modified and fully modified engines respectively.

TABLE 3. MAXIMUM CONTINUOUS CRUISE POWER AT ALTITUDE (35,000' & Mn 0.8) STANDARD RATED THRUST, 7388 POUNDS

Run Numbers	Engine Type	Compressor Pressure Ratio (CPR)	Fan Pressure Ratio (FPR)	Bypass Ratio (BPR)	Turbine Inlet Temp. T_4 (°R)	Net Thrust (lbs.)	Thrust Specific Fuel Consumption (TSFC)
101	Standard	29.3:1	1.58:1	5.8:1	2940	7388	0.7392
102	Standard	29.3:1	1.58:1	5.8:1	2800	7011	0.7037
103	Standard	29.3:1	1.58:1	5.8:1	2700	6714	0.6768
P/M 104	Partially Modified	29.3:1	1.58:1	9.0:1	2940	7480	0.6463
P/M 105	Partially Modified	29.3:1	1.58:1	9.0:1	2900	7388	0.6400
P/M 106	Partially Modified	29.3:1	1.58:1	9.0:1	2800	7029	0.6213
P/M 107	Partially Modified	29.3:1	1.58:1	9.0:1	2700	6660	0.606
F/M 108	Fully Modified	29.3:1	1.58:1	9.0:1	2940	8450	0.6463
F/M 109	Fully Modified	29.3:1	1.58:1	9.0:1	2800	7940	0.6213
F/M 110	Fully Modified	29.3:1	1.58:1	9.0:1	2700	7524	0.6039
F/M 111	Fully Modified	29.3:1	1.58:1	9.0:1	2670	7388	0.6000

Figures 3 and 4 present the altitude performance of the three types of high bypass engines. The partially modified engine, for example, 9.0:1 bypass ratio, reduced core airflow, and lower T_4 develops the same thrust as the standard engine at the flight condition but at a TSFC of 0.64 versus 0.7392 for the standard engine. The lower core airflow is required in order to make a direct comparison of the engines at both sea level static (SLS) and at the altitude flight condition. The fully modified engine at altitude cruise has a 9.0:1 bypass ratio, 1.58:1 fan pressure ratio, and 55.37 pounds of air per second core airflow and yields a TSFC of 0.60 (run number F/M 111) at a turbine inlet temperature of 2670°R.

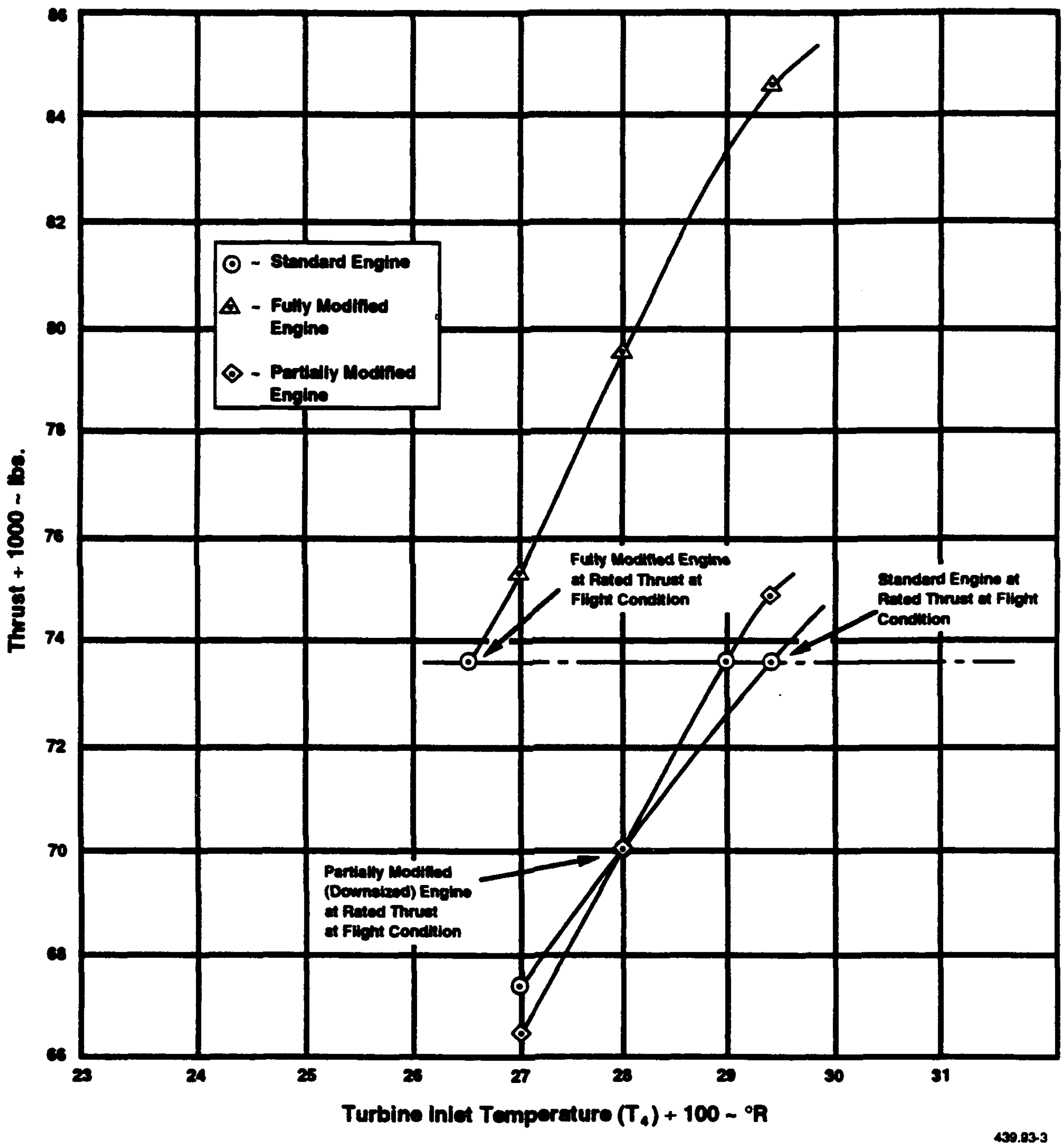

FIGURE 3. ALTITUDE DATA, NET THRUST VERSUS T_4

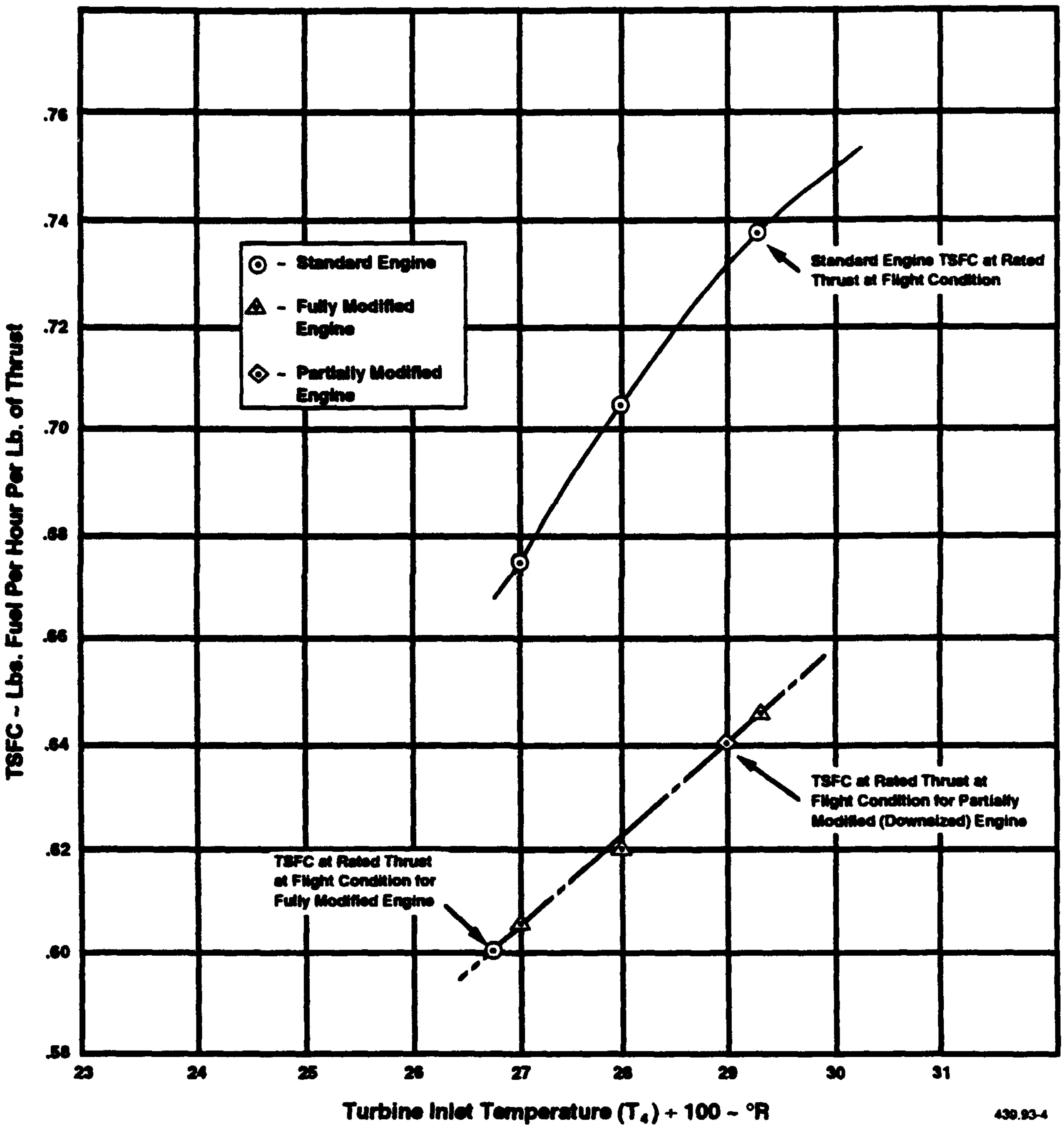

FIGURE 4. ALTITUDE DATA, TSFC VERSUS T_4

The fully modified engine described in this report would moderately increase the aerodynamic drag and moderately increase the engine weight but would more than compensate for this by greatly improving specific fuel consumption and reducing the engine operating temperatures. One of the major factors affecting engine life is the temperature level at which the engine operates. By lowering this level in the fully modified engine, engine hot section life would be increased.

The greatest improvement in TSFC takes place at the zero velocity and low mach number range because a large portion of the increase in gross thrust, resulting from a low fan pressure ratio and a high bypass ratio, is dissipated by the large increase in ram drag at high mach numbers. This is apparent when looking at run numbers 101 and F/M 111. Run number 101, a standard engine run at 35,000 feet, Mn 0.8, produces 16476 pounds of gross thrust with a ram drag of 9088 pounds. The net thrust is 7388 pounds with a TSFC of 0.7392. Run number F/M 111, a fully modified engine with a high BPR and a fan pressure ratio of 1.58:1, produces 20806 pounds of gross thrust, a ram drag of 13,418 pounds, a net thrust of 7388 pounds, and a TSFC of 0.60[illegible].

The improvements in overall engine efficiency obtained by rematching components and a variable geometry fan indicates that a more comprehensive analysis of the potential improvements derived from rematching is in order.

One aspect of the rematching, increasing the bypass ratio, would necessitate an increase in the fan diameter and a reduction in fan revolutions per minute (rpm). An increase in the bypass ratio would change total airflow at sea level static takeoff power for the fully modified engine from 1284 pounds per second to 1888 pounds per second. If the standard engine has an 8-feet-diameter fan with a 1.5-feet-diameter bullet nose, the air entering the fan has a velocity of 0.33 Mn. Using this same mach number for the larger (1888 pounds per second) air flow, the fan diameter would be 9.53 feet, assuming the same size bullet nose. The core components, for example, the compressors, combustor, high and medium pressure turbines, and exhaust nozzle would be approximately the same for the standard and the fully modified engine. The low pressure turbine of the fully modified engine would require extra turbine stages to provide the necessary power to the fan at the altitude maximum continuous cruise power condition.

ECONOMY.

The improved engine efficiency shown in tables 2 and 3 would have a major impact on an airline's annual fuel bill. An example of the potential savings can be shown by comparing the standard and the two types of modified engines' performance in a typical flight.

Assume a typical flight consists of 4 minutes at takeoff power and a 12-minute climb at 90 percent takeoff power, 3 hours at maximum continuous cruise and 15 minutes at 40 percent takeoff power for letdown and landing. If the partially modified engine and the fully modified engine produce the same thrust as the standard engine at the aforementioned four conditions and both modified engines have TSFC's for these conditions as shown in tables 2 and 3, the fuel consumed during the flight would be as shown in table 4.

TABLE 4. FLIGHT PROFILE DATA

Alt/Mn	Engine	Power Setting	Time @ Flight Cond.	T_4 (°R)	Net Thrust (lbs.)	Fuel per Engine per Flight (lbs.)	Fuel Saved (lbs.)	Gallons Saved
Sea Level Static	Standard	Takeoff	4 mins.	2940	43303	1152	—	—
Sea Level Static	Partially Modified	Takeoff	4 mins.	2880	43303	967	185	28.45
Sea Level Static	Fully Modified	Takeoff	4 mins.	2480	43303	781	371	57.1
Sea Level Climb	Standard	Climb at 90 Percent Takeoff Power	12 mins.	—	38972	3110	—	—
Sea Level Climb	Partially Modified	Climb at 90 Percent Takeoff Power	12 mins.	—	38972	2611	499	76.8
Sea Level Climb	Fully Modified	Climb at 90 Percent Takeoff Power	12 mins.	—	38972	2108	1002	154
35000 ft Mn 0.8	Standard	Maximum Continuous Cruise	3 hrs.	2940	7388	16384	—	—
35000 ft Mn 0.8	Partially Modified	Maximum Continuous Cruise	3 hrs.	2900	7388	14185	2199	338.3
35000 ft Mn 0.8	Fully Modified	Maximum Continuous Cruise	3 hrs.	2680	7388	13387	2997	461.8
Sea Level Low Mn	Standard	40 Percent Takeoff Power	15 mins.	—	17321	1727	—	—
Sea Level Low Mn	Partially Modified	40 Percent Takeoff Power	15 mins.	—	17321	1451	276	42.5
Sea Level Low Mn	Fully Modified	40 Percent Takeoff Power	15 mins.	—	17321	1171	556	85.5
	Partially Modified Engine	Total Fuel Reduction per Flight per Engine					3159	486
	Fully Modified Engine	Total Fuel Reduction per Flight per Engine					4926	758

The fully modified engine when operating at the levels described for this 3 1/2 hour flight would consume 22 percent less fuel than the standard engine. The partially modified engine would consume 16.5 percent less fuel during the flight.

COMPARISON OF COMPRESSOR WORK FOR STANDARD AND MODIFIED ENGINES.

In analyzing the cycle calculations the fact that the major driving force in improving engine efficiency is derived from the low fan pressure ratio and the high bypass ratio at sea level takeoff power and the high bypass ratio alone at altitude. The reason for this improvement can be explained by analyzing the mathematics of the thrust.

Full expansion jet thrust = $W/g\ (V_j)$

where: W = airflow; pounds per second

g = gravitational constant; 32.2 ft./sec^2

V_j = velocity of exhaust jet; feet per second

and $$V_j = \sqrt{2gJ\,C_p\,T_t\left[1-(P_s/P_t)^{\frac{\gamma-1}{\gamma}}\right]}$$

where: J = 778 feet-pounds/BTU

C_p = Specific heat at constant pressure; BTU/lb -°F

T_t = Stagnation Temperature; °R

In simplified form when working through the Gas Tables (reference. 1)

$$V_j = \sqrt{(\Delta h)2gJ}$$

Where: Δh is the BTU drop of the air expanding through the exhaust nozzle: for example, from P_{t5} to P ambient for the core thrust and from P_{t2} to P ambient for the fan thrust. The thrust, therefore, is directly proportional to the mass of air while the velocity term, Vj, contributes to the thrust by the 0.5 power of Δh. The impact of the higher bypass ratio can be seen in the following example. Assume an engine with fan airflow of 60 pounds per second, and a 5.8:1 bypass ratio, and a fan pressure ratio (FPR) of 1.58:1 at sea level static conditions. The Δh value resulting from the expansion of the fan air through the nozzle would be 17.148 BTU's per pound of fan air.

The resultant fan thrust would be:

$$\text{Fan Thrust} = w/g\sqrt{(\Delta h)2gJ} = 60/32.2\sqrt{(17.148)2(32.2)778}$$

Fan Thrust = 1727 pounds

If the engine's fan air flow is increased by 55 percent to 93.1 pounds per second, corresponding to a 9:1 bypass ratio, and the fan pressure ratio is reduced to 1.32:1, the BTU's derived from the expanding fan air through the nozzle would be 10.07 BTU's per pound of fan air. The resultant fan thrust in this case would be:

$$\text{Fan Thrust} = 93.1/32.2\sqrt{(10.07)2(32.2)778}$$

Fan Thrust = 2052 pounds

The latter condition yields an 18.8 percent increase in fan thrust. The low pressure turbine work required to power the fan for the two conditions would be 19.95 and 11.78 BTU's per pound of *total* engine airflow for the "standard" and the modified engine respectively. In this example therefore, the low BPR/high FPR turbine work required to power the fan section of the standard engine would be:

Low pressure turbine work required = [core airflow + fan airflow] x (Δh) BTU's per pound airflow = [10.34 + 60.0] x 19.95 = 1396 BTU'S

The high BPR, low FPR turbine work required to power the fan section of the modified engine would be:

Low pressure turbine work required = [core airflow + fan airflow] x BTU's per pound airflow = [10.34 + 93.1] x 11.78 = 1219 BTU's.

Thus, the low pressure turbine work to power the fan is 12.7 percent lower for the fully modified engine at the sea level static takeoff power condition.

At the altitude test condition the turbine work required is proportional to the total engine mass flows of the standard and modified engine, since the FPR for both engines is the same.

Standard Engine: 1070 BTU's

Fully Modified Engine: 1661 BTU's

In summarizing the results of the cycle study reported herein it is apparent that improvements in engine efficiency can be obtained with rearrangements and modifications of existing engine components, for example, higher bypass ratios and the development of a variable FPR fan. The analysis reported is not the optimum rematch but is intended to demonstrate the type of improvement which could be developed. More detailed data on the various cycles analyzed in this study are presented in tables 1 and 2 in the appendix.

SUMMARY OF RESULTS

The results of the cycle calculations, which were undertaken to determine factors which would improve overall engine efficiency, indicate that a rematching of components would improve the efficiency. The standard engine was compared to two types of modified engines at two conditions: (1) Sea level static takeoff power, and (2) 35,000 feet altitude, 0.8 Mn and maximum continuous cruise power. The two types of modified engines are (1) a partially modified engine, for example, an increased bypass ratio, a lower turbine inlet temperature, and an 11.5 percent lower core air flow, and (2) a fully modified engine, for example, an increased bypass ratio, a variable fan pressure ratio, and a lower turbine inlet temperature. The results indicate that improvements in thrust specific fuel consumption (TSFC) for the fully modified and partially modified engines at the sea level static and 35,000 feet, Mn 0.8 conditions, are as shown in table 5.

TABLE 5. ABBREVIATED RESULTS

FLIGHT CONDITION	ENGINE	TSFC	% CHANGE IN TSFC
SLS	Standard Engine	0.3988	------
SLS	Partially Modified Engine	0.335	-16%
SLS	Fully Modified Engine	0.2705	-32%
35K' & 0.8 Mn	Standard Engine	0.7392	------
35K' & 0.8 Mn	Partially Modified Engine	0.640	-12.6%
35K' & 0.8 Mn	Fully Modified Engine	0.604	-18.3%

CONCLUSION

Based on the results of the analysis it would appear that the direction that future high bypass engines should go for purposes of fuel efficiency, for example, thrust specific fuel consumption (TSFC), is toward higher bypass ratios for all flight conditions and lower fan pressure ratios at sea level takeoff power. At maximum continuous cruise power at altitude the fan pressure ratio should be raised to the level that the standard engine would produce. To do this, a variable geometry fan would be required. With these modifications the turbine inlet temperature of both the fully modified and the partially modified engine would be lowered by as much as 60°F and 460°F at the sea level takeoff power for the partially modified and the fully modified engines respectively. The improvement in engine efficiency resulting from higher bypass ratios has been recognized for many years but the advantages of a variable geometry fan has not been given much consideration. This aspect of engine design might be worthy of more study. Using this approach, an existing engine such as the one called "Standard" here (CF6-6 Type) could be modified to perform at the efficiency levels described in this report.

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APPENDIX A - ENGINE PROFILE

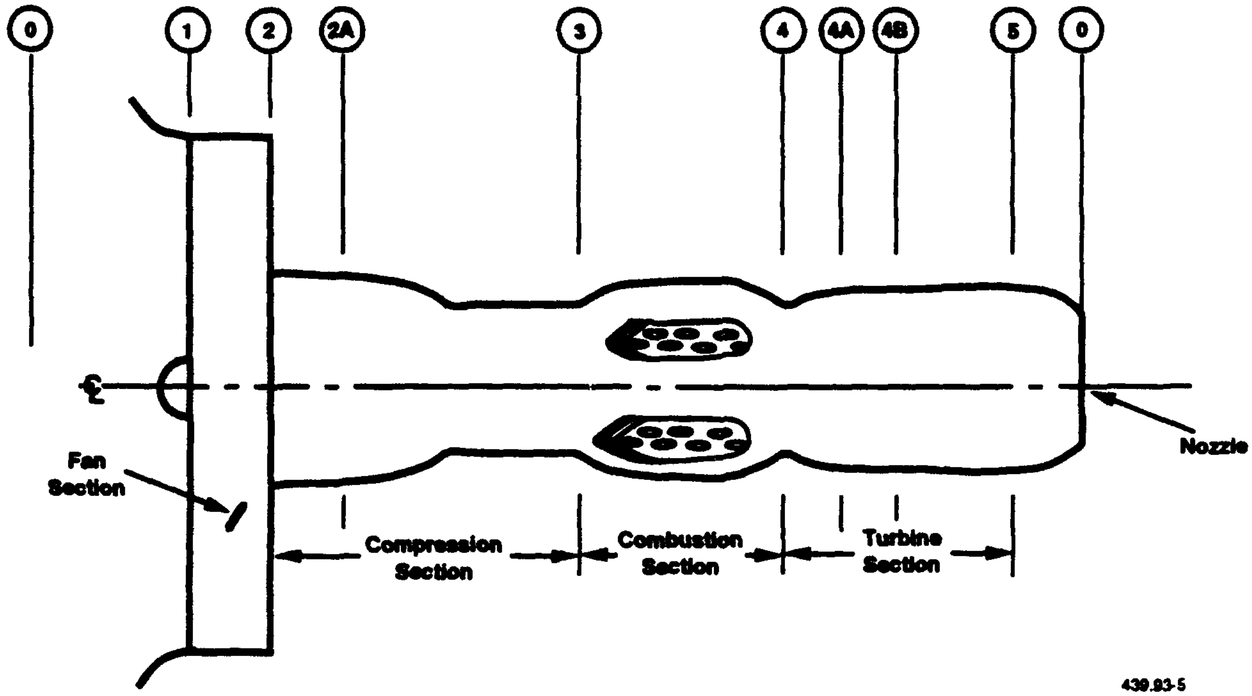

FIGURE A-1. STATION DIAGRAM

TABLE A-1. SEA LEVEL STATIC DATA, TAKEOFF POWER

(STANDARD ENGINE RATED TAKEOFF THRUST: 43303 POUNDS)

	STANDARD ENGINE						PARTIALLY MODIFIED					FULLY MODIFIED		
Run No.	X	G	H	Y	Z	AA	CC	DD	EE	BB	F	FF	GG	HH
Engine Type	Standard						Partially Modified					Fully Modified		
Core Air Flow #/Sec	188.84	same	same	same	same	same	167.19	same	same	same	same	188.84	same	same
Bypass Ratio (BPR)	5.8:1	same	same	same	same	same	9.0:1	same	same	same	same	9.0:1	same	same
Fan Pressure Ratio (FPR)	1.58:1	same	same	same	same	same	1.58:1	same	same	same	same	1.32:1	same	same
STA 1 Press. (psia)	14.7	same	same	same	same	same	14.7	same	same	same	same	14.7	same	same
STA 1 Temp. (°R)	518.7	same	same	same	same	same	518.7	same	same	same	same	518.7	same	same
STA 2 Press. (psia)	23.23	same	same	same	same	same	23.23	same	same	same	same	19.404	same	same
STA 2 Temp. (°R)	601.7	same	same	same	same	same	601.7	same	same	same	same	567.8	same	same
STA 2a Press. (psia)	69.68	same	same	same	same	same	69.68	same	same	same	same	77.616	same	same
STA 2a Temp. (°R)	853.5	same	same	same	same	same	853.5	same	same	same	same	880.7	same	same
STA 3 Press. (psia)	363.09	same	same	same	same	same	363.09	same	same	same	same	363.7	same	same
STA 3 Temp. (°R)	1408.7	same	same	same	same	same	1408.7	same	same	same	same	1406.1	same	same
STA 4 Press. (psia)	352.2	352.2	352.2	352.2	352.2	352.2	3. 2.2	352.2	352.2	352.2	352.2	352.2	352.2	352.2
STA 4 Temp. (°R)	2940.0	3000.0	2900.0	2800.0	2750.0	2700	2940	2892	2880	3100	3000	2940	2800	2500
STA 4a Press. (psia)	148.86	152.14	147.36	142.53	140.03	137.26	148.86	147.76	146.45	157.16	152.14	157.23	150.0	133.92
STA 4a Temp. (°R)	2454.0	2525.0	2411.6	2310	2239.5	2208.4	2454.0	2408.4	2392.9	2616	2513	2479.6	2335.8	2029.2
STA 4b Press. (psia)	97.36	100.83	93.61	90.612	87.302	85.390	97.356	95.567	94.634	105.669	100.62	92.653	85.324	69.387
STA 4b Temp. (°R)	2239.2	2298.0	2196.2	2093.2	2042.3	1986.6	2239.2	2193	2177.4	2404.1	2301.4	2212.5	2066.3	1753.2
STA 5 Press. (psia)	31.57	34.144	30.161	26.793	24.802	23.324	16.501	15.414	14.695	20.558	16.308	36.962	29.758	19.285
STA 5 Temp. (°R)	1749.4	1848.9	1705.1	1597.5	1545.8	1489.5	1511.8	1460.8	1445.6	1686.7	1576.5	1787.2	1636	1308.6
STA 0 Press. (psia)	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7
STA 0 Temp. (°R)	1448.2	1502.8	1426.1	1373.6	1354.5	1325.2	1468.4	1443.5	1439.0	1552.0	1536.2	1422.8	1371.6	1220.3
Core Δh (BTU)	80.58	93.181	74.295	59.091	50.241	42.98	11.394	4.562	0	36.021	10.701	97.551	69.937	22.739
Core Thrust (#)	11781	12669	11312	10088	9302.7	8604	3921	2481	0	6973.5	3800.6	12962	10975	6258
Fan Δh (BTU)	17.148	17.148	17.248	17.148	17.148	17.148	17.148	17.148	17.148	17.148	17.148	10.066	10.066	10.066
Fan Thrust #	31522	31522	31522	31522	31522	31522	43303	43303	43303	43303	43303	37476	37476	37476
Gross Thrust #	43303	44191	42834	41610	40827	40126	47224	45784	43303	50276	47103	50438	48451	43734
F/a Ratio	0.0254	0.0267	0.0247	0.0224	0.0217	0.0207	0.0254	0.0244	0.0241	0.0283	0.0265	0.0254	0.0228	0.0174
Fuel Flow (#/hr)	17267	18151	16791	15228	14752	14072	15286	14687	14505	17032	15949	17267.5	15500	11828
TSFC	0.3988	0.4107	0.392	0.366	0.3613	0.3507	0.3237	0.3208	0.3350	0.3388	0.3386	0.3423	0.3200	0.2705

TABLE A-2. ALTITUDE DATA: 35,000 FEET, Mn 0.8, CONTINUOUS CRUISE POWER

(STANDARD ENGINE RATED THRUST: 7388 POUNDS)

	STANDARD ENGINE				PARTIALLY MODIFIED				FULLY MODIFIED			
Run No.	M	N	O	S	P	Q	R	V	P	Q	R	V
Engine Type	Standard				Partially Modified				Fully Modified			
Core Air Flow #/Sec	55.37	same	same	same	49.02	same	same	same	55.37	same	same	same
Bypass Ratio (BPR)	5.8:1	same	same	same	9.0:1	same	same	same	9.0:1	same	same	same
Fan Pressure Ratio (FPR)	1.58:1	same	same	same	1.58:1	same	same	same	1.58:1	same	same	same
STA 1 Press. (psia)	5.285	same	same	same	5.285	same	same	same	5.285	same	same	same
STA 1 Temp. (°R)	444.5	same	same	same	444.5	same	same	same	444.5	same	same	same
STA 2 Press. (psia)	8.350	same	same	same	8.350	same	same	same	8.350	same	same	same
STA 2 Temp. (°R)	515.8	same	same	same	515.8	same	same	same	515.8	same	same	same
STA 2a Press. (psia)	33.401	same	same	same	33.401	same	same	same	33.401	same	same	same
STA 2a Temp. (°R)	801.7	same	same	same	801.7	same	same	same	801.7	same	same	same
STA 3 Press. (psia)	154.85	same	same	same	154.85	same	same	same	154.85	same	same	same
STA 3 Temp. (°R)	1283.7	same	same	same	1283.7	same	same	same	1283.7	same	same	same
STA 4 Press. (psia)	150.20	150.20	150.20	150.20	150.20	150.20	150.20	150.20	150.20	150.20	150.20	150.20
STA 4 Temp. (°R)	2940.0	2800	2700	2940	2940	2800	2700	2850	2940	2800	2700	2850
STA 4a Press. (psia)	72.772	70.187	67.750	72.776	72.772	70.187	67.750	71.331	72.772	70.287	67.750	71.331
STA 4a Temp. (°R)	2454	2379.6	2278.6	2524	2524	2379.6	2278.5	2429	2524	2379.6	2278.5	2429
STA 4b Press. (psia)	45.539	42.584	40.141	45.624	45.539	42.584	40.141	42.636	45.539	42.584	40.141	43.636
STA 4b Temp. (°R)	2280.9	2135.3	2032.7	2281.6	2280.9	2135.3	2032.7	2185.3	2280.9	2135.3	2031.7	2185.3
STA 5 Press. (psia)	18.071	15.691	13.9475	18.120	10.4784	8.5855	7.2851	8.812	10.478	8.5855	7.2851	8.812
STA 5 Temp. (°R)	1864	1713.5	1607.5	1865.7	1652.8	1497.7	1389.8	1535.1	1652.8	1497.7	1389.8	1535.1
STA 0 Press. (psia)	3.4676	3.4676	3.4676	3.4676	3.4676	3.4676	3.4676	3.4676	3.4676	3.4676	3.4676	3.4676
STA 0 Temp. (°R)	1236.8	1171.6	1131.2	1236.6	1250.7	1150.8	1148.8	1212.2	1250.7	1150.8	1148.8	1212.2
Core Δh (BTU)	166.62	142.27	124.45	166.60	105.71	80.186	62.013	84.732	105.71	80.186	62.016	84.732
Core Thrust (#)	4967	4590	4297	4967	3503	3051	2682	3136	3956	3446	3030.4	3542
Fan Δh (BTU)	26.632	26.632	26.632	26.589	26.632	26.632	26.632	26.632	26.632	26.632	26.632	26.632
Fan Thrust (#)	11518	11518	11518	11509	15822	15822	15822	15822	17872	17872	17872	17872
Gross Thrust (#)	16485	16108	15815	16476	19325	18873	18424	18958	21828	21318	20902	21414
Ram Drag (#)	9097	9097	9097	9097	11843	11843	11843	11843	13378	13378	13378	13378
Net Thrust (#)	7388	7011	6718	7379	7482	7030	6581	7115	8450	7940	7524	8036
F/a Ratio	0.0274	0.02475	0.0228	0.0274	0.0274	0.02475	0.0228	0.0257	0.0274	0.02475	0.0228	0.0257
Fuel Flow (#/hr)	5461	4933.5	4544	5461	4835	4367	4022	4535	5461	4933	4544	5122
TSFC	0.7392	0.7037	0.6768	0.7402	0.6463	0.6213	0.6111	0.6374	0.6463	0.6213	0.6039	0.6374