FINAL REPORT
ON THE
QUIET ENGINE DEFINITION PROGRAM
PWA-3516

by

John H. Lewis, III, Program Manager

VOLUME II
TASK I

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

October 4, 1968

CONTRACT NAS3-10497

Technical Management

NASA Lewis Research Center
Cleveland, Ohio
Propulsion Systems Acoustics Branch
J. J. Kramer
J. F. McBride

Pratt & Whitney Aircraft
DIVISION OF UNITED AIRCRAFT CORPORATION
UA®

EAST HARTFORD, CONNECTICUT

COPY NO.

Title page

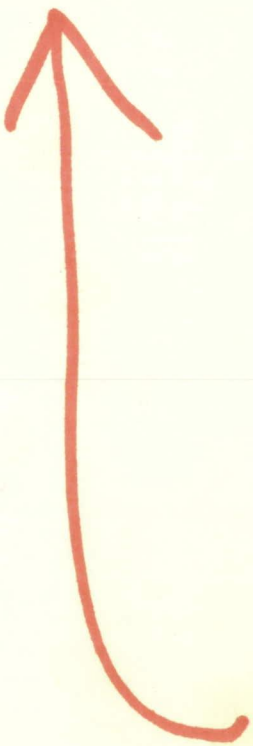
NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the National Aeronautics and Space Administration (NASA), nor any person acting on behalf of NASA:

A.) Makes any warranty or representative, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B.) Assumes any liabilities with respect to the use of or for damages resulting from the use of any information, apparatus, method or process disclosed in this report.

As used above, "person acting on behalf of NASA" includes any employee or contractor of NASA, or employee of such contractor, to the extent that such employee or contractor of NASA, or employee of such contractor prepares, disseminates, or provides access to any information pursuant to the employment or contract with NASA, or his employment with such contractor.



back up to cover-centered

PREFACE

The Final Report for the Quiet Engine Definition Program has been prepared in five volumes. This volume describes the work carried out under Task I, which was a parametric study of 242 possible cycle combinations for the Quiet Engine. Included are descriptions of the parametric methods used and the results and conclusions of the task. A summary of the over-all program and discussions of Tasks II and III are given in the other four volumes, which are listed below:

Volume I	Summary
Volume III	Task II
Volume IV	Task III
Volume V	QE-3 Performance

back up to title page

SUMMARY

The ultimate objective of the Quiet Engine Definition Program is to reduce the engine noise of future commercial jet transports to levels acceptable for airport neighborhood communities. This volume covers Task I of the program, which was a parametric cycle study of candidate engines.

The results of Task I were trends of variations in engine noise, performance, weight, and dimensions, as influenced by the primary engine thermodynamic cycle variables. Representative noise, fuel consumption, thrust, and physical characteristic values were obtained for a set of combinations of bypass ratio, over-all compressor and fan pressure ratios, and take-off and cruise turbine inlet temperatures. Noise values included peak noise (in PNdb levels) at take-off, approach, and cutback during climbout. Noise contours in the vicinity of the airport were computed at each of the aforementioned conditions for four representative cycle combinations.

Noise, performance, weights, and dimensions were tabulated for 242 combinations of cycle variables for each of two different levels of take-off thrust. A statistical regression analysis technique was used. With this technique, approximately 40 cycle combinations were used as a sample set and trends for the remaining 200 combinations were obtained by statistical inference.

With such a complex study, general over-all trends were difficult to discern, and each general conclusion was found to have its exceptions. Nevertheless, certain broad trends were inferred and used to select three candidate cycles for further study in Task II. Some of these trends are listed below:

- Lower noise levels occur with bypass ratio and fan pressure ratio combinations associated with lower cruise fuel consumption.
- Take-off turbine inlet temperature has an important influence on take-off noise levels.
- Cycle compression ratio has the least influence on noise levels of all cycle variables.
- Engines with lowest noise levels tend to be large and heavy.
- Particularly for cycle combinations suitably matched in cruise and take-off thrust levels, a wide range of cycle variations results in a relatively small variation in total noise level, which is fan dominated. This is true both for take-off and approach conditions.
- For most cycles, fan noise predominates.
- With several promising cycles, jet noise levels could be reduced from present levels by 15 PNdb for take-off and 20 PNdb for approach conditions.

The contractual effort centered on a specified range of values for the cycle variables and take-off thrust levels of 20,000 pounds (88,960 newtons) and 25,000 pounds (111,200 newtons) for an engine to be applied to an aircraft similar to the Boeing 707 and DC-8. The broad conclusions drawn are valid in the range of parameters studied. However, especially as a result of the last conclusion listed above, the study results could be extended somewhat beyond the ranges covered.

TABLE OF CONTENTS

		Page
PREFACE		ii
SUMMARY		iii
LIST OF ILLUSTRATIONS		vi
LIST OF TABLES		x
I	INTRODUCTION	1
II	THERMODYNAMIC CYCLE PERFORMANCE	5
	A. General Method	5
	B. Key Assumptions	7
	C. Problem Areas	10
	D. Discussion and Interpretation of Results	12
III	NOISE	17
	A. General Method	17
	B. Key Assumptions	33
	C. Discussion and Interpretation of Results	34
IV	ENGINE PHYSICAL DESCRIPTION	43
	A. Method of Solution	43
	B. Key Assumptions and Problem Areas	62
	C. Discussion and Interpretation of Results	68
APPENDIX		
	A. Tabulation of Results	73
	B. Noise Contour Plots	105
	C. Statistical Analysis	123
	D. Tabulation for Engine Physical Description of Sample Cases	135

LIST OF ILLUSTRATIONS

Figure	Title	Page
1	Current Turbofan Take-Off vs. Cruise Design	6
2	Fan Tip Speed and Efficiency	8
3	Effect of Bypass Ratio on Cruise TSFC with a Fan Pressure Ratio of 1.30	13
4	Effect of Bypass Ratio on Cruise TSFC with a Fan Pressure Ratio of 1.55	14
5	Effect of Bypass Ratio on Cruise TSFC with a Fan Pressure Ratio of 1.70	14
6	Effect of Cycle Pressure Ratio on Cruise TSFC	15
7	Octave Band Jet Noise vs. Strouhal Number	19
8	Fan Noise Frequency Spectrum	20
9	Rotor Stator Interaction Pattern	21
10	Supersonic Fan Blade Tip Noise	22
11	Take-Off and Climb-Out Procedure	24
12	Airplane Performance 707-320B Type. TOGW = 325,000 lb. Std. Day	26
13	Flight Path Comparison	27
14	Normalized Jet Noise vs. Relative Velocity	29
15	Maximum Overall Sound Pressure Level as a Function of Relative Jet Velocity	30
16	Relative Blade Passing Frequency Octave Sound Pressure Level vs. Relative Tip Mach Number	31
17	Total Noise vs. Overall Pressure Ratio	35

LIST OF ILLUSTRATIONS (Cont'd)

Figure	Title	Page
18	Total Noise vs. Bypass Ratio and Turbine Inlet Temperature	36
19	Total Noise vs. Bypass Ratio and Turbine Inlet Temperature	37
20	Total Noise vs. Bypass Ratio and Turbine Inlet Temperature	38
21	Total Noise vs. Fan Pressure Ratio	39
22	Perceived Noise Level Contours	40
23	Perceived Noise Level Contours	41
24	High Rotor Bearing Inboard of Diffuser	46
25	Intershaft Bearing	46
26	Transition Section Between High and Low Pressure Turbine	47
27	Basic Engine Design	47
28	Engine Weight vs. Bypass Ratio and Turbine Inlet Temperature	69
29	Engine Weight vs. Bypass Ratio and Turbine Inlet Temperature	69
30	Engine Weight vs. Bypass Ratio and Turbine Inlet Temperature	70
31	Effect of Cycle Pressure Ratio on Engine Weight	71

LIST OF ILLUSTRATIONS (Cont'd)

Figure	Title	Page
32	JT3D-3B Engine Takeoff Max.	106
33	JT3D-3B Engine Cutback at 1000 Ft. Alt.	106
34	JT3D-3B Engine Approach	107
35	10-30C30-30 Takeoff Max.	107
36	10-30C30-30 Cutback at 1000 Ft. Alt.	108
37	10-30C30-30 Approach	108
38	10*30C30-30 Takeoff Max.	109
39	10*30C30-30 Cutback at 1000 Ft. Alt.	109
40	10*30C30-30 Cutback at 3 Mi. Point	110
41	10*30C30-30 Approach	110
42	80-95A70-30 Takeoff Max.	111
43	80-95A70-30 Cutback at 1000 Ft. Alt.	111
44	80-95A70-30 Approach	112
45	80*95A70-30 Takeoff Max.	112
46	80*95A70-30 Cutback at 1000 Ft. Alt.	113
47	80*95A70-30 Cutback at 3 Mi. Point	113
48	80*95A70-30 Approach	114
49	80-95B55-24 Takeoff Max.	114
50	80-95B55-24 Cutback at 1000 Ft. Alt.	115
51	80-95B55-24 Approach	115

LIST OF ILLUSTRATIONS (Cont'd)

Figure	Title	Page
52	80*95B55-24 Takeoff Max.	116
53	80*95B55-24 Cutback at 1000 Ft. Alt.	116
54	80*95B55-24 Cutback at 3 Mi. Point	117
55	80*95B55-24 Approach	117
56	80-95B70-24 Takeoff Max.	118
57	80-95B70-24 Cutback at 1000 Ft. Alt.	118
58	80-95B70-24 Approach	119
59	80*95B70-24 Takeoff Max.	119
60	80*95B70-24 Cutback at 1000 Ft. Alt.	120
61	80*95B70-24 Cutback at 3 Mi. Point	120
62	80*95B70-24 Approach	121
63	Simplified Example of Multiple Regression Technique	124

LIST OF TABLES

Table	Title	Page
I	Engine Component Performance Assumptions	9
II	Impossible Cycles and Substitutes	11
III	Summary of Aircraft Characteristics	24
IV	Bearing Configuration	48
V	Quiet Engine Parametric Study	51
VI	Quiet Engine Parametric Study (International Units)	55
VII	Low Pressure Compressor Description	63
VIII	High Pressure Compressor Description	63
IX	Burner Description	65
X	Sample Mnemonic Code System	73
XI	Supplementary Designations of Bypass-Ratio	74
XII	Reference Cycle for JT3D-3B	75
XIII	Sampling Plan for Noise Study	126
XIV	Sampling Plan for Length and Weight Study	127
XV	Required Points for Linear Effects on Length and Weight	129
XVI	Required Points for Curvilinear Effects on Length and Weight	129
XVII	Revised Points for Linear Effects on Weight and Length	130
XVIII	Data Points for Noise Studies	131
	Check Points for Noise Response Surfaces	133

LIST OF TABLES (Cont'd)

Table	Title	Page
XX	Check Points for Weight and Length Response Surfaces	134
XXI	Quiet Engine Performance Study	137
XXII	Quiet Engine Performance Study (International Units)	139

SECTION I
INTRODUCTION

The contract work has been divided into three separate tasks. This report concerns Task I, which was devoted to parametric cycle studies. The ranges of interest for the variables in these studies are listed below:

Bypass Ratio	3 to 8	
Fan Pressure Ratio	1.3 to 1.7	
Cycle Pressure Ratio	15 to 30	
	Degrees, Kelvin	Degrees, Fahrenheit
Turbine Inlet Temperature at cruise (M_n = 0.82, 35,000 ft (10,670 meters))	(1140 - 1420)	1600 - 2100
Turbine Inlet Temperature at Take-off	(1140 - 1534)	1600 - 2300

Under Taks I, the contractor has calculated the following characteristics of each of 242 cycle combinations:

- Thrust per unit airflow at take-off and cruise.
- Specific fuel consumption at take-off and cruise conditions.
- Noise levels during take-off and landing.
- Engine length, diameter, and weight as a function of thrust.

Two cases of sea-level thrust, 20,000 to 25,000 pounds (88,960 newtons and 111,200 newtons), have been considered in the noise calculations. Engines were assumed to be utilized on a 325,000-pound (147,500 kilograms) aircraft of Boeing 707 or DC-8 type, cruising at 35,000 feet (10,670 meters) at 0.82 Mach number. The output at these two thrust levels over the range of cycle variables enumerated above will serve as a basis for the NASA Project Manager's selection of three cycle combinations for further study in Task II.

The work of Task I has been divided into two reporting categories: thermodynamic cycle calculations (including specific thrust and thrust specific fuel consumption) and a determination of noise levels, engine weight, and dimensions. The cycle characteristics calculated under Task I are as follows:

- Thrust per unit airflow at take-off and cruise.
- Specific fuel consumption at take-off and cruise.

- Noise levels during take-off and landing.
- Engine length, diameter, and weight as functions of thrust.

The noise calculations included the following:

- For all cycle combinations
  - Peak PNdB on take-off on the ground at a point three miles (4.83 Km.) from brake release.
  - Peak PNdB on take-off, on the ground after cutback during climb out.
  - Peak PNdB during approach, on the ground at a point one mile (1.609 Km.) from touchdown.
- For not less than four cycle combinations outlines of airport neighborhood areas subjected to 90, 95 and 100 PNdB during take-off and landing.

To present and discuss the output results, this report is divided into three main sections plus an appendix. These sections cover the broad areas of calculations indicated above which represent distinct and independent characteristics for the various cycle combinations. Engine thermodynamic performance is discussed in Section II; noise level calculations, are covered in Section III; and engine physical description, which involves mechanical design procedures necessary to determine weights and dimensions, is discussed in Section IV.

The appendix section presents a complete tabulation of all the output data. In addition, a discussion of statistical methods, a key technique utilized in generating the data, is included in the appendix.

All sections have been arranged to present a discussion of general methods, followed by enumeration of the assumptions used, and by a discussion of results and interpretation, where appropriate.

The nature of the results and trends of the Task I parametric study strongly depend on the assumptions inherent in performance and noise calculations. Broadly, the study assumptions are based on next-generation commercial transport engine technology typified by the JT9D engine. A particularly critical assumption in the engine noise calculations involves using empirical relationships established from fan testing related to JT9D development. These test results represent the most currently available information concerning noise production in advanced technology fans. Since the bulk of the Task I study engines have noise characteristics dominated by their fan noise generation, two qualifications

must be applied to future use of the study results presented in this report. First, empirical data covering a broader scope of fan noise generation could modify the noise calculation techniques. Secondly future testing could, and should, find means for reducing currently known levels of noise production emanating from the fan.

As a means for readily identifying cycle combinations, a code system was devised and used during the Task. This code is explained in Appendix A, page 73.

SECTION II
THERMODYNAMIC CYCLE PERFORMANCE

Turbofan cycle performance data in the Task I parametric study results includes predicted values of specific net thrust (Fn/Wa) and thrust specific fuel consumption (TSFC) for both cruise and sea-level static take-off conditions. The calculated results are presented in the Tables of Appendix A, for each of 242 cycle combinations within the range of the contract cycle parameters. In addition, cycle calculations were required to define design-point and off-design thermodynamic performance for the various cycle combinations used as samples in the regression analysis. Design-point performance data established key design parameters for each of the major engine components, as required to synthesize over-all engine physical descriptions. These results are discussed in Section IV. Off-design performance was determined as needed to establish noise predictions. At the take-off, approach, and climb conditions it was necessary to compute fan tip speed and engine exhaust velocities to be used in determining noise values. Results and methods for the noise calculations are further discussed in Section III. This section is devoted to discussions of the methods and assumptions used, and problems encountered in all cycle performance calculations involved in the Task I effort; it also covers the over-all cycle performance results.

A. GENERAL METHOD

In general, performance results were obtained by direct cycle and equilibrium matching calculations performed on an electronic computer.

For each cycle design at the cruise condition, thermodynamic performance was calculated. The calculations included determining values for effective controlling flow areas ($Aeff/Wa_{des}$) as well as the pertinent performance quantities. The "design point" calculations were performed directly from fixed pressure ratio, bypass ratio, and turbine inlet temperature basic cycle variables by means of standard thermodynamic relationships and gas properties.

In high-bypass-ratio turbofans, the cruise flight condition is usually the critical operating point from a performance standpoint. This is because of the emphasis on specific fuel consumption and because of the low cruise thrust, relative to take-off thrust, of high-bypass turbofans. Also, because of the lower exhaust expansion ratios of high-bypass-ratio turbofans, there is a relatively wide variation between the take-off and cruise aerodynamic operating points of the fan. For these reasons, the engine components are usually matched to give their best operating efficiency at the cruise, rather than the take-off flight condition. A comparison of the effect of designing a current turbofan at cruise with the same engine designed at take-off is shown in Figure 1.

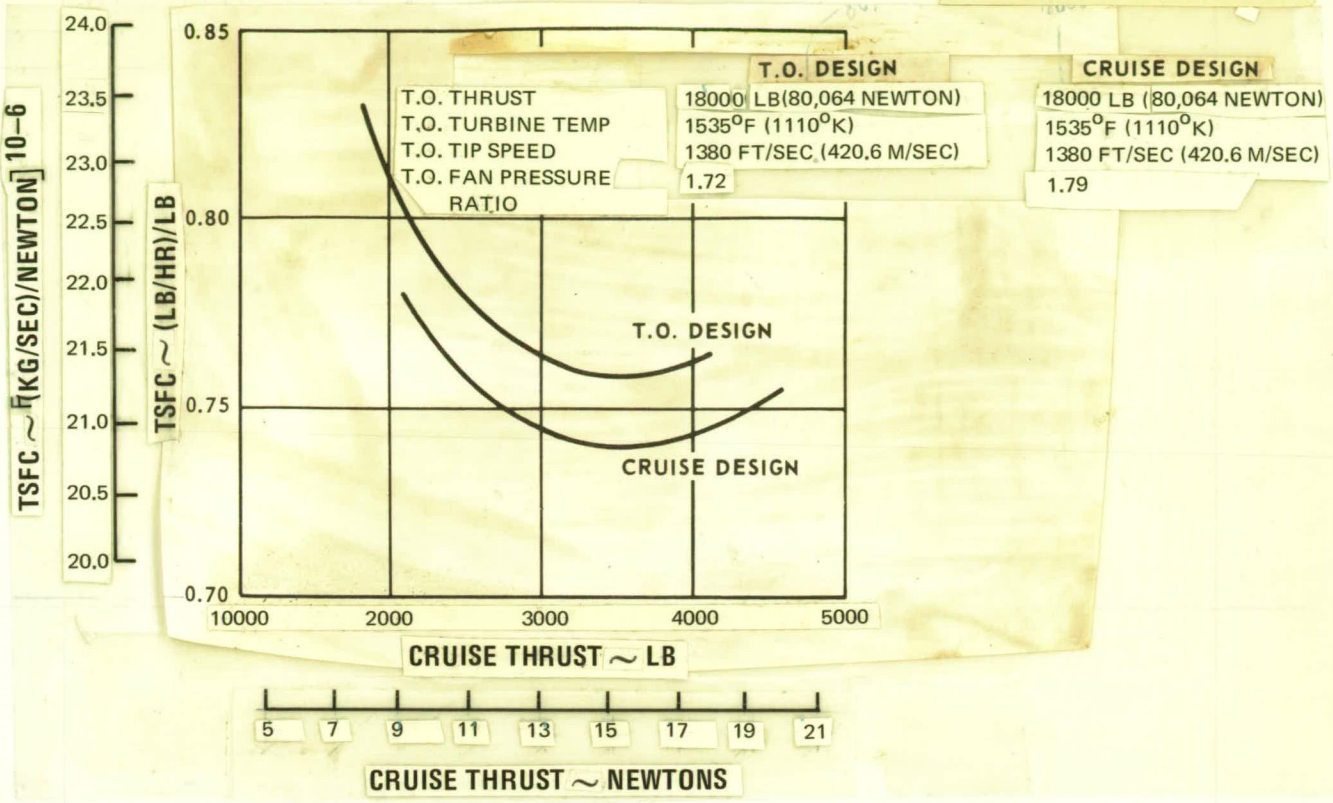


Figure 1 Current Turbofan Take-Off vs. Cruise Design

For off-design conditions, performance was obtained by using established trial-and-error iterative techniques in which the values of cycle parameters (bypass ratio, cycle pressure ratio and fan pressure ratio) and airflows were found to satisfy the cruise design values for controlling flow areas in high- and low-pressure turbines and in the engine and fan exhaust nozzles.

In the off-design calculation procedure, steady-state cycle and performance parameters were determined from the assumed component performance characteristics, from a given value of turbine inlet temperature, and from the ideal flow areas computed in the design point calculation. The complicated procedure employed involved a systematic process of guessing the various cycle parameter.

The design point and the take-off calculations were performed sequentially and automatically by the computer for the 242 cycle combinations.

In the tabulation of results given in the Appendix, it was necessary to provide values of cruise thrust as well as take-off thrust for each engine cycle, since not every cycle has sufficient thrust to cruise a 320,000-pound (145,000 kg.) gross weight airplane of the 707 or DC-8 type at a Mach number of 0.82, at 35,000 feet (10,700 meters).

B. KEY ASSUMPTIONS

In a parametric study of the scope performed under Task I, certain simplifying assumptions had to be made in order to ensure that the work would be completed in the alloted time. For example, it was not possible to estimate the efficiency of every component individually for each cycle under consideration. Estimates requiring that degree of detail will be obtained in the preliminary design phase under Tasks II and III.

A single-stage fan was assumed. Besides potentially lower engine weight, the single-stage fan at this time appears to offer compelling advantages in favor of low noise production. Use of a single-stage fan, even though it requires a somewhat higher tip speed at the upper end of the pressure-ratio range, would allow the application of several mechanical design features to reduce discrete-frequency fan noise. These features are more difficult to incorporate into the design of two-stage fans because of aerodynamic and structural considerations. They include large spacing between blades and vanes, the choice of an acoustically desirable number of vanes and blades, and space in which to install sound-absorbing liners in the fan's flow path.

Fan tip speed, upon which both efficiency and noise are heavily dependent, was assumed to vary with fan pressure ratio as shown in Figure 2. The assumed levels correspond approximately to constant stage loading and agree exactly with the design tip speed of the JT9D-1 fan at 1.55 pressure ratio. At the lower fan pressure ratio, the tip-speed level is consistent with fan designs under study for advanced engines with very high bypass ratios. The tip speed assumed at the 1.7 pressure-ratio level is consistent with the results of advanced single-stage rig testing at Pratt & Whitney Aircraft. It should be emphasized that the tip speeds given in Figure 2 are values of corrected tip speed at the design condition, i.e., 0.82 Mach number, 35,000 feet (10,700 meters) altitude, cruise. At take-off, the value of tip speed may exceed or be less than the design corrected value, depending on the levels of bypass ratio, fan pressure ratio, turbine inlet temperature at cruise, and turbine inlet temperature at take-off. This is a function of engine off-design matching characteristics which vary markedly with cycle designs.

The assumed values of fan efficiency are shown in the lower curve of Figure 2, and are consistent with the fan pressure ratio vs. tip speed relationship and with the JT9D design efficiency.

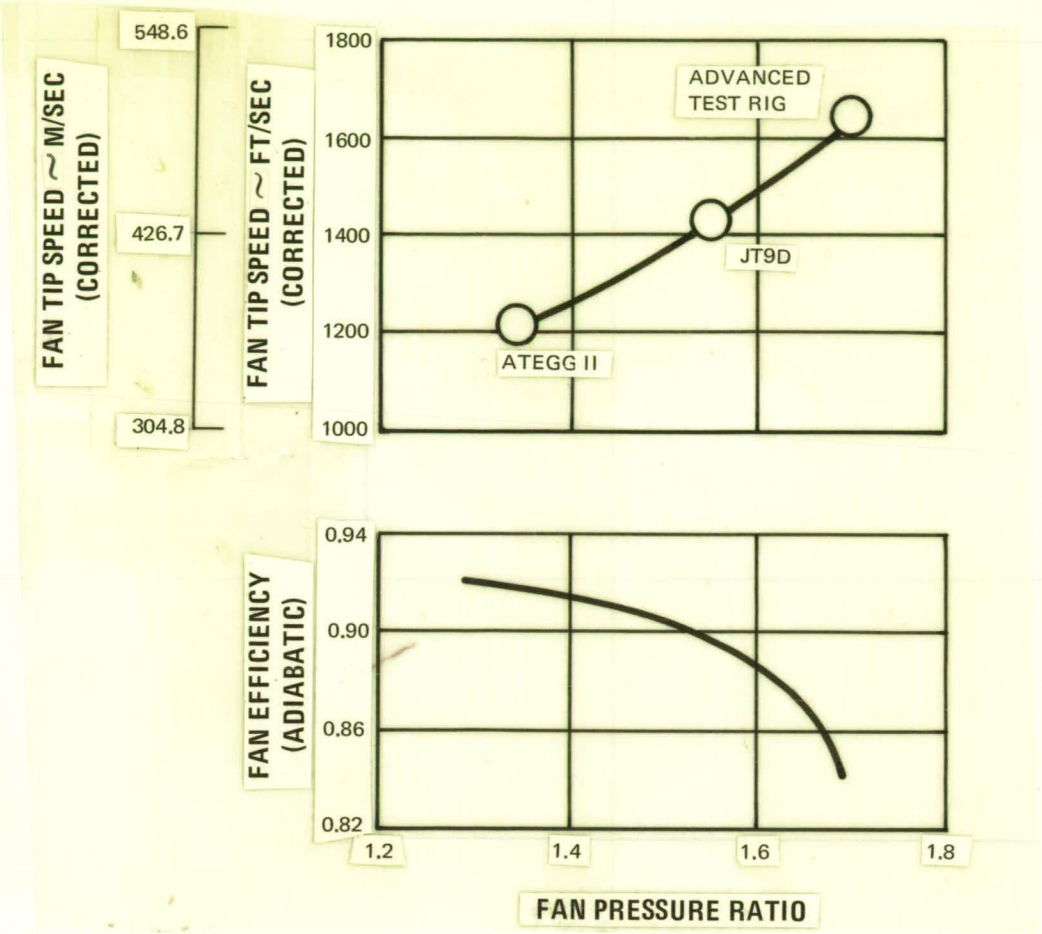


Figure 2 Fan Tip Speed and Efficiency

Table I lists the other component efficiency assumptions. Constant polytropic efficiencies were assumed for the compressors and turbines, as is customary in comprehensive parametric performance studies. The efficiency levels were consistent with next generation turbofan engines.

The burner temperature rise efficiency was assumed to be 100 percent. This assumption is borne out by extensive test experience. Pressure loss in the burner was assumed to vary with cycle pressure ratio and turbine inlet temperatures at take-off and cruise. Turbine cooling air levels, which include vane, blade and disc cooling requirements, also were assumed to vary with cycle pressure ratio and turbine inlet temperature. Precise levels of burner pressure loss are given in Section II. The levels of burner pressure loss and turbine cooling flow are based on JT9D technology as further explained in Section II.

The performance of high-bypass-ratio turbofans is critically dependent on good performance of the exhaust system. The nozzle velocity coefficients were assumed to be 0.99, and the exhaust-duct pressure losses were held constant at 1.0 percent. These levels have been verified by powered nacelle-model tests in a simulated cruise flow environment at a cruise Mach number.

TABLE I

ENGINE COMPONENT PERFORMANCE ASSUMPTIONS

COMPRESSOR EFFICIENCY (POLYTROPIC)	89%
TURBINE EFFICIENCY (POLYTROPIC)	90%
ENGINE EXHAUST PRESSURE LOSS	1.6%
FAN DUCT PRESSURE LOSS	1.0%
NOZZLE VELOCITY COEFFICIENT	0.99
BURNER PRESSURE LOSS	4.7-14.0%
TURBINE COOLING AIRFLOW (% OF COMPRESSOR FLOW)	1.5-10.5%

C. PROBLEM AREAS

Ordinarily, the nature of off-design rotor speed variation is of negligible significance to the result of a parametric performance study. However, the influence of fan tip speed upon noise level was sufficiently great that the rotor speed variation of the fan at off-design conditions had to be taken into account. Therefore, the performance calculation procedure employed a generalized off-design speed-flow-pressure-ratio performance map based on single-stage fan characteristics.

Off-design rotor speed variation has a secondary effect on turbofan matching via its influence on the turbine's flow capacity. This effect, however, is of little consequence in a parametric performance study. For this reason, no attempt was made in Task I to account for the speed-flow relationships of compressors or turbines.

All other component performance indices, including adiabatic fan, compressor, and turbine efficiencies, burner and duct pressure losses, nozzle velocity and flow coefficients, and the fraction of compressor airflow used for turbine cooling, were assumed not to vary from design-point levels. For all except the fan and compressor efficiencies these are reasonably accurate assumptions. Although fan and compressor efficiencies vary with off-design operation, the extent of variation is sensitive to the operating point at which the component is matched, as well as to the design characteristics of the individual component. Accounting for these secondary effects was beyond the scope of Task I and would not have contributed to an understanding of the interrelationships between performance, weight, noise, and cycle parameters.

The spool arrangement assumed for the calculations was a two-spool turbofan with a mechanically isolated fan. This system was chosen because of its simplicity.

A check on the accuracy of these assumptions was obtained by comparing the cycle performance of the scaled JT9D cycle computed at take-off and cruise with the JT9D-1 specification performance. The computations were made with a sophisticated procedure embodying compressor and turbine maps and Reynolds-Number effects. These performance numbers (specific thrust and TSFC) agreed within 2 percent.

Many of the cycle combinations initially included in the study were found to be impractical because they require an energy input to the fan which exceeded the capacity of the gas generator. These cycles were characterized by high bypass ratios in combination with high fan-pressure ratios and low cruise turbine inlet temperatures. In order to fulfill the program requirement of 240 or more cycles, certain substitute cycles having lower values of bypass-ratio were included in the matrix. The impractical cycle combinations and their lower bypass-ratio substitutes are listed in Table II.

TABLE II

IMPOSSIBLE CYCLES AND SUBSTITUTES

Failed Cycle (Code)	Bypass Ratio	Substituted Cycle	Bypass Ratio
60-95B70-24	5.0	60-95S70A24	4.5
60-30B70-24	5.0	60-30E70-24	4.0
60-30B55-30	5.0	60-30S55A30	4.5
60-60B70-30	5.0	60-60S70A30	4.5
60-95B70-30	5.0	60-95E70-30	4.0
60-30B70-30	5.0	60-30S70B30	3.5
60-30B70-30	5.0	60-30S70B30	7.75
60-95C55-15	8.0	60-95K55-15	7.25
60-30C55-15	8.0	60-30L55-15	6.85
60-60C70-15	8.0	60-60M70-15	5.8
80-60C70-15	8.0	80-60L70-15	6.85
60-95C70-15	8.0	60-95F70-15	5.4
80-95C70-15	8.0	80-95O70-15	6.75
60-30C70-15	8.0	60-30N70-15	5.1
80-30C70-15	8.0	80-30P70-15	6.25
60-60C55-24	8.0	60-60Q55-24	6.4
60-95C55-24	8.0	60-95R55-24	6.0
60-30C55-24	8.0	60-30F55-24	5.4
80-30C55-24	8.0	80-30T55-24	7.5
60-60C70-24	8.0	60-60U70-24	5.25
80-60C70-24	8.0	80-60X70-24	6.5
60-95C70-24	8.0	60-95M70-24	5.8
80-95C70-24	8.0	80-95P70-24	6.25
60-30C70-24	8.0	60-30V70-24	4.25
80-30C70-24	8.0	80-30M70-24	5.8
60-60C55-30	8.0	60-60P55-30	6.25
60-95C55-30	8.0	60-95M55-30	5.8
80-95C55-30	8.0	80-95T55-30	7.5
60-30C55-30	8.0	60-30W55-30	4.9
80-30C55-30	8.0	80-30X55-30	6.5
60-60C70-30	8.0	60-60H70-30	4.8
80-60C70-30	8.0	80-60R70-30	6.0
10-60C70-30	8.0	10-60Z70-30	7.0
60-95C70-30	8.0	-	-
80-95C70-30	8.0	80-95M70-30	5.8
10-95C70-30	8.0	10-95D70-30	6.0
60-30C70-30	8.0	60-30Y70-30	3.65
80-30C70-30	8.0	80-30U70-30	5.25
10-30C70-30	8.0	10-30X70-30	6.5

The cycle combinations comprised of the lowest level of cruise turbine inlet temperature tend to match at excessively high levels of take-off fan airflow. In order to maintain a corrected inlet flow per unit annulus area of 43.0 lb/sec/ft^2 (210.3 kg/sec. m^2) at take-off as a practical upper limit, the design flow area and hub/tip ratio were lowered below the original values of 41.0 lb/sec/ft^2 (200.5 kg/sec. m^2) and 0.38 for the affected engines. These cycles are identified by a numeral (2) in the remarks column of the table of results.

Excessive fan rotor physical speed was encountered in cycle combinations having high take-off turbine inlet temperature and low cruise turbine inlet temperature in combination with high fan pressure ratio and low bypass ratio. These effects are complex but typical of cycle-matching trends. The consequences of excessive tip speed are discussed in greater detail in the section on Engine Physical Descriptions. Engine cycles affected by fan overspeed are identified by a numeral (3) in the remarks column of the table of results.

Cycles having high turbine inlet temperature in combination with low cycle pressure ratio result in high values of burner temperature rise. In order to maintain acceptable radial temperature profiles at the turbine inlet, these burners must be long, requiring large amounts of liner cooling air and having high pressure losses. A few of these cycles will require more advanced cooling techniques and/or materials than are currently available in the state-of-the-art. The problem is discussed in greater detail in the Engine Physical Description section. The affected cycles are denoted by a (4) in the remarks column of the Table of Results.

It has been assumed that engine jet areas are fixed. For the engines with the lower fan pressure ratios, which during take-off operate with an unchoked fan exhaust nozzle, the fan operating conditions during static operation differ widely from the operating conditions at the cruise flight condition, where the higher ram pressure ratio level helps choke the fan exhaust nozzle. Some of the engines will therefore require more advanced fan off-design aerodynamics (increased stall margin at take-off) or a two-position duct jet area which would narrow the fan's operating band.

D. DISCUSSION AND INTERPRETATION OF RESULTS

The tables of results of the Task I parametric study presented in Appendix A include values of thrust, specific thrust, and thrust-specific fuel consumption (TSFC) at cruise and take-off for each of 242 turbofan cycle combinations. Two levels of scaled thrust are included for each cycle, corresponding to 20,000 and 25,000 pounds (88,960 and 111,200 newtons) respectively, at take-off. The cruise and take-off performance for each turbofan cycle are related to each other according to constant jet-area matching.

Interpretation of the results involves analyzing combined effects of, and interactions among, five distinct cycle variables. It is only possible to visualize the

effects of any two of the variables in combination with one another, provided that the other three variables are held constant. A few representative trends, where selected variables are kept constant, are provided as examples in the following graphs of thrust-specific fuel consumption versus various cycle parameters.

The engine cycles results presented in these curves represent only those combinations which have a cruise thrust which corresponds to the level required to fly a fully loaded airplane similar to the Boeing 707-320B (take-off gross weight of 325,000 pounds (147,500 Kg.)) at 35,00 ft(10,670 meters) altitude, 0.82 Mach number. These illustrated cycles came from interpolating from among the complete tabular set by varying the value of cruise (design-point) turbine inlet temperature, while holding constant the other cycle design variables.

Figure 3, 4 and 5 show the effect of bypass ratio and take-off turbine inlet temperature on cruise TSFC at three levels of fan pressure ratio. The trends are typical of turbofan cycle performance. They show TSFC generally decreasing with increasing bypass-ratio, but increasing again at the higher bypass ratios where the turbine inlet temperature and fan pressure ratio are not optimum.

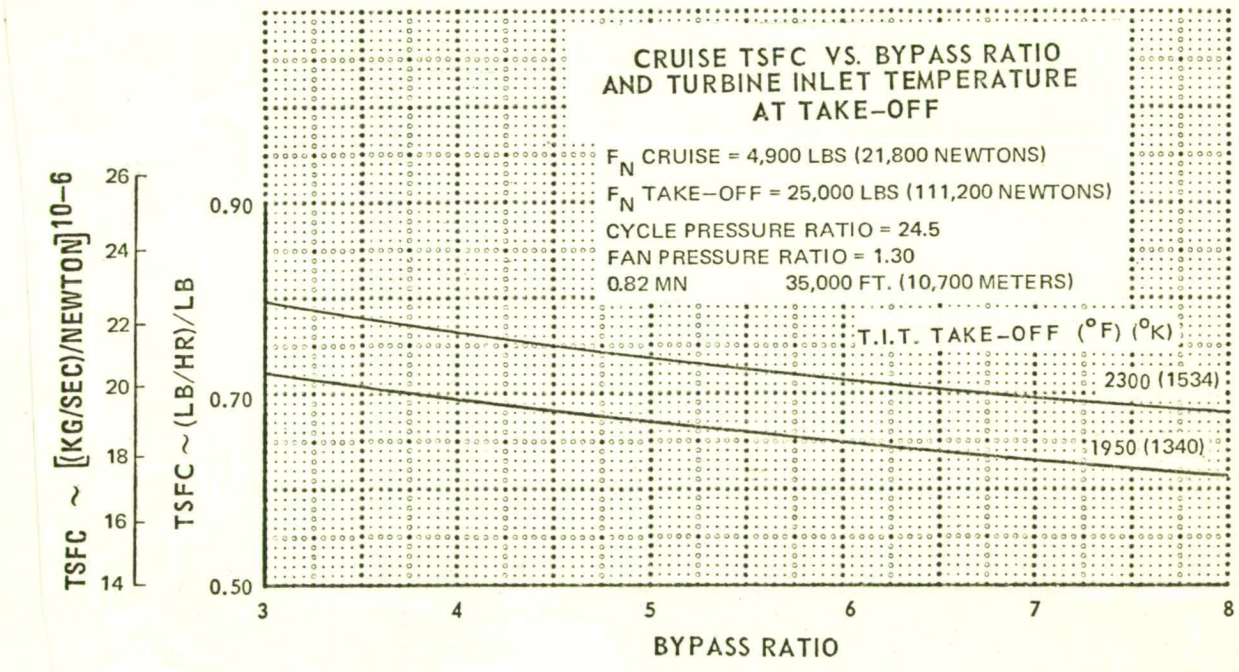


Figure 3 Effect of Bypass Ratio on Cruise TSFC with a Fan Pressure Ratio of 1.30

Hold for Dot pattern on this Figure and the rest like it.

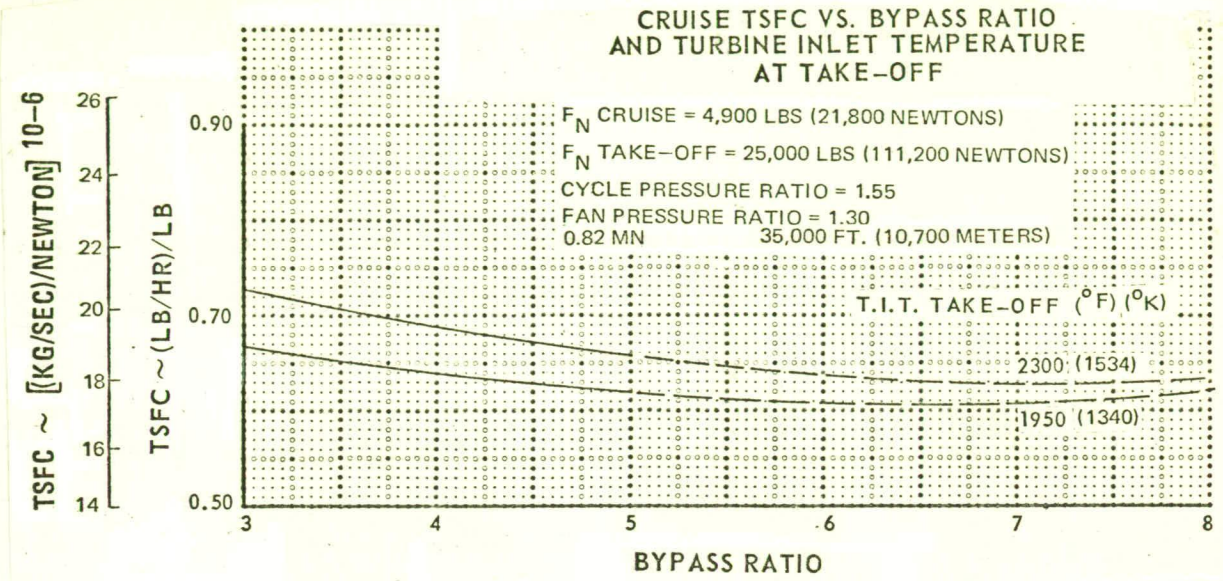


Figure 4 Effect of Bypass Ratio on Cruise TSFC with a Fan Pressure Ratio of 1.55

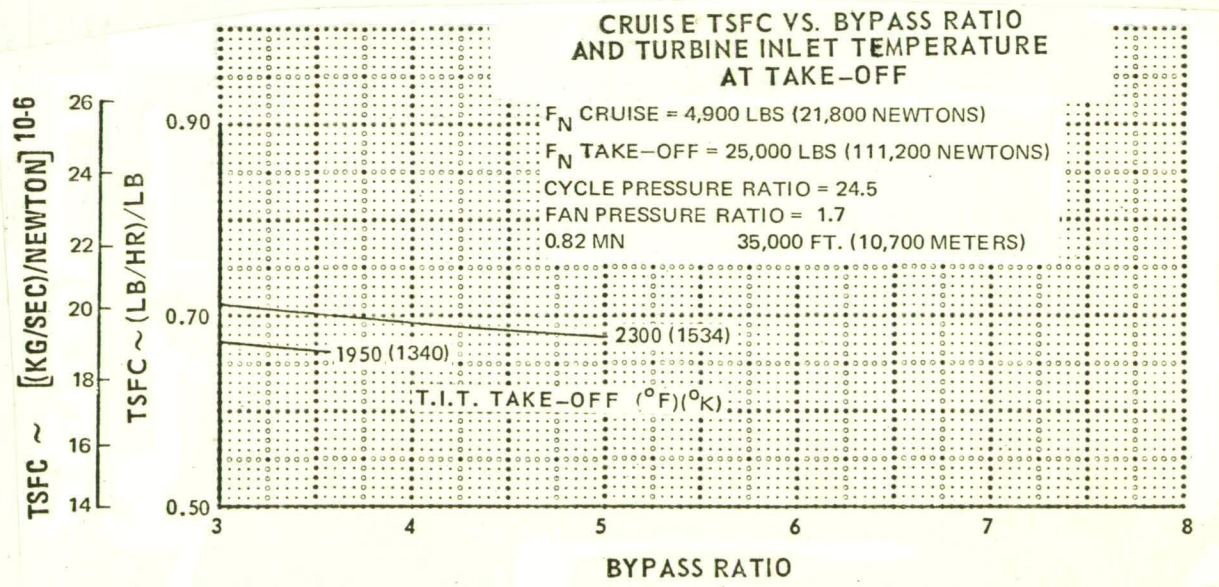


Figure 5 Effect of Bypass Ratio on Cruise TSFC with a Fan Pressure Ratio of 1.70

Although the cruise turbine inlet temperature, to which cruise TSFC is directly related, is not given on the curves, its value varies in the same direction as the take-off turbine inlet temperature because of the constant relationship between cruise and take-off thrust. In Figure 3, the 1950-degree fahrenheit (1340° Kelvin) take-off temperature appears closer to optimum than 2300-degree Fahrenheit (1534° Kelvin) for 1.3 fan pressure ratio. At the higher levels of fan pressure ratio and bypass-ratio, the higher levels of turbine inlet temperature are optimum.

At the highest levels of fan pressure ratio and bypass-ratio (Figures 4 and 5), insufficient cycle work is available to drive the fan at the specified overall thrust levels and within the limits of cruise turbine inlet temperature defined by the work statement.

Figure 6 shows a representative effect of cycle pressure ratio on TSFC at the constant levels of thrust and constant values of the other cycle variables. The curve shows TSFC to be decreasing with increasing pressure ratio, but leveling off and starting to rise again at the high end. Further analysis of the tabulated results in the appendix would indicate that TSFC will continue to improve at the higher cycle pressure ratios in combination with higher turbine inlet temperatures.

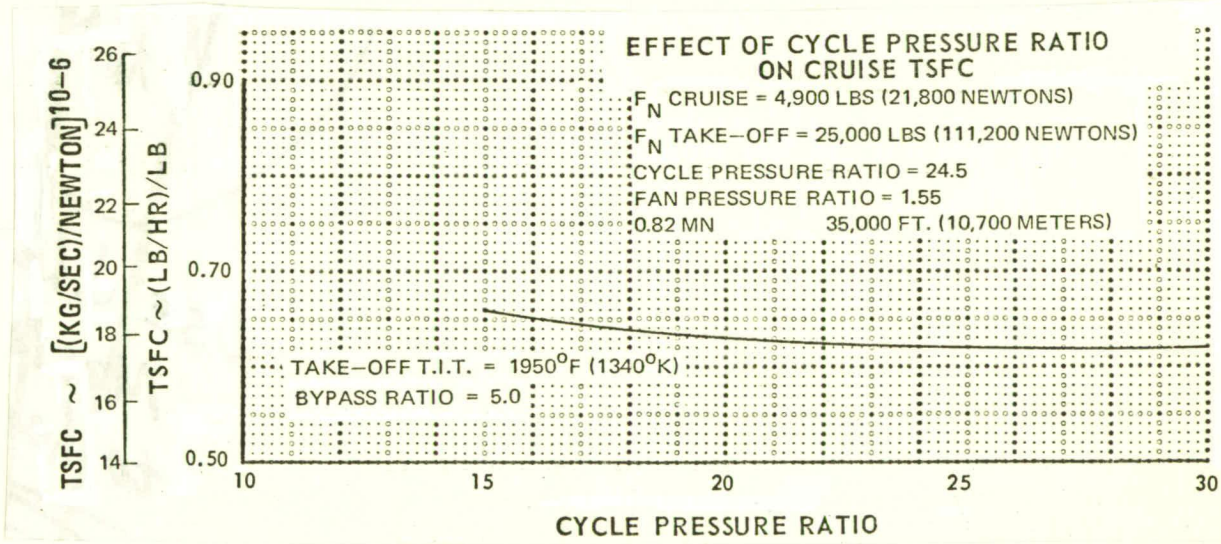


Figure 6 Effect of Cycle Pressure Ratio on Cruise TSFC

The curves are presented for specified values of the various cycle variables to represent the middle of the range in each case. It should be emphasized that the trends shown will vary when presented for the extremes of the ranges for the variables.

SECTION III
NOISE

A. GENERAL METHOD

Noise calculation requirements in Task I were to provide predictions of jet and total noise during takeoff, cutback, and landing for 240 engine cycles. These predictions were made using the most up-to-date turbofan prediction procedures available. Predictions in detail for 43 sample engine cycles served as the model for the regression analysis which provided noise estimates for the remaining cycles. Additional noise predictions were completed to validate the accuracy of the regression analysis technique.

Engine noise level estimation procedures neglected the influence of all sources of noise ordinarily found to be inconsequential, and considered only jet exhaust noise and overall fan noise as contributing sources. Jet exhaust noise levels were calculated by application of the Lighthill relationship; fan noise levels were approximated by using Pratt & Whitney Aircraft established empirical correlations of noise levels as a function of fan tip Mach number. All cycles were assumed to have single-stage fans with the basic noise reduction features of no inlet guide vanes, optimum fan blade and exit guide vane number combinations, and ample axial spacing between the fan blades and the exit guide vanes. Further details in noise calculation procedures and background are provided later in this section.

To aid in the selection process and to economize on the length and complexity of calculations, noise levels were computed for each sample engine cycle for the following points of interest:

- Peak jet and peak total (fan and jet) perceived noise levels (PNL's) on the ground at takeoff, three miles from brake release.
- Peak jet and peak total PNL's on the ground after cutback to 1000 ft/min (304.8 meter/min.) rate of climb at 1000 ft (304.8 m) alt.
- For cycles which resulted in an aircraft altitude of greater than 1000 ft. (304.8 m.) three miles (4.830 Km) from brake release, peak jet and peak total PNdb's on the ground after cutback to 1000 ft/min (304.8 $\frac{m}{min}$) rate of climb, three miles (4.830 Km) from brake release.
- Peak jet and peak total PNdb's on the ground during approach, one mile (1.609 Km) from touchdown.

In order to provide examples of the relationship between the peak perceived noise levels specified above, and noise level contours on the ground around the runaway, PNdb contours were calculated and plotted for four of the cycle combinations. These plots are provided in Appendix B.

The following consecutive steps were involved in obtaining the noise output values for the selected sample engines:

1. Select sample cycles.

2. Calculate cruise design cycle performance.

3. Calculate the sea level takeoff size for each cycle scaled to 20,000 and 25,000 lbs. (88,960 and 111,200 newtons) thrust.

4. Calculate performance for takeoff down the runway necessary to compute noise (both thrust levels).

5. Calculate performance for approach power necessary to compute noise (both thrust levels).

6. Determine the 3 mile (4.830 Km.) point aircraft altitude for each engine combination.

7. Calculate cutback performance necessary to compute noise (both thrust levels).

8. Compute jet and total noise for takeoff, cutback, and approach conditions (both thrust levels).

9. Perform regression analysis for all noise conditions to obtain values for 240 cycle combinations from the sample values computed in steps 1 through 8.

Calculation of engine performance in steps 1. through 5. followed the procedures and assumptions described in Section II of this report.

1. Noise Predictions Background

Two major sources for noise generation are inherent in turbofan cycle engines. Jet noise is generated aft of the engine nozzle in the region where the high velocity jet streams mix with the ambient air. Fan noise is generated internally in the fan section of the engine and is radiated forward out the inlet duct and rearward out the fan discharge duct. Noise is generated independently by these two sources and engine far field noise characteristics can be evaluated only by predicting separately the contribution from each source at pertinent locations and then combining these noise levels to determine the peak perceived noise level.

a. Jet Noise

Jet noise is generated in the region aft of a nozzle where the high velocity jet

mixes with the ambient air. This mixing region may extend for about 20 nozzle diameters aft of the nozzle exit plane. High frequency broadband noise is generated near the nozzle where the turbulent mixing boundary is relatively thin and consists of small size eddies. Lower frequencies are generated further downstream from the nozzle exit plane. Thus jet noise contains energy at all frequencies in the audible range from about 20 cps to 10 kcps. Peak noise levels are shifted lower in frequency as the nozzle size is increased, or as the jet velocity is reduced as shown by Figure 7 which relates spectral energy distribution to the Strouhal parameter, f/v/d .

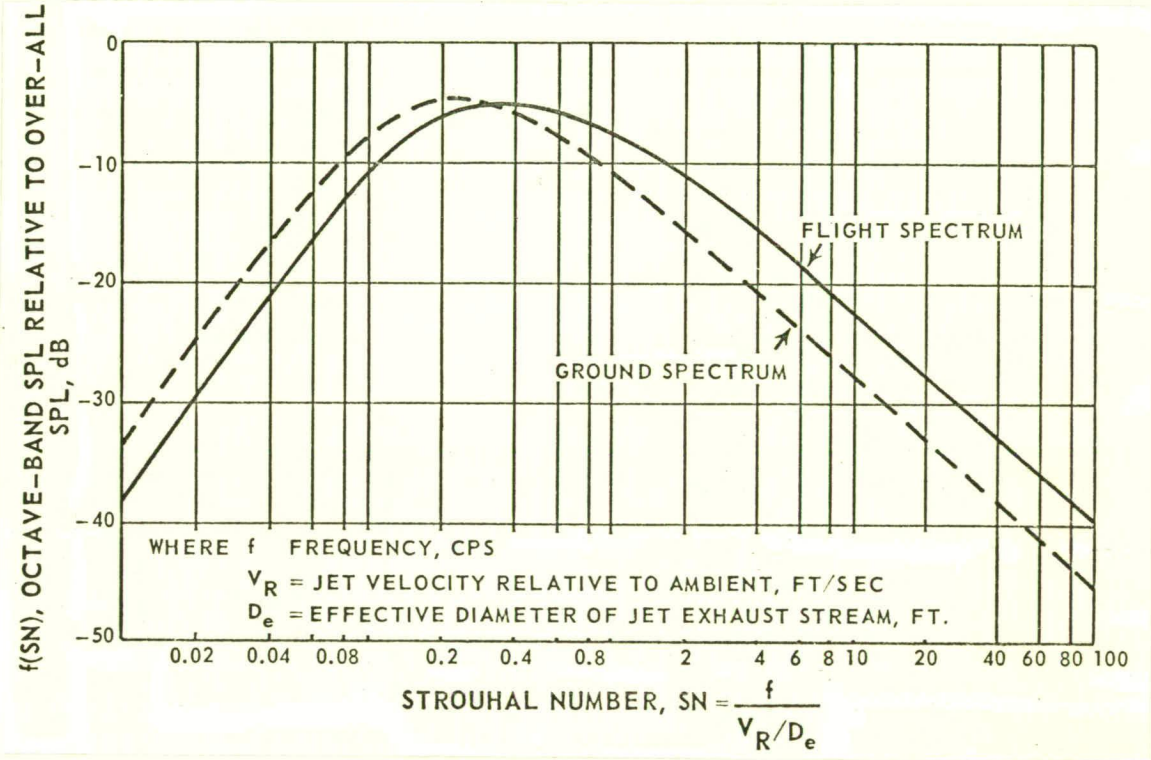


Figure 7 Octave Band Jet Noise vs. Strouhal Number

b. Fan Noise

Standard procedures for predicting fan noise levels have not been devised because the nature of fan noise generation does not lend itself to normalization as does jet noise. Fan noise cannot be related directly to fan performance parameters such as horsepower absorption, pressure rise, efficiency, airflow, etc., but is determined to a large extent by the geometric design of the fan and the tip speeds at which it is operated. Three basic types of fan noise illustrated on the typical spectral plot of Figure 8 must be accounted for in the prediction. These noises are described in the following paragraphs.

Figure 8 Fan Noise Frequency Spectrum

(1) Blade-Vane Interaction Noise

Generation of the very prominent "whine" emanating from the fans of current JT3D and JT8D engines can be attributed largely to the chopping of the fan blades through the wakes from upstream vanes and the interaction of fan blades wakes with the pressure fields of downstream stator vanes. Both these processes generate noise at the fundamental blade passing frequency, which is related to the number of rotor blades and the rotor RPM, and its harmonics. Whether or not these noises are propagated out the inlet and fan ducts, or decay within a short distance from the fan can be determined by the number of vanes used in the stationary rows fore and aft of the rotor, and to some extent by the axial flow velocity. Generally a vane number of greater than twice the rotor blade number is required to ensure decay of the noise. This discrete noise generating mechanism is explained briefly below.

For each choice of rotor-blade and stator-vane numbers, the interaction location of the blades with the vane wakes will progress circumferentially around the rotor at some speed other than rotor speed, much as the alignment locations on a

TOP

76%

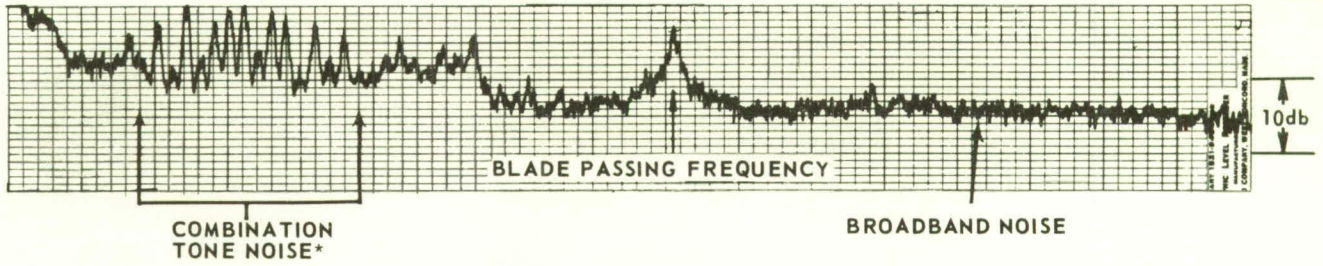
PRATT & WHITNEY AIRCRAFT

TEST CELL INLET NOISE SPECTRA

25 CYCLE BAND WIDTH ANALYSIS

SINGLE STAGE GUIDE-VANE-LESS FAN

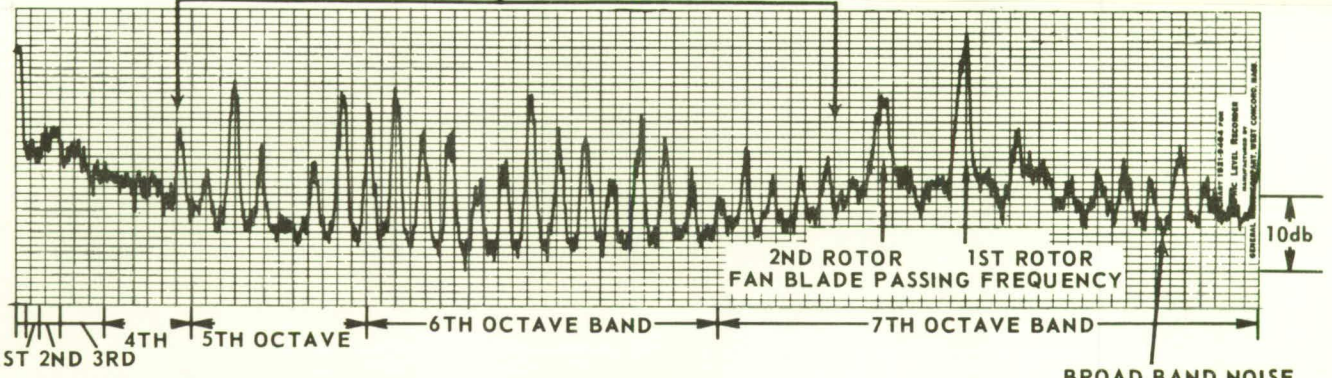
1255 FT/SEC (382.5 M/SEC) BLADE TIP SPEED



TWO STAGE CONVENTIONAL FAN WITH INLET GUIDE VANES

COMBINATION TONE NOISE*

1230 FT/SEC (374.9 M/SEC) BLADE TIP SPEED



SOUND PRESSURE LEVEL-db re 0.0002 DYNES/cm^2

FREQUENCY

*UNLABELED DISCRETE FREQUENCY PEAKS PRODUCE COMBINATION TONE NOISE

FREQUENCY SEPARATION IS ROTOR SPEED IN REVOLUTIONS/SECOND

PAGE NO. 3-20

OK

Fig. 8

FIG 11 pg 23

vernier scale move much faster than does the scale itself. Figure 9 illustrates the speed relationship for a two-lobe interaction pattern which rotates two times as fast as the rotor. When the circumferential wall Mach number of this spinning interaction pattern exceeds sonic speed to a small extent, depending on duct geometry and axial flow velocity, the pattern passes through a "cutoff speed". Above this "cutoff speed", the phasing is such that noise is propagated forward and aft of the rotor. When the pattern speed is below cutoff, the noise decays within a short distance from the rotor. The fan speed at which the "cutoff speed" of the spinning lobed interaction pattern is exceeded, causing the noise to propagate, can be selected by the choice of the number of vanes.

Figure 9 Rotor Stator Interaction Pattern

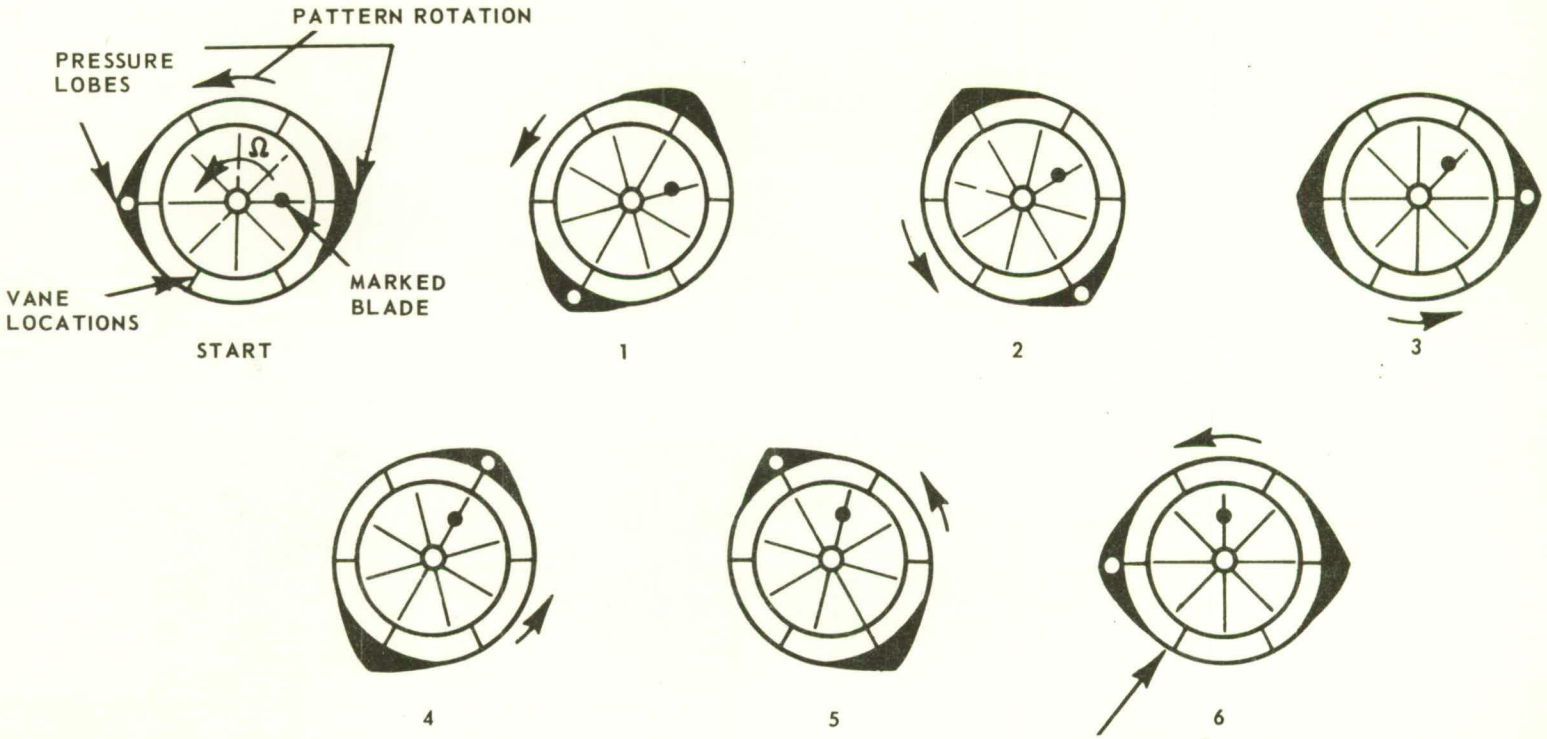
(2) Fan Broadband Noise

The underlying phenomena which generate fan broadband ("white") noise are less well understood than those which generate discrete noise. For a given design fan, broadband noise appears to increase at about the 5th power of the fan blade tip speed and is generated as a result of the turbulent flow of air past the aerodynamically loaded blade and vane rows in the fan.

PRATT & WHITNEY AIRCRAFT

72%

8 BLADE ROTOR – 6 VANE STATOR
"2 LOBE" SPINNING PRESSURE
PATTERN ROTATES 4 TIMES
ROTOR SPEED



PAGE NO.

Fig. 9

OK

(3) Combination Tone Noise

As the fan blades pass through transonic speeds, a shock wave pattern is formed by each blade in the rotor. Forward of the rotor, these waves decay to a system of Mach waves which propagate forward out of the inlet duct. If each blade in the rotor were identical, wave propagation as described by Figure 10a would be suggested and the resulting inlet radiated noise would be at blade passing frequency. In actual practice, the situation depicted in Figure 10a has not been noted. Small variations from blade to blade, within the normal manufacturing and assembly tolerances, result in a wave pattern which is represented more nearly by Figure 10b. Spectral analysis of this type of wave pattern, which repeats once per engine revolution, produces all harmonics of engine rotational speed in revolutions per second. The resulting combination tone noise is perceived as a low-pitched sound, quite unlike the typical discrete noise generated by blade-vane interaction noise.

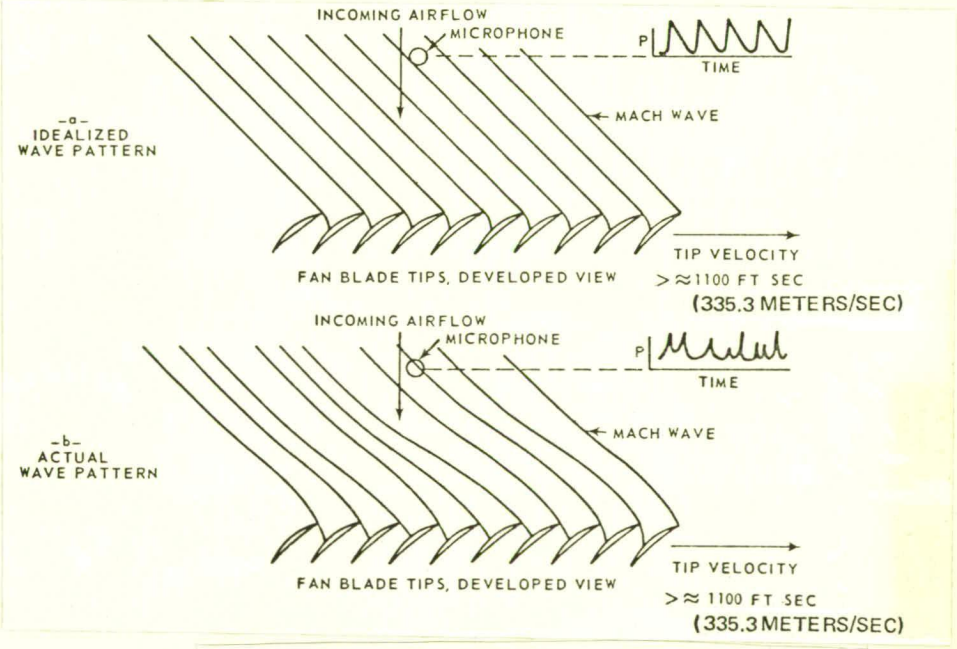


Figure 10 Supersonic Fan Blade Tip Noise

c. Other Engine Noise Sources

In addition to the major noise sources, the fan and the jet, other noises are generated by jet engines. At very low power operation, gear meshing and bearing noises may be of sufficient strength so as to be measured and identified. In many instances, primary engine compressor stages downstream of the fan radiate noise out the inlet. In the idle power range, turbine blade passing frequency noises from current engines normally can be detected. Narrow band analysis of data from current engines indicates that turbine noises quickly become overshadowed by fan and

jet noise as the engine thrust is increased to the power range normally used for approach. Although these other noises are generated by current engines, they normally are of little significance to the community noise problem. Only if the two major noise sources, the fan and the jet exhaust, were substantially eliminated would these other noise sources become a major factor in establishing engine noise levels. Even with engines where the latest technology is used to minimize fan and jet noise, it does not appear that noise from these other sources will be of importance to the overall noise characteristics of the engine. For the purposes of the present study, the contribution of these other engine noises were neglected.

2. Aircraft Performance

Before quantitative noise estimates could be made for the parametric engine cycles evaluated in this study, it was necessary to establish a procedure to predict aircraft take-off and climb-out performance so that engine noise estimates could be made at any point on the ground in the vicinity of the aircraft.

An approximate generalized procedure was established for use in Task I calculations to predict aircraft take-off distance to 35 ft (10.67 m) altitude (over the obstacle); and to predict the altitude during climb-out at a given horizontal distance from brake release.

Thrust requirements were also established for begin cruise at 35,000 ft (10,700m), Mach 0.82 at maximum take-off gross weight and landing at maximum landing weight.

In all cases a 707-320 type aircraft was assumed.

The general aircraft characteristics which were used in the study are as follows:

Take-off gross weight	325,000 lb.	(147,000 Kg.)
Wing Area	2890 ft.^{2}	(278 m^2)
CD_o clean	0.0140	
ΔCD_o gear	0.0189	
Induced drag factor	0.054	
Aspect Ratio	7.05	

Additional aircraft characteristics for the specific flight conditions of Maximum Take-off Power, Throttled Take-off Power, Approach and Cruise are given in Table III.

TABLE III
SUMMARY OF AIRCRAFT CHARACTERISTICS

The flight profile of the aircraft during take-off is shown in schematic form in Figure 11. This profile is the one recommended by Boeing in its 707-320 flight manual and meets or exceeds the minimum F.A.A. take-off requirements. The procedure followed is to accelerate to a lift-off speed such that at the obstacle height of 35 ft (10.7 m) the velocity will be 167 kts (85.8 meters/sec) (1.2 V_{stall}). The aircraft continues to accelerate, at 1 ft/sec^2 (3048 m/sec^2), until its velocity is 177 kts (89.98 meters/sec) (1.2 V_{stall} + 10 kts (5.14 meters/sec)). At this point an Equivalent Air Speed (E.A.S.) climb path of 177 kts (89.98 meters/sec) is established. The flaps are retracted at 1000 ft (304.8 m) altitude and the aircraft continues along the constant E.A.S. path.

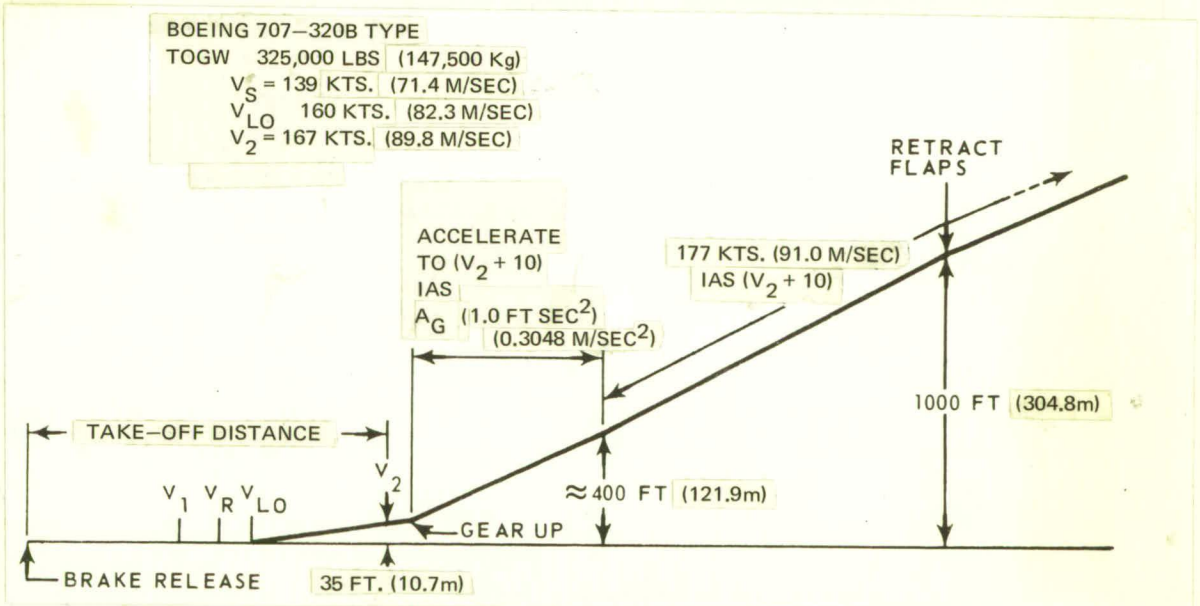


Figure 11 Take-off and Climb-out Procedure

TOP

	Take-Off		Approach	Cruise
	Max. Power	Throttled		
Aircraft Wt (lbs.) (Kg)	325000 (147,500)	325000 (147,500)	207000 (93,980)	307800 (139,700)
Flap Setting (deg.)	14	14	50	0
ΔCD_o flaps	.0108	.0108	.0745	---
$C_{L\ max.}$	1.71	1.71	2.12	1.21
V_{stall} (kts.) (meters/sec)(T.A.S.)	139.3 (71.4)	139.3 (71.4)	100 (51.4)	---
$V_{ref.}$ (kts) (meters/sec) (T.A.S.)	167.2 (85.8) (1.2Vs)	167.2 (85.8) (1.2Vs)	130 (66.8) (1.3Vs)	---
$V_{climb-out}$ (kts.) (meters/sec)	177 (91.0) (EAS)	177 (91.0) (EAS)	---	M=.82 (3500ft.) (10,668m)
Segment Average L/D	12.7	12.7	7.0	15.7
Flap Retraction Altitude (ft.)(meters)	1000 (304.8)	1000 (304.8)	---	---
Thrust per Engine (lbs.) (newtons)	Max. T.O.	10,300 (45,800)	4800 (21,350)	4900 (21,800)

TABLE III 63%

Under certain conditions during the climb-out it is feasible to reduce the engine power setting. At an E.A.S. of 177 kts (89.98 meters/sec.), 10300 lbs (45,814 newtons) was the computed thrust per engine that would be required to allow a 1000 ft/min (304.8 m/min) rate of climb at an altitude of at least 1000 ft (304.8 m).

The approach is conducted at maximum landing weight at a speed of 130 kts (1.3 V_{stall}) and maximum glide slope of 3°. The power setting, calculated at an altitude of 300 ft (9144 m), 1 mile (1.609 Km) from touchdown, was 4800 lbs thrust, as indicated in Table III.

Based on the Table III assumptions, cruise at 35000 ft (10,700 m), Mach 0.82 requires 4900 lbs (21,800 newton) of installed thrust per engine at an estimated begin cruise weight of 307,800 lbs (140,000 Kg). Roughly, installation penalties can be assumed equal to the required climb power margin for engine sizing approximations.

Take-off and climb-out profiles may be calculated by means of a computer program in accordance with specific input directions. The input consists of:

- the aircraft geometry
- lift coefficient vs drag coefficient data
- lift coefficient vs angle of attack data
- thrust vs velocity data

At each point along the flight path the program calculates:

- speed
- acceleration
- distance from brake release
- altitude
- flight path angle
- angle of attack
- lift coefficient
- time from brake release
- thrust
- lift to drag ratio

Because of the large number of parametric engines to be evaluated, a correlation using representative engine performance was felt to be in order. The resulting curves are given in Figure 12. In the top figure is shown the distance from brake release to the obstacle as a function of sea level thrust 114 kts. $(58.6 \frac{\text{meter}}{\text{sec}})$. In the bottom figure is shown, equivalent to the velocity at which the average value of dynamic pressure occurs during the take-off run, the altitude at any point from the obstacle as a function of the sea level thrust at 170 kts $(87.4 \frac{\text{meter}}{\text{sec}})$ (approximately the average velocity between sea level and 1000 ft (304.8m) alt). A straight line between the two points establishes a flight path.

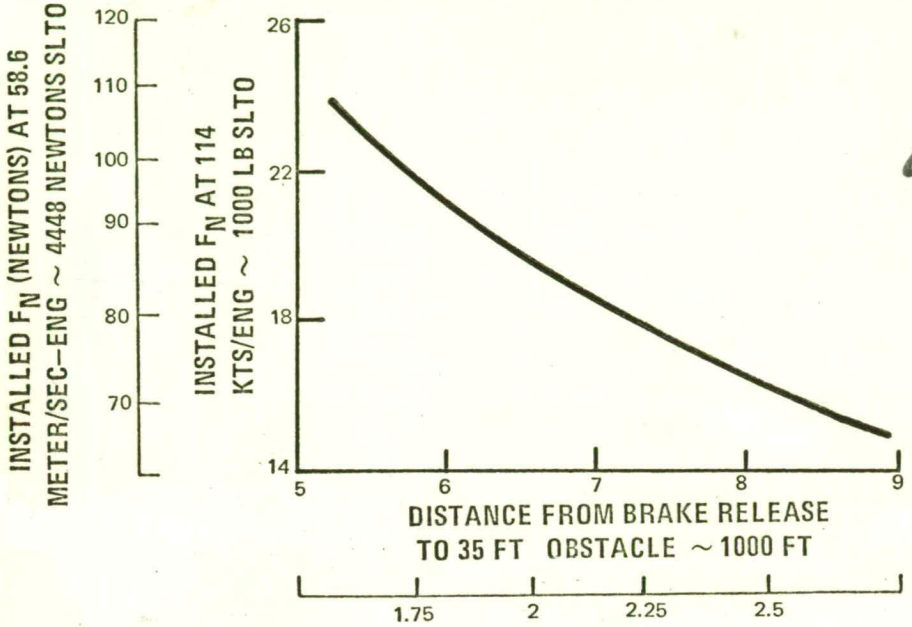
To verify the accuracy of Figure 12 a detailed check was completed. Figure 13 shows a comparison of the flight path of several engines run on the computer program and the flight path predicted by the correlation. The differences between the two is within ±50 ft (±15.24 m) altitude, which is considered within the allowable tolerance for noise calculations. The variations are due primarily to the differences in the take-off ground run caused by the difference between using a single value of thrust at some averaged velocity as opposed to the actual integral of thrust times velocity between zero and 1.2 V_{stall}*.

$$*\left(\int_{V=o}^{V=1.2V_{stall}} F_n \, d\,V\right)$$

Fig 12 747

Figure 12 Airplane Performance. 707-320B Type. TOGW = 325,000 lb. (147,500 Kg) Std. Day

Figure 12
747



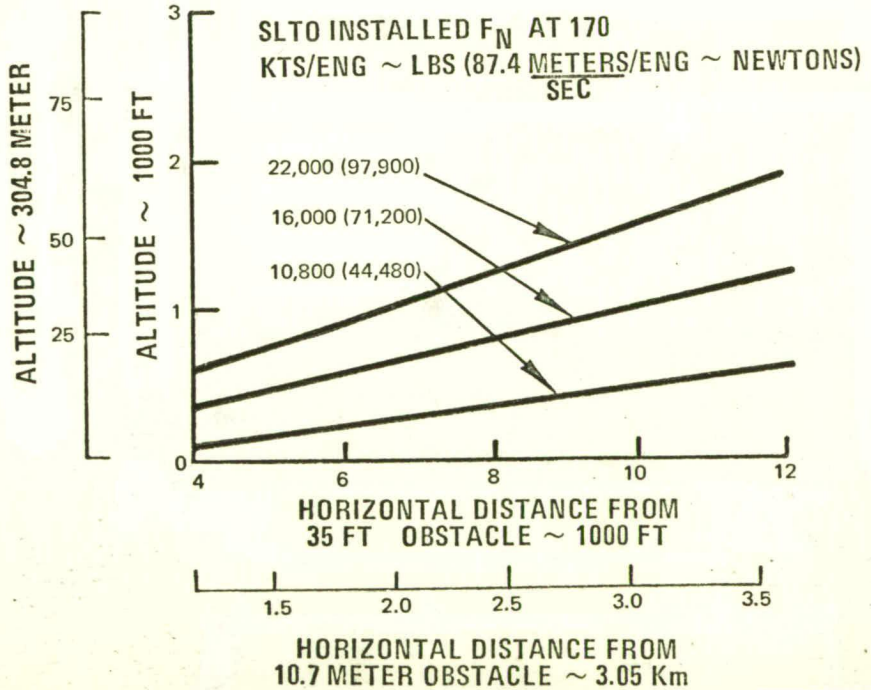


Figure 13 Flight Path Calculation Accuracy Check Results

3. Calculation Procedure

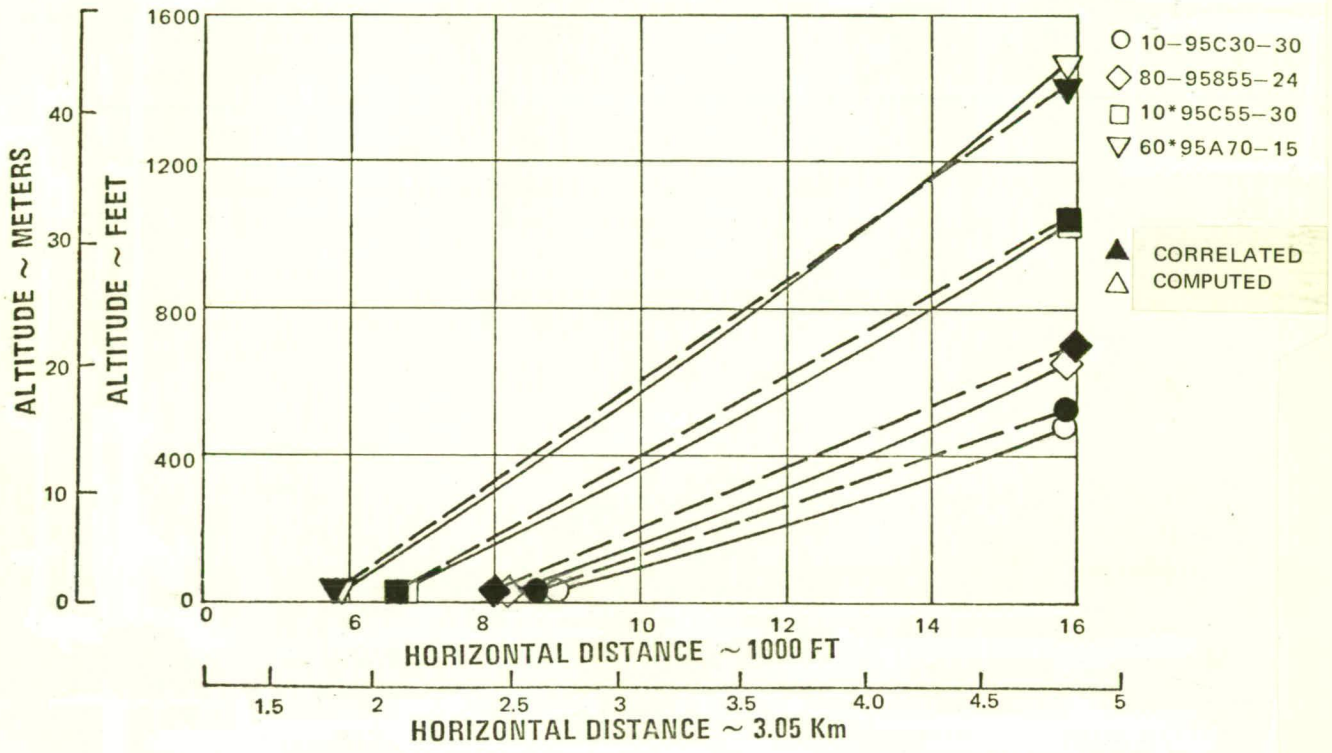
a. General

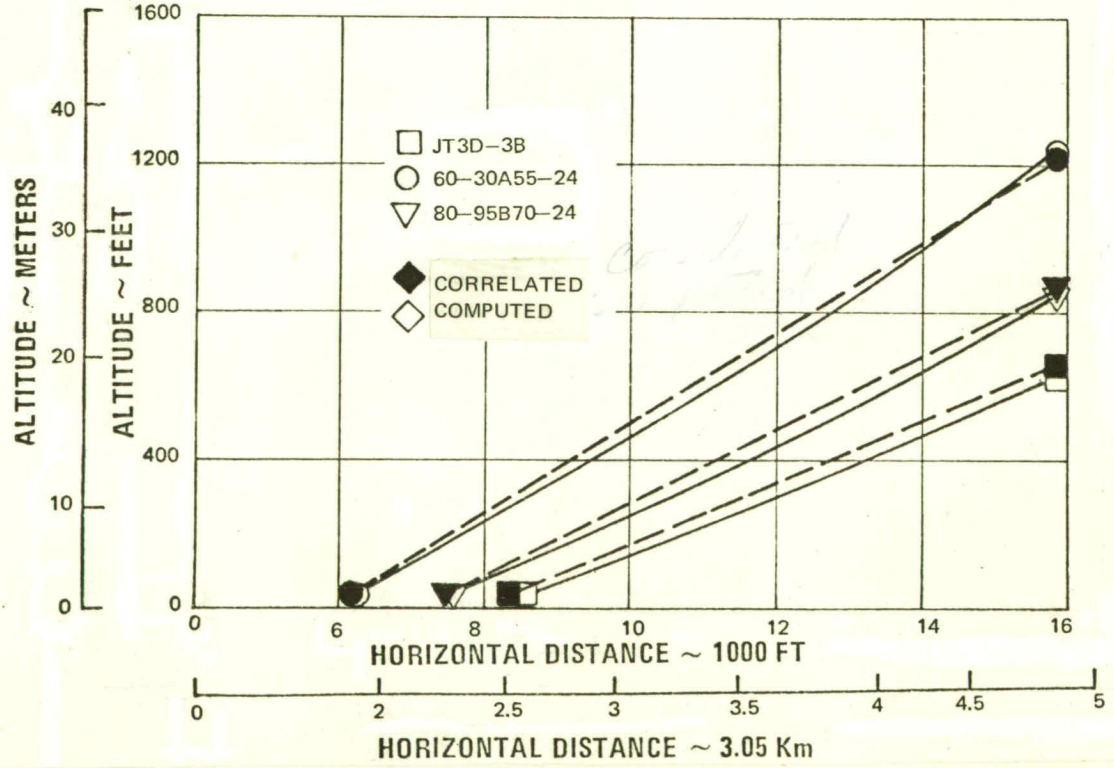
Engine off-design performance calculations for take-off, cutback and approach conditions determined values of fan tip speed and jet exhaust velocities. The output of the engine performance calculation was in the form of punched cards. These cards were used as input to the noise prediction computer program and noise levels at angles of peak inlet, fan discharge, and jet noise were calculated in the computer in accordance with the following consecutive steps:

1. Calculate relative jet velocity (V_j) and exhaust gas density (ρ) from cycle performance.

2. Using V_j, ρ, and other cycle performance, calculate peak 200 feet (60.96 m) sideline jet noise octave band sound levels using the procedure described in SAE document AIR876, "Jet Noise Prediction".

3. From cycle performance calculate relative fan blade tip Mach number.


ALTITUDE ~ METERS
ALTITUDE ~ FEET
HORIZONTAL DISTANCE ~ 1000 FT
HORIZONTAL DISTANCE ~ 3.05 Km
10–95C30–30
80–95855–24
10*95C55–30
60*95A70–15
CORRELATED
COMPUTED


ALTITUDE ~ METERS
ALTITUDE ~ FEET
HORIZONTAL DISTANCE ~ 1000 FT
HORIZONTAL DISTANCE ~ 3.05 Km
JT3D–3B
60–30A55–24
80–95B70–24
CORRELATED
COMPUTED

4. Using blade tip Mach number, determine blade passing frequency octave band level for the inlet and fan discharge 200 feet (60.96 m) sideline interaction and broadband fan noise and inlet 200 feet (60.96 m) sideline combination tone noise. These relationships are discussed in Section c.

5. Using the blade passing frequency octave band level as a reference, the levels of other octave bands influenced by the particular noise source are determined from empirically established spectra.

6. Directivity correction factors are then applied to determine the levels of jet noise at the inlet and fan discharge peak angles, the level of fan noise at the angle of peak jet noise, and the combination tone noise level at the angle of peak fan discharge noise.

7. Logarithmetically sum octave band noise levels from all noise sources, fan and jet, at each location to determine total octave band SPL at each location on the 200 feet (60.96 m) sideline.

8. Total and jet noise octave band sound levels at each 200 feet (60.96 m) sideline location are extrapolated to the required altitude using spherical divergence and standard day (59°F, (200°K), 70% R.H.) atmospheric absorption attenuation rates as defined in SAE document APR866, "Standard Values of Atmospheric Absorption as a function of Temperature and Humidity for Use in Evaluating Aircraft Flyover Noise."

9. Total and jet noise perceived noise levels at the required altitude are calculated in accordance with SAE document ARP865, "Definitions and Procedures for Computing the Perceived Noise Level of Aircraft Noise."

10. Perceived Noise Levels at each location at the required altitude are reviewed to determine the peak total and jet PNL at the altitude.

b. Jet Noise Calculation Method

The noise level generated by a jet is influenced most strongly by the jet relative velocity as shown in Figure 14. Increases in jet stream density and jet area also result in increased noise, but to a lesser degree than jet velocity.

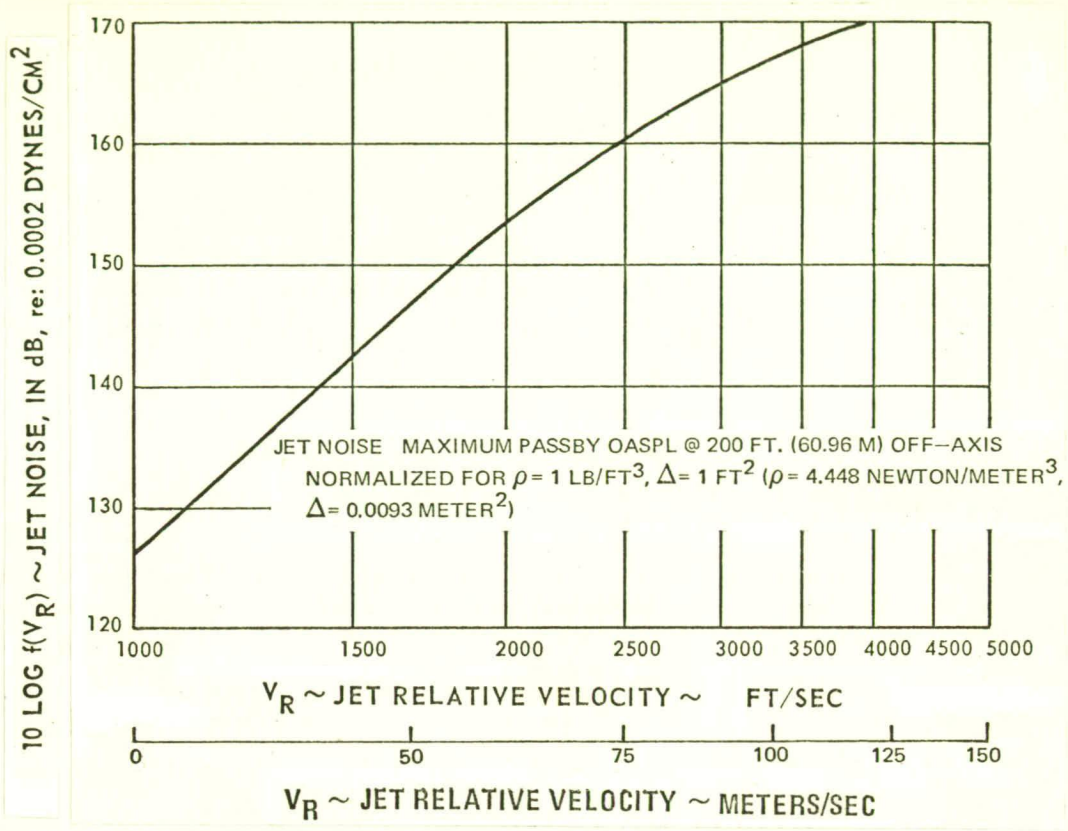


Figure 14 Normalized Jet Noise vs. Relative Velocity

These relationships have been embodied in a noise prediction method evolved by SAE committee A-21 and described in SAE document AIR 876. Pratt & Whitney Aircraft participated actively in the formulation of the procedures outlined in the AIR, and measured noise levels of Pratt & Whitney Aircraft engines agree well with predictions obtained using this procedure.

However, to predict noise levels for high bypass engines at low powers, and hence low jet velocities, it is required that the relationships between jet velocity and noise be extended to lower jet velocities than are covered by the AIR. Pratt & Whitney Aircraft experience indicates that Figure 14 does not hold at jet velocities below 1000 ft/sec (304.8 m/sec) and velocities of several cycles fell below 1000 ft/sec. (304.8 m/sec) at reduced power settings. Although definite relationships have not been confirmed and, therefore, prediction accuracy is decreased, there are indications that at lower velocities the jet noise relates to the jet velocity as shown in Figure 15. The relationship shown in this figure was used in making jet noise predictions.

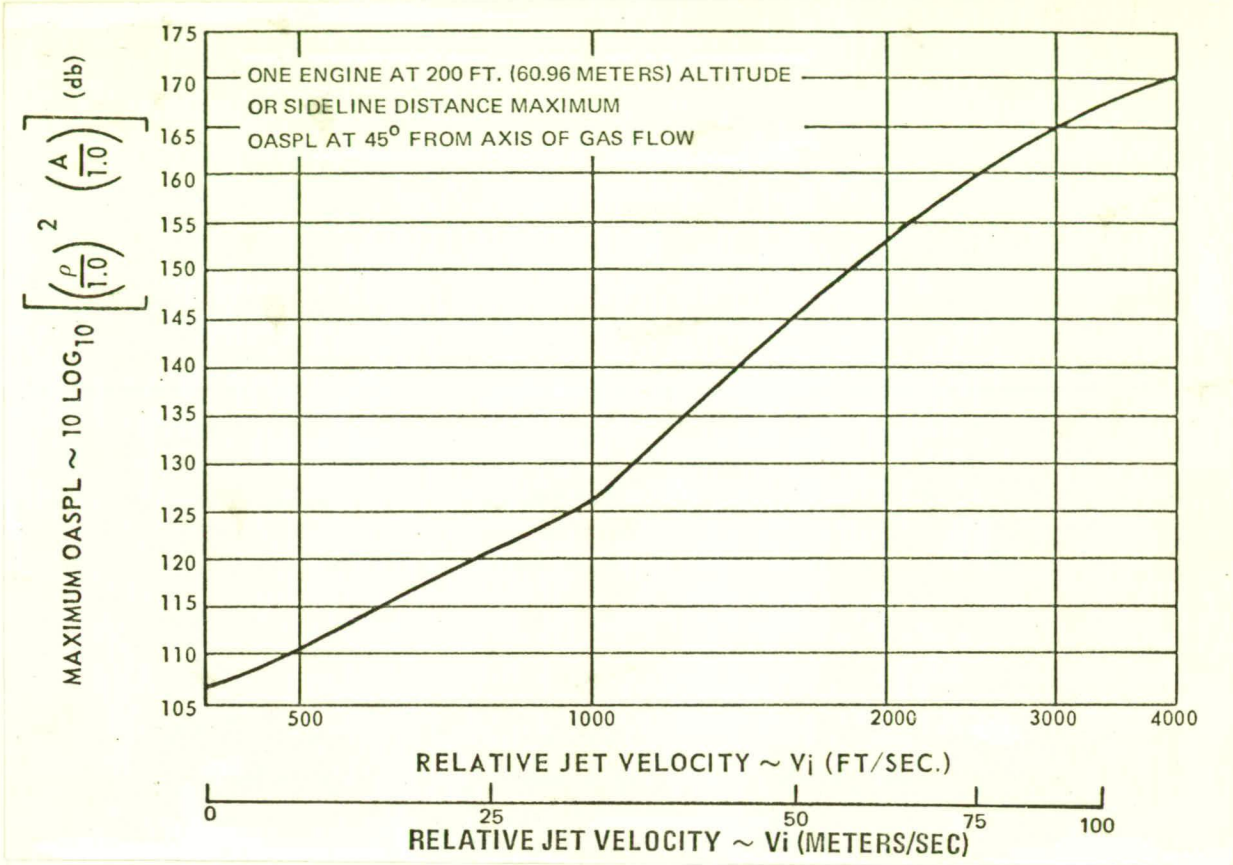


Figure 15 Maximum Overall Sound Pressure Level as a Function of Relative Jet Velocity

c. Fan Noise Calculation Methods

Predictions of fan noise levels for the engine considered in this proposal were made based on extensive noise measurements from Pratt & Whitney Aircraft tests of single stage JTF14E and JT9D type fans. These fans incorporate essentially all the noise reduction features, such as inlet guide vane removal, optimized blade-vane numbers, and optimum blade-vane spacing, which have been found to be practical in past Pratt & Whitney Aircraft noise research programs. In this way, the assumption of advanced noise technology features were made for the engine cycles of the Quiet Engine program. Fan tip speeds of the study engines were selected to be aerodynamically compatible with the cycle fan pressure ratio.

Measurements from the JTF14E fan provided the relationships of broadband and discrete and combination tone fan noise to the relative tip Mach number of the fan blades. Figure 16 shows these relationships as they were used in the noise prediction computer program. It should be noted that in Figure 16 the relative level of the different noise sources are shown only for the octave band containing the fundamental blade passing frequency for the purpose of the facilitating calculations. In the computer program, the blade passing frequency octave band was used as a reference and the levels of the other octave bands were related to the reference octave by empirically predetermined values to obtain a spectrum for the specific noise. As these adjustment values for any given octave band varied according to the noise source, the relative levels of the different noise sources shown in Figure 16 should not be interpreted to represent relative total energy levels or perceived noise levels.

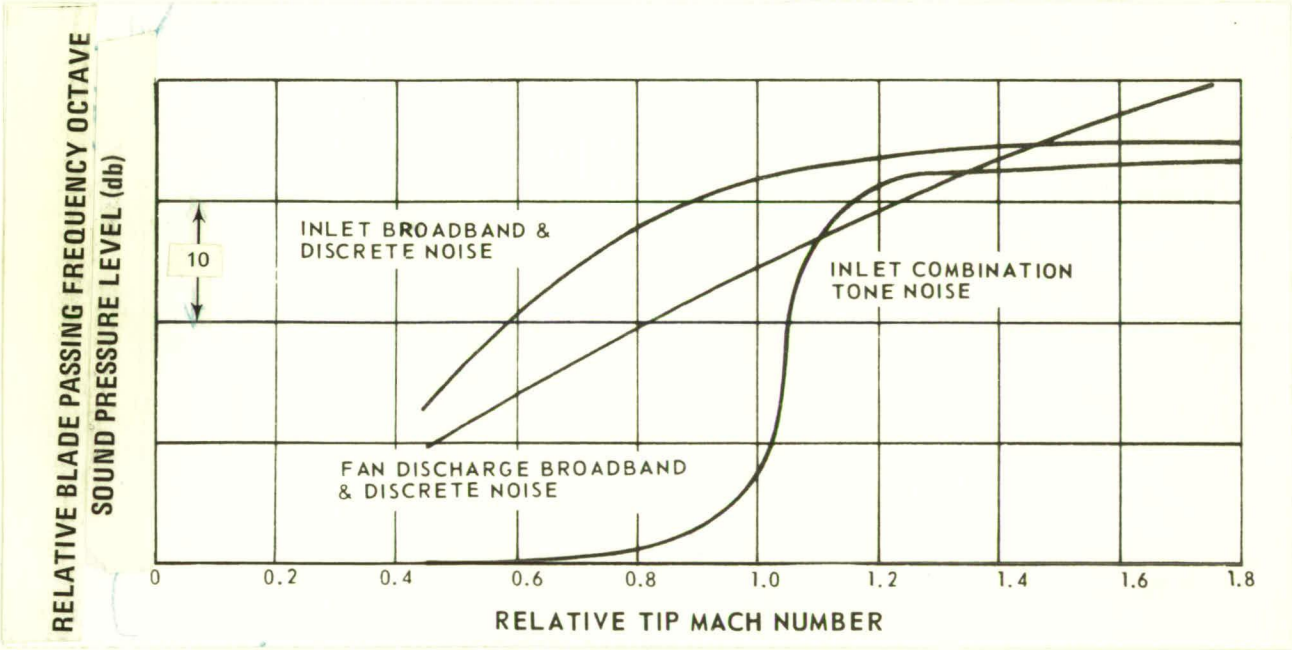


Figure 16 Relative Blade Passing Frequency Octave Sound Pressure Level vs Relative Tip Mach Number

Also for ease of calculation, the contributions of discrete (interaction) and broadband noise to each octave band were combined. The relative contribution of each of these sources for the types of fans considered was assumed constant for any given relative blade tip Mach number.

Noise measurements on which the relationships shown in Figure 16 are based were obtained from far field noise tests of the JTF14E fan engine. This engine, which incorporated state-of-the-art fan noise reduction design features, was tested up to blade tip Mach numbers of about 1.5. For the prediction method

used for this study, data from advanced fan rigs tested on indoor test stands were used to extrapolate the noise vs. tip Mach number curves to Mach 1.75. This extrapolation, made from indoor test rigs not suitable for accurate far field measurement, was necessary because full scale engines with Mach 1.75 tip speeds were not available for outdoor noise tests. Some of the engine cycles considered in the study were predicted to have tip Mach numbers of over 2.0, well beyond the range where data are available. Noise calculations for these cycles, denoted by the symbol "3" in the Data tabulation remarks column, should be disregarded as inaccurate because the tip speed was well outside of the range of empirical data available. Also, these cycles are impractical because they exceed current technology in fan aerodynamics on blade stress levels.

4. Calculation of Noise Level Contours

Coordinates for the contours of noise in the vicinity of the airport for the four selected engine cycles, provided in Appendix B, were calculated by a computer program which followed the following basic steps:

1. Curves of PNL vs. distance were prepared for each of the operating conditions; takeoff, cutback, and approach. These curves were obtained by extrapolating the noise data for the given engine cycle and operating condition to various distances. These curves were used as an input to the program.

2. The flight path of an aircraft equipped with four engines of the given cycle was also input to the program. This flight path was presented in terms of altitude vs. distance from start of takeoff roll or distance from touchdown and was computed based on the procedures described earlier in this section.

3. Coordinates were calculated for the location on the ground which provided the required distance from the aircraft to an observer to result in levels of 90, 95, and 100 PNdb as the aircraft moved along the flight path in 1/4 mile (402.25 meter) increments.

4. The coordinates were presented in the output in a form suitable for machine plotting of the contours.

B. KEY ASSUMPTIONS

1. Jet Noise Calculations

It was assumed that all engine cycles having jet velocities less than 1000 ft/sec will generate jet noise levels as indicated by Pratt & Whitney Aircraft test data (see Figure 15). There are no standard procedures for estimating jet noise levels at these velocities and no relationships have been developed. Measurements from engines operating at these low velocities may be influenced by noise sources other than jet shear noise. These sources include combustion noise, turbine noise, and noise generated by turbulence within the nozzle. The level of these noise sources tends to vary with jet velocity to the fifth power, but the intersection of these curves with the jet shear noise curve, which is related to velocity to the eighth power, may vary from engine to engine. At these low velocities the fan generated noise is much higher in level than the jet noise. Therefore, although the jet noise level is difficult to predict accurately, the total noise does not suffer in accuracy as it is controlled by fan noise and is not influenced by jet noise.

It was assumed that jet noise levels for all engine cycles at velocities above 1000 ft/sec (304.8 m/sec) can be estimated by the procedure described in SAE document AIR 876. This should be a valid assumption for standard circular nozzles as Pratt & Whitney Aircraft measured noise levels agree well with predictions obtained by the SAE procedure.

2. Fan Noise Calculations

It was assumed that fan noise levels from all of the studied cycles can be scaled from measurements from single stage JTF14E and JT9D type fans using relative fan tip Mach number as the reference parameter. This means that each of the studied cycles contains a single stage fan and low noise technology including no inlet guide vanes, optimum fan blade-exit guide vane number combinations, and optimum fan blade-exit guide vane spacing.

3. Inflight Noise Predictions

It was assumed that inflight noise levels can be estimated from sea level static data. All of the reference JTF14E and JT9D type fan measurements were obtained during sea level static operation. No standard procedures are available for predicting inflight noise levels from sea level static measurements. The procedure used by Pratt & Whitney Aircraft relates the sea level static to inflight noise levels on the basis of engine performance at the two operating conditions. Comparisons of JT3D and JT8D measured inflight and estimated inflight perceived noise levels using the Pratt & Whitney Aircraft estimation procedure have shown acceptable agreement.

4. Regression Analysis of Noise Levels

It was assumed that the "3 point curves" used in the regression analysis (described in the Appendix) are adequate to estimate noise levels. The ability to use regression analysis to obtain perceived noise levels with acceptable accuracy must be considered because of the large number of factors which influence the perceived noise level. Each of the cycle performance parameters which affect noise can influence different octave bands. Thus, as perceived noise level is calculated from the octave band levels, it can be seen that simple relationships do not necessarily exist between perceived noise level and the cycle performance parameters. In order to provide a check on the regression analysis, over 300 individual data points were calculated by the noise prediction computer program in addition to the 301 data points calculated for the 43 cycles used as the regression analysis model. A comparison of the noise levels calculated by regression analysis resulted in a very good agreement. The accuracy of the regression analysis is discussed from the purely mathematical viewpoint in Appendix C.

5. Airplane Installation

It was assumed that an airplane installation of any of the engines studied would provide an aerodynamically clean inlet. The basic engine design contains low noise technology which is intended to minimize interaction noise. The incorporation of struts or any other hardware in the aircraft inlet which would generate flow inconsistancies that could be chopped by the passing rotor blades, and thus generate interaction noise, would defeat the purpose of the low noise technology in the engine design.

6. Estimates Based on Current Technology

All of the engines and rigs which provided the basic data for the prediction procedure used in this study included current low noise technology in their design. Thus, the noise estimates for each of the cycles studied assumes that the engine design incorporates the current state-of-the-art in low noise technology.

C. DISCUSSION AND INTERPRETATION OF RESULTS

Because of the wide range of combinations of variables included in the Task I study, it is difficult to detect clear trends which hold without exception. Certain broad trends, however, are fairly evident.

At take-off power, some cycles produce noise levels where the dominant source is the jet exhaust velocity, while in others fan generated noise dominates. Generally, low fan pressure ratio, low bypass ratio, and high turbine inlet temperature engine cycles tend to have high exhaust noise levels.

Fan noise is dominant at cutback take-off power for the majority of the engine cycles considered; it is dominant for all engine cycles at approach power.

Engine size is an important factor in determining take-off noise levels because of the effect of take-off thrust on airplane climb rate. Airplane altitudes at the three mile point (4.827 Km) proved substantially higher in all cases where the aircraft is powered by the 25,000 lb. (111,200 newtons) thrust size engine rather than the 20,000 lb. (88,960 newtons) thrust engine. Increased altitude provides particularly greater attenuation of noise radiated directly toward the ground. Another advantage of the more powerful engine is its ability to make larger reductions in power for the cutback to 1000 ft/min (18.24 m/sec) climb rate at a shorter distance from STOR. The advantages of the higher thrust engines are illustrated by both the peak noise levels tabulated for the study cycles and by the representative noise contour plots presented in Appendices A and B, respectively.

Representative trends between noise and some cycle performance parameters are shown in selected cross plots of the data. Figure 17 illustrates that cycle pressure ratio has a negligible effect on noise. Figures 18, 19 and 20 illustrate the effect on noise of changes in bypass ratio for three levels of fan pressure ratio. The substantial increase in take-off noise at low bypass ratios for low fan pressure ratio cycles was observed to result from the high jet exhaust noise of these cycles. Figure 21 illustrates the effect on take-off noise of fan pressure ratio. Increased noise at low pressure ratios resulted from high levels of jet exhaust noise. These figures are representative of trends taken in the middle of the range of the various cycle variables.

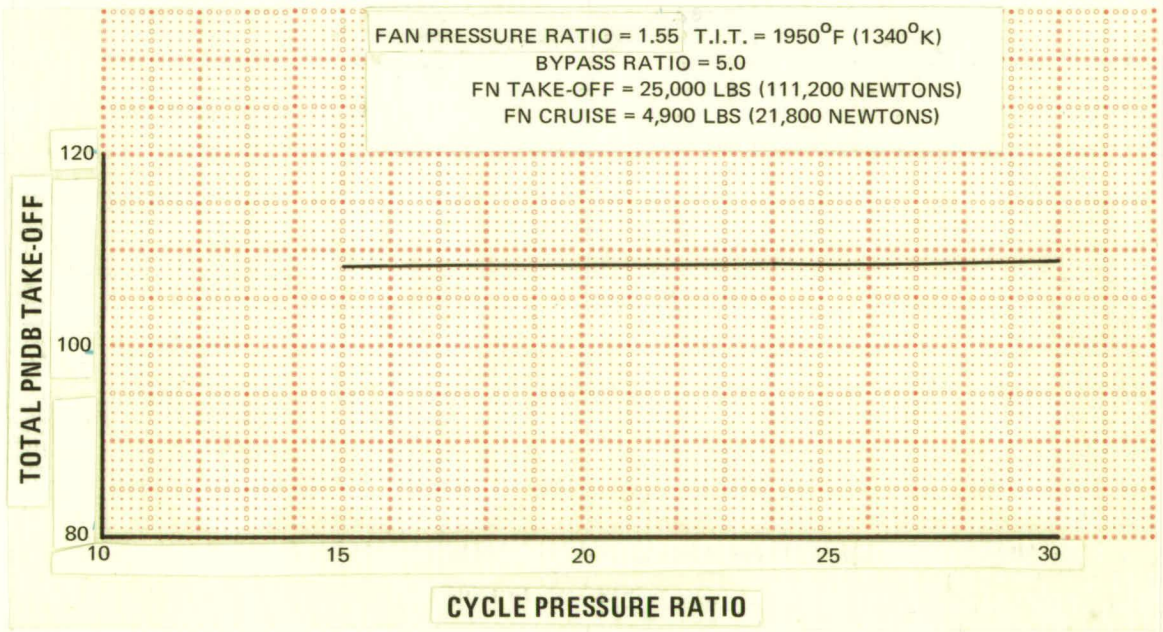


Figure 17 Total Noise vs Overall Pressure Ratio

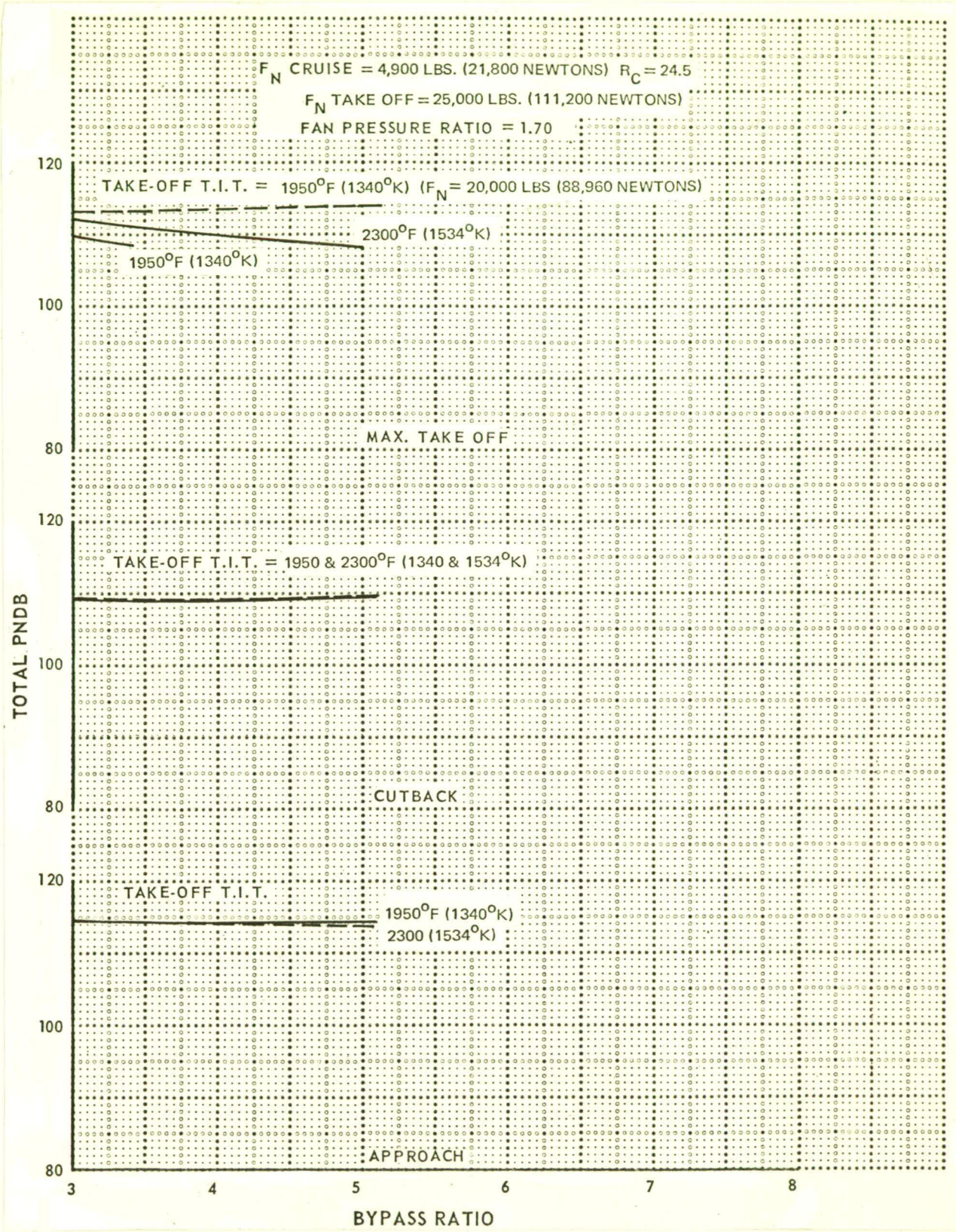


Figure 18 Total Noise vs Bypass Ratio and Turbine Inlet Temperature

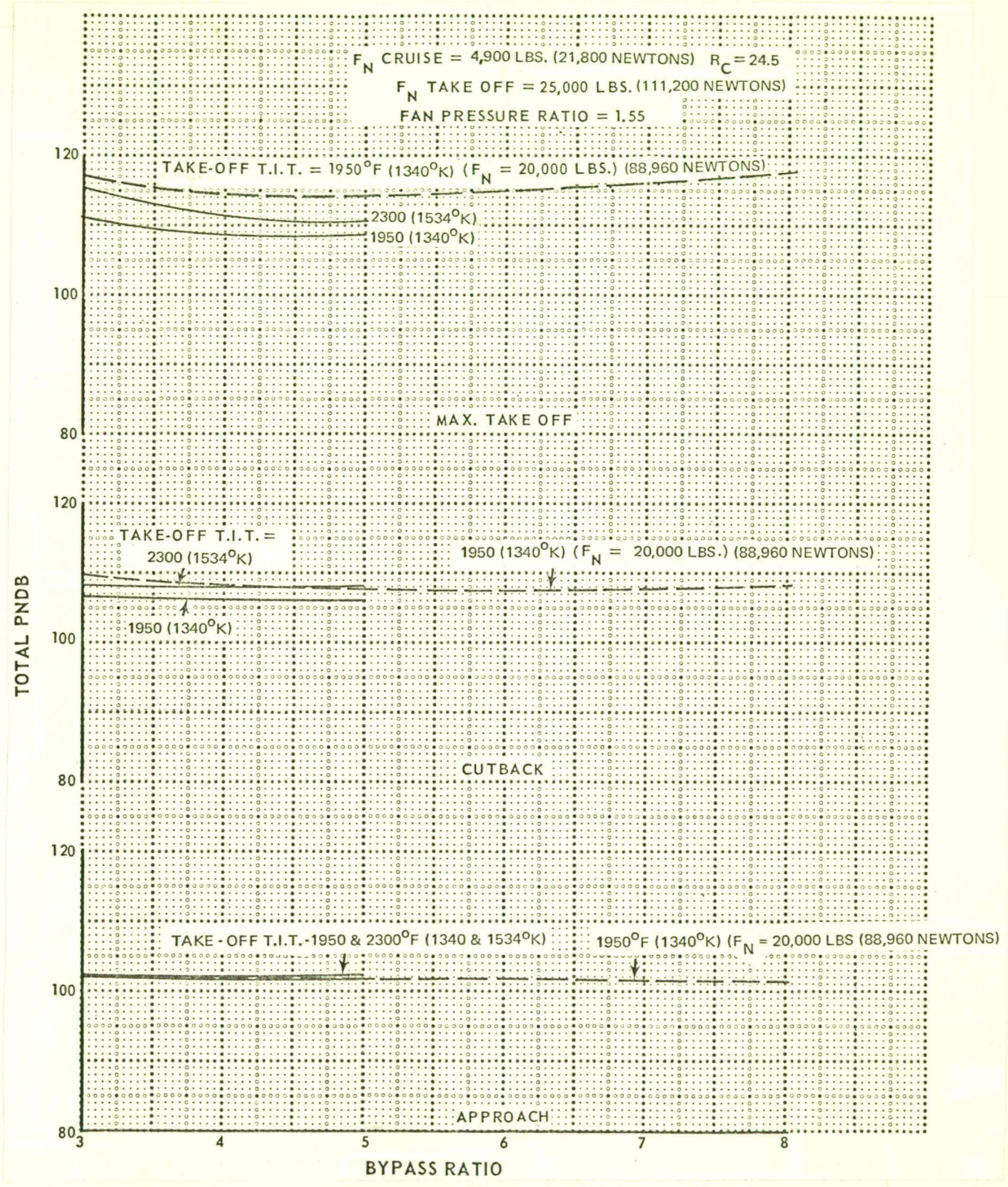


Figure 19 Total Noise vs Bypass Ratio and Turbine Inlet Temperature

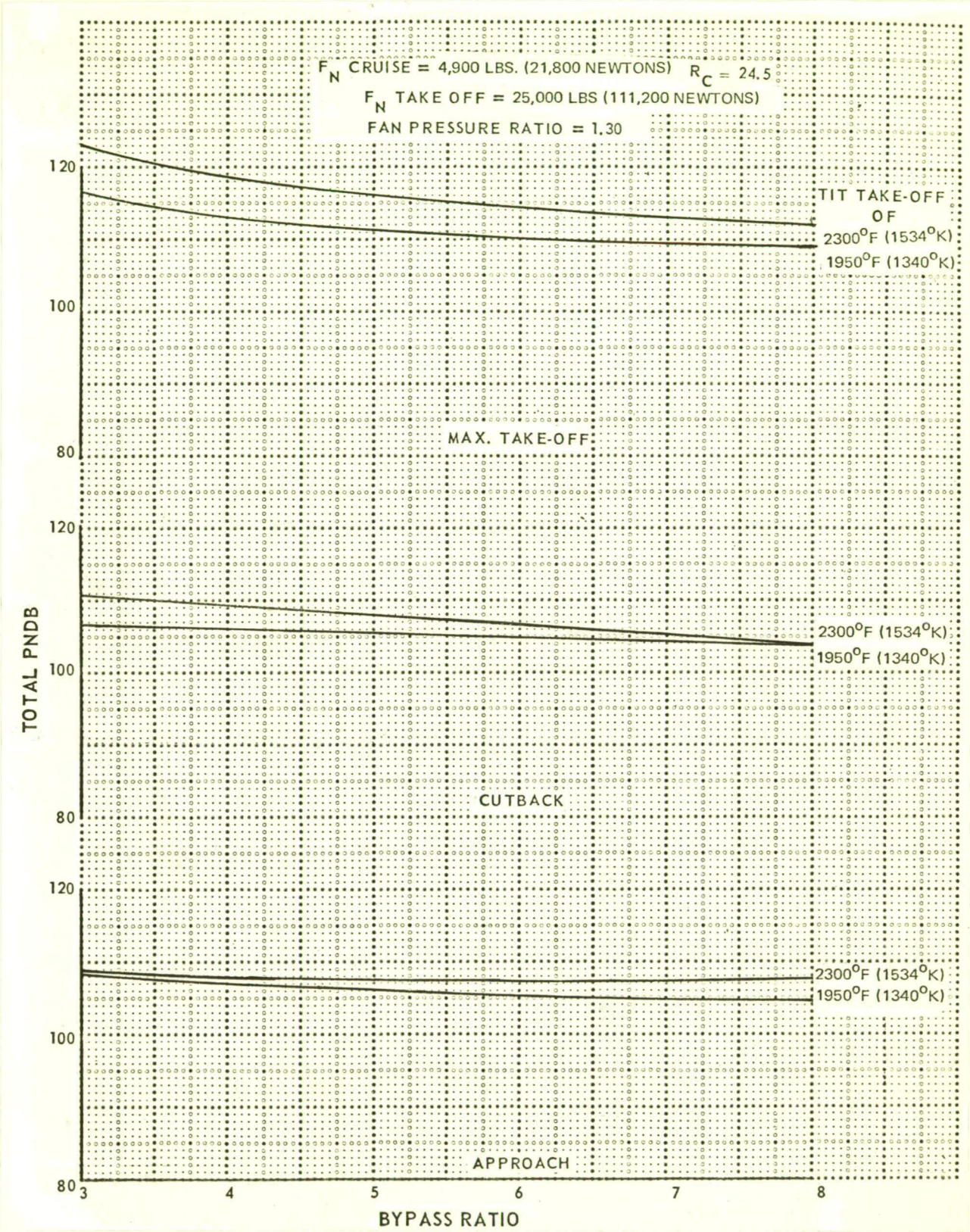


Figure 20 Total Noise vs Bypass Ratio and Turbine Inlet Temperature

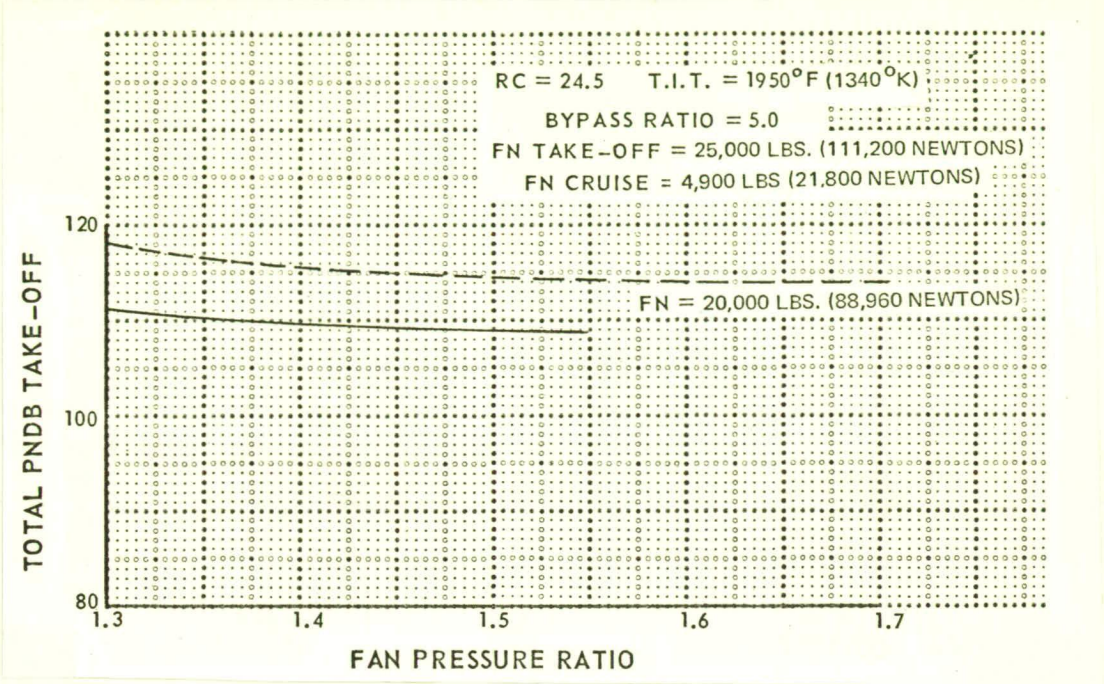


Figure 21 Total Noise vs. Fan Pressure Ratio

Typical noise contours for takeoff and landing for two different thrust size engines are shown on Figures 22 and 23 with comparable contours represented in the JT3D-3B, which currently powers DC-8 and Boeing 707 aircraft in Figure 22. Takeoff noise from the 20,000 lb. (88,960 newtons) thrust engine is shown to overlap that of the JT3D-3B, being quieter beneath the flight path near STOR but noisier further out from STOR. Power cutbacks are of little benefit for either engine. Approach path noise contours are reduced in size from those of the JT3D-3B.

Figure 23 illustrates the reduction in size of the takeoff noise contours for an engine having 25,000 lbs. (111,200 newtons) takeoff thrust. This reduced size takeoff noise contour can be achieved at no increase in landing noise over that of the smaller, 20,000 lb. (88,960 newtons) thrust size engine as the ability to operate the larger engine at reduced percent power to obtain the fixed approach thrust noise level tends to balance the effect of engine size on noise radiated.

Included in the tabulations in Appendix A are the noise levels predicted both for total noise and for jet noise only. The difference between these values reflects the ability to make noise reductions in the engine installation from the use of choked or lined inlet ducts, or the use of acoustically lined fan discharge ducts to suppress the internally generated fan noise.

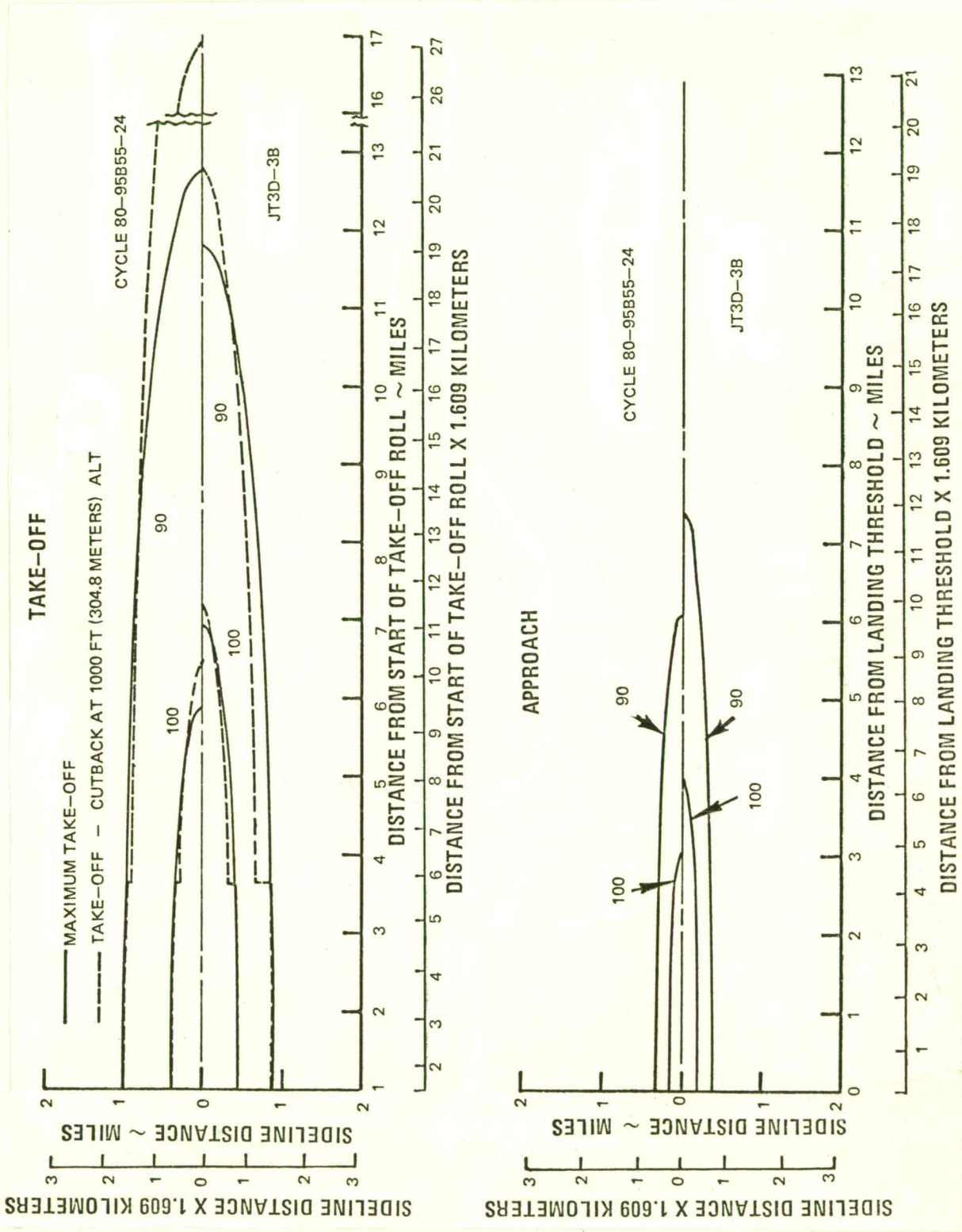


Figure 22 Perceived Noise Level Contours

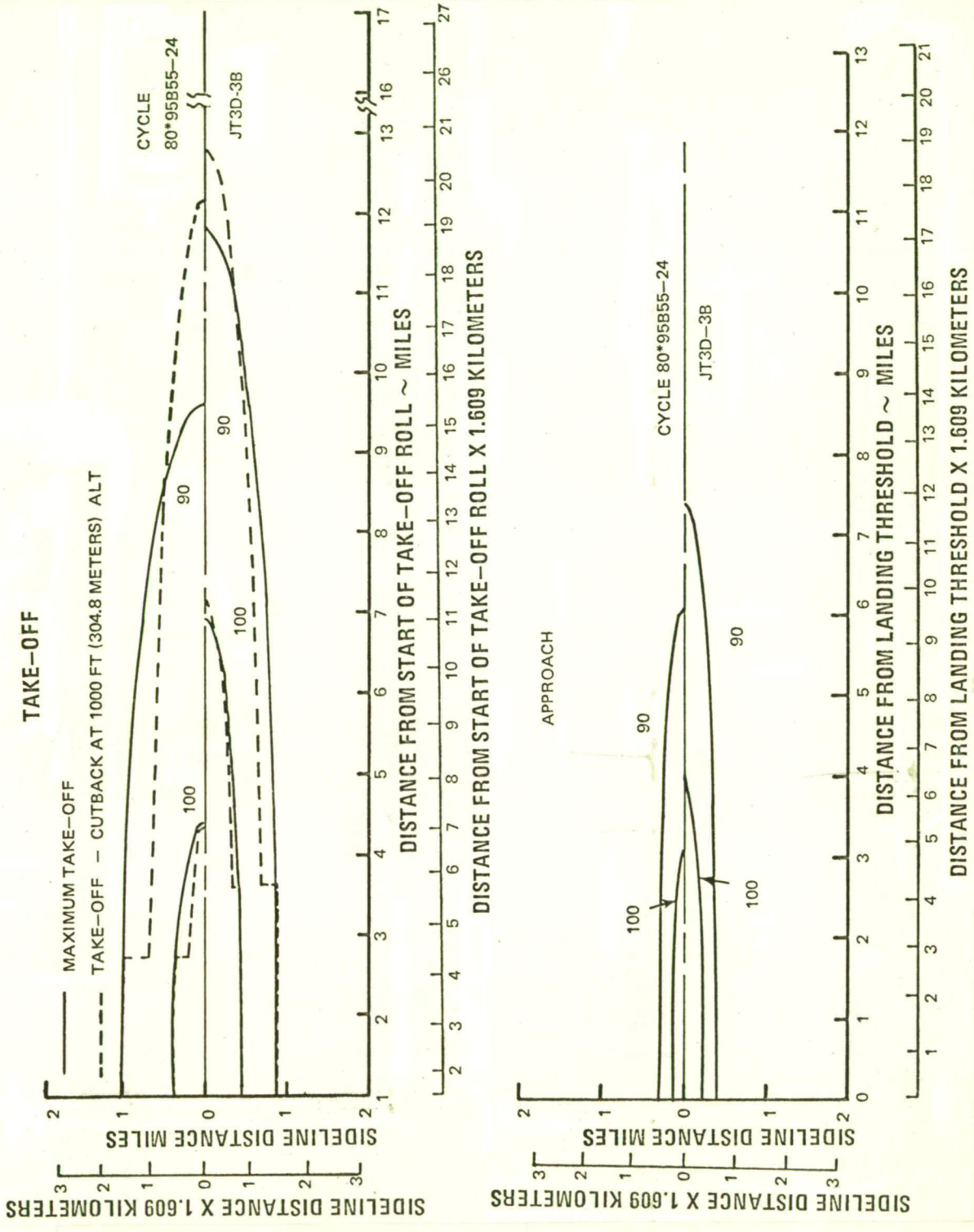


Figure 23 Perceived Noise Level Contours

SECTION IV

ENGINE PHYSICAL DESCRIPTION

Along with engine cycle performance and noise values, the Task I study output tabulated in appendix A includes an overall physical description for each cycle combination. Values are listed for engine weight, length and maximum diameter. This section discusses methods, assumptions, and problem areas associated with determining these output values.

A. METHOD OF SOLUTION

The method of determining weights and dimensions for the 242 discrete cycle combinations was based on a statistical regression analysis technique. In this technique, a smaller sample set was evaluated in detail by an analysis of the actual mechanical correlation. The determination of weights consisted of the following sequential steps:

1. Select sample combinations (35 in this case).

2. Compute design performance and check off-design critical operation performance for each sample.

3. Establish by rough components analysis a general configuration arrangement.

4. Establish bearing and structural arrangements for each sample.

5. From a known base configuration (the JT9D) vary weights of each component individually to reflect significant configuration changes such as the number of stages, airflow size, and radius ratios.

6. Vary structural weights according to over-all structural arrangement.

7. Synthesize individual component and structural weights into an over-all engine weight for each sample.

8. Scale to 20,000-pound and 25,000-pound (88,960 and 111,200 newtons) thrust sizes.

9. By regression analysis, compute from the sample cycles weights for all 242 cycle combinations.

The general background and discussion of results for the statistical regression technique and sample selection methods used in steps 1 and 9 are included in Appendix C of this volume. For the remainder of the sequential steps, the following paragraphs cover in detail the methods employed in establishing physical features for the basic set of 35 cycle combinations. The over-all validity and accuracy of the weights and dimensions tabulated in Appendix A directly reflect the methods and assumptions employed in deriving values for the basic set of 35 samples.

The methods and background involved in computing design and off-design thermodynamic performance are presented in Section II of this report, but design-point performance also served to establish values of thermodynamic design requirements for each of the components. These requirements included such values as turbine work, burner-temperature rise, and the turbine's cooling-flow temperature. Also, off-design performance related take-off thrust values to design airflows at curise to obtain correct engine sizes, and was used to check potential critical operation in the overspeed regions of fans and compressors. The cruise condition (35,000 feet (10,700 meters) altitude, 0.82 Mach number, as specified in the work statement) was set as the basic engine operating point at which the engine's cycle-design was established.

1. Design of Components

Based on the thermodynamic cycle design performance, standard preliminary design-analysis procedures were used to rough out the salient design characteristics for each of the major components. The extent of preliminary design effort was dictated by the degree of variation in each component from a previously established baseline design, usually the JT9D engine.

The sample compressor designs were established by using a scaled JT9D cycle as a well-established baseline, and adding or removing stages as appropriate to the particular cycle requirements. Variations in the number of stages assumed constant loading per stage, while the basic configuration in all cases remained the two-spool arrangement of the JT9D, with a fan and low-pressure compressor on one spool, and a high-pressure compressor on the other.

Combustor design was primarily concerned with length, height, and pressure-loss variations. These parameters were determined by referring to empirically derived curves which show changes in combustor performance with changes in the primary variables. The empirical data was largely derived from two- and three-dimensional rig tests, as modified by engine tests. The heart of the combustor design system, the test data relates combustor-liner pressure loss to the ratio of the combustor's length to height, and relates the combustor's length to its exit temperature profile (as measured by the ΔTVR ratio) for specific burner types. For the Task I studies the type of burner used on the JT9D and its attendant ΔTVR ratio were assumed in all cases.

As with the compressor design, turbine designs were established by adding or removing stages from the basic JT9D design. The number of stages selected was dictated by work requirements and wheel speeds. Wheel speed were established by the requirements for the compressor or fan. Work and wheel speed are related to the turbine's aerodynamic performance through common values for velocity ratio. Basic geometry was further established by common values for the exhaust's exit Mach number. Cooling air in the high-pressure turbine was varied in accordance with the cycle design turbine inlet temperature, cooling-air temperature as determined by cycle pressure ratio, and blade and vane metal temperatures used in current commercial practice. Performance calculations for each cycle have accounted for the appropriate penalties associated with the use of cooling air. Significant design values for the turbine are tabulated in Appendix D of this report.

2. Over-All Mechanical Design

Having established independently the individual components design with sufficient definition to establish over-all geometry and numbers of stages, each sample engine was synthesized as an integrated configuration. This was accomplished by allowing for transition sections between components, numbers of bearings, and rough shaft sizes established for rotor support structures. In each sample engine case, maximum expected rotor speeds were checked against a 20-percent margin over stiff-bearing critical-speed criteria. Critical-speed margins were determined using an approximating technique, and where exceeded, a bearing and its associated support structure were incorporated into the definition of the over-all engine designs.

Typical bearing support schemes assumed are shown in Figures 24 through 26. Figure 27 shows a cross section of the JT9D baseline engine. Supporting structures are shown in the intermediate case between high-pressure and low-pressure compressors, in the diffuser section, under the burner, and at the rear case behind the low-pressure turbine. The low-pressure spool is supported in the back by a bearing housed in the turbine's rear case, and in the front by a bearing housed in the compressor's intermediate case. The entire fan and low-pressure compressor unit is cantilevered from the front bearing. The high-pressure spool is supported by a front bearing (also housed in the compressor's intermediate case) and a rear bearing contained in the bearing compartment under the burner. This comprises a total of only four bearings in the structural arrangement for the basic engine.

6370

Figure 24 High Rotor Bearing Inboard of Diffuser

757.

Figure 25 Intershaft Bearing

Fig 24 6370

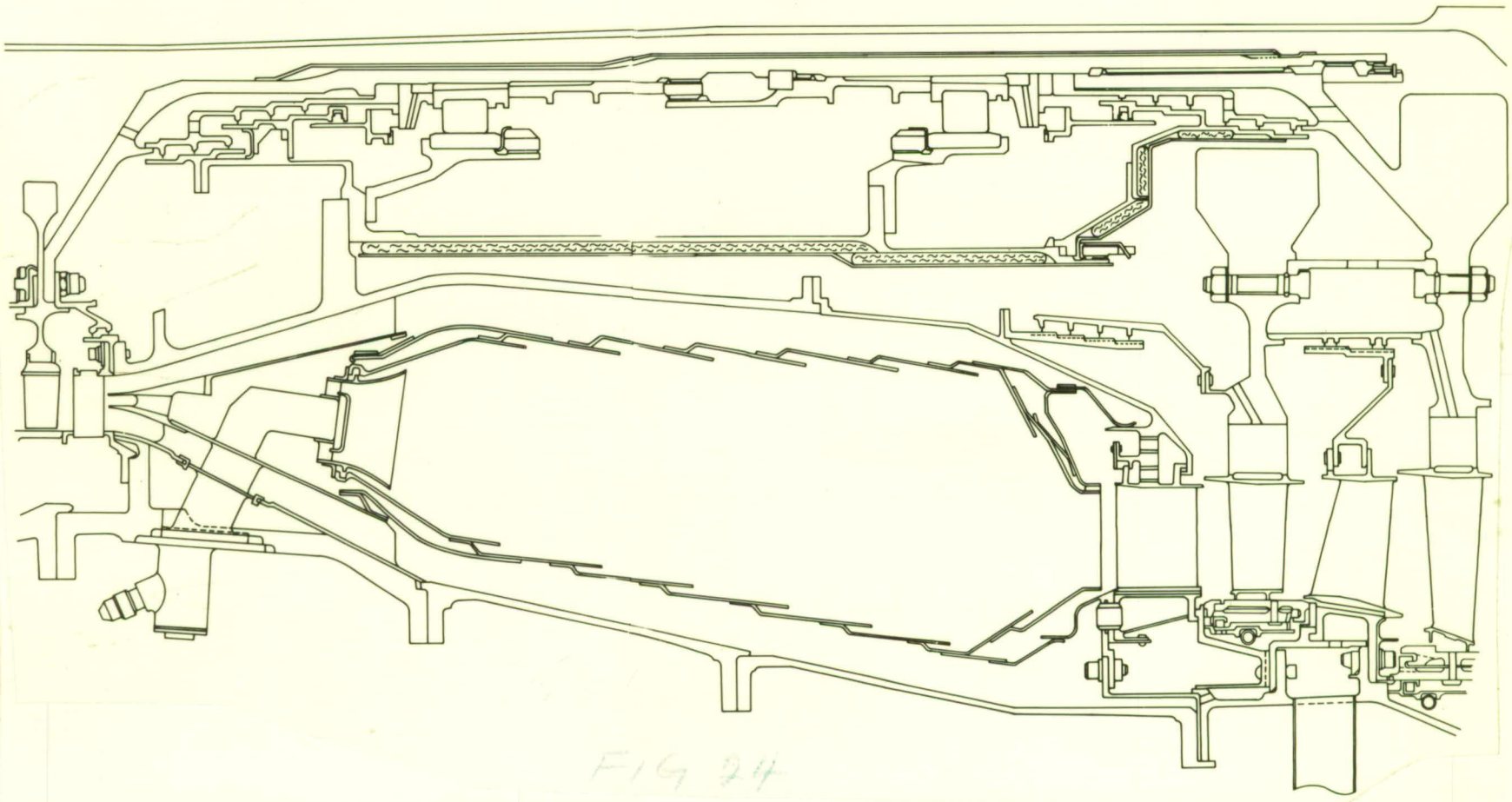


FIG 24

24

Type Caption

Fig 25

Top 75%

PRATT & WHITNEY AIRCRAFT

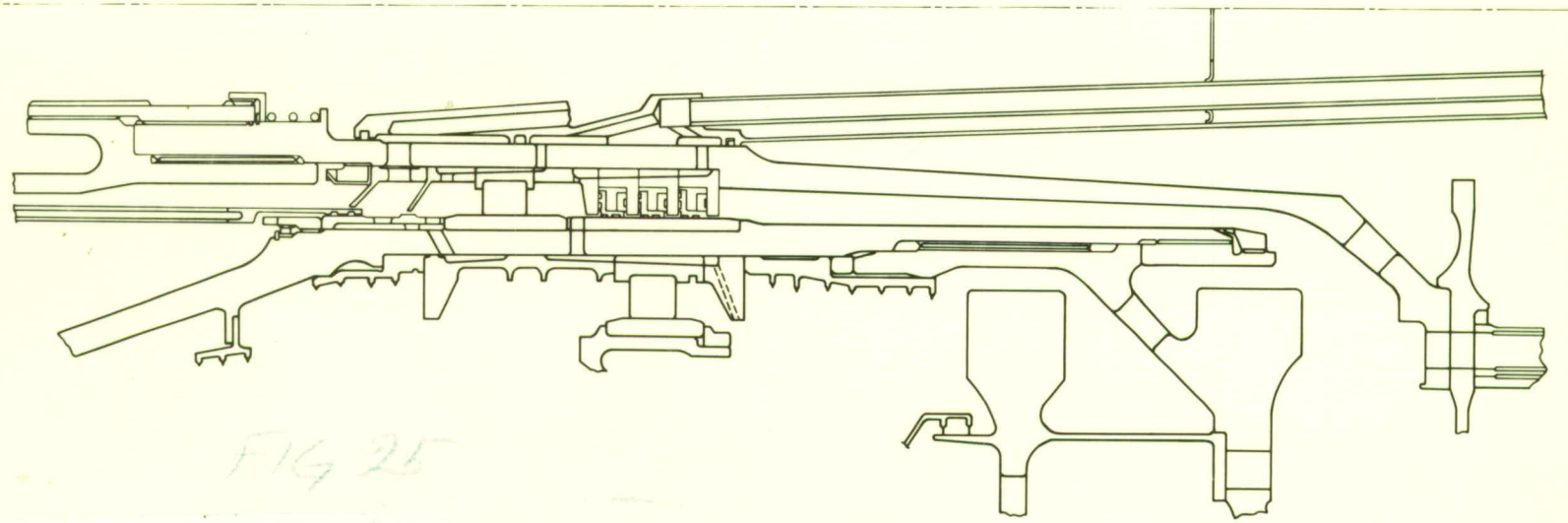


FIG 25

Figure 4-2. Intershaft Bearing

25

639.

Figure 26 Transition Section Between High and Low Pressure Turbine

757.

Figure 27 Basic Engine Design

In cases where the high-pressure spool exceeds the critical speed criterion, an extra bearing can be added underneath the diffuser, as shown in Figure 24. In this case a common bearing compartment with the original rear housing was assumed, with support through the diffuser case. When the low-pressure spool's critical speed is exceeded (assuming only two bearings) extra support comes either from an intershaft bearing, as depicted in Figure 25, or from a turbine transition case, as depicted in Figure 26. A summary of bearing arrangements required for the sample cycle is presented in Table IV.

Fig 26
REVERSE IMAGE
Top 6390

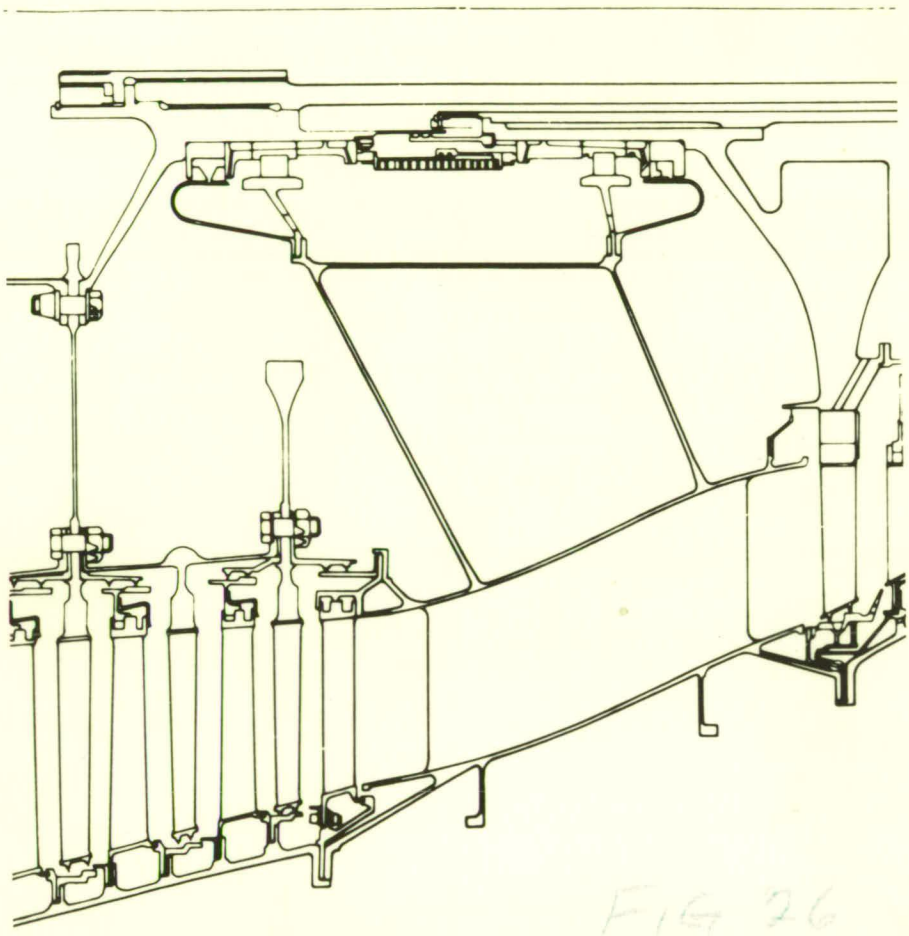


Figure 4-3. Transition Section Between High and Low Pressure Turbine

Top 75% Fig 27

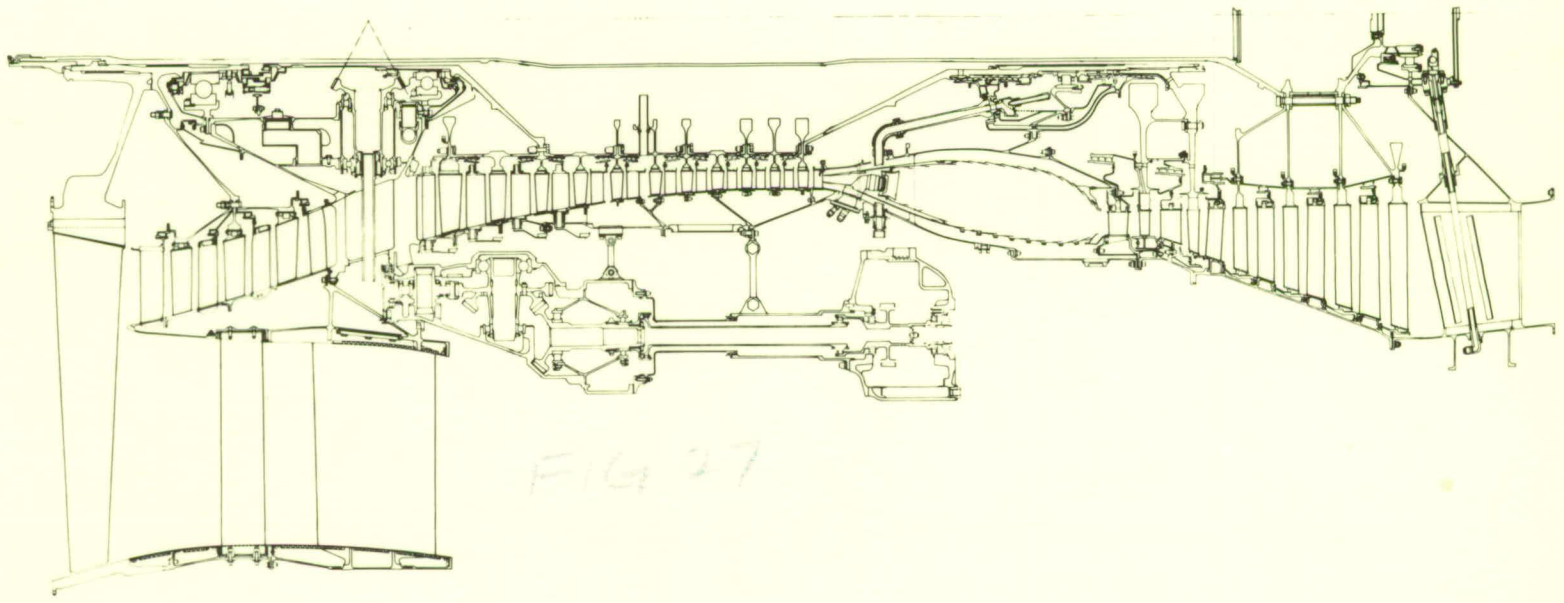


Figure 4-1. Basic Engine Design

TABLE IV

BEARING CONFIGURATION

Engine No.	Identification	High-Pressure Rotor Bearing Arrangement	Low-Pressure Rotor Bearing Arrangement
1	10-95D70-30	(2)	(4)
2	10-95C30-30	(2)	(3)
3	10-95D70-15	(2)	(4)
4	10-95C30-15	(2)	(4)
5	10-95A70-30	(2)	(2)
6	10-95A30-30	(2)	(2)
7	10-95A70-15	(2)	(2)
8	10-95A30-15	(2)	(2)
9	60-95E70-30	(2)	(2)
10	60-95C30-30	(1)	(3)
11	60-95D70-15	(2)	(2)
12	60-95C30-15	(2)	(4)
13	60-95A70-30	(2)	(2)
14	60-95A30-30	(1)	(3)
15	60-95A70-15	(2)	(2)
16	60-95A30-15	(2)	(2)
17	10-95B55-24	(2)	(4)
18	80-95C55-24	(2)	(3)
19	80-95A55-24	(2)	(2)
20	60-95B55-24	(2)	(2)
21	80-95B70-24	(2)	(2)
22	80-95B55-24	(2)	(2)
23	80-95B30-24	(2)	(2)
24	80-95B55-15	(2)	(2)
25	80-95B55-30	(1)	(3)
26	10-30B55-30	(2)	(4)
27	10-30B55-15	(2)	(2)
28	10-60B55-15	(2)	(2)
29	10-60B55-30	(2)	(4)
30	80-30B55-24	(2)	(2)
31	60-30B55-30	(2)	(4)
32	60-60B55-30	(2)	(4)
33	60-30B55-15	(2)	(4)
34	60-60B55-15	(2)	(2)
35	85-60D40-30	(2)	(3)

(1) 3rd bearing aft of the 3 stage high turbine
(2) 3rd bearing inboard of the diffuser case.
(3) 3rd bearing mounted from strut between high & low turbine.
(4) Intershaft bearing.

3. Weights by Components

Determining engine weights for the sample set of 35 engine combinations depended chiefly on analysis of weights for each major component, engine structure, and accessory on an individual basis. Largely, weights based on a well-established configuration were varied by applying the contractor's previous engine-design experience. Although this was an approximate method, not involving extensive design work, the results were accurate within the scope of the broad parametric evaluation required for Task I.

Accuracy levels depend primarily on the judgement and experience of the weight analysts. Each major component for each engine configuration was analyzed individually, with weights varying according to the principal design variables and past pertinent experience. Thus, as actually employed in the Task I effort, specific methods for determining weights varied from configuration to configuration as well as from component to component.

The base point for the component weight analyses was the JT9D engine scaled to 20,000 pounds (88,960 newtons) thrust. The engine weight was grouped into the following major components and was adjusted to exclude any sound absorption treatment.

Component	Weight (lbs)	Weight (Kg)	% of Total Weight
Fan Rotor, Stators, and Cases	520	(236)	14%
Low Pressure Compressors, Rotor Stators and Cases	219	(99.4)	6%
Intermediates Section	400	(181)	10%
High Pressure Compressor Rotor, Stators, and Cases	474	(215)	12%
Diffuser-Burner	376	(172)	10%
High Pressure Turbine, Rotor, Stators, and Case	460	(209)	12%
Low Pressure Turbine, Rotor Stators, and Case	460	(209)	12%
Shafting	219	(99.4)	6%
Turbine Exhaust	174	(78.9)	5%
Control Components	480	(218)	13%
Total Engine Weight	3782	(1717.7)	100%

Performance and design data, discussed in previous sections, was provided for all combinations with high pressure compressor exit corrected airflow as a common base. This allowed a substantial portion of the engine configuration to retain a common inner spool with the base engine. The input data is shown on Table V (in International Units on Table VI).

TABLE V

QUIET ENGINE PARAMETRIC STUDY

Data for Task I Weight Predictions

Engine Designation	Scaled JT9D-1	10-95 D70-30	10-95 C30-30	10-95 D70-15	10-95 C30-15	10-95 A70-30	10-95 A30-30	10-95 A70-15	10-95 A30-15	60-95 E70-30	60-95 C30-30	60-95 D70-15	60-95 C30-15	60-95 A70-30	60-95 A30-30	60-95 A70-15
BPR	5.0	6.0	8.0	6.0	8	3.0	3.0	3.0	3.0	4.0	8.0	6.0	8	3	3	3
OPR	24.5	30	30	15	15	30	30	15.0	15	30	30	15	15	30	30	15
Fn at SLTO	20000	19760	22090	11550	12820	15380	13210	9060	8060	21400	28482	15000	17901	19750	18800	12475
T_{t5} at SLTO °F	1953															
Fn at Cruise	4183	6530	6233	3875	3620	5540	4885	3248	2879	3530	4079	2245	2790	3630	3457	2499
T_{t5} at Cruise °F	1754	2100	2100	2100	2100	2100	2100	2100	2100	1600	1600	1600	1600	1600	1600	1600
N_1 Cruise	4739	4659	2910	6265	3890	6140	4360	8190	5850	5521	2910	6265	3890	6150	4360	8230
N_1 T.O.	4646	3525	2190	4810	3401	5536	3822	7238	5152	5325	2923	5890	4007	6593	5856	8953
N_2 T.O.	10800															
No. Variable Stators	4															
Fan																
Wa t2/ t2	775.8	1075	1380	600	763	608	608	340	340	768	1380	600	763	608	608	340
H/T	0.378															
U_t	1430	1640	1165	1640	1165	1640	1165	1640	1165	1640	1165	1640	1165	1640	1165	1640
W/A	41															
No. Stages	1															
$P_{t2.4}/P_{t2}$	1.55	1.70	1.30	1.70	1.30	1.70	1.30	1.7	1.3	1.70	1.30	1.70	1.30	1.70	1.30	1.70
D_{tip} inlet in	64.0	74.9	85.0	55.7	63.5	56.6	56.6	42.3	42.3	63.2	85.0	55.7	63.5	56.6	56.6	42.3
Low Pressure Compressor																
Wa t2.4/ T2.4	92	104.3	125.2	58.3	70.1	104.3	125.2	58.3	70.1	104.3	125.2	58.3	70.1	104.3	125.2	58.3
H/T	0.765	0.795	0.804		0.804	0.703	0.670		0.670	0.741	0.804		0.804	0.703	0.670	
No. Stages	3	3	4	0	1	3	4	0	1	3	4	0	1	3	4	0
P_{t3}/P_{t2}	2.45	3.0	2.40		1.50	3.0	2.40		1.5	3.0	2.40		1.5	3.0	2.4	
D_{tip} inlet	34.	38.3	43.0		32.1	32.8	34.4		25.7	34.7	43.0		32.1	32.8	34.4	
D_{tip} exit	28.2	32.0	33.7		30.5	27.4	26.9		24.4	29.0	33.7		30.5	27.4	26.9	
High Pressure Compressor																
Wa t3/ T3	60.9	60.9	73.5	58.3	60.9	60.9	73.5	58.3	60.9	60.9	73.5	58.3	60.9	60.9	73.5	58.3
H/T inlet	0.715	0.715	0.669	0.715	0.715	0.715	0.669	0.715	0.715	0.715	0.669	0.715	0.715	0.715	0.669	0.715
H/T exit	0.91															
No. Stages	11	11	12	11	11	11	12	11	11	11	12	11	11	11	12	11
P_{t4}/P_{t3}	10.0	10.0	12.5	9.5	10.0	10.0	12.5	9.5	10	10	12.5	9.5	10	10	12.3	9.5
D_{tip} inlet	25.2	25.2	26.8	25.2	25.2	25.2	26.8	25.2	25.2	25.2	26.8	25.2	25.2	25.2	26.8	25.2
D_{tip} exit	19.8															
Burner																
Length	16.7	19.5	19.5	24.0	24.0	19.5	19.5	24.0	24.0	14.5	16.0	18.5	18.5	14.5	16.0	18.5
High Pressure Turbine																
P_{t5}/P_{t6}	3.91	3.5	3.93	2.71	2.71	3.5	3.93	2.72	2.71	5.02	6.0	3.60	3.60	5.02	6.0	3.60
No. Stages	2	2	2	1	1	2	2	1	1	2	3	2	2	2	3	2
Δh	157	167	178	136	135	167	178	136	135	166	176	135	134	165	176	134
D_{root} inlet	22.6	22.6	22.6	26.13	26.13	22.6	22.6	26.13	26.13	22.6	18.95	22.6	22.6	22.6	18.95	22.6
D_{root} inlet	22.4	22.4	22.4	25.93	25.93	22.4	22.4	25.93	25.93	22.4	18.75	22.4	22.4	22.4	18.75	22.4
D_{tip} inlet	25.2	25.2	25.2	29.37	29.37	25.2	25.2	29.37	29.37	26.5	23.85	25.2	26.5	26.5	23.85	25.2
D_{tip} exit	27.2	26.8	27.2	29.47	29.47	26.8	27.2	29.47	29.47	28.5	26.85	26.8	26.8	28.5	26.85	26.8
No. of cooled rows	3	4	4	4	4	4	4	4	4	2	2	2	2	2	2	2
Low Pressure Turbine																
P_{t6}/P_{t7}	3.79	6.17	2.90	3.51	2.06	3.05	1.87	1.88	3.71	5.41	4.45	5.80	2.68	4.49	2.53	2.34
No. Stages	4	6	7	3	5	3.0	3.0	1	1.0	3	6.0	3.0	5	2	3	1
ΔH	113	181	114	155	93	115	66	89	45	136	111	154	92	114	65	88
D_{root} exit	21.8	21.8	29.7	25.3	25.3	21.8	21.8	25.3	25.3	21.8	27.2	21.8	21.8	21.8	18.15	21.8
D_{tip}	36.0	40.9	38.5	35.2	31.6	32.5	29.0	31.6	29.8	44.8	45.9	42.1	32.1	41.7	31.5	31.7
No. of cooled rows	0															
D_{root} inlet			30.35								27.8					
D_{tip} inlet			34.05								33.8					

TABLE V (Cont'd)

QUIET ENGINE PARAMETRIC STUDY

Data for Task I Weight Predictions

Engine Designation	60-96 A30-15	10-95 B55-24	80-95 C55-24	80-95 A55-24	60-95 B55-24	80-95 B70-24	80-95 B55-24	80-95 B30-24	80-95 B55-15	80-95 B55-30	10-30 B55-30	10-30 B55-15	10-60 B55-15	10-60 B55-30	80-30 B55-24	60-30 B55-30
BPR	3.0	5.0	8.0	3.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
OPR	15.0	24.5	24.5	24.5	24.5	24.5	24.5	24.5	15	30	30	15	15	30	24.5	30
Fn at SLTO	11247	16710	22750	15900	21521	19062	19700	18120	13590	21891	25350	15200	7300	12160	26700	23600
T_{t5} at SLTO °F											2300	2300	1600	1600	2300	2300
Fn at Cruise	2267	5362	4590	3990	3644	4445	4520	4083	3160	4991	5810	3545	3590	6120	4260	2895
T_{t5} at Cruise °F	1600	2100	1800	1800	1600	1800	1800	1800	1800	1800	2100	2100	2100	2100	1800	1600
N_1 Cruise	5840	4740	3900	5830	4740	5440	4740	3860	5850	4170	4170	5850	5850	4170	4740	4170
N_1 T. O.	6183	4123	3526	5701	4953	4215	4558	3717	5694	3958	4110	5800	4350	3060	5460	4310
N_2 T. O.																
No. Variable Stators																
Fan																
Wa t2/ t2	340	776	1146	513	776	776	776	776	508	907	907	508	508	907	776	907
H/T																
U_t	1165	1430	1430	1430	1430	1640	1430	1165	1430	1430	1430	1430	1430	1430	1430	1430
W/A																
No. Stages																
$P_{t2.4}/P_{t2}$	1.30	1.55	1.55	1.55	1.55	1.70	1.55	1.30	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55
D_{tip} inlet in	42.3	64	77.8	52.0	64	64	64	64	51.8	69.3	69.3	51.8	51.8	69.3	64	69.3
Low Pressure Compressor																
Wa t2.4/ $T_{2.4}$	70.1	92	92	92	92	88.1	92	106.7	60.9	109	109	60.9	60.9	109	92.0	109
H/T	0.670	0.765	0.822	0.694	0.765	0.772	0.765	0.741		0.765	0.765			0.765	0.765	0.765
No. Stages	1	3	3	3	3	2	3	3	0	4	4	0	0	4	3	4
$P_{t3}P_{t2}$	1.50	2.45	2.45	2.45	2.45	2.45	2.45	2.13		2.61	2.61			2.61	2.45	2.61
D_{tip} inlet	25.7	34.0	38.5	30.4	34.0	33.6	34.0	35.1		36.9	36.9			36.9	34.0	36.9
D_{tip} exit	24.4	28.5	32.2	25.4	28.5	30.1	28.5	29.4		28.9	28.9			28.9	28.5	28.9
High Pressure Compressor																
Wa t3/ t3	60.9	60.9	60.9	60.9	60.9	60.9	60.9	68.6	60.9	68.6	68.6	60.9	60.9	68.6	60.9	68.6
H/T inlet	0.715	0.715	0.715	0.715	0.715	0.715	0.715	0.669	0.716	0.669	0.669	0.715	0.715	0.669	0.715	0.669
H/T exit																
No. Stages	11	11	11	11	11	11	11	12	11	12	12	11	11	12	11	12
P_{t4}/P_{t3}	10	10	10	10	10	10	10	11.5	10	11.5	11.5	10	10	11.5	10.0	11.5
D_{tip} inlet	25.2	25.2	25.2	25.2	25.2	25.2	25.2	26.8	25.2	26.8	26.8	25.2	25.2	26.8	25.2	26.8
D_{tip} exit																
Burner																
Length	18.5	23.0	16.5	16.5	15.5	1.65	16.5	16.5	18.5	17.0	20.5	28.5	27.0	19.5	23.0	20.0
High Pressure Turbine																
P_{t5}/P_{t6}	3.60	3.25	3.96	3.96	4.74	3.90	3.91	4.14	3.06	5.84	3.42	2.48	2.48	3.42	3.96	5.04
No. Stages	2	2	2	2	2	2	2	2	2	3	2	1	1	2	2	2
Δh	134	157	157	157	157	154	155	161	132	172	172	132	132	172	157	172
D_{root} inlet	22.6	21.4	22.6	22.6	22.6	22.6	22.6	22.6	22.6	18.95	22.6	26.2	26.2	22.6	22.6	22.6
D_{root} exit	22.4	21.2	22.4	22.4	22.4	22.4	22.4	22.4	22.4	18.75	22.4	26.0	26.0	22.4	22.4	22.4
D_{tip} inlet	25.2	24.0	25.2	25.2	26.2	25.2	25.2	25.6	25.6	23.75	25.2	29.1	29.1	25.2	25.2	26.5
D_{tip} exit	26.8	25.6	27.2	27.2	28.2	27.2	27.2	27.6	26.3	26.75	26.7	29.2	29.2	26.7	27.3	28.5
No. of cooled rows	2	4	3	3	2	3	3	3	3	3	4	4	3	3	3	4
Low Pressure Turbine																
P_{t6}/P_{t7}	1.52	2.95	7.20	2.39	4.43	5.15	3.63	2.22	2.62	3.25	3.20	2.38	2.36	3.18	3.93	5.54
No. Stages	1	5	6	2	4	3	4.0	4.0	3.0	5.0	6	3	3	6	4	5
Δh	44	122	173	88	122	147	121	77	101	123	125	103	101	123	125	125
D_{root} exit	21.8	20.6	28.5	21.8	21.8	21.8	21.8	21.8	21.8	18.15	21.8	25.4	25.4	21.8	21.8	21.8
D_{tip} exit	28.2	31.1	48.8	31.6	40.3	40.5	35.4	31.1	30.9	36.6	32.5	31.6	31.6	32.5	36.6	44.3
No. of cooled rows																
D_{root} inlet			29.05													
D_{tip} inlet			32.95													

TABLE V (Cont'd)
QUIET ENGINE PARAMETRIC STUDY

Data for Task I Weight Predictions

Engine Designation	60-80 B55-30	60-30 B55-15	60-60 B55-15	85-00 D40-30
BPR	5.0	5.0	5.0	6.0
OPR	30	15	15	30
Fn at SLTO	15500	20450	10400	22150
T_{t5} at SLTO °F	1600	2300	1600	2000
Fn at Cruise	4175	2610	2810	6110
T_{t5} at Cruise °F	1600	1600	1600	1850
N_1 Cruise	4170	5850	5850	3550
N_1 T. O.	3240	7710	5160	2950
N_2 T. O.				
No. Variable Stators				
Fan				
Wa t2/ t2 H/T	907	508	508	1075
U_t W/A	1430	1430	1430	1250
No. Stages				
$P_{t2.4}/P_{t2}$	1.55	1.55	1.55	1.40
D_{tip} inlet in	69.3	51.8	51.8	74.9
Low Pressure Compressor				
Wa t2.4/ T2.4	109	60.9	60.9	104.3
H/T	0.765			0.795
No. Stages	4	0	0	3
P_{t3}/P_{t2}	2.61			3.0
D_{tip} inlet	36.9			38.3
D_{tip} exit	28.9			32.0
High Pressure Compressor				
Wa t3/ T_3	68.6	60.9	60.9	60.9
H/T inlet	0.669	0.715	0.715	0.715
H/T exit				
No. Stages	12	11	11	11
P_{t4}/P_{t3}	11.5	10	10	10.
D_{tip} inlet	26.8	25.2	25.2	25.2
D_{tip} exit				
Burner				
Length	13.5	28.5	14.5	15.5
High Pressure Turbine				
P_{t5}/P_{t6}	5.04	3.22	3.22	3.96
No. Stages	2	2	2	2
Δh	172	132	132	155
D_{root} inlet	22.6	22.6	22.6	22.6
D_{root} exit	22.4	22.4	22.4	22.4
D_{tip} inlet	26.5	25.2	25.2	25.2
D_{tip} exit	28.5	26.5	26.5	27.3
No. of cooled rows	0	4	0	
Low Pressure Turbine				
P_{t6}/P_{t7}	5.52	3.28	3.26	2.83
No. Stages	5	3	3	6
Δh	120	103	99	133
D_{root} exit	21.8	21.8	21.8	29.8
D_{tip} exit	44.3	33.3	33.3	40.1
No. of cooled rows				
D_{root} inlet				30.4
D_{tip} inlet				34.2

~~55~~ 54

backup to 53

TABLE 4-3

QUIET ENGINE PARAMETRIC STUDY

Data for Task I Weight Predictions (International Units)

Engine Designation	Scaled JT9D-1	10-95 D70-30	10-95 C30-30	10-95 D70-15	10-95 C30-15	10-95 A70-30	10-95 A30-30	10-95 A70-15	10-95 A30-15	60-95 E70-30	60-95 C30-30	60-95 D70-15	60-95 C30-15	60-95 A70-30	60-95 A30-30	60-95 A70-15
BPR	5.0	6.0	8.0	6.0	8	3.0	3.0	3.0	3.0	4.0	8.0	6.0	8	3	3	3
OPR	24.5	30	30	15	15	30	30	15.0	15	30	30	15	15	30	30	15
Fn at SLTO (newtons)	889,960	87,890	98,260	51,370	57,000	68,400	58,800	40,300	35,850	95,200	126,700	66,720	79,600	87,850	83,600	55,500
T_{t5} at SLTO (°K)	1340															
Fn at Cruise (newtons)	18600	29000	27700	17200	16100	24600	21700	14450	12800	15700	18200	9990	12410	16150	15390	11100
T_{t5} at Cruise (°K)	1230	1422	1422	1422	1422	1422	1422	1422	1422	1144	1144	1144	1144	1144	1144	1144
N_1 Cruise radians/sec	498	489	306	658	408	645	458	860	614	580	306	658	408	646	458	864
N_1 T.O. radians/sec	488	370	230	505	357	581	401	759	540	559	307	618	421	692	615	940
N_2 T.O. radians/sec	1134															
No. Variable Stators	4															
Fan																
Wa t2/ t2 (newtons/sec)	3450	4780	6140	2670	3390	2700	2700	1512	1512	3420	6140	2670	3390	2700	2700	1512
H/T	0.378															
U_t (meters/sec)	436.2	500	355	500	355	500	355	500	355	500	355	500	355	500	355	500
W/A (Kg/sec-meter^2)	200															
No. Stages	1															
$P_{t2.4}/P_{t2}$	1.55	1.70	1.30	1.70	1.30	1.70	1.30	1.7	1.3	1.70	1.30	1.70	1.30	1.70	1.30	1.70
D_{tip} inlet (cm)	162.5	190	216	141.5	161.5	144	144	107.5	107.5	160.5	216.	141.5	161.5	144.	144.	107.5
Low Pressure Compressor																
Wa t2.4/ T2.4 (N/sec)	409	464	557	259	312	464	557	259	312	464	557	259	312	464	557	259
H/T	0.765	0.795	0.804		0.804	0.703	0.670		0.670	0.741	0.804		0.804	0.703	0.670	
No. Stages	3	3	4	0	1	3	4	0	1	3	4	0	1	3	4	0
P_{t3}/P_{t2}	2.45	3.0	2.40		1.50	3.0	2.40		1.5	3.0	2.40		1.5	3.0	2.4	
D_{tip} inlet (cm)	86.5	97.4	109.1		81.5	83.4	87.5		65.4	88.2	109.1		81.5	83.4	87.5	
D_{tip} exit (cm)	71.7	81.2	85.7		77.5	69.6	67.8		62.0	73.8	85.7		77.5	69.6	67.8	
High Pressure Compressor																
Wa t3/ T3 (N/sec)	270.9	270.9	326.9	259.	270.9	270.9	326.9	259.	270.9	270.9	326.9	259.	270.9	270.9	326.9	259.
H/T inlet	0.715	0.715	0.669	0.715	0.715	0.715	0.669	0.715	0.715	0.715	0.669	0.715	0.715	0.715	0.669	0.715
H/T exit	0.91															
No. Stages	11	11	12	11	11	11	12	11	11	11	12	11	11	11	12	11
P_{t4}/P_{t3}	10.0	10.0	12.5	9.5	10.0	10.0	12.5	9.5	10	10	12.5	9.5	10	10	12.3	9.5
D_{tip} inlet (cm)	64.1	64.1	68.2	64.1	64.1	64.1	68.2	64.1	64.1	64.1	68.2	64.1	64.1	64.1	68.2	64.1
D_{tip} exit (cm)	50.4															
Burner																
Length (cm)	42.4	49.5	49.5	61.	61.	49.5	49.5	61.	61.	36.8	40.7	47.	47.	36.8	40.7	47.
High Pressure Turbine																
P_{t5}/P_{t6}	3.91	3.5	3.93	2.71	2.71	3.5	3.93	2.72	2.71	5.02	6.0	3.60	3.60	5.02	6.0	3.60
No. Stages	2	2	2	1	1	2	2	1	1	2	3	2	2	2	3	2
Δh	157	167	178	136	135	167	178	136	135	166	176	135	134	165	176	134
D_{root} inlet (cm)	57.5	57.5	57.5	66.4	66.4	57.5	57.5	66.4	66.4	57.5	48.2	57.5	57.5	57.5	48.2	57.5
D_{root} exit (cm)	57.0	57.0	57.0	65.9	65.9	57.0	57.0	65.9	65.9	57.0	47.6	57.0	57.0	57.0	47.6	57.0
D_{tip} inlet (cm)	64.1	64.1	64.1	73.6	73.6	64.1	64.1	73.6	73.6	67.4	60.6	64.1	67.4	67.4	60.6	64.1
D_{tip} exit (cm)	69.1	68.2	69.1	75.0	75.0	68.2	69.1	75.0	75.0	72.5	68.3	68.2	68.2	72.5	68.3	68.2
No. of cooled rows	3	4	4	4	4	4	4	4	4	2	2	2	2	2	2	2
Low Pressure Turbine																
P_{t6}/P_{t7}	3.79	6.17	2.90	3.51	2.06	3.05	1.87	1.88	3.71	5.41	4.45	5.80	2.68	4.49	2.53	2.34
No. Stages	4	6	7	3	5	3.0	3.0	1	1.0	3	6.0	3.0	5	2	3	1
ΔH	113	181	114	155	93	115	66	89	45	136	111	154	92	114	65	88
D_{root} exit (cm)	55.4	55.4	75.5	64.2	64.2	55.4	55.4	64.2	64.2	55.4	69.1	55.4	55.4	55.4	46.1	55.4
D_{tip} exit (cm)	90.5	104.	97.7	89.5	80.4	85.	73.6	80.4	75.6	114.	116.5	107.	81.5	106.	80.	80.5
No. of cooled rows	0															
D_{root} inlet (cm)			77.1								70.7					
D_{tip} inlet (cm)			86.5								86.0					

Table VI Cont 677

TABLE I-3 (Continued)

QUIET ENGINE PARAMETRIC STUDY

Data for Task I Weight Predictions (International Units)

Engine Designation	60-96 A30-15	10-95 B55-24	80-95 C55-24	80-95 A55-24	60-95 B55-24	80-95 B70-24	80-95 B55-24	80-95 B30-24	80-95 B55-15	80-95 B55-30	10-30 B55-30	10-30 B55-15	10-60 B55-15	10-60 B55-30	80-30 B55-24	60-30 B55-30
BPR	3.0	5.0	8.0	3.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
OPR	15.0	24.5	24.5	24.5	24.5	24.5	24.5	24.5	15	30	30	15	15	30	24.5	30
Fn at SLTO (newtons)	50,030	74,300	101,200	70,700	95,700	84,800	87,600	80,600	60,450	97,400	112,800	67,610	32,500	58,300	118,760	104,970
T_{t5} at SLTO (°K)											1534	1534	1144	1144	1534	1534
Fn at Cruise (newtons)	10100	23830	20900	17750	10220	19770	20100	18200	14050	22210	25830	15790	16430	27210	18960	1277
T_{t5} at Cruise (°K)	1144	1422	1255	1255	1144		1255	1255	1255	1255	1422	1422	1422	1422	1255	1144
N_1 Cruise (radians/sec)	613	498	410	612	498	571	498	405	614	438	438	614	614	438	498	438
N_1 T.O. (radians/sec)	649	433	370	599	520	443	479	390	598	416	432	609	457	321	573	453
N_2 T.O. (radians/sec)																
No. Variable Stators																
Fan																
Wa t2/ t2 (newtons/sec)	1512	3450	5100	2280	3450	3450	3450	3450	2260	4032	4032	2260	2260	4032	3450	4032
H/T																
U_t (meters/sec)	355	436.2	436.2	436.2	436.2	500	436.2	355	436.2	436.2	436.2	436.2	436.2	436.2	436.2	436.2
W/A																
No. Stages																
$P_{t2.4}/P_{t2}$	1.30	1.55	1.55	1.55	1.55	1.70	1.55	1.30	1.55	1.55	1.55	1.55	1.55	1.55	1.55	1.55
D_{tip} inlet (cm)	107.4	162.6	197.6	132.	162.6	162.6	162.6	162.6	131.6	176.	176.	131.6	131.6	176.	162.6	176.
Low Pressure Compressor																
Wa t2.4/ T2.4 (N/sec)	312.	409.3	409.3	409.3	409.3	392.	409.3	474.7	270.9	484.9	484.9	270.9	270.9	484.9	409.3	484.9
H/T	0.670	0.765	0.822	0.694	0.765	0.772	0.765	0.741		0.765	0.765			0.765	0.765	0.765
No. Stages	1	3	3	3	3	2	3	3	0	4	4	0	0	4	3	4
$P_{t3}P_{t2}$	1.50	2.45	2.45	2.45	2.45	2.45	2.45	2.13		2.61	2.61			2.61	2.45	2.61
D_{tip} inlet (cm)	65.3	86.5	97.8	77.2	86.5	85.3	86.5	89.2		93.7	93.7			93.7	86.5	93.7
D_{tip} exit (cm)	62.0	72.4	81.8	64.5	72.4	76.5	72.4	74.7		73.4	73.4			73.4	72.4	73.4
High Pressure Compressor																
Wa t3/ t3 (N/sec)	270.9	270.9	270.9	270.9	270.9	270.9	270.9	305.	270.9	305.	305.	270.9	270.9	305.	270.9	
H/T inlet	0.715	0.715	0.715	0.715	0.715	0.715	0.715	0.669	0.716	0.669	0.669	0.715	0.715	0.669	0.715	0.669
H/T exit																
No. Stages	11	11	11	11	11	11	11	12	11	12	12	11	11	12	11	12
P_{t4}/P_{t3}	10	10	10	10	10	10	10	11.5	10	11.5	11.5	10	10	11.5	10.0	11.5
D_{tip} inlet (cm)	64.1	64.1	64.1	64.1	64.1	64.1	64.1	68.2	64.1	68.2	68.2	64.1	64.1	68.2	64.1	68.2
D_{tip} exit (cm)																
Burner																
Length (cm)	47.0	58.4	41.9	41.9	39.4	41.9	41.9	41.9	47.0	43.2	52.1	72.4	68.6	49.5	58.4	50.8
High Pressure Turbine																
P_{t5}/P_{t6}	3.60	3.25	3.96	3.96	4.74	3.90	3.91	4.14	3.06	5.84	3.42	2.48	2.48	3.42	3.96	5.04
No. Stages	2	2	2	2	2	2	2	2	2	3	2	1	1	2	2	2
Δh	134	157	157	157	157	154	155	161	132	172	172	132	132	172	157	172
D_{root} inlet (cm)	37.5	54.4	57.5	57.5	57.5	57.5	57.5	57.5	57.5	48.2	57.5	66.5	66.5	57.5	57.5	57.5
D_{root} exit (cm)	57.0	53.8	57.0	57.0	57.0	57.0	57.0	57.0	57.0	47.6	57.0	66.0	66.0	57.0	57.0	57.0
D_{tip} inlet (cm)	64.1	61.0	64.1	64.1	66.5	64.1	64.1	65.0	65.0	60.3	64.1	73.9	73.9	64.1	64.1	67.3
D_{tip} exit (cm)	68.2	65.0	69.1	69.1	71.6	69.1	69.1	70.1	66.8	67.9	67.8	74.2	74.2	67.8	69.3	72.5
No. of cooled rows	2	4	3	3	2	3	3	3	3	3	4	4	3	3	3	4
Low Pressure Turbine																
P_{t6}/P_{t7}	1.52	2.95	7.20	2.39	4.43	5.15	3.63	2.22	2.62	3.25	3.20	2.38	2.36	3.18	3.93	5.54
No. Stages	1	5	6	2	4	3	4.0	4.0	3.0	5.0	6	3	3	6	4	5
Δh	44	122	173	88	122	147	121	77	101	123	125	103	101	123	125	125
D_{root} exit (cm)	55.4	52.3	72.4	55.4	55.4	55.4	55.4	55.4	55.4	46.0	55.4	64.5	64.5	55.4	55.4	55.4
D_{tip} exit (cm)	71.6	79.0	124.	80.3	102.7	102.9	89.9	79.0	78.5	93.0	82.6	80.3	80.3	82.6	90.3	112.5
No. of cooled rows																
D_{root} inlet (cm)			73.8													
D_{tip} inlet (cm)			83.7													

(poze 58) TABLE VI cont'd 6490

~~TABLE 4-3 (Continued)~~

QUIET ENGINE PARAMETRIC STUDY

Data for Task I Weight Predictions (International Units)

Engine Designation	60-80 B55-30	60-30 B55-15	60-60 B55-15	85-00 D40-30
BPR	5.0	5.0	5.0	6.0
OPR	30	15	15	30
Fn at SLTO (newtons)	68,900	90,960	46,300	98,500
T_{t5} at SLTO (°K)	1144	1534	1144	1367
Fn at Cruise (newtons)	18600	11610	12500	27200
T_{t5} at Cruise (°K)	1144	1144	1144	1288
N_1 Cruise (radians/sec)	437.9	614.3	614.3	372.8
N_1 T.O. (radians/sec)	340.	810.	542.	310.
N_2 T.O. (radians/sec)				
No. Variable Stators				
Fan				
Wa t2/ t2 (newtons/sec)	4032.	2260.	2260.	4780
H/T				
U_t (meters/sec)	436.2	436.2	436.2	381
W/A				
No. Stages				
$P_{t2.4}/P_{t2}$	1.55	1.55	1.55	1.40
D_{tip} inlet (cm)	176.0	131.6	131.6	190.2
Low Pressure Compressor				
Wa t2.4/ T2.4 (N/sec)	4085	270.9	270.9	
H/T	0.765			0.795
No. Stages	4	0	0	3
P_{t3}/P_{t2}	2.61			3.0
D_{tip} inlet (cm)	93.7			97.3
D_{tip} exit (cm)	73.4			81.3
High Pressure Compressor				
Wa t3/ T_3 (N/sec)	305.1	270.9	270.9	270.9
H/T inlet	0.669	0.715	0.715	0.715
H/T exit				
No. Stages	12	11	11	11
P_{t4}/P_{t3}	11.5	10	10	10
D_{tip} inlet (cm)	68.2	64.1	64.1	64.1
D_{tip} exit (cm)				
Burner				
Length (cm)	34.3	72.4	36.8	39.4
High Pressure Turbine				
P_{t5}/P_{t6}	5.04	3.22	3.22	3.96
No. Stages	2	2	2	2
Δh	172	132	132	155
D_{root} inlet (cm)	57.5	57.5	57.5	57.5
D_{root} exit (cm)	57.0	57.0	57.0	57.0
D_{tip} inlet (cm)	67.3	64.1	64.1	64.1
D_{tip} exit (cm)	72.5	67.3	67.3	69.3
No. of cooled rows	0	4	0	
Low Pressure Turbine				
P_{t6}/P_{t7}	5.52	3.28	3.26	2.83
No. Stages	5	3	3	6
Δh	120	103	99	133
D_{root} exit (cm)	55.4	55.4	55.4	75.7
D_{tip} exit (cm)	112.5	84.6	84.6	101.9
No. of cooled rows				
D_{root} inlet (cm)				77.2
D_{tip} inlet (cm)				86.9

TABLE VI (cont'd)

Page 58

With the design of the inner spool fixed, but varying cycle design parameters, the various engines in the sample set shown in Tables V & VI can be seen to have take-off thrust sizes that varied considerably around the basic 20,000 pound (88,960 newtons) or 25,000 pound (111,200 newtons) thrust size. Consequently, the engine weights determination consisted of three consecutive steps. First, each component weight was determined for the basic size. Next, components were scaled individually to correspond to a 20,000 pound (88,960 newtons) thrust or 25,000 pound (111,200 newtons) thrust size. Finally, the resultant component weights were added to obtain the total weight in each case.

The weight of the 35 cycles at 25,000 pounds (111,200 newtons) thrust were determined by recognizing that turbofans having bypass ratios of 3 to 8 have relatively constant thrust-to-weight ratios from (88,960 to 111,200 newtons) 20,000 to 25,000 pounds thrust. The JT9D-1 has a reduction of about 2 percent in thrust-to-weight from 20,000 to 25,000 pound (88,960 to 111,200 newtons) thrust. This percentage was assumed to apply for all cycles.

a. Fan Rotor, Stator and Case

The fan rotor, stator and case weight was scaled from the base engine assuming constant airflow per unit frontal area at the design point, constant blade and vane aspect ratios, and constant hub-tip ratios. The fan tip speed was increased and decreased and the weight changed accordingly to account for the changing stress and vibration characteristics of the fan disk and blades. The thickness of the fan case, hence the weight, varied with fan tip speed in an effort to provide equal fan blade containment. The length of the fan case or duct was changed to reflect the changes in the number of low pressure compressor stages.

b. Low Pressure Compressor Rotor Stators and Cases

The low pressure compressor sections for the 35 cycle combinations varied from four stages to no stages. The weight of a typical stage was added or removed as necessary together with changes to the hub, spacers, and case length. The weight of a typical stage was obtained from the base engine in which aspect ratio and material was held constant. Weights were adjusted to reflect variations in hub-tip ratio, size, and tip speed. All configurations with two or more stages require overboard bleed or variable inlet guide vane provisions.

c. Intermediate Section

The intermediate section weight is a major contributor to the total engine weight. It is composed of the main bearing support weldment. No. 1 and No. 2 bearings, and the towershaft. The weldment is basically two major assemblies, the inner assembly forms the flowpath transition between the low pressure compressor and the high pressure compressor while the outer assembly is in the fan flow-

path. The inner assembly weight was obtained by adjusting the base engine to accommodate the required geometry. Thicknesses were altered to reflect changes in fan and low pressure compressor weight and moment. The outer assembly weight was adjusted to account for the changes in fanduct flow made necessary by changes in by-pass ratio.

d. High Pressure Compressor

Twenty four of the 35 cycle combinations studied have high pressure compressors which are the same as the 20,000 pound (88,960 newton) thrust JT9D cycle base engine, i.e., same number of stages, same inlet and exit hub-tip ratios, and same inlet and exit diameters. These compressors weigh the same as the base engine compressor except as modified to account for lower over-all pressure ratios which allow the use of more titanium disk and blades, or higher over-all pressure ratios which require the use of more steel disks and blades. The remaining eleven cycle combinations have high pressure compressors which are supercharged versions of the base engine. The weight of these compressors was obtain by accounting for the added stage in the front of the base design compressors.

e. Diffuser-Burner

The diffuser-burner section includes the diffuser case, the burner liners and nozzles, the burner cases both inner and outer, and the no. 3 bearing compartment. Since the high pressure compressor exit diameters are the same for all 35 cycle combinations, weight variations assumed are related only to burner length changes and revisions to the high turbine inlet ratios. Weight changes due to length variations were determined from a weight-per-inch of length value compared to the base configuration. Case thicknesses were altered where burner pressures and temperatures dictated.

f. High Pressure Turbine Rotor, Stator and Cases

The base engine, 20,000 pound (88,960 newtons) thrust JT9D cycle has a two stage high pressure turbine with two stages having cooled vanes and one stage having cooled blades. The high p ressure turbines of the 35 sample engine combinations considered range in numbers of stages from one to three and in rows of cooled blades and vanes from two to four. Weight effects were further complicated by variation in hub-tip ratio. Since the high pressure turbines are vastly different for each configuration, the weights could not be estimated by merely referring to the JT9D base engine component. Consequently a system that predicted the weight of each turbine was developed. The blade and vane airfoil weights were first determined. Knowing blade foil weights a disk weight was then determined which was similar mechanically and structurally to the base engine.

g. Low Pressure Turbine Rotor Stators and Case

The base engine, 20,000 pound (88,960 newtons) thrust JT9D, has a four stage low pressure turbine with no cooled stages. It is an inline design with the rear bearing support located aft of the low pressure turbine section. The low pressure turbines of the 35 cycle combinations studied range in numbers of stages from one to seven with four turbines being offset and requiring an interturbine transition section. As in the case of the high pressure turbine, the weight estimates of the low pressure turbine could only be accomplished on an individual basis using the same technique previously described for the high pressure turbine.

h. Shafting

The shafting weight for the high and low spool was determined after preliminary artical speed analysis was completed. Weight increases for additional bearings were included where necessary. Weight estimates for the study engines are based on the structural arrangements described in section 2.

i. Turbine Exhaust Case

The turbine exhaust section on the base engine includes the No. 4 bearing compartment and the rear engine mount. The weight of this component was obtained by adjusting the base engine turbine exhaust section for diameter changes.

j. Controls and Accessories

This section includes the weight of the following:

Accessory gearbox
Fuel control and pump
Ignition system
Oil tank
Fuel-oil-cooler
Fuel heater
Fuel supply lines and manifolds
Oil supply lines
Instrumentation

It was assumed that all 35 cycle combinations when sized for constant high pressure compressor exit corrected airflow would require the same total control component weight. Components weights were scaled in rough proportion to high spool corrected (referred) airflow.

B. KEY ASSUMPTIONS AND PROBLEM AREAS

1. General

The following paragraphs explain in further detail the calculation procedures broadly described in Section A. These procedures were actually employed in deriving weights and physical dimensions for the sample engine, but they also apply universally to all cycle combinations by virtue of the regression analysis process.

2. Components

a. Fan

Key variables required to set the fan are its flow per unit area (W/A), hub/tip ratio, and chord length or aspect ratio. For the cruise design, W/A (referred to standard conditions) was set at 41.0 lb/sec/ft^2 (200.5^{K9}/sec M^2). However, off-design, take-off operation for some cycle combinations occurred with referred airflows considerably in excess of design, as an overflow condition. To avoid the aerodynamic limitations of overflow, a limit of W/A = 43.0 (210.3 Kg/sec. M^2) was set for take-off and this limit dictated inlet dimensions for some engines.

Fans in all cases were assumed to consist of a single stage with no inlet guide vane. Related aerodynamically to the JT9D engine technology, fans were assumed to have the same aspect ratio and hub/tip ratios equal to 0.38 in all cases.

b. Low Pressure Compressor

Flow paths were established by fixing design (referred) airflow per unit area at 35.2 lb/sec/ft^2 (172Kg/sec. M^2) for all engines, holding the ratio of fan tip-diameter-to-compressor inlet root diameter fixed, and holding the inlet-to-exit diameter ratios to give a constant inward slope. The resulting significant design values for all sample engines are present in Table VII.

c. High Pressure Compressor

Design details of the high pressure compressor are presented in Table VIII. Essentially, in keeping with cycle requirements imposed on the JT9D base line engine, all compressors were either an 11 stage, variable stator geometry spool, or a 12 stage spool, derived from 11 stage spool by the simple addition of a stage. Further definition of the spool geometry derived from a combination of holding exit Mach number at 0.27 for all spools, keeping inlet hub/tip ratio near 0.70, and having inlet referred flow per unit area near 35 lb/sec/ft^2 (171Kg/sec. M^2).

TABLE VIII 9090

VIII

TABLE 4-5

High Pressure Compressor Descriptions

PT4/PT3	# Stages	H/T (in) (Cm)	Dtip (in) (Cm)	$Wa\sqrt{\theta_{T3}}/\delta_{T3}$	W/A (lb/sec-ft^2) (Kg/sec-meter^2)
9.5	11	0.715 (1.82)	25.2 (64.0)	58.3 (.292)	34.5 (168)
10.0	11	0.715 (1.82)	25.2 (64.0)	60.9 (.305)	36.0 (175.3)
11.5	12	0.669 (1.70)	26.8 (68.2)	68.6 (.3439)	31.7 (154.5)
12.5	12	0.669 (1.70)	26.8 (68.2)	73.5 (.378)	34.0 (165.8)

Bottom of page 63

d. Burner

The overall burner arrangement used for all sample cycle designs in an annular, downstream injection combustor fed by an integrated diffuser. This arrangement represents the JT9D design. Variations in pressure losses as related to changes in combustor section length and temperature rise are predicated, generally, on JT9D technology capability. In certain extreme cases, the engine cycle dictates a combustor pressure loss in excess of 14 percent, which does not represent a practical design from a performance standpoint. For the purposes of the parametric study, these engine cycles were arbitrarily limited to that value and have been so noted in all tabulations of results.

The basic problem in pressure loss exists with all cycles having a cycle pressure ratio equal to 15:1 in combination with take-off turbine inlet temperature equal to 2300°F (1534°F), or cruise turbine temperature equal to 2100°F (1420°K). These cycles represent extremes in burner length required to accommodate a large temperature rise, and thus extremes in wetted liner surface area that require cooling. The high pressure loss associated with large quantities of cooling air results in combustor overall pressure losses exceeding 14 percent.

To offset the need for large quantities of cooling air, either an improved effectiveness in cooling technique or an improved capability of liner material to withstand higher metal temperatures must be developed. Consequently, the engine cycle combinations noted as exceeding current technology would, if selected, require additional development effort to improve their burner liner cooling capabilities.

Significant design variables for the burner sections of the sample are shown on Table IX.

e. Turbines

The primary design variable relating turbine performance to turbine design is the mean velocity ratio* per stage. In accordance with the current state-of-the art technology in turbine aerodynamic design, the high pressure turbine mean velocity ratio selected for all engine designs was 0.55; the selected low pressure turbine mean velocity ratio was 0.48. The combination of velocity ratio and cycle work requirements determined the numbers of stages required in each case.

To establish the turbine exhaust dimensions, the exit Mach number for all engine arrangements was set to be 0.4. With the I.D. of high and low pressure turbines assumed to slop slightly inwards (constant I.D., but with overlap descending downstream), all turbines were close-coupled where practical. In a few instances in the sample configurations, it was deemed necessary to couple high and low pressure turbines by means of an increasing diameter transition duct. These

PRATT & WHITNEY AIRCRAFT

Table IX

7690

Page 65

TABLE 4-6

Burner Descriptions

Case No.	Requirements Cruise Pt4/PT2	Cruise T_{T4} (°F)(°K)	Cruise T_{T5} (°F)(°K)	SLTO[1] T_{T4} (°F)(°K)	SLTO[1] T_{T5} (°F)(°K)	Combustor Section Length (CEGV to TIGV)	Combustor Section $\Delta P/P_{T4}$
1	15	597 586	1600 1145	759 675	1600 1145	14.5	4.7
2	15	597 586	1600 1145	759 675	1950 1340	18.5	5.3
3*	15	597 586	1600 1145	759 675	2300 1560	28.5	14.0
4	15	597 586	1800 1254	759 675	1600 1145	17.5	4.8
5	15	597 586	1800 1254	759 675	1950 1340	18.5	5.3
6*	15	597 586	1800 1254	759 675	2300 1560	28.5	14.0
7*	15	597 586	2100 1420	759 675	1600 1145	27.0	14.0
8*	15	597 586	2100 1420	759 675	1950 1340	27.0	14.0
9*	15	597 586	2100 1420	759 675	2300 1560	28.5	14.0
10	24.5	765 680	1600 1145	933 774	1600 1145	13.5	4.7
11	24.5	765 680	1600 1145	933 774	1950 1340	15.5	4.7
12	24.5	765 680	1600 1145	933 774	2300 1560	23.0	9.0
13	24.5	765 680	1800 1254	933 774	1600 1145	16.0	4.7
14	24.5	765 680	1800 1254	933 774	1950 1340	16.5	4.7
15	24.5	765 680	1800 1254	933 774	2300 1560	23.0	9.0
16	24.5	765 680	2100 1420	933 774	1600 1145	22.0	6.7
17	24.5	765 680	2100 1420	933 774	1950 1340	22.0	6.7
18	24.5	765 680	2100 1420	933 774	2300 1560	23.0	9.0
19	30	849 726	1600 1145	1036 830	1600 1145	13.5	4.7
20	30	849 726	1600 1145	1036 830	1950 1340	14.5	4.7
21	30	849 726	1600 1145	1036 830	2300 1500	20.5	6.0
22	30	849 726	1800 1254	1036 830	1600 1145	15.0	4.7
23	30	849 726	1800 1254	1036 830	1950 1340	15.5	4.7
24	30	849 726	1800 1254	1036 830	2300 1560	20.5	5.9
25	30	849 726	2100 1420	1036 830	1600 1145	19.5	6.4
26	30	849 726	2100 1420	1036 830	1950 1340	19.5	6.4
27	30	849 726	2100 1420	1036 830	2300 1560	20.5	5.9

* Cannot be achieved within JT9D technology due to excessive cooling requirements--will require high temperature liner materials or improved cooling technique. Pressure loss set from engine performance considerations.

(1) Standard Day

Design Data Supplied for Case 14 (Based on JT9D Scaled to 20,000 F_N)

	Cruise	Take-Off
Wagg (lb/sec)(N/sec)	47.8 (212.6)	112.5 (500.4)
TAC, %	7.0	7.0
P_{T4}, psia (lbf/in^2)(N/cm^2)	122.6 (84.5)	312.9 (216.0)
$\Delta P/P_T$, %	4.7	4.7

NOTE: Flow and pressure conditions for PR of 15 and 30 obtained assuming constant M_N at compressor exit and constant P_{T2}.

Page 65

cases occurred in every instance where high bypass ratio demanded large low pressure turbine diameters to properly balance mean wheel speed with numbers of stages, holding the fixed average velocity ratio. The transition section in these cases is able to serve double duty by providing space for a bearing support as well as directing the high pressure turbine exit flow outward to the increased diameter of the low pressure turbine.

Metal temperatures were held by use of impingement cooled vanes with slotted trailing edges, and convectively cooled blades. Consistent with these cooling schemes and with turbine materials currently in commercial service, cooling air variations were selected to reflect at least 3,000 hours TBO and 5,000 hours parts life capability for all cycle combinations studied.

3. Overall Engine Design Assumptions

Some of the primary design assumptions required in establishing the overall engine designs and dimensions included:

- Linear dimension scale by the square root of the thrust ratio between two engines.
- The ratio of blade length vs. chord kept constant for a particular stage (constant aspect ratio). This maintains desirable vibration characteristics.
- Although gaps between stages do not scale exactly linearly, it is assumed that they do scale linearly from the 20,000 pound (88,960 newton) base engine.
- Tip speed of rotating components remains constant. Rotor speeds are thus inversely proportional to physical dimensions.
- Critical speed scales with a linearly scaled engine, but because the engines are not directly scaled, critical speed characteristics were evaluated by comparing dimensions and speeds with data obtained from past studies on the (88,960 newtons) 20,000 pound thrust engine, and by judging from experience when additional bearing support is required.
- From past experience it was determined that the maximum acceptable physical fan tip speed is 1700 ft. (517 m) per sec.
- High pressure turbine length is dictated by cooling requirements rather than by maintaining constant aspect ratio.
- Stresses caused by steady state loads are constant.

- Bearing DN (Diameter times Speed) is a maximum of 1.9×10^6. This sets the bearing diameter.

Having established the key design variables for the components, a preliminary determination was made of the over-all engine length, mechanical arrangements, and structural arrangements. First, air-flow requirements set the basic diameters of the engine. Then, fan area was set, and the diameter was calculated with the requirement that the ratio of the fan-hub diameter to tip diameter be a constant. Next, the length was established with a constant-aspect-ratio fan blade. The diameter of the low-pressure compressor's hub is set by the fan hub, and performance requirements determine the number of low-pressure compressor stages. The length of the low-pressure compressor was established by comparing the ratio of the inlet blade length to the overall axial length to a reference engine with the same number of stages. This length was kept to a minimum of (19.1 cm) 7.5 inches since there must be sufficient length between the low- and high-pressure compressors to accomodate the bearings, tower shaft, and other accessories.

The intermediate case strut length was set at (12.1 cm) 4.75 inches for engines with three stages of low-pressure compressor or less. Strut length was raised to (14.0 cm) 5.50 inches for four-stage low-pressure compressor engines because the additional overhang requires a better support structure. Here, the minimum length was maintained for structural integrity and to provide passages to get the tower shaft and other services into the bearing compartment.

The same general technique was used to establish the length of the high-pressure compressor as was used for the low-pressure compressor. Additional length was provided when a 12-stage high-pressure compressor was used rather than the standard 11-stage compressor.

Chord length on the high-pressure turbine was set by the restrictions on the internal cooling flow passages. As a result, individual stage lengths were fixed, and over-all length was determined by the number of stages. The length of the low-pressure turbine was determined by calculating the average stage length from the baseline engine, and multiplying by the number of stages.

The exhaust-case length was kept constant for all the engines, since the rear bearing design does not change significantly from engine to engine.

In some cases, the basic requirement of maintaining a constant aerodynamic philosophy produced a large misalignment between the low- and high-pressure compressors and between the low- and high-pressure turbines. When this occurred, additional length was provided for a transition duct between the misaligned components. The tabulation in Appendix A summarizes all design dimensions established for the sample cycles.

4. Weights Determination

Because weight scaling is such an important part of the weight estimating technique used in this program, a brief discussion of the assumptions made relative to weight scaling is appropriate.

The thrust of a gas turbine engine does not scale at the same rate as weight. Briefly, thrust is proportional to the square of the engine diameter or directly proportional to engine airflow, while weight is theoretically proportional to the cube of the diameter or the 3/2 power of thrust. In actual practice, the well-known square cube law of scaling is rarely realized since the effects of weight scaling are dependent on size, complexity, and state-of-the-art. The scaling technique used in this study was based on an extensive study conducted by Pratt & Whitney Aircraft on reduced size JT9D engines. Scaling assumes that pressures, temperatures, flight conditions, and materials are not changed and that airflow per unit frontal area, tip speed(s), blade and vane aspect ratios, hub-tip ratios, and structural integrity are not changed. Modifications were made in the Task I study, where appropriate, to make the ordinary scaling techniques applicable to the 35 sample cycle combinations.

C. DISCUSSION AND INTERPRETATION OF RESULTS

The diameter, lengths, and weights for all cycle combinations studied under the contract are tabulated in Appendix A. Variations of weights and dimensions with thrust are indicated in the tabulation by including values for both 20,000 pounds (88,960 newtons) and 25,000 pounds (111,200 newtons) take-off thrust levels.

With so many cycle variables involved, no direct presentation of the resulting weight trends is possible. However, some representative trends may be inferred from selected plots taken from among the complete output data.

To select a limited range of variables for convenient presentation, all engine cycles were first narrowed to include just those cycles having a specified cruise thrust level (Fn cruise = 4900 pounds (21,800 newtons). Then, the middle of the overall compression ratio range was chosen as representative of overall trends with the other variables. The resulting trends of engine weight variation with bypass ratio and take-off turbine inlet temperature are shown for fan pressure ratios of 1.30, 1.55, and 1.70, respectively, on Figure 28, 29, and 30. Finally isolated effects of overall compression ratio are shown for the fixed combination of 5.0 bypass ratio, 1.55 fan pressure ratio, and 1950°F (1390°K) turbine inlet temperature, each value being in the center of its range.

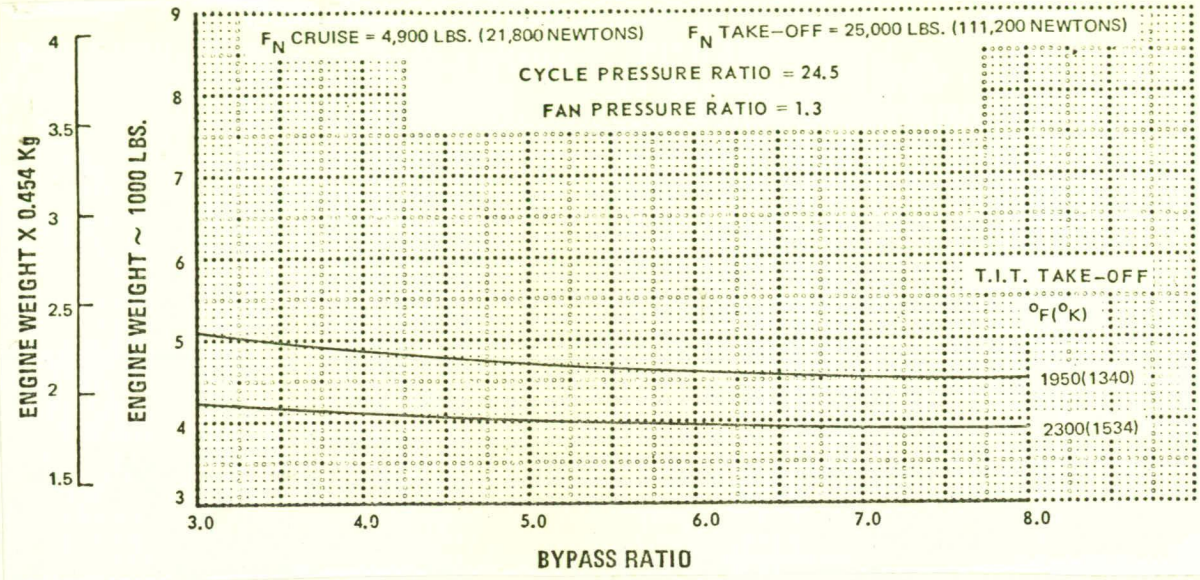


Figure 28 Engine Weight vs Bypass Ratio and Turbine Inlet Temperature

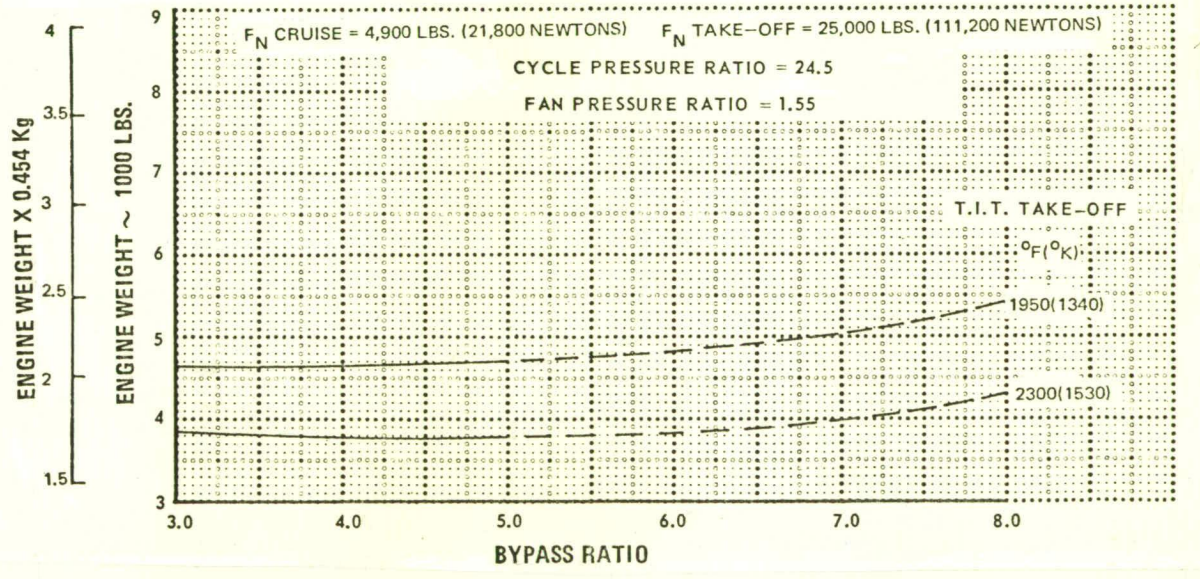


Figure 29 Engine Weight vs Bypass Ratio and Turbine Inlet Temperature

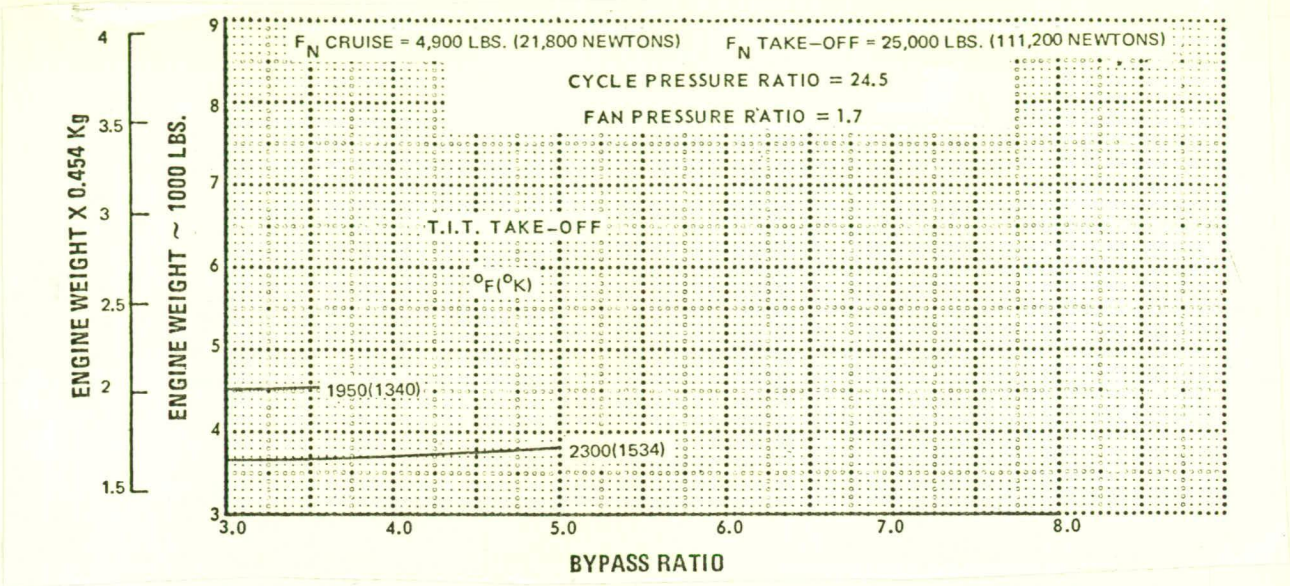


Figure 30 Engine Weight vs Bypass Ratio and Turbine Inlet Temperature

As would be expected, the engine weights are directly influenced by turbine inlet temperature levels, the lightest engines coming with the highest temperature levels. The bypass ratio and fan pressure ratio effects are less manifest. Since increasing bypass ratio tends to improve propulsive efficiency, overall engine size tends to reduce with increasing bypass ratio. However, this tendency is offset by the increased weight due to the larger diameters and larger fan drive turbines inherent with higher bypass ratios. As a net effect, (within the assumptions of engine design in this study,) there appears to be a gradual decrease in weight with bypass ratio at the 1.3 fan pressure level; while there is an increase in weight at the 1.55 and 1.7 fan pressure ratio levels. At these latter levels propulsive efficiency does not improve so rapidly with increasing bypass ratio, and turbine work levels are higher, and require larger turbines.

The trend with compression ratio depicted in Figure 31 shows a gradual decrease, then increase in weight. This reflects chiefly the conflicting effects of reduced engine size due to increased density in the engine core with supercharging from the increased pressure ratio, on the one hand, and increased numbers of stages required with greater pressure ratio, on the other.

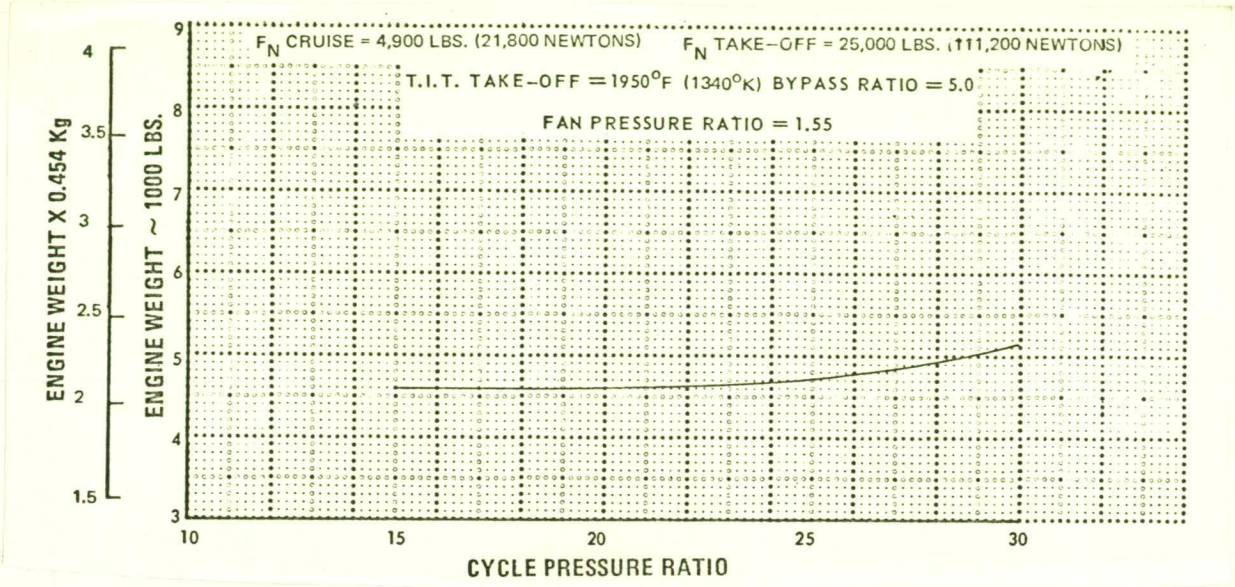


Figure 31 Effect of Cycle Pressure Ratio on Engine Weight

The trends of weight variation illustrated in Figures 28 through 31 are only representative, and should not be construed as being followed in every case listed in Appendix A. In addition, the absolute weight levels associated with the engine study are valid only within the listed assumptions and are accurate only to the consistency of a broad parametric study, as this Task I effort has been.

APPENDIX A
TABULATION OF RESULTS

EXPLANATION OF CYCLE IDENTIFICATION CODE AND REMARKS CODE

In order to identify as succinctly as possible each of the 243 distinct engine cycle combinations in the Task I parametric study, a mnemonic code system was adopted. The identification code is an 11-symbol "word", denoting the value of each engine cycle parameter as well as the engine's take-off thrust. The code is defined by example in Table X. Supplementary designations of bypass-ratio are given in Table XI. Table XII presents a reference cycle for the JT3D-3B engine.

TABLE X
SAMPLE MNEMONIC CODE SYSTEM

78 ~~82~~ 9.

TABLE A-1

Table X

78%

Symbol Position	Cycle Parameter	Value	Code
1 & 2	Cruise Turbine Inlet Temp., °F	1600	60
		1800	80
		2100	10
3	Take-Off Thrust, lb.	20000	-
		25000	*
4 & 5	Take-Off Turbine Inlet Temp., °F	1600	60
		1950	95
		2300	30
6	Bypass Ratio (Φ)	(See Table A-2)	
7 & 8	Fan Pressure Ratio (Rc_f)	1.30	30
		1.55	55
		1.70	70
9	Bypass Ratio	(See Table A-2)	
10 & 11	Overall Pressure Ratio (Rc)	15.0	15
		24.5	24
		30.0	30

Examples:

80-95B55-24

TIT_{cr} = 1800 F
TIT_{to} = 1950F
Φ = 5.0
Rc_f = 1.55
Rc = 24.5
Fn = 20,000 lb.

60*30S70B30

TIT_{cr} = 1600 F
TIT_{to} = 2300 F
Φ = 3.50
Rc_f = 1.70
Rc = 30.0
Fn = 25,000 lb.

page 73

TABLE XI

SUPPLEMENTARY DESIGNATIONS OF BYPASS-RATIO

Designation	Bypass Ratio
A	3
B	5
C	8
D	6
E	4
F	5.4
H	4.8
I	3.75
J	7.75
K	7.25
L	6.85
M	5.80
N	5.10
O	6.75
P	6.25
Q	6.40
R	6.0
T	7.50
U	5.25
V	4;25
W	4.90
X	6.50
Y	3.65
Z	7.0
S--A-	4.5
S--B-	3.5

The "Remarks" column on the tabulation sheets of the Task I parametric study results contains a code identifying certain aerodynamic or mechanical problems associated with the engine cycle. The code is defined as follows:

Code Number	Problem
2	Fan exceeds the maximum allowable ratio of flow to area. (W/A_{max} = 43 lb/sec/ft^2)
3	Fan Rotor exceeds the maximum allowable mechanical speed (maximum tip speed = 1700 fps)
4	Burner liner requires more advanced materials or more advanced cooling system than is available in state-of-the-art annular combustors.

The results of the parametric studies are shown on the computer tabulations complied in the remainder of this appendix.

TABLE XII

JT3D-3B ENGINE REFERENCE CYCLE

PERFORMANCE

	Std Day SLS T/O	Max Cruise 35000' Alt 0.82 MN
FN Total	18000	4440
WA Total	464	186
TSFC	.535	.80
BPR	1.415	1.41
TT5	1600°F	1415°F
FPR	1.74	1.74
OPR	13.5	14.1

GEOMETRY

Fan Tip Diameter	51"
Engine Length	137"
Engine Weight	4260 lbs.

NOISE

JT3D-3B (4 Engines)

	Altitude	Total	Jet
Takeoff	620'	119.7	112.2
Approach	327'	116.4	95.3

QUIET ENGINE PARAMETRIC STUDY RESULTS (TASK I) SHEET 1 OF 14

PREPARED BY PRATT & WHITNEY AIRCRAFT FOR NASA-LEWIS RESEARCH CENTER

CYCLE NUMBER	ENGINE PERFORMANCE						ENGINE INSTALLATION DATA			REMARKS
	TAKE-OFF			CRUISE						
	FN	FN/WA	TSFC	FN	FN/WA	TSFC	WEIGHT	DIAMETER	LENGTH	
60-60A30-15	20000.	29.01	.442	5757.	17.31	.786	5609.	66.8	100.	
80-60A30-15	20000.	27.75	.463	7280.	19.32	.849	6500.	71.0	105.	
10-60A30-15	20000.	24.80	.513	10170.	21.55	.953	8983.	79.5	123.	4
60*60A30-15	25000.	29.01	.442	7197.	17.31	.786	7152.	74.6	112.	
80*60A30-15	25000.	27.75	.463	9100.	19.32	.849	8288.	79.4	117.	
10*60A30-15	25000.	24.80	.513	12680.	21.55	.953	11424.	88.9	138.	4
60-95A30-15	20000.	35.17	.500	4035.	16.92	.786	4251.	56.5	98.	
80-95A30-15	20000.	33.81	.522	5145.	19.13	.847	4736.	60.2	101.	
10-95A30-15	20000.	30.70	.563	7140.	21.48	.952	6144.	66.8	111.	4
60*95A30-15	25000.	35.17	.500	5035.	16.92	.786	5411.	63.2	110.	
80*95A30-15	25000.	33.81	.522	6440.	19.13	.847	6046.	67.2	113.	
10*95A30-15	25000.	30.70	.563	8935.	21.48	.952	7842.	74.6	124.	4
60-30A30-15	20000.	41.02	.567	2885.	16.21	.808	3344.	48.8	97.	4
80-30A30-15	20000.	38.38	.585	3765.	18.25	.862	3706.	52.6	97.	4
10-30A30-15	20000.	36.30	.614	5260.	21.09	.944	4473.	57.8	99.	4
60*30A30-15	25000.	41.02	.567	3605.	16.21	.808	4262.	54.6	108.	4
80*30A30-15	25000.	38.88	.585	4700.	18.25	.862	4719.	58.8	109.	
10*30A30-15	25000.	36.30	.614	6560.	21.09	.944	5689.	64.5	110.	4
60-60A55-15	20000.	29.99	.408	5795.	18.89	.720	5369.	64.0	92.	
80-60A55-15	20000.	28.85	.426	7305.	21.16	.775	6147.	68.0	97.	
10-60A55-15	20000.	25.82	.476	10300.	23.58	.871	8502.	76.5	91.	4
60*60A55-15	25000.	29.99	.408	7245.	18.89	.720	6847.	71.5	104.	
80*60A55-15	25000.	28.85	.426	9129.	21.16	.775	7836.	76.0	109.	4
10*60A55-15	25000.	25.82	.476	12880.	23.58	.871	10844.	85.6	102.	4
60-95A55-15	20000.	36.21	.456	3975.	18.23	.723	4026.	54.0	91.	
80-95A55-15	20000.	35.23	.476	5125.	20.94	.774	4445.	57.2	93.	
10-95A55-15	20000.	32.19	.515	7060.	23.50	.870	5682.	63.9	116.	4
60*95A55-15	25000.	36.21	.456	4970.	18.23	.723	5135.	60.5	102.	
80*95A55-15	25000.	35.23	.476	6405.	20.94	.774	5667.	64.0	104.	
10*95A55-15	25000.	32.19	.515	8810.	23.50	.870	7232.	70.9	130.	4
60-30A55-15	20000.	42.30	.515	2880.	17.53	.746	3191.	47.6	89.	234
80-30A55-15	20000.	40.40	.530	3745.	19.89	.789	3487.	49.9	89.	4
10-30A55-15	20000.	37.90	.559	5190.	23.10	.862	4125.	54.6	103.	4
60*30A55-15	25000.	42.30	.515	3600.	17.53	.746	4069.	53.3	100.	234
80*30A55-15	25000.	40.40	.530	4680.	19.89	.789	4445.	55.7	100.	4
10*30A55-15	25000.	37.90	.559	6495.	23.10	.862	5266.	61.0	116.	4

PREPARED BY PRATT & WHITNEY AIRCRAFT FOR NASA-LEWIS RESEARCH CENTER

CYCLE NUMBER	ENGINE PERFORMANCE						ENGINE INSTALLATION DATA			REMARKS
	TAKE-OFF			CRUISE						
	FN	FN/WA	TSFC	FN	FN/WA	TSFC	WEIGHT	DIAMETER	LENGTH	
60-60A70-15	20000.	29.87	.411	5944.	19.22	.708	5369.	64.4	95.	
80-60A70-15	20000.	28.83	.426	7536.	21.74	.754	6105.	68.1	99.	
10-60A70-15	20000.	25.82	.476	10777.	24.34	.844	8500.	77.3	93.	4
60*60A70-15	25000.	29.87	.411	7435.	19.22	.708	6850.	72.0	106.	
80*60A70-15	25000.	28.83	.426	9407.	21.74	.754	7774.	76.0	111.	
10*60A70-15	25000.	25.82	.478	13471.	24.34	.844	10837.	86.1	104.	4
60-95A70-15	20000.	36.46	.452	4006.	18.65	.713	3936.	53.6	93.	3
80-95A70-15	20000.	35.41	.467	5156.	21.44	.754	4322.	56.7	95.	
10-95A70-15	20000.	32.50	.506	7156.	24.25	.843	5502.	62.9	118.	4
60*95A70-15	25000.	36.46	.452	5008.	18.65	.713	5019.	60.0	104.	3
80*95A70-15	25000.	35.41	.467	6445.	21.44	.754	5510.	63.5	107.	
10*95A70-15	25000.	32.50	.506	8945.	24.25	.843	7015.	70.4	132.	4
60-30A70-15	20000.	43.37	.494	2865.	17.65	.743	2908.	47.3	91.	234
80-30A70-15	20000.	41.51	.510	3768.	20.40	.770	3385.	49.3	92.	4
10-30A70-15	20000.	39.21	.534	5213.	23.80	.838	3963.	53.6	106.	4
60*30A70-15	25000.	43.37	.494	3582.	17.65	.743	3708.	52.8	102.	234
80*30A70-15	25000.	41.51	.510	4712.	20.40	.770	4318.	55.1	103.	4
10*30A70-15	25000.	39.21	.534	6516.	23.80	.838	5053.	60.0	118.	4
60-60A30-24	20000.	27.34	.384	5709.	15.97	.713	5640.	69.2	98.	
80-60A30-24	20000.	26.38	.405	7429.	18.30	.774	6283.	73.8	102.	
10-60A30-24	20000.	24.70	.435	10220.	21.05	.865	7879.	80.6	96.	
60*60A30-24	25000.	27.34	.384	7136.	15.97	.713	7191.	77.4	109.	
80*60A30-24	25000.	26.38	.405	9286.	18.30	.774	8010.	82.5	114.	
10*60A30-24	25000.	24.70	.435	12775.	21.05	.865	10046.	90.1	108.	
60-95A30-24	20000.	33.66	.440	3816.	15.43	.717	3962.	57.5	96.	
80-95A30-24	20000.	32.62	.461	5069.	18.02	.773	4355.	61.5	98.	
10-95A30-24	20000.	30.57	.491	7110.	20.97	.864	5382.	67.5	121.	
60*95A30-24	25000.	33.66	.440	4770.	15.43	.717	5052.	64.4	107.	
80*95A30-24	25000.	32.62	.461	6336.	18.02	.773	5552.	68.6	110.	
10*95A30-24	25000.	30.57	.491	8923.	20.97	.864	6890.	75.4	135.	
60-30A30-24	20000.	39.14	.503	2586.	14.49	.738	2903.	50.4	94.	2
80-30A30-24	20000.	38.02	.524	3577.	17.39	.781	3185.	52.9	95.	
10-30A30-24	20000.	35.44	.548	5160.	20.30	.862	3945.	58.5	108.	
60*30A30-24	25000.	39.14	.503	3233.	14.49	.738	3702.	56.5	106.	2
80*30A30-24	25000.	38.02	.524	4470.	17.39	.781	4060.	59.2	106.	
10*30A30-24	25000.	35.44	.548	6450.	20.30	.862	5030.	65.5	122.	

PREPARED BY PRATT & WHITNEY AIRCRAFT FOR NASA-LEWIS RESEARCH CENTER

CYCLE NUMBER	ENGINE PERFORMANCE						ENGINE INSTALLATION DATA			REMARKS
	TAKE-OFF			CRUISE						
	FN	FN/WA	TSFC	FN	FN/WA	TSFC	WEIGHT	DIAMETER	LENGTH	
60-60A55-24	20000.	26.06	.359	5822.	17.37	.655	5247.	67.0	89.	
80-60A55-24	20000.	27.32	.374	7520.	20.07	.706	5761.	70.9	94.	
10-60A55-24	20000.	25.65	.401	10336.	23.11	.788	7227.	77.4	88.	
60*60A55-24	25000.	28.06	.359	7278.	17.37	.655	6690.	74.9	100.	
80*60A55-24	25000.	27.32	.374	9399.	20.07	.706	7344.	79.2	105.	
10*60A55-24	25000.	25.65	.401	12920.	23.11	.788	9214.	86.5	98.	
60-95A55-24	20000.	34.61	.404	3779.	16.66	.664	3606.	55.1	88.	
80-95A55-24	20000.	33.94	.421	5036.	19.72	.706	3928.	58.9	90.	
10-95A55-24	20000.	32.04	.448	6753.	23.01	.787	4638.	63.7	112.	
60*95A55-24	25000.	34.61	.404	4724.	16.66	.664	4598.	61.6	98.	
80*95A55-24	25000.	33.94	.421	6295.	19.72	.706	5008.	65.5	101.	
10*95A55-24	25000.	32.04	.448	8441.	23.01	.787	5913.	71.7	126.	
60-30A55-24	20000.	40.58	.454	2560.	15.42	.708	2680.	49.1	86.	23
80-30A55-24	20000.	39.76	.472	3565.	18.91	.718	2900.	50.3	86.	
10-30A55-24	20000.	37.40	.494	5119.	22.31	.786	3545.	55.4	100.	
60*30A55-24	25000.	40.58	.454	3199.	15.42	.708	3416.	54.9	96.	23
80*30A55-24	25000.	39.76	.472	4456.	18.91	.718	3698.	56.2	97.	
10*30A55-24	25000.	37.40	.494	6399.	22.31	.786	4520.	61.9	112.	
60-60A70-24	20000.	27.76	.365	5996.	17.50	.650	5158.	67.7	82.	
80-60A70-24	20000.	27.31	.377	7741.	20.56	.689	5567.	71.0	87.	
10-60A70-24	20000.	25.72	.401	10727.	23.88	.762	7002.	77.5	81.	
60*60A70-24	25000.	27.76	.365	7494.	17.50	.650	6575.	75.7	92.	
80*60A70-24	25000.	27.31	.377	9676.	20.56	.689	7098.	79.4	97.	
10*60A70-24	25000.	25.72	.401	13409.	23.88	.762	8928.	87.5	91.	
60-95A70-24	20000.	34.11	.406	3786.	16.44	.669	3523.	55.6	81.	
80-95A70-24	20000.	33.34	.418	5075.	19.68	.695	3814.	58.8	83.	
10-95A70-24	20000.	32.73	.439	7136.	24.05	.763	4521.	63.0	106.	
60*95A70-24	25000.	34.11	.406	4732.	16.44	.669	4492.	62.1	91.	
80*95A70-24	25000.	33.34	.418	6344.	19.68	.695	4864.	65.7	93.	
10*95A70-24	25000.	32.73	.439	8903.	24.05	.763	5756.	70.5	118.	
60-30A70-24	20000.	40.46	.448	2524.	15.04	.709	2609.	49.0	79.	23
80-30A70-24	20000.	40.25	.460	3575.	19.18	.706	2758.	49.7	79.	23
10-30A70-24	20000.	38.11	.479	5143.	23.00	.762	3327.	54.6	93.	
60*30A70-24	25000.	40.46	.448	3154.	15.04	.709	3325.	54.9	89.	23
80*30A70-24	25000.	40.25	.460	4472.	19.18	.706	3519.	55.6	89.	23
10*30A70-24	25000.	38.11	.479	6429.	23.00	.762	4243.	61.0	105.	

PRATT & WHITNEY AIRCRAFT

PREPARED BY PRATT & WHITNEY AIRCRAFT FOR NASA-LEWIS RESEARCH CENTER

CYCLE NUMBER	ENGINE PERFORMANCE						ENGINE INSTALLATION DATA			REMARKS
	TAKE-OFF			CRUISE						
	FN	FN/WA	TSFC	FN	FN/WA	TSFC	WEIGHT	DIAMETER	LENGTH	
60-60A30-30	20000.	26.11	.362	5545.	15.12	.686	6136.	71.1	108.	
80-60A30-30	20000.	25.50	.383	7487.	17.65	.745	6801.	74.9	112.	
10-60A30-30	20000.	23.86	.413	10477.	20.51	.835	8269.	82.7	106.	
60*60A30-30	25000.	26.11	.362	6932.	15.12	.686	7824.	79.5	121.	
80*60A30-30	25000.	25.50	.383	9359.	17.65	.745	8672.	84.2	126.	
10*60A30-30	25000.	23.86	.413	13096.	20.51	.835	10543.	92.5	119.	
60-95A30-30	20000.	32.53	.416	3678.	14.45	.695	4215.	58.4	106.	
80-95A30-30	20000.	31.70	.437	5011.	17.28	.745	4592.	62.3	108.	
10-95A30-30	20000.	29.91	.467	7127.	20.41	.834	5569.	68.4	131.	
60*95A30-30	25000.	32.53	.416	4598.	14.45	.695	5375.	65.3	119.	
80*95A30-30	25000.	31.70	.437	6263.	17.28	.745	5854.	69.6	122.	
10*95A30-30	25000.	29.91	.467	8909.	20.41	.834	7100.	76.5	147.	
60-30A30-30	20000.	37.80	.481	2419.	13.34	.724	2972.	50.0	104.	2
80-30A30-30	20000.	36.97	.500	3472.	16.63	.749	3265.	53.5	105.	
10-30A30-30	20000.	34.67	.524	5109.	19.80	.826	4053.	59.3	119.	
60*30A30-30	25000.	37.80	.481	3023.	13.34	.724	3789.	56.0	117.	2
80*30A30-30	25000.	36.97	.500	4340.	16.63	.749	4163.	59.8	118.	
10*30A30-30	25000.	34.67	.524	6386.	19.80	.826	5167.	66.3	133.	
60-60A55-30	20000.	26.74	.343	5852.	16.36	.634	5783.	69.2	99.	
80-60A55-30	20000.	26.34	.356	7625.	19.33	.680	6134.	72.8	103.	
10-60A55-30	20000.	24.78	.382	10726.	22.52	.760	7538.	79.5	97.	
60*60A55-30	25000.	26.74	.343	7315.	16.36	.634	7374.	77.8	111.	
80*60A55-30	25000.	26.34	.356	9531.	19.33	.680	7820.	81.2	116.	
10*60A55-30	25000.	24.78	.382	13408.	22.52	.760	9611.	88.8	109.	
60-95A55-30	20000.	31.88	.393	3616.	14.57	.671	3970.	57.6	97.	
80-95A55-30	20000.	32.83	.400	4996.	18.87	.682	4065.	59.5	100.	
10-95A55-30	20000.	32.12	.428	7087.	23.00	.764	4802.	64.3	122.	
60*95A55-30	25000.	31.88	.393	4520.	14.57	.671	5062.	64.5	109.	
80*95A55-30	25000.	32.83	.400	6246.	18.87	.682	5183.	66.6	112.	
10*95A55-30	25000.	32.12	.428	8859.	23.00	.764	6123.	71.8	137.	
60-30A55-30	20000.	38.78	.437	2371.	13.80	.700	2720.	50.5	96.	23
80-30A55-30	20000.	38.62	.451	3445.	17.86	.699	2923.	50.8	96.	
10-30A55-30	20000.	36.48	.472	5082.	21.56	.761	3617.	56.2	110.	
60*30A55-30	25000.	38.78	.437	2964.	13.80	.700	3468.	56.4	107.	23
80*30A55-30	25000.	38.62	.451	4306.	17.86	.699	3727.	56.9	107.	
10*30A55-30	25000.	36.48	.472	6352.	21.56	.761	4611.	62.8	123.	

QUIET ENGINE PARAMETRIC STUDY RESULTS (TASK I) SHEET 5 OF 14

PREPARED BY PRATT & WHITNEY AIRCRAFT FOR NASA-LEWIS RESEARCH CENTER

CYCLE NUMBER	ENGINE PERFORMANCE						ENGINE INSTALLATION DATA			REMARKS
	TAKE-OFF			CRUISE						
	FN	FN/WA	TSFC	FN	FN/WA	TSFC	WEIGHT	DIAMETER	LENGTH	
60-60A70-30	20000.	26.35	.351	6017.	16.31	.636	5646.	70.3	87.	
80-60A70-30	20000.	26.18	.361	7924.	19.73	.666	5918.	73.4	91.	
10-60A70-30	20000.	24.80	.384	11067.	23.25	.737	7181.	79.9	110.	
60*60A70-30	25000.	26.35	.352	7521.	16.31	.636	7198.	78.6	97.	
80*60A70-30	25000.	26.18	.361	9905.	19.73	.666	7546.	82.0	102.	
10*60A70-30	25000.	24.80	.384	13834.	23.25	.737	9156.	89.3	123.	
60-95A70-30	20000.	32.59	.392	3672.	15.12	.664	3675.	57.0	85.	3
80-95A70-30	20000.	33.40	.396	5048.	19.60	.667	3744.	58.7	88.	
10-95A70-30	20000.	31.46	.419	7199.	23.12	.736	4622.	64.6	98.	
60*95A70-30	25000.	32.59	.392	4590.	15.12	.664	4686.	63.7	96.	3
80*95A70-30	25000.	33.40	.396	6310.	19.60	.667	4774.	65.7	98.	
10*95A70-30	25000.	31.46	.419	8998.	23.12	.736	5893.	72.1	110.	
60-30A70-30	20000.	38.25	.437	2297.	14.02	.690	2452.	50.6	84.	23
80-30A70-30	20000.	38.82	.441	3460.	18.02	.691	2753.	50.5	84.	23
10-30A70-30	20000.	37.13	.460	5097.	21.70	.755	3430.	55.3	86.	
60*30A70-30	25000.	38.25	.437	2872.	14.02	.690	3127.	56.6	94.	23
80*30A70-30	25000.	38.82	.441	4325.	18.02	.691	3510.	56.5	94.	23
10*30A70-30	25000.	37.13	.460	6371.	21.70	.755	4373.	61.9	96.	
60-60B30-15	20000.	27.38	.355	5110.	12.80	.708	5027.	72.5	102.	
80-60B30-15	20000.	23.27	.372	6458.	14.29	.765	5815.	77.5	107.	
10-60B30-15	20000.	20.82	.416	9065.	15.89	.862	8265.	88.0	126.	4
60*60B30-15	25000.	27.38	.355	6388.	12.80	.708	6410.	81.7	115.	
80*60B30-15	25000.	23.27	.372	8072.	14.29	.765	7414.	67.5	120.	
10*60B30-15	25000.	20.82	.416	11330.	15.89	.862	10537.	101.0	141.	4
60-95B30-15	20000.	29.42	.403	3574.	12.44	.708	3894.	62.0	101.	
80-95B30-15	20000.	27.95	.419	4592.	13.97	.762	4347.	66.2	103.	
10-95B30-15	20000.	25.86	.458	6310.	15.97	.864	5506.	72.5	113.	4
60*95B30-15	25000.	29.42	.403	4468.	12.44	.708	4965.	69.2	113.	
80*95B30-15	25000.	27.95	.419	5740.	13.97	.762	5543.	74.0	115.	
10*95B30-15	25000.	25.86	.458	7889.	15.97	.864	7021.	81.2	127.	4
60-30B30-15	20000.	34.28	.456	2569.	11.90	.733	3133.	53.7	99.	2 4
80-30B30-15	20000.	32.40	.473	3369.	13.45	.780	3402.	58.0	99.	4
10-30B30-15	20000.	30.10	.498	4703.	15.54	.854	4051.	63.7	101.	4
60*30B30-15	25000.	34.28	.456	3211.	11.90	.733	3994.	60.0	111.	2 4
80*30B30-15	25000.	32.40	.473	4211.	13.45	.780	4337.	64.8	111.	4
10*30B30-15	25000.	30.10	.498	5879.	15.54	.854	5165.	71.0	113.	4

PREPARED BY PRATT & WHITNEY AIRCRAFT FOR NASA-LEWIS RESEARCH CENTER

CYCLE NUMBER	ENGINE PERFORMANCE						ENGINE INSTALLATION DATA			REMARKS
	TAKE-OFF			CRUISE						
	FN	FN/WA	TSFC	FN	FN/WA	TSFC	WEIGHT	DIAMETER	LENGTH	
60-60B55-15	20000.	24.94	.339	5430.	14.07	.645	5338.	71.5	97.	
80-60B55-15	20000.	24.07	.350	6862.	16.00	.683	5955.	75.5	102.	
10-60B55-15	20000.	21.43	.392	9849.	17.91	.765	8338.	86.2	120.	4
60*60B55-15	25000.	24.94	.339	6786.	14.07	.645	6804.	80.4	109.	
80*60B55-15	25000.	24.07	.350	8578.	16.00	.683	7593.	43.5	114.	
10*60B55-15	25000.	21.43	.392	12290.	17.91	.765	10612.	102.5	135.	4
60-95B55-15	20000.	30.36	.371	3616.	13.59	.652	3936.	59.6	95.	
80-95B55-15	20000.	29.49	.382	4655.	19.79	.684	3349.	62.7	98.	
10-95B55-15	20000.	26.96	.415	6467.	17.84	.764	5297.	69.5	108.	4
60*95B55-15	25000.	30.36	.371	4520.	13.59	.652	5018.	66.6	107.	
80*95B55-15	25000.	29.49	.382	5819.	19.79	.684	4271.	70.0	110.	
10*95B55-15	25000.	26.96	.415	8084.	17.84	.764	6754.	77.7	121.	4
60-30B55-15	20000.	35.70	.408	2553.	12.75	.681	3155.	54.6	94.	234
80-30B55-15	20000.	34.10	.420	3371.	14.80	.709	3325.	54.7	94.	4
10-30B55-15	20000.	32.22	.440	4677.	17.49	.760	3760.	59.5	96.	4
60*30B55-15	25000.	35.70	.408	3191.	12.75	.681	4022.	60.9	105.	234
80*30B55-15	25000.	34.10	.420	4214.	14.80	.709	4239.	61.0	105.	4
10*30B55-15	25000.	32.22	.440	5846.	17.49	.760	4794.	66.5	107.	4
60-60B70-15	20000.	24.44	.354	5521.	13.65	.664	5683.	73.4	101.	
80-60B70-15	20000.	23.71	.362	7236.	16.14	.677	6262.	77.2	105.	
10-60B70-15	20000.	21.15	.404	10608.	18.41	.744	8668.	88.5	124.	4
60*60B70-15	25000.	24.44	.354	6902.	13.65	.664	7247.	82.4	113.	
80*60B70-15	25000.	23.71	.362	9045.	16.14	.677	7984.	87.2	118.	
10*60B70-15	25000.	21.15	.404	13260.	18.41	.744	11051.	100.5	139.	4
60-95B70-15	20000.	29.72	.385	3554.	12.92	.686	4309.	60.5	99.	
80-95B70-15	20000.	29.20	.389	4793.	15.86	.681	4328.	63.6	101.	
10-95B70-15	20000.	26.82	.420	6791.	18.33	.744	5369.	70.0	112.	4
60*95B70-15	25000.	29.72	.385	4443.	12.92	.686	5494.	67.7	111.	
80*95B70-15	25000.	29.20	.389	5991.	15.86	.681	5519.	71.0	114.	
10*95B70-15	25000.	26.82	.420	8489.	18.33	.744	6846.	78.5	125.	4
60-30B70-15	20000.	35.09	.413	2450.	11.61	.753	3371.	51.8	97.	234
80-30B70-15	20000.	34.14	.419	3200.	14.60	.717	3218.	55.0	98.	34
10-30B70-15	20000.	32.63	.432	4752.	17.90	.743	3701.	58.9	99.	4
60*30B70-15	25000.	35.09	.413	3064.	11.61	.753	4300.	57.5	109.	234
80*30B70-15	25000.	34.14	.419	4000.	14.60	.717	4102.	61.3	109.	34
10*30B70-15	25000.	32.63	.432	5940.	17.90	.743	4719.	65.8	111.	4

PREPARED BY PRATT & WHITNEY AIRCRAFT FOR NASA-LEWIS RESEARCH CENTER

CYCLE NUMBER	ENGINE PERFORMANCE						ENGINE INSTALLATION DATA			REMARKS
	TAKE-OFF			CRUISE						
	FN	FN/WA	TSFC	FN	FN/WA	TSFC	WEIGHT	DIAMETER	LENGTH	
60-60B30-24	20000.	22.93	.309	5118.	11.80	.643	5108.	76.0	100.	
80-60B30-24	20000.	22.16	.325	6603.	13.57	.696	5563.	80.6	104.	
10-60B30-24	20000.	20.63	.350	9095.	15.57	.780	7080.	89.0	123.	
60*60B30-24	25000.	22.93	.309	6398.	11.80	.643	6514.	85.5	112.	
80*60B30-24	25000.	22.16	.325	8254.	13.57	.696	7093.	91.2	117.	
10*60B30-24	25000.	20.63	.350	11368.	15.57	.780	9026.	101.0	138.	
60-95B30-24	20000.	28.11	.353	3369.	11.26	.652	3597.	63.4	98.	
80-95B30-24	20000.	27.36	.372	4510.	13.34	.696	3867.	67.3	101.	
10-95B30-24	20000.	25.47	.395	6328.	15.51	.778	4800.	73.7	111.	
60*95B30-24	25000.	28.11	.353	4211.	11.26	.652	4585.	70.5	110.	
80*95B30-24	25000.	27.36	.372	5640.	13.34	.696	4933.	74.0	113.	
10*95B30-24	25000.	25.47	.395	7910.	15.51	.778	6120.	82.7	124.	
60-30B30-24	20000.	32.71	.405	2278.	10.54	.675	2651.	54.5	97.	2
80-30B30-24	20000.	31.77	.424	3198.	12.82	.704	2854.	59.4	97.	
10-30B30-24	20000.	29.43	.444	4627.	15.00	.778	3520.	64.0	98.	
60*30B30-24	25000.	32.71	.405	2848.	10.54	.675	3381.	60.8	108.	2
80*30B30-24	25000.	31.77	.424	3998.	12.82	.704	3640.	65.0	109.	
10*30B30-24	25000.	29.43	.444	5784.	15.00	.778	4489.	71.9	110.	
60-60B55-24	20000.	23.30	.302	5413.	12.70	.598	5419.	75.4	94.	
80-60B55-24	20000.	22.80	.310	7048.	15.12	.625	5672.	78.9	98.	
10-60B55-24	20000.	21.40	.328	9765.	17.60	.689	6961.	86.7	117.	
60*60B55-24	25000.	23.30	.302	6767.	12.70	.598	6909.	84.7	105.	
80*60B55-24	25000.	22.80	.310	8810.	15.12	.625	7232.	89.0	110.	
10*60B55-24	25000.	21.40	.328	12206.	17.60	.689	8875.	98.0	131.	
60-95B55-24	20000.	28.63	.335	3386.	11.91	.619	3684.	61.9	92.	
80-95B55-24	20000.	28.30	.341	4590.	14.77	.629	3782.	64.4	95.	
10-95B55-24	20000.	26.87	.358	6417.	17.52	.689	4465.	69.8	105.	
60*95B55-24	25000.	28.63	.335	4232.	11.91	.619	4697.	68.9	103.	
80*95B55-24	25000.	28.30	.341	5737.	14.77	.629	4822.	71.8	106.	
10*95B55-24	25000.	26.87	.358	8021.	17.52	.689	5693.	73.0	117.	
60-30B55-24	20000.	33.14	.375	2168.	10.43	.683	2745.	54.5	91.	2
80-30B55-24	20000.	33.11	.379	3192.	13.96	.647	2784.	55.1	91.	
10-30B55-24	20000.	31.32	.394	4622.	16.89	.692	3239.	60.4	92.	
60*30B55-24	25000.	33.14	.375	2710.	10.43	.683	3500.	60.9	101.	2
80*30B55-24	25000.	33.11	.379	3990.	13.96	.647	3550.	61.6	102.	
10*30B55-24	25000.	31.32	.394	5778.	16.89	.692	4130.	62.5	104.	

PRATT & WHITNEY AIRCRAFT

PREPARED BY PRATT & WHITNEY AIRCRAFT FOR NASA-LEWIS RESEARCH CENTER

CYCLE NUMBER	ENGINE PERFORMANCE						ENGINE INSTALLATION DATA			REMARKS
	TAKE-OFF			CRUISE						
	FN	FN/WA	TSFC	FN	FN/WA	TSFC	WEIGHT	DIAMETER	LENGTH	
60-60B70-24	20000.	22.70	.318	5290.	11.62	.653	5805.	77.5	89.	
80-60B70-24	20000.	22.40	.324	7370.	15.02	.629	5927.	80.1	93.	
10-60B70-24	20000.	21.17	.338	10402.	18.10	.670	7056.	88.5	112.	
60*60B70-24	25000.	22.70	.318	6590.	11.62	.653	7376.	86.5	99.	
80*60B70-24	25000.	22.40	.324	9214.	15.02	.629	7558.	91.5	104.	
10*60B70-24	25000.	21.17	.338	13002.	18.10	.670	8995.	100.5	125.	
60-95S70A24	20000.	28.90	.364	3344.	11.80	.679	3683.	61.5	86.	
80-95B70-24	20000.	27.88	.352	4664.	14.53	.639	3879.	65.5	89.	
10-95B70-24	20000.	26.72	.362	6693.	17.99	.671	4436.	70.3	99.	
60*95S70A24	25000.	28.90	.364	4178.	11.80	.679	4694.	68.7	96.	3
80*95B70-24	25000.	27.88	.352	5830.	14.53	.639	4946.	73.0	100.	
10*95B70-24	25000.	26.72	.362	6368.	17.99	.671	5656.	78.7	111.	
60-30E70-24	20000.	35.40	.413	2254.	11.80	.727	2704.	52.7	82.	23
80-30B70-24	20000.	32.89	.385	3145.	13.32	.678	2854.	55.5	86.	3
10-30B70-24	20000.	31.50	.390	4700.	17.20	.680	3161.	60.2	87.	
60*30E70-24	25000.	35.40	.413	2815.	11.80	.727	3444.	58.9	92.	23
80*30B70-24	25000.	32.89	.385	3905.	13.32	.678	3615.	62.1	96.	3
10*30B70-24	25000.	31.50	.390	5875.	17.20	.680	4030.	67.2	97.	
60-60B30-30	20000.	21.95	.293	5128.	11.14	.620	5934.	78.4	110.	
80-60B30-30	20000.	21.37	.308	6689.	13.08	.670	6233.	82.9	115.	
10-60B30-30	20000.	19.97	.332	9334.	15.18	.792	7585.	91.7	133.	
60*60B30-30	25000.	21.95	.293	6409.	11.14	.620	7564.	88.4	123.	
80*60B30-30	25000.	21.37	.308	8362.	13.08	.670	7948.	93.6	128.	
10*60B30-30	25000.	19.92	.332	11668.	15.18	.792	9671.	104.3	149.	
60-95B30-30	20000.	27.20	.335	3261.	10.55	.635	3932.	64.3	108.	
80-95B30-30	20000.	26.58	.351	4440.	12.78	.672	4166.	68.9	111.	
10-95B30-30	20000.	25.00	.378	6333.	15.11	.751	5069.	74.8	121.	
60*95B30-30	25000.	27.20	.335	4077.	10.55	.635	5014.	71.7	121.	
80*95B30-30	25000.	26.58	.351	5540.	12.78	.672	5302.	75.9	124.	
10*95B30-30	25000.	25.00	.378	7916.	15.11	.751	6463.	84.1	135.	
60-30B30-30	20000.	31.46	.387	2100.	9.65	.667	2731.	55.3	107.	2
80-30B30-30	20000.	30.92	.403	3077.	12.20	.681	2974.	58.7	107.	
10-30B30-30	20000.	28.81	.424	4590.	14.61	.748	3724.	63.7	109.	
60*30B30-30	25000.	31.46	.387	2626.	9.65	.667	3484.	61.5	120.	2
80*30B30-30	25000.	30.92	.403	3847.	12.20	.681	3792.	65.6	120.	
10*30B30-30	25000.	28.81	.424	5690.	14.61	.748	4709.	72.8	122.	

PREPARED BY PRATT & WHITNEY AIRCRAFT FOR NASA-LEWIS RESEARCH CENTER

CYCLE NUMBER	ENGINE PERFORMANCE						ENGINE INSTALLATION DATA			REMARKS
	TAKE-OFF			CRUISE						
	FN	FN/WA	TSFC	FN	FN/WA	TSFC	WEIGHT	DIAMETER	LENGTH	
60-60B55-30	20000.	22.16	.292	5346.	11.71	.590	6279.	78.4	104.	
80-60B55-30	20000.	21.91	.295	7135.	14.47	.605	6334.	81.5	108.	
10-60B55-30	20000.	20.64	.315	10054.	17.14	.666	7401.	89.5	127.	
60*60B55-30	25000.	22.16	.292	6732.	11.71	.590	8005.	88.5	117.	
80*60B55-30	25000.	21.91	.295	8962.	14.47	.605	8077.	92.3	121.	
10*60B55-30	25000.	20.64	.315	12567.	17.14	.666	9436.	101.4	142.	
60-95B55-30	20000.	27.17	.327	3205.	10.59	.632	4080.	63.1	102.	
80-95B55-30	20000.	27.31	.328	4551.	14.00	.613	4091.	66.0	104.	
10-95B55-30	20000.	26.13	.342	6488.	17.04	.666	4712.	71.0	114.	
60*95B55-30	25000.	27.17	.327	4007.	10.59	.632	5203.	70.9	115.	
80*95B55-30	25000.	27.31	.328	5700.	14.00	.613	5215.	73.5	117.	
10*95B55-30	25000.	26.13	.342	8110.	17.04	.666	6008.	79.8	128.	
60-30S55A30	20000.	32.60	.362	2024.	9.68	.726	2878.	55.0	100.	3
80-30B55-30	20000.	31.97	.368	3072.	13.14	.634	2890.	56.3	101.	
10-30B55-30	20000.	30.49	.379	4578.	16.36	.669	3396.	61.3	102.	
60*30S55A30	25000.	32.60	.362	2528.	9.68	.726	3667.	61.5	112.	23
80*30B55-30	25000.	31.97	.368	3840.	13.14	.634	3684.	63.0	113.	
10*30B55-30	25000.	30.49	.379	5723.	16.36	.669	4330.	68.5	114.	
60-60S70A30	20000.	20.42	.347	4920.	9.52	.767	7268.	83.5	92.	23
80-60B70-30	20000.	21.47	.313	7420.	14.17	.618	6584.	83.9	97.	
10-60B70-30	20000.	20.37	.326	10734.	17.54	.651	7502.	91.5	116.	
60*60S70A30	25000.	20.42	.347	6150.	9.52	.767	9267.	94.0	103.	
80*60B70-30	25000.	21.47	.313	9275.	14.17	.618	8395.	95.0	109.	
10*60B70-30	25000.	20.37	.326	13418.	17.54	.651	9566.	104.0	130.	
60-95E70-30	20000.	28.70	.367	3304.	11.70	.689	3964.	61.5	88.	
80-95B70-30	20000.	26.72	.342	4573.	13.45	.636	4207.	67.2	94.	
10-95B70-30	20000.	25.95	.349	6763.	17.40	.652	4671.	71.8	104.	
60*95E70-30	25000.	28.70	.367	4125.	11.70	.689	5049.	68.8	99.	
80*95B70-30	25000.	26.72	.342	5717.	13.45	.636	5365.	75.3	105.	
10*95B70-30	25000.	25.95	.349	8453.	17.40	.652	5955.	80.6	116.	
60-30S70B30	20000.	37.90	.407	2340.	13.30	.673	2526.	50.8	85.	
80-30B70-30	20000.	31.17	.380	2942.	12.00	.693	2985.	57.0	90.	3
10-30B70-30	20000.	30.48	.379	4673.	16.51	.662	3334.	61.4	92.	
60*30S70B30	25000.	37.90	.407	2929.	13.30	.673	3225.	56.9	95.	23
80*30B70-30	25000.	31.17	.380	3677.	12.00	.693	3805.	63.8	101.	3
10*30B70-30	25000.	30.48	.379	5841.	16.51	.662	4250.	68.7	103.	

PRATT & WHITNEY AIRCRAFT

PREPARED BY PRATT & WHITNEY AIRCRAFT FOR NASA-LEWIS RESEARCH CENTER

CYCLE NUMBER	ENGINE PERFORMANCE						ENGINE INSTALLATION DATA			REMARKS
	TAKE-OFF			CRUISE						
	FN	FN/WA	TSFC	FN	FN/WA	TSFC	WEIGHT	DIAMETER	LENGTH	
60-60C30-15	20000.	20.69	.288	4685.	9.57	.632	4757.	81.0	104.	
80-60C30-15	20000.	19.82	.300	5930.	10.78	.676	5408.	86.5	109.	
10-60C30-15	20000.	17.59	.337	8495.	12.00	.761	7928.	99.4	128.	4
60*60C30-15	25000.	20.69	.288	5855.	9.57	.632	6064.	91.5	117.	
80*60C30-15	25000.	19.82	.300	7410.	10.78	.676	6893.	97.5	122.	
10*60C30-15	25000.	17.59	.337	10640.	12.00	.761	10129.	108.8	143.	4
60-95C30-15	20000.	25.14	.320	3170.	9.28	.637	3647.	67.5	103.	
80-95C30-15	20000.	24.17	.332	4095.	10.65	.676	3916.	71.5	105.	
10-95C30-15	20000.	21.90	.359	5650.	11.96	.760	5031.	79.5	115.	4
60*95C30-15	25000.	25.14	.320	3960.	9.28	.637	4647.	75.7	115.	
80*95C30-15	25000.	24.17	.332	5110.	10.65	.676	4985.	80.0	118.	
10*95C30-15	25000.	21.90	.359	7060.	11.96	.760	6412.	89.0	129.	4
60-30C30-15	20000.	29.14	.360	2250.	8.73	.666	3000.	58.7	101.	2 4
80-30C30-15	20000.	27.66	.373	2970.	10.04	.696	3119.	62.9	101.	4
10-30C30-15	20000.	25.70	.392	4170.	11.72	.756	3593.	68.8	103.	4
60*30C30-15	25000.	29.14	.360	2815.	8.73	.666	3829.	65.6	113.	2 4
80*30C30-15	25000.	27.66	.373	3715.	10.04	.696	3979.	70.0	114.	4
10*30C30-15	25000.	25.70	.392	5210.	11.72	.756	4579.	77.0	115.	4
60-60J55-15	20000.	20.84	.291	4763.	9.68	.642	5838.	81.0	102.	
80-60C55-15	20000.	20.10	.299	6500.	11.72	.622	6397.	86.5	107.	
10-60C55-15	20000.	17.92	.333	9800.	13.59	.672	8850.	101.0	126.	4
60*60J55-15	25000.	20.84	.291	5954.	9.68	.642	7443.	91.7	115.	
80*60C55-15	25000.	20.10	.299	8100.	11.72	.622	8131.	98.2	120.	
10*60C55-15	25000.	17.92	.333	12250.	13.59	.672	11283.	109.5	141.	4
60-95K55-15	20000.	26.01	.330	3159.	9.80	.656	4826.	65.6	100.	
80-95C55-15	20000.	24.27	.322	4250.	11.46	.629	4410.	70.4	104.	
10-95C55-15	20000.	22.58	.345	6235.	13.52	.672	5394.	78.5	114.	4
60*95K55-15	25000.	26.01	.330	3949.	9.80	.656	6154.	73.1	112.	
80*95C55-15	25000.	24.27	.322	5315.	11.46	.629	5626.	78.8	116.	
10*95C55-15	25000.	22.58	.345	7760.	13.52	.672	6865.	88.5	127.	4
60-30L55-15	20000.	30.04	.376	2228.	8.30	.719	3363.	55.4	97.	234
80-30C55-15	20000.	27.70	.359	2930.	10.10	.692	3553.	61.0	99.	4
10-30C55-15	20000.	26.70	.364	4340.	13.15	.674	3679.	65.8	101.	4
60*30L55-15	25000.	30.04	.376	2785.	8.30	.719	4288.	61.8	109.	234
80*30C55-15	25000.	27.70	.359	3650.	10.10	.692	4527.	68.4	112.	4
10*30C55-15	25000.	26.70	.364	5410.	13.15	.674	4677.	73.5	114.	4

PREPARED BY PRATT & WHITNEY AIRCRAFT FOR NASA-LEWIS RESEARCH CENTER

CYCLE NUMBER	ENGINE PERFORMANCE						ENGINE INSTALLATION DATA			REMARKS
	TAKE-OFF			CRUISE						
	FN	FN/WA	TSFC	FN	FN/WA	TSFC	WEIGHT	DIAMETER	LENGTH	
60-60M70-15	20000.	22.81	.343	5137.	11.63	.688	5855.	76.7	103.	
80-60L70-15	20000.	20.80	.335	6222.	12.30	.677	6208.	85.0	110.	
10-60C70-15	20000.	17.51	.355	9940.	13.09	.698	9378.	103.0	132.	4
60*60M70-15	25000.	22.81	.343	6422.	11.63	.688	7466.	86.4	115.	
80*60L70-15	25000.	20.80	.335	8260.	12.30	.677	8426.	96.2	123.	
10*60C70-15	25000.	17.51	.355	12400.	13.09	.698	11933.	113.0	147.	4
60-95F70-15	20000.	26.60	.379	3405.	11.83	.703	4195.	62.0	100.	
80-95D70-15	20000.	25.72	.359	4340.	12.14	.689	4533.	68.8	106.	
10-95C70-15	20000.	22.26	.366	6210.	12.95	.701	5659.	80.0	119.	4
60*95F70-15	25000.	23.60	.379	4255.	11.83	.703	5348.	69.2	112.	
80*95D70-15	25000.	25.72	.359	5410.	12.14	.689	5764.	77.0	119.	
10*95C70-15	25000.	22.26	.366	7750.	12.95	.701	7231.	90.4	134.	4
60-30N70-15	20000.	33.59	.427	2320.	11.13	.772	3305.	54.2	98.	234
80-30P70-15	20000.	29.75	.408	3098.	11.52	.751	3592.	58.1	101.	
10-30C70-15	20000.	26.08	.387	4205.	12.84	.689	3684.	63.0	107.	4
60*30N70-15	25000.	33.59	.427	2902.	11.13	.772	4217.	60.6	109.	234
80*30P70-15	25000.	29.75	.408	3873.	11.52	.751	4580.	65.0	113.	
10*30C70-15	25000.	26.08	.387	5260.	12.84	.689	4700.	76.1	120.	4
60-60C30-24	20000.	19.45	.255	4695.	8.74	.580	5003.	85.7	102.	
80-60C30-24	20000.	18.86	.264	6075.	10.22	.616	5294.	90.2	106.	
10-60C30-24	20000.	17.56	.282	8400.	11.80	.686	6760.	99.7	125.	
60*60C30-24	25000.	19.45	.255	5865.	8.74	.580	6375.	96.5	114.	
80*60C30-24	25000.	18.86	.264	7600.	10.22	.616	6755.	102.0	119.	
10*60C30-24	25000.	17.56	.282	10450.	11.80	.686	8578.	108.5	140.	
60-95C30-24	20000.	23.92	.285	2990.	7.25	.595	3465.	69.6	100.	
80-95C30-24	20000.	23.33	.294	4010.	10.01	.618	3570.	73.1	103.	
10-95C30-24	20000.	21.81	.311	5610.	11.75	.685	4364.	80.0	113.	
60*95C30-24	25000.	23.92	.285	3740.	8.25	.595	4420.	79.6	112.	
80*95C30-24	25000.	23.33	.294	5010.	10.01	.618	4549.	82.0	115.	
10*95C30-24	25000.	21.81	.311	7030.	11.75	.685	5579.	90.3	126.	
60-30C30-24	20000.	27.95	.321	1920.	7.41	.643	2540.	59.8	111.	2
80-30C30-24	20000.	27.30	.331	2610.	9.49	.635	2640.	59.0	99.	
10-30C30-24	20000.	25.42	.346	4055.	11.35	.686	3162.	69.8	101.	
60*30C30-24	25000.	27.95	.321	2395.	7.41	.643	3232.	67.0	98.	2
80*30C30-24	25000.	27.30	.331	3510.	9.49	.635	3363.	65.9	111.	
10*30C30-24	25000.	25.42	.346	5105.	11.35	.686	4031.	78.0	113.	

PRATT & WHITNEY AIRCRAFT

PREPARED BY PRATT & WHITNEY AIRCRAFT FOR NASA-LEWIS RESEARCH CENTER

CYCLE NUMBER	ENGINE PERFORMANCE						ENGINE INSTALLATION DATA			REMARKS
	TAKE-OFF			CRUISE						
	FN	FN/WA	TSFC	FN	FN/WA	TSFC	WEIGHT	DIAMETER	LENGTH	
60-60Q55-24	20000.	21.06	.282	5027.	10.25	.600	5776.	80.9	97.	
80-60C55-24	20000.	18.96	.269	6490.	10.68	.590	6618.	91.0	104.	
10-60C55-24	20000.	17.50	.289	9590.	12.99	.623	7875.	102.0	123.	
60*60Q55-24	25000.	21.06	.282	6283.	10.25	.600	7364.	91.5	108.	
80*60C55-24	25000.	18.96	.269	8110.	10.68	.590	8435.	103.5	117.	
10*60C55-24	25000.	17.50	.289	11950.	12.99	.623	10010.	110.9	138.	
60-95R55-24	20000.	26.41	.319	3127.	9.96	.634	3829.	64.9	94.	
80-95C55-24	20000.	23.41	.293	4035.	10.13	.611	4340.	72.7	100.	
10-95C55-24	20000.	22.08	.308	6110.	12.89	.624	4888.	79.5	110.	
60*95R55-24	25000.	26.41	.319	3910.	9.96	.634	4883.	72.2	106.	
80*95C55-24	25000.	23.41	.293	5050.	10.13	.611	5540.	81.7	112.	
10*95C55-24	25000.	22.06	.308	7640.	12.89	.624	6234.	90.0	124.	
60-30F55-24	20000.	31.79	.368	2061.	9.48	.705	2792.	55.7	91.	23
80-30T55-24	20000.	27.82	.332	2723.	9.67	.660	3047.	61.3	96.	4
10-30C55-24	20000.	25.73	.336	4190.	12.06	.646	3460.	68.4	98.	
60*30F55-24	25000.	31.79	.368	2576.	9.48	.705	3559.	62.2	102.	
80*30T55-24	25000.	27.82	.332	3403.	9.67	.660	3864.	68.5	107.	
10*30C55-24	25000.	25.73	.336	5250.	12.06	.646	4421.	76.0	110.	
60-60U70-24	20000.	21.90	.321	5080.	10.80	.675	5925.	79.2	89.	23
80-60X70-24	20000.	20.40	.312	6420.	11.56	.654	6269.	86.1	101.	23
10-60C70-24	20000.	17.49	.299	9550.	12.61	.641	8211.	100.5	119.	
60*60U70-24	25000.	21.90	.321	6320.	10.80	.675	7519.	88.5	100.	23
80*60X70-24	25000.	20.40	.312	8010.	11.56	.654	7978.	96.0	113.	
10*60C70-24	25000.	17.49	.299	11900.	12.61	.641	10436.	112.0	134.	
60-95M70-24	20000.	27.81	.361	3180.	10.78	.707	3877.	62.8	86.	
80-95P70-24	20000.	25.10	.336	4140.	11.44	.671	4108.	69.4	97.	34
10-95C70-24	20000.	22.02	.318	6040.	12.42	.648	5101.	80.5	107.	
60*95M70-24	25000.	27.81	.361	3924.	10.78	.707	4879.	70.0	97.	
80*95P70-24	25000.	25.10	.336	5170.	11.44	.671	5233.	77.5	109.	34
10*95C70-24	25000.	22.02	.318	7550.	12.42	.648	6504.	91.0	120.	
60-30V70-24	20000.	33.62	.416	2150.	10.40	.784	2870.	53.3	83.	23
80-30M70-24	20000.	29.91	.380	2845.	11.00	.725	2977.	58.5	93.	3
10-30C70-24	20000.	24.40	.359	3905.	10.45	.743	3787.	69.1	95.	
60*30V70-24	25000.	33.62	.416	2687.	10.40	.784	3659.	59.6	93.	23
80*30M70-24	25000.	29.91	.380	3560.	11.00	.725	3800.	65.5	104.	3
10*30C70-24	25000.	24.40	.359	4870.	10.45	.743	4818.	77.5	106.	

PREPARED BY PRATT & WHITNEY AIRCRAFT FOR NASA-LEWIS RESEARCH CENTER

CYCLE NUMBER	ENGINE PERFORMANCE						ENGINE INSTALLATION DATA			REMARKS
	TAKE-OFF			CRUISE						
	FN	FN/WA	TSFC	FN	FN/WA	TSFC	WEIGHT	DIAMETER	LENGTH	
60-60C30-30	20000.	18.56	.244	4695.	8.13	.567	6159.	88.6	112.	
80-60C30-30	20000.	18.16	.252	6205.	9.82	.595	6290.	93.8	117.	
10-60C30-30	20000.	16.98	.269	8650.	11.50	.662	7593.	102.5	135.	
60*60C30-30	25000.	18.56	.244	5850.	8.13	.567	7827.	100.5	126.	
80*60C30-30	25000.	18.16	.252	7750.	9.82	.595	8014.	102.5	131.	
10*60C30-30	25000.	16.98	.269	10830.	11.50	.662	9696.	112.0	152.	
60-95C30-30	20000.	17.53	.353	2865.	7.49	.596	4014.	71.4	110.	
80-95C30-30	20000.	22.62	.281	3975.	9.53	.600	4070.	74.5	113.	
10-95C30-30	20000.	21.32	.296	5660.	11.44	.662	4875.	81.5	123.	
60*95C30-30	25000.	17.53	.353	3590.	7.49	.596	5131.	80.0	124.	
80*95C30-30	25000.	22.62	.281	4985.	9.53	.600	5206.	83.8	126.	
10*95C30-30	25000.	21.32	.296	7060.	11.44	.662	6203.	92.0	138.	
60-30C30-30	20000.	26.76	.308	1655.	5.88	.731	2906.	60.5	109.	2
80-30C30-30	20000.	26.70	.316	2705.	9.00	.616	2873.	64.4	109.	
10-30C30-30	20000.	25.00	.329	4165.	11.05	.661	3623.	70.6	111.	
60*30C30-30	25000.	26.76	.309	2070.	5.88	.731	3708.	67.5	122.	2
80*30C30-30	25000.	26.70	.316	3375.	9.00	.616	3657.	71.9	122.	
10*30C30-30	25000.	25.00	.329	5075.	11.05	.661	4503.	79.2	124.	
60-60P55-30	20000.	20.00	.277	4850.	9.24	.619	6843.	84.3	106.	
80-60C55-30	20000.	18.16	.262	6350.	9.75	.599	7882.	93.2	114.	
10-60C55-30	20000.	17.26	.269	9750.	12.87	.591	8588.	103.2	133.	
60*60P55-30	25000.	20.00	.277	6060.	9.24	.619	8722.	95.2	119.	
80*60C55-30	25000.	18.16	.262	7950.	9.75	.599	10065.	104.2	127.	
10*60C55-30	25000.	17.26	.269	12195.	12.87	.591	10957.	112.1	148.	
60-95M55-30	20000.	25.10	.318	2855.	8.64	.664	4297.	66.2	104.	
80-95T55-30	20000.	23.05	.292	4000.	10.62	.617	4414.	73.6	109.	
10-95C55-30	20000.	21.91	.288	6140.	12.75	.593	5343.	80.1	120.	
60*95M55-30	25000.	25.10	.318	3570.	8.64	.684	5481.	73.9	116.	
80*95T55-30	25000.	23.05	.292	5000.	10.62	.617	5628.	82.7	122.	
10*95C55-30	25000.	21.91	.288	7660.	12.75	.593	6799.	90.6	135.	
60-30W55-30	20000.	31.55	.307	1871.	8.84	.741	2835.	56.8	100.	
80-30X55-30	20000.	28.95	.334	2760.	10.56	.626	3007.	60.3	104.	
10-30C55-30	20000.	25.80	.314	9500.	12.27	.595	8404.	68.8	108.	
60*30W55-30	25000.	31.55	.307	2339.	8.84	.741	3614.	63.4	112.	23
80*30X55-30	25000.	28.95	.334	3450.	10.56	.626	3834.	67.5	116.	
10*30C55-30	25000.	25.80	.314	11850.	12.27	.595	10693.	76.7	121.	

PRATT & WHITNEY AIRCRAFT

QUIET ENGINE PARAMETRIC STUDY RESULTS (TASK I) SHEET 14 OF 14

PREPARED BY PRATT & WHITNEY AIRCRAFT FOR NASA-LEWIS RESEARCH CENTER

CYCLE NUMBER	ENGINE PERFORMANCE						ENGINE INSTALLATION DATA			REMARKS
	TAKE-OFF			CRUISE						
	FN	FN/WA	TSFC	FN	FN/WA	TSFC	WEIGHT	DIAMETER	LENGTH	
60-60H70-30	20000.	21.46	.319	5115.	10.56	.677	6622.	80.5	92.	
80-60R70-30	20000.	19.71	.303	6871.	11.70	.642	7164.	89.5	100.	
10-60Z70-30	20000.	17.76	.302	10350.	13.53	.629	8658.	99.5	122.	
60*60H70-30	25000.	21.46	.319	6410.	10.56	.677	8465.	91.2	104.	
80*60R70-30	25000.	19.71	.303	8589.	11.70	.642	9134.	101.5	112.	
10*60Z70-30	25000.	17.76	.302	12950.	13.53	.629	11050.	111.5	136.	
80-95M70-30	20000.	24.76	.335	4191.	11.22	.675	4497.	70.5	96.	
10-95D70-30	20000.	24.12	.330	6610.	15.39	.632	4858.	75.4	109.	
80*95M70-30	25000.	24.76	.335	5238.	11.22	.675	5733.	79.0	107.	
10*95D70-30	25000.	24.12	.330	8260.	15.39	.632	6192.	84.5	122.	
60-30Y70-30	20000.	37.20	.402	2295.	12.80	.677	2546.	51.3	86.	
80-30U70-30	20000.	30.26	.378	2830.	11.16	.716	3053.	58.0	91.	
10-30X70-30	20000.	28.50	.344	4440.	14.50	.628	3336.	64.0	96.	
60*30Y70-30	25000.	37.20	.402	2870.	12.80	.677	3247.	57.3	96.	23
80*30U70-30	25000.	30.26	.378	3535.	11.16	.716	3890.	65.1	102.	4
10*30X70-30	25000.	28.50	.344	5560.	14.50	.628	4261.	72.1	107.	

PREPARED BY PRATT & WHITNEY AIRCRAFT FOR NASA-LEWIS RESEARCH CENTER

CYCLE NUMBER	AIRPLANE PERFORMANCE		PEAK FLYOVER NOISE - MAJOR COMPONENTS								REMARKS
			T/O-MAX		T/O-C/B 1000'		T/O-C/B 3 MI.		APPROACH		
	ALTITUDE	DISTANCE	JET	TOTAL	JET	TOTAL	JET	TOTAL	JET	TOTAL	
60-60A30-15	730.	3.50	117.5	117.5	106.5	107.0			97.1	108.2	
80-60A30-15	725.	3.52	116.3	116.3	106.0	106.0			96.6	107.0	
10-60A30-15	662.	3.03	112.8	112.8	102.4	103.6			95.7	106.0	4
60*60A30-15	1280.	2.62	112.5	112.5	100.5	101.7	98.1	98.6	95.0	107.0	
80*60A30-15	1265.	2.62	111.3	111.3	101.0	101.4	99.1	99.5	95.1	105.6	
10*60A30-15	1220.	2.70	107.8	107.9	97.1	101.0	96.7	97.8	95.4	103.0	4
60-95A30-15	830.	3.30	125.0	124.9	114.8	115.2			103.0	110.0	
80-95A30-15	800.	3.33	125.7	125.7	115.4	115.4			103.0	108.7	
10-95A30-15	775.	3.38	122.8	125.1	115.9	114.7			102.6	107.7	4
60*95A30-15	1400.	2.47	120.8	121.1	108.8	108.8	106.1	106.5	98.5	109.0	
80*95A30-15	1370.	2.50	120.8	120.8	108.4	108.4	107.0	107.4	98.7	107.8	
10*95A30-15	1339.	2.53	118.3	118.8	108.0	108.0	104.5	105.7	99.2	105.5	4
60-30A30-15	900.	3.17	128.8	129.3	120.9	121.0			106.0	111.0	4
80-30A30-15	880.	3.21	130.0	130.0	121.4	121.4			106.2	109.8	4
10-30A30-15	870.	3.25	128.3	129.2	119.9	120.9			106.3	108.7	4
60*30A30-15	1470.	2.39	123.4	124.3	115.1	115.8	112.3	112.3	102.2	111.0	4
80*30A30-15	1452.	2.41	125.0	125.0	115.5	115.5	113.2	113.2	102.5	110.0	
10*30A30-15	1420.	2.45	123.5	124.4	114.1	114.9	110.7	111.5	103.2	108.0	4
60-60A55-15	750.	1.77	107.3	114.3	95.9	107.2			92.9	111.5	
80-60A55-15	740.	3.50	106.4	113.7	97.3	105.3			92.9	110.2	
10-60A55-15	680.	3.62	106.9	111.2	96.0	101.5			93.0	109.1	4
60*60A55-15	1300.	2.59	101.9	107.9	91.2	105.7	88.8	100.5	92.4	110.2	
80*60A55-15	1280.	2.63	103.3	107.4	92.9	104.2	91.5	99.3	92.5	109.1	4
10*60A55-15	1230.	2.70	102.4	106.3	92.0	102.0	91.7	96.2	91.5	106.9	4
60-95A55-15	825.	3.29	116.8	117.7	103.4	110.2			95.5	113.3	
80-95A55-15	710.	3.32	119.2	119.2	107.8	109.8			95.5	112.0	
10-95A55-15	760.	3.38	118.8	119.8	108.9	108.2			95.5	110.9	4
60*95A55-15	1395.	2.73	102.1	102.1	97.9	108.1	95.2	102.5	94.1	111.9	
80*95A55-15	1370.	2.49	112.8	112.8	101.2	107.4	98.3	101.8	94.6	111.0	
10*95A55-15	1340.	2.53	113.4	113.4	102.8	106.3	99.1	99.6	94.0	109.1	4
60-30A55-15	890.	3.17	117.7	117.7	111.9	113.4			97.8	114.4	234
80-30A55-15	870.	3.20	125.1	125.1	113.5	113.5			97.8	113.1	4
10-30A55-15	790.	3.22	125.8	125.8	112.7	112.7			97.7	111.9	4
60*30A55-15	1480.	2.38	114.6	114.6	103.6	110.5	100.0	102.4	96.0	113.6	234
80*30A55-15	1460.	2.41	116.4	116.4	107.3	110.5	103.5	102.3	96.7	112.9	4
10*30A55-15	1440.	2.43	118.8	118.8	109.5	110.7	104.9	100.8	96.6	111.3	4

PRATT & WHITNEY AIRCRAFT

PREPARED BY PRATT & WHITNEY AIRCRAFT FOR NASA-LEWIS RESEARCH CENTER

CYCLE NUMBER	AIRPLANE PERFORMANCE		PEAK FLYOVER NOISE - MAJOR COMPONENTS								REMARKS
			T/O-MAX		T/O-C/B 1000'		T/O-C/B 3 MI.		APPROACH		
	ALTITUDE	DISTANCE	JET	TOTAL	JET	TOTAL	JET	TOTAL	JET	TOTAL	
60-60A70-15	735.	3.49	101.2	114.5	93.5	108.9			92.1	113.5	
80-60A70-15	730.	3.50	101.7	114.3	93.1	107.4			92.1	112.1	
10-60A70-15	660.	3.63	99.2	112.2	91.4	104.1			92.3	110.9	4
60*60A70-15	1280.	2.60	94.5	108.4	86.7	109.4	82.2	104.6	92.1	111.9	
80*60A70-15	1275.	2.62	95.3	107.0	86.9	107.2	84.0	103.3	92.4	110.9	
10*60A70-15	1210.	2.70	93.0	105.3	84.6	104.0	82.8	101.1	90.5	109.0	4
60-95A70-15	830.	3.29	111.8	114.4	98.9	108.8			93.8	115.3	3
80-95A70-15	810.	3.30	114.8	116.3	101.7	109.0			93.6	114.0	
10-95A70-15	760.	3.38	112.7	117.5	102.4	108.2			93.3	112.8	4
60*95A70-15	1400.	2.47	106.8	109.8	92.1	109.0	89.3	105.2	92.8	113.5	3
80*95A70-15	1360.	2.47	109.0	109.8	94.3	108.1	91.8	104.8	93.4	112.6	
10*95A70-15	1340.	2.53	106.9	110.1	94.9	106.8	91.6	104.0	92.2	111.0	4
60-30A70-15	910.	3.16	118.5	120.0	107.4	110.5			97.1	116.4	234
80-30A70-15	890.	3.17	122.1	122.1	110.3	111.3			96.6	115.1	4
10-30A70-15	860.	3.22	122.3	123.5	109.0	111.7			95.8	113.9	4
60*30A70-15	1490.	2.38	111.9	111.9	97.7	108.7	94.9	103.8	93.6	115.0	234
80*30A70-15	1470.	2.39	113.1	113.1	100.5	109.0	98.0	104.3	94.6	114.4	4
10*30A70-15	1450.	2.42	115.4	115.4	102.3	109.5	98.9	104.8	94.0	113.0	4
60-60A30-24	660.	3.62	112.7	113.4	103.8	104.7			95.5	108.2	
80-60A30-24	695.	3.60	114.3	114.3	105.9	105.9			97.0	106.9	
10-60A30-24	660.	3.70	114.0	114.0	105.5	106.6			99.3	105.8	
60*60A30-24	1210.	2.69	107.1	109.2	98.2	101.2	94.0	98.1	93.7	108.1	
80*60A30-24	1235.	2.68	109.1	109.4	101.0	101.1	97.9	99.2	94.2	106.4	
10*60A30-24	1160.	2.74	110.4	110.4	100.5	100.9	99.8	99.9	95.3	103.4	
60-95A30-24	735.	3.36	117.7	117.7	112.0	113.6			101.3	109.8	
80-95A30-24	780.	3.37	124.1	124.1	115.0	115.0			102.6	108.6	
10-95A30-24	760.	3.41	125.8	125.9	116.0	116.3			104.4	107.6	
60*95A30-24	1350.	2.52	115.9	117.4	106.6	106.6	103.9	105.0	96.6	109.4	
80*95A30-24	1350.	2.52	119.1	119.1	106.1	106.1	105.7	105.7	96.9	108.1	
10*95A30-24	1320.	2.55	120.8	120.8	105.4	105.4	105.7	105.7	97.7	105.6	
60-30A30-24	855.	3.22	124.9	126.8	118.2	119.0			103.9	110.8	2
80-30A30-24	850.	3.25	128.6	128.6	119.9	119.9			104.9	109.6	
10-30A30-24	825.	3.30	129.3	129.6	117.1	120.1			106.4	108.7	
60*30A30-24	1440.	2.42	119.4	121.2	112.1	112.1	109.8	109.8	98.8	110.8	2
80*30A30-24	1420.	2.44	123.4	123.4	111.3	111.2	110.1	110.1	99.0	109.8	
10*30A30-24	1390.	2.46	125.4	125.9	109.8	109.8	109.5	109.5	99.4	107.8	

CYCLE NUMBER	AIRPLANE PERFORMANCE		PEAK FLYOVER NOISE - MAJOR COMPONENTS								REMARKS
			T/O-MAX		T/O-C/B 1000'		T/O-C/B 3 MI.		APPROACH		
	ALTITUDE	DISTANCE	JET	TOTAL	JET	TOTAL	JET	TOTAL	JET	TOTAL	
60-60A55-24	700.	3.58	101.2	112.5	92.9	105.2			92.1	111.5	
80-60A55-24	700.	3.57	103.9	112.5	94.8	104.8			93.7	110.2	
10-60A55-24	630.	3.66	107.5	110.8	97.5	103.1			96.2	109.1	
60*60A55-24	1230.	2.66	94.5	106.5	86.9	104.7	83.3	101.4	91.6	110.9	
80*60A55-24	1230.	2.66	98.6	106.8	90.3	102.7	88.1	99.4	92.4	109.3	
10*60A55-24	1200.	2.72	103.6	107.6	92.1	99.7	91.4	97.3	92.4	106.5	
60-95A55-24	760.	3.36	110.5	114.9	99.8	109.2			94.2	113.3	
80-95A55-24	790.	3.36	115.7	117.1	104.6	109.8			95.7	112.0	
10-95A55-24	780.	3.39	119.6	118.7	109.3	109.8			97.9	110.9	
60*95A55-24	1360.	2.50	104.2	109.4	94.1	107.0	90.5	104.1	93.5	112.2	
80*95A55-24	1360.	2.52	110.6	111.2	98.7	105.8	95.5	102.5	94.3	111.1	
10*95A55-24	1350.	2.54	114.4	114.4	102.1	104.1	99.1	100.8	94.3	109.0	
60-30A55-24	860.	3.22	113.9	119.6	107.7	112.4			96.1	114.4	23
80-30A55-24	860.	3.23	121.7	122.0	112.5	113.1			97.5	113.1	
10-30A55-24	850.	3.26	125.9	123.9	113.2	113.2			99.4	112.0	
60*30A55-24	1450.	2.42	108.6	110.6	100.4	109.2	96.2	104.7	94.8	113.4	23
80*30A55-24	1450.	2.42	114.0	114.0	104.9	108.9	101.3	103.5	95.0	112.8	
10*30A55-24	1410.	2.45	119.6	119.6	108.1	108.5	105.2	102.3	95.5	111.5	
60-60A70-24	700.	3.60	94.2	114.1	90.3	107.2			91.8	113.5	
80-60A70-24	700.	3.60	96.1	113.5	90.2	106.6			93.1	112.3	
10-60A70-24	665.	3.66	98.4	110.8	91.9	104.9			95.2	111.1	
60*60A70-24	1230.	2.68	87.6	108.7	83.3	108.2	78.8	104.1	91.6	112.4	
80*60A70-24	1230.	2.68	90.8	107.2	84.9	105.1	82.1	101.5	92.6	110.8	
10*60A70-24	1230.	2.67	94.4	105.9	84.7	100.4	83.4	99.4	92.0	108.1	
60-95A70-24	760.	3.38	103.7	111.9	94.8	108.3			93.0	115.5	
80-95A70-24	780.	3.39	108.7	113.9	98.2	109.2			94.2	114.1	
10-95A70-24	780.	3.39	112.2	115.2	102.9	109.7			94.0	112.9	
60*95A70-24	1340.	2.53	97.8	107.8	89.2	108.6	86.1	106.6	93.0	113.5	
80*95A70-24	1340.	2.53	103.6	108.4	92.7	107.0	90.4	104.7	94.1	112.6	
10*95A70-24	1240.	2.53	108.1	110.5	95.1	104.7	93.1	103.9	93.5	110.7	
60-30A70-24	845.	3.23	107.3	115.3	102.2	110.1			95.7	116.6	23
80-30A70-24	870.	3.20	115.4	116.0	106.2	111.6			96.8	115.2	23
10-30A70-24	840.	3.25	120.2	120.3	109.5	113.0			98.6	113.9	
60*30A70-24	1430.	2.42	102.7	107.4	95.4	108.9	91.9	106.9	93.8	114.7	23
80*30A70-24	1460.	2.41	110.3	110.3	99.3	109.0	97.2	105.9	94.9	114.4	23
10*30A70-24	1410.	2.44	115.8	115.8	102.5	109.1	101.3	106.2	94.5	113.4	

PRATT & WHITNEY AIRCRAFT

PREPARED BY PRATT & WHITNEY AIRCRAFT FOR NASA-LEWIS RESEARCH CENTER

CYCLE NUMBER	AIRPLANE PERFORMANCE		PEAK FLYOVER NOISE - MAJOR COMPONENTS								REMARKS
			T/O-MAX		T/O-C/B 1000'		T/O-C/B 3 MI.		APPROACH		
	ALTITUDE	DISTANCE	JET	TOTAL	JET	TOTAL	JET	TOTAL	JET	TOTAL	
60-60A30-30	665.	3.65	109.7	110.5	100.5	103.0			94.3	108.1	
80-60A30-30	740.	3.62	111.0	112.7	103.4	104.4			95.4	106.8	
10-60A30-30	640.	3.73	114.2	114.2	105.7	105.4			97.0	105.6	
60*60A30-30	1200.	2.91	105.4	105.4	94.3	100.9	91.7	98.2	92.8	108.0	
80*60A30-30	1280.	2.70	106.9	107.1	98.4	100.9	95.7	99.4	93.6	106.2	
10*60A30-30	1070.	2.88	106.8	109.2	99.9	100.8	97.8	101.4	95.1	103.0	
60-95A30-30	765.	3.36	118.9	118.9	108.7	110.8			100.0	109.8	
80-95A30-30	775.	3.40	122.1	122.2	112.0	112.0			100.4	108.5	
10-95A30-30	745.	3.45	123.7	125.4	112.9	112.9			101.1	107.5	
60*95A30-30	1360.	2.53	114.7	115.0	102.5	105.4	100.2	102.8	95.3	109.0	
80*95A30-30	1340.	2.54	116.8	116.8	104.8	104.8	102.4	103.3	95.8	107.6	
10*95A30-30	1316.	2.58	118.4	119.2	103.8	103.8	101.9	104.4	96.7	105.0	
60-30A30-30	830.	3.29	122.4	124.1	114.6	114.6			102.4	110.7	2
80-30A30-30	830.	3.27	126.2	126.5	114.7	114.7			102.3	109.5	
10-30A30-30	807.	3.32	126.0	128.4	113.8	114.0			102.1	108.7	
60*30A30-30	1400.	2.47	118.7	119.2	108.0	109.9	105.2	105.2	96.8	110.1	2
80*30A30-30	1410.	2.46	121.2	121.2	108.7	108.7	105.1	105.1	96.8	109.0	
10*30A30-30	1370.	2.49	122.7	123.9	106.9	106.9	104.5	105.2	97.2	107.1	
60-60A55-30	685.	3.66	100.0	112.1	89.4	105.3			91.4	111.5	
80-60A55-30	665.	3.67	102.1	112.4	91.8	104.6			93.0	110.3	
10-60A55-30	650.	3.71	106.5	111.2	96.7	102.7			93.6	109.2	
60*60A55-30	1200.	2.71	93.2	106.4	84.0	104.2	82.3	102.3	90.3	110.6	
80*60A55-30	1160.	2.72	96.7	106.1	88.5	101.8	86.7	99.9	91.6	108.8	
10*60A55-30	1160.	2.75	101.9	106.5	91.7	98.3	89.5	98.3	92.2	105.6	
60-95A55-30	750.	3.45	109.2	113.5	95.9	108.4			93.2	113.4	
80-95A55-30	770.	3.40	114.0	115.1	101.0	108.6			93.9	112.1	
10-95A55-30	760.	3.41	118.2	118.2	107.8	107.9			95.0	111.0	
60*95A55-30	1305.	2.58	102.5	108.5	90.1	106.3	87.5	103.7	92.4	111.6	
80*95A55-30	1320.	2.54	108.4	110.0	95.4	104.9	91.9	101.5	93.4	110.5	
10*95A55-30	1320.	2.55	113.2	113.2	99.8	102.8	94.8	100.2	93.7	108.3	
60-30A55-30	835.	3.27	111.4	117.2	103.5	110.1			94.9	114.5	23
80-30A55-30	850.	3.26	118.8	120.1	108.4	110.2			95.4	113.1	
10-30A55-30	850.	3.29	122.7	122.7	109.3	109.3			96.1	112.0	
60*30A55-30	1410.	2.46	106.8	108.9	95.2	108.5	91.1	103.0	93.5	112.6	23
80*30A55-30	1420.	2.45	112.3	112.3	100.0	108.0	95.6	101.0	94.2	112.1	
10*30A55-30	1400.	2.47	118.2	118.2	103.9	107.2	98.5	100.1	94.1	110.9	

CYCLE NUMBER	AIRPLANE PERFORMANCE		PEAK FLYOVER NOISE - MAJOR COMPONENTS								REMARKS
			T/O-MAX		T/O-C/B 1000'		T/O-C/B 3 MI.		APPROACH		
	ALTITUDE	DISTANCE	JET	TOTAL	JET	TOTAL	JET	TOTAL	JET	TOTAL	
60-60A70-30	670.	3.68	94.1	115.3	86.7	108.3			91.4	113.6	
80-60A70-30	665.	3.67	95.3	114.4	86.8	107.3			91.8	112.3	
10-60A70-30	660.	3.72	98.1	111.3	90.5	104.9			92.5	111.3	
60*60A70-30	1180.	2.73	87.2	110.1	82.3	107.5	80.3	104.2	90.2	112.0	
80*60A70-30	1160.	2.72	89.6	107.4	84.8	103.6	83.0	100.8	91.7	110.1	
10*60A70-30	1160.	2.77	93.5	104.9	85.6	98.3	83.2	98.8	91.7	106.9	
60-95A70-30	760.	3.42	103.0	111.3	90.6	108.6			92.2	115.5	3
80-95A70-30	775.	3.39	107.6	113.4	94.4	109.1			92.7	114.2	
10-95A70-30	760.	3.43	112.2	114.8	101.5	108.8			93.4	113.0	
60*95A70-30	1320.	2.55	96.5	107.7	87.1	108.3	85.2	106.0	92.0	113.0	3
80*95A70-30	1346.	2.53	102.1	107.8	91.2	106.4	89.0	103.3	93.4	111.9	
10*95A70-30	1320.	2.57	107.2	109.5	94.6	103.5	90.9	102.4	93.0	110.0	
60-30A70-30	815.	3.30	104.8	113.1	97.5	109.1			94.6	116.7	23
80-30A70-30	843.	3.23	112.9	116.2	102.1	110.0			95.1	115.3	23
10-30A70-30	810.	3.28	119.0	119.0	108.1	110.4			95.8	114.0	
60*30A70-30	1390.	2.47	100.6	105.9	91.9	109.1	88.5	105.7	92.8	113.9	23
80*30A70-30	1430.	2.43	108.8	108.8	96.5	109.0	93.5	103.7	94.0	113.7	23
10*30A70-30	1400.	2.47	114.6	114.6	100.6	108.8	97.1	103.9	93.6	113.0	
60-60B30-15	640.	3.74	109.4	110.1	99.4	104.0			93.2	108.2	
80-60B30-15	630.	3.88	107.5	107.5	99.1	102.1			91.9	107.1	
10-60B30-15	588.	3.92	103.3	103.3	91.7	98.3			89.8	106.2	4
60*60B30-15	1150.	2.77	105.4	110.4	95.4	101.9	92.6	97.9	95.4	107.8	
80*60B30-15	1130.	2.80	103.8	107.7	95.4	101.5	93.1	97.6	91.7	106.4	
10*60B30-15	1050.	2.92	98.6	101.9	93.6	100.9	93.5	93.9	95.0	103.8	4
60-95B30-15	885.	3.19	122.4	123.7	112.6	117.2			104.7	116.3	
80-95B30-15	710.	3.52	118.4	118.4	108.7	110.2			97.7	108.9	
10-95B30-15	680.	3.63	116.9	116.9	104.2	107.8			96.3	107.7	4
60*95B30-15	1410.	2.39	118.4	118.4	113.1	113.1	99.0	109.6	105.6	116.3	
80*95B30-15	1255.	2.63	115.9	115.9	100.9	106.5	99.9	101.8	96.1	108.9	
10*95B30-15	1200.	2.70	111.5	111.5	101.2	105.7	97.6	97.6	99.7	106.4	4
60-30B30-15	795.	3.34	122.6	122.6	112.5	113.9			100.9	111.6	2 4
80-30B30-15	790.	3.37	121.7	121.7	112.9	112.9			100.4	110.0	4
10-30B30-15	752.	3.44	120.0	120.0	109.8	110.4			99.5	108.5	4
60*30B30-15	1365.	2.51	119.8	119.8	103.2	112.3	105.4	107.0	102.3	112.7	2 4
80*30B30-15	1340.	2.53	118.8	118.8	104.7	111.6	106.0	106.0	99.1	111.3	4
10*30B30-15	1300.	2.57	115.8	115.8	105.3	110.5	101.2	101.2	103.1	108.9	4

PRATT & WHITNEY AIRCRAFT

PREPARED BY PRATT & WHITNEY AIRCRAFT FOR NASA-LEWIS RESEARCH CENTER

CYCLE NUMBER	AIRPLANE PERFORMANCE		PEAK FLYOVER NOISE - MAJOR COMPONENTS								REMARKS
			T/O-MAX		T/O-C/B 1000'		T/O-C/B 3 MI.		APPROACH		
	ALTITUDE	DISTANCE	JET	TOTAL	JET	TOTAL	JET	TOTAL	JET	TOTAL	
60-60B55-15	650.	3.72	95.0	112.0	87.9	107.1			91.0	111.2	
80-60B55-15	635.	3.76	95.9	106.9	87.1	104.2			90.0	110.0	
10-60B55-15	592.	3.91	94.0	103.9	82.7	98.9			88.4	109.1	4
60*60B55-15	1160.	2.76	90.1	105.0	85.9	104.7	82.5	104.1	92.0	110.6	
80*60B55-15	1140.	2.78	89.8	105.4	86.7	103.7	83.3	102.4	88.6	109.4	
10*60B55-15	1060.	2.90	86.3	101.0	87.3	102.2	84.3	98.7	90.7	107.2	4
60-95B55-15	750.	3.47	101.6	114.8	91.9	109.6			92.9	112.8	
80-95B55-15	730.	3.49	105.0	114.2	94.5	108.2			92.2	111.7	
10-95B55-15	695.	3.53	103.1	113.1	92.9	105.2			91.0	110.8	4
60*95B55-15	1308.	2.58	98.3	109.1	89.0	107.2	86.7	104.2	94.9	111.8	
80*95B55-15	1275.	2.60	100.0	108.1	90.9	106.6	87.9	102.8	91.7	111.1	
10*95B55-15	1230.	2.67	96.4	106.4	93.3	105.6	89.3	99.3	94.3	109.5	4
60-30B55-15	808.	3.31	109.0	117.6	99.6	110.1			94.5	113.7	234
80-30B55-15	795.	3.34	114.6	117.6	102.7	109.3			94.1	112.6	4
10-30B55-15	745.	3.40	112.7	117.3	99.5	107.2			93.5	111.8	4
60*30B55-15	1375.	2.49	103.0	108.4	93.4	109.7	90.6	104.4	96.4	113.0	234
80*30B55-15	1365.	2.51	108.2	109.3	95.3	109.4	92.1	103.1	93.5	112.7	4
10*30B55-15	1330.	2.55	107.1	110.1	97.5	109.0	94.0	99.9	96.4	111.9	4
60-60B70-15	640.	3.77	90.1	115.3	84.9	110.5			90.4	113.0	
80-60B70-15	630.	3.78	89.7	111.8	81.9	107.9			89.1	111.8	
10-60B70-15	560.	3.92	85.9	106.3	76.5	103.1			87.3	110.8	4
60*60B70-15	1140.	2.78	84.8	109.8	81.2	107.8	77.4	107.5	89.0	112.1	
80*60B70-15	1130.	2.79	83.0	105.9	80.3	106.4	76.5	106.3	85.7	111.0	
10*60B70-15	1040.	2.93	77.2	100.4	79.1	104.4	74.9	104.3	87.1	109.0	4
60-95B70-15	640.	3.79	102.0	120.5	91.7	116.4			97.3	120.4	
80-95B70-15	730.	3.54	98.4	112.8	86.5	109.5			90.4	113.4	
10-95B70-15	692.	3.60	94.6	111.7	83.6	107.5			88.9	112.7	4
60*95B70-15	1265.	2.61	98.8	113.7	94.8	114.6	83.1	111.6	97.1	118.5	
80*95B70-15	1260.	2.62	93.2	105.4	83.7	108.0	81.4	106.6	88.0	112.2	
10*95B70-15	1210.	2.68	88.9	103.3	84.1	107.0	80.4	105.3	89.9	111.2	4
60-30B70-15	800.	3.33	103.2	114.5	92.6	109.4			93.8	115.0	234
80-30B70-15	790.	3.37	107.6	115.0	93.6	109.7			93.1	114.2	34
10-30B70-15	780.	3.38	103.9	115.5	89.4	109.0			92.1	113.8	4
60*30B70-15	1365.	2.50	95.7	104.8	86.6	109.5	86.1	106.9	91.8	113.0	234
80*30B70-15	1360.	2.51	99.8	105.4	88.4	109.5	86.0	106.8	89.1	113.3	34
10*30B70-15	1335.	2.54	97.0	106.7	88.4	109.6	85.5	106.3	91.4	113.4	4

PREPARED BY PRATT & WHITNEY AIRCRAFT FOR NASA-LEWIS RESEARCH CENTER

CYCLE NUMBER	AIRPLANE PERFORMANCE		PEAK FLYOVER NOISE - MAJOR COMPONENTS								REMARKS
			T/O-MAX		T/O-C/B 1000'		T/O-C/B 3 MI.		APPROACH		
	ALTITUDE	DISTANCE	JET	TOTAL	JET	TOTAL	JET	TOTAL	JET	TOTAL	
60-60B30-24	610.	3.84	104.4	110.3	97.0	101.7			90.4	108.5	
80-60B30-24	600.	3.89	106.9	109.0	97.8	101.3			91.0	107.0	
10-60B30-24	570.	3.93	106.5	106.5	94.9	99.7			92.0	105.6	
60*60B30-24	1100.	2.83	99.3	108.2	92.6	101.5	88.3	98.0	93.6	108.4	
80*60B30-24	1070.	2.86	100.5	107.0	94.2	101.2	91.2	97.1	90.4	106.9	
10*60B30-24	1030.	2.94	101.2	104.4	94.9	100.8	95.1	94.7	94.5	104.3	
60-95B30-24	700.	3.58	111.9	119.5	102.6	109.8			95.8	110.1	
80-95B30-24	690.	3.62	116.6	119.4	106.1	109.8			96.3	108.8	
10-95B30-24	682.	3.65	119.0	119.0	105.3	108.7			97.1	107.6	
60*95B30-24	1235.	2.66	108.6	115.7	96.5	105.9	95.7	102.5	97.8	107.9	
80*95B30-24	1200.	2.73	112.2	115.0	99.1	105.1	98.2	101.0	94.5	107.5	
10*95B30-24	1200.	2.71	113.2	113.2	101.2	104.0	101.8	97.8	98.4	106.6	
60-30B30-24	760.	3.40	117.8	123.1	108.5	112.4			98.0	111.1	2
80-30B30-24	760.	3.42	122.4	122.4	111.8	111.8			98.3	109.8	
10-30B30-24	735.	3.48	121.0	121.0	108.7	109.9			98.9	108.8	
60*30B30-24	1330.	2.54	114.4	117.9	99.8	110.3	102.7	106.9	99.8	107.4	2
80*30B30-24	1320.	2.55	117.7	117.7	102.1	109.0	105.0	104.9	96.4	108.2	
10*30B30-24	1290.	2.59	116.6	116.6	103.9	107.2	100.8	100.8	100.1	108.9	
60-60B55-24	610.	3.87	90.6	112.8	85.1	104.7			89.6	111.1	
80-60B55-24	605.	3.88	93.1	110.1	85.7	103.0			90.5	110.0	
10-60B55-24	590.	3.91	96.4	105.6	86.2	99.3			91.7	109.2	
60*60B55-24	1080.	2.85	83.8	107.2	80.8	104.7	76.8	105.2	92.4	111.4	
80*60B55-24	1070.	2.85	86.2	105.2	83.5	103.1	80.0	102.6	89.7	110.2	
10*60B55-24	1045.	2.68	88.6	102.6	87.1	100.8	84.2	99.7	92.8	107.8	
60-95B55-24	700.	3.58	96.5	114.7	88.7	108.9			91.4	112.9	
80-95B55-24	705.	3.56	101.3	114.6	92.3	108.2			92.1	111.7	
10-95B55-24	690.	3.62	104.7	114.2	95.1	106.1			93.2	110.9	
60*95B55-24	1230.	2.66	90.7	108.9	84.5	107.0	81.6	105.9	95.0	112.1	
80*95B55-24	1240.	2.45	95.9	108.3	87.7	105.9	84.6	103.6	92.2	111.4	
10*95B55-24	1210.	2.68	99.5	107.9	91.9	104.3	88.9	100.9	95.2	109.9	
60-30B55-24	760.	3.39	100.8	116.6	96.0	110.1			92.9	113.8	2
80-30B55-24	780.	3.39	108.1	117.2	99.7	109.5			93.5	112.7	
10-30B55-24	755.	3.44	111.5	117.8	100.4	107.6			94.4	111.8	
60*30B55-24	1340.	2.54	94.0	108.9	89.5	109.3	86.0	106.6	95.4	112.7	2
80*30B55-24	1345.	2.54	102.1	109.8	91.9	108.7	89.0	104.5	92.5	112.6	
10*30B55-24	1320.	2.58	106.9	111.6	95.0	107.8	93.3	102.1	95.5	112.1	

PRATT & WHITNEY AIRCRAFT

PREPARED BY PRATT & WHITNEY AIRCRAFT FOR NASA-LEWIS RESEARCH CENTER

CYCLE NUMBER	AIRPLANE PERFORMANCE		PEAK FLYOVER NOISE - MAJOR COMPONENTS								REMARKS
			T/O-MAX		T/O-C/B 1000'		T/O-C/B 3 MI.		APPROACH		
	ALTITUDE	DISTANCE	JET	TOTAL	JET	TOTAL	JET	TOTAL	JET	TOTAL	
60-60B70-24	610.	3.86	86.0	116.4	82.0	108.1			89.8	112.7	
80-60B70-24	790.	3.96	87.0	112.8	80.5	106.4			90.4	111.9	
10-60B70-24	570.	3.93	88.0	107.0	80.1	103.0			91.4	111.3	
60*60B70-24	1070.	2.83	79.6	109.8	77.0	108.0	73.9	106.1	90.7	113.0	
80*60B70-24	1050.	2.84	80.6	106.0	78.1	105.7	75.2	104.7	88.2	111.9	
10*60B70-24	1020.	2.95	80.7	101.5	80.0	102.2	76.7	103.2	90.8	109.7	
60-95S70A24	710.	3.56	93.1	112.6	85.4	109.7			93.5	111.7	
80-95B70-24	700.	3.59	94.4	112.7	84.5	109.7			91.2	113.5	
10-95B70-24	690.	3.62	95.7	112.2	86.6	108.4			91.9	112.8	
60*95S70A24	1240.	2.67	87.6	107.9	82.1	109.0	79.8	108.0	92.3	114.2	3
80*95B70-24	1230.	2.68	89.1	106.2	81.8	107.8	80.2	106.1	89.7	113.5	
10*95B70-24	1200.	2.69	90.9	104.7	84.0	105.8	82.0	105.5	92.3	111.7	
60-30E70-24	790.	3.37	99.7	114.3	95.2	110.3			94.3	116.0	23
80-30B70-24	730.	3.40	100.3	114.3	91.2	110.5			93.4	114.4	3
10-30B70-24	760.	3.43	101.8	115.7	91.4	110.0			94.0	113.5	
60*30E70-24	1360.	2.51	94.3	106.9	89.6	109.6	86.5	108.5	92.5	115.3	23
80*30B70-24	1330.	2.56	94.1	106.9	86.8	109.9	85.0	107.4	89.1	115.1	3
10*30B70-24	1300.	2.57	97.5	108.5	87.4	109.5	87.0	107.8	91.6	113.8	
60-60B30-30	585.	3.90	101.3	110.0	95.3	101.4			90.3	108.6	
80-60B30-30	575.	3.92	103.5	109.3	96.7	100.9			90.5	107.0	
10-60B30-30	535.	3.95	107.9	107.9	96.5	99.0			90.8	105.3	
60*60B30-30	1045.	2.91	97.4	106.7	90.2	101.2	88.1	98.3	92.5	108.1	
80*60B30-30	1030.	2.93	98.1	105.4	92.8	101.1	90.8	97.2	89.6	106.6	
10*60B30-30	1000.	2.99	98.9	103.1	95.0	100.8	94.5	95.6	94.1	103.9	
60-95B30-30	690.	3.62	108.8	113.8	100.4	108.6			95.7	110.1	
80-95B30-30	670.	3.66	113.0	119.1	104.3	108.2			95.4	108.7	
10-95B30-30	655.	3.71	117.2	119.3	105.5	106.5			95.0	107.5	
60*95B30-30	1210.	2.69	106.4	114.3	92.4	105.2	93.4	101.0	96.7	105.9	
80*95B30-30	1200.	2.71	109.4	113.3	95.7	104.3	95.5	99.2	93.5	106.1	
10*95B30-30	1150.	2.75	110.6	111.4	98.9	103.0	98.3	96.6	97.5	106.1	
60-30B30-30	750.	3.12	113.6	122.1	105.9	109.7			97.8	110.7	2
80-30B30-30	750.	3.46	120.0	121.5	108.4	108.4			97.1	109.7	
10-30B30-30	770.	3.42	120.2	120.2	105.4	105.4			96.0	109.0	
60*30B30-30	1310.	2.58	111.9	116.6	94.0	109.1	98.4	103.7	98.2	103.7	2
80*30B30-30	1285.	2.59	115.6	115.8	96.8	107.5	99.9	101.1	94.8	105.7	
10*30B30-30	1320.	2.55	114.3	114.3	99.2	105.2	101.8	97.5	98.4	108.3	

PREPARED BY PRATT & WHITNEY AIRCRAFT FOR NASA-LEWIS RESEARCH CENTER

CYCLE NUMBER	AIRPLANE PERFORMANCE		PEAK FLYOVER NOISE - MAJOR COMPONENTS								REMARKS
			T/O-MAX		T/O-C/B 1000'		T/O-C/B 3 MI.		APPROACH		
	ALTITUDE	DISTANCE	JET	TOTAL	JET	TOTAL	JET	TOTAL	JET	TOTAL	
60-60B55-30	575.	3.92	90.4	113.9	83.2	106.0			90.4	111.1	
80-60B55-30	579.	3.92	92.4	111.4	84.5	103.8			90.7	110.0	
10-60B55-30	540.	3.94	96.4	107.2	87.8	99.7			91.2	109.3	
60*60B55-30	1060.	2.89	83.1	107.3	79.5	104.7	77.9	106.1	92.0	111.3	
80*60B55-30	1051.	2.77	84.9	104.7	83.2	102.8	80.7	103.1	89.6	109.9	
10*60B55-30	1000.	2.99	87.5	101.7	88.4	100.0	84.5	100.6	93.3	107.5	
60-95B55-30	690.	3.61	95.8	112.9	86.6	109.6			92.1	112.9	
80-95B55-30	680.	3.62	100.1	115.1	90.7	108.3			92.0	111.8	
10-95B55-30	670.	3.66	104.3	115.1	96.0	105.4			91.9	110.9	
60*95B55-30	1210.	2.70	89.3	109.4	81.9	106.9	80.5	105.5	94.3	111.6	
80*95B55-30	1200.	2.69	93.9	108.1	85.8	105.5	83.1	102.7	91.7	110.9	
10*95B55-30	1190.	2.73	97.7	106.9	91.1	103.5	86.5	100.5	95.0	109.5	
60-30S55A30	770.	3.43	101.3	116.8	96.0	109.8			91.1	114.5	3
80-30B55-30	770.	3.42	105.2	116.9	97.6	108.3			93.1	112.7	
10-30B55-30	750.	3.48	109.4	118.0	100.5	105.1			92.5	111.7	
60*30S55A30	1320.	2.57	95.5	109.7	87.3	109.0	84.3	104.6	93.9	112.1	23
80*30B55-30	1318.	2.56	99.3	109.8	88.4	108.3	85.1	102.2	91.2	111.9	
10*30B55-30	1290.	2.59	104.3	110.5	92.0	107.0	88.2	100.2	94.2	111.6	
60-60S70A30	500.	4.13	88.0	117.6	81.4	110.0			93.8	114.0	23
80-60B70-30	540.	3.93	87.9	114.7	79.2	108.1			91.1	111.9	
10-60B70-30	530.	3.95	89.5	108.8	81.9	103.9			91.2	111.6	
60*60S70A30	940.	3.09	81.2	110.7	78.3	107.9	77.3	106.9	90.0	112.8	
80*60B70-30	1018.	2.97	80.6	106.2	79.8	105.2	78.4	104.2	88.5	111.7	
10*60B70-30	1000.	3.00	81.1	100.8	83.5	100.9	79.4	102.9	91.8	109.4	
60-95E70-30	730.	3.53	95.9	112.7	85.3	110.5			91.8	115.0	
80-95B70-30	670.	3.65	94.5	113.7	83.0	110.9			91.6	113.6	
10-95B70-30	655.	3.68	96.5	113.4	87.9	108.5			91.1	112.9	
60*95E70-30	1020.	2.98	89.8	108.6	82.7	108.8	81.5	107.1	91.5	113.9	
80*95B70-30	1200.	2.71	88.3	106.8	82.1	107.7	81.1	104.5	89.6	113.6	
10*95B70-30	1160.	2.74	90.3	104.2	85.3	105.2	82.1	104.3	92.5	111.3	
60-30S70B30	840.	3.24	101.0	113.2	94.6	109.8			90.9	112.8	
80-30B70-30	750.	3.48	98.5	114.0	90.3	110.7			93.5	114.5	3
10-30B70-30	750.	3.42	100.8	116.4	92.2	108.8			92.6	113.4	
60*30S70B30	1420.	2.46	96.4	106.6	89.2	109.4	86.2	106.4	92.0	114.6	23
80*30B70-30	1300.	2.59	92.3	108.0	85.6	110.1	83.4	104.7	88.0	115.4	3
10*30B70-30	1295.	2.59	96.1	108.2	86.6	109.5	84.4	105.6	90.6	113.3	

PRATT & WHITNEY AIRCRAFT

PREPARED BY PRATT & WHITNEY AIRCRAFT FOR NASA-LEWIS RESEARCH CENTER

CYCLE NUMBER	AIRPLANE PERFORMANCE		PEAK FLYOVER NOISE - MAJOR COMPONENTS								REMARKS
			T/O-MAX		T/O-C/B 1000'		T/O-C/B 3 MI.		APPROACH		
	ALTITUDE	DISTANCE	JET	TOTAL	JET	TOTAL	JET	TOTAL	JET	TOTAL	
60-60C30-15	545.	4.00	97.5	109.5	89.7	103.5			91.8	108.7	
80-60C30-15	530.	4.05	99.4	109.1	92.6	103.3			91.1	107.7	
10-60C30-15	458.	4.28	99.1	110.1	90.1	102.1			90.0	107.0	4
60*60C30-15	1015.	2.97	92.0	104.1	83.3	102.2	81.8	102.0	91.3	108.0	
80*60C30-15	999.	3.01	93.5	104.6	82.5	101.6	81.6	103.6	82.0	106.6	
10*60C30-15	890.	3.17	92.9	103.7	83.9	100.7	86.2	102.8	89.7	104.0	4
60-95C30-15	650.	3.73	101.2	116.8	93.0	110.3			94.1	111.2	
80-95C30-15	640.	3.75	105.7	118.1	99.9	110.8			93.9	109.7	
10-95C30-15	610.	3.86	105.8	121.7	101.1	110.5			93.5	108.2	4
60*95C30-15	1160.	2.75	99.7	109.3	87.3	104.6	86.2	101.6	93.8	111.0	
80*95C30-15	1140.	2.78	104.1	110.6	88.2	103.7	86.7	102.3	85.0	109.4	
10*95C30-15	1060.	2.88	104.5	111.1	92.4	102.3	92.3	100.2	93.2	106.5	4
60-30C30-15	718.	3.52	112.1	115.1	100.8	109.5			93.1	113.0	2 4
80-30C30-15	500.	4.13	116.1	116.1	108.7	109.6			93.4	111.0	4
10-30C30-15	670.	3.65	119.3	119.3	108.8	108.8			93.8	108.7	4
60*30C30-15	1265.	2.63	106.5	109.2	94.1	107.0	92.2	104.2	92.8	114.0	2 4
80*30C30-15	1230.	2.76	111.4	111.4	95.6	105.8	93.3	104.0	84.3	112.2	4
10*30C30-15	1199.	2.72	113.1	113.1	100.7	103.9	99.9	100.6	93.2	109.2	4
60-60J55-15	540.	4.08	91.2	116.8	83.5	105.5			92.3	111.3	
80-60C55-15	520.	4.07	92.2	115.0	84.9	104.1			91.8	110.3	
10-60C55-15	460.	4.04	89.8	112.6	83.8	101.3			90.4	109.6	4
60*60J55-15	1000.	3.00	83.0	107.7	80.8	103.4	82.2	104.6	94.0	110.3	
80*60C55-15	980.	3.02	84.1	107.3	79.8	103.0	80.8	106.0	85.5	108.9	
10*60C55-15	890.	3.16	82.9	106.5	82.9	102.5	82.9	107.1	92.3	106.6	4
60-95K55-15	670.	3.68	92.2	114.8	83.8	108.6			91.4	112.6	
80-95C55-15	650.	3.74	93.6	116.1	87.6	108.5			91.2	110.7	
10-95C55-15	608.	3.86	91.1	118.7	90.1	108.1			91.2	111.2	4
60*95K55-15	1180.	2.75	86.1	105.1	84.8	106.2	83.3	103.0	96.0	111.0	
80*95C55-15	1140.	2.78	87.9	106.0	84.6	105.4	82.0	103.0	87.8	110.2	
10*95C55-15	770.	3.29	89.4	109.0	88.2	104.6	84.4	103.7	95.0	109.1	4
60-30L55-15	750.	3.46	100.5	112.7	91.7	107.4			91.4	113.3	234
80-30C55-15	730.	3.58	102.1	111.7	94.9	106.9			90.3	112.5	4
10-30C55-15	699.	3.60	99.6	116.2	96.6	107.5			91.7	112.1	4
60*30L55-15	1305.	2.59	89.9	102.2	91.5	109.0	86.4	103.8	95.7	111.9	234
80*30C55-15	1200.	2.68	90.7	103.0	92.8	107.7	84.7	103.2	86.4	111.4	4
10*30C55-15	1210.	2.69	94.8	109.9	95.2	106.6	87.4	103.3	94.0	111.6	4

PREPARED BY PRATT & WHITNEY AIRCRAFT FOR NASA-LEWIS RESEARCH CENTER

CYCLE NUMBER	AIRPLANE PERFORMANCE		PEAK FLYOVER NOISE - MAJOR COMPONENTS								REMARKS
			T/O-MAX		T/O-C/B 1000'		T/O-C/B 3 MI.		APPROACH		
	ALTITUDE	DISTANCE	JET	TOTAL	JET	TOTAL	JET	TOTAL	JET	TOTAL	
60-60M70-15	590.	3.89	89.3	116.9	83.3	110.4			90.1	114.6	
80-60L70-15	540.	4.04	89.9	115.5	79.8	107.6			89.3	111.7	
10-60C70-15	420.	4.38	89.8	116.1	79.3	104.5			88.9	111.1	4
60*60M70-15	1070.	2.69	83.5	110.5	80.0	109.3	78.0	107.0	92.2	114.5	
80*60L70-15	1010.	2.99	82.2	108.0	77.3	105.7	77.8	105.7	82.9	110.6	
10*60C70-15	860.	3.26	82.1	108.1	77.8	105.0	80.2	107.6	89.2	108.0	4
60-95F70-15	740.	3.57	94.6	113.3	84.1	110.2			91.0	114.2	
80-95070-15	670.	3.72	92.9	113.4	80.6	109.6			89.3	113.0	
10-95C70-15	600.	3.89	87.9	117.7	81.1	110.4			89.2	113.0	4
60*95F70-15	1205.	2.65	89.9	106.5	82.8	108.6	81.5	107.0	91.0	112.3	
80*95070-15	1170.	2.76	86.8	104.3	80.3	107.9	79.8	104.9	85.4	111.3	
10*95C70-15	1000.	2.99	85.4	107.8	81.2	107.3	80.6	105.9	91.3	110.5	4
60-30N70-15	790.	3.40	102.7	114.3	92.0	109.4			93.6	114.9	234
80-30P70-15	680.	3.48	101.8	111.9	87.7	108.8			90.5	113.1	
10-30C70-15	660.	3.65	93.2	114.1	85.1	110.4			91.0	114.2	4
60*30N70-15	1330.	2.54	94.9	104.5	88.4	109.6	85.9	106.9	91.7	112.8	234
80*30P70-15	1300.	2.59	92.0	102.2	86.2	108.3	83.1	106.4	88.7	113.7	
10*30C70-15	1200.	2.73	87.7	108.0	87.5	109.6	82.6	107.3	89.8	113.0	4
60-60C30-24	495.	4.14	92.2	111.7	83.4	101.1			87.8	109.5	
80-60C30-24	470.	4.31	96.0	111.0	87.2	101.5			89.0	107.7	
10-60C30-24	450.	4.28	101.2	111.6	88.9	101.2			90.9	106.0	
60*60C30-24	960.	3.07	85.4	105.0	79.8	101.9	77.3	102.7	90.4	107.8	
80*60C30-24	710.	3.48	89.7	105.8	79.6	101.4	78.7	102.8	81.6	106.6	
10*60C30-24	870.	3.19	94.8	106.2	82.2	100.6	85.6	101.9	90.0	104.4	
60-95C30-24	625.	3.79	93.8	118.1	84.8	109.3			90.3	111.1	
80-95C30-24	610.	3.81	100.8	118.6	92.9	110.2			91.6	109.6	
10-95C30-24	585.	3.92	107.2	121.0	99.0	110.5			93.5	108.1	
60*95C30-24	1120.	2.82	90.5	109.8	81.9	104.7	80.8	103.6	93.9	104.5	
80*95C30-24	1090.	2.83	98.1	111.1	84.1	103.6	83.2	102.9	85.2	105.6	
10*95C30-24	1050.	2.90	105.2	112.2	90.1	102.0	91.6	100.8	93.7	106.9	
60-30C30-24	680.	3.61	100.5	115.5	90.5	108.8			89.6	112.0	2
80-30C30-24	695.	3.61	110.5	115.1	100.1	109.2			90.9	110.7	
10-30C30-24	650.	3.70	116.4	116.4	106.0	108.9			92.9	109.5	
60*30C30-24	1210.	2.69	94.6	109.3	86.8	107.6	85.9	107.5	93.0	101.2	2
80*30C30-24	1210.	2.69	105.5	111.1	90.1	105.8	89.2	106.0	84.4	104.6	
10*30C30-24	1170.	2.75	112.9	112.9	97.8	103.1	99.1	102.7	93.0	109.4	

PRATT & WHITNEY AIRCRAFT

CYCLE NUMBER	AIRPLANE PERFORMANCE		PEAK FLYOVER NOISE - MAJOR COMPONENTS								REMARKS
			T/O-MAX		T/O-C/B 1000'		T/O-C/B 3 MI.		APPROACH		
	ALTITUDE	DISTANCE	JET	TOTAL	JET	TOTAL	JET	TOTAL	JET	TOTAL	
60-60Q55-24	530.	4.10	88.0	114.4	80.7	103.8			89.5	111.0	
80-60C55-24	460.	4.32	92.0	115.0	80.4	101.7			92.5	110.3	
10-60C55-24	380.	4.38	94.6	112.7	85.7	100.0			94.9	109.8	
60*60Q55-24	1010.	2.99	79.7	107.4	77.4	104.7	75.4	106.1	94.4	111.5	
80*60C55-24	890.	3.18	82.3	107.8	75.9	103.8	77.4	106.2	90.0	110.3	
10*60C55-24	820.	3.29	87.0	108.5	82.1	102.4	83.2	108.0	97.8	108.6	
60-95R55-24	650.	3.67	91.8	114.7	83.9	108.6			90.5	112.7	
80-95C55-24	600.	3.85	91.3	115.6	82.3	108.3			91.4	111.8	
10-95C55-24	590.	3.92	93.8	118.4	90.3	108.1			93.7	111.3	
60*95R55-24	1170.	2.73	85.0	108.4	81.5	107.0	85.1	105.8	96.1	111.8	
80*95C55-24	1080.	2.86	83.5	108.7	80.2	106.1	78.2	104.0	90.8	110.8	
10*95C55-24	1050.	2.91	90.7	111.3	85.7	104.6	83.4	105.7	98.5	110.3	
60-30F55-24	680.	3.45	98.7	115.8	93.8	109.6			92.3	113.8	23
80-30T55-24	710.	3.61	97.0	111.7	90.0	107.8			93.4	114.4	4
10-30C55-24	660.	3.69	97.8	115.6	95.2	107.8			92.2	112.0	
60*30F55-24	1310.	2.59	91.1	108.5	88.3	109.4	84.6	106.7	95.5	112.5	
80*30T55-24	1220.	2.69	86.5	107.9	87.4	108.4	81.1	104.8	88.2	111.6	
10*30C55-24	1200.	2.67	93.5	112.4	90.9	106.7	85.2	106.4	94.7	111.9	
60-60U70-24	560.	3.98	85.9	116.8	81.2	108.0			94.0	115.9	23
80-60X70-24	510.	4.15	88.6	115.0	77.5	105.6			94.4	116.4	23
10-60C70-24	360.	4.39	96.5	115.3	82.9	103.0			95.5	112.1	
60*60U70-24	1030.	2.97	79.3	109.9	76.5	108.0	73.9	107.0	90.9	113.1	23
80*60X70-24	970.	3.05	80.9	107.5	75.4	106.1	75.9	104.6	87.9	112.3	
10*60C70-24	840.	3.28	88.7	109.9	79.8	104.9	83.9	107.4	97.8	110.9	
60-95M70-24	680.	3.60	88.8	113.2	79.1	109.9			90.4	112.9	
80-95P70-24	650.	3.75	91.0	113.0	79.3	109.7			91.4	113.8	34
10-95C70-24	570.	3.95	91.3	117.7	82.8	110.4			93.2	113.2	
60*95M70-24	1210.	2.71	81.9	109.1	79.1	107.2	78.5	106.6	88.8	112.0	
80*95P70-24	1140.	2.82	84.7	106.5	78.7	109.9	78.5	105.0	86.2	112.4	34
10*95C70-24	1040.	2.92	88.4	110.6	80.8	107.5	82.5	106.6	96.7	112.1	
60-30V70-24	790.	3.42	98.1	113.9	93.6	110.3			93.6	113.9	23
80-30M70-24	730.	3.52	96.6	112.3	86.8	110.2			92.3	113.7	3
10-30C70-24	630.	3.81	91.2	114.9	84.8	110.9			92.4	113.4	
60*30V70-24	1340.	2.53	92.3	106.9	88.6	109.7	85.5	108.6	92.3	115.4	23
80*30M70-24	1270.	2.64	88.7	106.5	84.6	110.3	82.6	106.9	87.3	115.2	3
10*30C70-24	1150.	2.78	87.2	112.0	84.5	110.2	82.6	108.9	91.1	113.2	

PREPARED BY PRATT & WHITNEY AIRCRAFT FOR NASA-LEWIS RESEARCH CENTER

CYCLE NUMBER	AIRPLANE PERFORMANCE		PEAK FLYOVER NOISE - MAJOR COMPONENTS								REMARKS
			T/O-MAX		T/O-C/B 1000'		T/O-C/B 3 MI.		APPROACH		
	ALTITUDE	DISTANCE	JET	TOTAL	JET	TOTAL	JET	TOTAL	JET	TOTAL	
60-60C30-30	460.	4.15	89.0	112.4	81.4	103.0			89.9	109.9	
80-60C30-30	455.	4.26	92.4	111.5	85.7	102.7			90.6	107.8	
10-60C30-30	420.	4.37	98.6	111.8	90.0	101.4			91.6	105.4	
60*60C30-30	900.	3.17	83.3	105.3	79.8	101.7	80.3	103.5	89.8	107.0	
80*60C30-30	885.	3.18	86.9	105.3	80.1	101.4	81.0	102.7	81.3	106.0	
10*60C30-30	835.	3.27	92.1	104.9	83.2	100.8	86.9	101.7	90.2	104.0	
60-95C30-30	600.	3.89	89.3	123.9	81.7	110.5			92.5	111.0	
80-95C30-30	600.	3.86	96.2	117.9	90.6	110.7			93.0	109.5	
10-95C30-30	560.	3.96	104.1	119.6	99.4	109.9			93.7	108.0	
60*95C30-30	1080.	2.88	86.8	109.9	79.3	104.8	80.8	103.4	93.8	100.0	
80*95C30-30	1080.	2.87	94.1	110.1	82.2	103.6	82.6	101.9	85.3	102.8	
10*95C30-30	1018.	2.93	101.8	110.1	89.2	101.7	90.2	99.7	93.9	106.5	
60-30C30-30	660.	3.67	93.5	114.4	86.3	108.8			92.0	111.4	2
80-30C30-30	660.	3.67	103.9	113.3	96.9	108.4			92.2	110.5	
10-30C30-30	640.	3.74	113.4	113.4	105.9	106.8			92.5	109.9	
60*30C30-30	1060.	2.65	89.3	109.1	81.6	107.9	82.8	106.4	93.1	93.1	2
80*30C30-30	1170.	2.74	100.3	109.6	85.9	105.8	85.8	104.1	84.4	99.6	
10*30C30-30	1145.	2.79	110.1	110.1	95.1	102.7	95.1	100.8	92.8	109.0	
60-60P55-30	490.	4.14	88.5	115.5	79.5	205.9			91.3	111.0	
80-60C55-30	450.	4.33	92.7	115.6	79.4	104.2			95.7	110.2	
10-60C55-30	400.	4.38	96.3	113.3	88.5	101.5			97.7	110.0	
60*60P55-30	950.	3.10	79.7	107.8	77.3	105.0	77.8	107.1	94.4	111.4	
80*60C55-30	885.	3.20	82.1	107.7	78.0	104.2	81.5	106.7	91.9	110.5	
10*60C55-30	830.	3.30	86.9	107.8	86.1	102.4	87.0	108.9	100.3	109.1	
60-95M55-30	600.	3.89	92.1	115.4	82.9	110.1			92.1	112.8	
80-95T55-30	595.	3.89	91.4	115.3	82.1	110.0			90.5	112.5	
10-95C55-30	570.	3.95	94.0	118.4	92.2	109.0			95.4	111.3	
60*95M55-30	1110.	2.85	84.8	109.7	80.0	107.2	79.2	105.4	95.5	111.4	
80*95T55-30	1070.	2.89	83.1	109.2	80.6	106.3	79.3	103.2	91.6	110.7	
10*95C55-30	1025.	2.93	89.0	110.7	87.1	104.6	84.0	105.5	99.8	110.3	
60-30W55-30	720.	3.47	99.0	116.0	94.1	109.8			92.2	113.1	
80-30X55-30	700.	3.58	97.8	113.7	91.5	108.3			90.9	111.8	
10-30C55-30	650.	2.66	95.5	115.1	96.1	107.5			92.8	111.8	
60*30W55-30	1280.	2.60	92.6	109.8	86.0	109.1	83.0	104.8	94.1	111.9	23
80*30X55-30	1230.	2.67	89.3	109.5	85.1	108.5	80.6	102.6	89.1	111.4	
10*30C55-30	1190.	3.67	90.2	111.9	89.7	106.7	82.6	105.2	94.5	111.5	

PRATT & WHITNEY AIRCRAFT

PREPARED BY PRATT & WHITNEY AIRCRAFT FOR NASA-LEWIS RESEARCH CENTER

CYCLE NUMBER	AIRPLANE PERFORMANCE		PEAK FLYOVER NOISE - MAJOR COMPONENTS								REMARKS
			T/O-MAX		T/O-C/B 1000'		T/O-C/B 3 MI.		APPROACH		
	ALTITUDE	DISTANCE	JET	TOTAL	JET	TOTAL	JET	TOTAL	JET	TOTAL	
60-60H70-30	540.	4.04	87.6	118.0	80.5	110.2			91.0	112.7	
80-60R70-30	470.	4.22	89.0	115.8	77.4	108.1			92.3	111.8	
10-60Z70-30	420.	4.38	93.7	112.2	82.7	104.5			95.4	112.3	
60*60H70-30	1000.	2.98	80.7	110.8	77.8	108.0	77.3	107.1	90.3	112.9	
80*60R70-30	930.	3.10	80.7	107.0	78.6	105.9	79.5	104.4	88.9	112.3	
10*60Z70-30	830.	3.30	83.9	104.6	84.8	103.5	84.8	106.3	97.1	111.3	
80-95M70-30	630.	3.79	92.4	113.9	79.9	111.5			91.9	113.4	
10-95D70-30	610.	3.87	92.8	114.1	85.3	109.2			91.6	112.9	
80*95M70-30	1120.	2.87	85.4	107.4	80.4	108.2	80.4	103.8	89.1	114.0	
10*95D70-30	1070.	2.87	89.8	108.6	83.4	106.0	81.1	104.9	93.6	111.8	
60-30Y70-30	830.	3.29	100.0	173.2	93.8	110.0			95.4	112.3	
80-30U70-30	730.	3.51	97.3	113.6	88.2	110.8			89.8	112.7	
10-30X70-30	730.	3.57	93.0	115.7	86.6	109.4			92.5	112.6	
60*30Y70-30	1390.	2.48	95.2	106.9	88.6	109.6	85.6	106.5	91.8	114.8	23
80*30U70-30	1130.	2.80	90.7	108.1	85.0	110.3	82.8	104.6	87.5	115.6	4
10*30X70-30	1230.	2.66	87.9	108.4	83.0	110.0	80.9	106.4	90.0	113.1	

APPENDIX B
NOISE CONTOUR PLOTS

SUMMARY LISTING OF NOISE CONTOUR PLOTS

Cycle	Condition	Figure
JT3D-3B	Takeoff Max.	32
JT3D-3B	Cutback at 1000 ft. Alt.	33
JT3D-3B	Approach	34
10-30C30-30	Takeoff Max.	35
10-30C30-30	Cutback at 1000 ft. Alt.	36
10-30C30-30	Approach	37
10*30C30-30	Takeoff Max.	38
10*30C30-30	Cutback at 1000 ft. Alt.	39
10*30C30-30	Cutback at 3 Mile Point	40
10*30C30-30	Approach	41
80-95A70-30	Takeoff Max.	42
80-95A70-30	Cutback at 1000 ft. Alt.	43
80-95A70-30	Approach	44
80*95A70-30	Takeoff Max.	45
80*95A70-30	Cutback at 1000 ft. Alt.	46
80*95A70-30	Cutback at 3 Mile Point	47
80*95A70-30	Approach	48
80-95B55-24	Takeoff Max.	49
80-95B55-24	Cutback at 1000 ft. Alt.	50
80-95B55-24	Approach	51
80*95B55-24	Takeoff Max.	52
80*95B55-24	Cutback at 1000 ft. Alt.	53
80*95B55-24	Cutback at 3 Mile Point	54
80*95B55-24	Approach	55
80-95B70-24	Takeoff Max.	56
80-95B70-24	Cutback at 1000 ft. Alt.	57
80-95B70-24	Approach	58
80*95B70-24	Takeoff Max.	59
80*95B70-24	Cutback at 1000 ft. Alt.	60
80*95B70-24	Cutback at 3 Mile Point	61
80*95B70-24	Approach	62

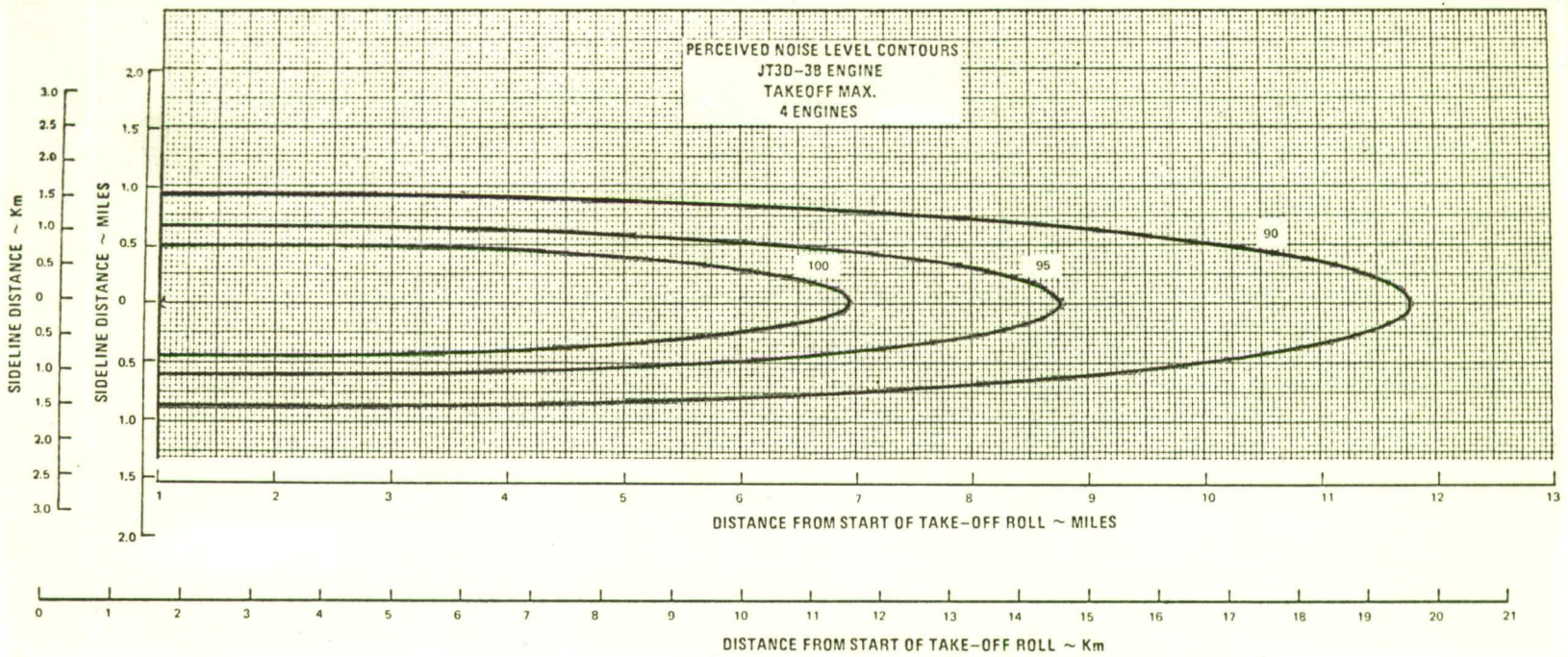


Figure 32

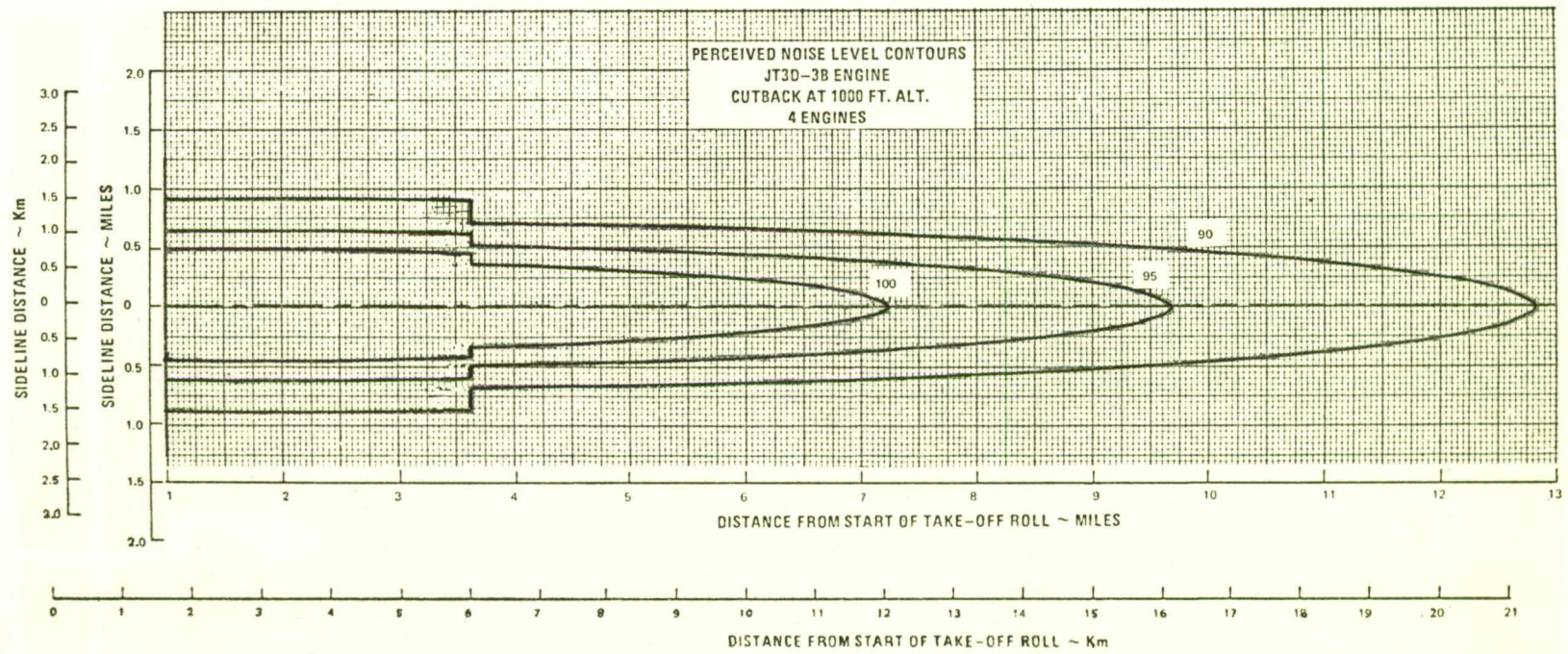


Figure 33

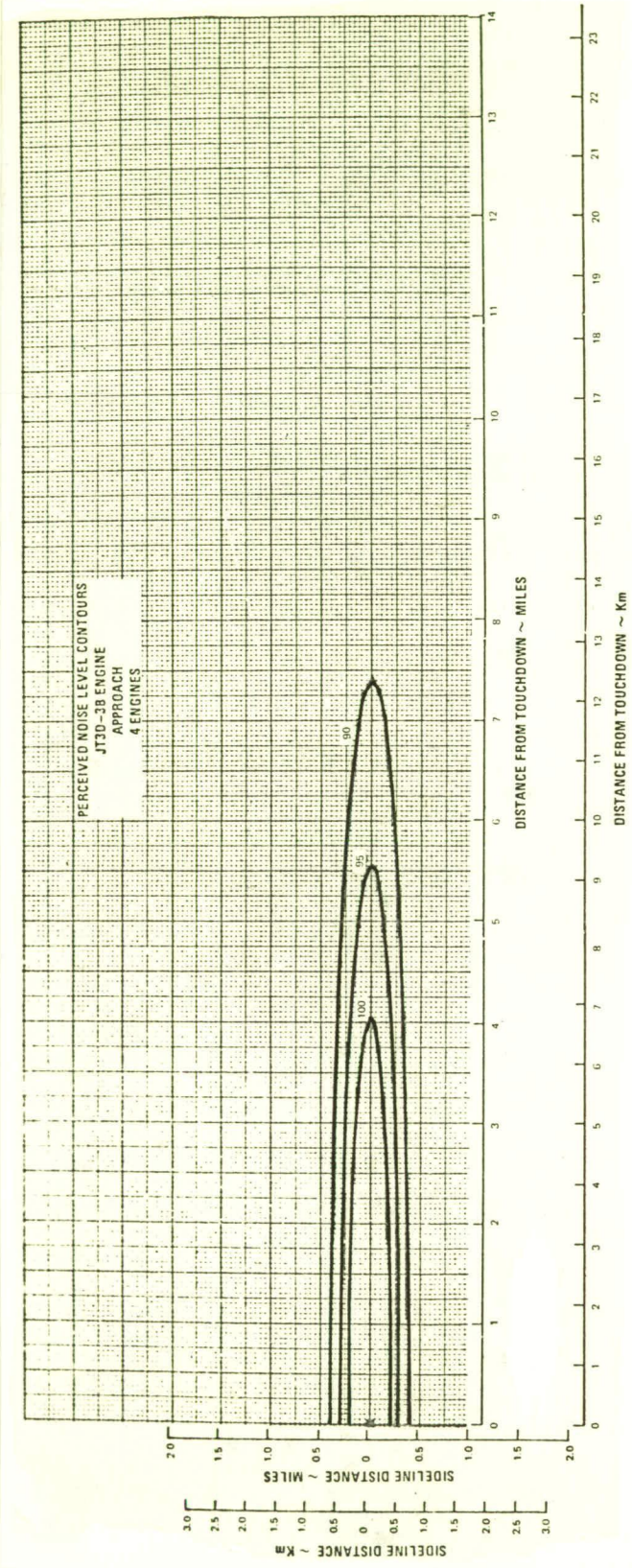


Figure 34

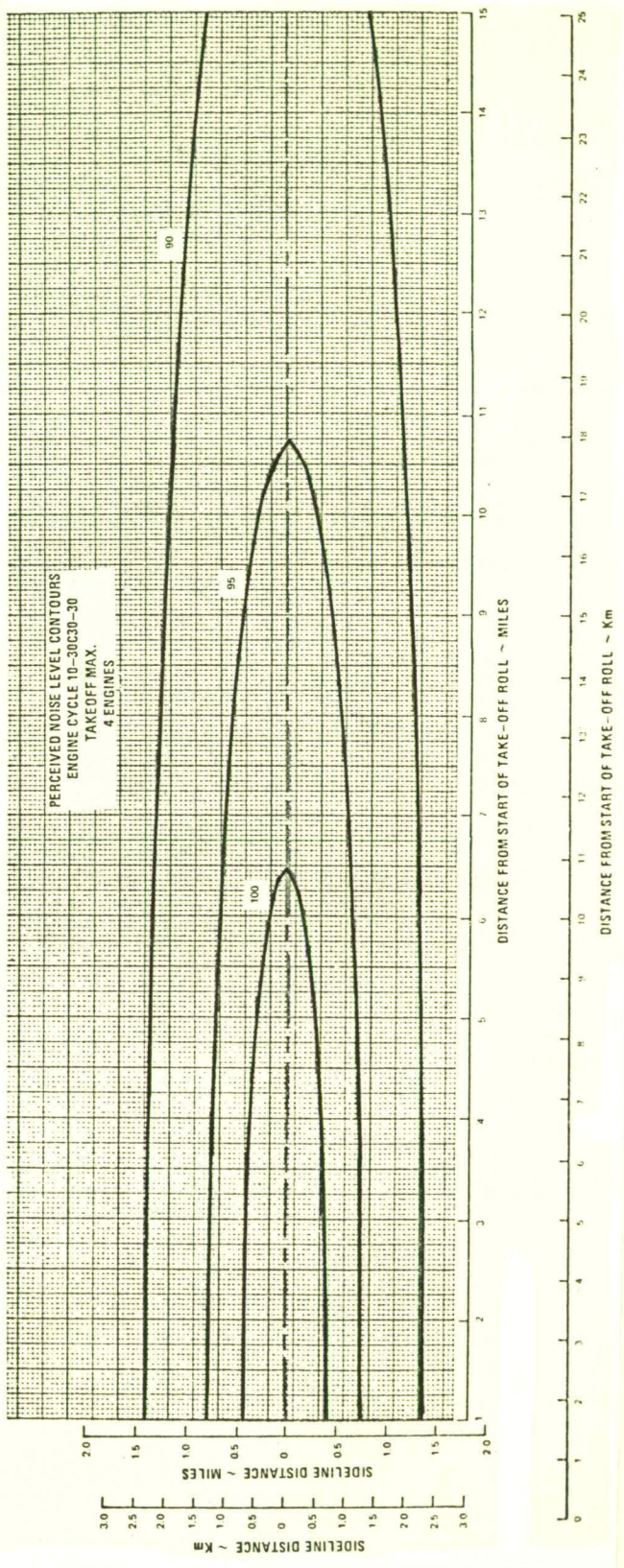


Figure 35

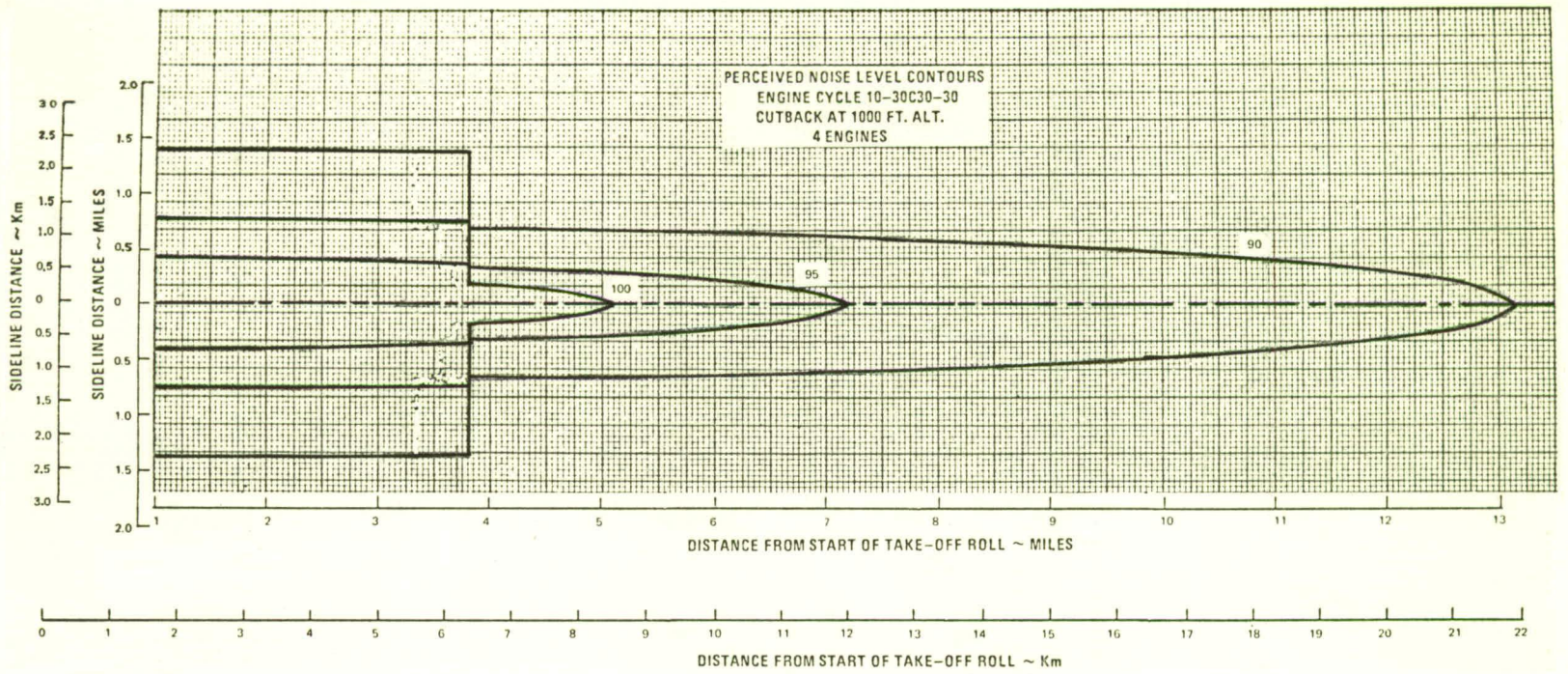


Figure 36

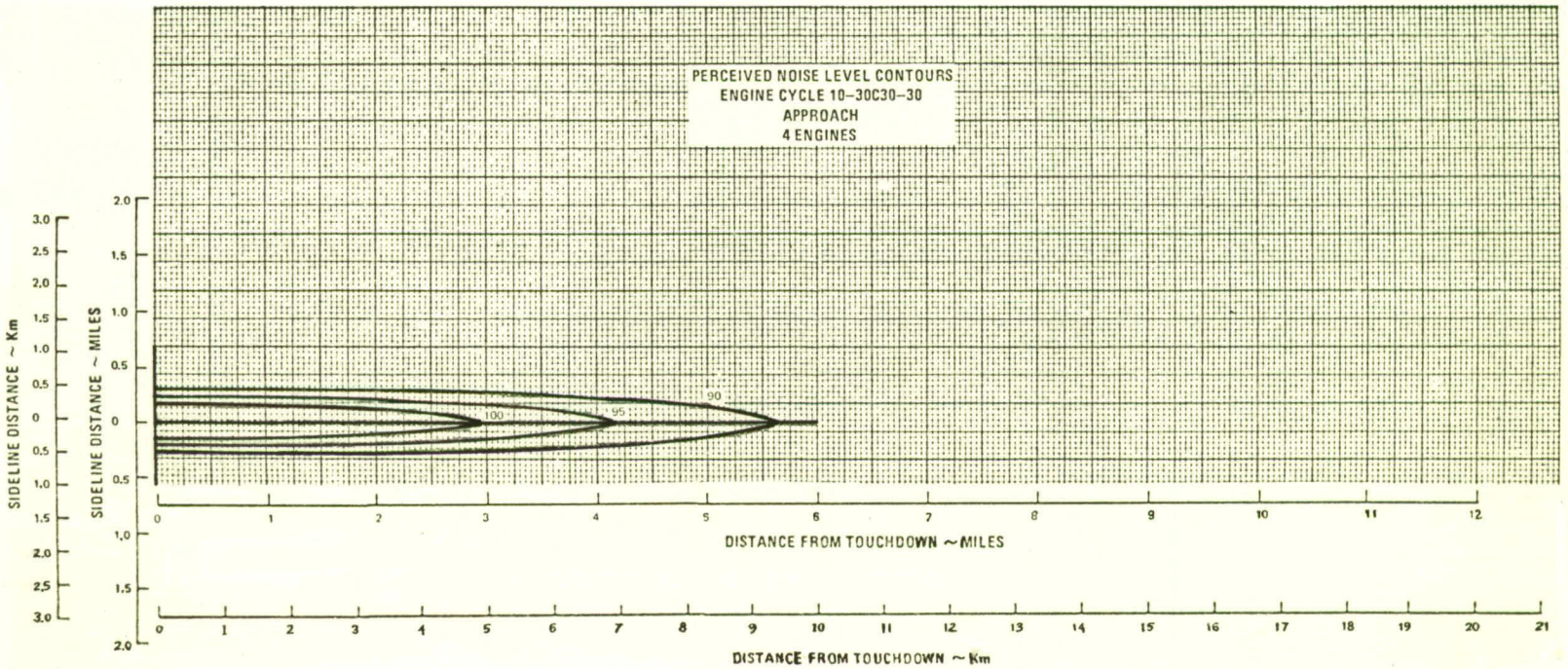


Figure 37

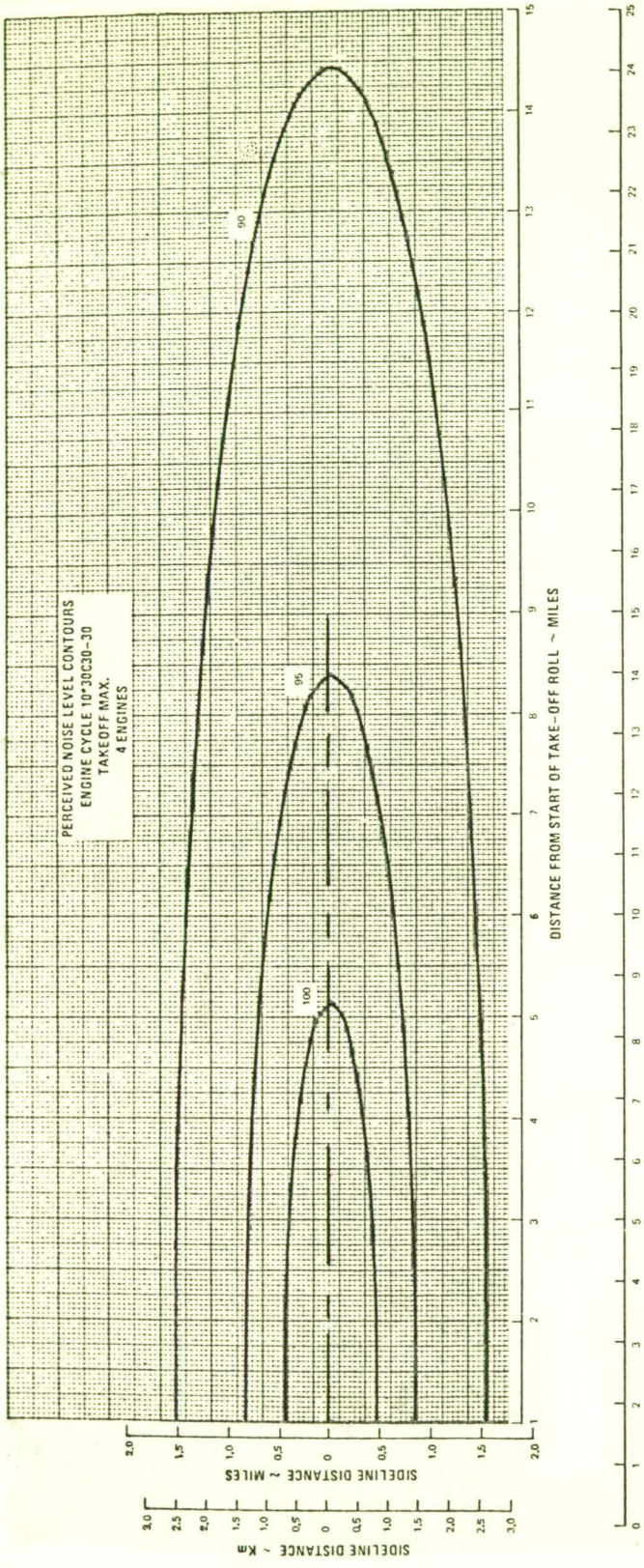


Figure 38

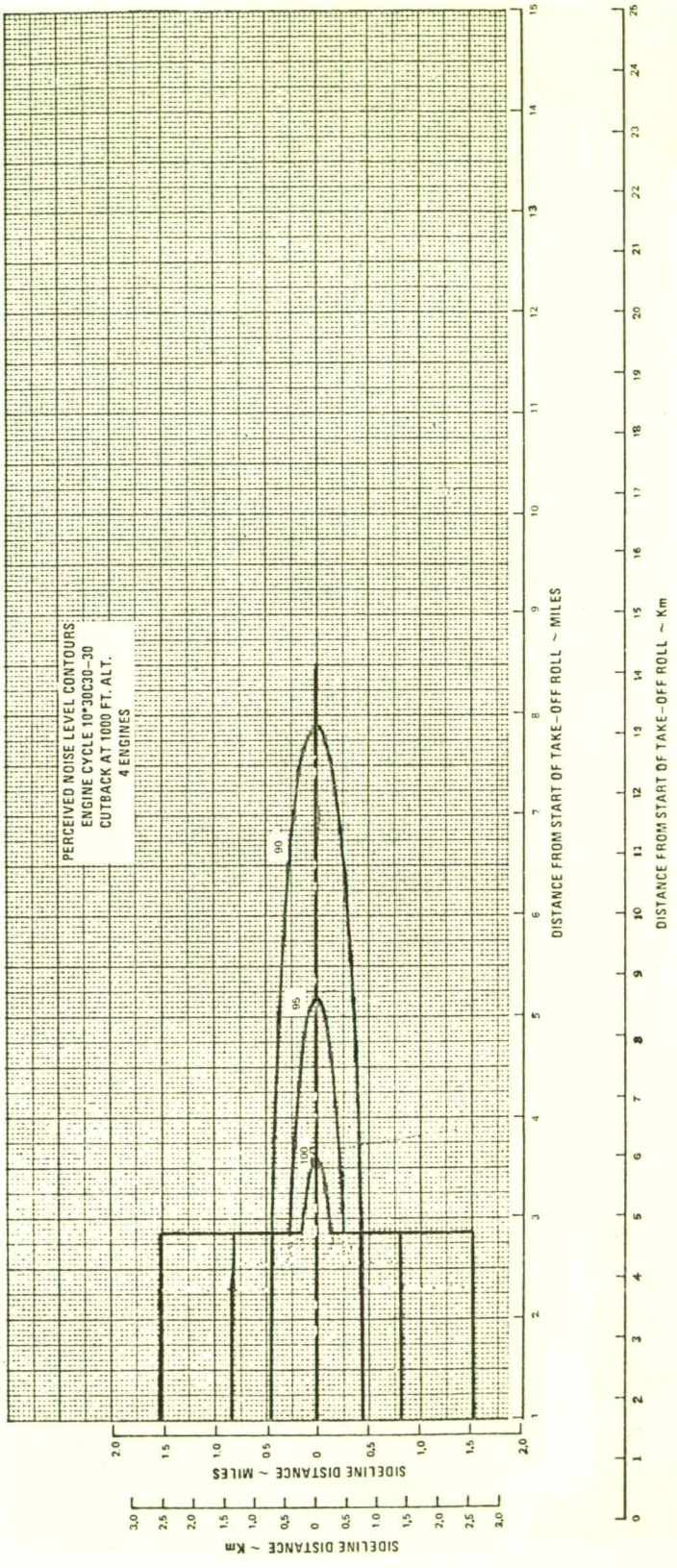


Figure 39

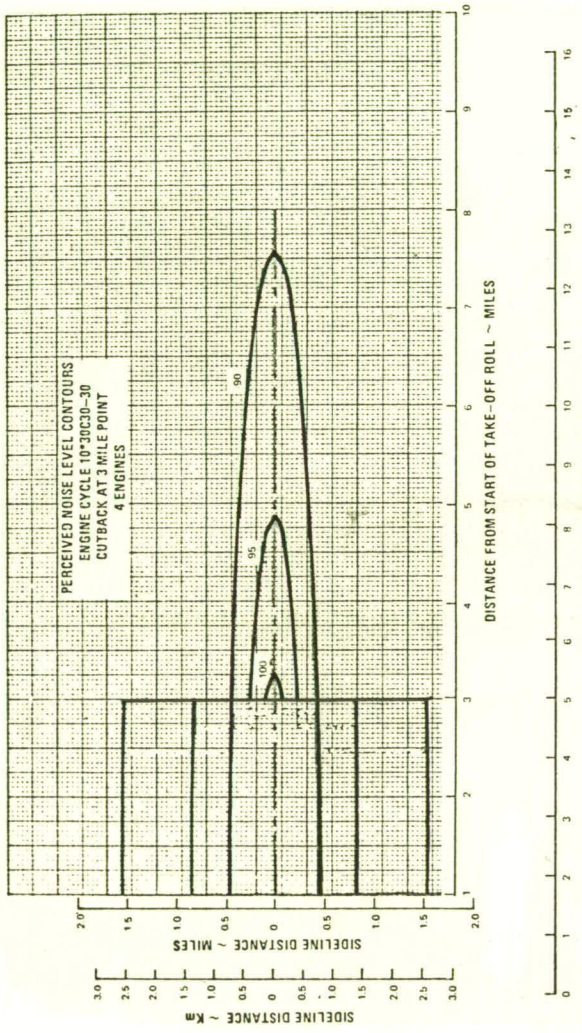


Figure 40

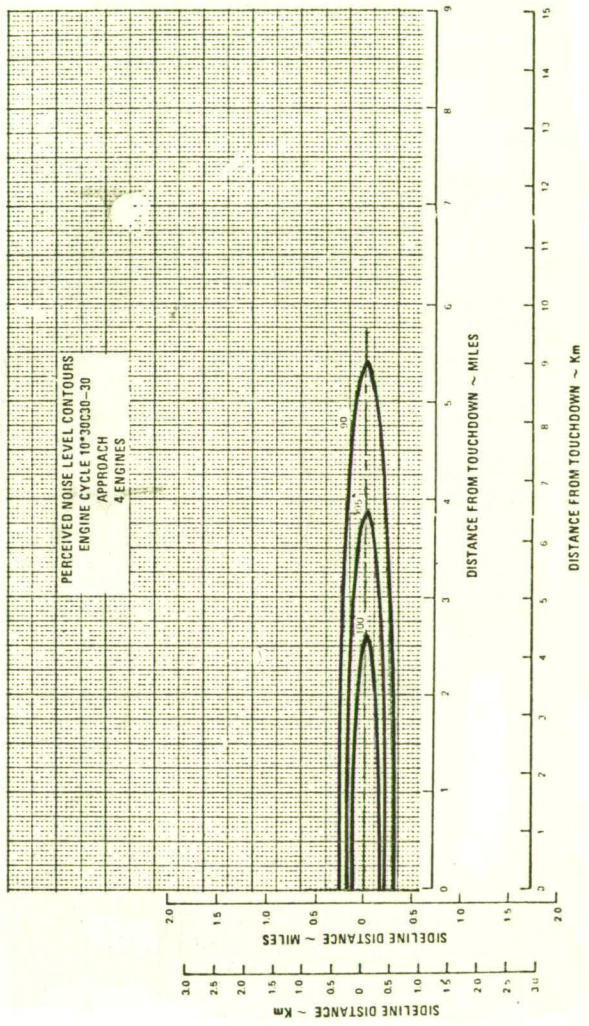


Figure 41

PERCEIVED NOISE LEVEL CONTOURS
ENGINE CYCLE 80-95A70-30
CUTBACK AT 1000 FT. ALT.
4 ENGINES

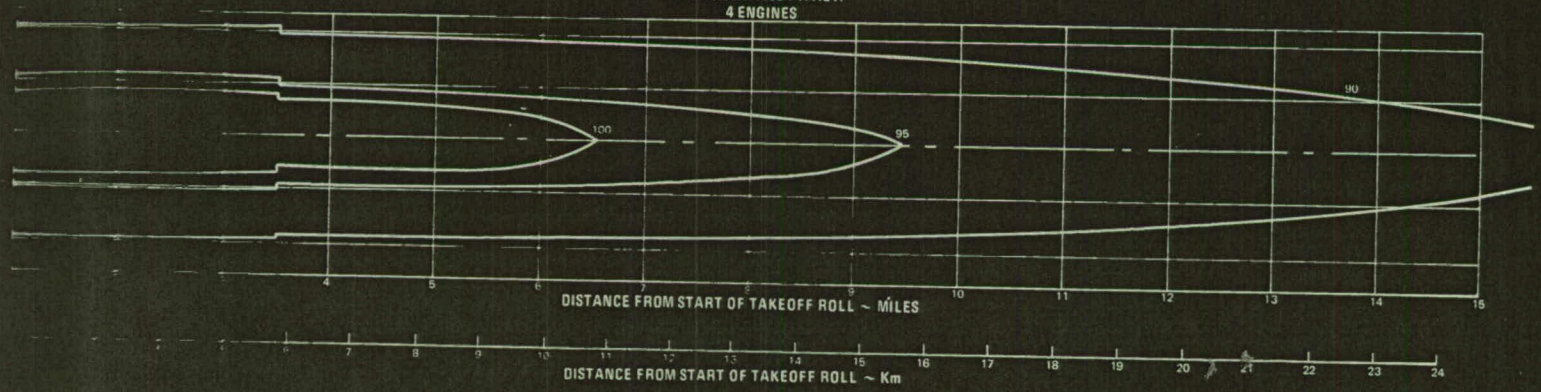


fig 43

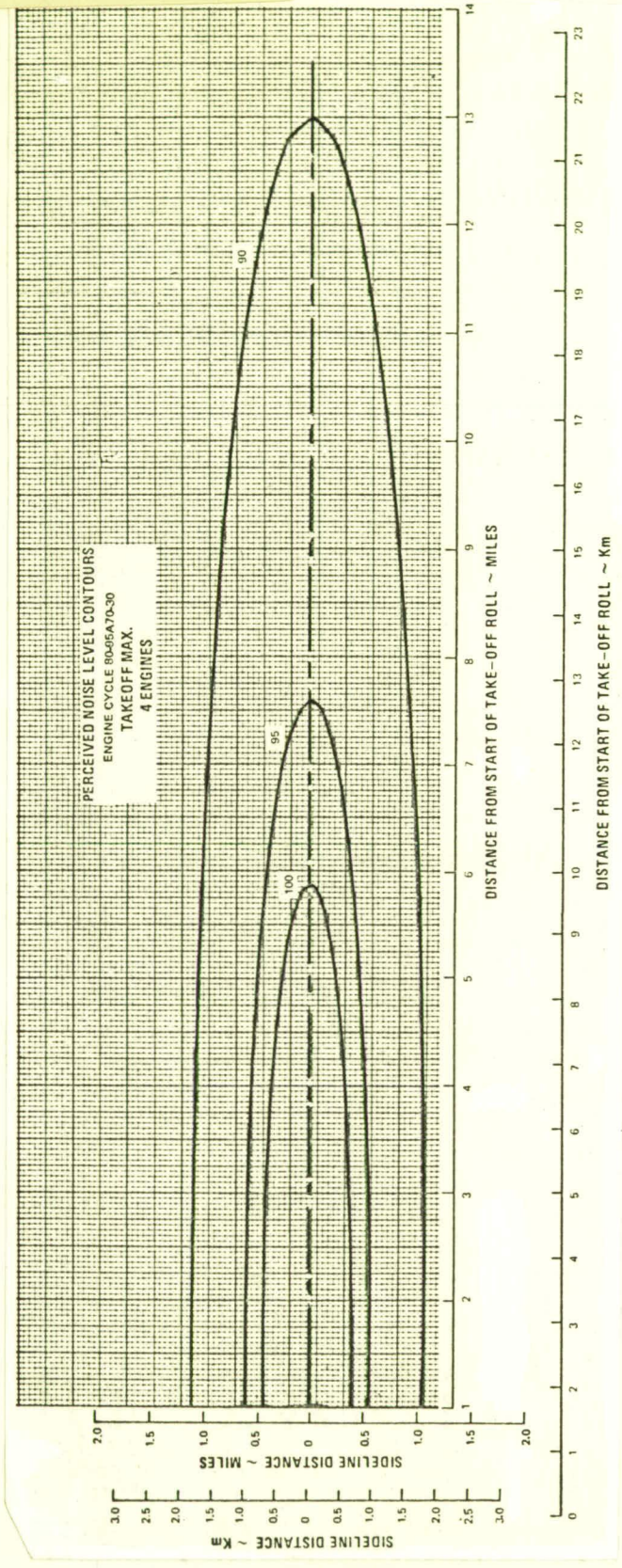


Figure 42

Figure 43

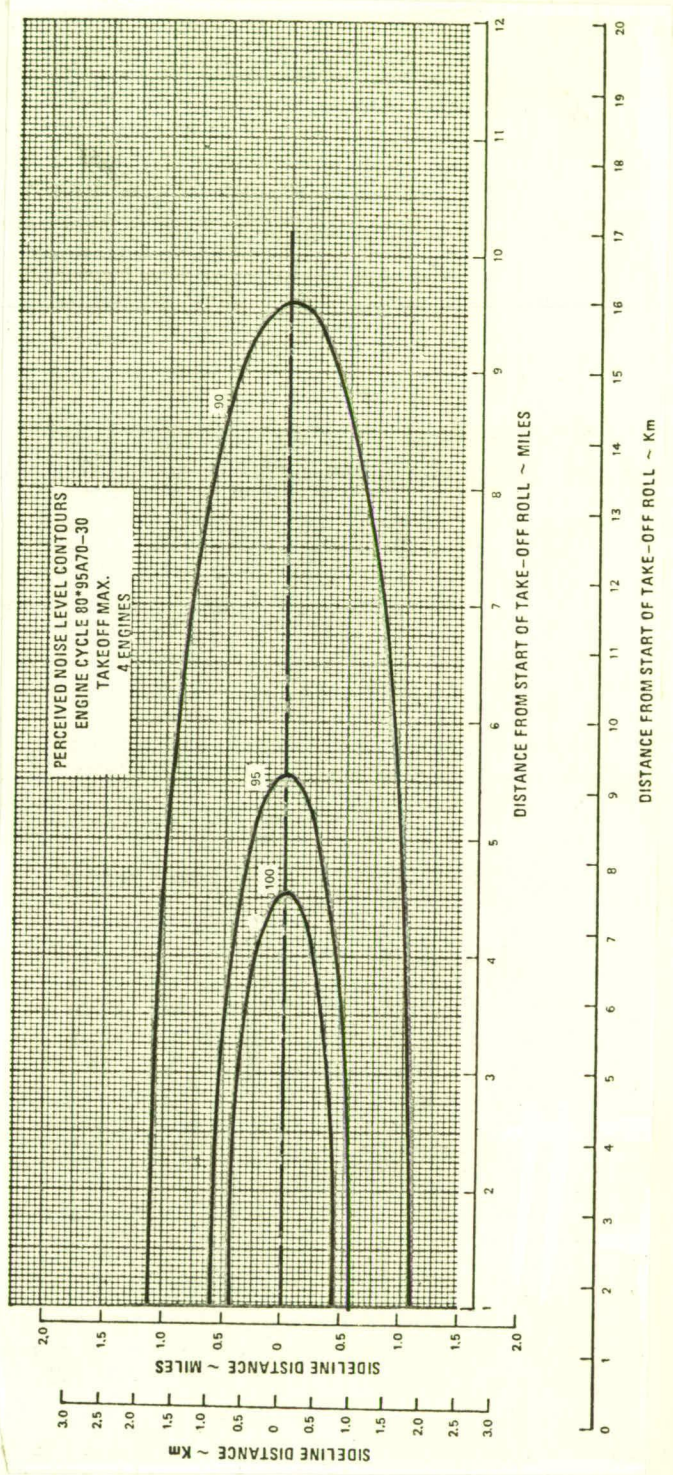


Figure 44

Figure 45

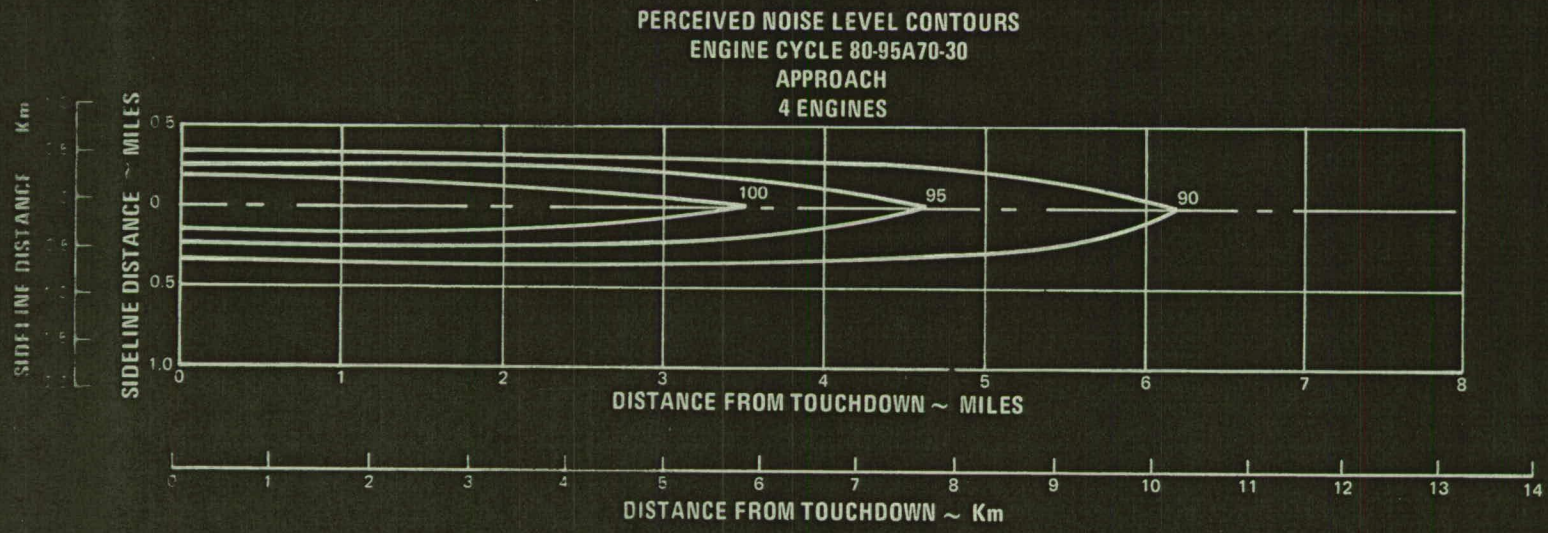

PERCEIVED NOISE LEVEL CONTOURS
ENGINE CYCLE 80-95A70-30
APPROACH
4 ENGINES
SIDELINE DISTANCE ~ Km
SIDELINE DISTANCE ~ MILES
0.5
0
0.5
1.0
100
95
90
0
1
2
3
4
5
6
7
8
DISTANCE FROM TOUCHDOWN ~ MILES
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
DISTANCE FROM TOUCHDOWN ~ Km

Fig 44

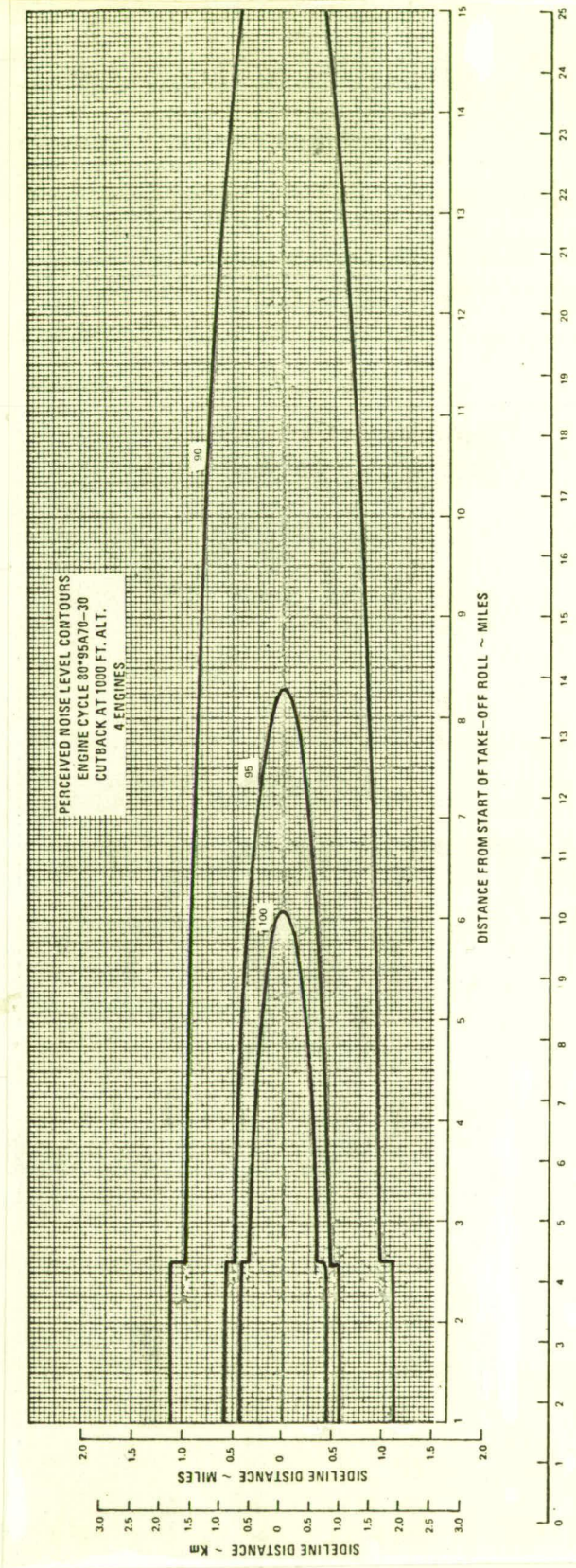


Figure 46

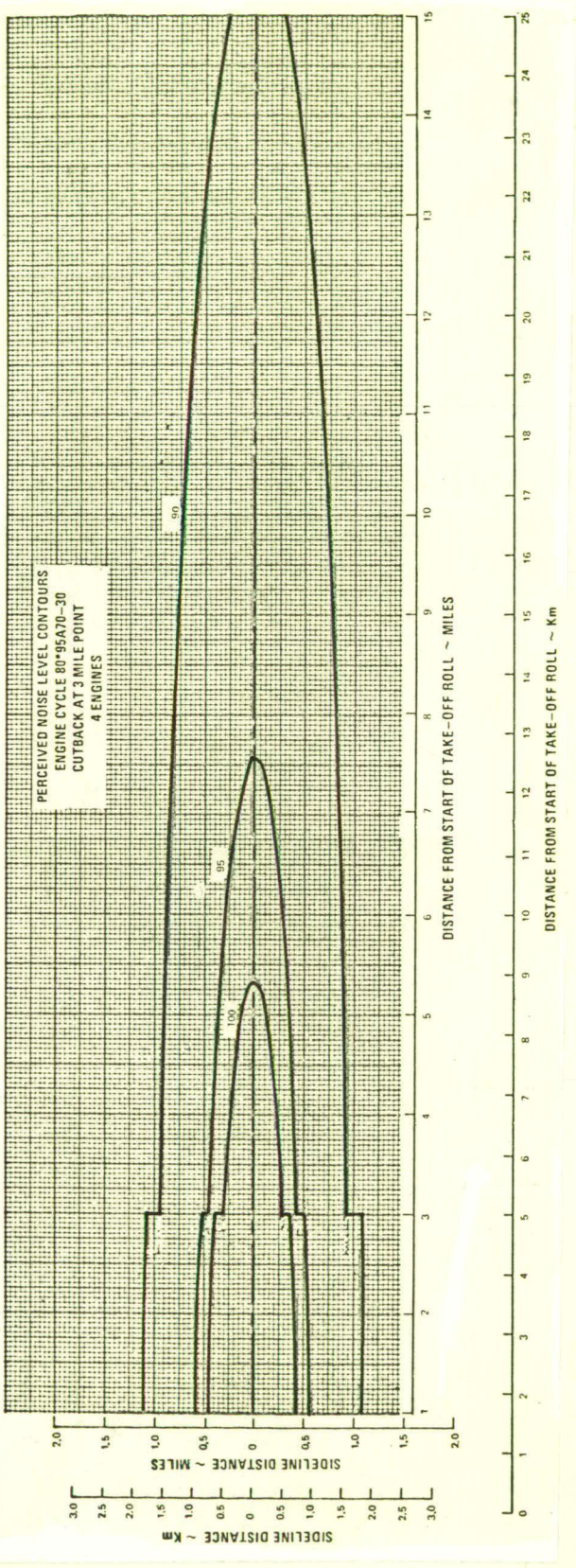


Figure 47

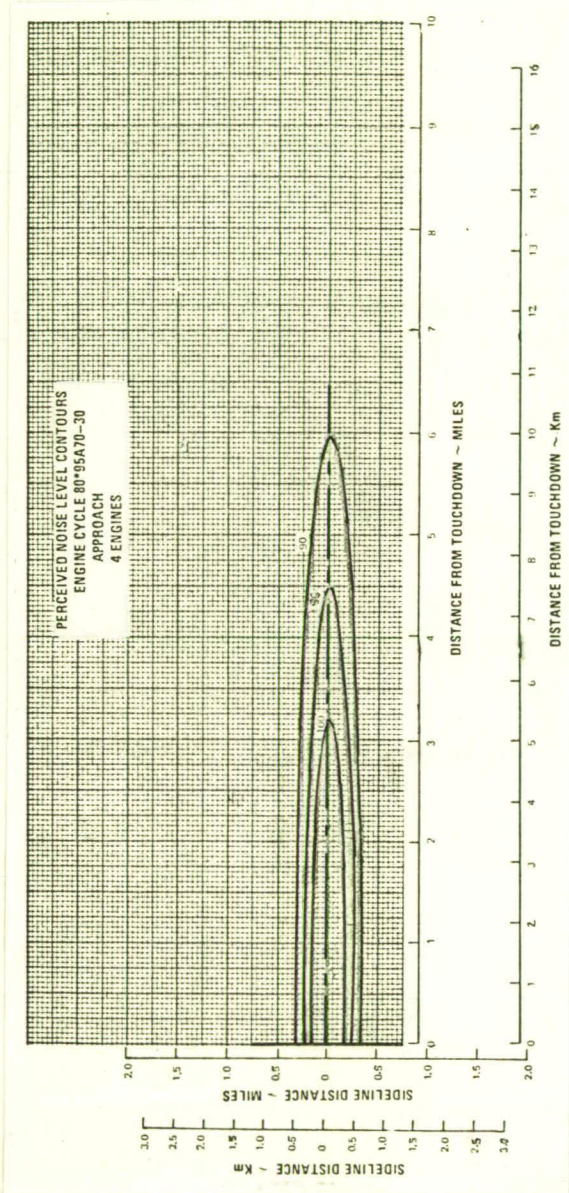


Figure 48

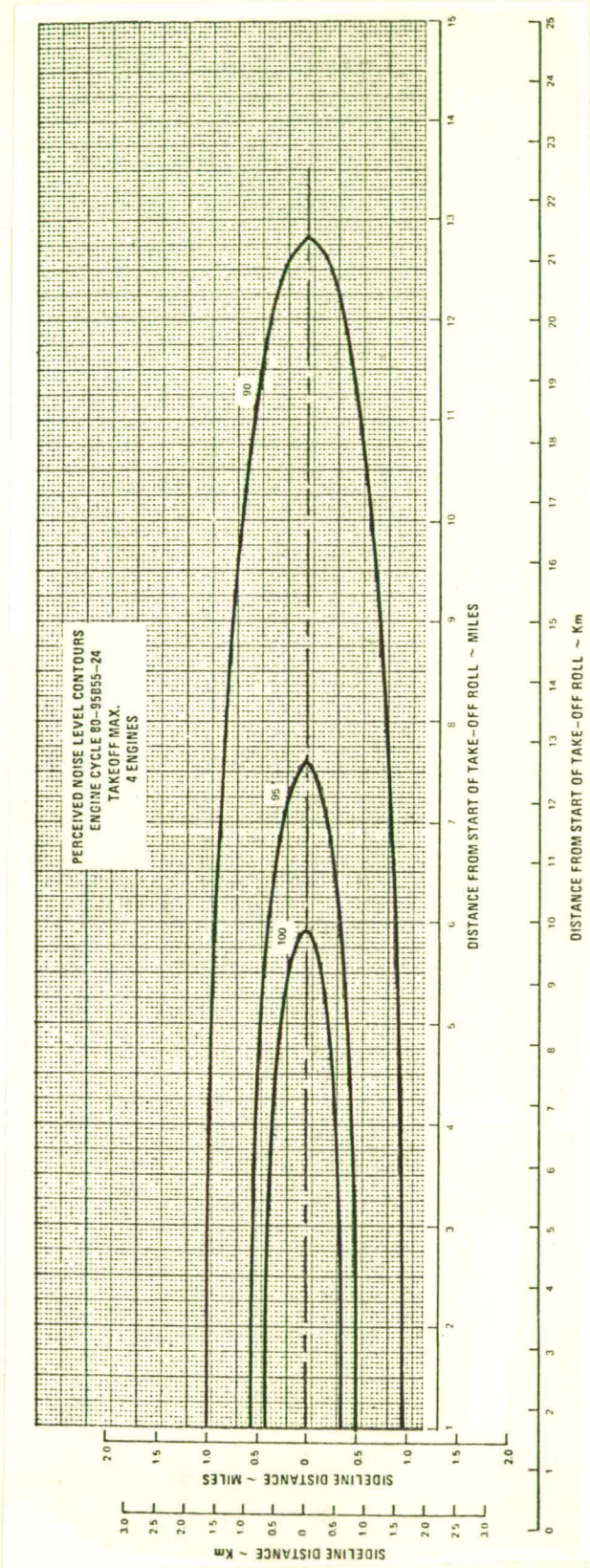


Figure 49

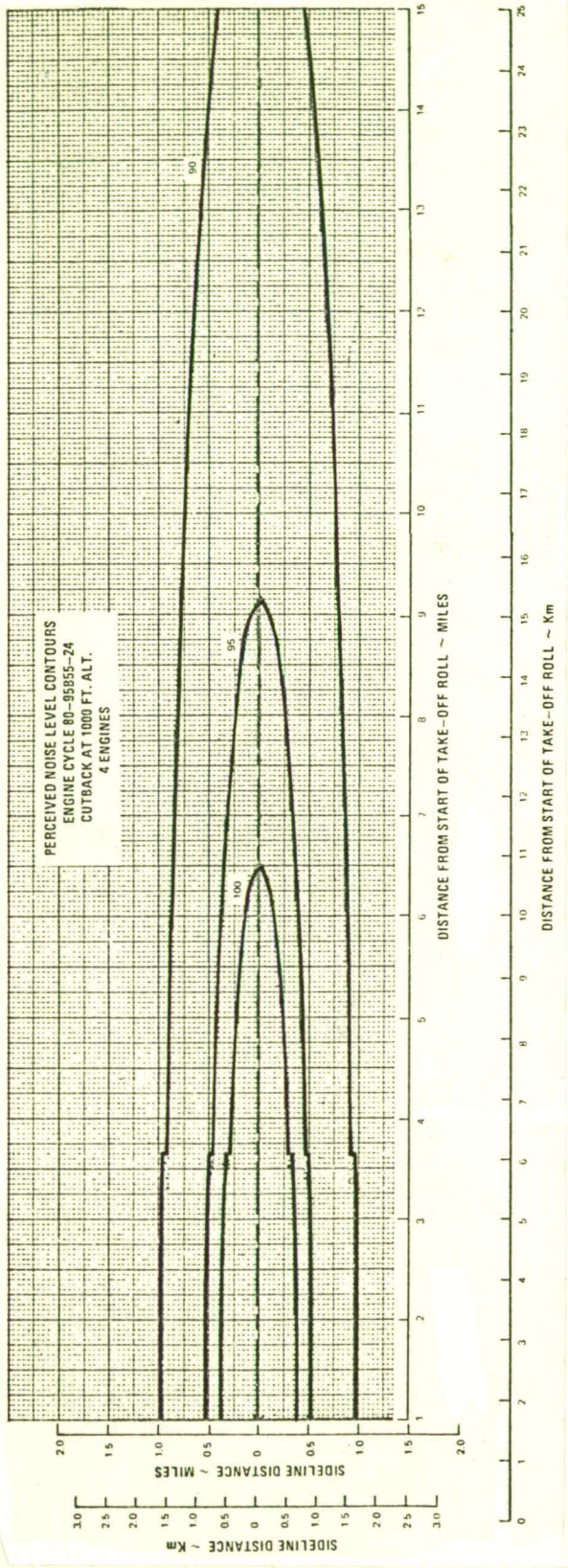


Figure 50

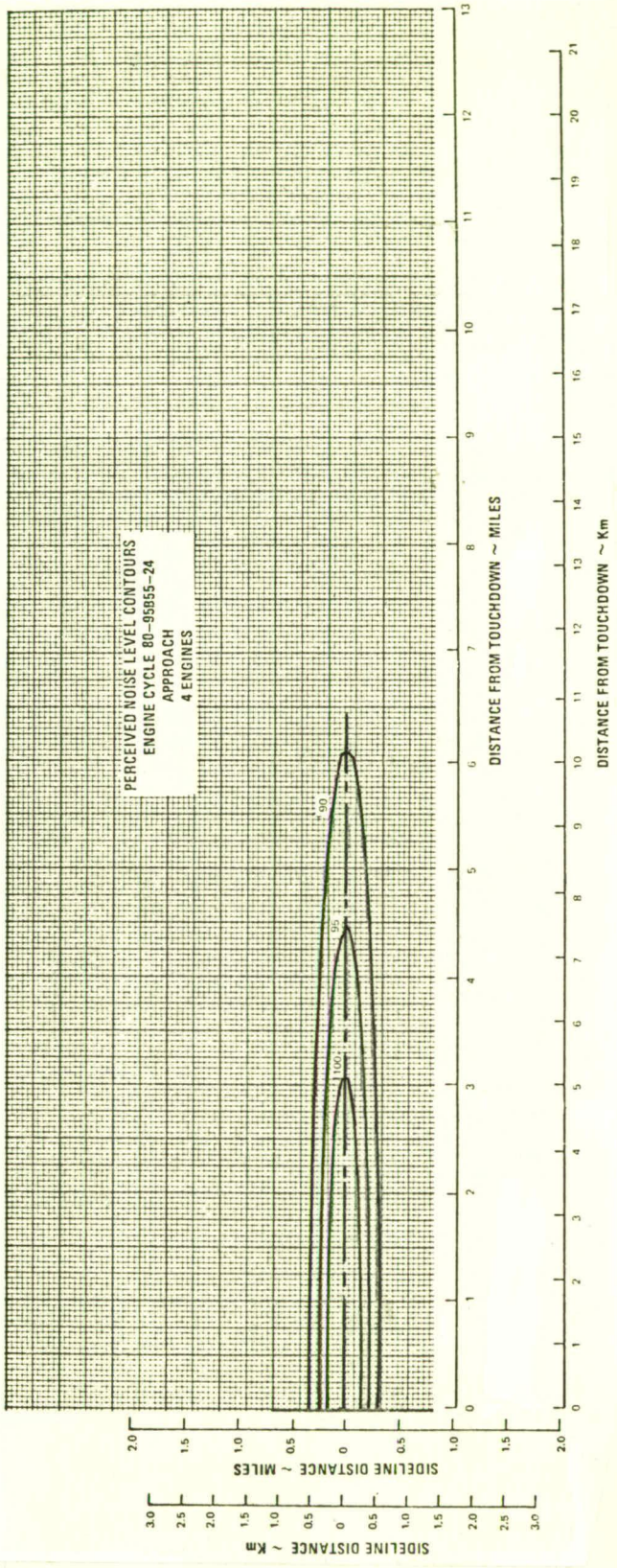


Figure 51

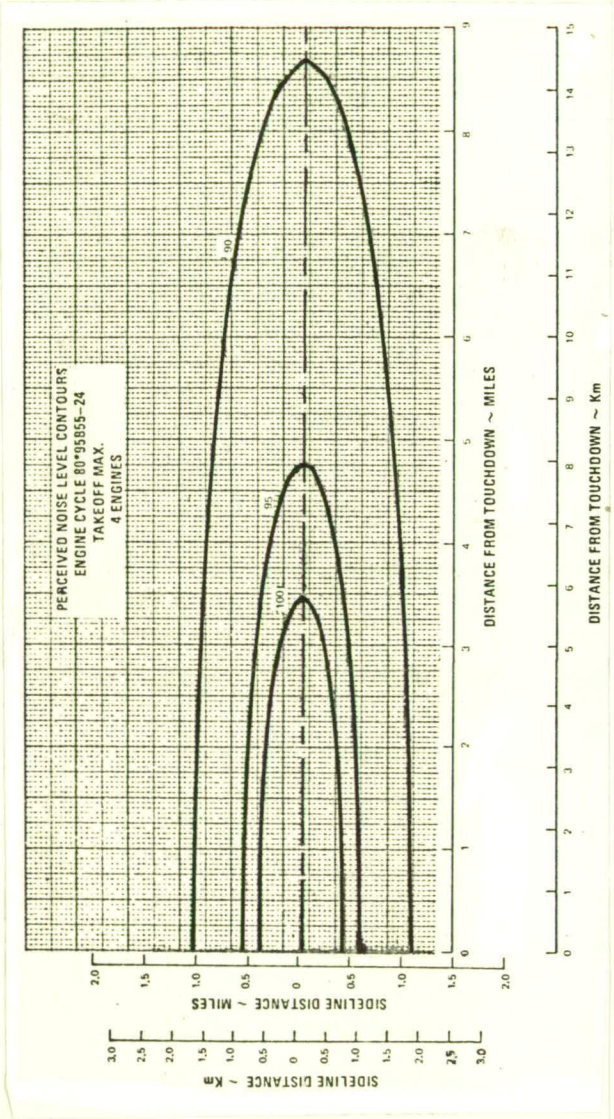


Figure 52

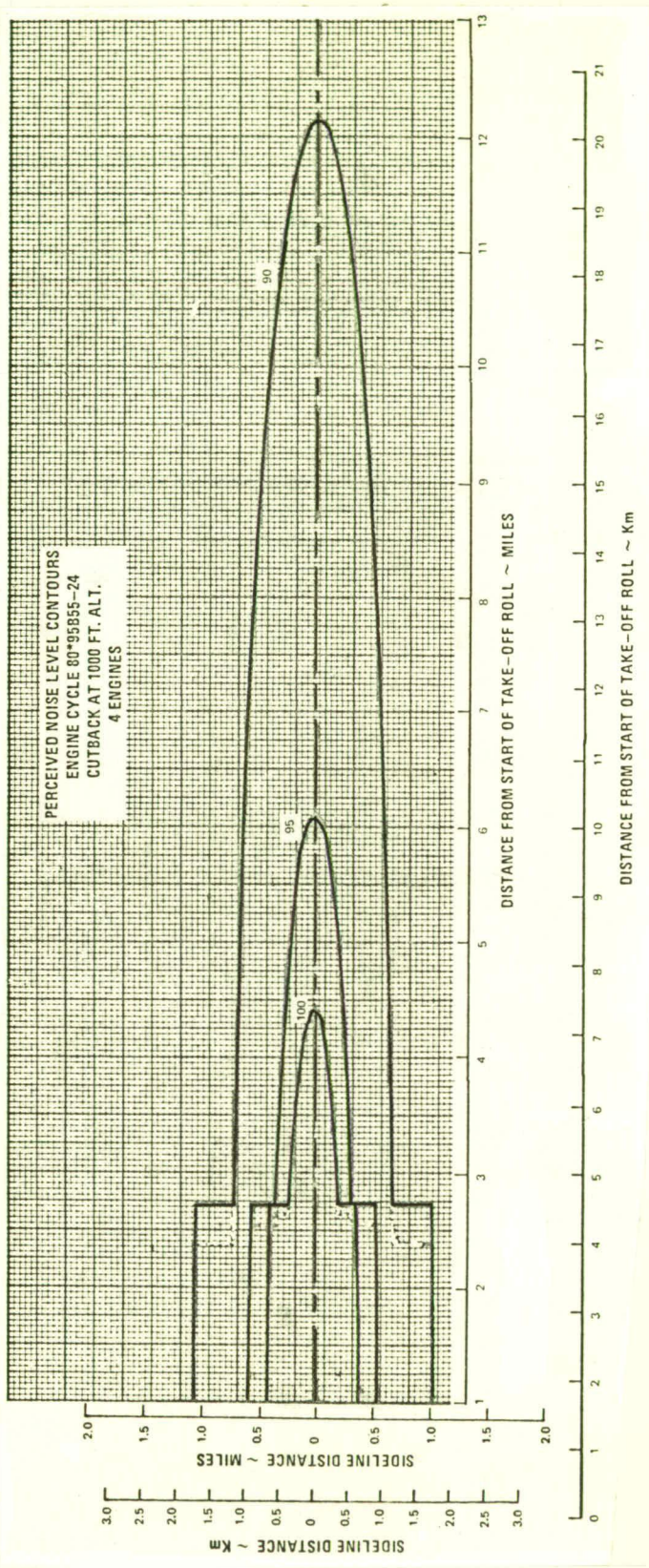


Figure 53

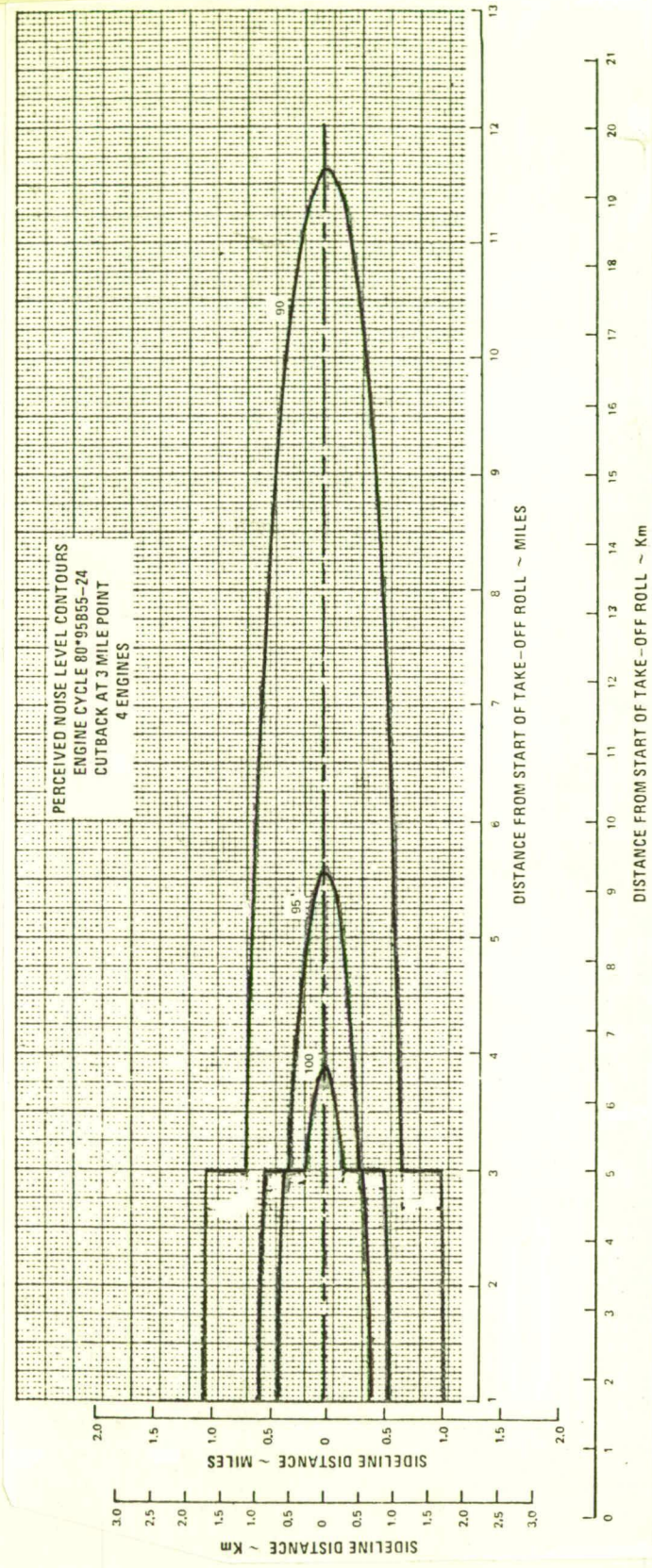


Figure 54

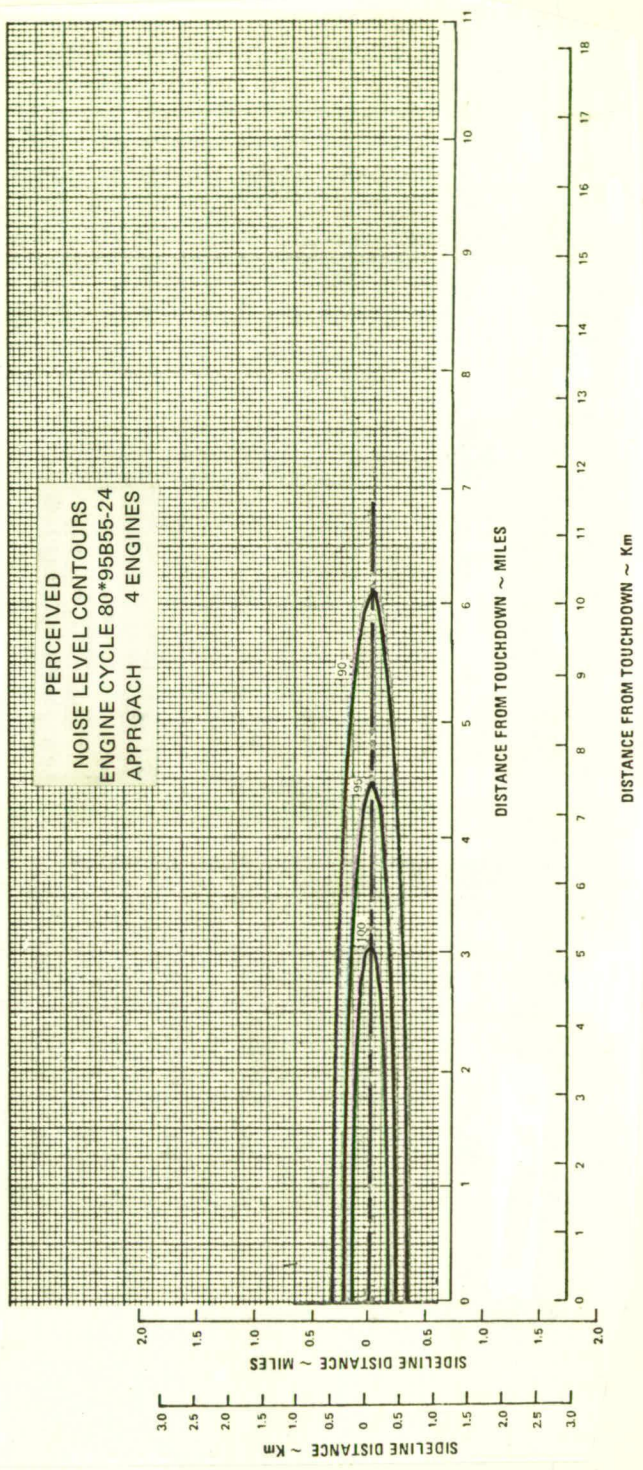


Figure 55

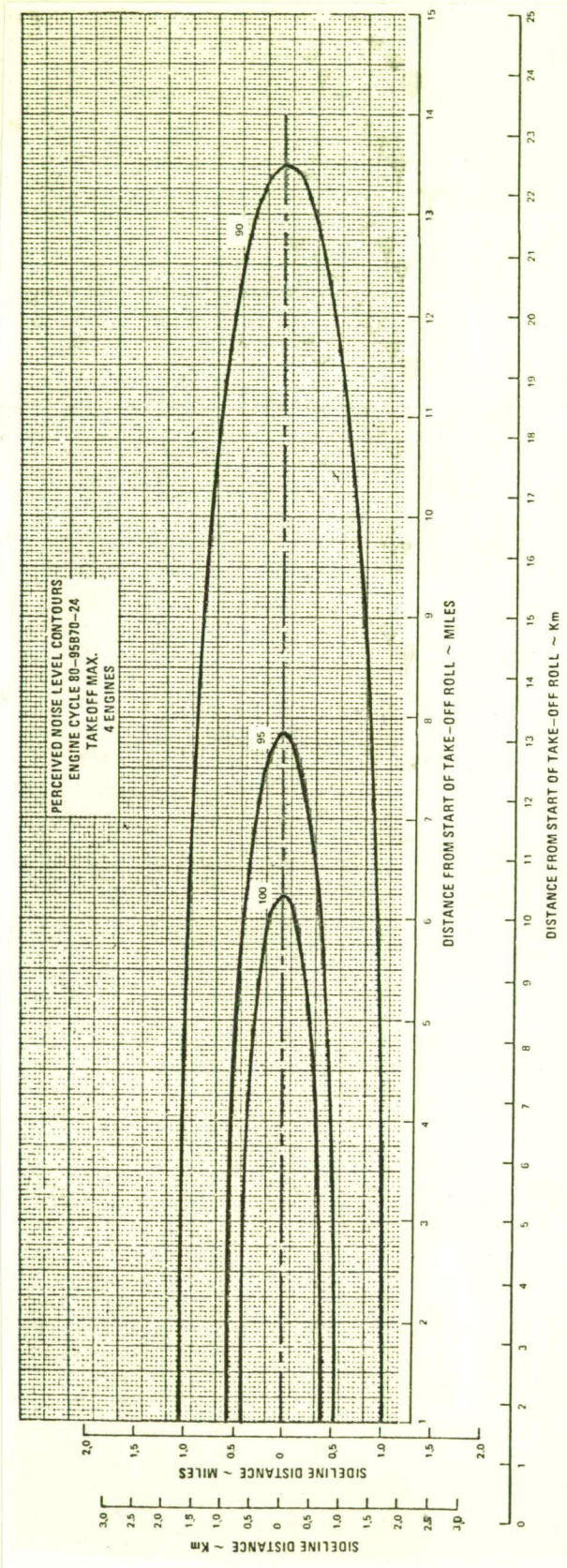


Figure 56

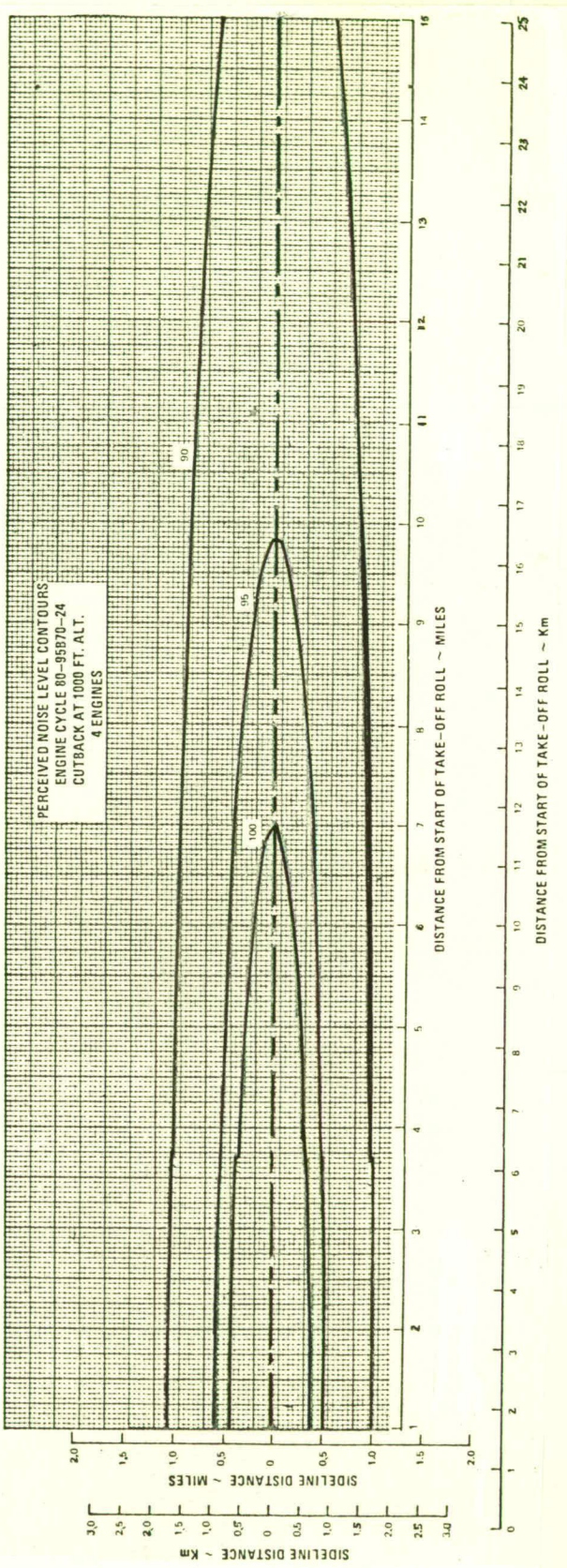


Figure 57

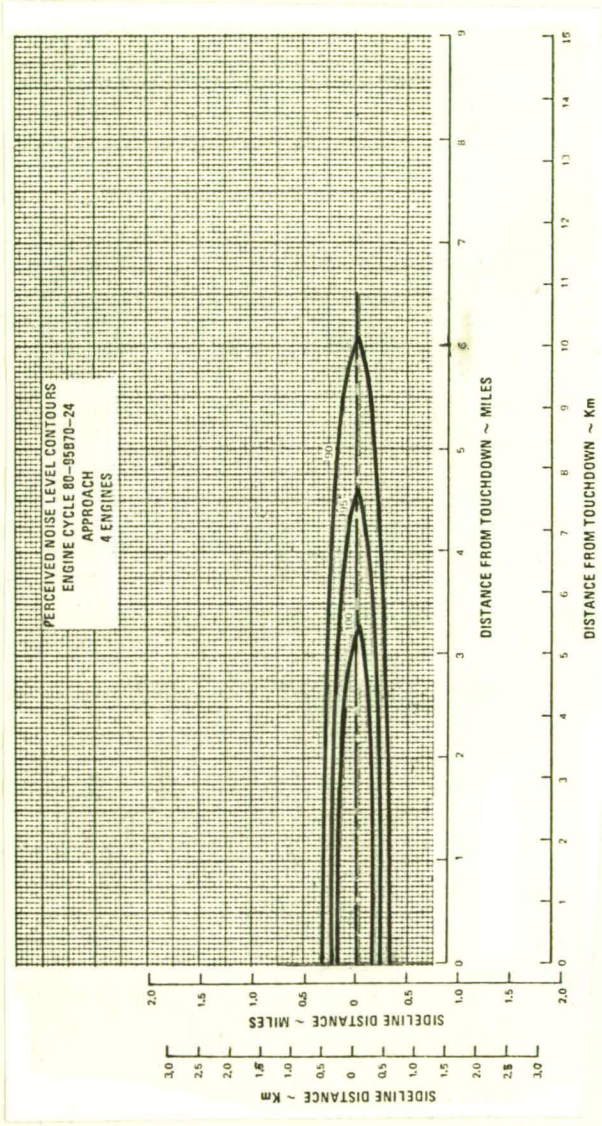


Figure 58

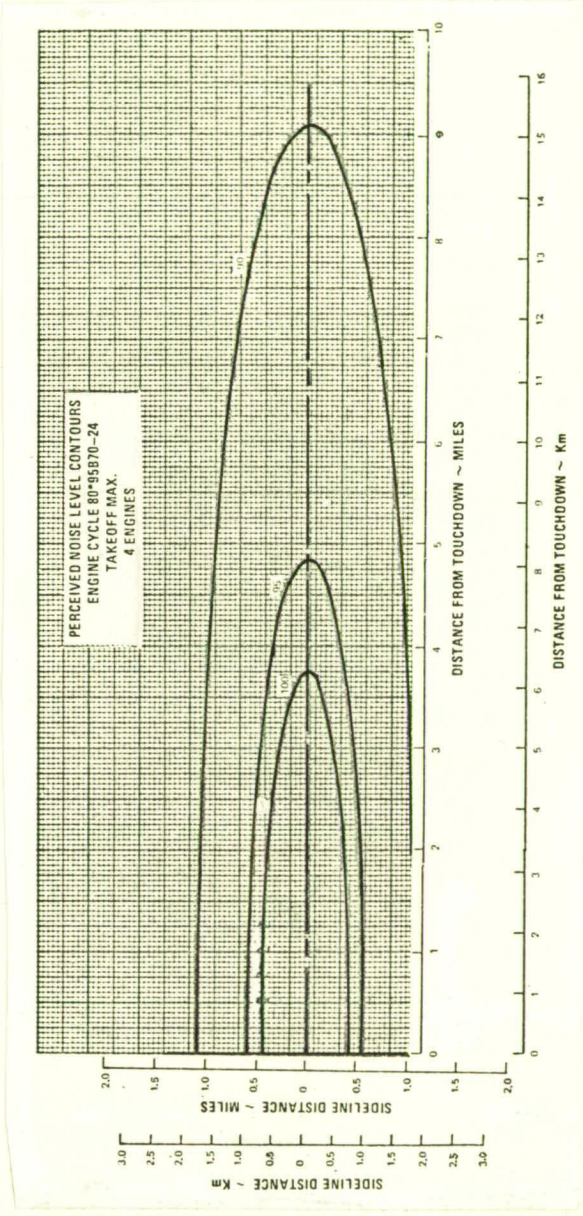


Figure 59

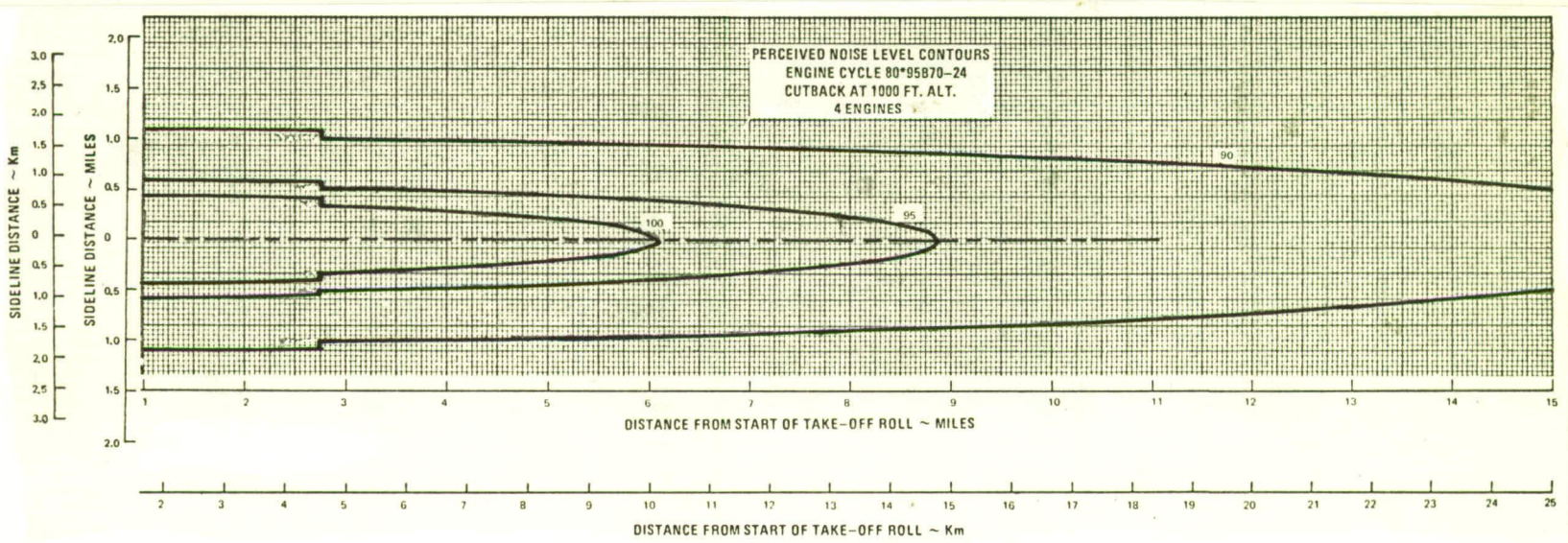


Figure 60

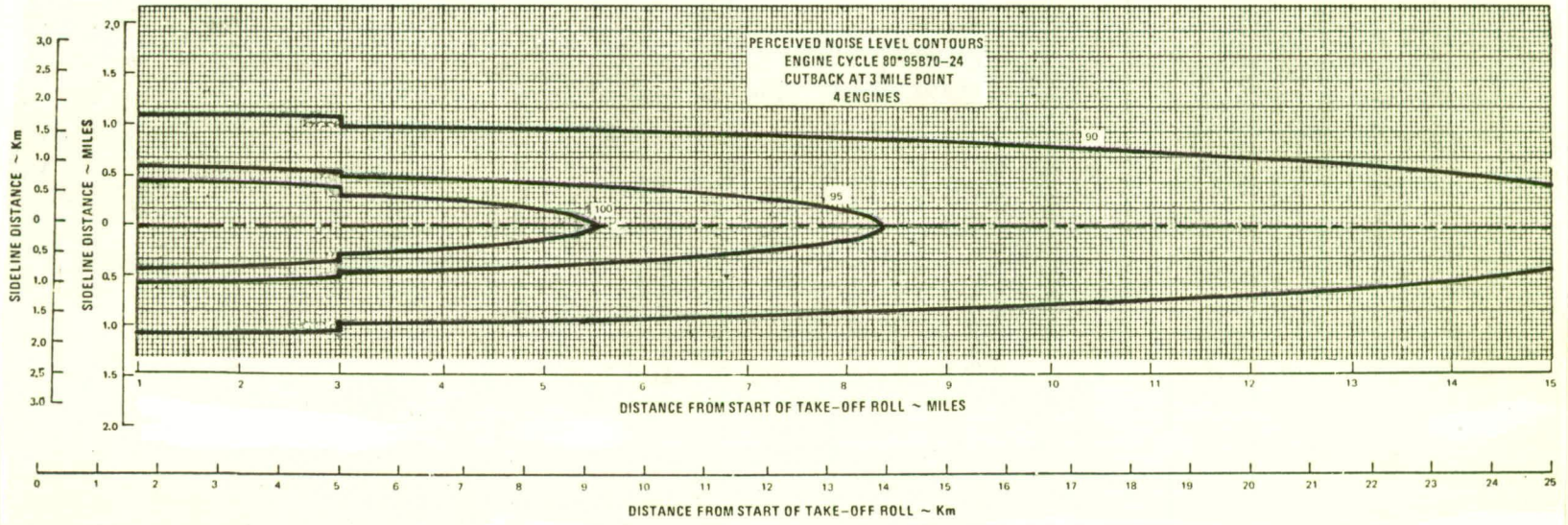


Figure 61

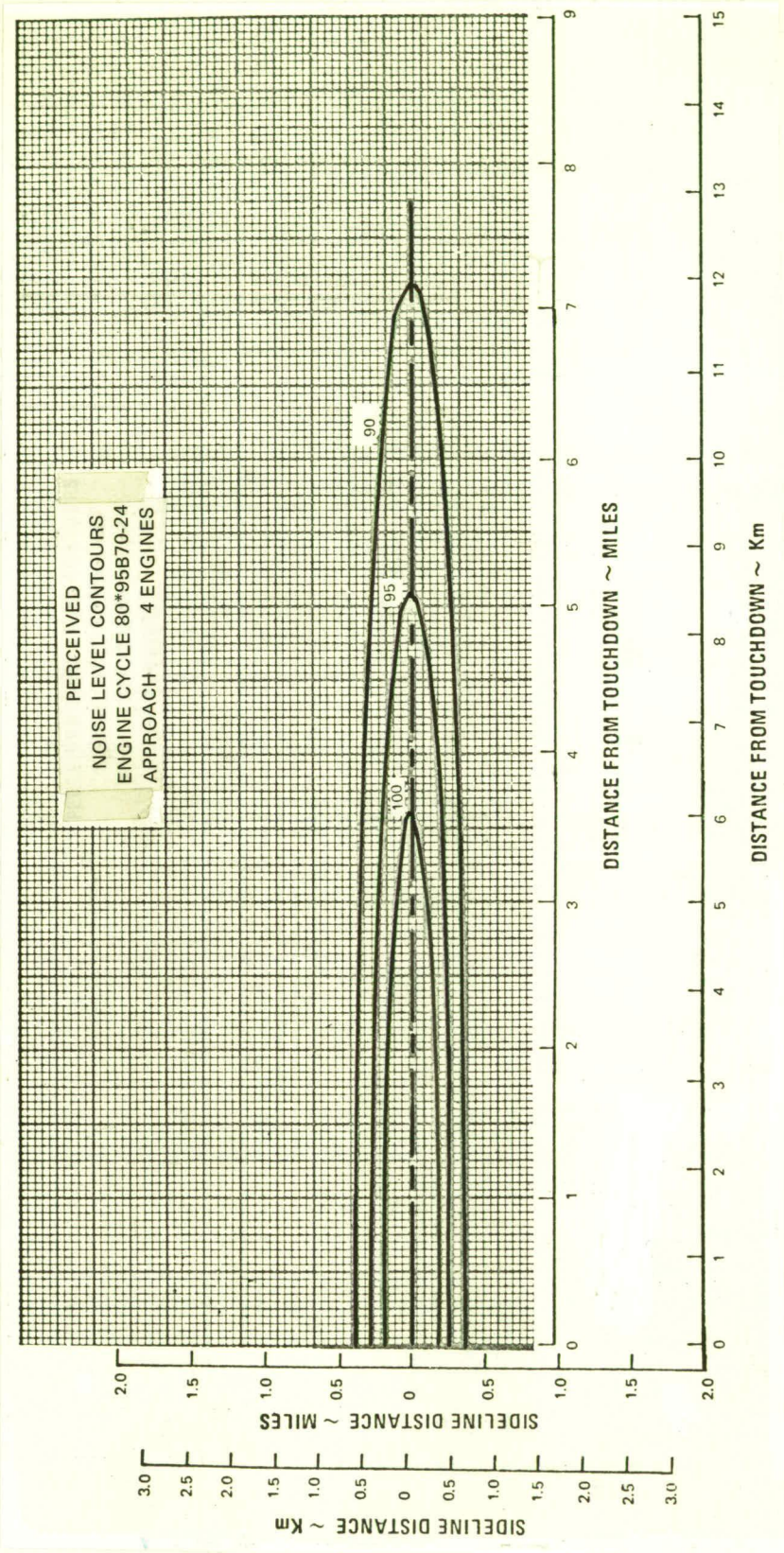

PERCEIVED
NOISE LEVEL CONTOURS
ENGINE CYCLE 80*95B70-24
APPROACH 4 ENGINES
90
95
100
DISTANCE FROM TOUCHDOWN ~ MILES
DISTANCE FROM TOUCHDOWN ~ Km
SIDELINE DISTANCE ~ MILES
SIDELINE DISTANCE ~ Km

Figure 62

APPENDIX C

STATISTICAL ANALYSIS

In general, to investigate all linear and curvilinear effects for N variables at L levels would require L^N tests. For example, if three levels of each variable were desired, it would require three tests for one variable, nine tests for two variables, 27 for three variables, 243 for five variables, 729 for six variables, and so on. Generally, when five or more variables are to be investigated, such a series of experiments becomes prohibitively expensive. Statistical engineering methods such as the multiple regression analysis bridge the gap between the practical aspects of the problem and all possible theoretical considerations. The hypothesized mathematical model and the subsequent sampling scheme are the result of planning and tailoring the experiments to attain the required information. For example, an expert in the particular field might know that certain variables have no effect on the desired results, or that one particular variable has only a linear effect, or that there is no interdependent effect between two of the variables. In such a case it would be unnecessary to use a full-factorial test design, since that design would test for information already known. Refining the basic design eliminated unnecessary test combinations, while obtaining the desired information.

The objective of Task I was to perform engineering calculations on engine thermodynamics and cycles and on exhaust and fan noise generation and propagation in a study directed toward providing the basis for selection of engine cycle and engine component characteristics for a quiet engine design. Calculations were to be performed for not less than 240 discrete cycle combinations to determine 14 noise characteristics, and the weights and dimensions of engines for 20,000 pounds (88,960 newtons) thrust and 25,000 pounds (111,200 newtons) thrust. This makes a total of eighteen characteristics to be determined for each discrete cycle, for a total of more than 4,370 calculations. Since these calculations would be too expensive and too time-consuming if performed individually, the contractor has chosen to use a multiple regression analysis to determine most of the required characteristics.

A. GENERAL METHOD

To illustrate the general method used in the statistical analysis for Task I, let us consider the problem of finding the equation of the curve through the data points shown in Figure 63. The general ploynominal equation of the curve must be $Y = C_0 + C_1X + C_2X^2 + C_3X^3 + \ldots + C_nX^n$. In this case, let us assume that a parabola will produce a sufficiently accurate fit. The equation of the parabola will then be $Y = C_0 + C_1X + C_2X^2$. The constants in this equation are called regression coefficients, and they are found by solving simultaneously the equations

$$\Sigma Y = C_0 N + C_1 \Sigma X + C_2 \Sigma X^2$$

$$\Sigma XY = C_0 \Sigma X + C_1 \Sigma X^2 + C_2 \Sigma X^3$$

$$\Sigma X^2 Y = C_0 \Sigma X^2 + C_1 \Sigma X^3 + C_2 \Sigma X^4$$

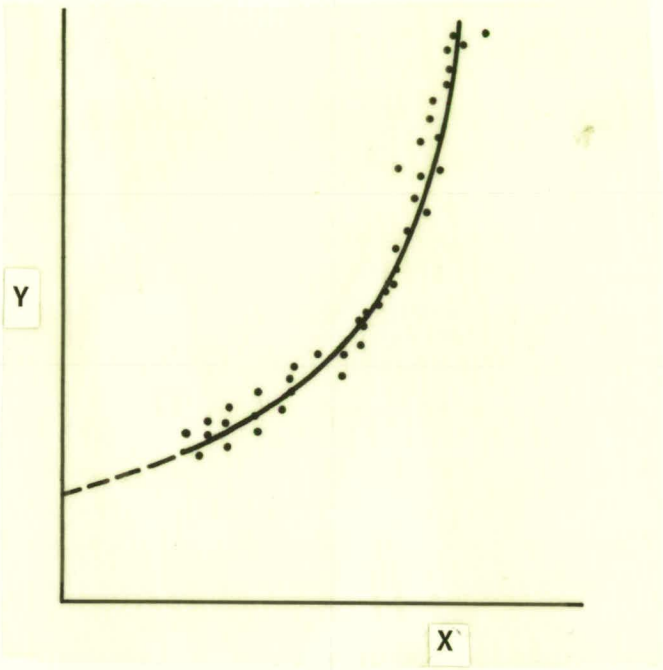


Figure 63. Simplified Example of Multiple Regression Technique

The fit of the equation to the data by this method results in minimizing the square of the difference between the test data and the values predicted by the equation. That is, $\Sigma (Y_{actual} - Y_{equation})^2$ is minimized. Although this method produces the least squares fit, in some cases, a second-order equation may not represent the data with sufficient accuracy. To measure the accuracy with which the equation fits the data, the coefficient of correlation is used.

The coefficient of correlation is the square root of the ratio between the explained variation and the total variation. The total variation is the sum of the squares of the differences between the individual Y and the mean $\bar{Y}$, and the explained variation is the sum of the squares of the differences between the individual Y estimates and the mean $\bar{Y}$. A coefficient of correlation of 0 would indicate no relationship between the data and the curve, while a coefficient of ±1 would indicate a perfect correlation.

In general, the order of importance of each term in the equation is not known. Initially, the single best correlating term is solved. The sequence then proceeds to solve the equation with the preceeding term(s) and the next best correlating

terms. This procedure is carried out until terms no longer contributing to the solution are encountered or until the complete hypothesized equation is solved for the best fit coefficient. If the former prevails and the equation adequately represents the data, the problem is solved. If the equation does not adequately represent the data, this would imply the wrong model equation, and new models could be hypothesized and the procedure repeated. If the latter prevails, that is, the equation has been solved for the best fit coefficient and the adequacy of the fit is acceptable, the problem is solved. The final equation evolved in this manner will quantitatively specify the ability of the equation to predict the function under study.

The preceeding discussion can be extended to include as many variables as desired, and variations in the model equation are possible. The basic requirement is to preplan the designed experiment so that the required test combinations are available to fit the model equation suggested by the existing knowledge. The final adequacy of the equation is the ability of the model to predict points which were not tested. Several additional test points should be made available to compare the observed values with the predicted values from the model equation. The test points which were available for the regression analysis used in Task I are shown in Table XIII for the noise analyses and in Table XIV for the weight and length analyses.

TABLE XIII

SAMPLING PLAN FOR NOISE STUDY

TIT (Take Off)		2300°F (1560°K)									1950°F (1340°K)									1600°F (1145°K)								
TIT (Cruise)		2100°F (1420°K)			1800°F (1254°K)			1600°F (1145°K)			2100°F (1420°K)			1800°F (1254°K)			1600°F (1145°K)			2100°F (1420°K)			1800°F (1254°K)			1600°F (1145°K)		
BPR		8	5	3	8	5	3	8	5	3	8	5	3	8	5	3	8	5	3	8	5	3	8	5	3	8	5	3
	1.3	X		X				X		X										X		X				X		X
15	1.55														X													
	1.7	X		X				X		X										X		X				X		X
	1.3														X													
24.5	1.55					X						X		X	X	X		X						X				
	1.7														X													
	1.3	X		X				X		X										X		X				X		X
30	1.55														X													
	1.7	X		X				X		X										X		X				X		X

OPR
FPR

TABLE XIV

SAMPLING PLAN FOR LENGTH AND WEIGHT STUDY

TIT (Take Off)		2300°F (1560°K)									1950°F (1340°K)									1600°F (1145°K)								
TIT (Cruise)		2100°F (1420°K)			1800°F (1254°K)			1600°F (1145°K)			2100°F (1420°K)			1800°F (1254°K)			1600°F (1145°K)			2100°F (1420°K)			1800°F (1254°K)			1600°F (1145°K)		
BPR		8	5	3	8	5	3	8	5	3	8	5	3	8	5	3	8	5	3	8	5	3	8	5	3	8	5	3
	1.3										X		X				X		X									
15	1.55		X						X						X						X						X	
	1.7										X		X				X		X									
	1.3														X													
24.5	1.55					X						X		X	X	X												
	1.7														X													
	1.3										X		X				X		X									
30	1.55		X						X						X						X						X	
	1.7										X		X				X		X									

OPR
FPR

B. KEY ASSUMPTIONS

The statistical program plan for response-surface development was designed to accurately predict the 4374 requested points while staying within the time and budgetary limitations of the program. These limitations made it mandatory to design a sampling scheme for response surface development using an absolute minimum of test points.

The statistical methodology used in Phase I of this program was based on the assumption that there exists a relatively smooth response surface for each of the required operating levels which can be mathematically described with the five engine cycle variables and a minimum of test points. By using a small, statistically designed sample of test points within each response surface, a regression equation can be developed that will adequately describe the entire response surface of interest. Using this regression equation, the 242 required points for each response surface can then be generated.

The basic consideration of this program was to develop the best sampling scheme possible with the allotted number of test points.

For the estimates of engine weight, it was initially assumed that take-off turbine inlet temperature could be eliminated as a variable and assumed to be constant at 1950 degrees Fahrenheit. By using only the extremes of the remaining four parameters, the total number of cycle combinations was reduced to 16, as shown in Table XV. These 16 combinations reveal all the linear and gross interacting effects of each of the variables on engine weight. Curvilinear effects were inferred by sampling intermediate points. In the case of the weight analysis, a sample set of intermediate points was taken using the JT9D cycle as a basis. Subsequent points were derived by changing each parameter up or down by one level. The nine points so obtained are given in Table XVI. By using the 25 points from Table XV and XVI, the contractor derived the weights of engines using 81 combinations of cycle parameters.

After a more thorough examination of the effect of take-off turbine inlet temperature, it was determined that this parameter does have a significant effect on engine weight because of its influence on burner length. It was also determined that the only other parameters which would have this effect are cycle pressure ratio and cruise turbine inlet temperature. In other words, engine weight is independent of bypass ratio and fan pressure ratio. By taking the extremes of the remaining three variables, their linear effects on weight were determined from only eight additional cycles. These cycles are listed in Table XVII as cases 26 through 33. To obtain curvilinear effects, two additional cycles (cases 34 and 35 in Table XVII) were derived by the same method used to derive the cycles in Table XVI. Actually, sufficient intermediate data was available from the

cycles of Table XVI so that cycle 35 was dropped. When the regression analysis had been performed, an arbitrary cycle (case 36) was used to check the results of the analysis, and was found to be in good agreement. Table XIV shows the design of the experiment in matrix form.

TABLE XV
REQUIRED POINTS FOR LINEAR EFFECTS ON
LENGTH AND WEIGHT

Case Number	Bypass Ratio	Fan Pressure Ratio	Cycle Pressure Ratio	Turbine Inlet Temperature Cruise (°F) (°K)	Take-Off (°F) (°K)
1	3	1.3	15	1600 1144	1950 1340
2	3	1.3	15	2100 1422	1950 1340
3	3	1.3	30	1600 1144	1950 1340
4	3	1.3	30	2100 1422	1950 1340
5	3	1.7	15	1600 1144	1950 1340
6	3	1.7	15	2100 1422	1950 1340
7	3	1.7	30	1600 1144	1950 1340
8	3	1.7	30	2100 1422	1950 1340
9	8	1.3	15	1600 1144	1950 1340
10	8	1.3	15	2100 1422	1950 1340
11	8	1.3	30	1600 1144	1950 1340
12	8	1.3	30	2100 1422	1950 1340
13	8	1.7	15	1600 1144	1950 1340
14	8	1.7	15	2100 1422	1950 1340
15	8	1.7	30	1600 1144	1950 1340
16	8	1.7	30	2100 1422	1950 1340

TABLE XVI
REQUIRED POINTS FOR CURVILINEAR EFFECTS ON
LENGTH AND WEIGHT

17	5	1.55	24.5	1800 1255	1950 (JT9D Cycle)
18	5	1.55	24.5	1600 1144	1950 1340
19	5	1.55	24.5	2100 1422	1950 1340
20	5	1.55	15	1800 1255	1950 1340
21	5	1.55	30	1800 1255	1950 1340
22	5	1.3	24.5	1800 1255	1950 1340
23	5	1.7	24.5	1800 1255	1950 1340
24	3	1.55	24.5	1800 1255	1950 1340
25	8	1.55	24.5	1800 1255	1950 1340

TABLE XVII

REVISED POINTS FOR LINEAR EFFECTS ON WEIGHT AND LENGTH

Case Number	Bypass Ratio	Fan Pressure Ratio	Cycle Pressure Ratio	Cruise (°F)	Cruise (°K)	Take-Off (°F)	Take-Off (°K)	
26	5	1.55	15	1600	1144	1600	1144	
27	5	1.55	15	1600	1144	2300	1534	
28	5	1.55	15	2100	1422	1600	1144	
29	5	1.55	15	2100	1422	2300	1534	
30	5	1.55	30	1600	1144	1600	1144	
31	5	1.55	30	1600	1144	2300	1534	
32	5	1.55	30	2100	1422	1600	1144	
33	5	1.55	30	2100	1422	2300	1534	
34	5	1.55	24.5	1800	1255	1600	1144	(Deleted)
35	5	1.55	24.5	1800	1255	2300	1534	
36	6	1.4	30	1850	1283	2050	1394	(Check Cycle)

For the noise analysis, all five variables were assumed to have possible interaction effects. Therefore, a two-level full-factorial sampling design was chosen. This design ensured that linear and curvilinear effects would be considered. To obtain the linear and interacting effects, 32 cycles were required. Again, using the method by which Table XVI was constructed, the curvilinear effects were obtained by using the JT9D cycle as the center point and perturbing each of the cycle variables up or down individually. This procedure adds 11 cases for a total of 43 cases, which are listed in Table XVIII. The design of the experiment is shown in Table XIII in matrix form.

In all cases, there remained a number of additional available points that could be used to predict with confidence the inherent error of each response-surface equation.

C. LIMITATION OF RESULTS

An equation for each of the 14 noise-response surfaces was developed with the sample test points through the use of multiple curvilinear regression analysis techniques as previously discussed. If an adequate mathematical model could be developed using the original sample test points, the remaining 200 points for

TABLE XVIII

DATA POINTS FOR NOISE STUDIES

Case Number	Bypass Ratio	Fan Pressure Ratio	Cycle Pressure Ratio	Turbine Inlet Temperature Cruise (°F) (°K)	Turbine Inlet Temperature Take-Off (°F) (°K)
1	3	1.3	15	1600 1144	1600 1144
2	3	1.3	15	1600 1144	2300 1534
3	3	1.3	15	2100 1422	1600 1144
4	3	1.3	15	2100 1422	2300 1534
5	3	1.3	30	1600 1144	1600 1144
6	3	1.3	30	1600 1144	2300 1534
7	3	1.3	30	2100 1422	1600 1144
8	3	1.3	30	2100 1422	2300 1534
9	3	1.7	15	1600 1144	1600 1144
10	3	1.7	15	1600 1144	2300 1534
11	3	1.7	15	2100 1422	1600 1144
12	3	1.7	15	2100 1422	2300 1534
13	3	1.7	30	1600 1144	1600 1144
14	3	1.7	30	1600 1144	2300 1534
15	3	1.7	30	2100 1422	1600 1144
16	3	1.7	30	2100 1422	2300 1534
17	8	1.3	15	1600 1144	1600 1144
18	8	1.3	15	1600 1144	2300 1534
19	8	1.3	15	2100 1422	1600 1144
20	8	1.3	15	2100 1422	2300 1534
21	8	1.3	30	1600 1144	1600 1144
22	8	1.3	30	1600 1144	2300 1534
23	8	1.3	30	2100 1422	1600 1144
24	8	1.3	30	2100 1422	2300 1534
25	8	1.7	15	1600 1144	1600 1144
26	8	1.7	15	1600 1144	1600 1534
27	8	1.7	15	2100 1422	1600 1144
28	8	1.7	15	2100 1422	2300 1537
29	8	1.7	30	1600 1144	1600 1144
30	8	1.7	30	1600 1144	2300 1534
31	8	1.7	30	2100 1422	1600 1144
32	8	1.7	30	2100 1422	2300 1534

TABLE XVIII (Cont'd)

Case Number	Bypass Ratio	Fan Pressure Ratio	Cycle Pressure Ratio	Turbine Inlet Temperature Cruise (°F) (°K)	Take-Off (°F) (°K)
33	5	1.55	24.5	1800 1255	1950 1340
34	5	1.55	24.5	1800 1255	1600 1144
35	5	1.55	24.5	1800 1255	2300 1534
36	5	1.55	24.5	1600 1144	1950 1340
37	5	1.55	23.5	2100 1422	1950 1340
38	5	1.55	15.0	1800 1255	1950 1340
39	5	1.55	30.0	1800 1255	1950 1340
40	5	1.3	24.5	1800 1255	1950 1340
41	5	1.7	24.5	1800 1255	1950 1340
42	3	1.55	24.5	1800 1255	1950 1340
43	8	1.55	24.5	1800 1255	1950 1340

each of the 14 noise-response surfaces could then be generated. In most cases, however, the unanticipated peculiarities of the response surface were such that a number of additional available test points had to be utilized in order to adequately define the response surface. These additional points were to be used to calculate the error of each of the mathematical models. Because of the necessity to use these additional points, confident error predictions of each response surface could not be realistically attained. However, 3 check points were made available for each response surface in order to check the accuracy of each equation. Table XIX compares the actual check point values for each noise-response surface with the values that were generated by the mathematical model. Also included, is the 95 percent confidence limits of each regression equation which demonstrates how well each regression equation fits the sampled data used to develop each equation.

The weight per pound of airflow regression equation and the length regression equation for the 20,000-pound (88,960 newtons) thrust engine were developed in a manner similar to the noise regression equations. However, because of program limitations, only one check point for each response surface could be made available. A comparison of these check points with the values generated by their respective math model is shown in Table XX.

Utilizing JT9D configuration scaling factors, the weight per pound of airflow and length of each 25,000-pound (111,200 newtons) thrust engine was generated from its respective 20,000-pound (77,960 newtons) thrust engine having the identical engine cycle parameters.

TABLE XIX
CHECK POINTS FOR NOISE RESPONSE SURFACES

TAKE OFF		95% Confidence Limit (± PNDB)	Observed (PNDB)	Predicted (PNDB)	Δ
Fn=20,000 lb (88,960N)	Total Noise	2.4679	119	118	1
			108	112	4
			112	114	2
	Jet Noise	2.9093	92	94	2
			116	116	0
			109	108	1
Fn=25,000 lb (111,200N)	Total Noise	2.5082	102	103	1
			113	113	0
			101	102	1
	Jet Noise	3.0286	97	98	1
			109	110	1
			84	82	2
TAKE OFF C/B AT 3 MILES					
Fn=25,000 lb (111,200N)	Total Noise	2.3720	99	96	3
			100	97	3
			100	98	2
	Jet Noise	2.106	100	96	4
			93	93	0
			77	79	2
TAKE OFF C/B AT 1000 FT.					
Fn=20,000 lb. (88,960N)	Total Noise	2.2257	109	107	2
			103	101	2
			105	106	1
	Jet Noise	3.2732	109	110	1
			91	90	1
			88	90	2
Fn=25,000 lb (111,200N)	Total Noise	2.0227	102	101	1
			104	102	2
			101	98	3
	Jet Noise	2.9148	86	86	0
			102	102	0
			77	79	2

TABLE XIX (Cont'd)

CHECK POINTS FOR NOISE RESPONSE SURFACES

APPROACH		95% Confidence Limit (±PNDB)	Observed (PNDB)	Predicted (PNDB)	Δ
Fn=20,000 lb (88,960N)	Total Noise	0.7971	106	107	1
			106	103	3
			101	101	0
	Jet Noise	1.3480	88	90	2
			87	86	1
			97	97	0
Fn=25,000 lb (111,200N)	Total Noise	0.7000	99	100	1
			103	102	1
			106	107	1
	Jet Noise	2.0633	87	87	0
			89	90	1
			91	93	2

TABLE XX

CHECK POINTS FOR WEIGHT AND LENGTH RESPONSE SURFACES

	95% Confidence Limits	Observed	Predicted	Δ
WEIGHT PER POUND OF AIRFLOW	0.3406 wt/lb airflow	4.29 wt/lb airflow	4.42 wt/lb airflow	0.13 wt/lb airflow
LENGTH	±15.8 cm.	273.8 cm	262.8 cm	11.0 cm

PRATT & WHITNEY AIRCRAFT

TABLE XXI

TABLE XXI
QUIET ENGINE PERFORMANCE STUDY

DATA FOR TASK I

ALL DATA FOR 20,000 LB THRUST ENGINES UNLESS OTHERWISE SPECIFIED

PWA-3516

DESIGNATION	0 SCALED 27,500	1 10-95D70-30	2 10-95C30-30	3 10-95D70-15	4 10-95C30-15	5 10-95A70-30	6 10-95A30-30	7 10-95A70-15	8 10-95A30-15	9 60-95D70-30	10 60-95C30-30	11 60-95D70-15	12 60-95C30-15	13 60-95A70-30	14 60-95A30-30	15 60-95A70-15	16 60-95A30-15	17 80-95B35-24	18 80-95C35-24	19 80-95A35-24	20 80-95B55-24	21 80-95B70-24	22 80-95B30-24	23 80-95B70-24	24 80-95B35-15	25 80-95B55-30	26 10-30B55-30	27 10-30B55-15	28 10-60B55-15	29 10-60B55-30	30 80-30B55-24	31 60-30B55-30	32 60-60B55-30	33 60-30B55-15	34 60-60B55-15	35 85-00D40-30	10 60-95C30-30	15 60-95A70-15	20 60-95B55-24	DESIGNATION
N_1 CRUISE	4739	4720	3053	4740	3112	5385	3544	5496	3702	5710	3464	5410	3635	6119	4212	6480	4309	4705	4148	5205	4911	5312	4716	3676	4874	4580	4920	5086	3545	3410	5476	5330	3850	5730	4208	3730	3100	5820	4400	N_1 CRUISE
N_1 T.O.	4646	3500	2300	3650	2720	4670	3110	4860	3260	5500	3480	5100	3740	6560	5660	7060	4640	3750	3750	5100	5142	4320	4340	3540	4710	4540	4860	5040	2630	2500	6300	5320	2990	7360	3710	3100	3120	6330	4610	N_1 T.O.
N_1 MAX (3)	5300	5260	3400	5280	3470	6000	3950	6130	4430	6360	3860	6030	4050	6900	6000	7480	4900	4800	4630	5800	5450	5320	5250	4100	5300	5110	5420	5660	3930	3800	6700	5970	4300	8020	4700	4160	3960	6670	4900	N_1 MAX 3
N_2 T.O.	10800	10750	11332	8200	8640	9473	8780	7248	5835	11160	7405	9370	10093	10746	10840	8503	8120	9818	11489	9642	11191	10546	10746	10285	8925	10900	12134	9391	6545	8437	12456	13840	9515	10909	7769	11340	12000	7430	9380	N_2 T.O.
N_2 MAX (4)	11550	11500	12100	8780	9250	10650	9400	7760	7310	11950	7478	10000	10800	11500	11600	9100	8700	10500	12300	10320	11970	11300	11150	10000	9360	11650	13000	10050	7000	9030	13320	14800	10220	11700	8310	12100	12840	7350	10600	N_2 MAX 4
N_1 CRIT SPEED	OK	(7)	(6)	(7)	(7)	OK	OK	OK	OK	OK	(2)	OK	(7)	OK	(2)	OK	OK	(7)	(6)	OK	OK	OK	OK	OK	OK	(7)	(7)	OK	OK	(7)	OK	(7)	(7)	OK	(6)	(2)	OK	OK	N_1 CRIT SPEED
N_2 CRIT SPEED	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	(2)	OK	OK	OK	(2)	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	(9)	OK	OK	OK	OK	(9)	(7)	(7)	OK	OK	(2)	OK	OK	N_2 CRIT SPEED
FAN																																								FAN
DIA TIP	64.0	75.2	81.005	73.5	79.375	64.524	69.618	63.027	66.854	61.2	71.4	64.4	67.945	56.883	58.581	53.721	56.259	70.4	73.132	58.24	61.76	65.536	64.320	67.2	62.678	66.25	61.677	59.57	85.47	88.704	55.488	56.646	78.655	54.20	72.002	71.50	79.80	6000	6910	DIA TIP
DIA ROOT																																								DIA ROOT
b_X	4.2	4.87	5.213	4.75	5.100	4.024	4.342	4.018	4.282	3.94	4.595	4.04	4.355	3.548	3.654	3.442	3.591	4.510	4.681	3.741	3.957	4.189	4.121	4.0	4.017	4.235	3.943	3.818	5.478	5.670	3.533	3.485	5.028	3.287	4.615	4.500	5.140	3.84	4.44	b_X
b_r TIP																																								b_r TIP
NO. BLADES																																								NO. BLADES
NO. VANES																																								NO. VANES
LPC																																								LPC
NO. STAGES	3	3	4	0	1	3	4	0	1	3	4	0	1	3	4	0	1	3	3	3	3	2	3	3	0	4	4	0	0	4	3	4	4	0	0	3	4	0	3	NO. STAGES
DIA IN. TIP	34.0	38.50	40.979	—	40.125	37.392	92.312	—	40.606	33.6	36.12	—	37.347	32.964	35.604	—	34.181	37.4	36.19	34.048	32.81	34.406	34.17	36.855	—	35.276	32.841	—	—	47.232	29.478	29.595	41.882	—	—	36.5	40.40	—	36.70	DIA IN. TIP
DIA IN. ROOT																																								DIA IN. ROOT
DIA EXIT TIP	28.2	32.20	32.116	—	38.125	31.236	33.087	—	38.552	28.1	28.308	—	32.635	27.537	27.842	—	32.452	31.34	30.286	28.448	27.553	30.822	28.643	30.87	—	27.268	25.721	—	—	36.992	24.710	23.150	32.802	—	—	30.45	31.60	—	30.70	DIA EXIT TIP
DIA EXIT ROOT																																								DIA EXIT ROOT
L	11.2	10.05	12.818	7.5	7.5	14.752	22.386	7.5	7.5	11.650	11.298	7.5	7.500	13.005	18.837	7.5	7.5	14.674	8.620	13.888	12.873	7.500	11.200	12.737	7.5	14.416	13.421	7.5	7.5	19.302	11.566	11.749	17.116	7.5	7.5	9.53	12.60	8.4	14.40	L
INTERMEDIATE SEC.																																								INTERMEDIATE SEC.
b_r	4.75	4.75	5.50	4.75	4.75	4.75	5.50	4.75	4.75	4.75	5.58	4.75	4.75	4.75	5.50	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	5.50	5.50	5.50	5.50	4.75	4.75	5.50	4.75	5.50	6.50	4.75	4.75	5.50	6.20	5.2	5.20	b_r
NO. STAGES	11	11	12	11	11	11	12	11	11	11	12	11	11	11	12	11	11	11	11	11	12	11	11	12	11	12	12	11	11	12	11	12	12	11	11	12	HPC NO. STAGES			
DIA IN. TIP	25.2	25.3	25.54	33.2	31.5	28.728	32.694	37.548	39.66	24.2	22.532	29.1	26.964	25.326	27.738	32.004	33.516	27.72	23.688	28.224	24.318	25.605	25.326	26.14	30.492	25.621	23.852	28.97	41.58	34.304	21.848	20.308	30.418	24.948	35.028	24.0	25.20	35.70	27.20	DIA IN. TIP
DIA IN. ROOT																																								DIA IN. ROOT
DIA EXIT TIP	19.8	19.9	18.869	26.1	24.75	22.527	24.354	29.502	31.224	19.2	16.632	22.9	21.186	19.899	20.493	25.146	26.334	21.78	18.612	22.176	19.107	20.275	19.899	20.79	23.958	18.929	17.622	22.77	32.67	25.344	17.167	15.447	22.473	19.602	27.522	18.87	18.60	28.10	21.30	DIA EXIT TIP
DIA EXIT ROOT																																								DIA EXIT ROOT
L	25.7	25.900	27.065	33.750	32.138	29.309	34.932	38.308	40.622	24.900	23.856	29.700	27.510	25.839	29.394	32.652	34.194	28.281	24.167	28.795	24.810	26.327	25.839	26.820	31.109	27.150	25.276	29.567	42.422	36.400	22.291	22.169	32.234	25.351	35.737	24.50	26.71	36.57	27.80	L
BURNER																																								BURNER
b_r	16.7	19.600	18.233	31.700	30.000	22.230	23.985	33.800	36.222	14.050	13.500	21.390	19.795	14.573	16.500	23.495	24.605	25.300	15.500	18.500	14.958	16.900	16.500	17.350	22.385	14.800	18.243	29.800	38.800	24.960	19.941	16.612	15.323	28.230	20.150	14.800	15.10	26.30	16.70	L
HPT																																								HPT
DIA IN. TIP	25.2	22.5	24.016	38.700	36.713	28.728	30.936	43.761	46.425	25.800	20.024	29.100	26.964	26.663	24.685	32.004	33.516	26.4	23.688	28.224	25.283	25.805	25.326	26.88	30.976	22.705	24.428	33.465	48.015	32.256	21.848	20.674	30.078	24.948	35.028	24.000	22.80	35.70	28.20	DIA IN. TIP
DIA IN. ROOT	22.6																																							DIA IN. ROOT
DIA EXIT TIP	27.2																																							DIA EXIT TIP
DIA EXIT ROOT	22.4																																							DIA EXIT ROOT
L	5.58	5.58	5.58	2.55	2.55	5.58	5.58	2.55	2.55	5.58	7.02	3.58	5.58	5.58	7.02	5.58	5.58	5.58	3.58	3.58	5.58	5.58	5.58	5.58	5.58	5.58	5.58	2.55	2.55	5.58	5.58	5.58	5.58	5.58	5.58	5.58	7.02	5.58	5.58	L
NO. STAGES	2	2	2	1	1	2	2	1	1	2	3	2	2	2	3	2	2	2	2	2	2	2	2	2	2	2	2	1	1	2	2	2	2	2	2	2	3	2	2	NO. STAGES
LPT																																								LPT
NO. STAGES	4	6	7	3	5	3	3	1	1	3	6	3	5	2	3	1	5	6	2	4	4	3	4	4	3	6	6	3	3	6	4	5	5	3	3	6	6	1	4	NO. STAGES
DIA EXIT TIP	36.0	41.2	36.691	46.500	39.50	37.05	35.67	47.084	47.284	44.00	38.556	48.600	34.347	41.903	32.603	40.259	37.506	34.2	45.872	35.392	36.890	41.472	35.577	32.655	37.389	47.8	28.925	36.34	52.14	41.60	31.732	34.561	50.281	32.967	46.287	38.200	43.10	45.00	43.50	DIA EXIT TIP
DIA EXIT ROOT	21.8																																							DIA EXIT ROOT
L	11.20	18.120	21.085	15.100	15.100	9.060	9.060	3.020	3.220	9.080	18.120	18.120	15.100	6.040	9.060	3.020	3.020	15.100	18.120	6.040	12.080	9.060	12.080	9.060	15.100	18.120	9.060	9.060	9.060	18.120	12.080	15.100	15.100	9.060	9.060	18.120	20.30	3.38	13.50	L
EXHAUST CASE																																								EXHAUST CASE
	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	9.50	9.50	9.50	L
TURBINE TRANS. DUCT	—	—	12.1	—	—	—	—	—	—	—	12.1 (2)	—	—	—	10.0 (2)	—	—	—	10.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	13.60	—	—	TURBINE TRANS. DUCT
FRONT FACE TO NO 1 BRG																																								FRONT FACE TO NO 1 BRG
NO 1 TO NO 4 BRG																																								NO 1 TO NO 4 BRG
FRONT FACE TO NO 2 BRG																																								FRONT FACE TO NO 2 BRG
NO 2 TO NO 3 BRG																																								NO 2 TO NO 3 BRG
COMP TRANS. DUCT		4.0	2.8		5.0						1.7		2.4						3.6			1.4															1.90			COMP TRANS. DUCT
HI ROTOR L	47.98	51.1	50.9	68.2	64.7	57.1	64.5	76.2	87.2	44.5	44.4	56.7	52.9	46.0	52.9	61.7	64.4	59.2	45.2	52.9	45.3	46.8	47.9	52.8	67.1	50.4	49.1	61.9	83.8	66.9	47.8	44.36	53.1	59.3	61.5	44.9	48.83	68.45	50.08	HI ROTOR L
MISC. L (1)	2.6	2.61	2.1	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.1	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.35	2.9	2.9	MISC. L (1)
TOTAL L F_{Fn}=20,000	90.93	103.980	120.994	111.400	113.238	100.805	115.0	107.066	111.624	85.03	108.469	122.18	108.090	84.415	111.029	91.559	94.54	109.295	105.555	92.394	90.72	88.806	91.165	97.452	95.501	97.881	101.185	98.145	121.660	126.632	90.863	91.268	106.981	95.469	98.492	107.78	TOTAL L F_{Fn}=20,000
TOTAL L F_{Fn}=25,000	102.00	116.458	135.513	124.768	126.872	112.902	130.911	119.914	125.243	95.23	121.465	114.444	121.060	94.567	124.352	102.524	105.861	122.410	118.222	103.481	101.626	97.222	102.105	109.146	106.961	109.627	113.327	109.922	134.260	141.828	101.767	102.220	119.819	106.925	110.311	120.714	120.42	101.67	100.70	TOTAL L F_{Fn}=25,000
SCALE FACTOR TO 20K	1.00	1.005	.953	1.320	1.25	1.14	1.23	1.49	.58	.968	84	1.155	1.07	1.005	1.035	1.27	1.33	1.10	.94	1.12	.965	1.024	1.005	1.05	1.21	.936	.89	1.15	1.65	1.28	.867	.781	1.135	.99	1.39	.953	.938	1.418	1.078	SCALE FACTOR TO 20K
NO.3 BRG DIA.	6.300	6.329	6.004	8.297	7.847	7.182	7.749	9.386	9.253	6.096	5.577	7.261	6.741	6.331	6.276	8.001	8.378	6.929	5.921	7.056		6.451	6.331	6.615	7.623	6.241	5.607	7.244	10.394	8.064	5.462	4.961	7.15	6.236	8.757	5.993	5.686	8.961	6.808	NO.3 BRG DIA.
HI ROTOR L/NO.3 BRG DIA	7.630	8.075	8.478	8.22	8.217	7.951	8.124	8.118	8.76	7.5	5.745	7.809	7.848	7.266	8.429	7.712	7.687	8.544	7.633	7.497	7.452	7.565	7.566	7.982	8.803	8.075	8.757	8.545	8.062	8.297	8.752	9.023	7.427	9.509	7.023	7.493	8.590	7.638	7.356	HI ROTOR L/NO.3 BRG DIA
U_T(PHYSICAL) MAX	1480	1700	1200	1700	1200	1700	1200	1700	1200	1700	1206	1700	1200	1720	1540	1760	1200	1480	1480	1480	1480	1700	1480	1200	1480	1480	1480	1480	1480	1480	1640	1480	1480	1810	1480	1300	1200	1750	1480	U_T(PHYSICAL) MAX
OVERALL L/NO.3 BRG DIA	14.433	16.429	20.152	13.427	14.381	14.036	15.084	11.407	11.225	13.948	21.365	14.072	16.035	15.337	17.691	11.441	11.260	15.774	17.827	13.094	14.924	13.766	14.4	14.732	12.528	16.94	18.046	13.548	11.705	15.704	16.635	18.569	14.962	15.309	11.247	17.984	21.178	11.345	14.791	OVERALL L/NO.3 BRG DIA
FAN TIP DIA/NO.3 BRG DIA	10.159	11.882	13.492	8.852	10.081	8.984	8.984	6.715	6.714	10.039	14.063	8.869	10.079	8.985	9.334	6.714	6.715	10.160	12.351	8.254	10.16	10.159	10.16	10.159	8.222	10.615	11.0	8.223	8.223	11.0	10.159	11.523	11.007	8.224	8.222	11.93	14.034	6.696	10.150	FAN TIP DIA/NO.3 BRG DIA

1. This includes the gaps between the following sections: a) fan and low compressor; b) low compressor and intermediate case; c) intermediate case and high compressor; d) high and low turbine.

2. The high rotor requires a third bearing because it has a 3 stage turbine. The additional length between the high and low turbine provides spacing for a strut to support the high rotor bearing. Because extra length was added the low rotor is also supported from 3 bearings.

3. $N_{1\,max.} = 1.115\,N_{1\,cruise}$ or $1.06\,N_{1\,T.O.}$, whichever is greater.

4. $N_{2\,max.} = 1.07\,N_{2\,T.O.}$

5. Third bearing, supported inboard of the diffuser case, is required to obtain high rotor critical speed margin.

6. Low rotor has a third bearing supported through the transition duct between high and low turbine.

7. Intershaft bearing required.

ENGINES SCALED DIRECTLY TO 25,000 LBS

TABLE XXII

DATA FOR TASK I (INTERNATIONAL UNITS)
ALL DATA FOR 20,000 LB. THRUST ENGINES
UNLESS OTHERWISE SPECIFIED

TABLE XXII 537o

Page 139/140

	DESIGNATION	0 SCALED JT9D-1	1 10-95D70-30	2 10-95C30-30	3 10-95D70-15	4 10-95C30-15	5 10-95A70-30	6 10-95A30-30	7 10-95A70-15	8 10-95A30-15	9 60-95E70-30	10 60-95C30-30	11 60-95D70-15	12 60-95C30-15	13 60-95A70-30	14 60-95A30-30	15 60-95A70-15	16 60-95A30-15	17 10-95B55-24	18 80-95C55-24	19 80-95A55-24	20 60-95B55-24	21 80-95B70-24	22 80-95B55-2A	23 80-95B30-24	24 80-95B55-15	25 80-95B55-30	26 10-30B55-30	27 10-30B55-15	28 10-60B55-15	29 10-60B55-30	30 80-30B55-24	31 60-30B55-30	32 60-60B55-30	33 60-30B55-15	34 60-60B55-15	35 85-00D40-30	ENGINES SCALED DIRECTLY TO 111,200 NEWTONS 10 60-95C30-30	15 60-95A70-15	20 60-95B55-24	DESIGNATION
1	N_1 Cruise	497.6	495.6	320.6	497.7	326.8	565.4	372.1	577.1	388.7	599.6	363.7	568.1	381.7	642.5	442.3	680.4	452.4	452.4	435.3	546.5	515.7	557.8	495.2	386.0	507.6	480.9	516.6	534	372.2	358.1	575	551.8	404.3	601.7	441.8	391.7	325.5	611.1	462	N_1 Cruise
2	N_1 TO	487.8	367.5	241.5	383.3	285.6	490.4	326.6	510.3	342.3	577.5	365.4	535.5	392.7	688.8	594.3	741.3	487.2	393.8	393.8	535.5	539.7	432.6	476.7	371.7	494.6	455.7	510.3	529.2	276.2	266.5	661.5	579.6	314	798.8	389.6	325.5	327.6	664.7	484.1	N_1 TO
3	N_1 Max[3]	556.5	552.3	357	554.4	364.4	630	414.8	643.7	433.7	667.8	405.3	633.2	425.3	724.5	630	785.4	514.5	504	486.2	609	572.3	621.6	551.3	430.5	556.5	536.6	569.1	594.3	412.7	399	700.4	620.2	451.5	842.1	493.5	436.8	363.3	700.4	514.5	N_1 Max 3
4	N_2 Cruise																																							N_2 Cruise
5	N_2 TO	1134	1128.8	1189.9	861	907.2	994.7	921.9	761	717.7	1171.8	1407	983.9	1059.8	1128.3	1138.2	892.8	862.6	1030.9	1206.3	1012.4	1175.1	1107.3	1128.3	1079.9	937.1	1144.5	1274.1	986.6	687.2	885.9	1307.9	1453.2	999.1	1145.5	815.7	1190.7	1260	780.2	1047.9	N_2 TO
6	N_2 Max[4]	1212.8	1207.5	1270.5	921.9	971.3	1118.3	987	814.8	767.6	1254.8	150.2	1050	1134	1207.5	1218	955.5	913.5	1102.5	1291.5	1083.6	1256.9	1186.5	1170.8	1155	1003.8	1223.3	1365	1055.6	735	948.2	1398.6	1554	1071	1228.5	872.6	1270.5	1348.2	834.8	1113	N_2 Max 4
7																																								
8	N_1 Crit Speed	OK	[7]	[6]	[7]	[7]	OK	OK	OK	OK	OK	[2]	OK	[7]	OK	[2]	OK	OK	[7]	[6]	OK	OK	OK	OK	OK	OK	[7]	[7]	OK	OK	OK	[7]	[7]	[7]	OK	[6]	[2]	OK	OK	N_1 Crit Speed
9	N_2 Crit Speed	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	[2]	OK	OK	OK	[2]	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	[5]	OK	[5]	OK	OK	[2]	OK	OK	N_2 Crit Speed
10																																								
11	Fan																																							Fan
12	Dia Tip	162.6	199.0	205.8	186.7	201.6	163.9	176.8	160.1	169.8	155.4	181.4	163.6	172.6	144.5	148.8	136.5	142.9	178.8	185.8	147.9	156.9	166.5	163.4	170.7	159.2	168.3	156.7	151.3	207.1	225.3	140.9	143.9	199.8	137.7	182.9	181.6	202.7	152.4	175.5	Dia Tip
13	Dia Root																																								Dia Root
14	bx	4.2	4.87	5.213	4.75	5.100	4.024	4.342	4.038	4.282	3.94	4.595	4.04	4.355	3.548	3.654	3.442	3.591	4.510	4.681	3.741	3.957	4.189	4.121	4.0	4.017	4.235	3.943	3.818	5.478	5.670	3.555	3.485	5.028	3.287	4.615	4.500	5.140	3.84	4.44	bx
15	b Root																																								b Root
16	b Tip																																								b Tip
17	No Blades																																								No Blades
18	No Vanes																																								No Vanes
19	LPC																																								LPC
20	No Stages	3	3	4	0	1	3	4	0	1	3	4	0	1	3	4	0	1	3	3	3	3	2	3	3	0	4	4	0	0	4	3	4	4	0	0	3	4	0	3	No Stages
21	Dia in Tip	86.4	97.8	104.1	–	104.8	95.0	234.5	–	103.1	85.3	91.7	–	94.9	83.7	90.4	–	86.8	95	91.9	86.5	83.3	87.4	86.8	93.6	–	89.6	83.4	–	–	120.0	74.9	75.2	106.4	–	–	92.7	102.6	–	93.2	Dia in Tip
22	Dia in Root																																								Dia in Root
23	Dia Exit Tip	71.6	81.8	81.6	–	96.8	79.3	84.0	–	98.0	74.1	71.9	–	82.9	69.9	70.7	–	82.4	79.6	76.9	72.3	69.9	78.3	72.8	78.4	–	69.3	65.3	–	–	94.0	62.8	59.0	83.3	–	–	77.3	80.3	–	78	Dia Exit Tip
24	Dia Exit Root																																								Dia Exit Root
25	L	28.4	25.5	32.6	19.1	19.1	37.5	56.9	19.1	19.1	29.6	28.7	19.1	19.1	33	47.8	19.1	19.1	37.2	21.9	35.3	32.7	19.1	28.4	32.4	19.1	36.6	34.1	19.1	19.1	49.0	29.4	29.8	43.5	19.1	19.1	24.2	32	21.3	36.6	L
26	Intermediate Sec																																								Intermediate Sec
27	L	12.1	12.1	14	12.1	12.1	12.1	14	12.1	12.1	12.1	14	12.1	12.1	12.1	14	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	14	12.1	14	14	12.1	14	12.1	14	14	12.1	12.1	12.1	15.7	13.2	13.2	L
28	HPC No Stages	11	11	12	11	11	12	11	11	11	11	12	11	11	12	12	11	11	12	11	11	11	11	12	12	11	12	12	11	11	12	11	12	12	11	11	11				HPC No Stages
29	Dia in Tip	64	64.3	64.9	84.3	80	73.0	83	95.4	101.2	61.5	57.3	73.9	68.5	64.3	70.5	81.3	85.1	70.4	60.2	71.7	61.8	65.5	64.3	71.5	77.4	65.1	60.6	73.6	105.6	87.1	55.5	53.1	77.3	63.4	89.0	61.0	64	90.7	69.1	Dia in Tip
30	Dia in Root																																								Dia in Root
31	Dia Exit Tip	50.3	50.5	47.9	66.3	62.9	57.2	61.9	74.9	79.5	48.8	42.2	58.2	53.8	50.5	52.1	63.9	66.9	55.3	47.3	56.3	48.5	51.5	50.5	52.8	60.9	48.1	44.8	57.8	83.0	64.4	43.6	39.2	57.1	49.8	69.9	47.9	47.2	77.4	54.1	Dia Exit Tip
32	Dia Exit Root																																								Dia Exit Root
33	L	65.3	65.8	68.7	85.7	81.6	74.4	88.7	97.3	103.2	63.2	60.8	75.4	69.9	65.6	74.7	82.9	86.9	71.8	61.4	73.1	63.0	66.9	65.6	75.7	79.0	69.0	64.2	75.1	107.8	92.5	56.6	56.3	81.9	65.9	90.8	62.2	67.8	92.9	70.6	L
34	Burner																																								Burner
35	L	42.4	49.8	46.3	80.5	76.2	56.5	61	90.9	96.5	35.7	34.3	54.3	50.3	37.0	41.9	59.7	62.5	64.3	39.4	47.0	38	42.9	41.9	44.1	56.9	37.6	46.3	75.7	98.6	63.4	50.7	42.2	38.9	71.7	51.2	37.6	38.4	66.8	42.4	L
36	HPT																																								HPT
37	Dia in Tip	64	57.2	61.0	98.3	93.3	73.0	78.7	111.2	117.9	65.5	50.9	73.9	68.5	67.7	62.7	81.3	85.1	67.1	60.2	71.7	64.2	65.5	64.3	68.3	78.7	57.7	62.0	85.0	122.0	81.9	55.5	52.5	76.4	63.4	89.0	61.0	57.9	90.7	71.6	Dia in Tip
38	Dia in Root	57.4																																							Dia in Root
39	Dia Exit Tip	69.1																																							Dia Exit Tip
40	Dia Exit Root	56.9																																							Dia Exit Root
41	L	14.2	14.2	14.2	6.5	6.5	14.2	14.2	6.5	6.5	14.2	17.8	14.2	14.2	14.2	17.8	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	6.5	6.5	14.2	14.2	14.2	14.2	14.2	14.2	14.2	17.8	14.2	14.2	L
42	No Stages	2	2	2	1	1	2	2	1	1	2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	2	2	2	2	2	2	2	3	2	2	No Stages
43	LPT																																								LPT
44	No Stages	4	6	7	3	5	3	3	1	1	3	6	3	5	2	3	1	1	5	6	2	4	3	4	4	3	6	6	3	3	6	4	5	5	3	3	6	6	1	4	No Stages
45	Dia Exit Tip	91.4	104.6	93.2	118.1	97.8	94.1	90.6	119.6	119.6	111.8	97.9	123.4	87.2	106.4	82.8	102.3	95.3	86.9	116.5	89.9	98.8	105.3	90.4	82.9	95.0	121.4	65.8	92.3	132.4	105.7	80.6	87.8	127.7	83.7	117.6	97.0	109.5	114.3	110.5	Dia Exit Tip
46	Dia Exit Root	55.4																																							Dia Exit Root
47	L	28.4	46.0	53.6	38.4	38.4	23	23	7.7	7.7	23	53.6	53.6	38.4	15.3	23	7.7	7.7	38.4	46.0	15.3	30.7	23.0	30.7	30.7	23.0	38.4	46.0	23.0	23.0	46.0	30.7	38.4	38.4	23.0	23.0	46.0	51.6	8.6	34.3	L
48	Exhaust Case																																								Exhaust Case
49	L	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	24.1	24.1	24.1	L
50	Turbine Trans Duct	–	–	12.1	–	–	–	–	–	–	–	[2]	–	–	–	[2]	–	–	–	10.0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	11.9	1360	–	–	Turbine Trans Duct
51	Front Face to No. 1 Brg																																								Front Face to No. 1 Brg
52	No. 1 to No. 4 Brg																																								No. 1 to No. 4 Brg
53	Front Face to No. 2 Brg																																								Front Face to No. 2 Brg
54	No. 2 to No. 3 Brg																																								No. 2 to No. 3 Brg
55	Comp Trans Duct		4.0	2.8		5.0						1.7		2.4					3.6				1.4													3.5	1.90	–	–	Comp Trans Duct
56	Hi Rotor L	121.9	129.8	129.3	173.2	164.3	145.0	163.8	193.5	221.5	113.0	112.8	144	134.4	116.8	134.4	156.7	163.6	150.4	114.8	134.4	15.1	124.0	121.7	134.1	170.4	128	124.7	157.2	212.9	169.9	121.4	112.7	134.9	150.6	156.2	114.0	124.0	173.9	127.2	Hi Rotor L
57	Misc L[1]	6.6	6.6	5.3	6.6	6.6	6.6	6.6	6.6	6.6	6.6	5.3	6.6	6.6	6.6	6.6	6.6	6.6	6.6	5.3	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	5.3	6.0	7.4	7.4	Misc L[1]
58	Total L																																								Total L
	FN = 88,960 N	231	264.1	307.3	283.0	287.6	256.0	287	271.9	284.0	216	275.5	259.5	274.5	214.5	282	232.5	239.6	277.6	268.1	234.7	230.4	225.6	231.6	247.5	242.6	248.6	257.0	249.3	309.2	321.6	230.8	231.8	271.7	242.5	250.2	273.8				Fn = 88,960 N
59	Total L																																								Total L
	FN = 111,200 N	259.1	295.8	344.2	316.9	322.3	286.8	332.5	304.6	318.1	241.9	305.6	290.7	307.5	240.2	315.9	260.4	268.4	310.9	300.3	262.8	258.1	246.9	259.3	277.2	271.7	278.5	287.9	279.2	346.1	360.2	258.5	259.6	304.3	271.6	280.2	306.6	305.9	258.2	255.8	Fn = 111,200 N
60																																								
61	Scale Factor to 20K	1.00	1.005	.953	1.320	1.25	1.14	1.23	1.49	1.58	.968	.84	1.155	1.07	1.005	1.035	1.27	1.33	1.10	.94	1.12	.965	1.024	1.005	1.05	1.21	.956	.89	1.15	1.65	1.28	.867	.781	1.135	.99	1.39	.953	.938	1.418	1.078	Scale Factor to 20K
62																																								
63	No. 3 Brg Dia	16.0	16.1	15.3	21.1	19.9	18.2	19.7	23.8	25.3	15.5	12.9	18.4	17.1	16.1	15.9	20.3	21.3	17.6	15.0	17.9	–	16.4	16.1	16.8	19.4	15.9	14.2	18.4	26.4	20.5	13.9	12.6	18.2	15.8	22.2	15.2	14.4	22.8	17.3	No. 3 Brg Dia
64	Hi Rotor L/No. 3 Brg Dia	19.4	20.5	21.5	20.9	20.9	20.2	21.1	20.8	22.3	18.5	22.2	19.8	19.9	18.5	21.4	19.6	19.5	21.7	19.4	19.0	18.9	19.2	19.2	20.3	22.4	20.5	22.2	21.7	20.5	21.1	22.2	22.9	18.9	24.2	17.8	19.0	21.8	19.4	18.7	High Rotor L/No. 3 Brg Dia
65	U_T (Physical) Max	1480	1700	1200	1700	1200	1700	1200	1700	1200	1700	1200	1700	1200	1720	1540	1760	1200	1480	1480	1480	1480	1700	1480	1200	1480	1480	1480	1480	1480	1480	1640	1480	1480	1810	1480	1300	1200	1750	1480	U_T (Physical) Max
66	Overall L No. 3 Brg Dia	36.7	41.7	51.2	34.1	36.5	35.7	38.3	29.0	28.5	35.4	54.3	35.7	40.7	33.9	44.9	29.1	28.6	40.1	45.3	33.3	37.9	35.0	36.6	37.4	31.8	42.8	45.8	34.4	29.7	39.9	42.3	47.2	38.0	38.9	28.6	45.7	53.8	28.8	37.6	Overall L/No. 3 Brg Dia
67	Fan Tip Dia/No. 3 Brg Dia	25.8	30.2	34.3	22.5	25.6	22.8	22.8	17.1	17.1	25.5	35.7	22.5	25.6	22.8	23.7	17.1	17.1	25.8	31.4	21.0	25.8	25.8	25.8	25.8	20.9	27.0	27.9	20.9	20.9	27.9	25.8	29.3	28.0	20.9	20.9	30.3	35.6	17.0	25.8	Fan Tip Dia/No. 3 Brg Dia

[1] This includes the gaps between the following sections: a) fan and low compressor; b) low compressor and intermediate case; c) intermediate case and high compressor; d) high and low turbine.

[2] The high rotor requires a third bearing because it has a 3 stage turbine. The additional length between the high and low turbine provides spacing for a strut to support the high rotor bearing. Because extra length was added the low rotor is also supported from 3 bearings.

[3] $N_{1\ max.} = 1.115\ N_{1\ cruise}$ or $1.06\ N_{1\ T.O.}$, whichever is greater.

[4] $N_{2\ max.} = 1.07\ N_{2\ T.O.}$

[5] Third bearing supported inboard of the diffuser case, is required to obtain high rotor critical speed margin.

[6] Low rotor has a third bearing supported through the transition duct between high and low turbine.

[7] Intershaft bearing required.

TASK I REPORT

QUIET ENGINE DEFINITION PROGRAM

By

John H. Lewis, III, Program Manager

ABSTRACT

Trends of noise, performance, weight, and dimensions were tabulated for 242 combinations of cycle variables for each of two different levels of take-off thrust. The five cycle variables considered were bypass ratio, fan pressure ratio, cycle pressure ratio, and turbine inlet temperature at cruise and take-off. A multiple regression analysis technique was used to establish the trends. Several cycles gave promise of meeting the program's noise-reduction goals.