[redacted]

LYC 78-36

NASA

DESIGN OF AN EXHAUST MIXER NOZZLE FOR THE AVCO LYCOMING QUIET CLEAN GENERAL AVIATION TURBOFAN (QCGAT)

by John F. Hurley, Leonard I'Anson and Craig A. Wilson

AVCO-LYCOMING DIVISION
550 South Main Street
Stratford, Connecticut 06497

(NASA-CR-159426) DESIGN OF AN EXHAUST MIXER NOZZLE FOR THE AVCO-LYCOMING QUIET CLEAN GENERAL AVIATION TURBOFAN (QCGAT) (Avco Lycoming Div.) 46 p HC A03/MF A01 CSCL 21E

N81-19120

Unclas
G3/07 19163

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA Lewis Research Center
Cleveland, Ohio 44135

Contract NAS 3-20584

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
CR-159426		

4. Title and Subtitle	5. Report Date
Design of an Exhaust Mixer Nozzle for the AVCO-Lycoming Quiet Clean General Aviation Turbofan (QCGAT)	August, 1978
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
John F. Hurley, Leonard I'Anson and Craig Wilson	LYC 78-36

9. Performing Organization Name and Address	10. Work Unit No.
AVCO-Lycoming Division 550 South Main Street Stratford, Connecticut 06497	
	11. Contract or Grant No. NAS 3-20584

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
National Aeronautics and Space Administration Washington, DC 20546	Contractor Report
	14. Sponsoring Agency Code

15. Supplementary Notes

Project Manager, G. K. Sievers, V/STOL and Noise Division, NASA Lewis Research Center, Cleveland, Ohio

16. Abstract

This report describes the design configuration and method used to design the forced engine exhaust - to - bypass air mixing system for Lycoming's QCGAT engine. This mixer is an integral part of the total engine and nacelle system and was configured to reduce the propulsion system noise and fuel consumption levels.

17. Key Words (Suggested by Author(s))

Exhaust Mixer Nozzle
Quiet Clean General Aviation
Turbofan (QCGAT)
Noise Emission
Specific Fuel Consumption

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	46	

[redacted]

NASA-C-168 (Rev. 10-75)

TABLE OF CONTENTS

PRECEDING PAGE BLANK NOT FILMED

LIST OF ILLUSTRATIONS

LIST OF TABLES

1.0 SUMMARY

An exhaust mixer nozzle system designed for the Avco Lycoming quiet, clean, general aviation turbofan (QCGAT) uses a multilobe mixer to promote fan and core stream mixing, thus giving it an overall thermodynamic propulsive advantage when compared with more conventional split-flow nozzle configuration. Reduced exhaust jet-sound pressure levels are also realized because of more favorable jet exit conditions. These propulsive and noise benefits are examined for a typical six-place twin-engine business aircraft.

Parametric studies addressing the mixer system flow areas, length, and lobe number were generated, thereby enabling an optimum design to be determined by considering both sea level takeoff and 7620 meters (25,000 feet) altitude cruise conditions. Operating behavior which includes pressure losses, efficiencies, and flow characteristics of the selected mixer nozzle system were determined as a function of power level and flight speed. At the sea level takeoff rating, a 2.1 percent thrust benefit is obtained when compared with the referee split-flow nozzle. A noise reduction of 4 EPNdB is also estimated for the takeoff flyover measurement condition. At the altitude cruise condition, a reduction in thrust specific fuel consumption of 2.9 percent is obtained.

2.0 INTRODUCTION

This report describes the design configuration and the methods used to design the forced engine exhaust-to-bypass air mixing system for Lycoming's QCGAT turbofan engine. The mixer system, an integral part of the total engine and nacelle system, was configured to reduce the propulsion system noise and fuel consumption levels.

The design objective of the QCGAT program was performed to apply known technology to a small turbofan engine that is sized for general aviation applications and to show that noise and emissions can be reduced substantially below current regulatory requirements.

In accordance with general aviation requirements, Lycoming's design objective was to provide for minimum fuel consumption in a cruise condition (7620 meters (25,000 ft) M = 0.6) that was considered as prime by aircraft manufacturers and did not sacrifice maximum takeoff capability.

To most effectively achieve this objective, a mixed exhaust-flow nozzle system was selected to obtain the best propulsive efficiency achievable with a simple, but state-of-the-art technology core engine. Fan pressure ratio was 1.36 with a bypass ratio of 9.65.

The Lycoming QCGAT exhaust nozzle system shown in Figure 1 comprises a fan duct, a multilobe mixer nozzle, and a mixing chamber/final nozzle. This type of exhaust mixing system was chosen because of its propulsive efficiency and reduced noise-emission benefits. Multilobe mixer nozzles such as that shown in Figure 1 have been reported (Reference 1) to yield a considerable amount of noise suppression when compared with the more conventional split-flow nozzles. The suppression is believed to result from reduced jet turbulence levels and a reduction in the mean-relative jet-velocity gradients (Reference 2).

But, this is a complicated phenomenon and, to date, only empirical methods have yielded feasible analytical representations (Reference 3). Consequently, the analysis reported herein was confined to determining the bounds of noise suppression. The upper limit was assumed to be the noise emitted by separate primary and secondary coaxial nozzles. The lower bound was determined by assuming a single-nozzle design and using turbojet prediction procedures (Reference 4). A multi-element of lobe-suppressor procedure was then used to estimate the performance between these bounds.

Aerodynamic design of the forced-exhaust mixer nozzle is based on an optimized procedure that considers all essential components of the mixing system. State-of-the-art technology developed by Lycoming and others, as listed in the references, forms the core of this analysis procedure.

Figure 2 shows a typical six-place, twin-engine turbofan business aircraft configured with Lycoming QCGAT engines. Aircraft gross weight is 3538 kg (7800 pounds) with a usable fuel weight of 975 kg (2150 pounds). The effect of a mixed-flow exhaust nozzle on aircraft gross weight, fuel consumption, and life-cycle costs was examined.

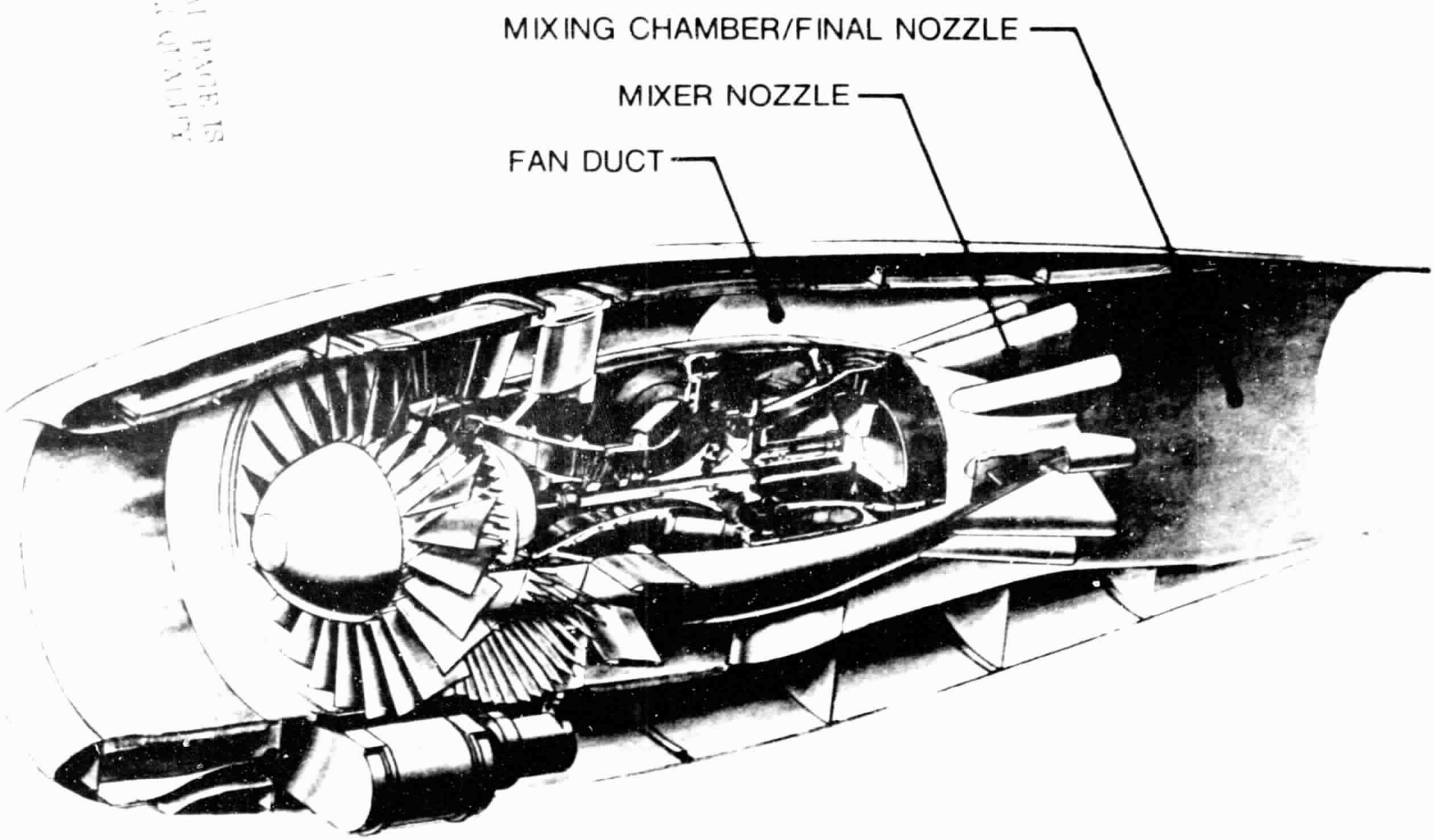


Figure 1. QCGAT Exhaust Nozzle System.

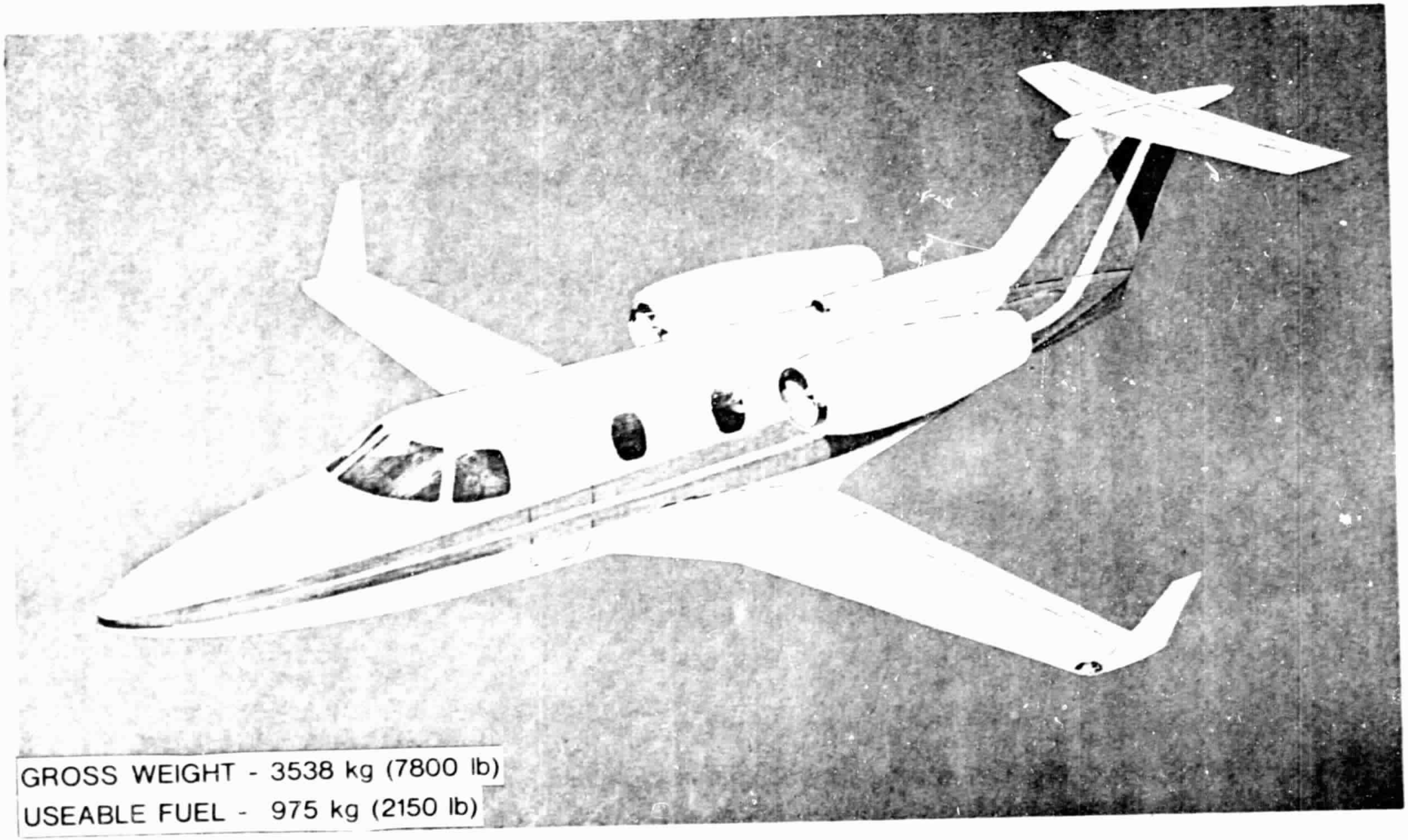


Figure 2. Six-Place QCGAT Aircraft.

3.0 DESIGN AND PERFORMANCE

3.1 DESIGN CONSIDERATIONS

The aerodynamic design of a turbofan exhaust mixer nozzle that is used to provide improved cruise fuel economy and reduced operating noise levels requires a series of careful parametric studies if the system is to be successful. Once the basic turbine engine cycle is optimized in terms of fan bypass ratio, pressure ratio, etc., a study to assess the optimum mixer nozzle areas must be conducted. These areas include core engine, bypass-mixer inlet areas, and a final mixed-nozzle exit area. A study must also address the degree of mixingdesired, the proper length of a mixing chamber, and stream interface requirements. Finally, the analysis must assess the system pressure loss and flow characteristics over a range of operating pressure ratios and flight conditions including takeoff, climb, and altitude cruise.

The effect of the mixer nozzle on the acoustic performance of the aircraft is the greatest at the takeoff power setting. This condition corresponds to two of the three QCGAT program nosie emission goals, i.e., the take off flyover and the take off sideline noise measurement conditions. The effect of the mixer nozzle on aircraft noise at the approach power setting is small due to the dominance of the fan noise. Thus, the take off power setting was selected as the design point to analyze the effect of the mixer nozzle on aircraft noise.

For the purposes of jet-noise prediction, the noise from a multielement nozzle can be considered to consist of two parts: 1) premerging noise, and 2) postmerging noise. The premerging noise is generated in the region close to the nozzle where the structure of the individual jets can be identified. The postmerging noise is generated in a region downstream from the nozzle, after the individual core jets and bypass secondary air have merged into a single "uniform" jet of lower bulk velocity. Th high-frequency portion of the resultant total jet-noise spectrum is usually dominated by the premerging noise, while that of the low-frequency portion is associated with the postmerging noise. The noise for each component is predicted in a manner similar to that for a circular nozzle. The total jet noise is then obtained by summing, on an energy basis, the spectra for premerging and postmerging noise (Reference 4).

3.2 DESIGN OPTIMIZATION

Figure 3 presents an optimized study of the fundamental mixer areas for the Lycoming QCGAT engine. The study was generated using stream flows, pressures, and temperatures obtained from a thermodynamic cycle analysis. This particular mixing-analysis model assumes isentropic, one-dimensional compressible flow, and, as such, is a design starting point. Fan and core mixer inlet areas, Mach numbers, mixed exit area, and propulsive thrust are shown as a function of mixer inlet-plane static pressure for two flight conditions: 1) sea level, 15°C (59°F), at takeoff rating and 2) 7620 meters (25,000 ft) altitude at 0.6 Mach number cruise. Mixer inlet static pressure is used as an independent parameter since it is a direct indication of the speed at which the mixing process occurs. Very large areas, indicative of slow mixing, are associated with higher inlet static pressures. Smaller areas are associated with more rapid mixing and corresponding lower inlet static pressures. As Reference 5 indicates, when mixing occurs at different stream total pressure, an optimum area-split will exist.

The rationale behind this claim can be seen by looking at two extremes. With high-speed mixing (small areas), stream dynamic energies and corresponding mixing losses are large. As the mixing process slows (areas open), one stream will approach its stagnation state more rapidly than the other, and the loss will approach that of a free expansion. These characteristics are shown in Figure 3. The design selection of a core area of 0.0484 m^2 (75 in.^{2}) and a fan duct area of 0.155m^2 (240 in.^{2}) was based on thrust and size. Effective areas were selected to provide maximum propulsive thrust while keeping the mixer size and weight minimal. At the critical altitude, 0.6 Mach cruise condition, fan mixer Mach numbers are seen to be approximately 0.47, while the core Mach number is less than 0.3. Exit effective area is seen to be approximately 0.139 m^2 (215 in.^{2}).

In an actual turbofan installation, the mixer system will experience thermodynamic conditions that are different from design conditions, since the engine components are continually rematching. Figure 4 presents a study that assesses the optimum mixed-nozzle exit area and considers the effects of engine component rematch. Changes in thrust and thrust specific fuel consumption from the preliminary cycle analysis optimization are presented for two flight conditions as a function of effective nozzle exit area. At the sea level takeoff condition, high thrust requirements indicate that a more open nozzle is desirable. Altitude cruise, however, indicated a sharp increase in thrust specific fuel consumption beyond effective areas of 0.145 m^2 (225 in.^{2}). This condition is due

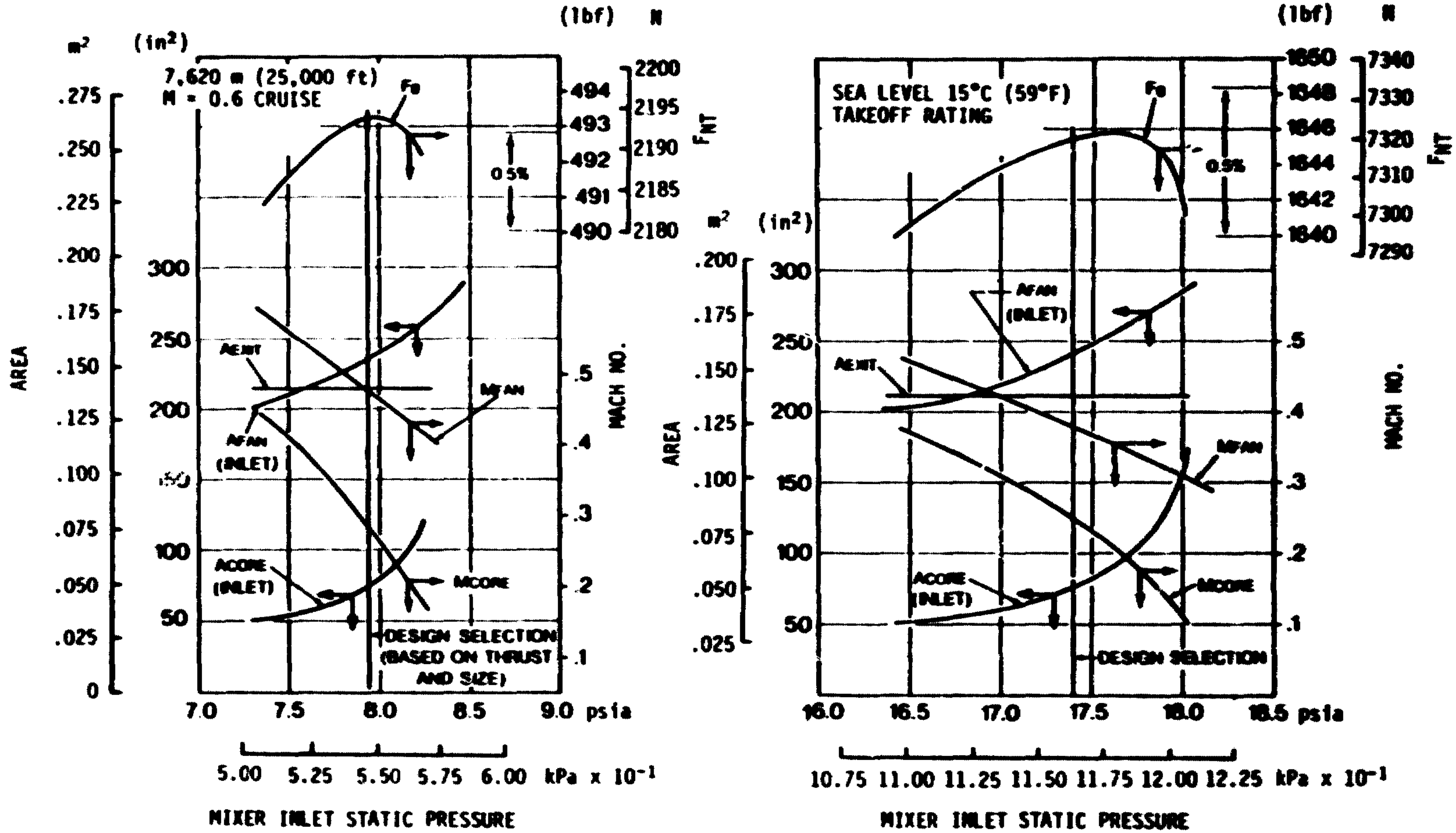


Figure 3. Exhaust Mixer Area Optimization.

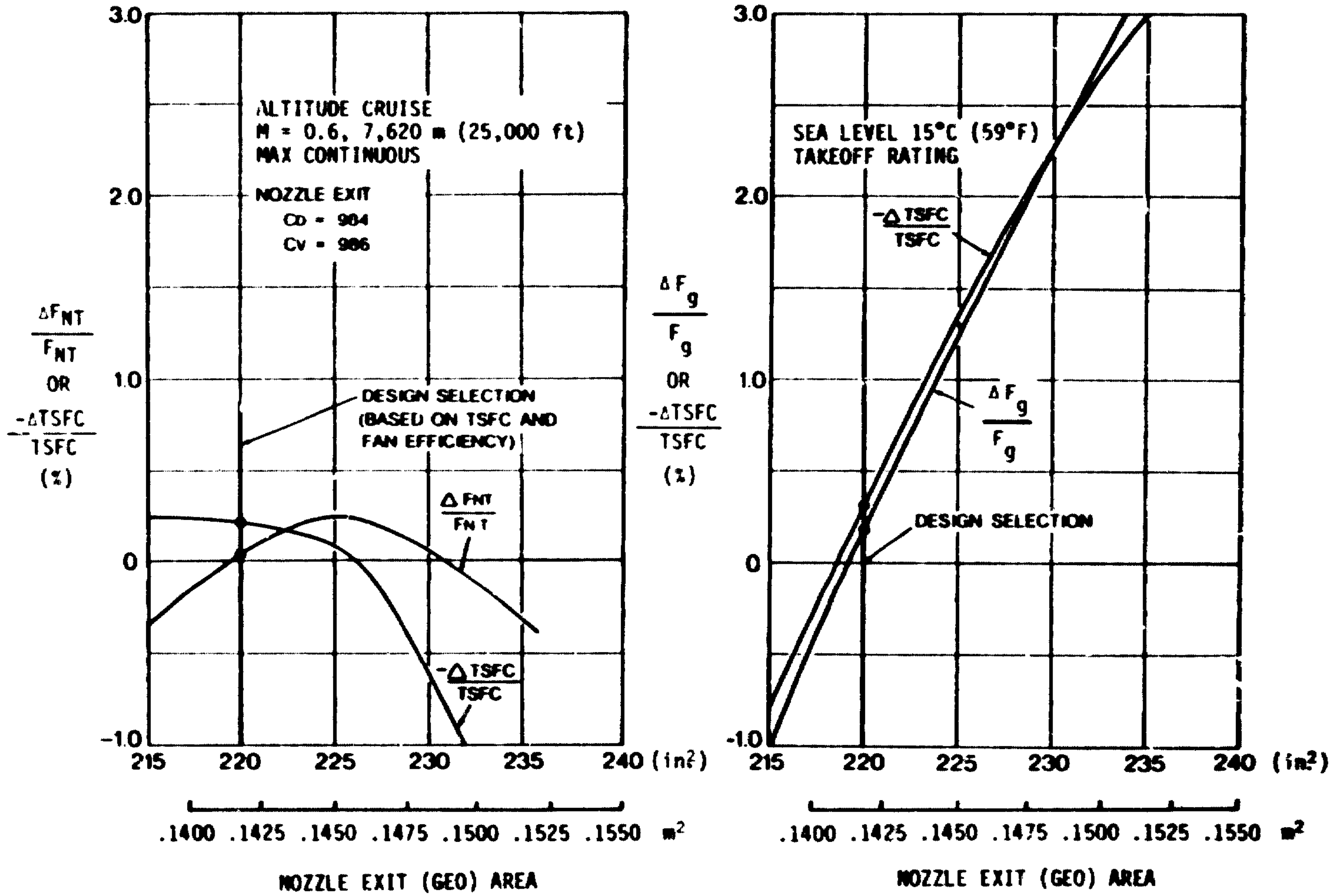


Figure 4. Mixer Nozzle Exit Area Optimization.

primarily to a drop in fan efficiency as the fan unloads with the more open areas. Based on fuel economy at the altitude cruise condition, an effective area of 0.142 m^2 (220 in.^{2}) was selected as the best compromise.

To a large extent, the optimum degree of mixing will be determined by mixing chamber geometry once the basic mixing areas are determined. Figure 5 presents a study that investigated the effects of mixing-chamber length on performance for a selected interface condition representative of a high-performance multilobe mixer nozzle. Increasing the length of the mixing chamber affects propulsive performance in two ways. As mixing length increases, the potential to transfer energy from one stream to another increases, which provided better propulsive efficiency. This is seen in Figure 5 as a thrust gain due to mixing. However, as mixing length increases, the wetted surface area also increases, thus causing an increased friction loss. This is seen as an increase in internal drag in Figure 5. The algebraic sum of these two effects will provide the net propulsive thrust response as a function of mixing length. As seen in Figure 5 for the QCGAT engine, this composite response is presented as a function of mixing length-to-mixing section inlet hydraulic diameter ratio. As a best compromise between altitude cruise and sea level takeoff flight conditions, a nondimensional length of 1.3 was selected. Although Reference 1 indicates that an increase in mixer-nozzle noise suppression can be expected with increasing mixing length-to-hydraulic diameter ratios (2.5 or greater), Figure 5 clearly indicates that mixers of this configuration are too long in consideration of propulsive efficiency. Correspondingly, with the selected 1.3 mixing length-to-hydraulic diameter ratio design, no significant reduction in premerging noise is expected, and the prediction techniques for a minimal mixing-length suppressor are assumed valid for the selected design.

To provide guidance in the configuration definition of the detailed mixer nozzle, the classical work of Frost (Reference 5) was examined. Figure 6 presents Frost's original work. A mixing function, defined as the actual-to-ideal thrust gain due to mixing, is presented as a function of a mixing interface function defined as the stream-wetted perimeter multiplied by mixing length and divided by the square of the mixer-inlet hydraulic diameter. The study basically indicates that as the stream interface wetted surface increases and mixing length increases, propulsive thrust increases. As hydraulic diameter of the mixing chamber increases for fixed wetted-surface area and mixing length, propulsive efficiency decreases. This correlation, based on an extensive experimental background, provides the basic guidance for the

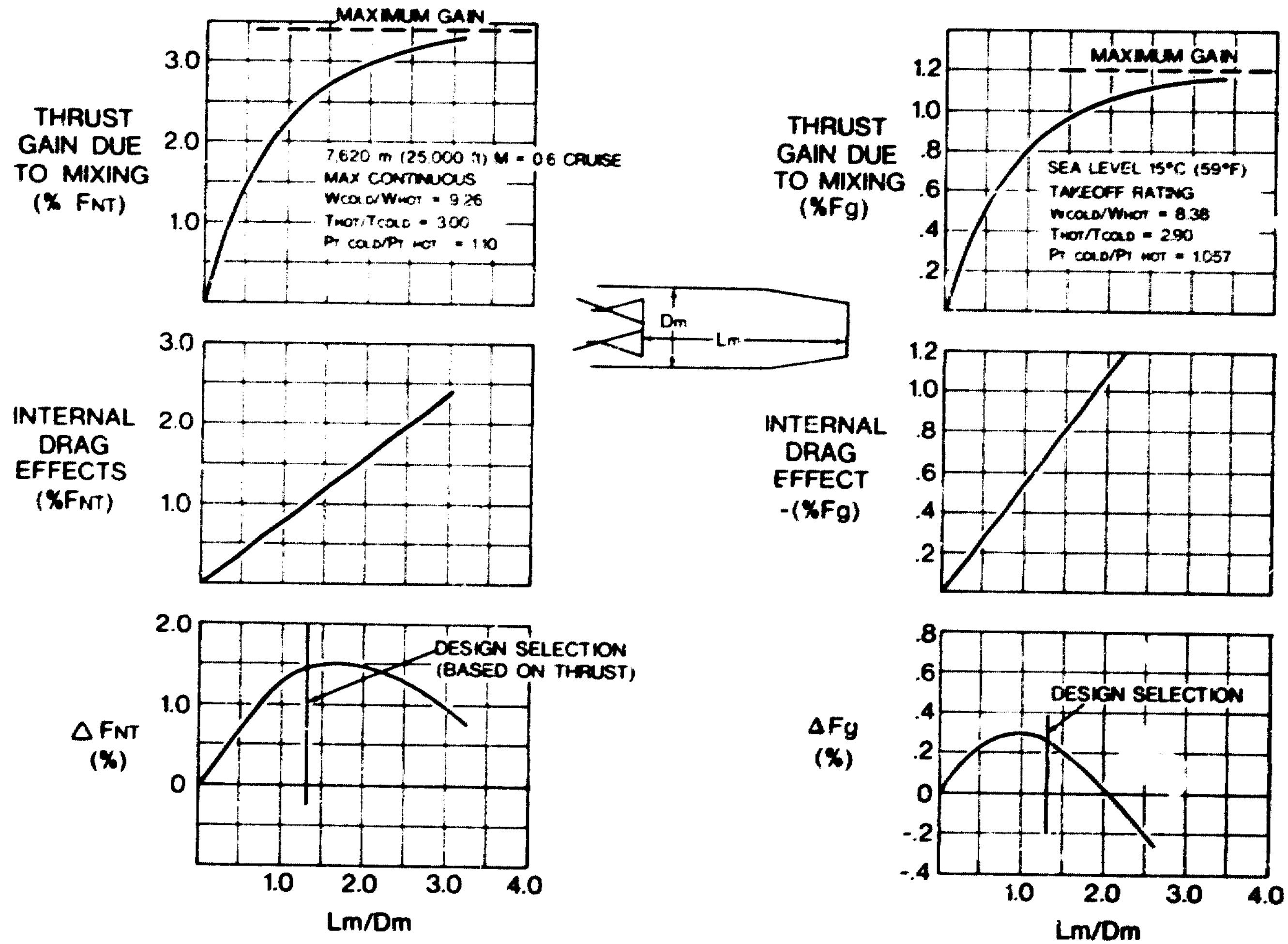


Figure 5. Mixer Length Optimization.

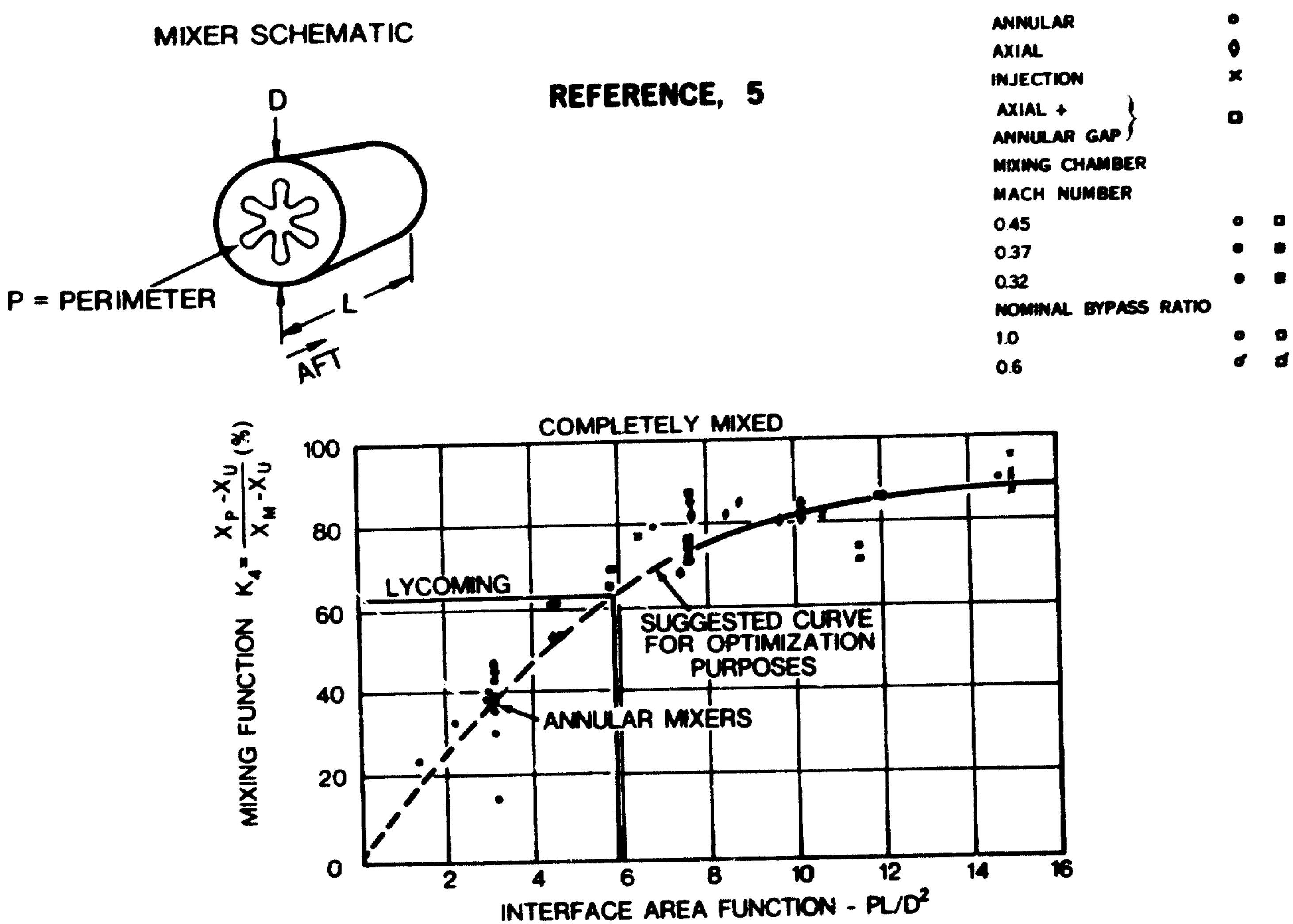


Figure 6. Correlation of Mixing Effectiveness and Mixer Geometry.

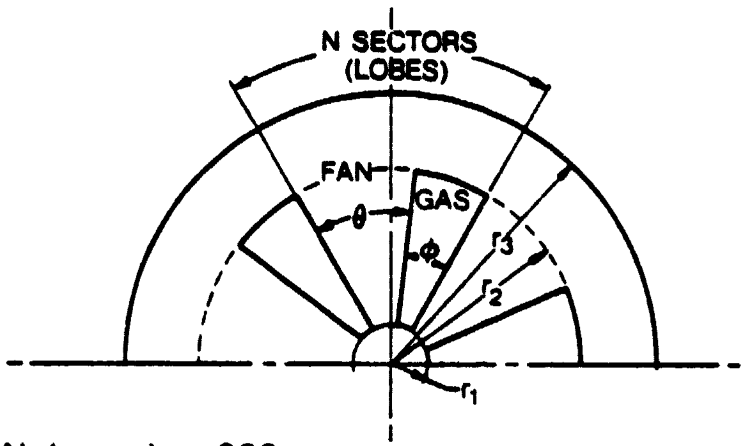
Lycoming mixer-nozzle analysis. Mixer-nozzle designs in Figure 6, (left side) (low interface function values) are indicative of confluent or annular mixers, and the propulsive benefits are not large. As larger thrust benefits are realized, it is seen that multilobe chute-type mixers are required. Beyond 60 to 70 percent mixing function, the mixing process generally becomes one of diminishing returns in performance. Size, weight, and design complexity tend to counteract the performance benefits due to mixing. The particular operating area assessed as best for the Lycoming QCGAT is shown on Frost's correlation. Mixing function or efficiency is seen to be in excess of 60 percent with a mixing interface function of approximately 6.

To obtain mixing efficiencies of approximately 60 percent, it was assessed that a multiple-lobe mixer would be required. Figure 7 shows the simplified mixer lobe geometry approximation used to assess the nozzle interface function, PL/D^2, as a function mixer-nozzle lobe number. The study was based on a selected nozzle penetration into the fan stream and on the area ratio between fan and core streams established from the Figure 3 studies. Circumferential outer-lobe surface and radial vanes are assumed.

Figure 8 presents the results of a mixer lobe number study, using the Figure 7 geometric simplifications. Propulsive thrust, referenced against ideal separate nozzle expansion, is presented as a function of nozzle lobe number for the two flight conditions of interest. As the nozzle lobe number is increased, the mixing function increases to provide improved thrust characteristics. At the same time, the wetted-surface area of the mixer nozzle and corresponding chute losses increase. Figure 8 shows these combined effects; therefore, six lobes were selected as the best compromise favoring the altitude cruise flight condition. Figure 9 substantiates the reason for selecting six nozzle lobes. This figure indicates that the nozzle lobe number should be less than seven or greater than fourteen, to prevent potential power turbine vibration excitation. Nozzle lobe numbers satisying these conditions will ensure operating compatibility of the power-turbine mixer-nozzle.

3.3 AERODYNAMIC PERFORMANCE

The efficiency or extent to which the core and bypass streams are mixed can be determined by a number of analytical techniques. In Reference 5, Frost correlates the actual thrust gain-to-ideal gain due to mixing as a function of a geometric interface function. The Lycoming mixing analysis, which was formulated for IR suppressor



$$N\,(\theta + \phi) = 360$$

$$A_{GAS} = N\pi(r_2^2 - r_1^2)\,\phi/360$$

$$A_{FAN} = \pi(r_3^2 - r_2^2) + N\pi(r_2^2 - r_1^2)\,\theta/360$$

$$AR = \frac{A_{FAN}}{A_{GAS}} = \frac{(r_3^2 - r_2^2) + N\,(r_2^2 - r_1^2)\,\theta/360}{N\,(r_2^2 - r_1^2)\,\phi/360}$$

$$\text{Perimeter}_{\text{(Interface)}} = 2N\,(r_2 - r_1) + N2\pi\,r_2\,\phi/360$$

$$\text{Perimeter}_{\text{(Fan Duct)}} = 2\pi r_3 + N2\pi r_1\,\theta/360 + 2N(r_2 - r_1) + N2\pi r_2\,\phi/360$$

$$\text{Perimeter}_{\text{(Core Duct)}} = N2\pi r_1\,\phi/360 + 2N\,(r_2 - r_1) + N2\pi r_2\,\phi/360$$

Figure 7. Simplified Mixer Nozzle Geometric Relationships.

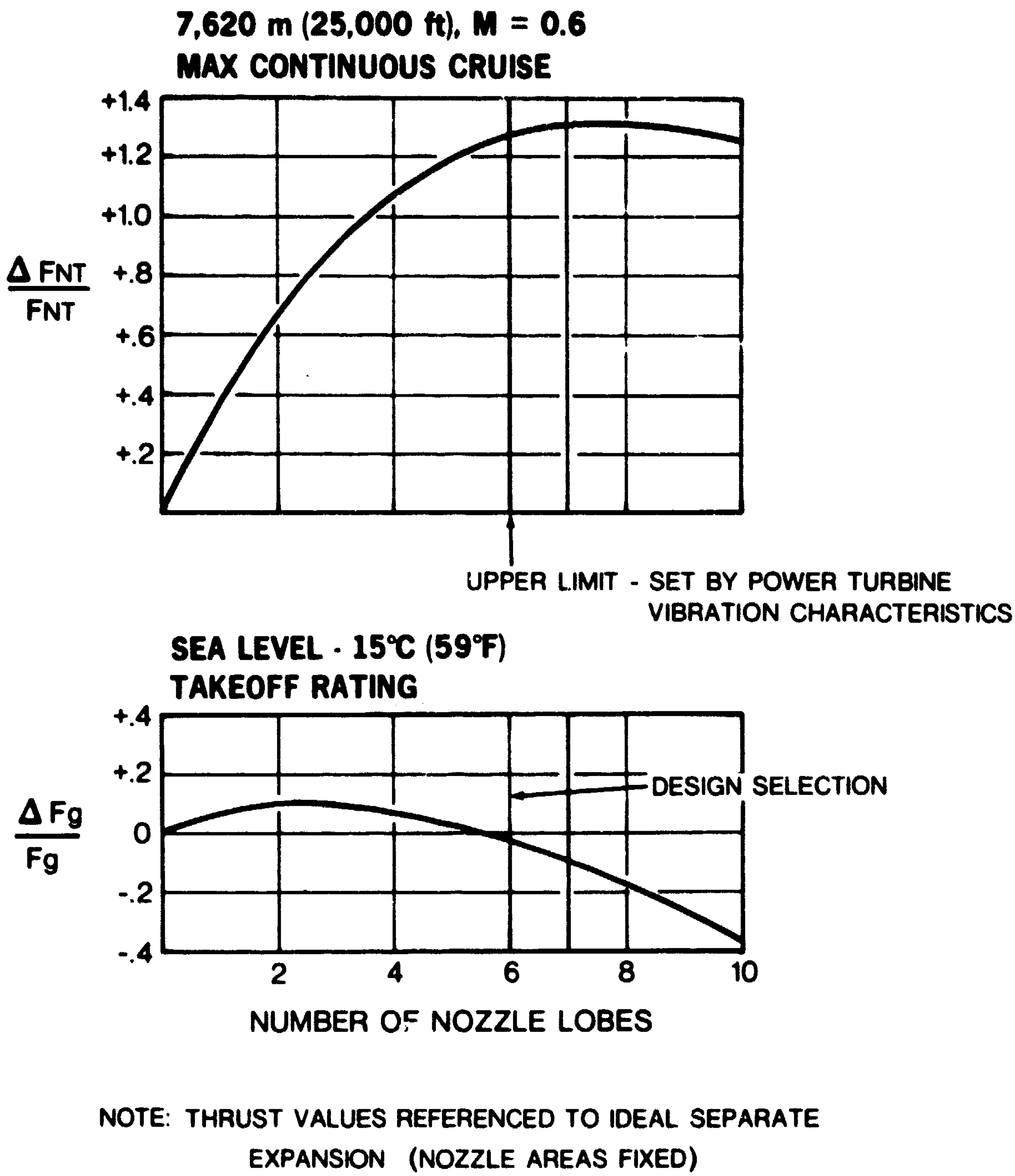


Figure 8. Mixer Lobe Number Selection.

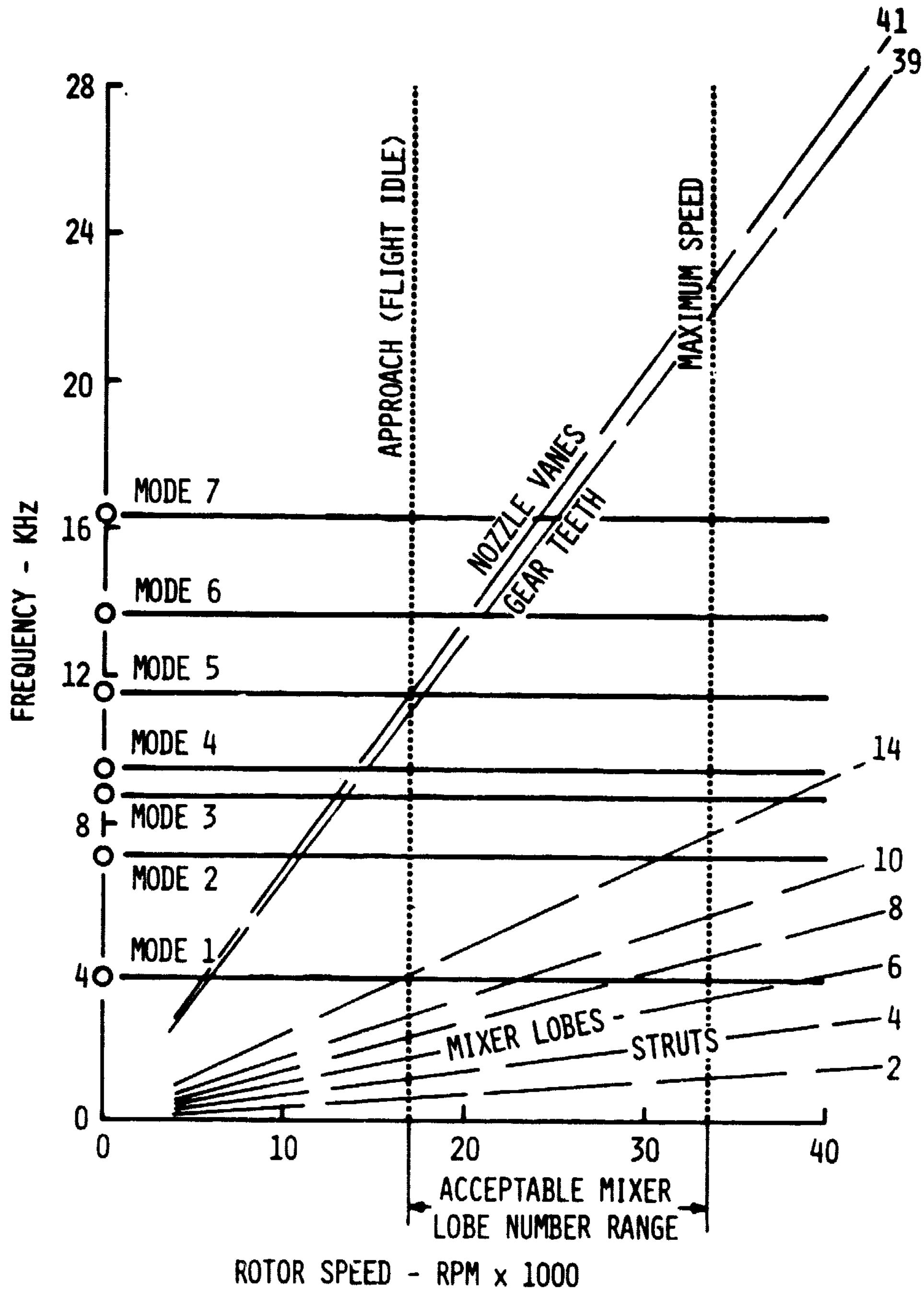


Figure 9. Power Turbine Blade Excitation Diagram.

thermal mixers and which has substantial test backup, also relates a stream-mixing function (Km) to a geometric interface function. The geometric interface functions are different in each analysis, as are the mixing effectiveness parameters. However, the two are related and, in essence, describe the same phenomena. Figure 10 presents Frost's correlation in terms of the Lycoming mixing parameter Km for both a six-and seven-lobe mixer configuration as a function of mixing chamber length-to-inlet hydraulic diameter. Using Figures 6 and 10, it is seen that for the QCGAT mixer configuration, a momentum-transfer function (Km) of 1.01 is equivalent to approximately 60 percent mixing effectiveness as defined by Frost.

The primary benefit of using the Lycoming analysis is that the programmed technique enables assessment of mixer performance as a function of engine operating power and flight condition. Parametric studies separating the effects of momentum transfer and friction drag can also be quickly performed.

Figure 11 presents results of such a study examining mixed total pressure loss of the QCGAT exhaust mixer-nozzle as a function of mixed total flow, the integrated momentum flux-to-average momentum flux at the mixing chamber exit. With the design Km of 1.01, the loss in mixed total pressure resulting from momentum transfer and wall friction is seen to be approximately 0.5 percent at the sea level takeoff rating. As can be determined from the Figure 11 study, this loss has the characteristic of varying linearly with the square of referred flow.

The loss in mixed total pressure because of partial mixing is only part of the loss assessment that must be performed for a total system analysis. As Figure 1 indicates, there is also a fan ducting and fan-side mixer nozzle loss. A similar loss occurs on the gas side of the mixer nozzle. Lycoming's experience with thermal mixer design, as well as the published data of a number of other investigators, i.e., References 5 and 6, provided guidelines in the design of the mixer nozzle, and aided the evaluation of the loss characteristics. Beyond these general guidelines, a two-dimensional meridional flow channel analysis was used to assess both main stream characteristics and local wall curvature effects to provide a minimum-loss design. Reference 6 suggests keeping the mixer lobe through angles 20 degrees or less from axial centerline and outer lobe wall angles 17 degrees or less. Figure 12 shows the final fan duct, mixing chamber, and final nozzle flow path obtained using the general design guidelines and channel analysis. Surface Mach numbers were examined as a function of surface

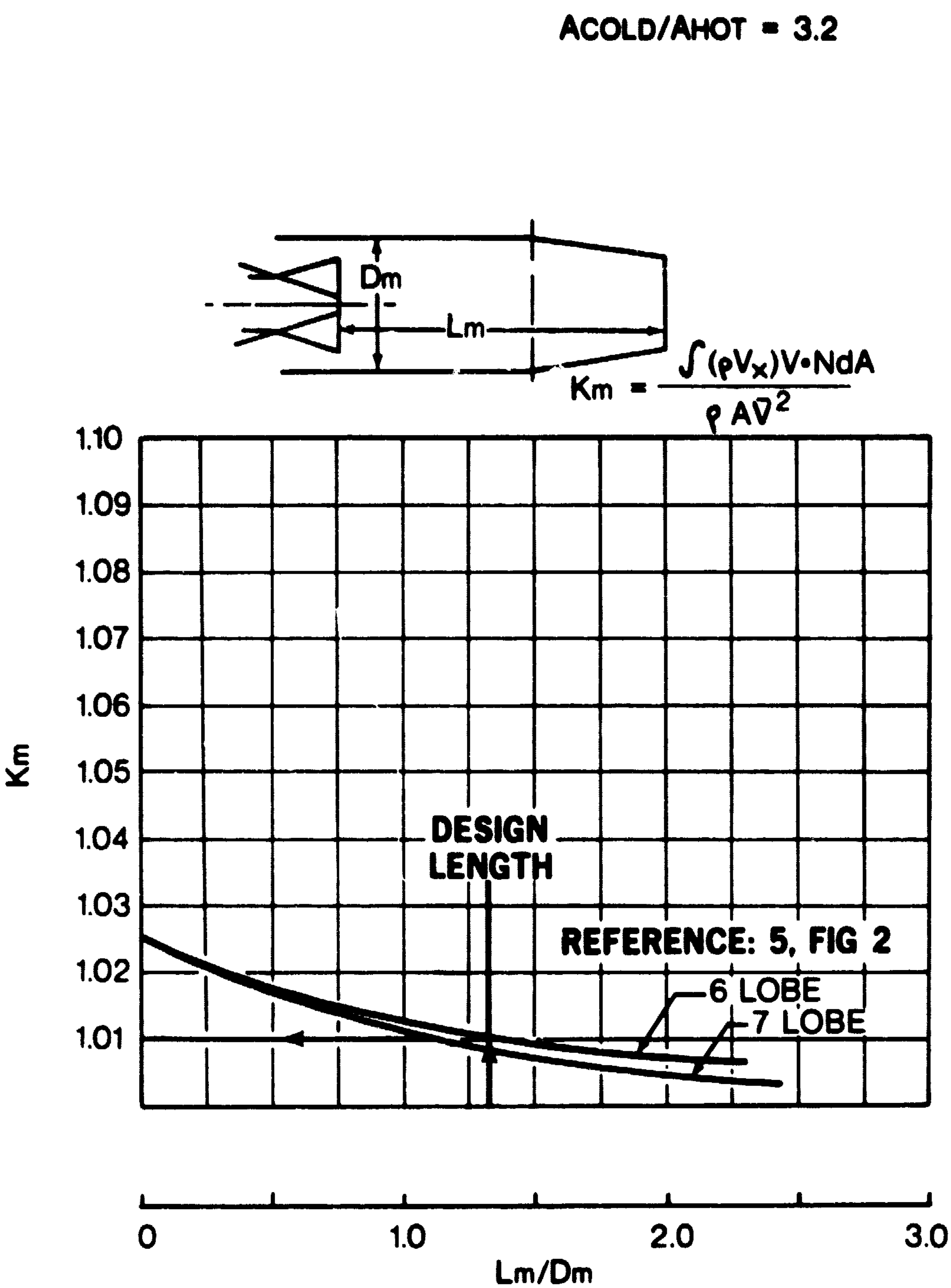
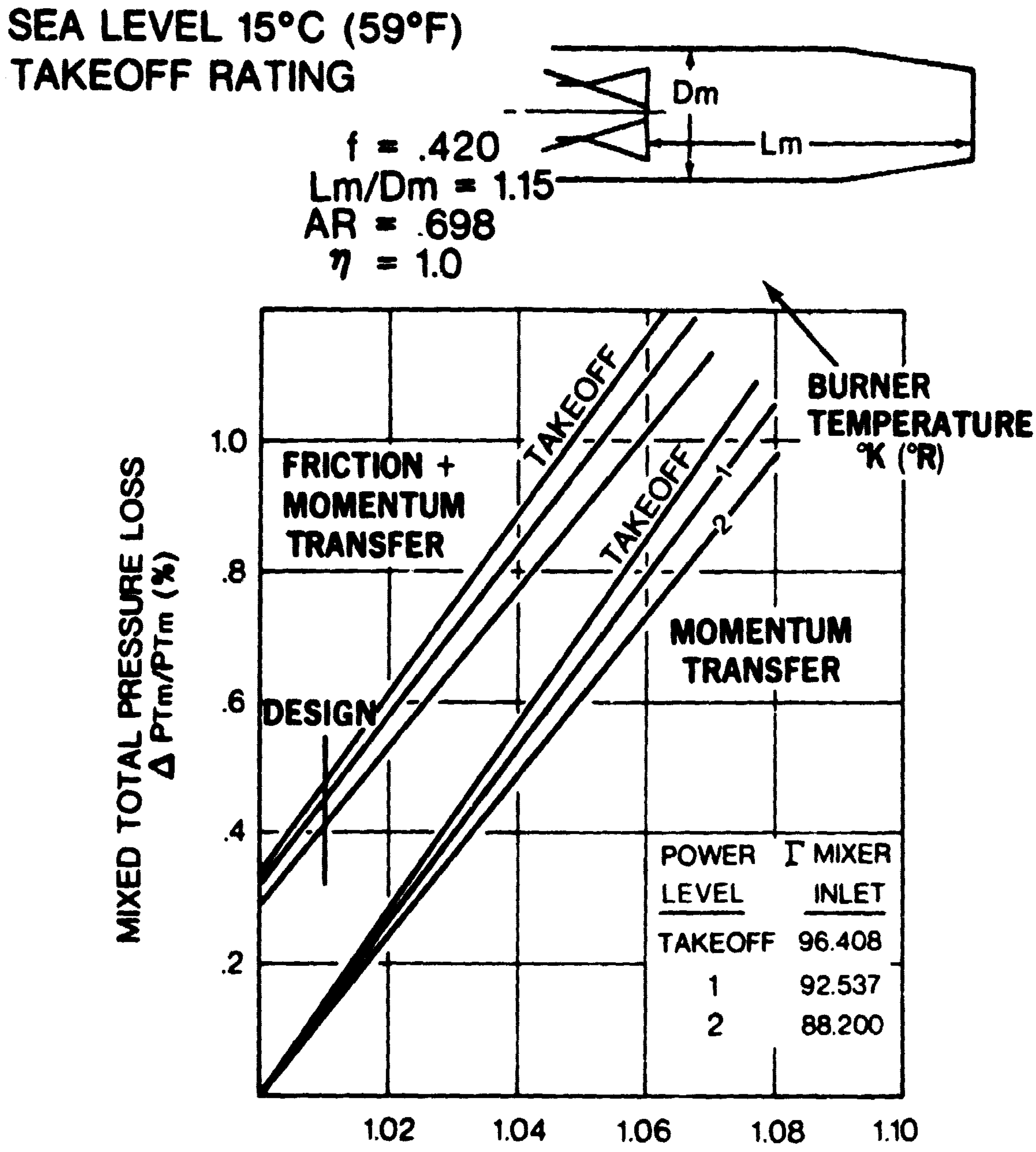


Figure 10. Mixing Factor Versus Mixing Length.



$$K_M = \frac{\int (\rho V_x)\, V \cdot N dA}{\rho A \bar{V}^2}$$

Figure 11. Mixer Total Pressure Loss Characteristic.

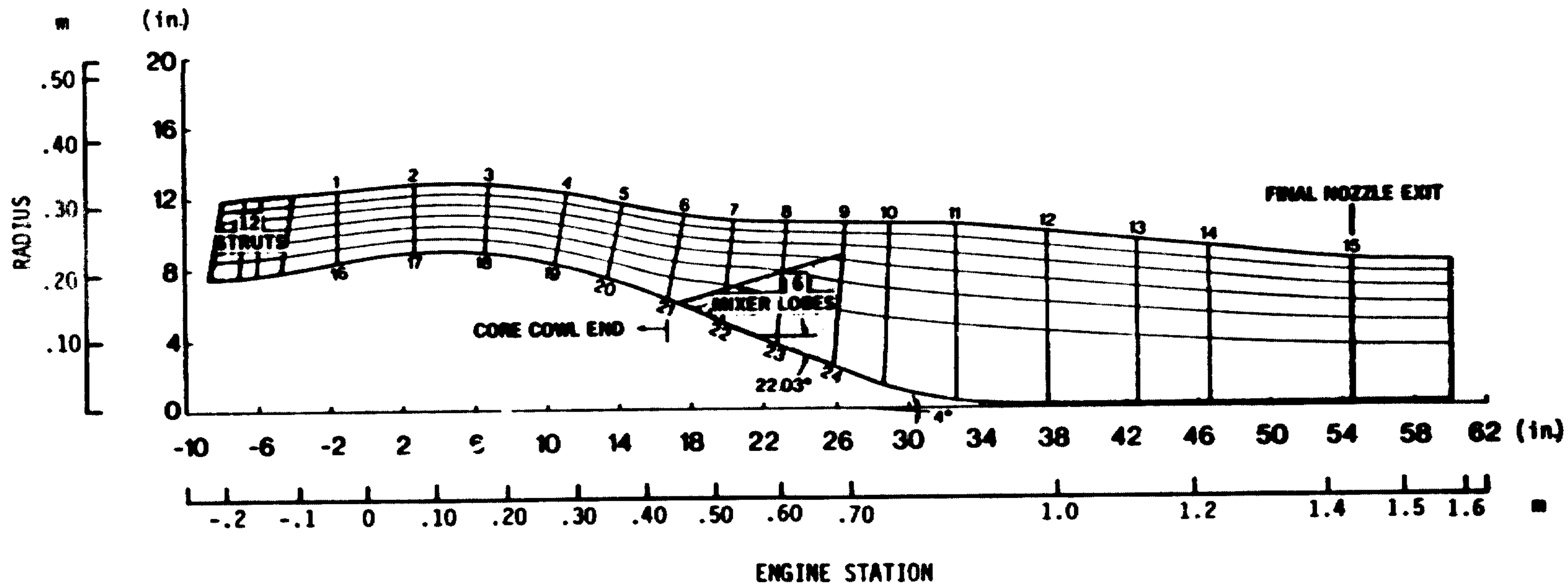


Figure 12. Fan Duct/Mixing Chamber/Final Nozzle Geometric Definition.

length and wall contours were modified to provide smooth flow transitions. The fan duct is essentially of constant area with an acceleration through the mixer lobes. Lycoming test experience, as well as the Reference 6 test experience, indicates that this provides more controlled flow with less losses when compared with diffusing flow. The fan duct total pressure loss from the fan exit plane to the mixer nozzle inlet plane was assessed using the test data from Reference 5 and recent NASA QSRA/YF102 engine test data to be 1.01 percent with the hardwall panel installed. When the sound-treatment panels were incorporated in place of the hardwall panels, the fan duct total pressure loss increased to 1.16 percent. Duct losses with the sound-treatment panels were assessed using guidance from Reference 7. These investigators essentially recommend a Fanning friction-loss calculation based on an increased surface relative roughness which is related to the sound treatment porosity and surface area. Duct losses for both hardwall and noise-treated ducts behave as a linear function of referred duct flow squared.

Final design lines for the gas side of the mixer nozzle are depicted in Figure 13. The area studies presented in Figure 3 indicated that an effective core mixer inlet area of 0.0484 m^2 (75 in.^{2}) would be optimum. The power turbine exit area which is only 0.0316 m^2 (49 in.^{2}) thus requires a diffusion. In this design, the diffusion was performed in an annular diffuser of appropriate length based on a well-proven design guideline (Reference 8). Flow through the mixer lobes was accomplished at constant area. Total pressure losses, based on the analysis in Reference 5 and similar mixer-lobe test experience, were assessed as 1.5 percent at the sea level takeoff rating. Again, the loss is a function of referred-flow squared.

Equally as important as the duct losses in terms of performance impact are the final mixed-nozzle velocity and flow characteristics. Reference 9 and in-house Lycoming test correlations were used to provide these operating characteristics. The Lycoming analysis is a curve-fit of a number of mixer-nozzle geometries that relate flow characteristic to geometry, pressure ratio and flight speed. Reference 9 experimentally investigated a multilobe exhaust mixer similar in terms of mixing function (Km) to the Lycoming QCGAT configuration. A number of operating pressure ratios and flight speeds were examined. Figure 14 presents the tested-nozzle flow characteristics of the Reference 9 investigation, along with the estimated performance of the Lycoming QCGAT. It should be noted that Reference 9 also investigated a confluent or "free mixer configuration". The more uniform "ideal" performance trend of the multilobe or forced mixer is clearly seen.

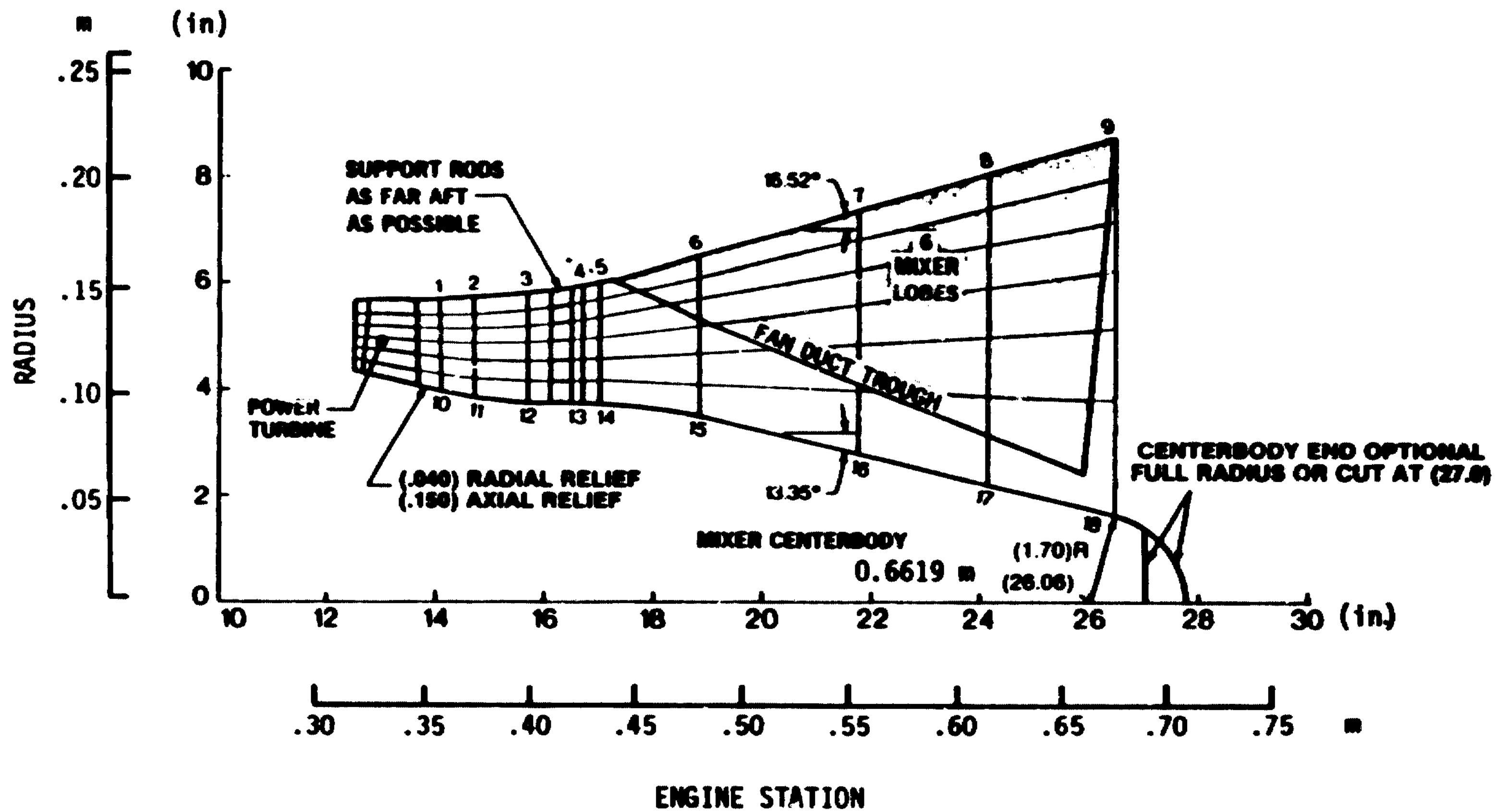


Figure 13. Core Engine Mixer Nozzle Geometric Definition.

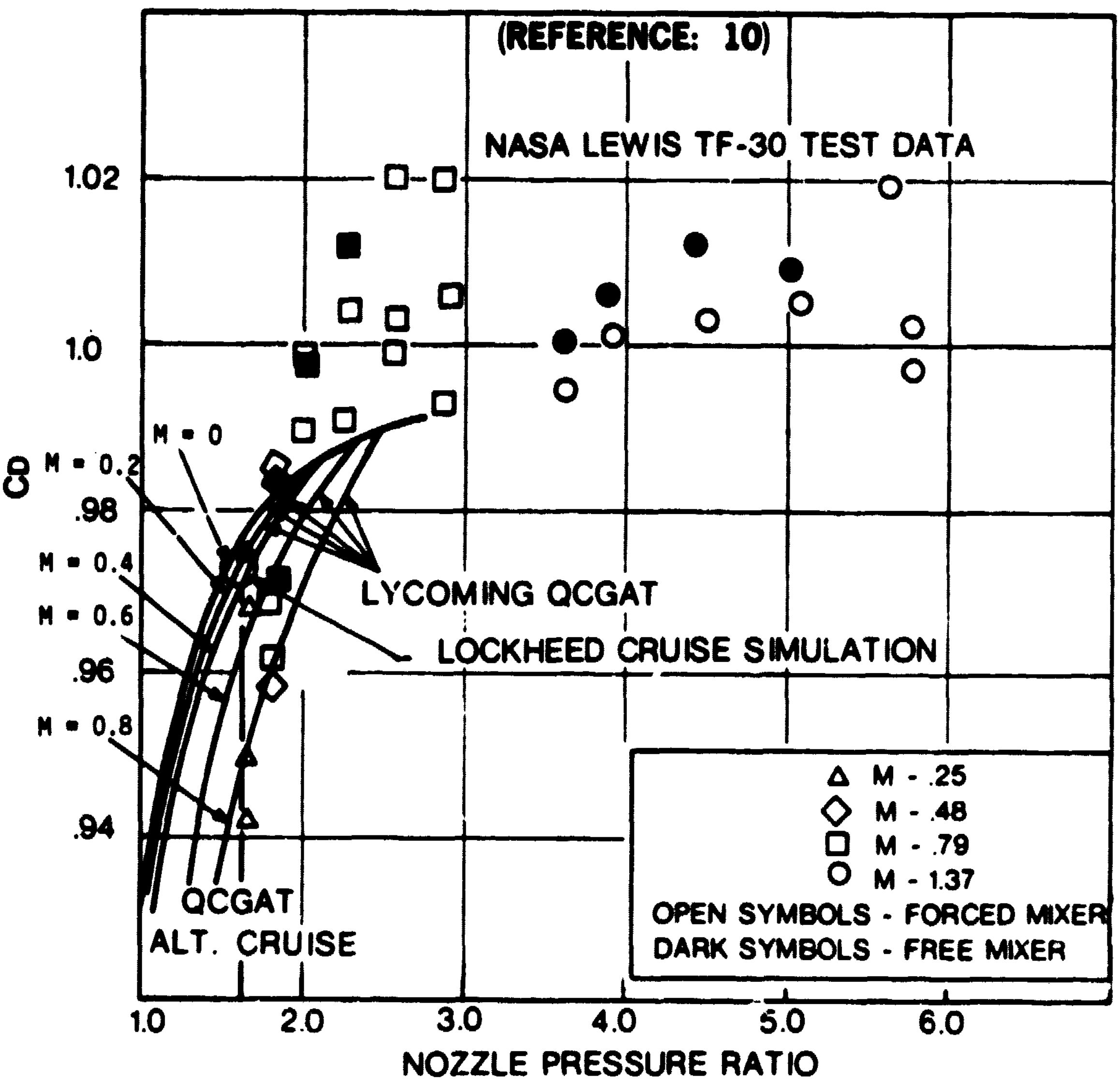


Figure 14. Mixer Exhaust Nozzle Flow Coefficients.

Figure 14 indicates the expected trends of increased C_D with nozzle pressure ratio and decreased C_D with increased flight speed. Figure 15 presents the corresponding C_V information. The increased efficiency of the Reference 9 forced mixer is clearly evidenced when compared with the confluent nozzle. The Lycoming QCGAT nozzle with high mixing effectiveness (low Km) is expected to be similar to the Reference 9 forced mixer.

Table 1 is a summary of the Lycoming QCGAT nozzle system geometry and aerodynamic performance. As indicated at the altitude cruise condition, a thrust specific fuel consumption reduction of 2.9 percent is obtained.

3.4 ACOUSTIC PERFORMANCE

A procedure to predict the noise suppression was constructed from the jet-noise prediction procedures given in Reference 4. First, a nonmixed, confluent exhaust configuration was assumed, and noise emissions were calculated. A second prediction was then made for a short mixing-length suppressor. The difference between these two noise predictions was then assumed to be the noise reduction of the mixer. As a check, noise predictions were also made for the single-jet case. The expected noise reduction will be bounded by these estimates and, as such, these predictions will define the limits of the expected noise suppression of the mixer.

The takeoff jet-noise emissions for a split-flow configured QCGAT engine are given in Table II. The jet-noise emissions, treating the mixed flow as a single jet, and the combined sound pressure levels for the suppressor configuration are also given on Table II. All of these are summarized on Figure 16.

The noise for a takeoff flyover is dominated by the jet noise component. Consequently, a reduction in the time-corrected perceived noise level (PNLT) will result in a corresponding reduction in the effective perceived noise level (EPNL) for the flyover event. Consequently, a 4 EPNdB reduction in the takeoff EPNL is estimated for the QCGAT engine with the mixer installed.

3.5 AIRCRAFT MISSION PERFORMANCE

The effect of the mixer nozzle on the gross weight, fuel consumption, and life-cycle cost of a typical twin-engine turbofan business aircraft is discussed below.

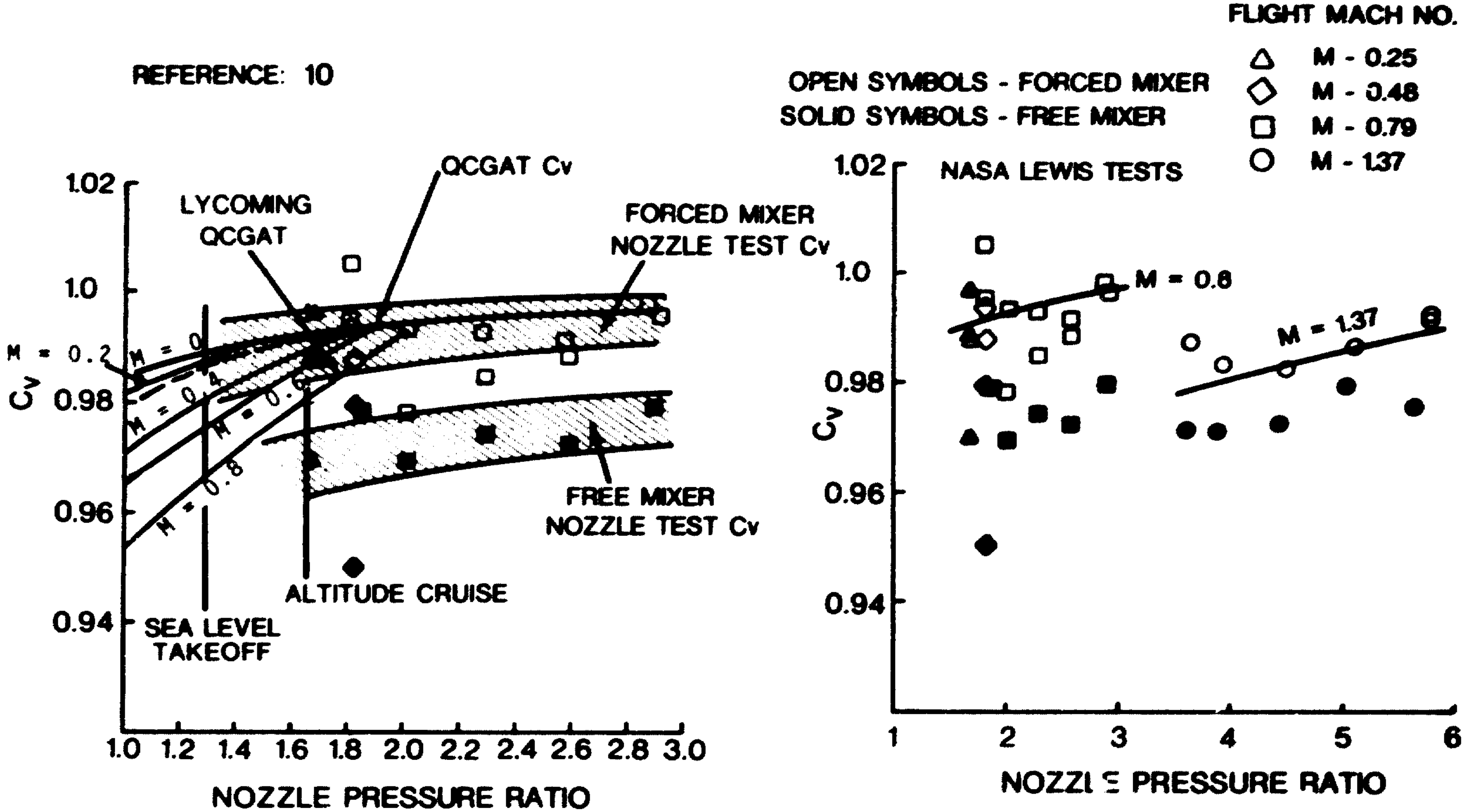


Figure 15. Exhaust Nozzle Velocity Coefficients.

TABLE 1. NASA QCGAT EXHAUST MIXING SUMMARY		
GEOMETRY	GEOMETRIC	EFFECTIVE
$A_{HOT\ DUCT\ INLET}$ $m^2(in^2)$	0.0516 (80)	0.0484 (75)
$A_{COLD\ DUCT\ INLET}$ $m^2(in^2)$	0.1645 (255)	0.1548 (240)
$A_{MIXER\ INLET}$ $m^2(in^2)$	0.2219 (344	--
$A_{NOZZLE\ EXIT}$ $m^2(in^2)$	0.1439 (223)	0.1387 (215)
CONSTANT AREA MIXING (L/D)	0.4	
TOTAL MIXING LENGTH (L/D)	1.29	
PERFORMANCE	SEA LEVEL TAKEOFF	25K. M = 0.6 MAX CONT
MIXER FLOW CONDITIONS		
HOT DUCT MIXER INLET		
P_t, rpm (psia)	126.2 (18.30)	58.6 (8.50
T_t, °K (°R)	910.2 (1653)	859 (1546)
W, Kg/sec(lbm/sec)	3.366 (7.42)	1682 (4.02)
M	0.26	0.29
COLD DUCT MIXER INLET		
P_t, rpm(psia)	133.3 (19.34)	64.26 (9.32)
T_t, °K (°R)	316.8 (570)	282.9 (509)
W, kg/sec (lbm/sec)	27.96 (61.64)	16.9 (37.21)
M	0.38	0.47

TABLE 1 - Continued

PERFORMANCE	SEA LEVEL TAKEOFF	25K. M = 0.6 MAX CONT
NOZZLE EXIT		
P_t, kPa (psia)	130.5 (18.93)	62.1 (9.01)
T_t, °K (°R)	386.3 (695)	342.9 (617)
W, kg/sec (lbm/sec)	31.3 (69.06)	18.7 (41.23)
M	0.61	0.87
DUCT P_t LOSSES		
BYPASS DUCT (%)	1.01	1.40
CORE DUCT (%)	1.48	1.89
MIXING P_t LOSS (%)	0.50	0.68
COMPARATIVE PERFORMANCE *		
THRUST (%)	2.1	3.1
TSFC (%)	-1.9	-2.9

*COMPARISON BASIS IS SPLIT NOZZLE

TABLE II. LIST OF MIXER SOUND PRESSURE LEVELS

AVCO LYCOMING QUIET CLEAN GENERAL AVIATION TURBOFAN NOISE EMISSIONS PREDICTIONS USING JET NOISE PREDICTIONS PROCEDURES FOR SUPPRESSORS
SOUND PRESSURE LEVELS AT 140 DEGREES FROM INLET CENTER-LINE AT 30 METERS

PROBE NUMBER	100% MIXING		SPLIT FIN EXHAUST		SIX ELEMENT SUPPRESSOR	
FREQ. HZ	SOUND PRESSURE LEVEL, dB RE: 20 MICROPASCALS AT 30.0 METERS					
25.0	77.8		70.1		67.5	
31.5	81.1	86.6	73.2	78.8	69.5	75.7
40.0	84.3		76.5		73.5	
50.0	86.4		79.3		76.5	
63.0	88.5	93.3	82.4	88.1	79.5	84.4
80.0	90.0		85.9		81.5	
100	91.1		89.0		85.5	
125.0	91.6	96.5	91.0	96.2	87.5	93.7
160.0	92.3		93.2		91.5	
200.0	92.3		94.8		92.5	
250.0	91.7	96.4	95.9	100.6	93.5	98.1
315.0	90.9		96.7		94.0	
400.0	90.0		97.2		94.1	
500.0	88.8	93.7	97.2	101.8	94.0	98.5
630.0	87.5		96.6		93.1	
800.0	86.0		95.7		92.0	
1000.0	84.7	89.6	94.9	99.6	90.8	95.6
1250.0	83.3		93.5		89.2	
1600.0	81.7		92.3		88.0	
2000.0	80.0	84.9	90.8	95.8	87.3	91.8
2500.0	78.0		89.4		85.3	
3150.0	77.3		87.9		82.5	
4000.0	75.8	80.7	86.2	91.3	81.0	85.8
5000.0	74.2		85.0		78.9	
6300.0	72.5		82.0		75.9	
8000.0	70.8	75.7	81.3	85.8	74.5	79.3
10000.0	68.6		79.5		72.5	
12500.0	66.6		77.3		69.5	

TABLE II - Continued

PROBE NUMBER / FREQ. HZ	100% MIXING		SPLIT FIN EXHAUST		SIX ELEMENT SUPPRESSOR	
	SOUND PRESSURE LEVEL, dB RE: 20 MICROPASCALS AT 30.0 METERS					
16000.0	65.2	70.1	75.7	80.8	67.5	72.6
20000.0	63.8		74.5		65.5	
OVERALL SPL, dB	101.8		106.6		103.4	
A-WEIGHT SL, dBA	95.1		103.9		100.1	
FNL, PNdB	108.5		116.1		112.1	
PNLT, PNdB	108.6		116.3		112.3	

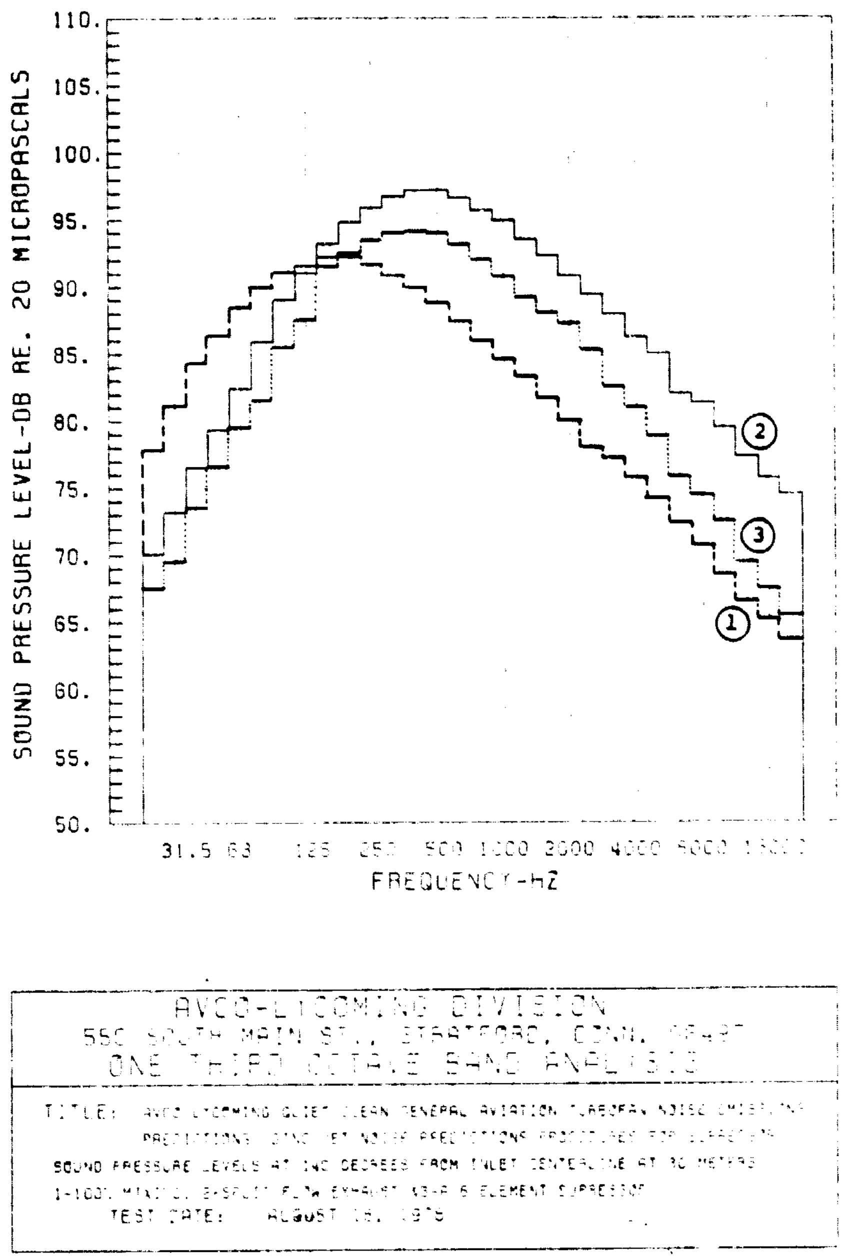


Figure 16. Mixer Sound Pressure Levels.

The aircraft shown in Figure 2 operated through a cruise mission at 7620 meters (25,000 feet) altitude and 0.6 Mach No. has been used as a basis evaluation.

The changes in gross weight and fuel consumption resulting from the use of a mixer nozzle system in place of a conventional, separate core and fan nozzle, or confluent nozzles are presented in Table III.

The nacelle with a mixer nozzle is 3.8 kilograms (8.5 pounds) heavier than that for a nonmixed exhaust system; this includes additional weight of the mixer nozzle and the longer nacelle. For the twin-engine aircraft, the additonal engine and nacelle weight is 7.7 kilograms (17 pounds), as shown in Table III. For the fixed payload, range, and altitude cruise condition, the total impact on aircraft gross weight is 19.5 kilograms (43 pounds). The SFC reduction applied to the range mission, using the available fuel of 975 kilograms (2,150 lbs), results in an overall fuel savings of 23.6 kilograms (52 pounds) and an aircraft gross weight savings of 40.8 kilograms (90 pounds).

The empty weight of the aircraft would be approximately the same for both types of exhaust-nozzle flow systems. However, the net fuel savings with the mixer nozzle results in an overall gross weight savings of 21.3 kilograms (47 pounds).

The mission fuel reduction of 19.9 kilograms (44 pounds) corresponds to about 7.61 liters (2.0 gallons) per hour of operation. Based on a fuel cost of 15.8 cents per liter (60 cents per gallon), the reduction in direct operating cost would be $1.2 per hour, which amounts to $18,000 for an aircraft life cycle of 15,000 hours.

4.0 MECHANICAL DESIGN AND FABRICATION

4.1 MECHANICAL ARRANGEMENT

The mixer nozzle, identified in Figure 17, provides the matched exit area for the core exhaust. The nozzle divides the core and fan exhaust streams into six separate segments to induce mixing of the two streams downstream of its exit plane. In addition, the mixer nozzle deflects the core exhaust segments outwards and the fan flow segment inwards to further promote the mixing process prior to the final combined exit flow to the free stream.

TABLE III. IMPACT OF MIXER ON AIRCRAFT WEIGHTS

(Compared With a Split or Confluent Nozzle System)

ENGINE PARAMETER CHANGES	RESULTING AIRCRAFT WEIGHT CHANGES kg (lb)		
	EMPTY WEIGHT	MISSION FUEL	GROSS WEIGHT
PROPULSION SYSTEM WEIGHT INCREASE (7.7 kg (17 lbs))	+15.9 (35)	+3.6 (8)	+19.5 (43)
(Mixer Nozzle & Extended Nacelle)			
MISSION SFC REDUCTION (2.4%)	-17.2 (38)	-23.6 (52)	-40.8 (90)
COWLING DRAG			
Effective Frontal Area	0	0	0
TOTAL CHANGE	-1.4 (3)	-19.9 (44)	-21.3 (47)

FIXED: FLIGHT CONDITION, SPEED, PAYLOAD, AND RANGE

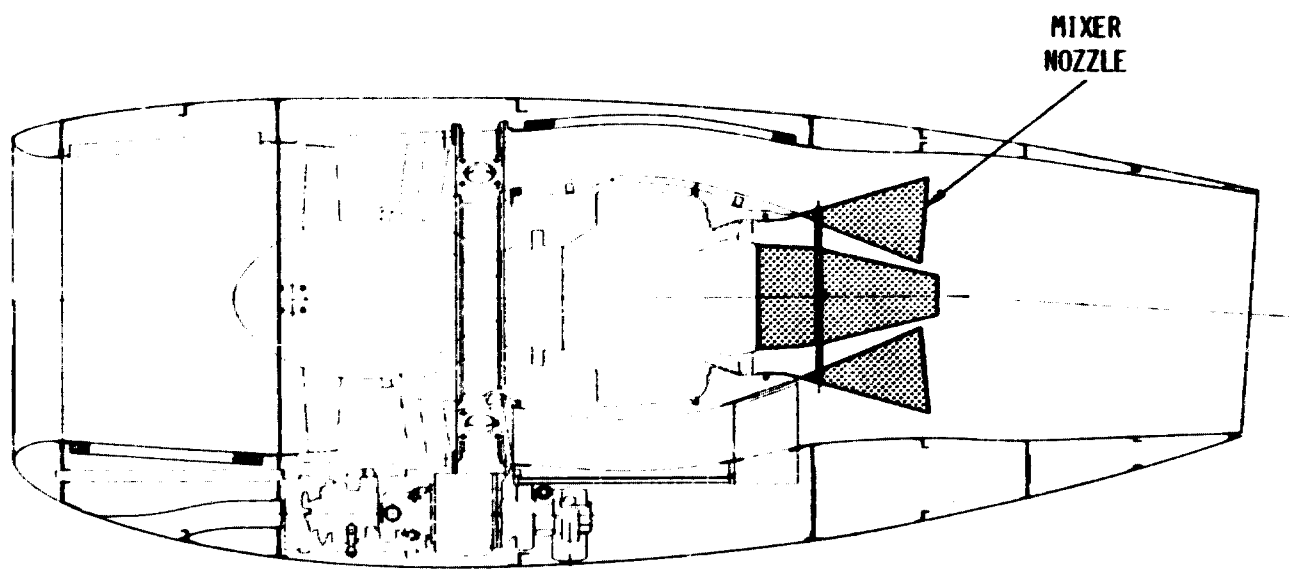


Figure 17. QCGAT Flight Nacelle.

The nozzle assembly comprises a fluted outer nozzle and a centerbody, as shown in Figure 18. The center body which forms the inner wall of the nozzle inlet annulus is attached to the outer portion by two support rods, as shown in Figure 18. This method of attachment provides radial freedom between the inner and outer components to accommodate thermal expansion, which has proved to be desirable in other Lycoming engine installations.

The flange on the outer component of the nozzle assembly is bolted to the mating flange on the turbine exit casing of the core engine (see Figures 17 and 18). A clearance is maintained between the up-stream free end of the nozzle core and the turbine exit hub to accommodate thermal expansion.

4.2 DETAIL DESIGN AND FABRICATION

The nozzle was designed to provide the desired areas under hot operating conditions. Details of the hot-nozzle geometry are shown in Figure 19. The corresponding geometry of the nozzle, when cold as required for manufacturing, is shown in Figure 20. The total nozzle assembly is constructed from 0.04 in. Inco 718 sheet and plate. The outer fluted component of the mixer nozzle and the inner core component are fabricated separately and then are attached together by the two support rods. The main fluted portion is made up of six elements. Each element comprises a segment extending from the longitudinal centerline of a fluted lobe to the centerline of the adjacent lobe, which includes one valley. These elements are shaped by form-block operations. The edges are then trimmed to provide a fore and aft joint line through each lobe. The elements are assembled into position in a jig and welded together along the lobe seams. The nozzle's mounting flange is machined from plate and welded to the nozzle in the same welding jig. Welding is accomplished in an inert atmosphere.

The inner core's centerbody is fabricated in a manner similar to that of the outer portion. Inner and outer components are assembled in their relative positions in a jig, and clearance holes to accommodate the attachment rods are drilled through both elements.

The two components of the nozzle finally go through a stress-relieve operation before being finally assembled by the attachment rods; they are then checked for cracks by dye-penetration inspection before and after the heat-treatment operation prior to final assembly.

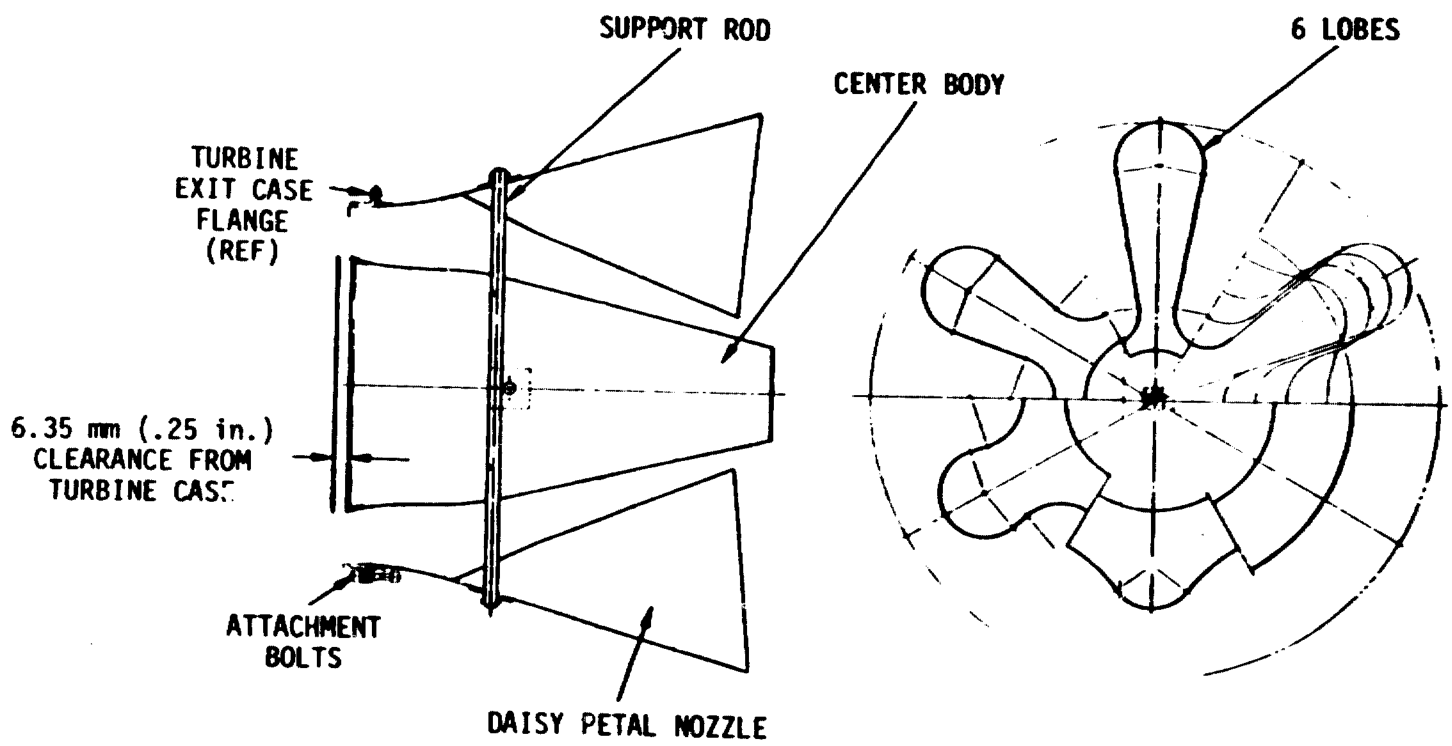


Figure 18. QCGAT Mixer Nozzle.

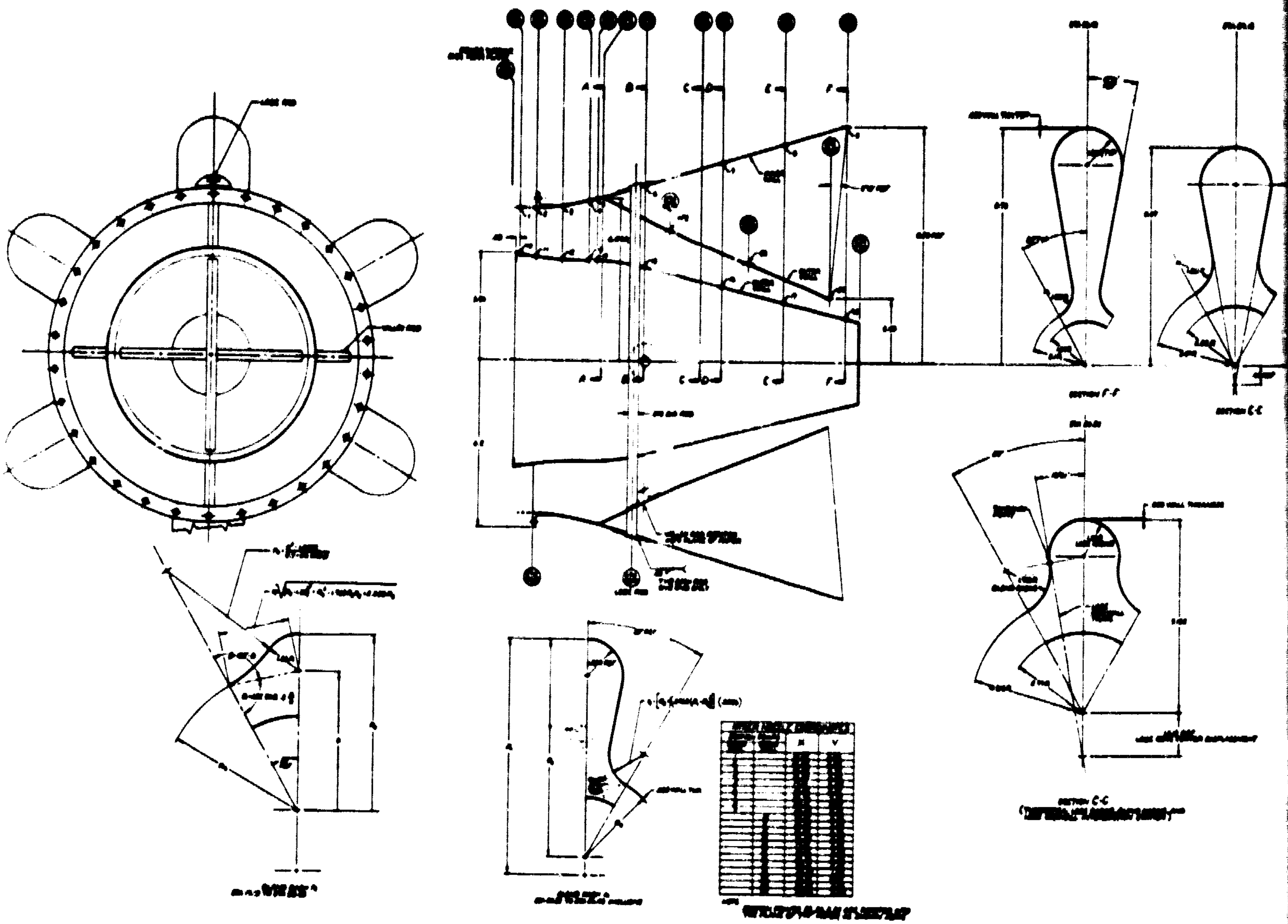
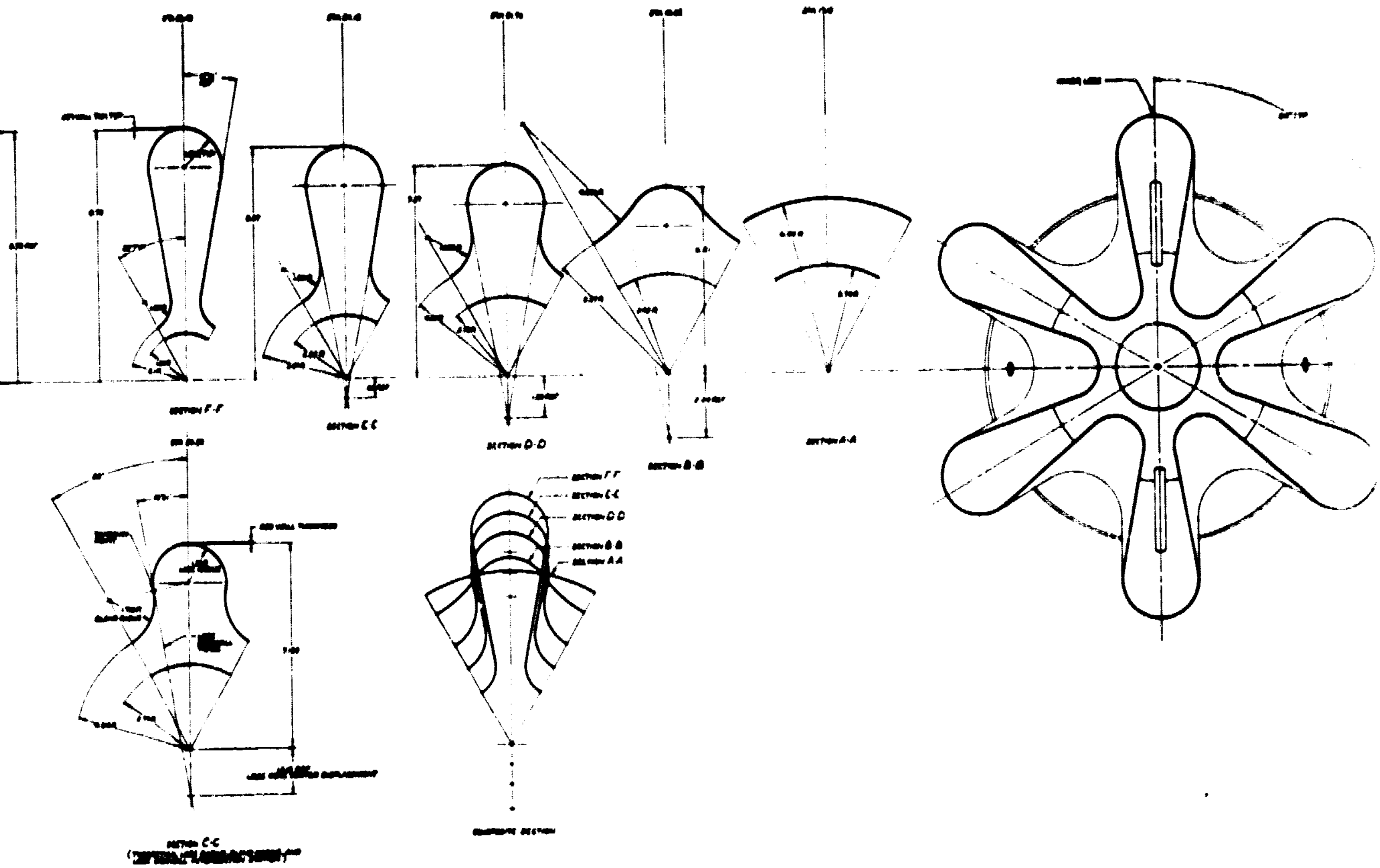
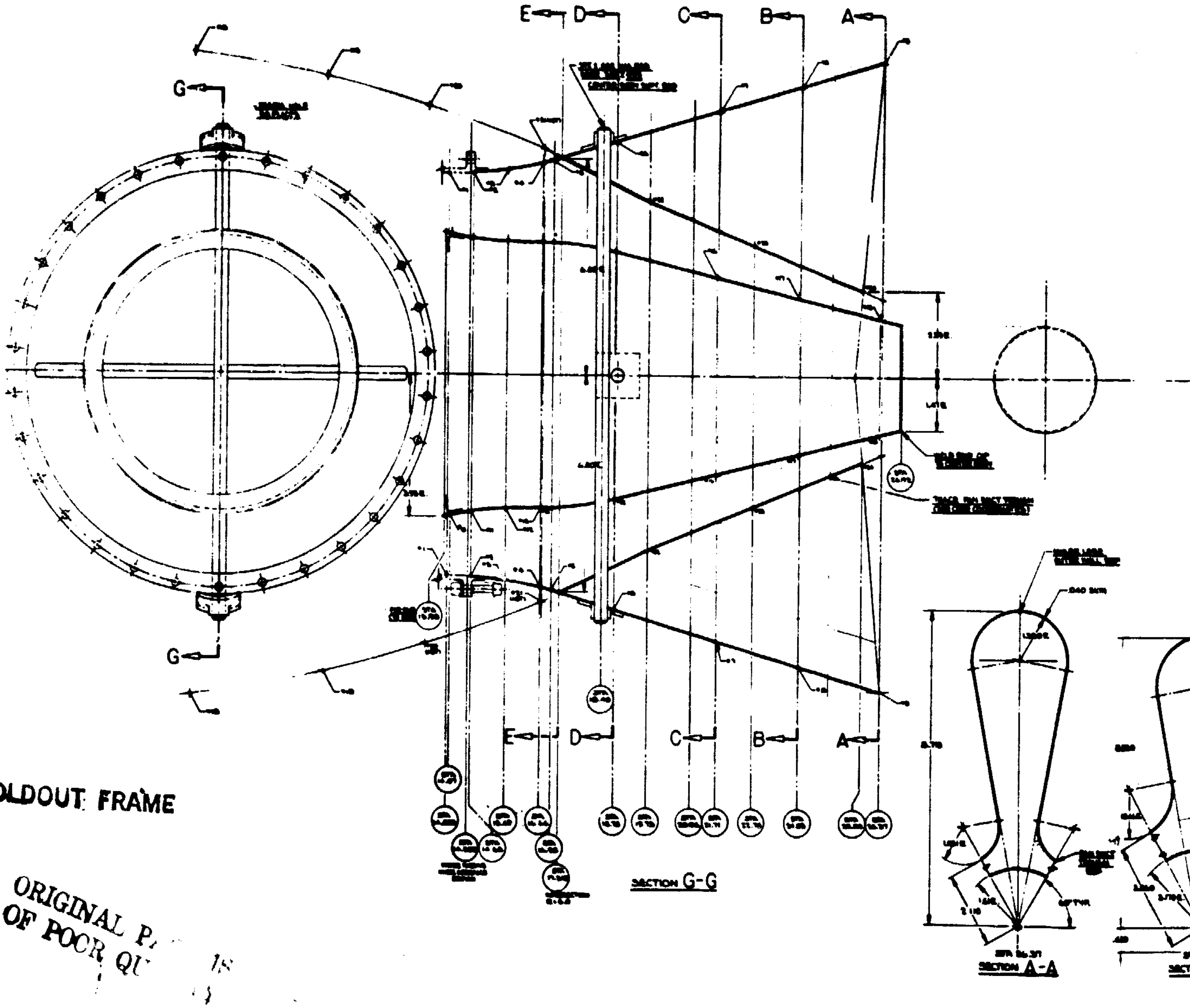


Figure 19. Mixer Nozzle Hot Geometry.



2 FOLDOUT FRAME

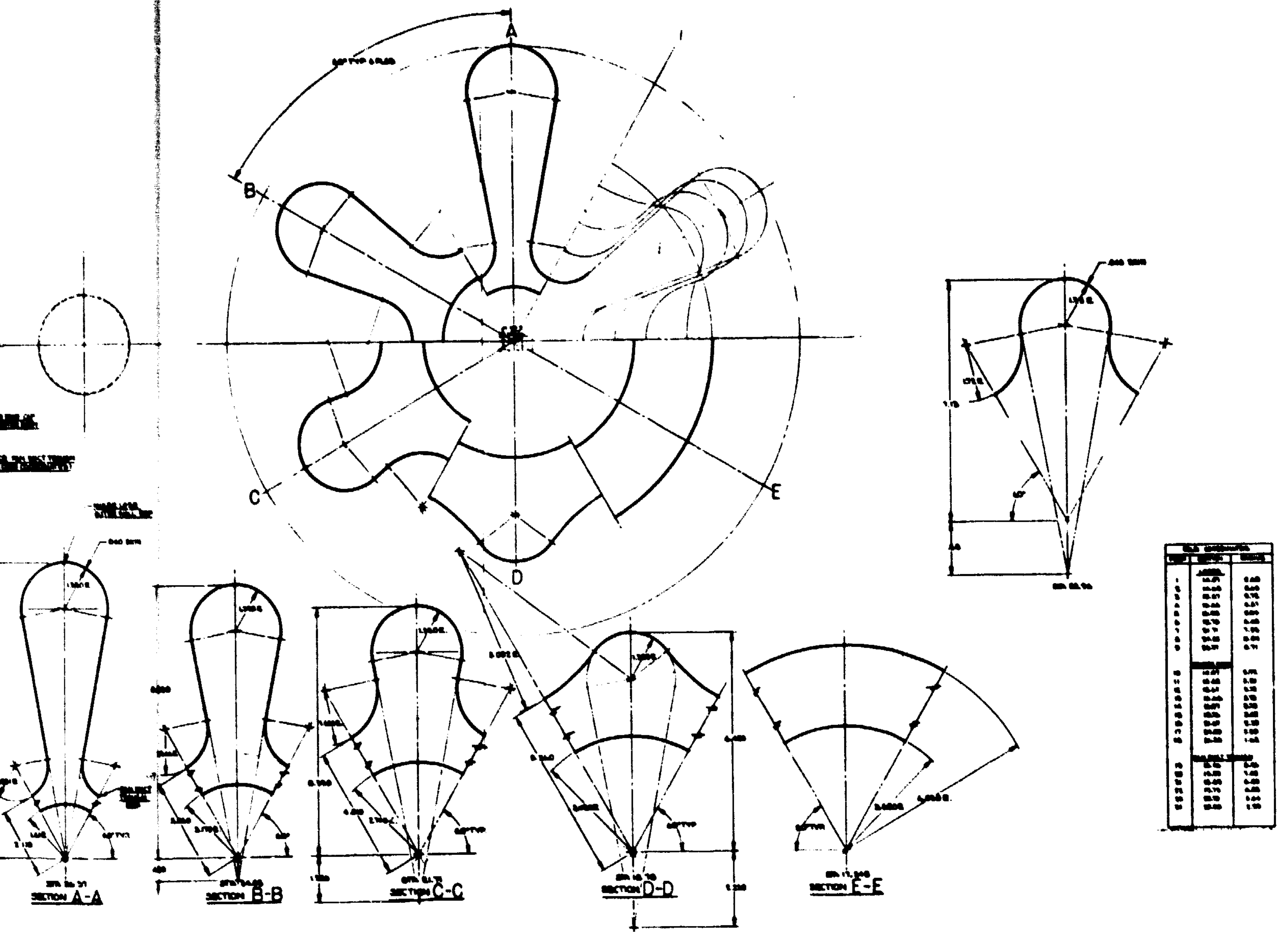


FOLDOUT FRAME

ORIGINAL P
OF POOR QU

PRECEDING PAGE BLANK NOT FILMED

Figure 20. Mixer Nozzle Cold Geometry for Fabrication.


A
B
C
D
E
SECTION A-A
SECTION B-B
SECTION C-C
SECTION D-D
SECTION E-E

REFERENCES

1. Dunn, D. G. and Peart, N. A., "AIRCRAFT NOISE SOURCE AND CONTOUR ESTIMATION", NASA CR 114649, July 1973.

2. Laurence, J. C. and Benninghoff, J. M., "TURBULENCE MEASUREMENTS IN MULTIPLE INTERFACING AIR JETS", NASA TN 4029.

3. Anderson, J. R., Redley, H. G., and Smith, J. W., "727 NOISE RETROFIT FEASIBILITY - VOLUME II: UPPER GOAL DESIGN AND GROUND TESTING", FAA-RD-72-40, II November 1972.

4. Stone, J. R., "INTERIM PREDUCTION METHOD FOR JET NOISE", NASA TM X71618.

5. Frost, T. H., "PRACTICAL BYPASS MIXING SYSTEMS FOR FAN JET AERO ENGINES", The Aeronautical Quarterly, May 1966.

6. Charmay, A., Edkins, D. P., Mishler, R. B., and Clapper, W. T., "DESIGN OF A TF34 TURBOFAN MIXER FOR REDUCTION OF FLAP IMPINGEMENT NOISE", NASA Lewis Report CR-120916, February 1972.

7. Wharton, H. E., "AVCO LYCOMING QUIET CLEAN GENERAL AVIATION TURBOFAN (QCGAT) ENGINE NACELLE SOUND ABSORPTION PANEL DESIGN", Lockheed California Company Report LR 28254, July 1977.

8. Sovran, G., and Klomp, E., "EXPERIMENTALLY DETERMINED OPTIMUM GEOMETRIES FOR RECTILINEAR DIFFUSER WITH RECTANGULAR, CONICAL OR ANNULAR CROSS SECTION", Fluid Mechanics of Internal Flow, Elsevior Publishing Company, 1967.

9. Cullom, R., and Johnson, R., "FULL SCALE ALTITUDE ENGINE TEST OF A TURBOFAN EXHAUST GAS FACED MIXER TO REDUCE THRUST SPECIFIC FUEL CONSUMPTION, NASA Lewis Technical Memorandum TM X-3568, July 1977.

10. Cullom, R. and Johnson, R. "ALTITUDE TEST OF A TURBOFAN EXHAUST MIXER TO CONSERVE FUEL" - ASME Paper 77-GT-97.

APPENDIX
LIST OF SYMBOLS

A	Flow area, m^2 ($in.^2$)
AR	Area ratio
C	Flow coefficient
D	Diameter, m (in.)
F	Thrust, N (lb_f)
f	Friction factor
K	Mixing function
L	Length, m (in.)
M	Mach number
N	Number of lobes
P	Pressure, kPa (psi),
	Perimeter, m (in.)
r	Radius, m (in.)
T	Temperature , ^oK (^oR)
TSFC	Specific Fuel Consumption kg/hr. Watt (lb/hr-HP)
V	Velocity, m/sec (ft/sec)
W	Mass flow, kg/sec (lbm/sec)
X	Thrust, N (lb_f)
r	Mixed total flow function
η	Diffuser Efficiency, %
θ	Secondary flow angular spacing, Degrees

ρ	Density, kg/m^3 (lb/ft^3)
ϕ	Primary flow angular spacing, degrees

SUBSCRIPTS

D	Drag
g	Gross
M	Mixed
m	Mixing
NT	Net
P	Partial
t	Total
U	Unmixed
V	Velocity
X	Axial
1	mixer inner radius
2	mixer outer radius
3	duct radius
4	Frost mixing function