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CONCEPTUAL DESIGN STUDY OF ADVANCED ACOUSTIC - COMPOSITE NACELLES

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16. ABSTRACT

Conceptual nacelle designs for wide bodied and for advanced technology transports were studied with the objective of achieving significant reductions in community noise with minimum penalties in airplane weight, cost, and operating expense by the application of advanced composite materials to nacelle structure and sound suppression elements.

Nacelle concepts using advanced liners, annular splitters, radial splitters, translating centerbody inlets, and mixed flow nozzles were evaluated and a preferred concept selected. A preliminary design study of the selected concept, a mixed flow nacelle with extended inlet and no splitters, was conducted and the effects on noise, direct operating cost, and return on investment determined.

The preliminary design study applied to the wide bodied transport showed that noise levels could be reduced to within 3 db of the noise floor (aircraft plus jet noise) at a penalty of 0.33% in direct operating cost. The application of advanced composites to the nacelle gave a weight savings of 15%. Recommendations for technology development were made.

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FOREWORD

This is the final report of a Conceptual Design Study of Advanced Acoustic-Composite Nacelles which was conducted from June 1974 through February, 1975.

The study was performed under Contract NAS 1-13233 for the NASA-Langley Research Center. Mr. Richard C. Dingeldein was the NASA Project Manager and Mr. Harry T. Norton, Jr. the NASA Deputy Project Manager.

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SECTION 1

SUMMARY

This study of the advanced acoustic composite nacelle was sponsored by the Langley Research Center of NASA and performed between June of 1974 and February of 1975. The primary contractor was the Lockheed-California Company who was supported by subcontracts with Rolls-Royce Limited and Pratt & Whitney Aircraft. TWA and the Woven Structures Division of HITCO also provided consultation and data.

This summary follows the arrangement of the report, which, in turn, reflects the general procedure of the study. The summary presents a brief statement of the procedures used, the results obtained, and references to the pertinent sections of the report.

1.1 OBJECTIVE - Section 2

The broad objective of the study is to define nacelle designs which achieve a significant reduction in community noise with a minimum penalty in airplane weight, cost, and operating expense by the use of advanced composite materials integrated into the nacelle primary structure and sound suppression elements.

1.2 APPROACH - Section 3

The study considers both the current wide body transport and an Advanced Technology Transport (ATT) intended for operational use in 1985. The study approach used is to establish a baseline configuration for each airplane and to determine the effects of various nacelle configurations on the noise reduction achieved, on the direct operating cost, and on the return on investment. The L-1011 equipped with the Rolls-Royce RB.211-22B engine is the baseline for the wide body study. The baseline ATT is a 200 passenger airplane designed for a range of 5556 km (3000 n mi) with a payload of 200 passengers and uses three Pratt & Whitney STF 433 engines.

The existence of a noise floor, a noise level created by the airframe and by jet noise, which cannot be treated by variations in the nacelle, is recognized.

Reducing engine generated noise to values below this floor is not productive, and by using this floor as a boundary for the attenuation desired, uneconomical and impractical configurations are avoided.

The acoustic composite nacelle studied for the wide body transport is treated as a production change with no accompanying changes in major airplane configuration. As the ATT is entirely in the future, the studies maintain a constant design point and the entire airplane is reoptimized for each of the candidate nacelles. The changes in wing, fuselage, and other components of the airplane are accounted for and reflected in the Direct Operating Cost (DOC) and Return on Investment (ROI) figures.

Several candidate concepts are first evaluated for their potential noise vs cost performance. The most promising is then examined in the preliminary design study.

1.3 CONCEPT EVALUATION - Section 4

The various concepts examined for achieving the suppression goals are illustrated in Figure 1 and compared with the baseline proportions of the wide body nacelle. These concepts present a progressive increase in noise suppression capability and in complexity.

The acoustic and cost effects of the various wide body configurations are summarized in Figure 2. It is evident that only those configurations that incorporate extensive treatments in the inlet, the fan duct, and in the tail pipe achieve appreciable noise reductions. It is also evident that the penalty in direct operating cost due to the added length, weight and increased fuel consumption of the longer nacelles is markedly less for the mixed flow than for any other type. The mixed flow nozzle with the long inlet is therefore chosen for the more detailed preliminary design task which is used as a basis for the cost and technology development phases of the study.

The ATT nacelles, shown in Figure 3, also require extensive treatment in all three areas, inlet, fan duct, and tail pipe. As the STF 433 engine is designed specifically for one mission and to meet FAR 36 without treatment, the core and fan velocities are matched at takeoff for minimum noise and the fan pressure ratio at cruise is selected for minimum fuel consumption. The resulting tail pipe pressures in the fan and core jet are too different for efficient mixing, so the mixed flow nozzle is not considered for the ATT airplanes.

1.4 PRELIMINARY DESIGN - Section 5

The nacelle configuration for the wide body airplane resulting from the preliminary design study is shown in Figure 4. This nacelle differs from the mixed flow conceptual design shown in Figure 1 in that the inlet is shorter and uses broadband liners, liners of high acoustic resistance with aerodynamically smooth surfaces are used in the inlet and fan duct, and a broader application of composite materials is incorporated. The core noise is treated by the liner in the aft end of the nozzle. This liner features a series of small horns rather than the conventional honeycomb core and achieves low frequency suppression with minimum depth. This liner is shown in Figure 82 and the acoustical concept is described in Appendix B.

A minimum fuel configuration is derived from the above nacelle by reducing inlet length and removing some acoustic treatment. This nacelle reduces the baseline fuel flow by about 1%, but the noise reduction is only 1.5 dB.

1.5 ACOUSTIC ANALYSIS - Section 6

The acoustic composite nacelle on the wide bodied transport reduces the approach noise to 9.4 EPNdB below the FAR 36 requirement, a reduction of 5.3 EPNdB from the baseline value. The area enclosed by the 90 EPNdB contour is reduced by 45%. The source noise suppression, the EPNL values, and the footprints are shown in Figures 5 through 6, Table 1, Figures 7 and 8, and Table 2.

The ATT approach noise is reduced to 10.3 EPNdB below the FAR 36 requirement; the ATT noise data is summarized in Tables 1 and 2 and Figures 9 through 12.

1.6 COMPOSITE STRUCTURE - Sections 8, 9, 10

Composite materials are used in the primary shell of the nacelle, the suppression liners, the frames and beams supporting the thrust reverser and for many parts of the thrust reverser and mechanism. The exterior shell, which is designed by durability considerations, consists of composite skins using graphite and Kevlar outer layers supported by syntactic resin. The impact tests conducted on this type of laminate and on various sandwich configurations sized for the outer shell of the inlet show that this arrangement provides impact resistance equivalent to the .040 aluminum used in the baseline. The sandwich types, because of the very thin skins and the poor support offered by the honeycomb core, suffered severe damage from both blunt instruments and screw drivers dropped from working level heights.

Although the repair frequency for the selected panel design is expected to be comparable to that for metal, a need for reliable inspection and economical repair techniques is indicated. The possibility of sub-surface delamination or fiber damage makes a fail safe capability desirable in critical areas.

The use of composite materials, primarily graphite-epoxy, in the baseline nacelle reduces the weight by 15%. The cost study of Section 10 shows that this application of composites has little effect on manufacturing cost as the higher material costs are balanced by savings in assembly time. Composite material costs of $44/kg ($20/lb) in the 1980 time period are anticipated in this cost study. The nacelle shell design in composites uses concepts that have been developed in prior work, but the application of composites to mechanical parts, to the thrust reverser supports, and to parts exposed to high temperature requires further development. About half of the weight savings expected are available in current state-of-the-composite components.

1.7 ECONOMIC EVALUATION - Section 11

The economic evaluation is made using ATA methods supplemented by airline data. The effect of each complete configuration is determined in terms of direct operating cost and return on investment; and, for use in tradeoff studies, the increment of DOC attributable to each of the major design parameters is also determined. These sensitivities are shown in Figure 13 for 6.87¢/liter (26¢/gal) fuel. The chart shows the increment in DOC that would occur for a change in the specified parameter with all other parameters held constant. The specific fuel consumption, weight, and cost excursions shown represent the expected impact of advanced technology.

The change in direct operating cost for each configuration is shown in Table 3. The effect of fuel cost on the direct operating cost for mixed flow configuration is shown in Figure 14.

1.8 CONCLUSIONS

The conclusions drawn from this study are:

- The total community noise can be reduced to values close to the noise floors created by airframe and jet noise for both the wide body and the ATT.
- The wide body noise reduction is possible with a penalty of 0.33% in DOC.
- The effect of the acoustic-composite nacelle on the ATT are shown on Table 4.

- Broadband liners are effective in the inlet to reduce buzz-saw and other types of low frequency noise. A particular broadband liner "Schizophonium" is effective in suppressing low frequency core noise using the depth available in nozzle shell.

- Achieving the desired inlet liner performance requires face sheets of 4 ρc resistance and high linearity. Such facings, which are also aerodynamically smooth, are available in felted metals. Similar performance at less weight and cost is anticipated by the development of composite facings.

- The construction of the acoustic composite nacelle with the above performance is possible with some extension and verification of the present state of the art. Neither fundamental research nor any break-through is required.

Specific technology development activities needed are:

- Long-term demonstration in service of the ability of composite materials to perform in the acoustic environment of the nacelle and to be economically maintained.

- Development of light, economical composite panels with high acoustic resistance, linearity, and smooth surfaces for use in suppression panels.

- Development of economical techniques for applying composite materials to mechanical components and for processing high temperature resins.

- Verification of the performance of broadband liners in the inlet environment.

- Refined analysis techniques for determining mixing chute losses, mixing length and area ratio effects on mixing effectiveness, tradeoffs of mixing length, performance, and weight.

- The funding requirements for this development are shown in Figure 15.

WIDE BODY NACELLE CONFIGURATIONS

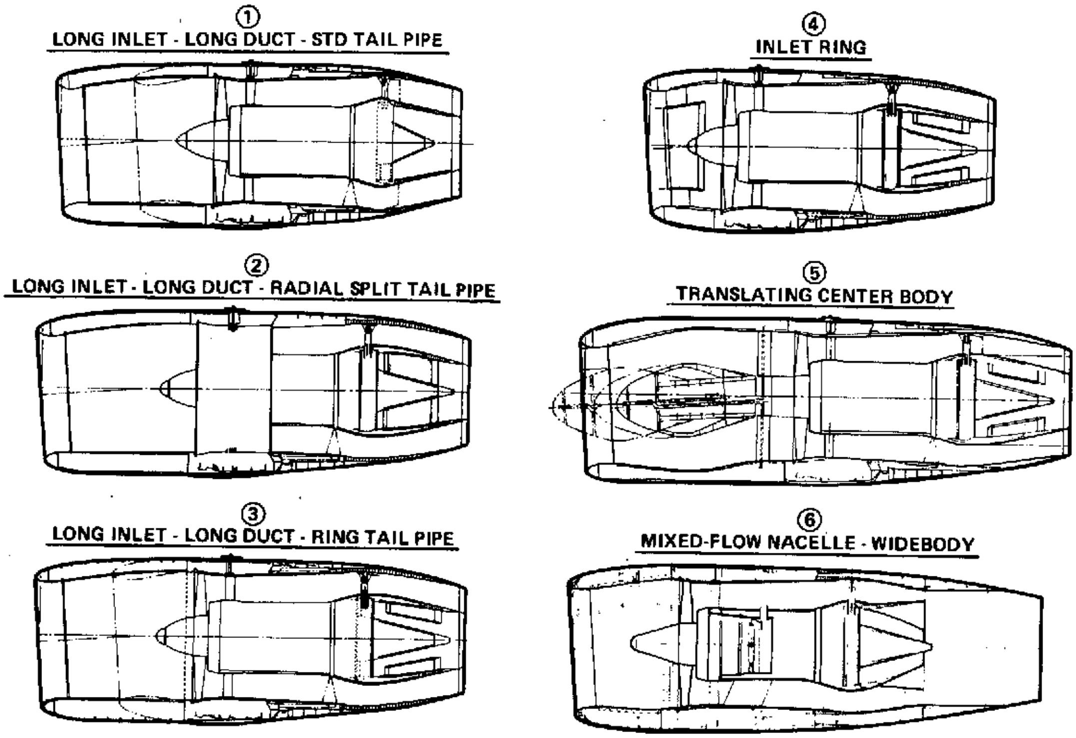

FIGURE 1

WIDE-BODY CONFIGURATION EVALUATION

5556 km (3000 NM) 6.9 ¢/LITER (26 ¢/GAL) FUEL

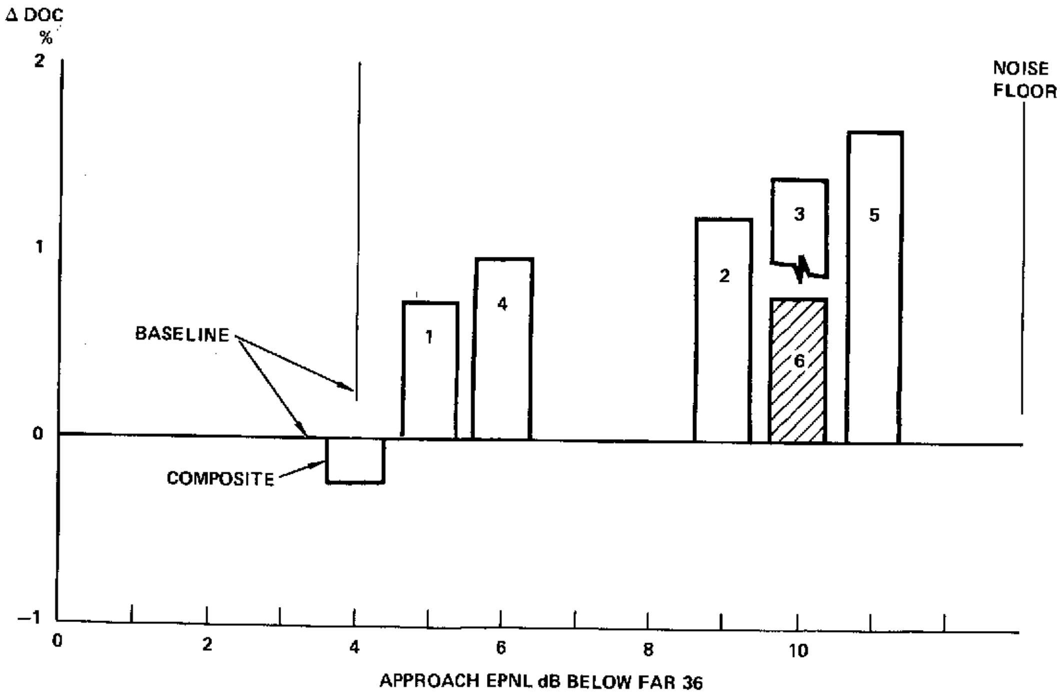

FIGURE 2

ATT NACELLE CONFIGURATIONS

LONG INLET - LONG DUCT - LONG TAIL PIPE - ATT

m (in)

TRANSLATING CENTER BODY - ATT

m (in)

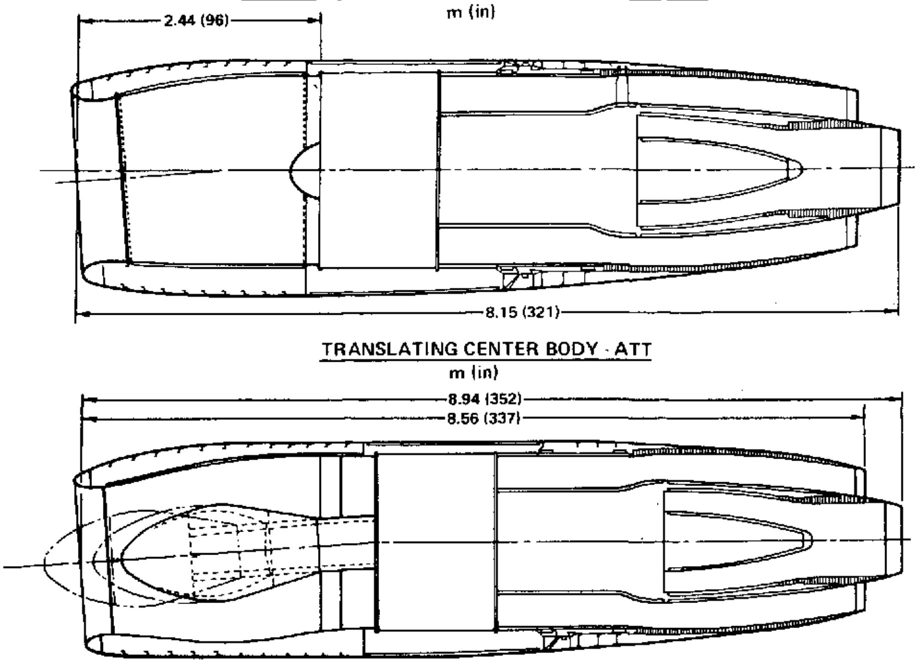

FIGURE 3

PRELIMINARY DESIGN MIXED - FLOW NACELLE - WIDE-BODY

m (in.)

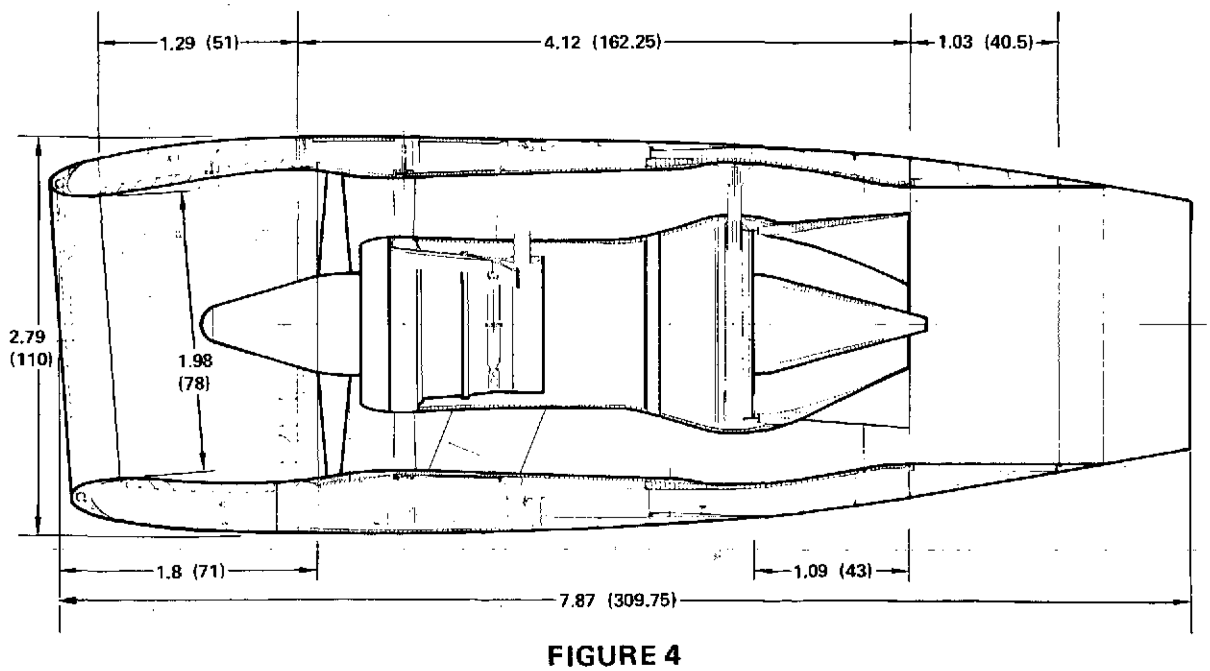

FIGURE 4

NOISE SUPPRESSION

WIDE - BODY AIRCRAFT - APPROACH

(FREE FIELD)

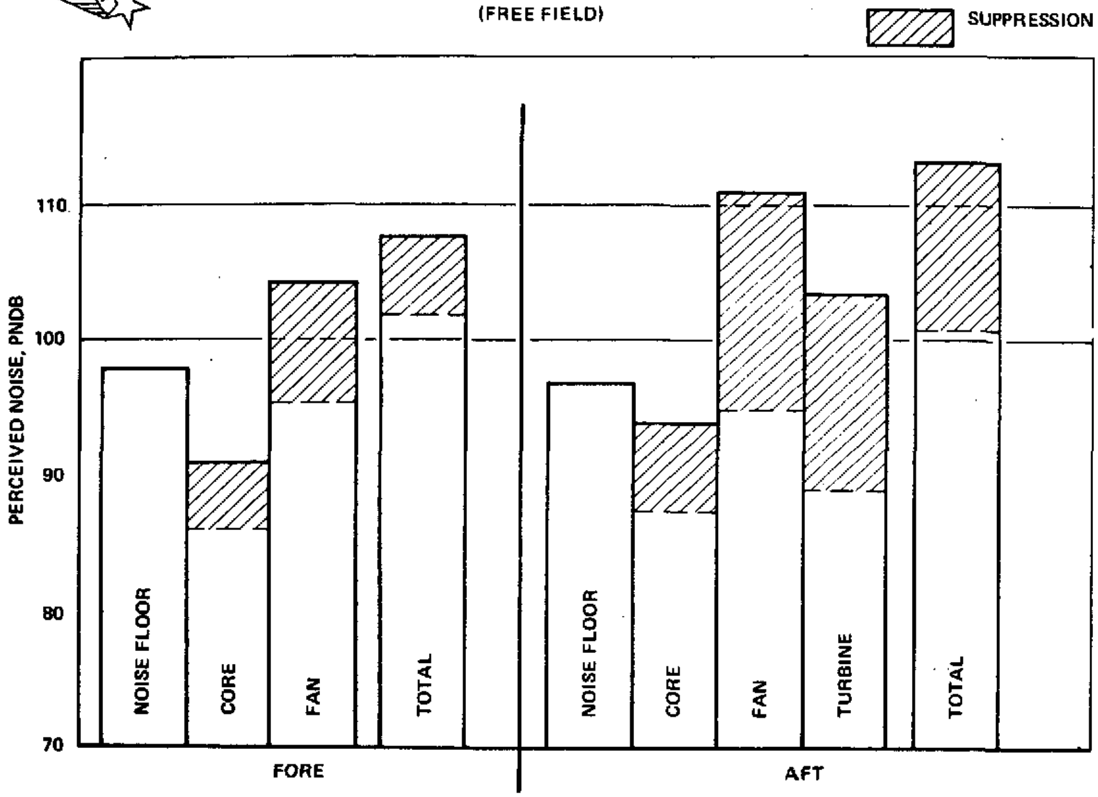

FIGURE 5

NOISE SUPPRESSION

WIDE BODY AIRCRAFT-TAKEOFF

(FREE FIELD)

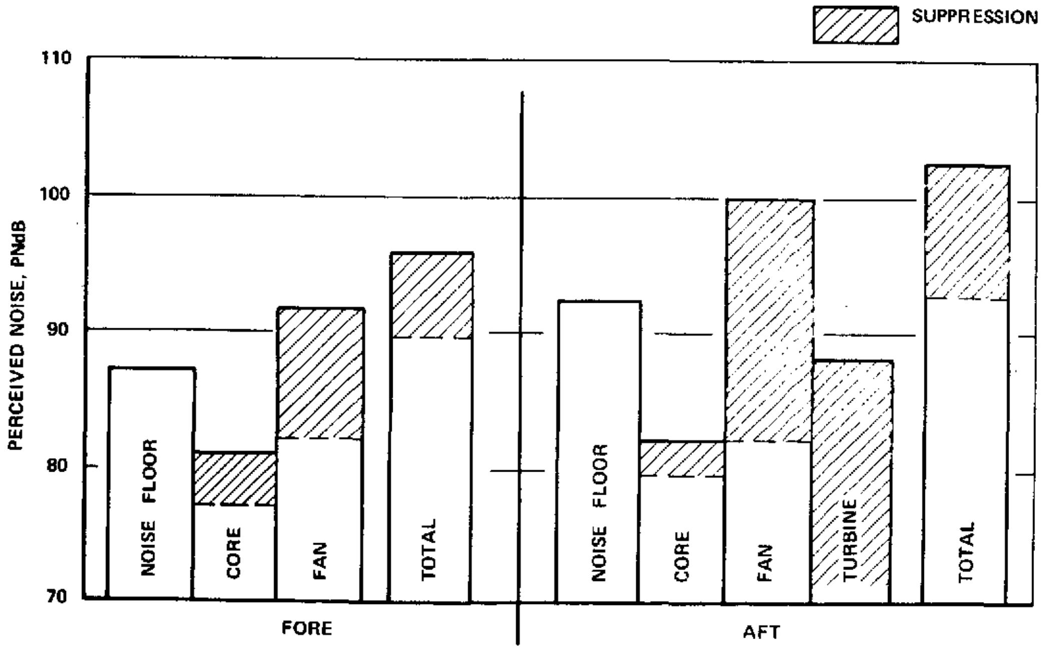

FIGURE 6

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NOISE SUPPRESSION SUMMARY

EPNL

	WIDE BODY			ATT	
	FAR PART 36 LIMIT	CERTIFIED LEVELS	WITH QUIET COMPOSITE NACELLE	FAR PART 36 LIMIT	WITH QUIET COMPOSITE NACELLE
TAKE OFF	105.6	96.2	93.3	103	94.2
APPROACH	107.0	102.9	97.6	106	95.7
SIDELINE	107.0	95.0	92.1	106	92.8

TABLE 1

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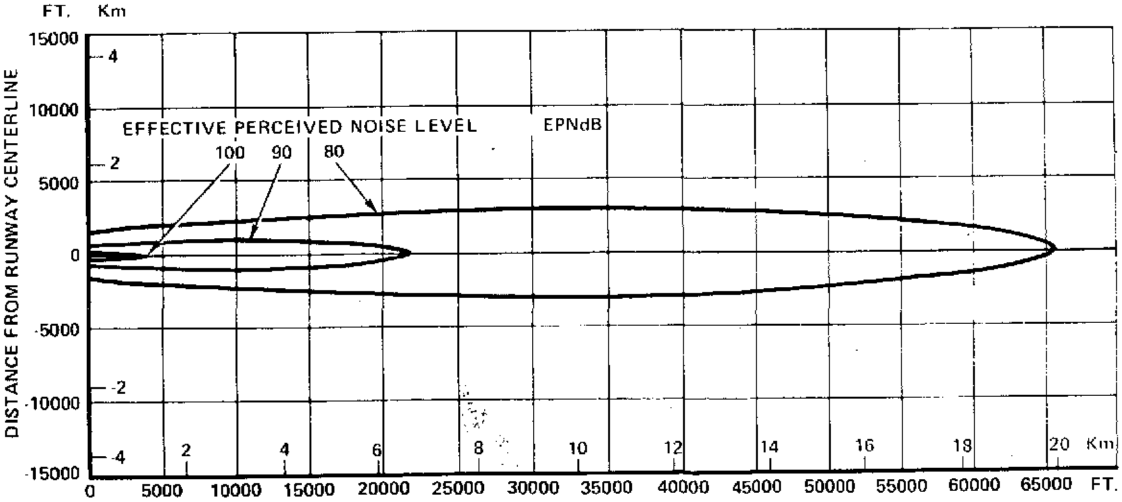
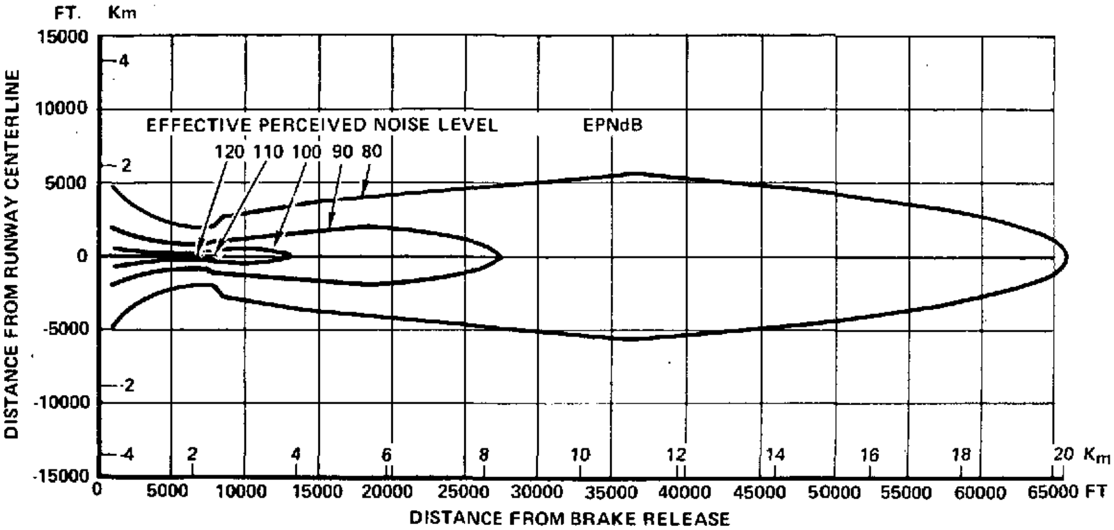
WIDE-BODY NOISE CONTOURS
APPROACH



CONTOUR PLOTS
L-1011-1/RB.211-228 WITH COMPOSITE NACELLE
SEA LEVEL, 25 DEG. C., 70% RELATIVE HUMIDITY
162385 Kg (358000 LB) LANDING WEIGHT, 42 DEG. FLAPS. 1.3V STALL + 10 KNOTS

FIGURE 7

WIDE BODY NOISE CONTOURS
TAKE-OFF



CONTOUR PLOTS
L-1011-1/RB.211-22B WITH COMPOSITE NACELLE
SEA LEVEL, 25 DEG. C., 70% RELATIVE HUMIDITY
195044 Kg (430000 LB.) TAKEOFF GROSS WEIGHT, 10 DEG. FLAPS, V2+10 KNOT CLIMB SPEED

FIGURE 8

ENCLOSED AREAS OF NOISE CONTOURS

SQ Km (SQ. STATUTE MILE)

	EPN dB 80	90	100	110	120
L-1011-1/RB.211-22B BASELINE					
TAKEOFF (FROM ROTATION)	51.18 (19.76)	8.52 (3.29)	1.11 (0.43)	0.18 (0.07)	0.00
APPROACH	60.55 (23.38)	7.72 (2.98)	0.67 (0.26)	0.00*	–
L-1011-1/RB.211-22B WITH COMPOSITE NACELLE					
TAKEOFF	44.60 (17.22)	5.62 (2.17)	0.41 (0.16)	0.02 (0.01)	0.00
APPROACH	28.75 (11.10)	3.34 (1.29)	0.13 (0.05)	–	–
ADVANCED TECHNOLOGY TRANSPORT					
TAKEOFF	47.71 (18.42)	6.42 (2.48)	0.62 (0.24)	0.02 (0.01)	0.00
APPROACH	26.16 (10.10)	2.05 (0.79)	0.05 (0.02)	–	–

TABLE 2

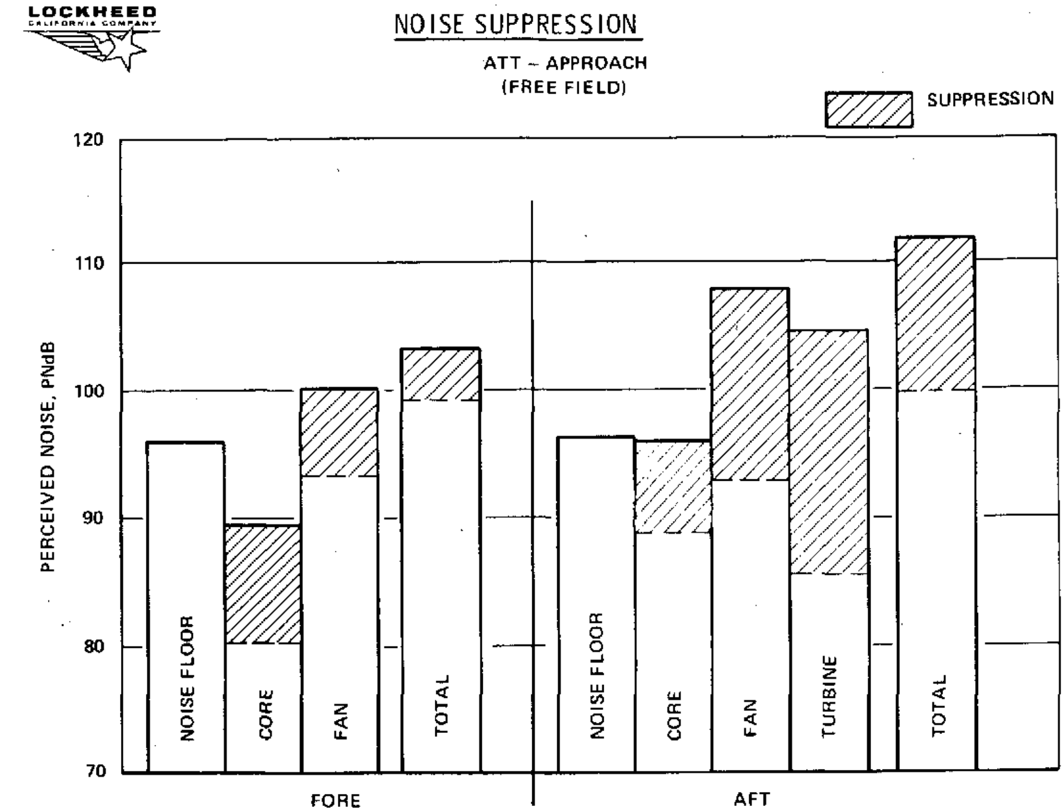


FIGURE 9

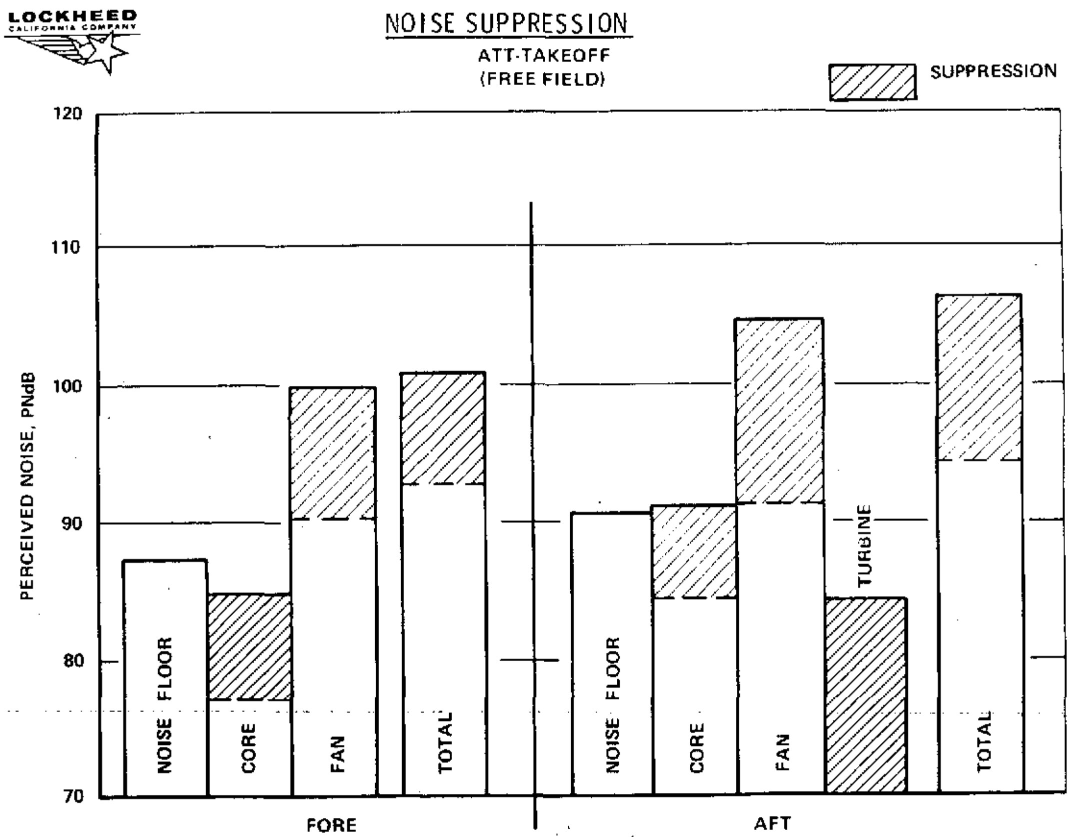
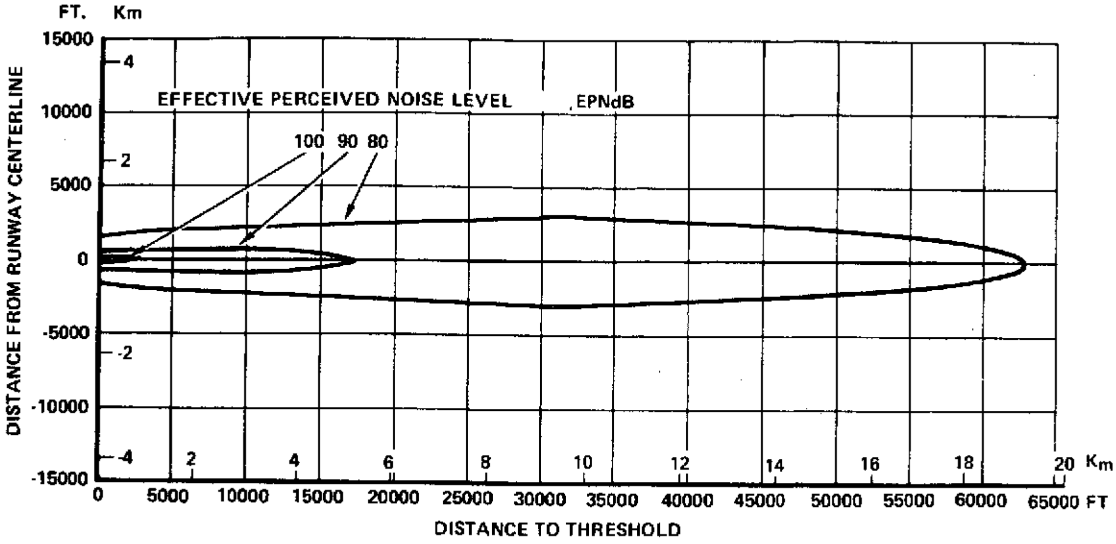


FIGURE 10

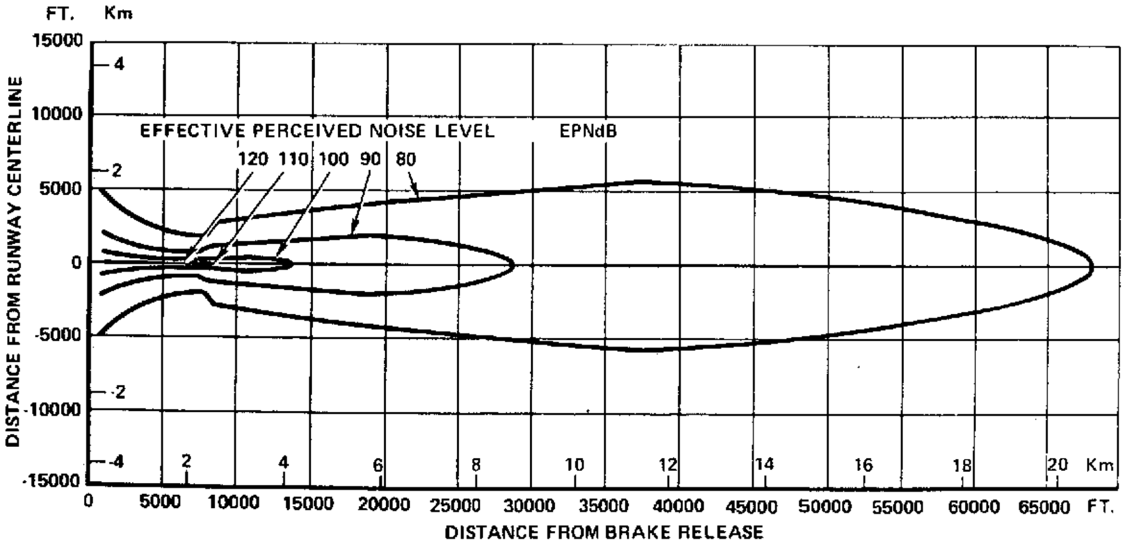
ATT NOISE CONTOURS
APPROACH



CONTOUR PLOTS
ADVANCED TECHNOLOGY TRANSPORT WITH PRATT AND WHITNEY STF433
SEA LEVEL, 25 DEG., C., 70% RELATIVE HUMIDITY
95026 Kg (209492 LB) LANDING WEIGHT, 42 DEG. FLAPS, 1.3V STALL + 10 KNOTS

FIGURE 11

ATT NOISE CONTOURS
TAKE-OFF



CONTOUR PLOTS
ADVANCED TECHNOLOGY TRANSPORT WITH PRATT AND WHITNEY STF433
SEA LEVEL, 25 DEG., C., 70% RELATIVE HUMIDITY
129094 Kg (284599 LB.) TAKEOFF GROSS WEIGHT, 10 DEG. FLAPS, V2+10 KNOT CLIMB SPEED

FIGURE 12

ECONOMIC EFFECT

RANGE 5556 km (3000 NM) – FUEL @ 6.9 c/LITER (26 c/GAL)
BASELINE EPNL FAR 36–4dB
WIDE BODY

		CHANGE FROM METAL BASELINE		
CONFIGURATION	BASELINE	MINIMUM FUEL	MIX FLOW	MIX FLOW
MATERIAL	COMP	COMP	COMP	METAL
EPNL △ dB	0	-2	-6	-6
SFC %	0	-1.2	-0.70	-0.70
NACELLE WEIGHT/AIRPLANE kg	-538	395	694	1422
NACELLE WEIGHT/AIRPLANE LB	-1187	871	1530	3135
FUEL FLOW %	-0.35	-0.94	-0.25	+0.23
DIRECT OPERATING COST $/km	-0.0050	-0.00032	0.00686	0.0136
DIRECT OPERATING COST $/NM	-0.0093	+0.0006	0.0127	0.0253
DIRECT OPERATING COST %	-0.244	+0.016	0.333	0.663
RETURN ON INVESTMENT △ %	0.0390	-0.0025	-0.0532	-0.1061

TABLE 3

DOC SENSITIVITY
WIDE BODY

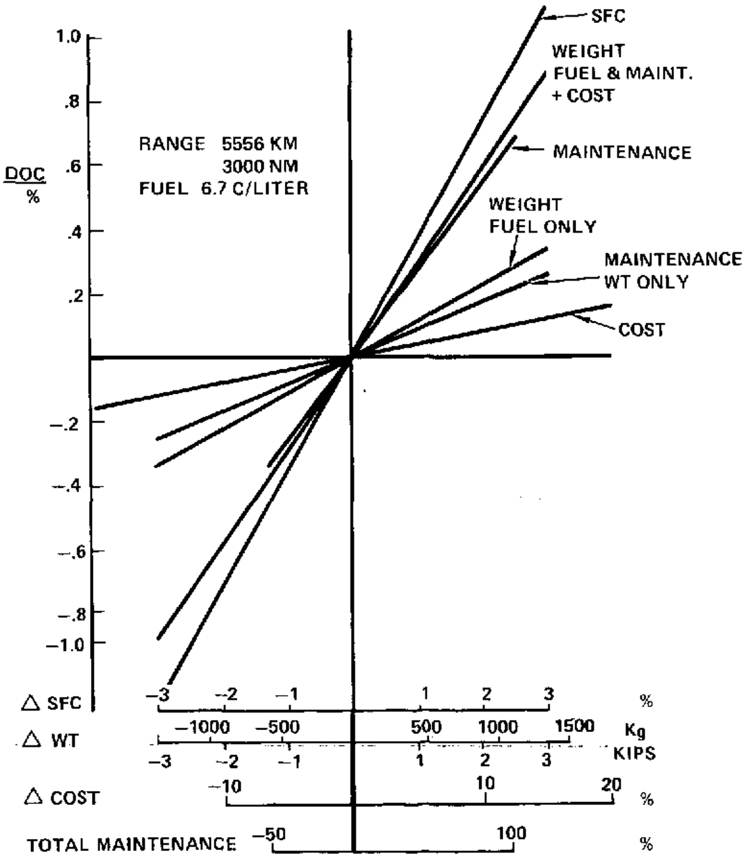


FIGURE 13

DIRECT OPERATING COST - WIDE-BODY

5556 km (3000 NM) RANGE

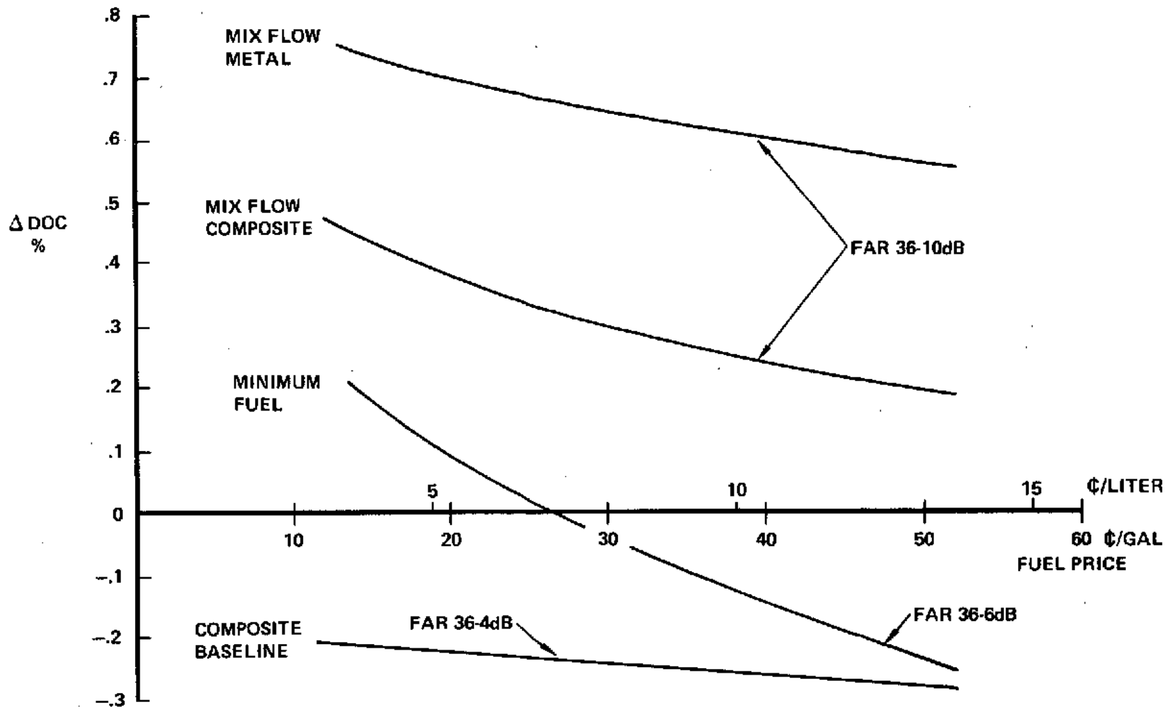


FIGURE 14

EFFECT ON COST & RETURN ON INVESTMENT - ATT

RANGE 5556 km (3000 NM) • FUEL @ 6.9 c/LITER (26 c/GAL)

	CHANGE FROM BASELINE
SPECIFIC FUEL CONSUMPTION	1.7%
NACELLE WEIGHT PER AIRPLANE	708 kg (1561 LB)
AIRPLANE GROSS WEIGHT	3010 kg (6635 LB)
DIRECT OPERATING COST	.033 \$/km (.062 \$/NM)
DIRECT OPERATING COST	2.0%
RETURN ON INVESTMENT (Δ %)	-0.38%

TABLE 4

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TECHNOLOGY FUNDING SCHEDULE

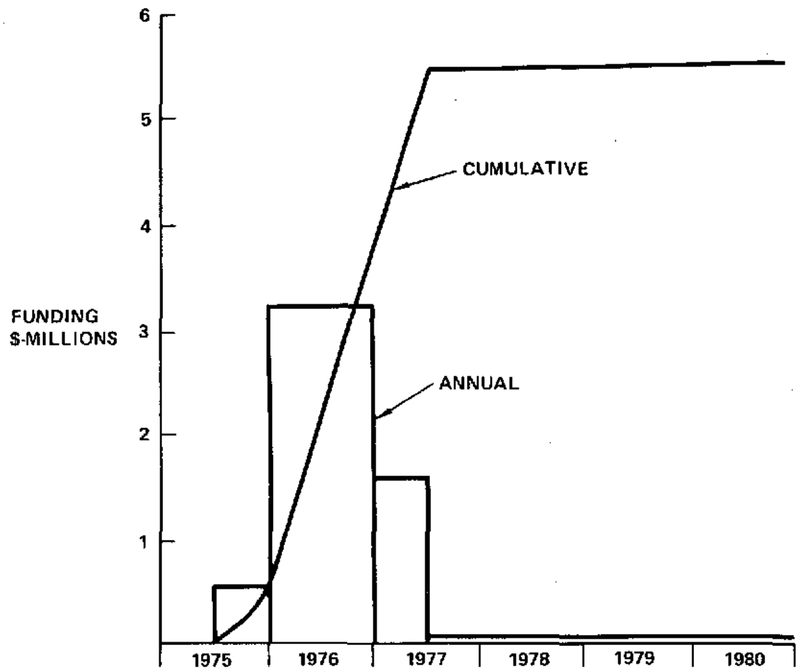

FIGURE 15

SECTION 2

INTRODUCTION

Previous studies of the advanced technology transport (ATT) and of composite structures have indicated that appreciable improvements in community noise can be attained at the expense of increased operating cost and structural complexity. Likewise, previous studies of composite structures have indicated that considerable weight might be saved by use of these materials. The broad objective of this study is to apply the advanced materials to a nacelle design to achieve significant noise reductions for the minimum penalty in airplane weight, cost, and operating expense. The study was sponsored by the Langley Research Center at NASA and conducted by the Lockheed-California Company as prime contractor. As the study embraced both the wide-body aircraft and the advanced technology transport the Lockheed-California Company was assisted by sub-contractors expert in the engines applicable to each type. Rolls-Royce Ltd. supplied the support for the wide-body transport engines and Pratt Whitney Aircraft for the engines used for the advanced technology transport phase of the study. TWA, under an existing consulting contract with the Lockheed-California Company, supplied advice as to the operational aspects of the study. The study was conducted from June of 1974 to February of 1975. The Woven Structures Division of HITCO assisted with consultation and supplied a sample panel of high acoustic resistance for test.

2.1 OBJECTIVES

The objective of the study is to determine what improvements in community noise can be achieved by the application of composite materials in the nacelle, recognizing the economic realities and the necessity for minimizing fuel consumption. These reductions in community noise are therefore to be obtained with a minimal penalty in direct operating cost and fuel consumption. The primary thrust to achieve these ends is to employ the advanced composite materials for both the sound suppression and primary structural members. As the technology for using these materials is not fully developed, the final output of the study consists of a program plan for filling the existing gaps in the technology required as well as a projection of the acoustic and economic gains that might be realized by using these materials.

2.2 STUDY PLAN AND PRESENTATION

The study proceeded from general concepts through a preliminary design phase and finally to the identification of specific developmental problems and of a program to solve these problems. The report follows the general plan of the study. In Section 3 the technical approach is presented in which the use of the baseline concept for developing cost and performance comparisons and the baselines used for both the wide-body and the ATT phases of the study are defined. The specific ground rules used in evaluating both airplanes are presented, and the concept of a noise floor as a limit on the acoustic treatment to be used is developed. In Section 4, the various basic concepts for each airplane are described. The design features necessary to achieve the desired reductions in noise are developed and the impact of these on operating cost and return on investment for each concept are shown. A concept is selected for detailed examination for each airplane. In Section 5, Preliminary Design, the selected concept is described in detail. Using this design as a point of reference, the technical aspects in each of the major disciplines concerned are presented in the following sections of the report. Section 6 discusses the source noises for each airplane and the theory underlying the selection of the suppression concepts used. The propulsion performance aspects are discussed in Section 7, and the structural considerations in Section 8. A summary of the weights involved is in Section 9, and the manufacturing and repair considerations in Section 10. The study included a limited test program both on the acoustic affects of flow generated noise and on the durability aspects of various component panel designs. The economic evaluation of the designs considered, presented in Section 11, includes the calculation of the direct operating cost and return on investment impact of the total installation and presents the tradeoff data of weight vs manufacturing cost, maintenance and drag for use in developing the rationale for a development program that would lead to a maximum payoff. Those technology items requiring further development before they can be incorporated in a production design are identified in Section 12 and the plan to carry out the necessary development is shown in Section 13.

2.3 SYMBOLS AND UNITS

The study results are presented in SI units and the corresponding English units are shown in parenthesis following the SI value. The study was conducted in the conventional English units.

SYMBOLS

B	Blade count
c	chord length, speed of sound
c_p	Pressure coefficient
D,d	Diameter
DOC	Direct operating cost
db	Decibels
EPNL	Effective perceived noise level
f	frequency
IGV	Inlet guide vane
kPa	kilopascal
L,l	Length
M	Mach number
M_T	Tip Mach number
n.mi.	Nautical mile
n_x	Longitudinal load factor
n_y	Lateral load factor
n_z	Vertical load factor
N	Newtons
OB	Octave band
OGV	Outlet guide vane
PNdB	Perceived noise decibels
PNL	Perceived noise level
PNLT	Tone corrected perceived noise level

R	Resistance
ROI	Return on investment
SFC	Specific fuel consumption
V	Vane count
x	Distance from leading edge
X	Reactance
α	Angle of attack
Δ	Increment
λ	Wave length
ρ	Density of air
ω	Circular frequency

ABBREVIATIONS

ART	Acoustic Research Tunnel
ASSET	Advanced Systems Synthesis and Evaluation Technique computer program
ATA	Air Transport Association
ATT	Advanced Technology Transport
FAR	Federal Air Regulations
NASTRAN	NASA Structural Analysis computer program
UARL	United Aircraft Research Laboratories

SECTION 3

TECHNICAL APPROACH

3.1 BASELINE DEFINITION

The effect of the various concepts considered is evaluated by comparing the performance and cost impact on an airplane using the specific concept relative to a baseline airplane of known characteristics. The baseline used as a reference for the wide-body concepts is the Lockheed L-1011 powered by the Rolls-Royce RB.211-22B engine. The major dimensions of this aircraft are shown in Figure 16 and the pertinent data in Table 5. An inboard profile of the baseline nacelle used on the L-1011 is shown in Figure 17. The salient features of this design are the short inlet and the three-quarter length cowl. This baseline utilizes the "15° aftbody". This aftbody is a recent improvement over the original design in which the thrust spoiler used for the hot stream has been removed and the aftbody shape refined, resulting in an appreciable increase in performance. Reverse thrust is provided by a set of cascades just aft of the fan case which are uncovered by a translating cowl in the reverse thrust mode. Engine accessories are external from the core engine and housed in the fan cowl. The access to the equipment is gained by two large cowl doors which extend from the fan to the thrust reverser and uncover the entire equipment section from top to bottom. The inlet, fan duct and tail cone are treated for noise suppression using honeycomb panels with perforated face sheets. These suppression features, combined with the inherent low noise source provided by the high bypass ratio fan, an inlet without guide vanes, and wide spacing of the outlet guide vanes, give a baseline nacelle which represents the best of the current state of the art in community noise performance. The efficient inlet cowl and highly developed aftbody likewise result in aerodynamic performance representative of the best current practice.

The ATT configuration is shown in Figure 18, and the baseline nacelle used for the ATT stuides is shown in Figure 19. This nacelle incorporates the features found desirable in the L-1011 nacelle modified as required for the geometry of the

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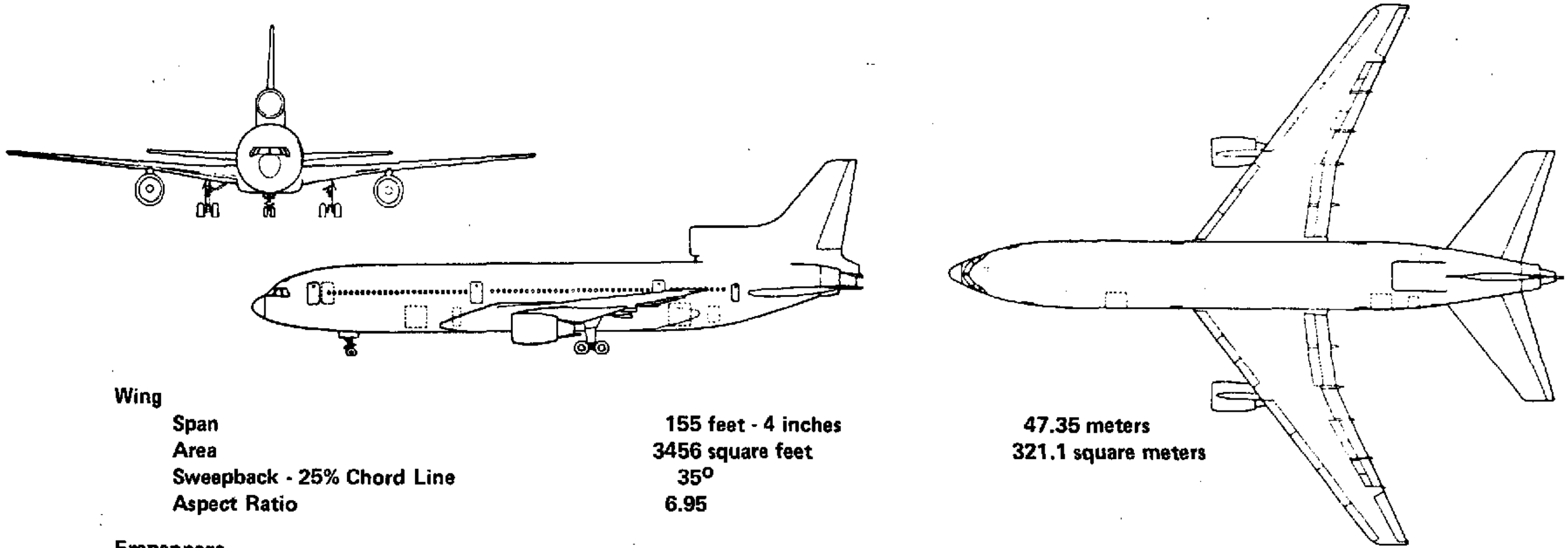
WIDE-BODY BASELINE



Wing				
Span	155 feet - 4 inches	47.35 meters		
Area	3456 square feet	321.1 square meters		
Sweepback - 25% Chord Line	35°			
Aspect Ratio	6.95			
Empennage				
Horizontal Tail - Span	71 feet - 7 inches	21.82 meters		
- Area	1282 square feet	119.1 square meters		
- Sweepback	35°			
Vertical Tail - Span	29 feet - 8 inches	9.04 meters		
- Area	550 square feet	51.1 square meters		
- Height - overall	55 feet - 4 inches	16.87 meters		
Fuselage				
Length	178 feet - 4 inches	54.3 meters		
Diameter	19 feet - 7 inches	6.0 meters		
Operating Weight Empty	240,700 lb	109,182 kg		
Cruise Mach No.	.85			
Range for Study	3,000 nm	5,556 km	1,000 nm	1,852 kg
Payload	65,000 lb	29,484 kg	84,300 lb	38,238 kg
Passengers	273		273	
Takeoff gross wt	430,000 lb	195,048 kg	385,000	174,636 kg

FIGURE 16

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ENGINE CHARACTERISTICS

	RB.211	STF 433
THRUST SL STATIC kg (lb)	19050 (42,000)	13,900 (30,700)
BYPASS RATIO	4.6	6.7
FAN DIA. m (in)	2.17 (85.5)	1.82 (71.6)
FAN BLADE NO. (STG 1/STG 2)	33/0	32/40
FAN OGV NO. (STG 1/STG 2)	70/0	58/70
FAN JET VELOCITY TAKEOFF M/S F.P.S.	285 (936)	328 (1075)
FAN JET VELOCITY APPROACH	196 (642)	215 (705)
CORE JET VELOCITY TAKEOFF	419 (1375)	389 (1275)
CORE JET VELOCITY APPROACH	233 (766)	189 (619)
FAN RPM TAKEOFF	3695	3604
FAN RPM APPROACH	2684	2516
ENGINE WEIGHT kg (lb)	3771 (8314)	2359 (5200)

TABLE 5

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BASELINE NACELLE L-1011

m (in)

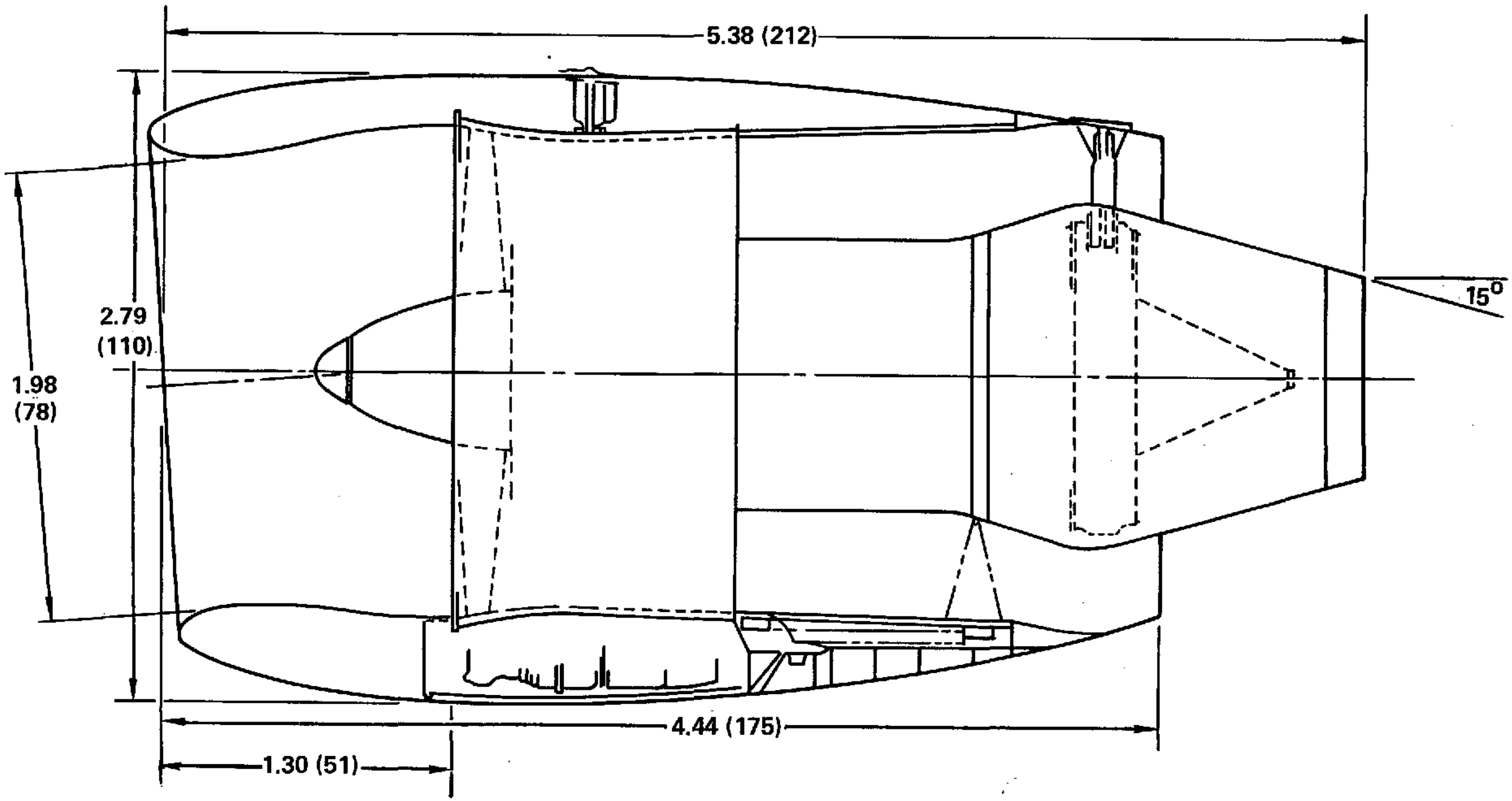

FIGURE 17

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ATT MODEL

CHARACTERISTICS		WING	HORIZ	VERT
AREA	$m^2 (ft^2)$	209(2250)	48.8 (525)	46.4 (500)
ASPECT RATIO		7.6	3.72	0.8
SPAN	m (ft)	39.9 (131)	13.5 (44.2)	6.10 (20)
ROOT CHORD	m (in.)	7.52 (296)	5.46 (215)	7.62 (300)
TIP CHORD	m (in.)	3.01 (1185)	1.78 (70)	6.10 (240)
TAPER RATIO		0.4	0.33	0.8
MAC	m (in.)	5.59 (220)	3.94 (155)	6.88 (271)
SWEEP @ 25%C	(DEG)	36.5	32	10
T/C	(%)	11	10	10

ENGINE - P&W STF 433
PAYLOAD Kg (lb) 18144 (40000)

OPERATING WT. EMPTY Kg (lb) 69425 (153054)
TAKEOFF GROSS WT Kg (lb) 126518 (278920)
RANGE Km (nm) 5556 (3000)
CRUISE = M = .9

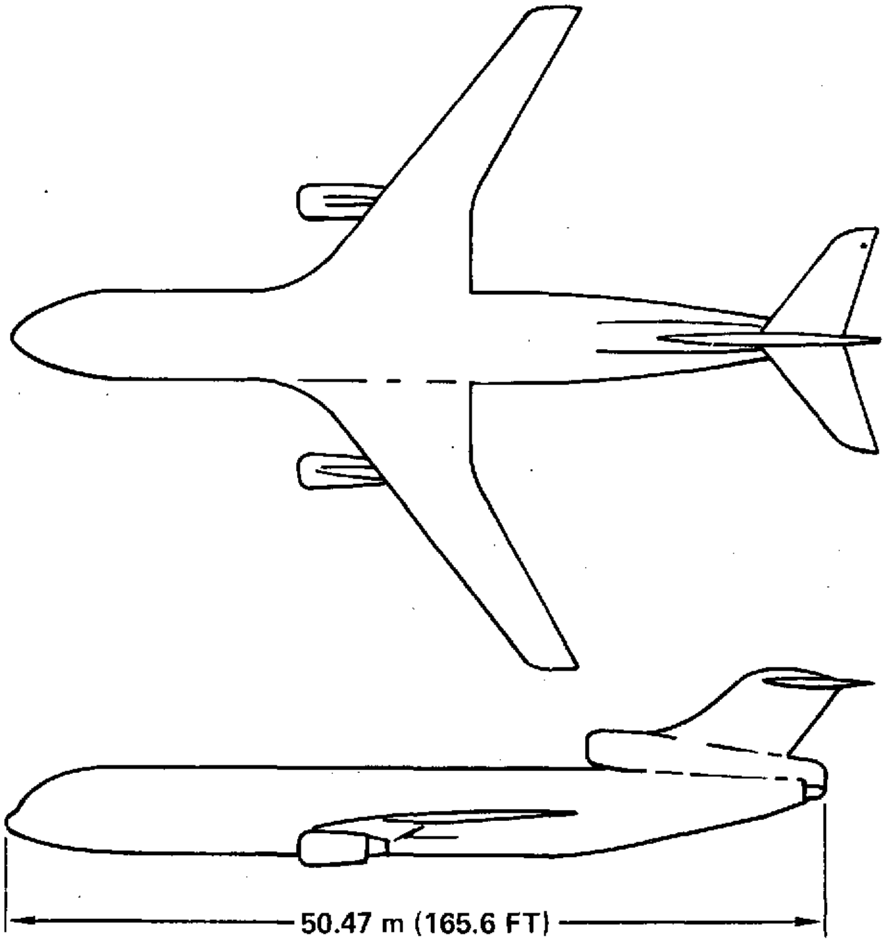

FIGURE 18

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BASELINE NACELLE ATT

m (in)

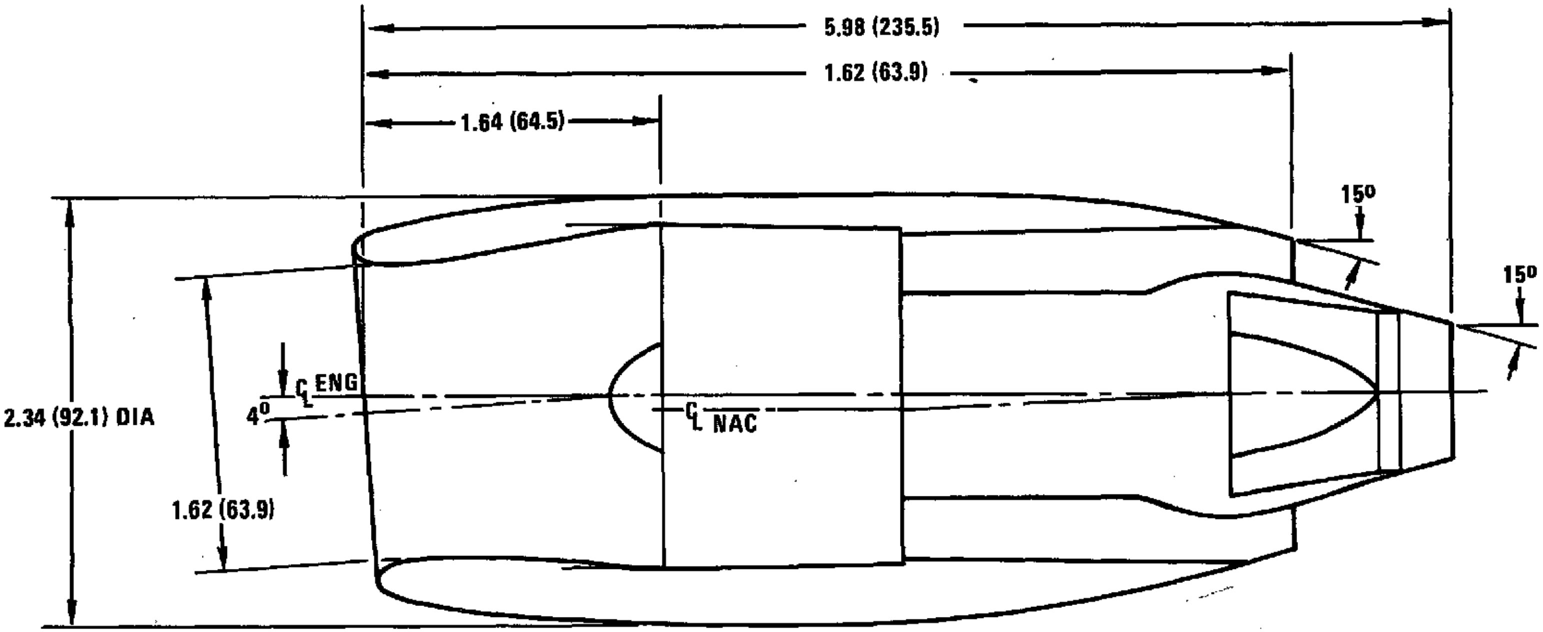

FIGURE 19

2-stage STF 433 engine. As the STF 433 engine approximates the FAR 36 noise requirements without treatment, the nacelle incorporates no additional treatment. This baseline therefore represents a concept that just meets the FAR 36 noise requirements but makes no concession in the nacelle design to further noise suppression.

3.2 WIDE-BODY GROUND RULES

A dominant factor in selecting the design approach for the wide-body nacelles is the rule that the concept is to be suitable for serialization on production airplanes. A corollary of this rule is that the installation of the acoustic composite nacelle would not be accompanied by other major changes in the airframe; that is, there would be no changes in span or wing area. As the major dimensions of the airplane are not to be changed, there is no "growth factor" involved in evaluating the impact of changes in nacelle weight. The impact on cost is therefore calculated by determining the increments accruing to carry the extra weight and accounting for the changes in drag and engine performance for the acoustic composite nacelle. A second consequence of the ground rule that the new nacelle is to be serialized into production is that changes to the engine or to the system involved in the nacelle are held to a minimum. For instance, nacelle geometry is chosen to use the thrust reverser mechanism with no changes in geometry. The design, however, is considered to be a production change and no provisions for retrofit in the existing fleet are considered.

3.3 ATT GROUND RULES

Unlike the wide-body study, the advanced technology transport is considered to be a completely new design that incorporates from inception the acoustic composite nacelle; therefore, the engine airframe and systems are matched to the specified design point and changes in weight or propulsive efficiency are reflected by corresponding changes in the entire airframe. The results of the ATT study, therefore, reflect the effect of the growth factor. Likewise, the ATT has no existing hardware to be saved, so changes in systems and engine were considered to be possible if the result would provide even slight improvements in the nacelle engine combination.

3.4 NOISE FLOOR CONCEPT

Two of the major sources of noise are the airframe itself and the noise of the jet behind the aircraft. Neither of these sources can be attacked by treating the nacelle, while both may be attacked by major changes in the airframe and engine. For instance, increasing the aspect ratio reduces the induced drag, which is directly related to airframe noise, and the use of high by-pass ratio engines with resulting lower jet velocities is a primary contribution of the current wide-bodies to noise reduction. Design changes of this nature are not part of this study which is confined to the nacelle; these two noise sources, therefore, constitute a "floor", that is a noise level which cannot be reduced by changes in the components studied in this report. By recognizing this floor and designing nacelle noise suppression systems to only reduce the noise level of the nacelle to that generated by the airframe and engine, it is possible to avoid unnecessarily heavy or expensive installations. Our noise reduction goal is therefore to reduce the treatable noise sources to the level of the noise floor giving a total combined noise of approximately 3 db over the noise floor. The determination of the floor for each airplane and the calculation of the approximate attenuation levels for each source is discussed in Section 6.

SECTION 4

CONCEPT SELECTION

4.1 WIDE-BODY CANDIDATE CONFIGURATIONS

A wide spectrum of nacelle configurations is considered for the wide-body case. The simplest approach consists of adding additional lining in the few places where it is possible in the baseline and of changing the existing lining to advanced liners with a broadband capability. As a next step, the use of advanced liners with lengthened inlets and lengthened fan ducts is considered and then the application of advanced liners to rings and splitters. The final step in complexity and effectiveness is the use of near sonic inlets, that is, inlets designed with flows approaching the speed of sound which effectively suppress the forward transmission of noise. The use of such inlets and inlet velocities in the takeoff and approach conditions can result in very poor cruise performance unless a variable area inlet is used. As the areas required in the takeoff condition when flows are relatively high is not greatly different from that required for the cruise, the mechanical problems are not too great. However, to provide near sonic velocities in the approach condition, area changes of the order of 40% are required and the mechanical problems become quite severe. Ameliorating these problems by the use of variable fan nozzles to change the mass flow as well as the inlet area is possible, but in this study were found unnecessary to achieve the goals desired. Many variants of the above parameters are possible and those which were developed to the point of performance and acoustic evaluation are discussed in the following paragraphs.

4.1.1 Long Inlet - Long Duct Configuration

The simplest configuration evaluated is shown in Figure 20, Config (1). The inlet is lengthened to accommodate the required liner length and becomes about twice the length of the baseline inlet. The fan duct likewise is extended to about twice the length of the baseline duct. A slight extension is made to the tail pipe to accomodate additional advanced lining treatment. These changes to the inlet and duct effectivity suppress the fan noise. However, this configuration suffers from excessive tail pipe noise.

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LONG INLET - LONG DUCT - STD TAILPIPE

m (in)

CONFIG 1

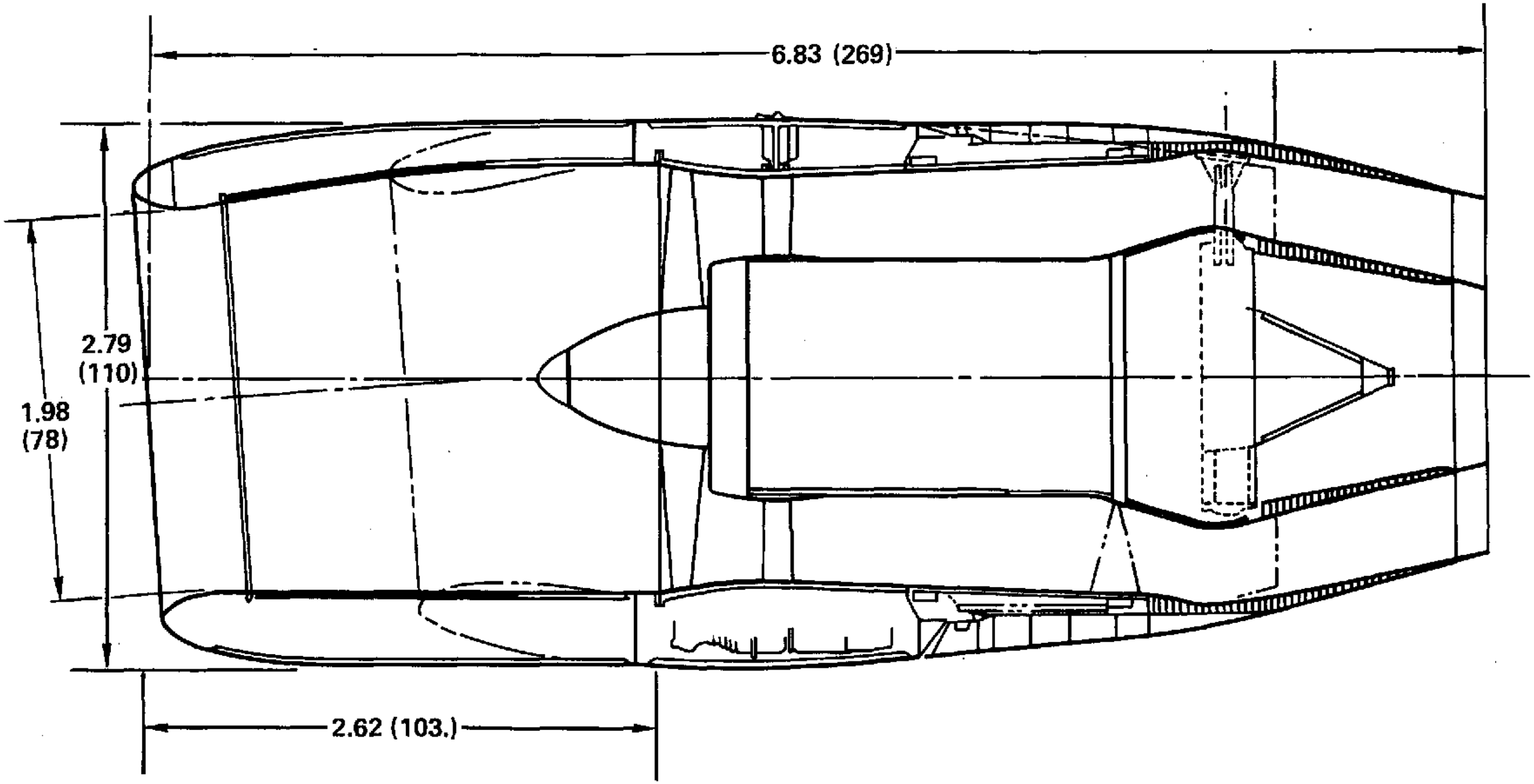

FIGURE 20

4.1.2 Long Inlet - Long Duct Radial Splitter Tail Pipe

Figure 21, Config (2) shows a configuration which incorporates the same inlet and fan duct as that of Figure 4-1 but has additional treatment in the tail pipe. The tail pipe is lengthened and also incorporates 6 radial splitters. This combination is quite effective, but still does not attain the noise goals desired.

4.1.3 Long Inlet - Long Duct-Ring Tail Pipe

A further development of the previous concepts is shown in Figure 22, Config (3), in which the radial splitters in the tail pipe have been replaced by an annular ring. This configuration achieves the noise reduction goals desired.

4.1.4 Ring Inlet - Long Duct-Ring Tail Pipe

The initial approach to the inlet had been to lengthen the inlet and avoid the use of rings or splitters. Rings in the inlet are not only aerodynamically undesirable but introduce additional structural and deicing problems, and create an additional hazard to the rotating machinery. The long inlets, on the other hand, produce somewhat increased loads on the fan case, pylon, and engine attachments so this configuration is included to evaluate the trade off. Only a short (baseline length) inlet is included as no advantage is seen in a long inlet plus splitters. The attenuation achieved is small, about one dB. This arrangement, Config (4) is shown in Figure 23.

4.1.5 Near Sonic Inlet

Previously published work, has shown that almost complete suppression of forward noise can be obtained with low internal losses by use of a near sonic inlet utilizing a translating centerbody. A nacelle using this concept, Config (5), is shown in Figure 24. As complete suppression is not necessary to reduce the noise below the noise floors for this airplane, the travel of the centerbody is selected to produce .75 Mach number at approach, a travel about .41 m (16 inches) less than that for the maximum suppression. Even so, this configuration as shown in Figure 24 is considerably longer, heavier, and more complex, than the previous configurations.

4.1.6 Long Inlet-Mixed Flow Nozzle

The long inlets, long fan ducts, and the extensive treatment required in the tail pipe of the configuration which achieves the desired noise reduction all contribute to additional drag on the nacelle and losses in the propulsion system.

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LONG INLET - LONG DUCT - RADIAL SPLIT TAIL PIPE

m (in)

CONFIG 2

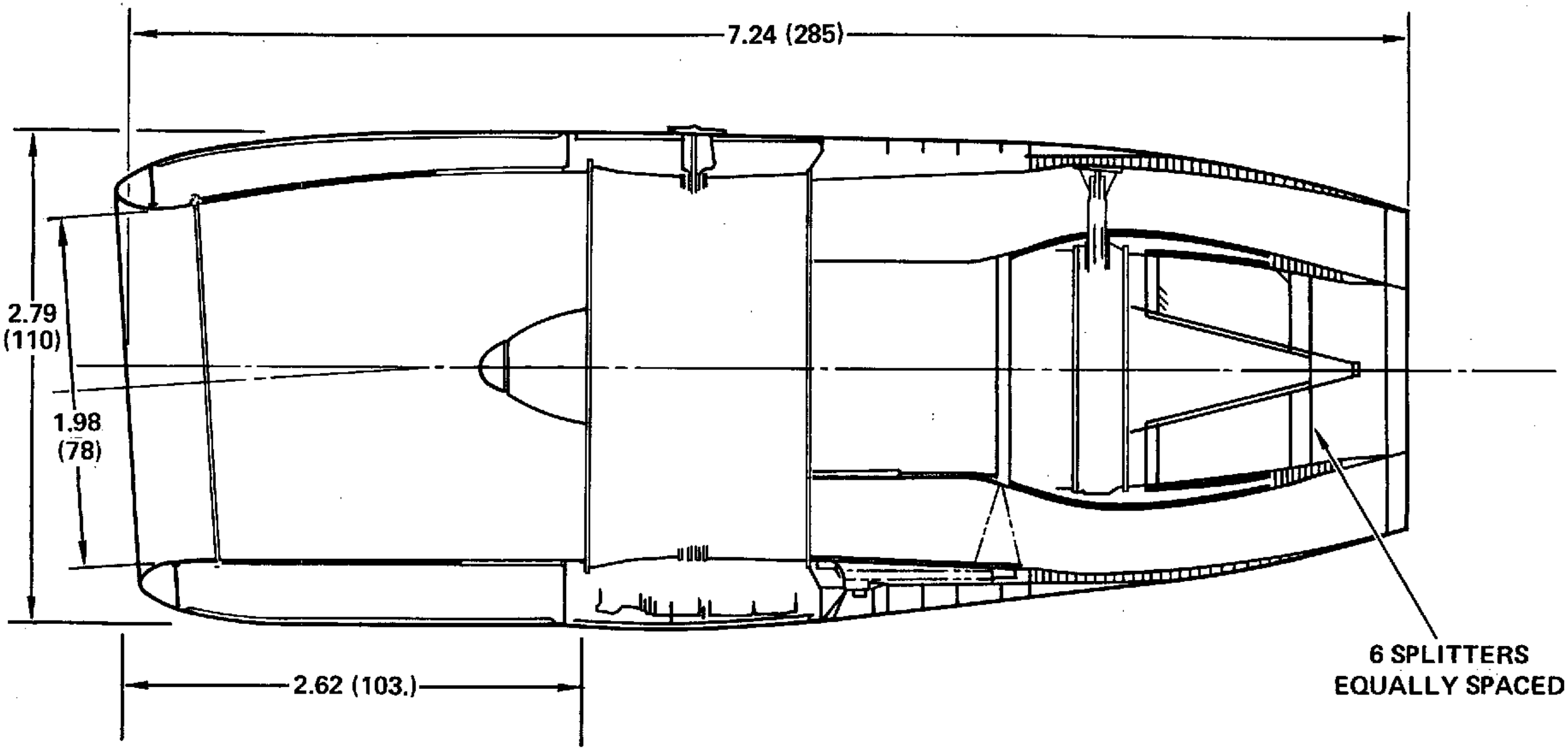

FIGURE 21

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LONG INLET LONG DUCT RING TAILPIPE

m (in)

CONFIG 3

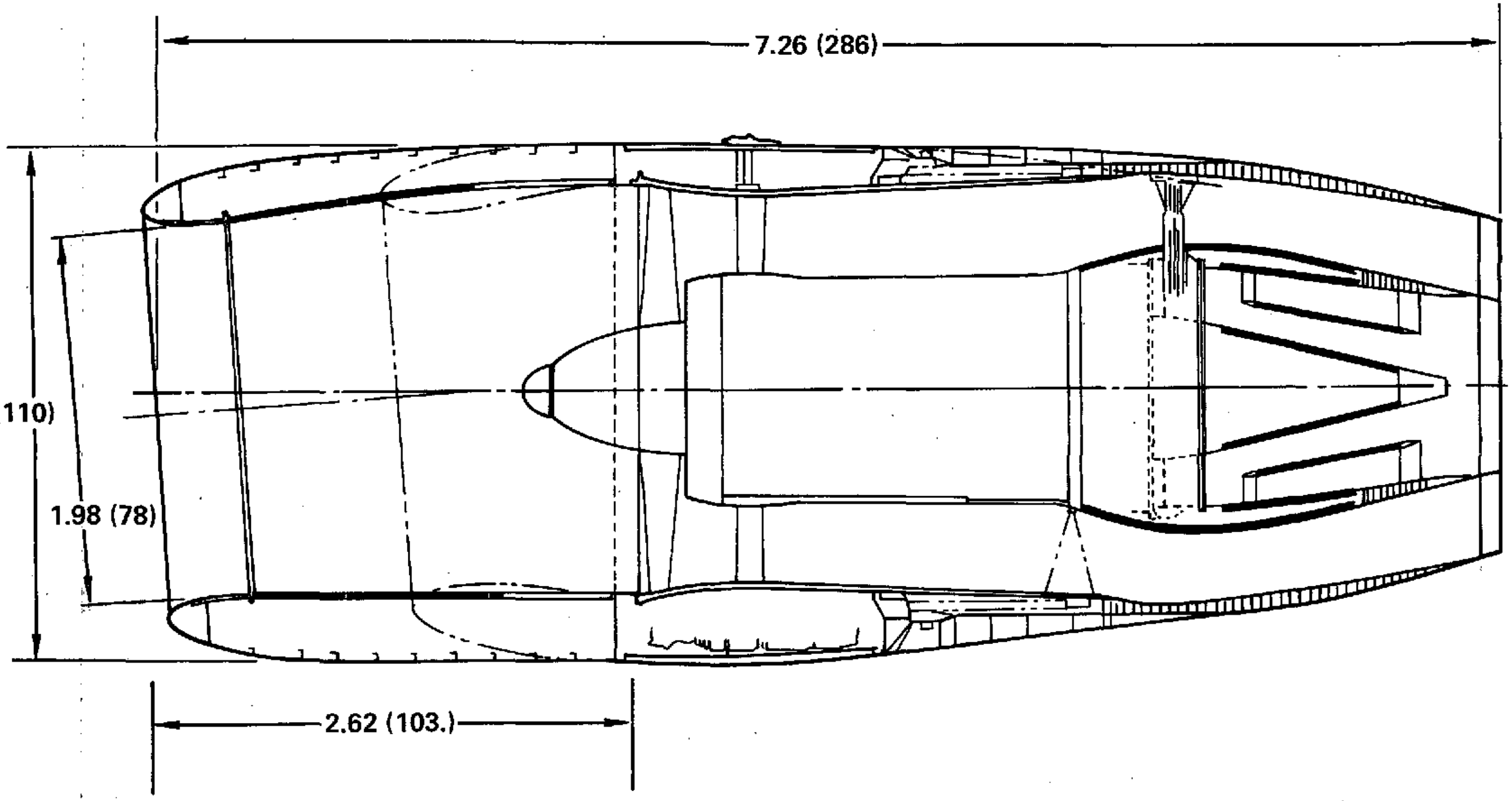

FIGURE 22

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INLET RING

m (in)

CONFIG 4

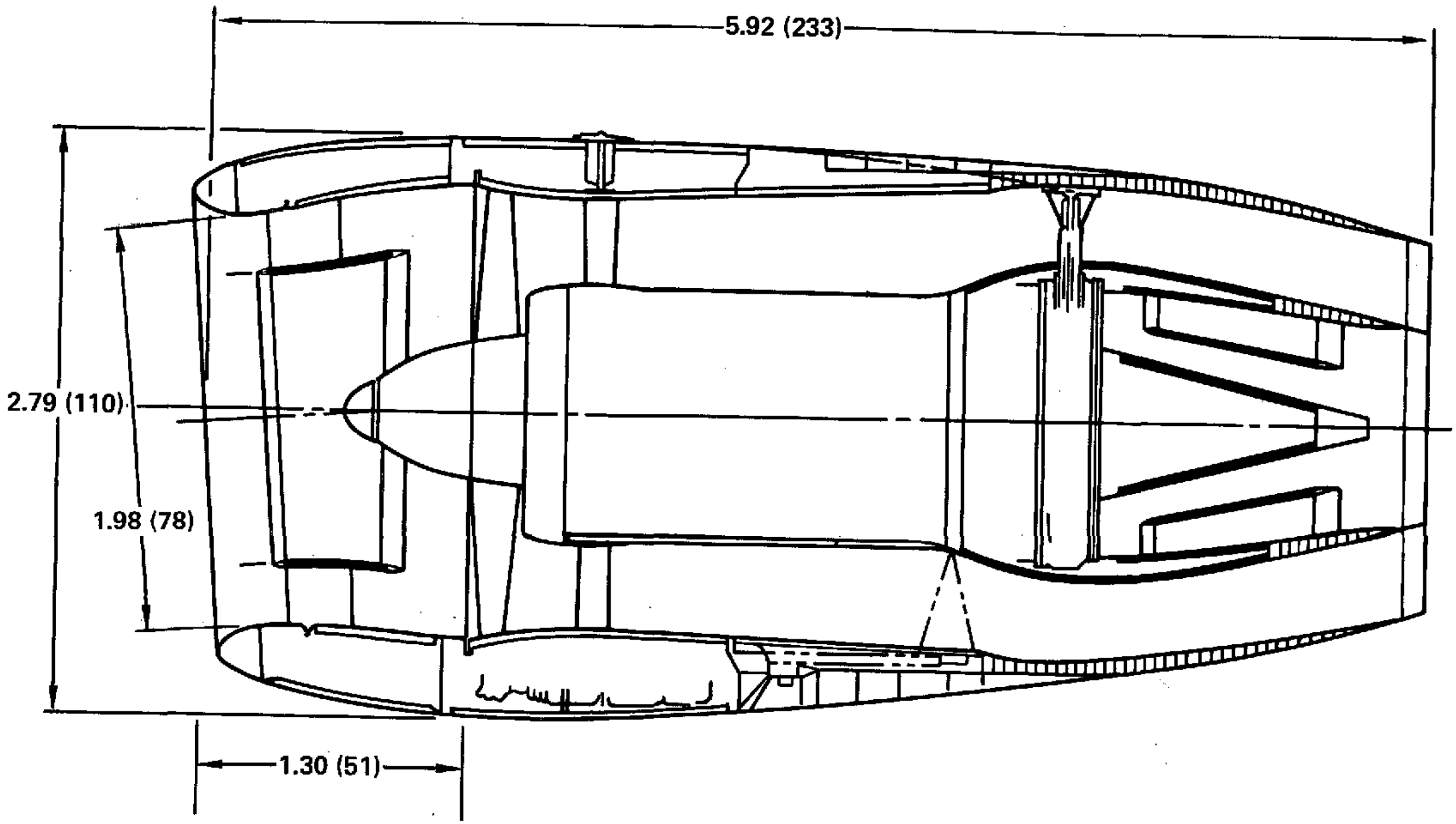

FIGURE 23

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TRANSLATING CENTER BODY

m (in)

CONFIG 5

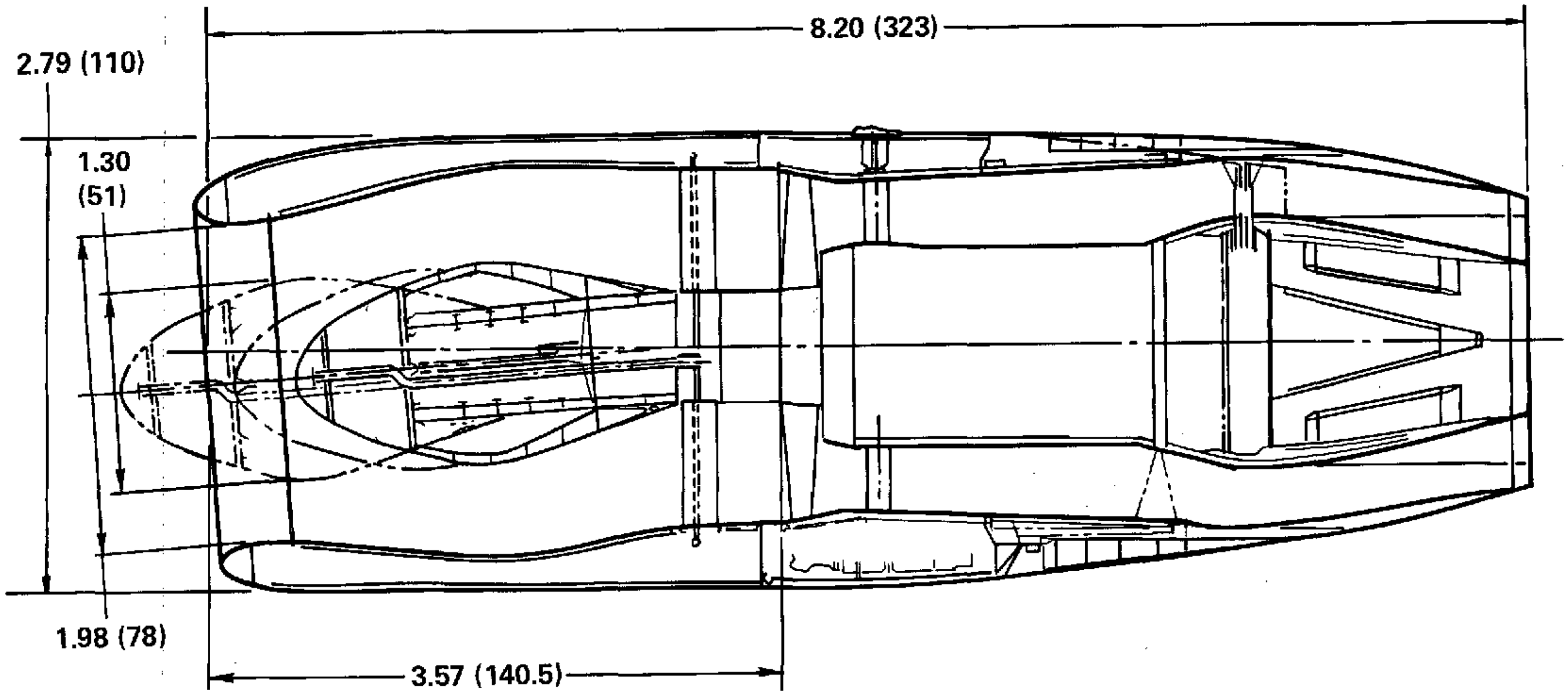

FIGURE 24

Observing that these components are nearly as large and as heavy as the components of a mixed flow nozzle, and that the specific fuel consumption improvement attainable by the use of mixed flow might offset the losses of the long duct, the configuration shown in Figure 25, Config (6) is considered. This configuration retains the long inlet without splitters of the previous configurations. The tail pipe treatment consisting of an annular ring is replaced with a nozzle to mix the fan and the core flows. The fan duct is extended to cover the nozzle and to produce the required mixing lengths and nozzle areas. This extended fan duct provides adequate opportunity to treat the fan noise and the core noise emanating from the tail pipe.

4.1.7 Wide-body Configuration Comparison

The characteristics of each of the configurations considered are summarized in Appendix A. The data for each configuration is used to calculate the increment in direct operating cost (DOC) by the techniques in Section 11, and the effective perceived noise level below the FAR 36 requirement is calculated as described in Section 6. These results are plotted in Figure 26 for the configurations considered. The increases in direct operating cost indicated for all of the configurations reflect the combination of several factors. First, there is a reduction in cost achieved by the reduction in weight by using composite materials. However, the length of the inlet and of the fan duct have been essentially doubled, thereby producing an increase in weight that cannot be countered by changing material, and the additional treatment in the tail pipe represents a weight increment of high temperature material that cannot be reduced by the advanced composites presently known. Further, as shown in Section 11, the influence of aerodynamic drag and the degradation of engine performance are powerful effects compared to the weight changes. The result is that the only configuration that does not show a marked increase in DOC is the mixed flow exhaust configuration which takes advantage of the added hardware to improve rather than degrade engine performance. The mixed flow configuration is, therefore, chosen as the example to be carried forward into the preliminary design and on which the detailed technical analysis in the remainder of the report is based.

4.2 ATT CANDIDATE CONFIGURATIONS

As the basic noise suppression problems for the ATT are similar to those considered for the wide-body, the results of the wide-body configuration comparison were used to proceed directly to the most promising types for the ATT evaluation. The STF 433 engine was designed from the outset to meet the FAR 36 noise requirements

MIXED-FLOW NACELLE - WIDEBODY

m (in.)

CONFIG 6

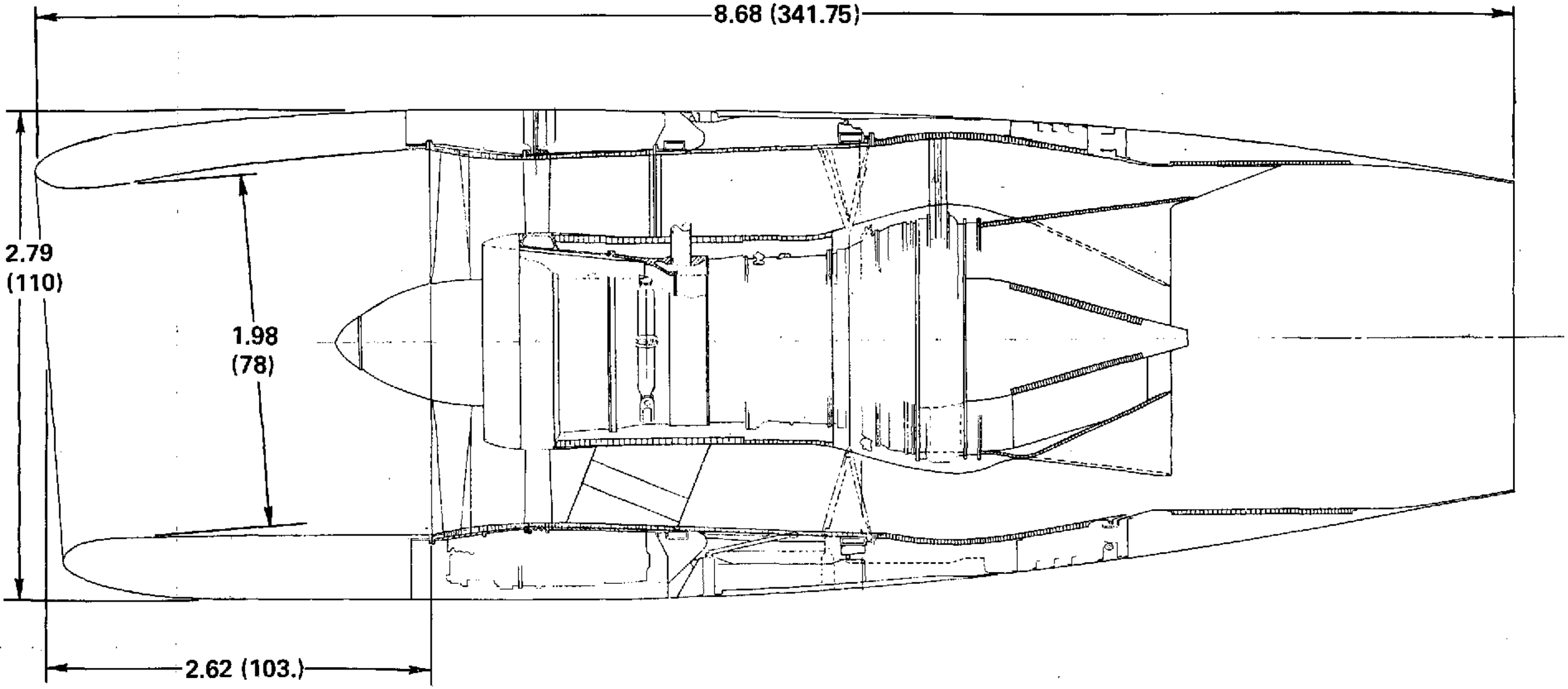

FIGURE 25

WIDE-BODY CONFIGURATION EVALUATION

5556 km (3000 NM) 6.9 ₵/LITER (26 ₵/GAL) FUEL

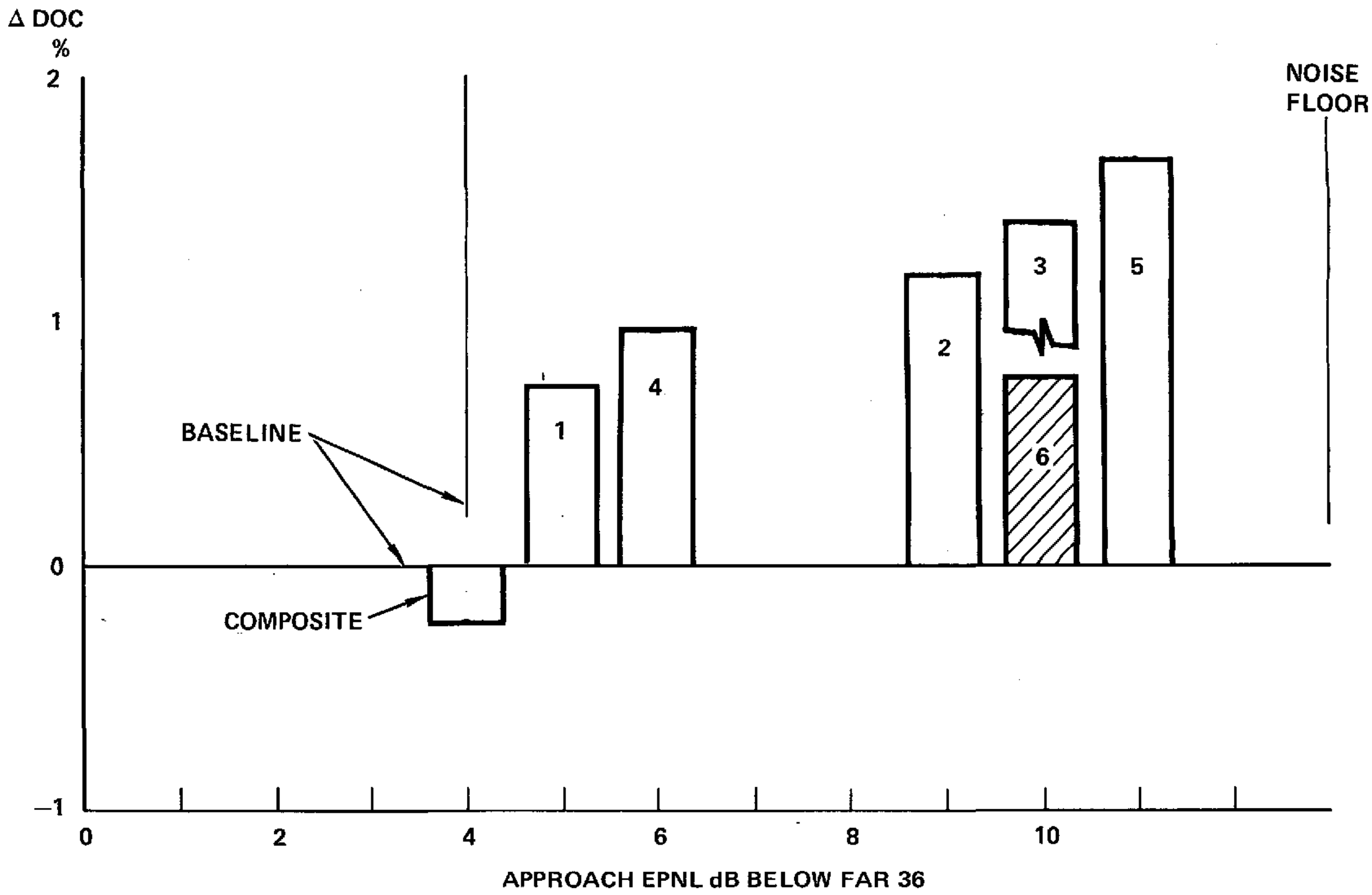

FIGURE 26

and the design cruise condition. As discussed in Section 7, re-matching the engine to accept a mixed flow nozzle is not advantageous.

4.2.1 Long Inlet - Long Duct - Long Tail Pipe Configuration

The configuration shown in Figure 27 is comparable to that shown in Figure 4-4 for the widebody airplane in that the essential features are a long inlet, a long fan duct, and extensive treatment in the tail pipe. In this case, the fan duct required so much treatment that it extended beyond the end of the tail pipe. As the tail pipe was lengthened to accommodate this increased length in fan duct, enough area became available to produce the required suppression without the addition of splitters or rings.

4.2.2 Near Sonic Inlet

This configuration, Figure 28, simply replaces the long inlet of Figure 4-9 with a near sonic inlet achieved by use of the translating centerbody.

4.3 ATT CONCEPT SELECTION

Both configurations shown for the ATT achieve the desired noise reduction. The impact on the airplane characteristics for the two configurations is shown in Appendix A. The direct operating cost impact of the changes in airplane characteristics for the two nacelles are shown in Figure 29. As in the case of the widebodies, the increase in size overshadows the weight savings that might be gained by the use of composites and the decrement in performance from the added wetted area, both internal and external, overshadows the changes due to the weight. These costs include the growth factor as this airplane is sized to do exactly the design mission, so the relative changes in DOC are greater than indicated for the wide-body and the changes due to the added losses of the near sonic inlet are correspondingly magnified.

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LONG INLET - LONG DUCT - LONG TAIL PIPE - ATT

m (in)

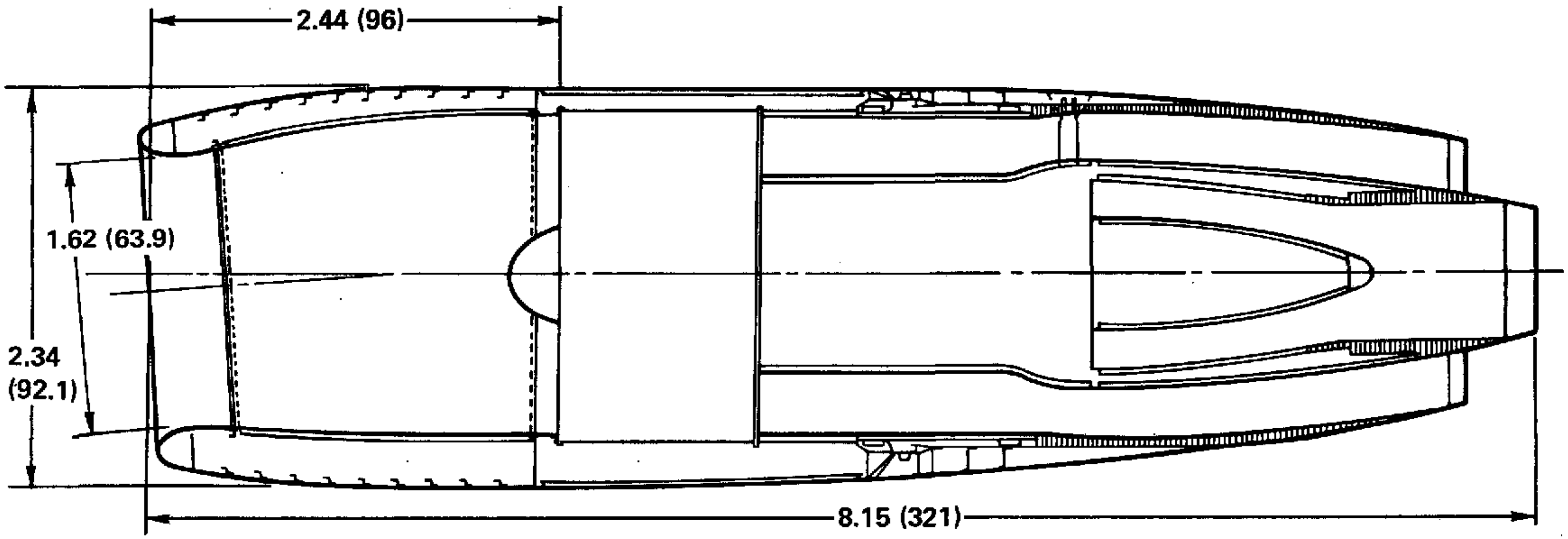

FIGURE 27

TRANSLATING CENTER BODY - ATT

m (in)

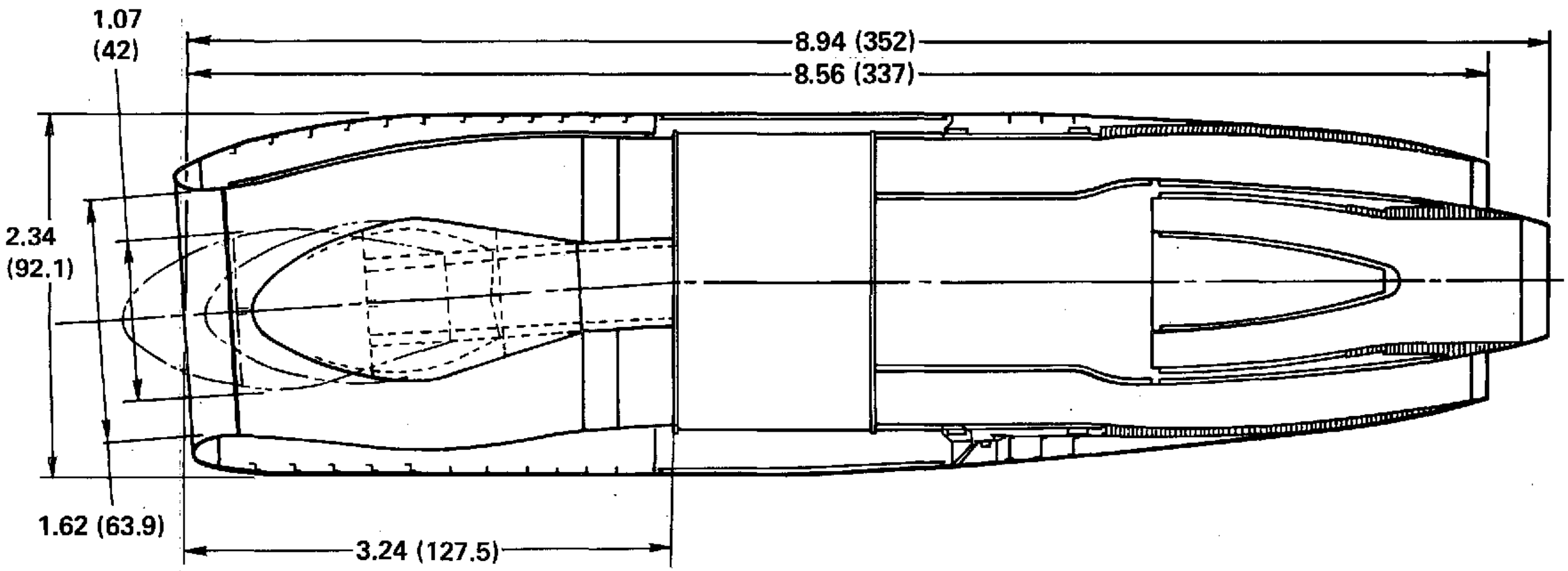

FIGURE 28

ATT COST SUMMARY

FAR 36 – 8

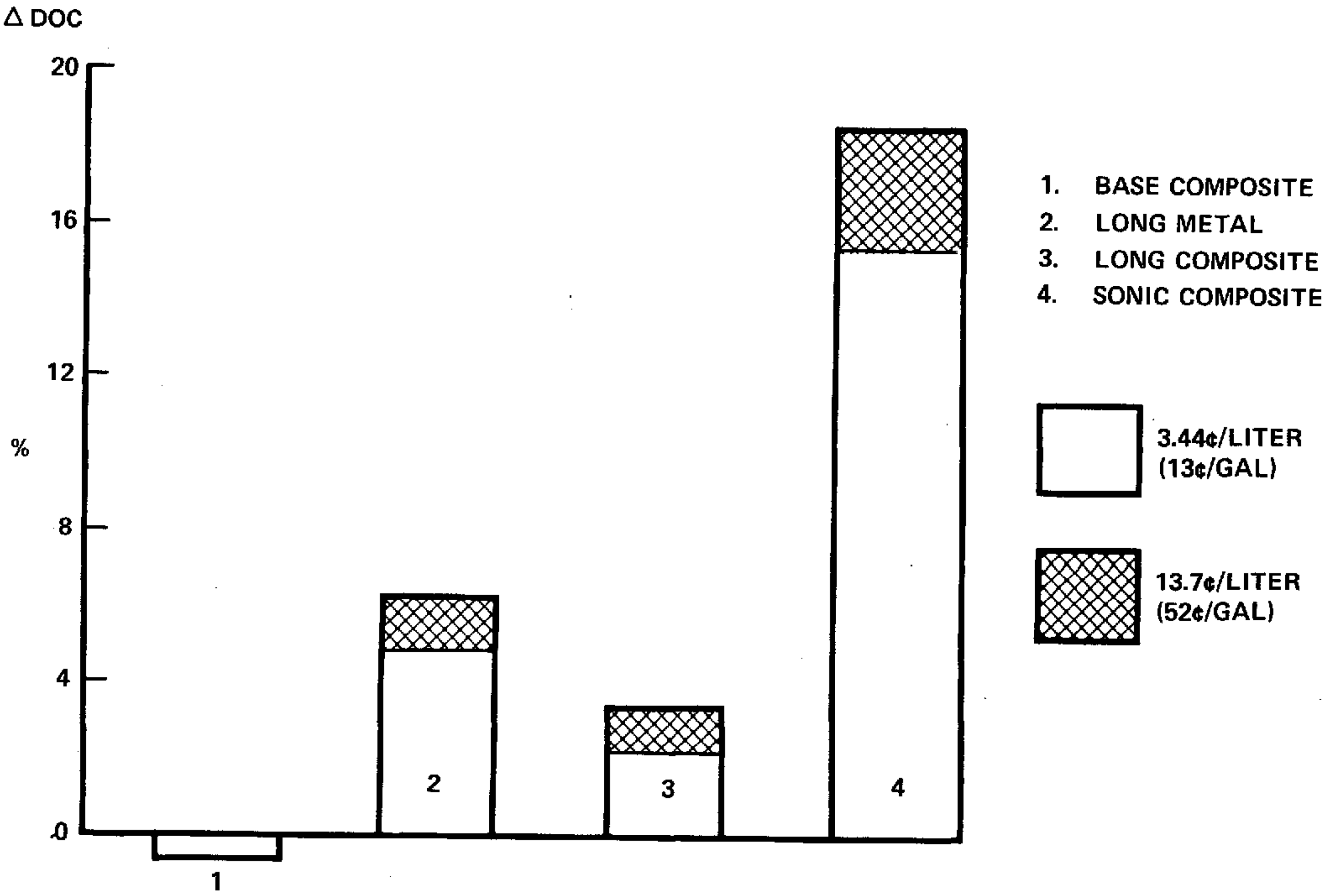

FIGURE 29

SECTION 5

PRELIMINARY DESIGN

5.1 GENERAL ARRANGEMENT

The mixed flow concept selected for the widebody concept evaluation as developed in the preliminary design phase of the study is shown in Figure 30. The long inlet without rings or splitters is used as developed in the concept evaluation. However, a trade is possible between inlet length and the type of liner used. Single degree of freedom liners would achieve the desired noise reduction with a treated length of 1.52 m (60 in). By the use of broadband liners, which are somewhat heavier and more complex to manufacture, the treated length of the inlet can be reduced to 1.22 m (48 in). The shorter inlet is lighter, imposes lower loads on the pylon and wing attachment, and minimizes the potential high angle of attack interference between inlet and wing, therefore, the shorter nacelle with the more sophisticated liners described in para. 6.4.1 is chosen. Just aft of the inlet the accessory section of the nacelle is retained essentially as found in the baseline. The accessories are mounted on the engine fan case, and large cowl doors extending from the pylon to the bottom centerline are used on each side of the nacelle for ready access. Aft of the equipment section, the cold stream thrust reverser is also retained using the same basic geometry and mechanical design as that of the baseline. However, the thrust reverser structure is entirely redesigned and beefed up in composites to account for the higher loads inposed by the extended nozzle. An alternate method for supporting the long nozzle weight by means of an added support from the nozzle to the pylon was considered, but using composite materials to reduce the added weight as much as possible and taking advantage of the high stiffness of composites to reinforce the forward ring and prevent local overloading of the fan case was found to be a preferable arrangement. The translating cowl actuation is similar to that of the baseline but the cowl itself is slightly longer to accommodate the gentler lines of the extended nacelle. The thrust reverser structure (including the mounts

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NACELLE - RB211 ENG. MIXED FLOW ACOUSTIC COMPOSITE

m (in.)

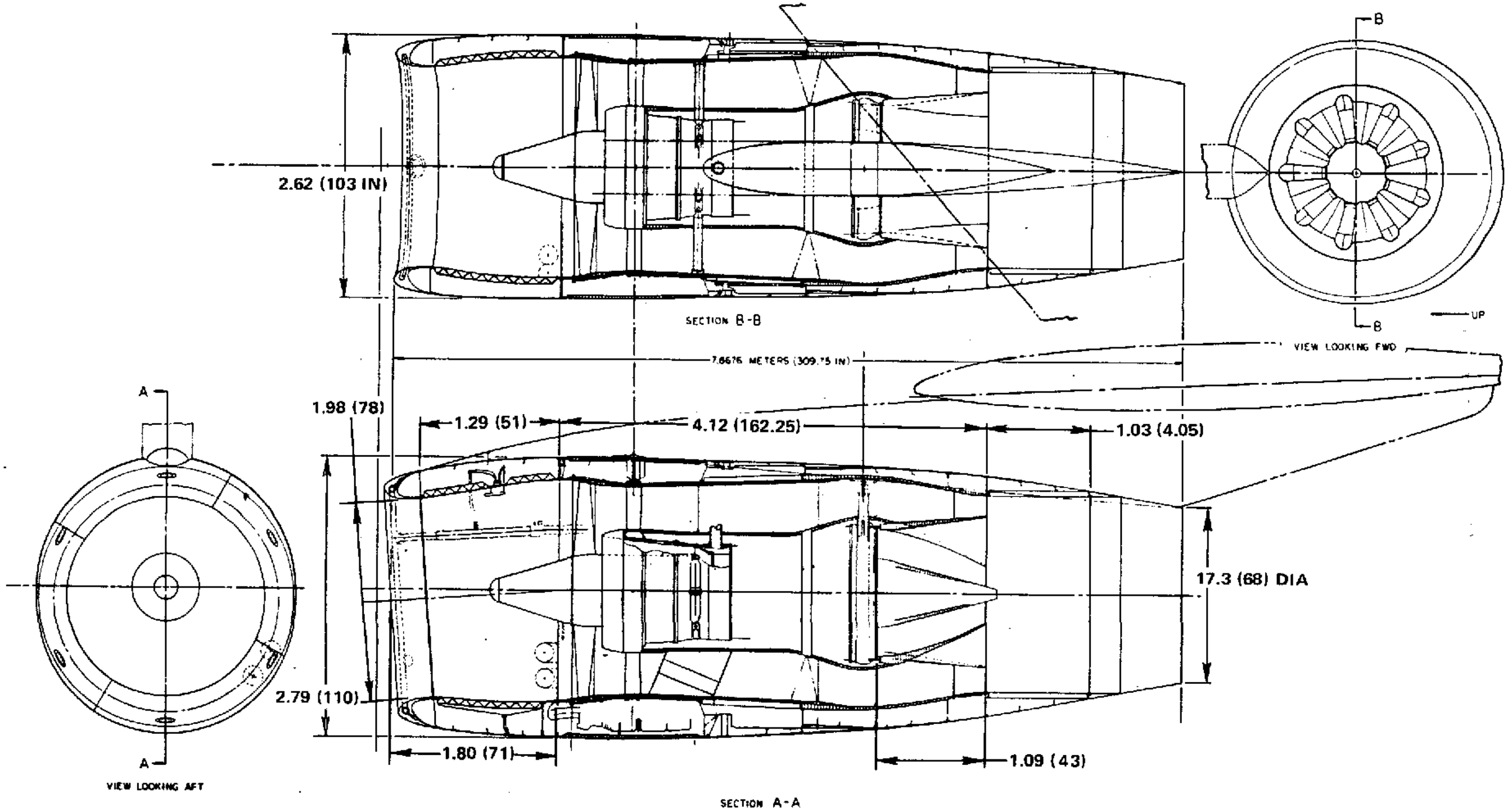

FIGURE 30

for the blocker door and translating cowl actuation) and the nozzle from the thrust reverser to the primary nozzle exit are built as an integral unit in composites. Aft of the primary nozzle the fan duct is subjected to the hot primary gases in the reverse thrust mode as the cooling fan air is blocked off. A service joint is provided at the end of the cool structure just ahead of the primary nozzle exit by which the transition to the high temperature structure used for the remainder of the nozzle is made. The position of this joint is chosen far enough ahead of the lobes on the mixer so that, with the tail cone removed, a man can enter the duct for maintenance work on the engine without other disassembly. Just aft of the primary nozzle exit, the outer shell consists of the inner liner of stainless steel and an outer, cooler, shell made of composites, but using polyimide resins to accommodate the high temperatures encountered in this section. An additional service joint is provided just aft of the treated section of the nozzle so that the tail cone may be removed if necessary. The mixer nozzle consists of 9 flutes which conduct the fan air radially inward and the primary jet outward into the mixing chamber. This mixer is fully treated to suppress the turbine noise; and, to account for the range of frequencies encountered, the treatment depth varies from 4.44 cm (1-3/4 in) at the forward end to 1.27 cm (1/2 in) at the trailing edge. A short fairing completes the mixer.

The inlet liner characteristics developed in Paragraph 6.4.2 require physical characteristics which differ from the liners used in the baseline and concept evaluation nacelles. The recommended liner is 6.35 cm (2.5 in) deep, requires facings and internal members of high linearity, and requires acoustical resistance in the face of $4\rho c$. These characteristics are obtainable with a felted metal - honeycomb arrangement, and experimental panels made by Woven Structures Div of HITCO also have the desired resistance. Realizing such acoustic resistances requires very small interstices, and the surfaces of such sheets are aerodynamically smooth. Eliminating the performance loss associated with the roughness of perforated sheet makes this type of facing attractive for use in the fan duct as well as the inlet. The long fan duct presents enough treatable area so that sophisticated liners are not required so single degree of freedom liners of varying depth in the neighborhood of 1 inch are used. The acoustic treatment in the fan duct aft of the primary nozzle is designed to suppress the low frequency core noise and as such would require rather great depths. The desired suppressions are achieved in the depth available by using Schizophonium 4.44 cm (1-3/4 in) deep for a length of .96 m (38 in).

The Schizophonium consists of a perforated face sheet backed by a series of small horns. The horns do not extend quite to the solid backing face and are open at the outer end. The combination thereby effectively doubles the "acoustic" depth of the liner.

5.2 ACCESS PROVISIONS

In addition to the large cowl doors, numerous small doors are provided for inspection and servicing. These are shown in Figure 31. Access to the core engine is provided through the thrust reverser with the translating cowl open and through the tail pipe.

5.3 FIRE ZONES AND DESIGN TEMPERATURES

Elevated temperatures occur in the nacelle from a variety of sources. Hot air anti-icing of the cowl lip is used. The operating temperatures necessary to perform the anti-icing function as well as the higher local temperatures that might occur if a hot air duct should burst are accounted for. The outside structure and most of the inner fan duct are cooled by fan air in normal operation, the maximum temperature condition. Aft of the primary exit the fan air is mixed with the primary air in normal operation, but the hot stream may impinge on the tail cone. During reverse thrust operation the fan air is diverted through the thrust reverser and nearly all of the hot stream can impinge on the tail cone. The nacelle is divided into fire zones as indicated in Figure 32, which also shows the operating temperatures in the various parts of the nacelle.

5.4 WING-NACELLE INTERFERENCE

An analysis of the probable interference effects of three different nacelle configurations is conducted using a compressible potential flow generalized vortex lattice method. The three different nacelle configurations are as follows:

1. The present L-1011 15° -afterbody nacelle (baseline or short nacelle);
2. The mid term, or acoustic nacelle; and
3. The mixed-flow nacelle.

A schematic comparison of the three nacelle arrangements is shown in Figure 33.

The surface pressure distributions on the above configurations are computed at the cruise Mach number ($M = 0.85$) by a generalized vortex lattice method developed

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ACCESS DOORS

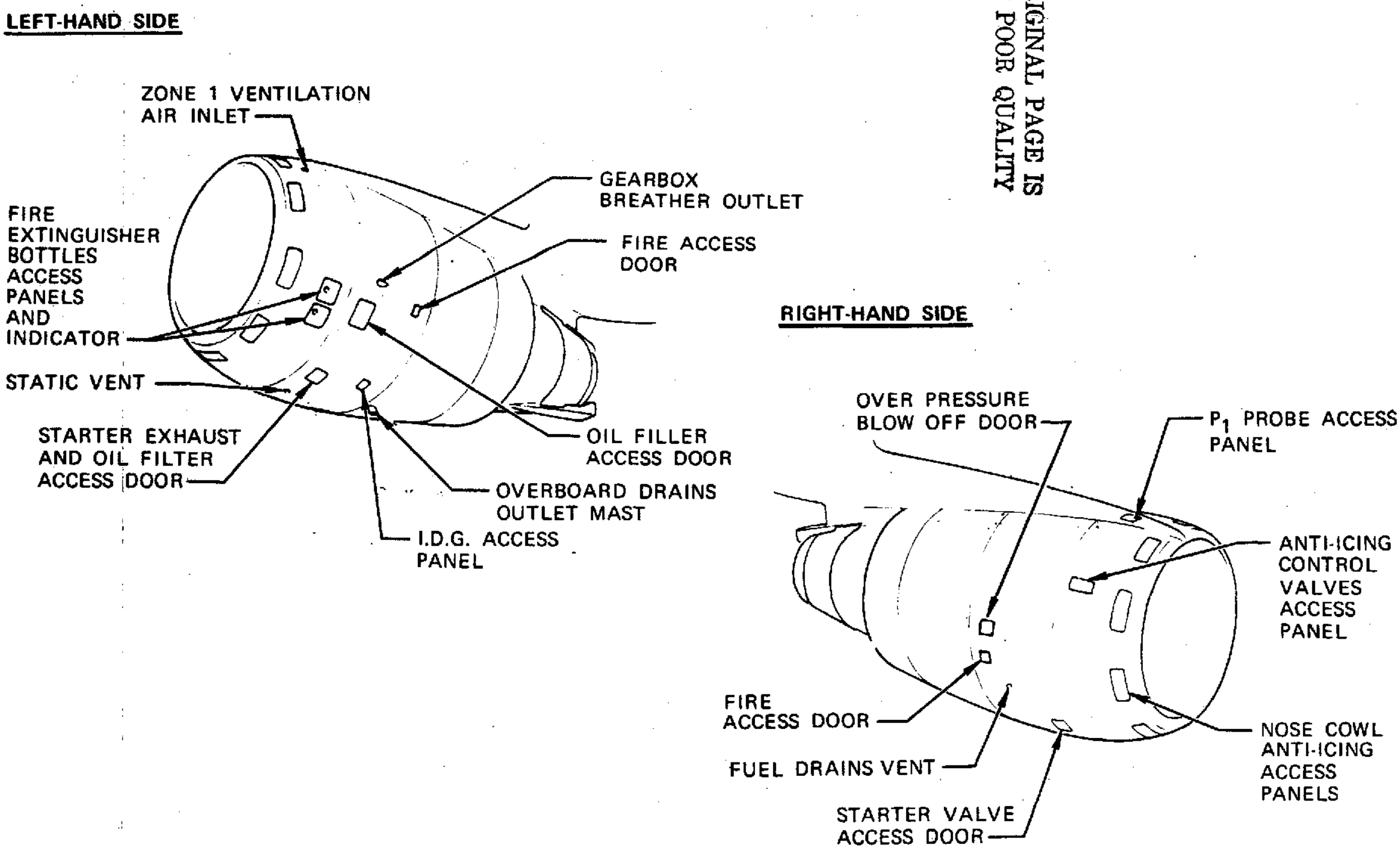

FIGURE 31

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NORMAL LOCAL OPERATING TEMPERATURES

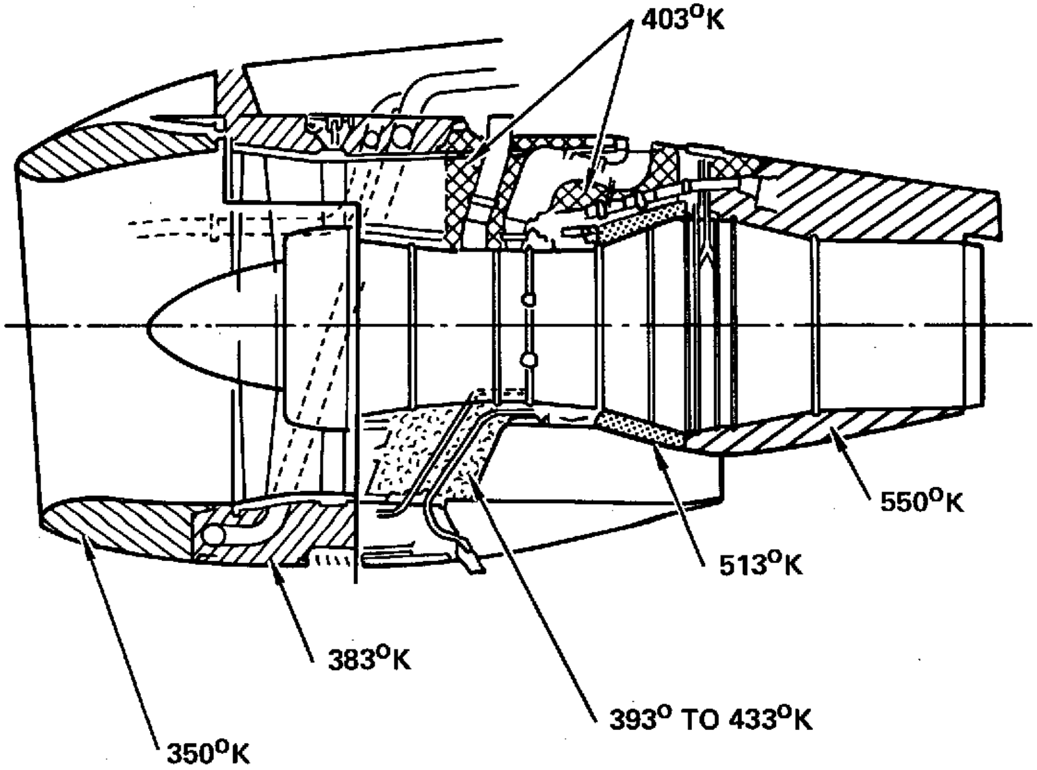

FIGURE 32

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NACELLE PROFILES

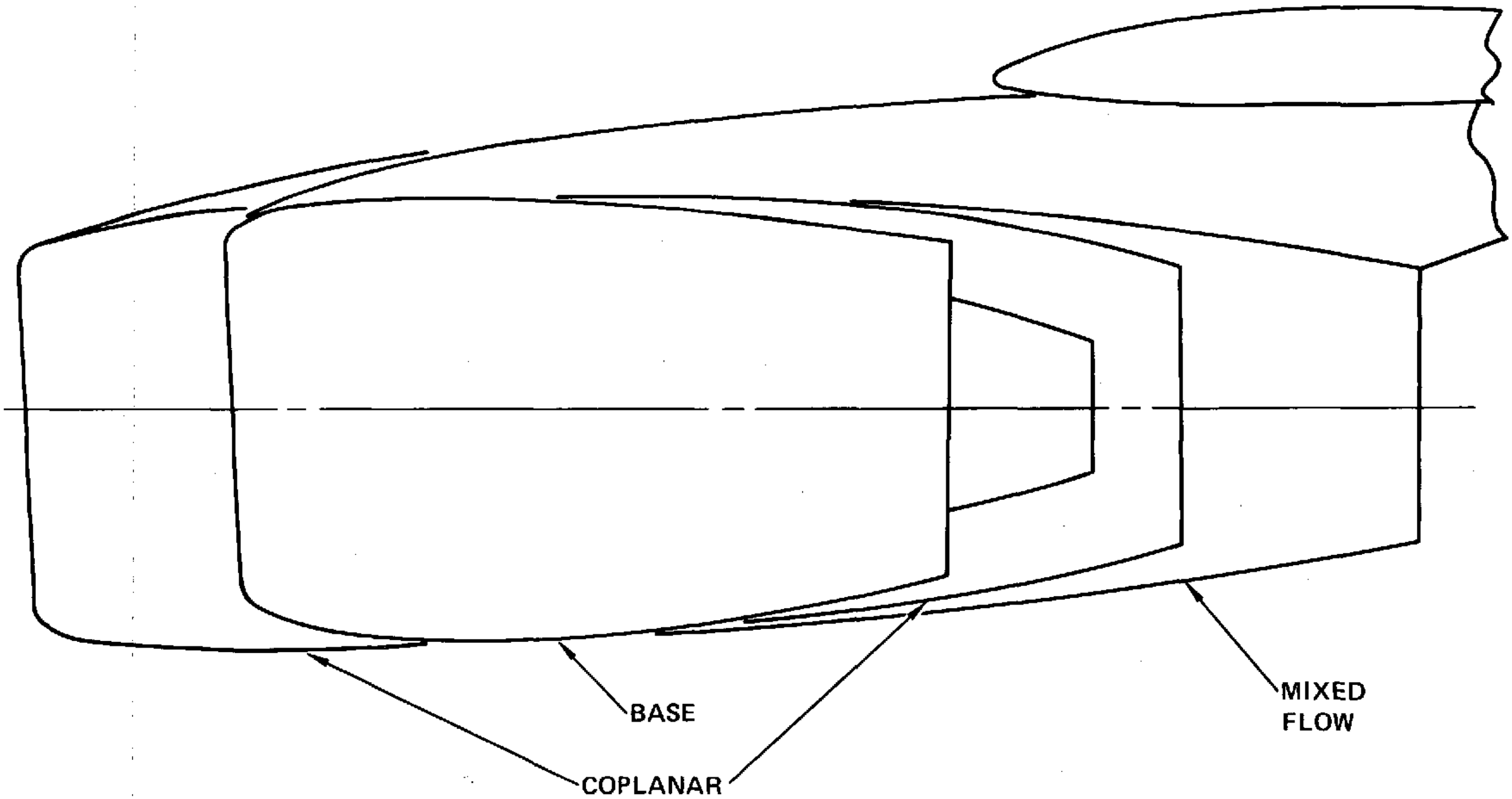

FIGURE 33

at the Lockheed-California Company. This method computes the pressure distribution on complete aircraft configurations in potential subsonic and supersonic flow. Thickness and lift effects, as well as the corresponding interference, are properly accounted for by the solution of the corresponding boundary conditions.

Representative comparisons of the effects of the various configurations analyzed are shown in Figures 34 and 35. Since neither power effects nor transonic flow condition can be presently computed by the above theoretical method, only a first order qualitative evaluation of the interference effects can be made by examining these pressure distributions. From such an examination the following can be concluded:

- The acoustic, or mid term, nacelle shows no significant difference in the pressure distribution interference when compared with the baseline configuration.
- At cruise angle of attack, the mixed-flow nacelle does not appear to be significantly different from the other two configurations.
- Therefore, the installation of a mixed-flow nacelle would probably require some more extensive aerodynamic development work, but it shows no potential interference problems that could not be solved by proper configuration tailoring.

5.5 MINIMUM FUEL CONFIGURATIONS

The mixed flow composite nacelle configuration is designed to meet the noise reduction goals with a minimum penalty in direct operating cost. The current interest in saving fuel suggests the alternate approach of minimizing weight, drag, and specific fuel consumption as the primary objective and accepting the noise level and direct operating cost effects as fallouts. Reviewing the configuration of Figure 30 with this approach we observe that the mixed flow nozzle, the smooth liners in the inlet and fan duct, and the use of composites all contribute to reduced fuel consumption. However, the extended inlet increases weight and drag, the broad band liners in the inlet increase weight, perforated face sheets of the mixer and nozzle increase internal losses, and the Schizophonium in the nozzle adds weight. The minimum fuel configuration is therefore derived by making the following modifications to the configuration of Figure 30:

- Using the baseline inlet 1.3 m (51 in.) long instead of the 1.8 m (71 in.) inlet required for noise reduction. The inlet weight is reduced from 235 kg (518 lb) to 143 kg (316 lb), a saving of 92 kg (202 lb). The reductions in external wetted area and internal losses improve the SFC by 0.3%.

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PRESSURE DISTRIBUTION ON WING LOWER SURF. (INB'D OF PYLON)

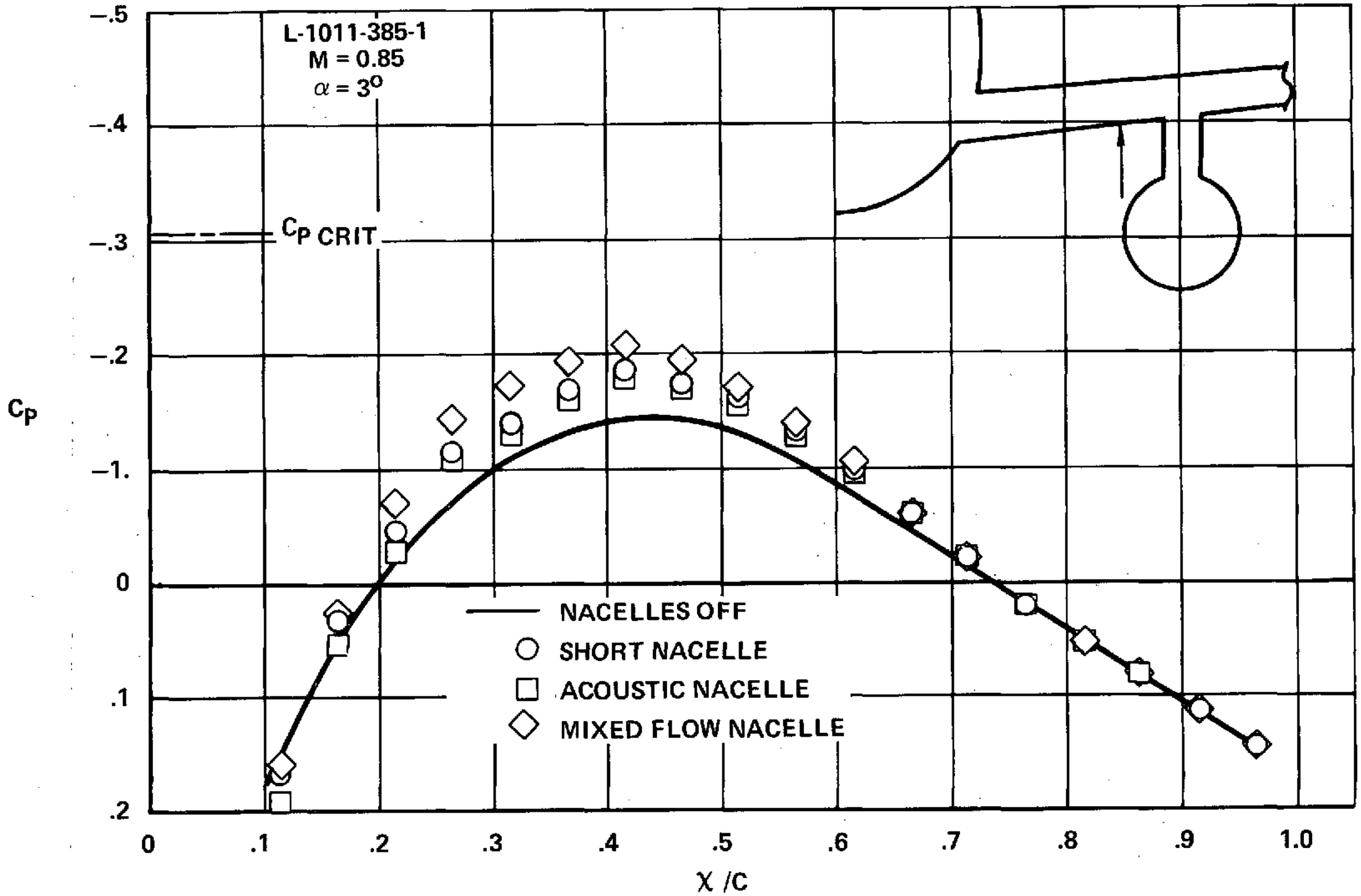

FIGURE 34

PRESSURE DISTRIBUTION ON WING LOWER SURFACE (OUT'D OF PYLON)

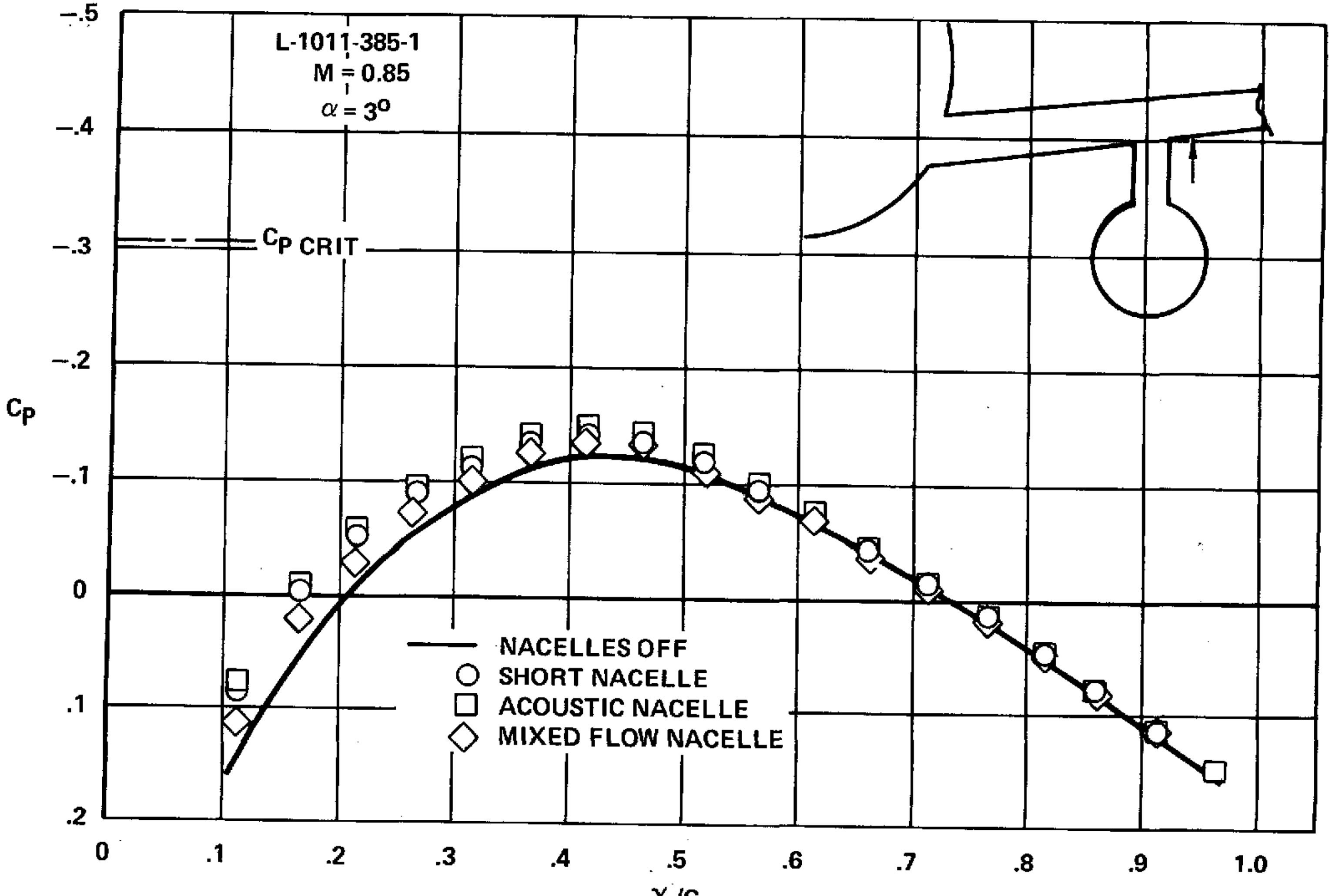

FIGURE 35

- Removing the acoustic treatment from the mixer and aft nozzle. This treatment uses perforated steel face sheets and replacing these with smooth hard walls improves the SFC by 0.2%. The mixer weight is not affected, but replacing the Schizophonium in the nozzle with stiffened sheets saves 39 kg (85 lb) per nacelle. A treated center body is retained as some turbine noise suppression is obtained with negligible loss.

- Acoustic treatment in the inlet and fan duct is retained, but smooth face sheets are used throughout. This configuration obtains about 1.5 EPNdB reduction below the baseline in approach.

This configuration shown in Figure 36, is 299 kg (659 lb)/airplane lighter than the composite mixed flow and has 0.5% lower SFC than the mixed flow with perforated fan duct and tail pipe treatment. Relative to the baseline, the minimum fuel configuration is 395 by (871 lb)/airplane heavier, and has 1.2% lower SFC.

5.6 ATT PRELIMINARY DESIGN NACELLE

The acoustic analysis of the ATT nacelle described in Paragraph 6.4.2 resulted in the following changes to the configuration shown in Figure 27:

- Inlet - The effective treated length of the inlet is reduced from 1.78 m (70 in.) to 1.07 m (42 in.). The inlet length becomes 1.68 m (66 in.). The treatment is similar to that recommended for the wide-body, Permoblique 6.35 cm (2.5 in.) deep.

- Tail pipe - The honeycomb liners on the centerbody and on 1.52 m (60 in.) of the primary nozzle are changed to Schizophonium 7.1 cm (2.8 in.) deep.

The final configuration is shown in Figure 37. The structure is similar to that described for the wide-body nacelle. Although the initial operational date for the ATT is five years later than that expected for the wide-body acoustic composite nacelle, no radical development in composite technology is foreseen in that period that would lead to a marked weight reduction. For each component, the weight reduction that might be achieved by using composite materials is therefore expected to be comparable to that found for the wide body nacelle.

The changes to the inlet and liners improve the SFC by 0.4%, resulting in the SFC for this configuration being 1.7% higher than the baseline.

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MINIMUM FUEL CONFIGURATION

m (in)

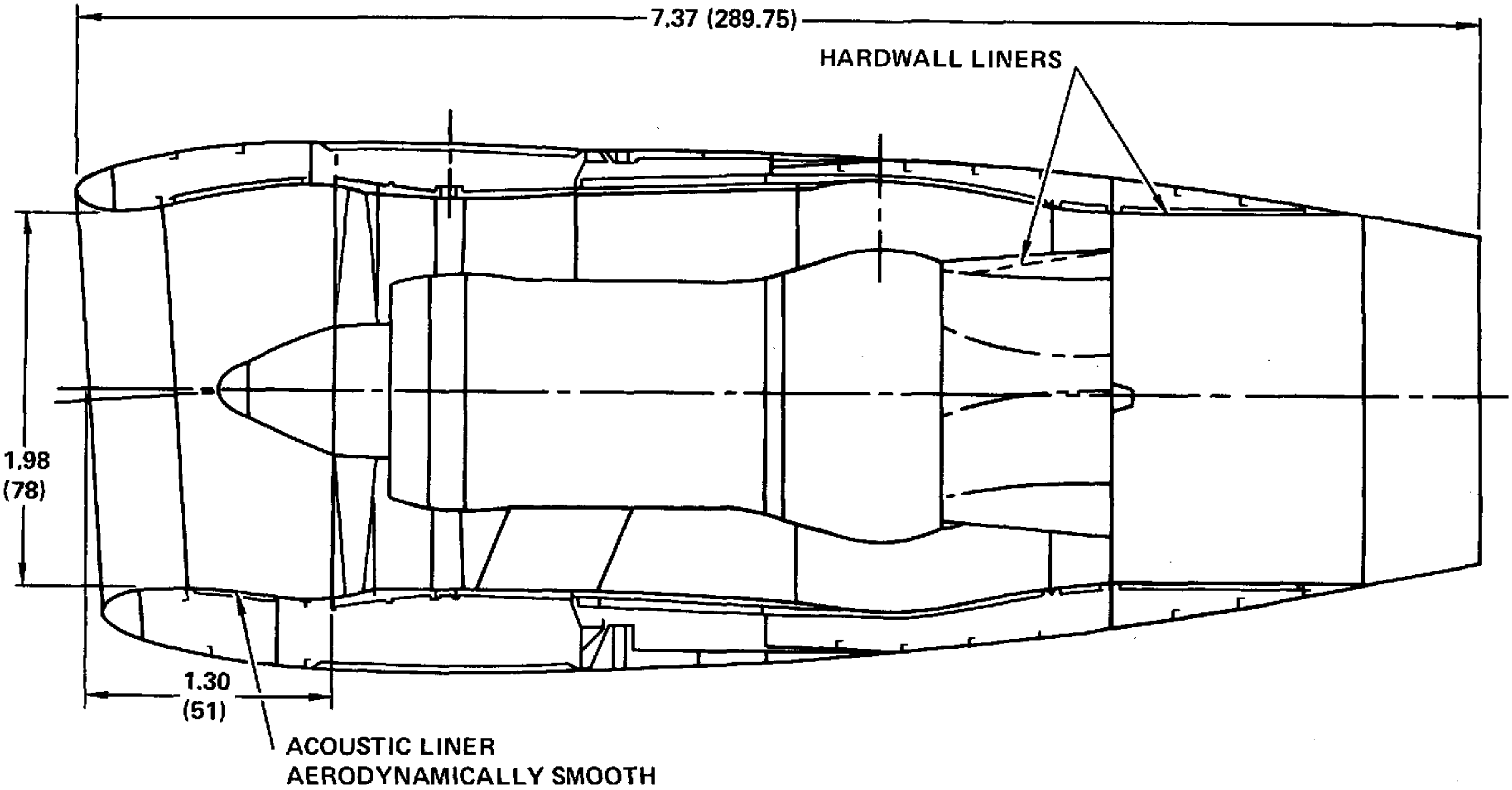

FIGURE 36

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PRELIMINARY DESIGN NACELLE - ATT

m (in.)

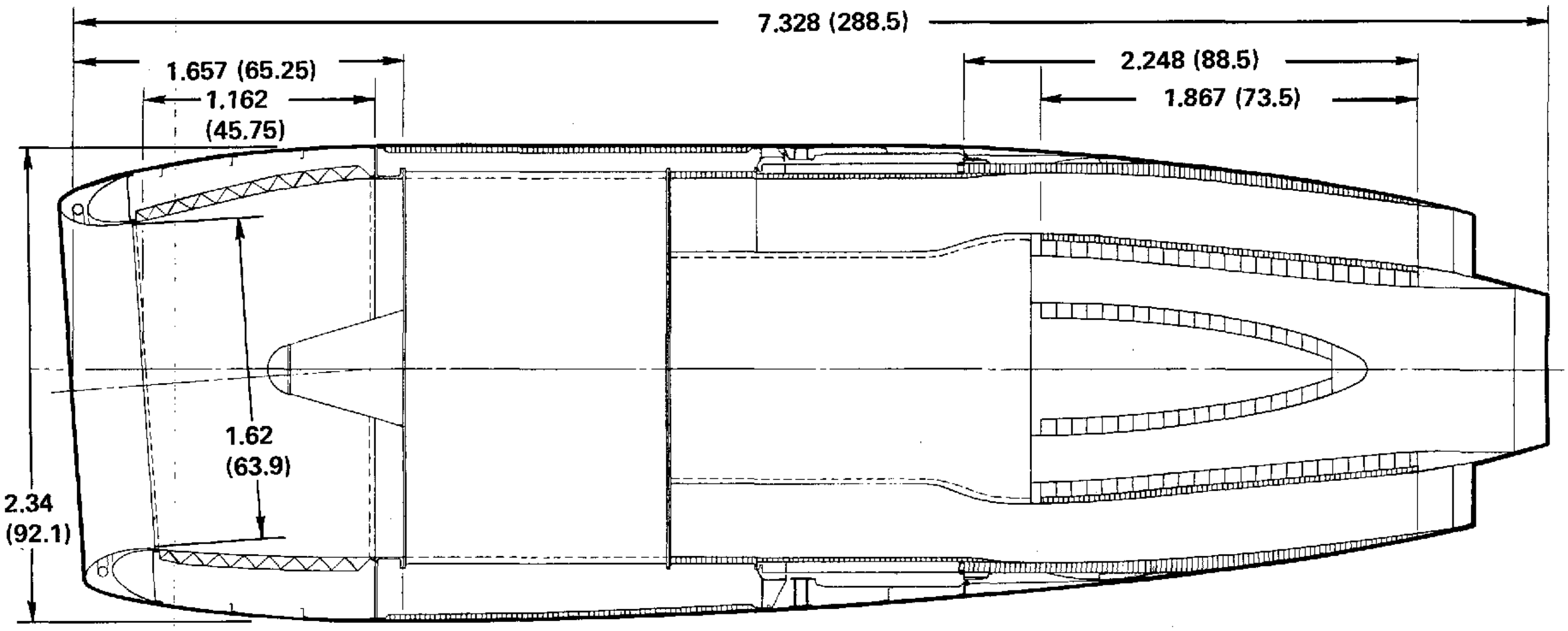

FIGURE 37

SECTION 6

ACOUSTICS

6.1 INTRODUCTION AND OBJECTIVES

This section presents the noise reduction goals for the composite nacelles and the rationale for the selection of these goals. The procedures employed in determining the amount of noise reduction required for the various noise sources and in defining the acoustical characteristics of duct lining designs are also discussed. The section concludes with a description of duct lining designs and predictions of the amount of noise reduction which they will provide.

In past studies of a similar nature involving engine noise reduction, the practice has been to assume that future reductions in noise will increase nearly linearly with the passage of time. This approach has led to the design of "quiet" propulsion systems which have achieved the maximum noise reduction goals, but, unfortunately, have been unsatisfactory as a result of the performance penalties incurred in attaining these goals.

In the present study, the approach to choosing target levels of noise reduction differs from previous similar investigations. In its proposal to undertake a program devoted to the preliminary design of quiet composite nacelles for wide body and advanced technology aircraft, Lockheed stated that realistic noise reduction objectives must be based on the recognition of the existence of certain noise sources which, at least within the foreseeable future, appear to be irreducible without fundamental changes in design. These sources consist of airframe and jet mixing noise which in combination constitute a "noise floor." Once the existence of such a noise floor is accepted, it becomes evident that a point of diminishing returns is rapidly reached as the noise from treatable engine sources are further reduced to levels below that of the noise floor.

In consideration of the above rationale, the specific noise reduction objective chosen, for both wide-body and ATT aircraft is as follows: <u>To reduce the subjective noise produced by the combined treatable engine noise sources to that of the noise floor.</u>

The acceptance of the "noise floor" concept implies acceptance of the assumption that the technology for reducing jet and airframe noise will proceed at a significantly slower rate than the reduction of treatable sources. The consideration of jet noise as an irreducible source is of course valid only when it is assumed that the final jet efflux velocity is fixed. Such a proven method for reducing jet noise as increasing the by-pass ratio of an engine is considered to be a means for reducing the strength of the jet noise source rather than for inhibiting noise radiation from a given noise source. The RB.211-22 engine incorporating a mixed exhaust was chosen in this study for its excellent propulsion performance. This configuration is not expected to change the jet mixing noise level. The effect of mixing on jet noise is based on mixer tests performed by Rolls Royce on a model rig, and on model tests at the National Gas Turbine Establishment using their co-axial jet facility (which involved no mixing). Model data was then applied to predicted full-scale, hot stream levels on the basis of the 1973 proposed SAE jet noise prediction method. The predicted levels for the mixed configuration were lower than with no mixing at large angles to the intake. At angles less than approximately 115° an increase due to mixing is indicated. For the angle of maximum noise directivity associated with the wide-body composite nacelle, the predicted change in noise level due to mixing is negligible.

Although jet noise tends to control the noise floor during takeoff, airframe noise is predicted to be virtually entirely responsible for the noise floor during approach. The potential significance of airframe noise was first discovered at Lockheed in 1969 during a flyover test program that was conducted for the purpose of estimating noise that would be produced by surveillance aircraft designed to totally suppress engine noise. The flight tests involved taking flyover noise measurements on a number of small propeller-driven aircraft flying at low altitude with the engines not operating. On the basis of these data, an empirical prediction method was developed which allowed airframe noise to be estimated on the basis of weight, velocity, wing area and aspect ratio (Reference 12). More recently, Revell, et al, have developed a theoretical basis for providing airframe noise predictions which are in good agreement not only with data obtained from small aircraft but also with recent flyover tests conducted on the C-5A. This method, which is still in the process of evaluation, is based on the theory that airframe noise is produced primarily by pressure fluctuations that are generated at the trailing edges of aircraft major structural components. Of these, the wing is the major contributor. The airframe noise spectra estimated for this study are based on the above method.

6.2 AIRCRAFT NOISE SOURCES

For the purposes of this study, jet and airframe noise are considered to be nontreatable noise sources. Conversely, noises generated by the fan and within the core engine are considered to be treatable, since acoustically absorbent liners can be successfully employed for reducing the noise radiated into the far field.

It is convenient to consider the treatable noise sources as consisting of the following:

- Fan inlet
- Fan discharge duct
- Turbine
- Low frequency core engine

Each of the above sources is composed of a multiplicity of noise generating mechanisms, many of which are still not well understood. For instance, contributors to fan and turbine noise include blade vortex noise, blade passage pure tones (including harmonics), and rotor blade/stationary vane interaction tones. Low frequency core engine noise has been attributed to a number of basic sources including the combustion process and interaction between combustion products and the turbine.

A necessary first step in this study was the determination of the strength of the four treatable noise sources and of the jet and airframe noise. It was required not only to describe the noise in terms of one-third octave band (1/3 O.B.) spectra, but also on the basis of subjective noise levels. The necessity of obtaining measures and/or predictions of subjective noise follows directly from the noise reduction objective chosen for this study, i.e., "to reduce the <u>subjective</u> noise produced by the combined treatable engine noise sources to that of the noise floor." Although there are a number of methods in existence for specifying subjective noise and the aircraft operating conditions on which it is based, this study has employed the noise level terminology associated with FAR Part 36 noise certification procedures.

In this regard, although effective perceived noise level (EPNL) is the subjective noise measure specified in FAR Part 36 procedures, the more simple perceived noise level (PNL) and tone corrected perceived noise level (PNLT) have been considered to be adequate in most instances for the purposes of this study. This choice was motivated on the basis of time and economy. The EPNL scale reflects duration in addition to PNLT. The chosen noise reduction goal involves the relation between subjective levels associated with the noise floor and treatable sources. Since it is reasonable to assume that duration differences associated with candidate acoustical treatments will not be significant and because accurate predictions of these differences would be virtually impossible to obtain, the PNLT scale is considered to be an appropriate choice. Since the acoustical treatment is designed to eliminate discrete frequency noise, PNL is generally adequate. A further useful simplification is provided by expressing noise sources and floors in terms of a free field environment.

The EPNL scale is used when the noise level of the total treated airplane is specified. This has been done in paragraph 6.5 where the noise levels of aircraft incorporating various nacelle designs are presented. Ground reflections are of course considered in EPNL determinations.

6.2.1 Approach to Defining Noise Reduction Requirements

The following procedures were involved in determining the noise attenuation spectra that would be required for each of the treatable noise sources; (i.e., the noise radiating from the fan inlet and exhaust duct, turbine noise, and low frequency engine core noise):

1. Unattenuated one-third octave band (1/3 O.B.) spectra were obtained for both treatable and non-treatable noise sources during take-off and approach operation.

2. Perceived noise levels were determined for each of the treatable sources and for the noise floor.

3. Suppression requirements were determined in terms of 1/3 O.B. noise attenuation spectra for each treatable source such that the total aircraft noise exceeds the noise floor by no more then 3 PNdB. It is noted that this is consistent with the aforementioned noise reduction objective.

The approach to determine the spectra of the jet noise, and unattenuated fan inlet, fan duct, turbine, and core noise differed for the two engines involved in this study. In the case of the RB.211-22 engine, noise data were available from both flight and static tests. Unattenuated source spectra were derived as follows:

1. Noise measurements taken during L-1011 FAR-36 compliance tests were used to provide total noise spectra for approach and takeoff operations. These spectra were converted to represent a free-field condition by subtracting out the estimated contribution of ground reflections.

2. The principal noise source contribution to the total spectra consisted of treated fan inlet and exhaust noise, treated turbine noise, unattenuated engine core noise, jet mixing noise, and airframe noise. Spectra for jet mixing noise were determined on the basis of the SAE AIR 876 prediction method and incorporated a full relative velocity effect. Airframe noise spectra were obtained by the procedures described in Reference 1. Jet and airframe noise were then subtracted from the total to provide composite spectra consisting of treated fan and turbine noise plus core noise.

3. By employing static test data, where numerous donfigurations incorporating a wide range of engine modifications have been tested it was possible to estimate the 1/3 O.B. spectra for the remaining treated individual sources. This eduction was carried out statically and the transformation of these results to the in-flight case was performed using further data available from in-flight diagnostic work. Since it was desirable to establish an unattenuated source baseline, 1/3 O.B. noise attenuation spectrum envelopes, also derived from static engine tests, were added to the noise spectra derived for the treated fan inlet, fan exhaust, and turbine. The spectra obtained for the approach condition are shown in Figure 38.

Estimates of 1/3 O.B. noise spectra for the STF 433 were derived by Pratt and Whitney by employing a noise prediction computer program that is based on a data bank obtained from extensive static tests on a number of engine models. Perceived noise levels were then derived from the spectra of the treatable sources and the noise floors.

6.2.2 Noise Sources and Floors/Reduction Goals

Predictions of unattenuated 1/3 O.B. source spectra for a three engine airplane powered by STF 433 engines are given in Figure 39. Source attenuation spectra that would result in meeting the noise reduction goals for wide bodied and for ATT airplanes are shown in Figure 40 and 41 respectively. Free field PNL's for treated and unattenuated STF 433 and RB.211-22 sources (considering the total airplane) are given in Figures 42 through 45. The associated noise floors for airplanes equipped with STF 433 and RB.211-22 engines are presented in Figure 46 and 47, respectively.

Although some will be interested in using Figures 42 through 45 for comparing the unattenuated noise source PNL's derived for the two engines involved in this program, it is noted that such comparisons fall outside the scope of this study. Furthermore, it is emphasized that the PNL values presented herein for the RB.211-22 and STF 433 were obtained by very different procedures. PNL's for the RB.211-22 are to a large extent based on actual flight measurements. Since the STF 433 has never

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FREE FIELD NOISE SPECTRA - UNTREATED

APPROACH AFT – 113m (370 FT ALTITUDE)
FREE FIELD SOURCE SPECTRA
WIDE BODY

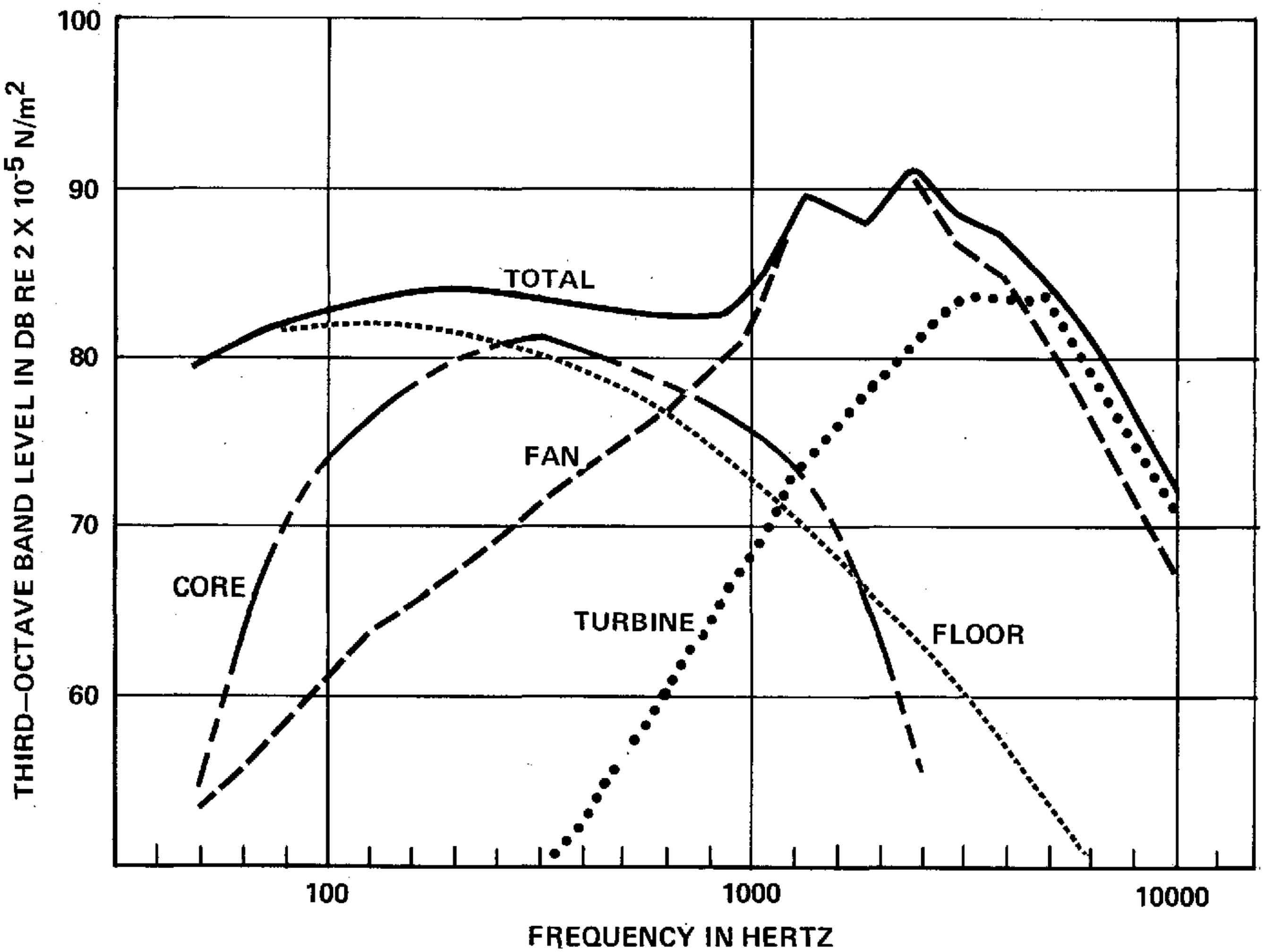

FIGURE 38

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UNTREATED ATT

APPROACH - AFT - 113 m (370 FT) ALTITUDE
FREE FIELD SOURCE SPECTRA

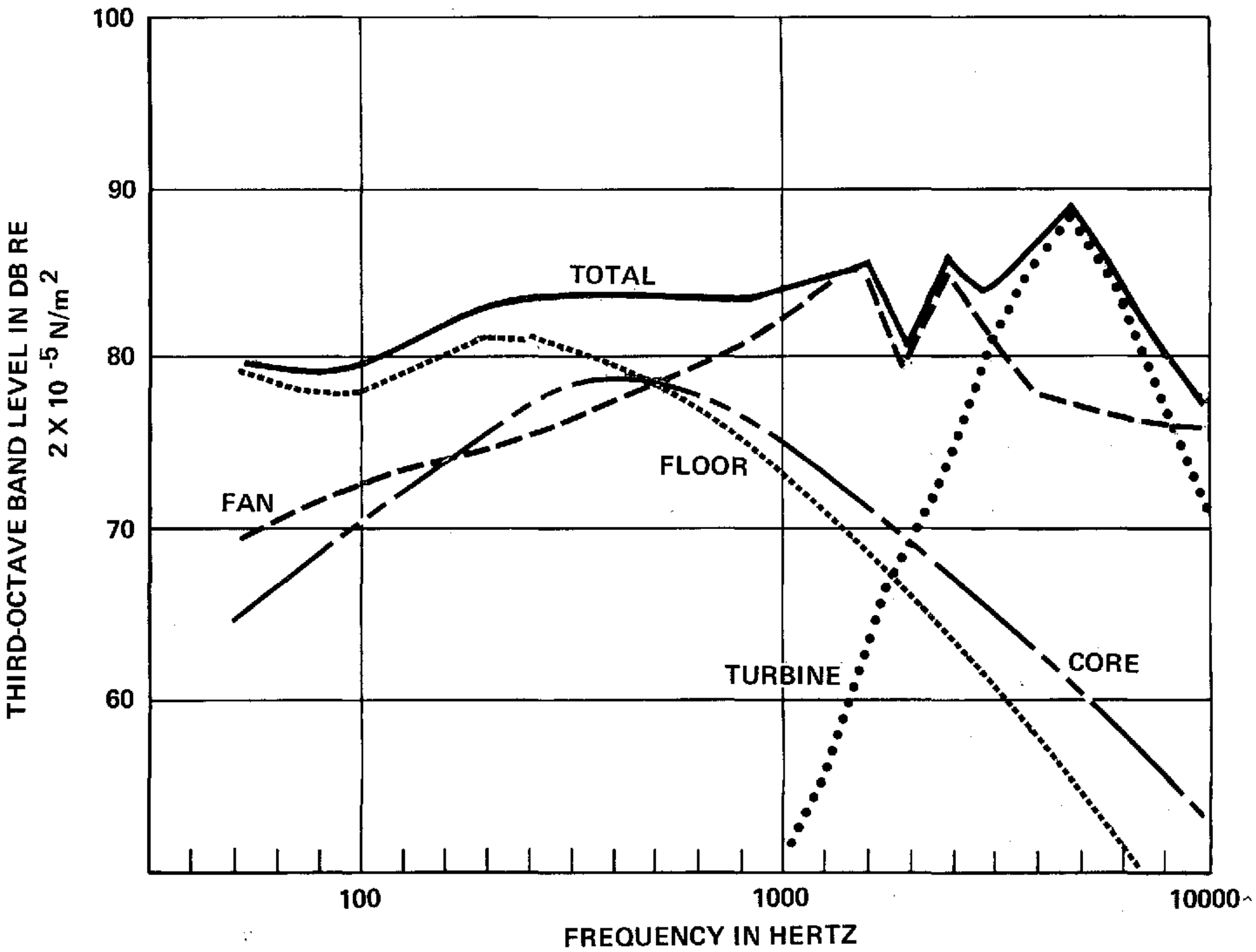

FIGURE 39

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REQUIRED ATTENUATION

WIDEBODY (APPROACH AFT)

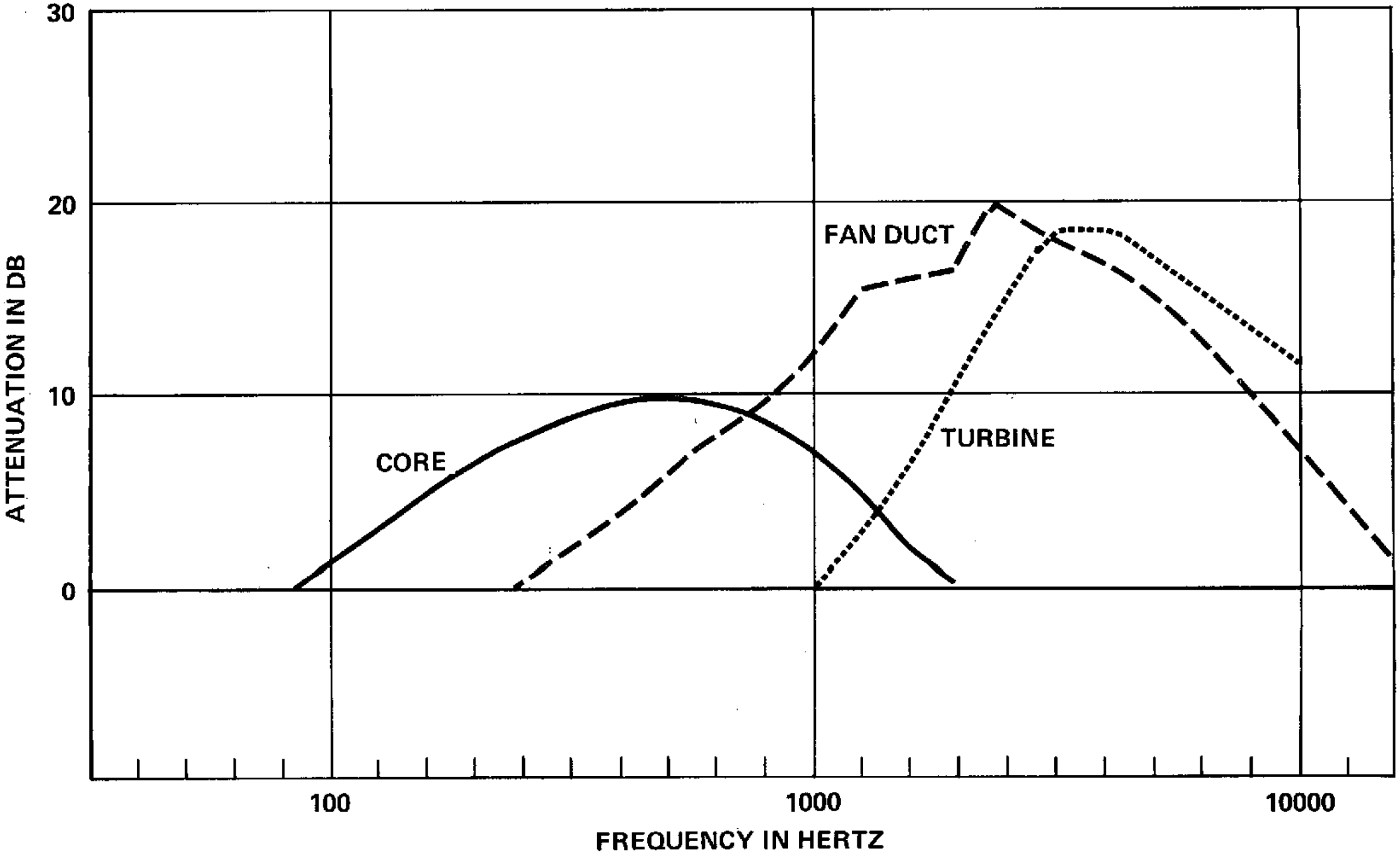

FIGURE 40

REQUIRED ATTENUATION

ATT - APPROACH - AFT

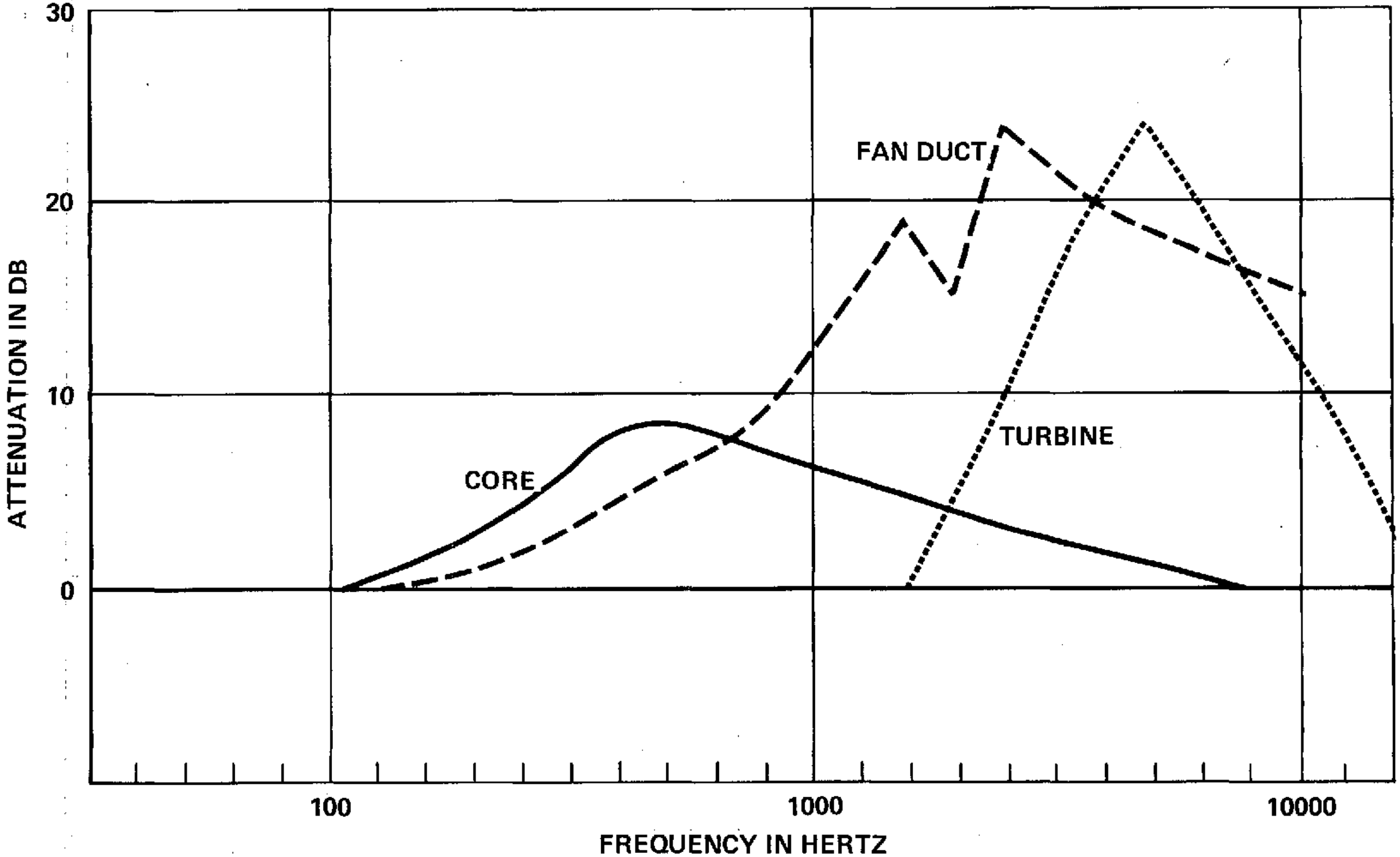

FIGURE 41

NOISE SUPPRESSION GOALS

ATT–APPROACH – 113 m (370 FT) ALTITUDE
(FREE FIELD)

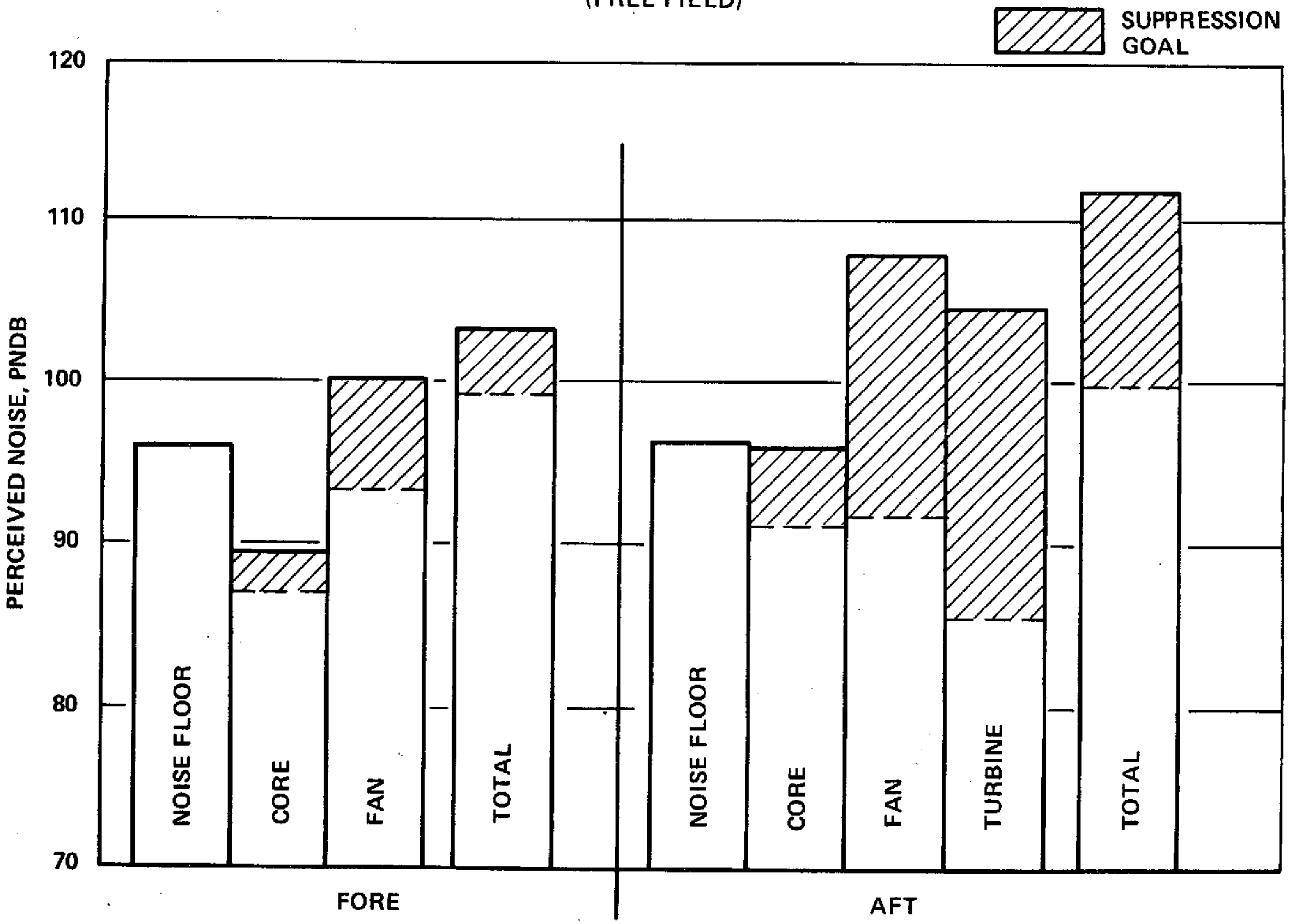

FIGURE 42

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NOISE SUPPRESSION GOALS

ATT-TAKEOFF - 449 M (1470 FT) ALTITUDE
(FREE FIELD)

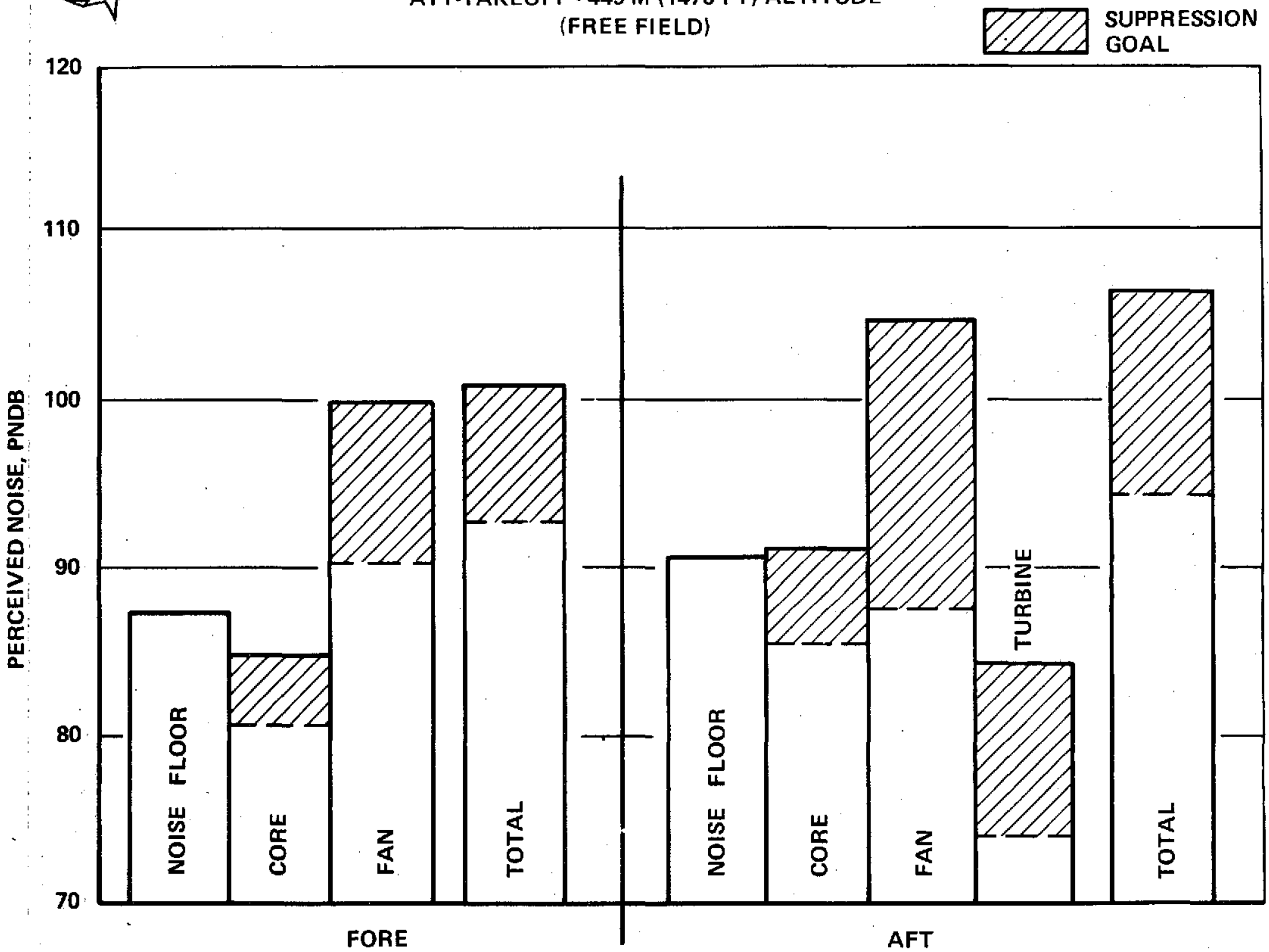
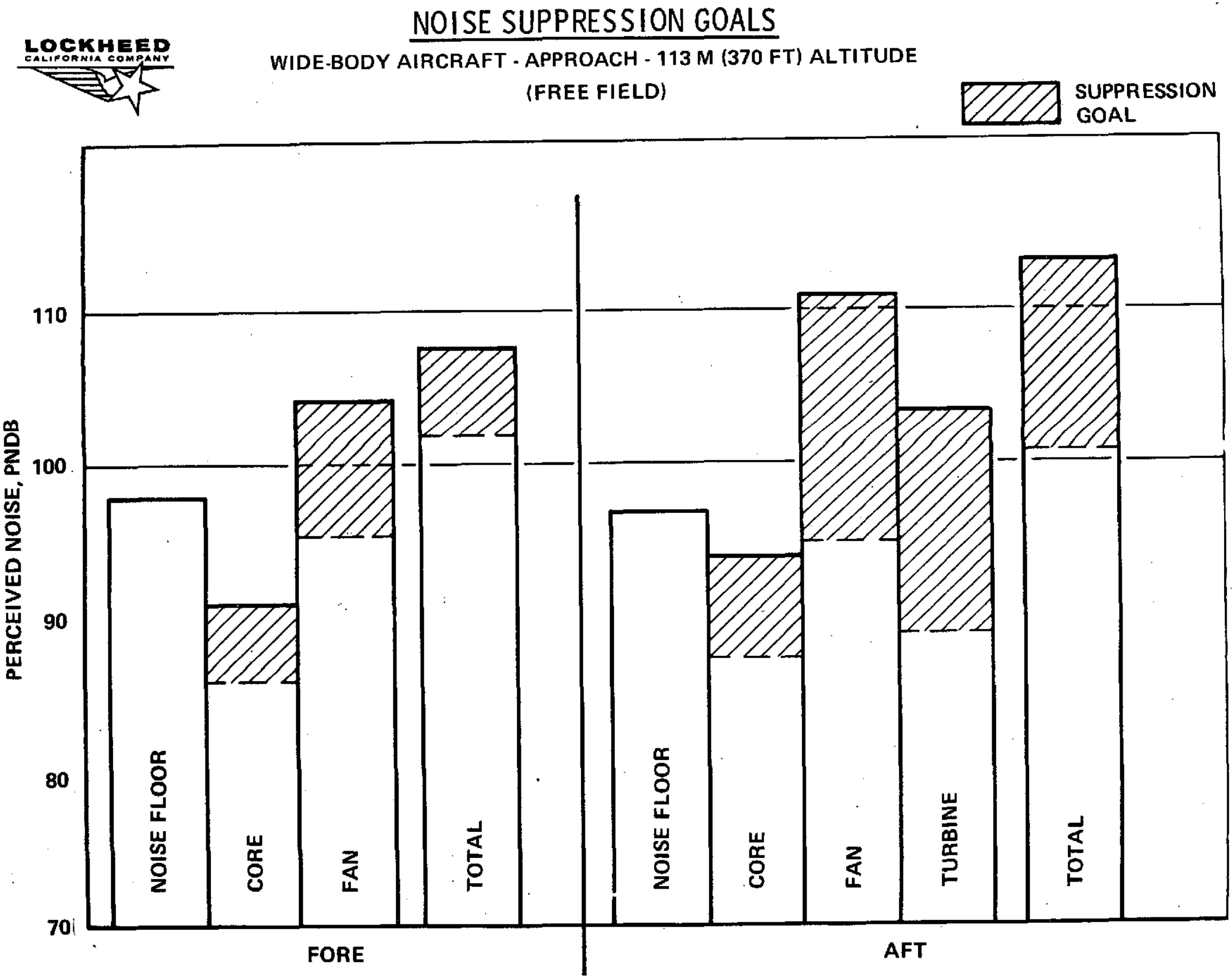


FIGURE 43



NOISE SUPPRESSION GOALS
WIDE-BODY AIRCRAFT - APPROACH - 113 M (370 FT) ALTITUDE
(FREE FIELD)
SUPPRESSION GOAL
PERCEIVED NOISE, PNDB
110
100
90
80
70
NOISE FLOOR
CORE
FAN
TOTAL
NOISE FLOOR
CORE
FAN
TURBINE
TOTAL
FORE
AFT

FIGURE 44

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NOISE SUPPRESSION GOALS

WIDE BODY AIRCRAFT-TAKEOFF- 457 M (1500 FT) ALTITUDE
(FREE FIELD)

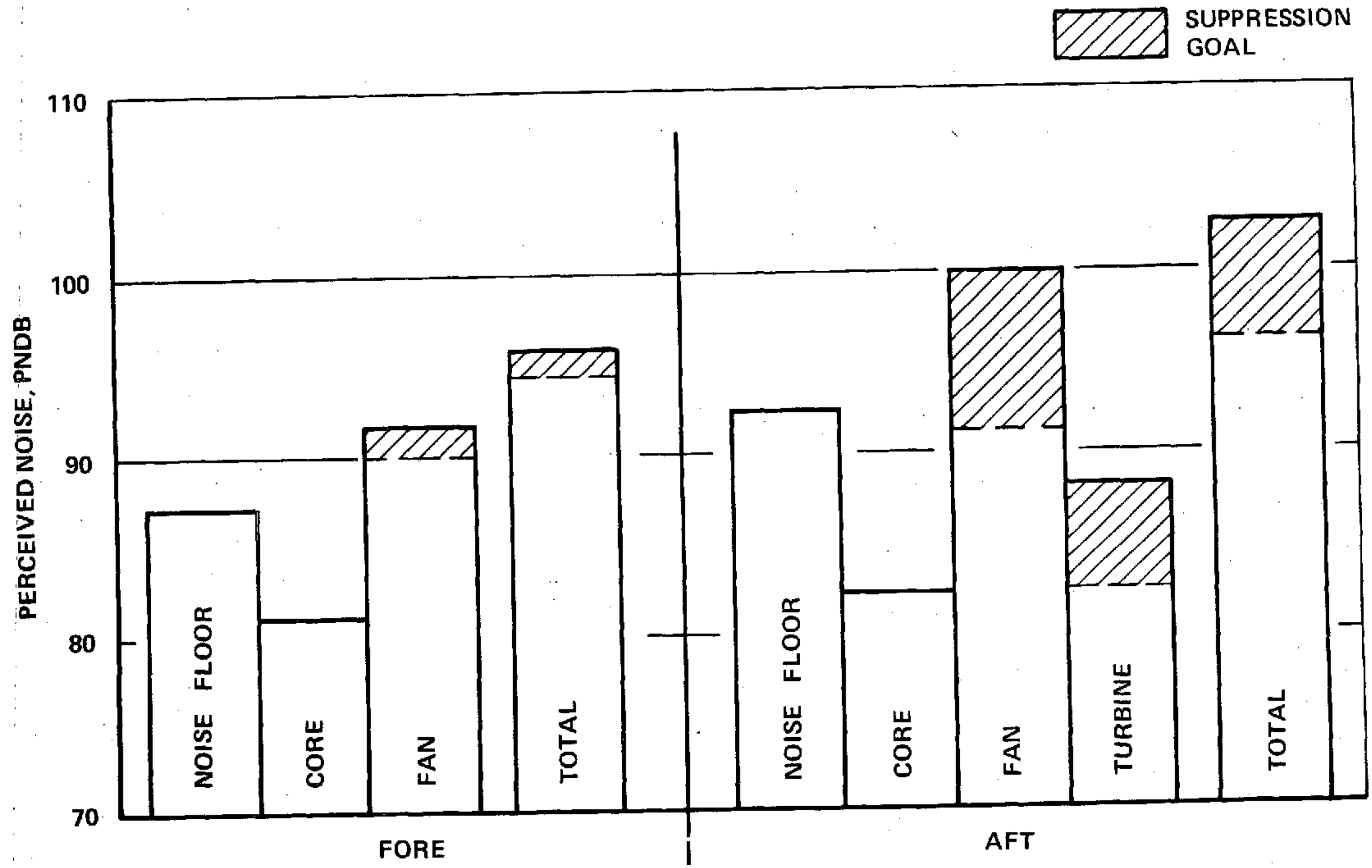

FIGURE 45

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ATT NOISE FLOORS

(FREE FIELD)

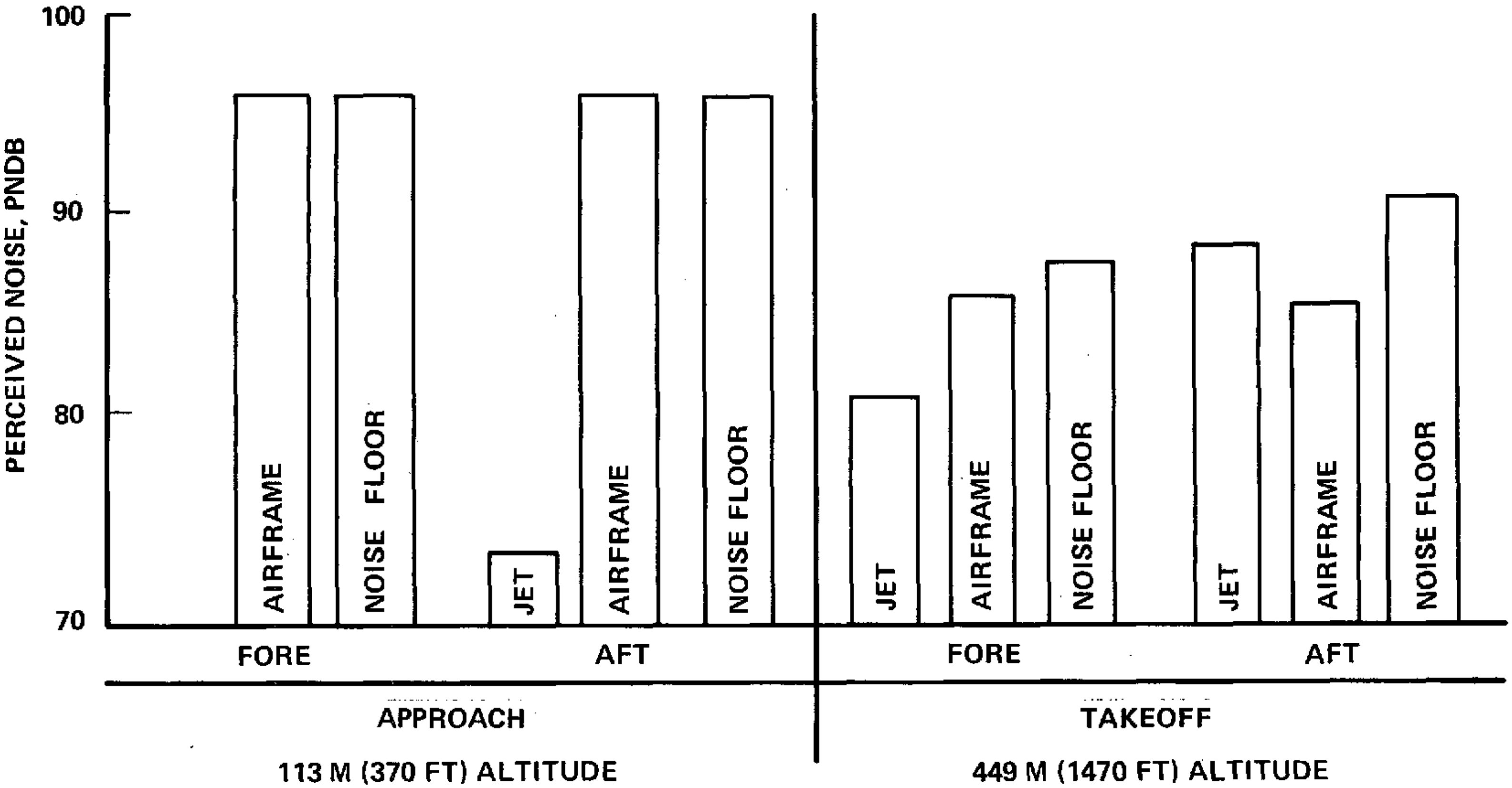

FIGURE 46

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WIDE BODY NOISE FLOORS

(FREE FIELD)

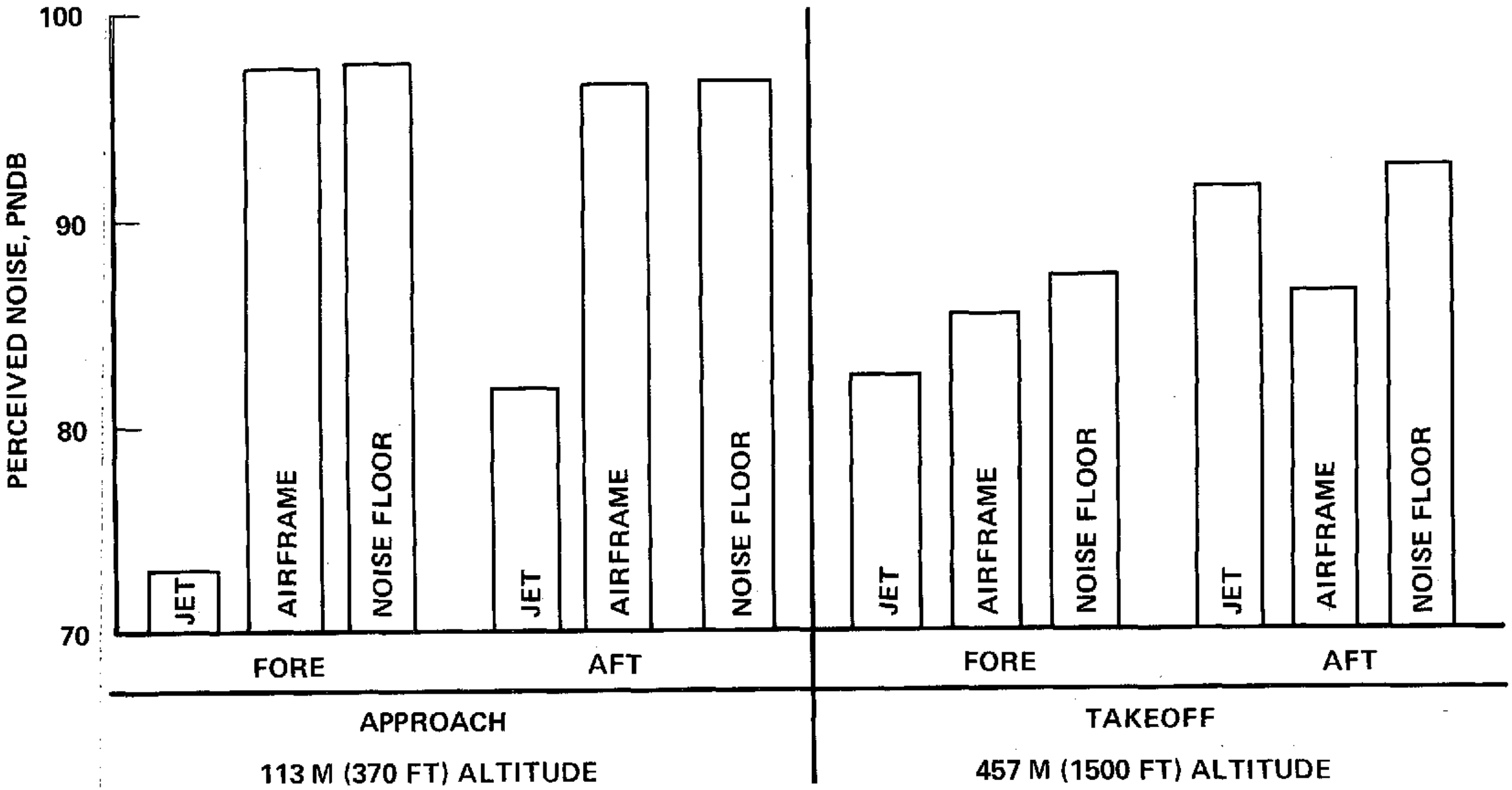

FIGURE 47

been built it was necessary to employ a noise estimation program derived from static test stand measurements on other engines with two stage fans. However, these other engines have inlet guide vanes, while the STF 433 does not. Because this difference would be expected to affect the static to flight noise difference, the STF 433 noise estimates have not been corrected for flight effects. Thus it is to be expected that indicated differences in the subjective noise levels estimated for the two engines may be strongly dependent upon the methods used in deriving them.

6.3 ANALYSIS OF ACOUSTICAL LINING REQUIREMENTS

In Phase I of this study it was required to consider a number of candidate nacelle designs for the wide-bodied and ATT aircraft while Phase II was devoted to the preliminary design of the optimum concepts. These requirements resulted in the implementation of analytical procedures for estimating the performance of acoustical liners which differed for the two phases.

6.3.1 "Quick Look" Method

Since a number of suppression concepts were to be scanned in Phase I, it was necessary to utilize a method which would allow estimates of the required lining areas to be determined quickly and at minimum cost. To satisfy this requirement, the Lockheed "quick look" method, based on empirical and theoretical results, was used. The method involves the trial selection and evaluation of a set of lining segments for the suppression of a given noise source. For each iteration, program inputs include the following:

- The spectrum of the unattenuated noise source
- Duct height
- Flow Mach number
- Tuned (center) frequency of liner segments selected for each design iteration
- Shape of attenuation curves for liner segments
- Segment lengths

The program output is the attenuation spectrum of the combined liner segments. Included in the method is a correction for flow generated noise based on the premise that such noise is produced at the nozzle lip as a result of fluctuating pressures generated by the turbulent boundary layer. At present some uncertainty exists as to the validity of the flow noise prediction method used. Therefore, a program devoted to establishing the mechanism of flow noise generation and experimentally determining its sound spectrum is in progress. The major application of the flow noise prediction method lies in the determination of the minimum flow passage areas. These are so designed as to make flow velocities low enough to keep flow noise well below the level of the attenuated source noise.

6.3.2 Convected Wave Equation

Although the aforementioned approach is well suited for its intended purpose, a considerably more sophisticated method is required for determining the optimum acoustical impedance and associated design configuration of sound absorbing liners. It is also highly desirable to confirm analytical predictions with experimental test results. Accordingly, in Phase II of the study, lining designs were based on solutions to the convected wave equation which allows the decay of individual duct modes to be investigated as a function of the acoustical impedance of a liner. In the case of the RB.211-22 engine, static and flight test results were used to confirm analytical predictions. A detailed discussion of this analytical approach is provided in Appendix B.

6.3.3 Analytical Problem Areas

The accuracy of the analytical predictions is, of course, dependent upon the impact of factors not included in the mathematical model and the accuracy of the "inputs" involved. Analytical problem areas include the following:

- The distribution of sound energy among the many normal modes
- Validity of method used for estimating flow generated noise
- Accuracy of existing methods for estimating acoustical impedance modification by grazing flow for nonlinear liners having unusually high resistance.
- Sound absorption modification introduced by the presence of sheared flow.

The above items are discussed in detail in Section 12 of this report and are of sufficient importance to warrant an adequate assessment of their significance prior to undertaking a quiet nacelle development effort based on the acoustical treatment concepts that have been generated by this study. Proposed test programs designed to provide the necessary information are also presented in Section 12.

6.4 ACOUSTICAL TREATMENT

This section is devoted to a discussion of the considerations involved in the design of acoustical liners. Attention is centered on the nacelle configurations which, at the completion of Phase II, were chosen to be superior on the basis of cost and performance. Although the same basic design philosophy was followed for wide-body and ATT nacelle liners, the introduction of the exhaust mixer in the case of the wide-body nacelle led to substantial differences in the treatments of the fan duct and tailpipe. However, the fan inlet treatments chosen for the two nacelles differ but little.

Prior to discussing the lining designs chosen for specific flow passages, it is of interest to discuss some of the underlying assumptions and motivations which led to their selection.

6.4.1 Liner Design Philosophy

Fan Inlet - Previous studies directed to achieving a noise control objective such as FAR 36 minus 20 dB made the use of inlet splitters virtually mandatory. Empirical design methods based on an analogy to a square duct reinforced this conclusion because of the high d/λ* ratio of simple inlets. The only apparent alternative to splitters was an extremely long inlet duct. Neither is desirable. Splitters induce performance losses and structural problems, increase the hazards of foreign object ingestion, and actually increase the noise source strength by introducing upstream turbulence. Very long inlets create severe structural, aerodynamic and weight problems.

Recognition of the fact that spinning modes in cylindrical ducts attenuate very differently from zero order circumferential modes changes the problem greatly. It was first noticed that buzz-saw tones were attenuated more than might be expected for such low frequencies, even by liners not specifically designed for them. Our analysis revealed that the attenuation rate for spinning modes can attain very large values if the lobe count is large or if they are near cutoff. (These results agree very closely with those provided by Reference 6). On the basis of assuming that the energy among circumferential modes excited by broadband noise is equally distributed and that potentially hard-to-attenuate modes produced by interactions can

*Ratio of duct diameter to wave length

be discounted (for reasons given below), it is possible to show that the noise reduction objectives can be met in an inlet of moderate length by the application of wall treatment only.

In determining the amount of acoustical treatment required it was necessary to consider the energy in low order, hard-to-attenuate modes excited by blade/vane interactions. Both the RB.211-22 and STF 433 engines have the potential for exciting modes having a circumferential lobe count of four due to fan blade/OGV interaction tones. During Phase I of this study there was some concern that such modes might prove very difficult to attenuate to the desired degree, particularly in the inlet. For this reason Pratt & Whitney examined the feasibility of modifying STF 433 fan blade and guide vane numbers in order to increase the minimum number of circumferential lobes in the potentially excited modes (unpublished data). This study, which demonstrated the feasibility of increasing the mininum number of lobes from 4 to 6, also indicated the possibility that even though modes having a low lobe count are more difficult to attenuate, they may contain less acoustical energy than modes of higher order.

Subsequent information relating to the importance of such interaction tones in the RB.211-22 strongly suggest that the initial concern was overly pessimistic. Firstly, the fan blades are in much closer proximity to the engine section stators than to the outlet guide vanes. Thus, it would be expected that this interaction will dominate. Secondly, RB.211-22 inlet noise directivity measurements taken at fan speeds representative of approach operation display a peak in the second harmonic at an angle which corresponds to the zero order radial mode produced by an interaction between the fan blades and the compressor inlet guide vanes. It has been hypothesized that even at speeds this low, there exist regions between the fan blades (near the tips) where the flow velocities approach Mach one. This condition can partially block sound generated by the blade/OGV source which must pass between the fan blades to reach the inlet flow passage. Blockage increases and spreads radially toward the hub as the fan rotational speed is increased until, finally, even the interaction noise involving the compressor inlet vanes cannot radiate upstream of the fan.

On the basis of the foregoing considerations, a lining design based on the existence of the difficult-to-attenuate four-lobed modes associated with the fan/OGV interaction would appear to be over-conservative. Instead, the assumption has been made that during approach the fan/compressor vane interaction is the dominant source. Since the associated modes have 12 circumferential lobes, such modes would attenuate at approximately the same rate as the "average" mode excited by broadband noise (assuming equipartition of modal energy). Additional support for assuming that upstream radiation of fan blade/OGV interaction tones is minimal is provided by Balombin and Stakolich (Reference 11), who found that although the harmonics of the fan blade/OGV radiated from the fan duct, there was virtually no evidence of their presence in the forward quadrant. For the foregoing reasons it has been assumed that modes excited by pure tones in the fan inlet will attenuate at approximately the same rate as the average mode produced by broadband excitation. This assumption is employed for both the wide body and ATT nacelle inlets.

Exhaust Ducts - In the case of fan and tailpipe liner designs it was assumed that all possible modes which may be excited by blade/vane interaction are free to propagate (above the cut-off frequency). As with the fan inlet, the presence or absence of splitters in the exhaust flow passage is a prime design decision. Since the penalties for using them include performance losses, structural complexity, impaired access, and flow noise generation, a decision was made to attempt to achieve aft quadrant noise reduction goals with wall linings only. Analysis confirmed that this approach was feasible for both wide-body and ATT nacelles. In the wide-body nacelle the extended fan duct necessary for attaining exhaust mixing provides more than adequate treatment area for attaining the noise reduction goal.

Tailpipe - For the same general reasons as described for the fan inlet and discharge, it was desirable to avoid the use of splitters in the tailpipe. In the case of the STF 433 engine, the tailpipe must be treated to attenuate both the low frequency core noise and the high frequency turbine noise. This dual requirement, plus severe space limitations both in the radial and axial directions, clearly suggested the use of a dual frequency range absorptive structure, namely, the newly developed horn structure known as Schizophonium which is described in Appendix C.

Consideration of the RB.211-22 nacelle design utilizing mixed flow was found to require a very different approach. A deeply fluted tailpipe of very limited length and quite thin wall is required to accomplish the required mixing of the primary and secondary jets. When provided with a tapered treatment depth this geometry provides the essential features of a Lockheed proprietary duct silencing device which has been named the "Zeno duct." The Zeno duct concept combines a constant flow area of progressively varying shape, a progressively varying duct height, a constant wall resistance R and a wall reactance X which is functionally related to local duct height. The net result is an efficient silencing device of broad bandwidth. This tailpipe suppressor would be addressed primarily to turbine noise. The cowl extension beyond the tailpipe required to provide a mixing section is available for the absorption of core noise.

In order to minimize the overall length of the nacelle, the mixing section must be kept as short as possible. Aerodynamic considerations required a length of about 101.6 cm (40 in.) beyond the end of the tailpipe. The wave equation analysis indicates that this is marginally sufficient if a Schizophonium liner is used, there being a minor deficit of attenuation at very low frequencies.

The remainder of this section provides descriptions of the acoustical liner designs. The liners selected for wide-body and ATT aircraft nacelles are discussed separately, with the primary intent of demonstrating the approach to liner optimization rather than presenting the noise source characteristics of a given engine.

6.4.2 Wide Bodied Aircraft

6.4.2.1 Acoustical Design of the Fan Inlet

The initial step in the analysis of the inlet is the calculation of a complete set of attenuation contours covering each 1/3 octave band of broadband noise requiring attenuation (from 250 Hz to 10K Hz) and each pure tone and harmonic which can contribute significantly to the inlet noise spectrum. Four examples are shown in Figures 48 through 51. Figure 48 applies to the second harmonic of blade passage frequency generated by 33 blades and 70 vanes. Figure 49 applies to the case of 33 blades and 54 vanes (compressor inlet guide vanes); Figure 50 applies to the 2500 Hz 1/3 octave band of broadband noise and Figure 51 applies to the 1250 Hz band of broadband noise. Other inputs include the following:

Flow Mach number	$M = -0.4$
Tip Mach number	$M_t = 0.83$
Temperature	$T = 291K$
$\frac{\text{Duct length}}{\text{Duct diameter}}$	$\frac{L}{D} = 0.5$

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RB. 211-22 FAN INLET, ATTENUATION CONTOUR

(n = 2, B = 33, V = 70, L = .5 DIA.)

Mach No. -.400

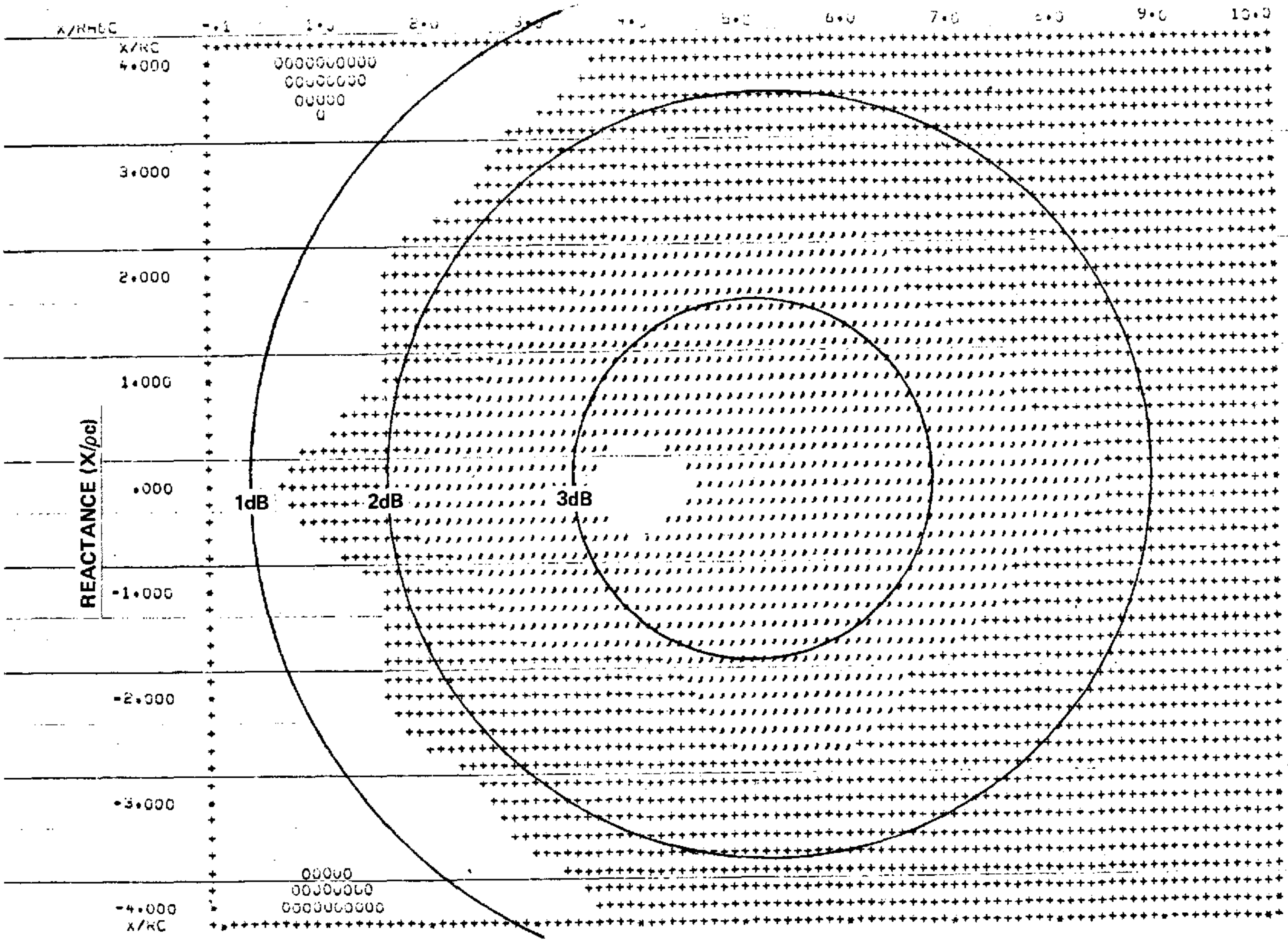

FIGURE 48

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RB. 211-22 FAN INLET, ATTENUATION CONTOUR

(n = z, B = 33, V = 54, L = .5 DIA.)

Mach No. -.400

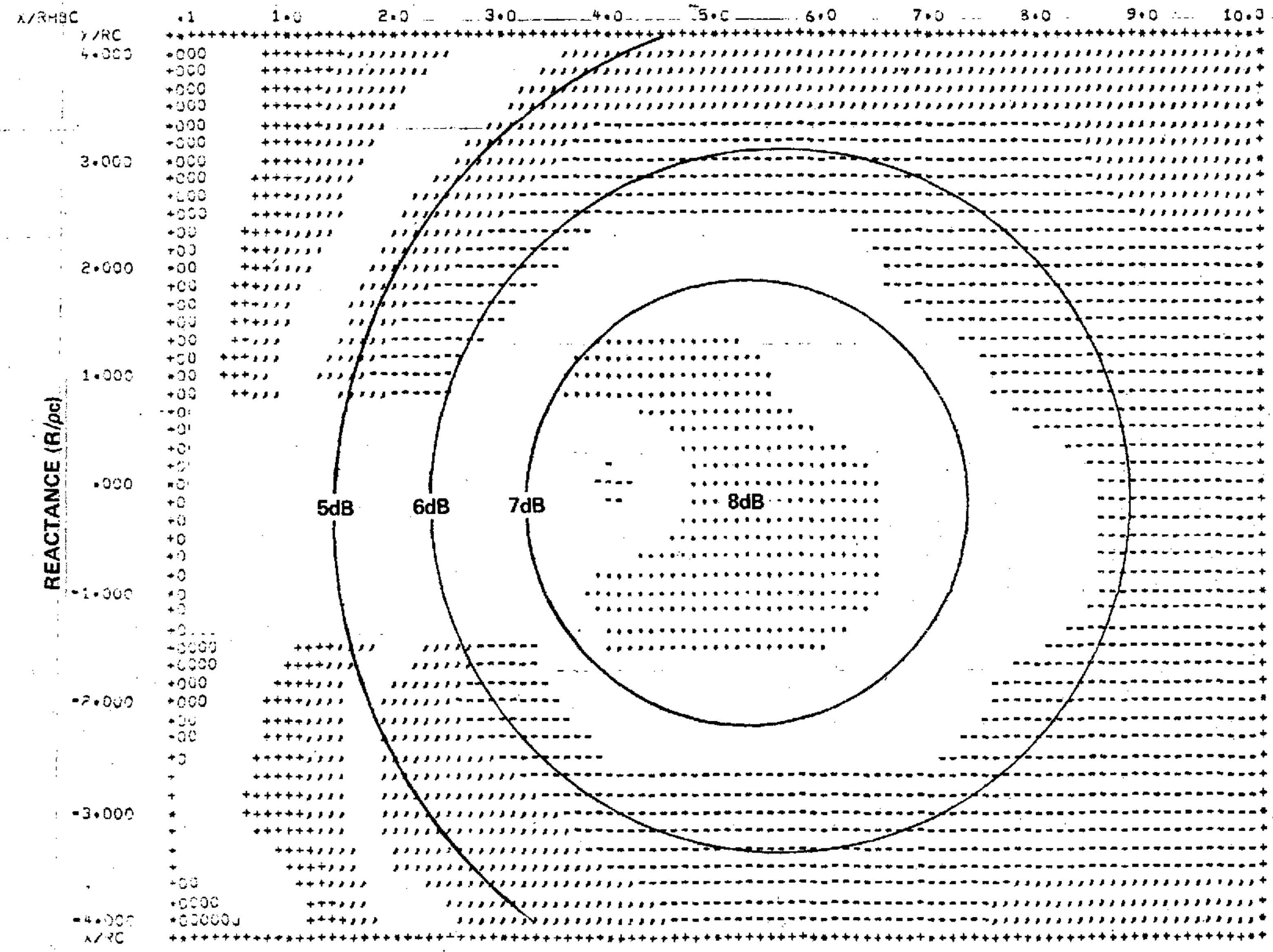

FIGURE 49

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TYPICAL CONVECTED WAVE PROGRAM OUTPUT

(RB.211-22 FAN INLET, ATTENUATION CONTOURS, L = .5 DIA.)
(2500 HZ 1/3 O.B BROADBAND NOISE)

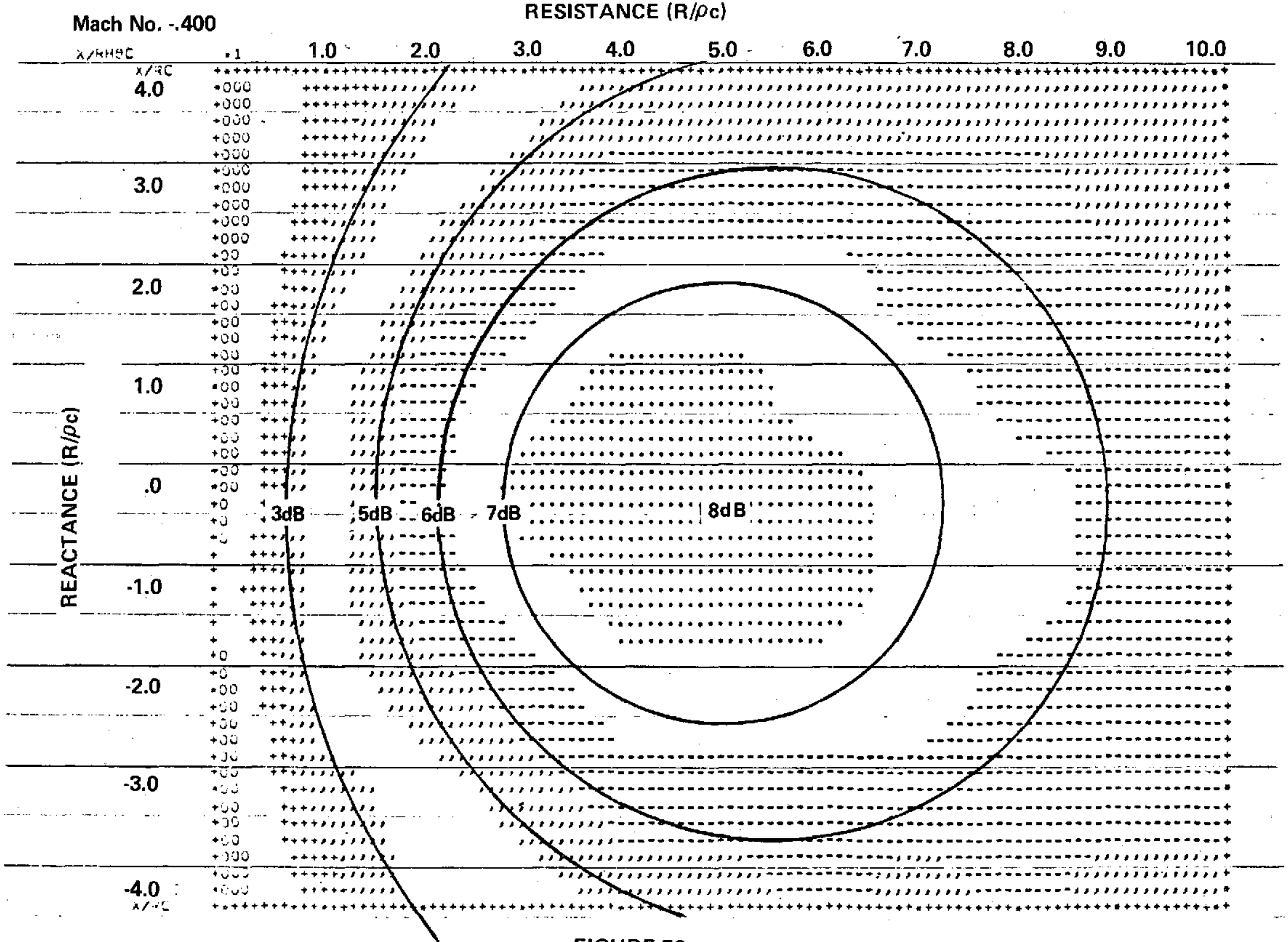

FIGURE 50

RB. 211-22 FAN INLET, ATTENUATION CONTOUR

(1250 Hz 1/3 O.B. BROADBAND NOISE)

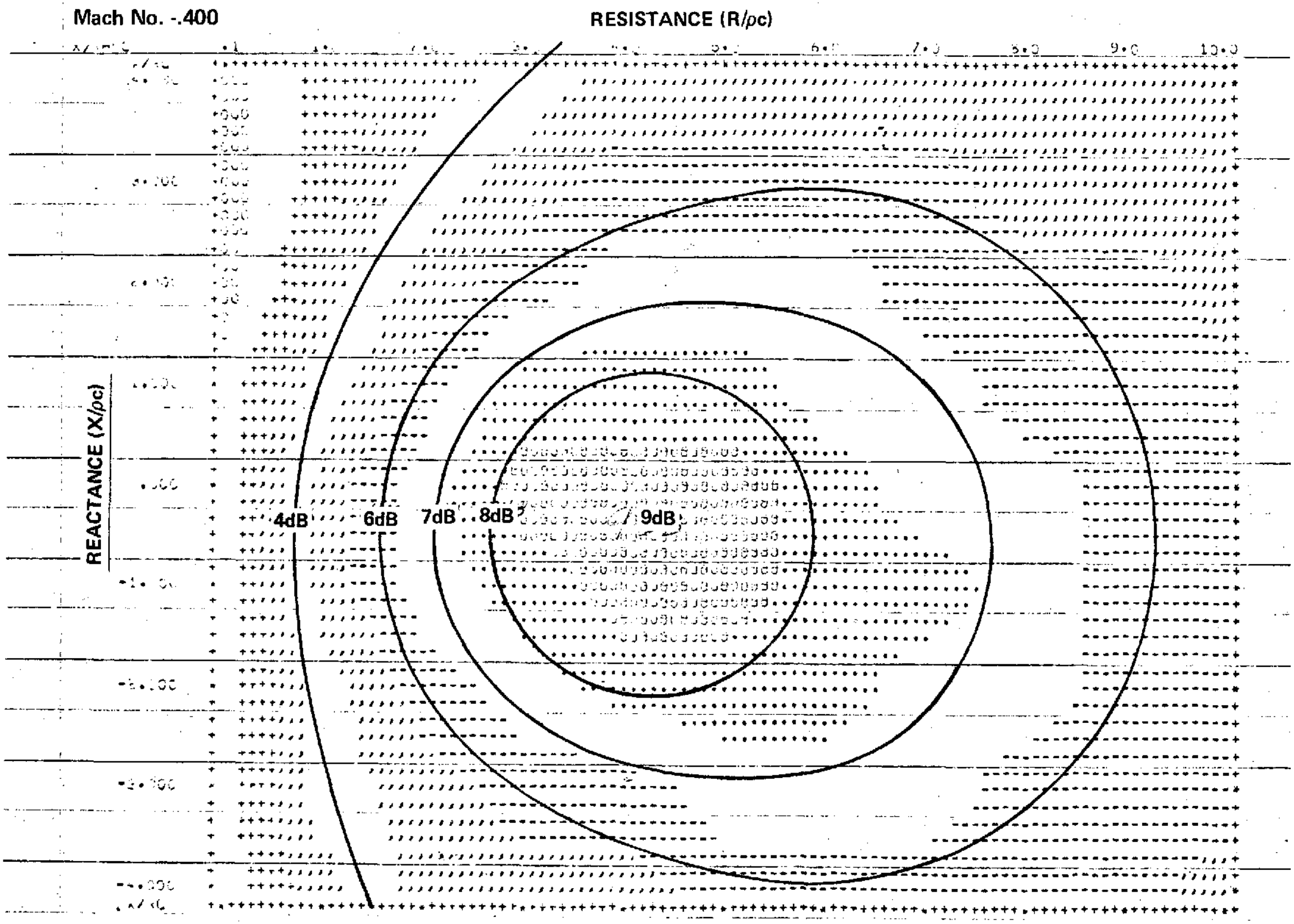

FIGURE 51

The contours remain invariant regardless of the liner being considered, or the level or spectrum shape of the noise, or the attenuation requirement. Their shape, however, does depend somewhat on the length. Increasing length causes the regions of large attenuation to shift to the right to higher resistances. Predicted attenuation spectra may now be read directly from the contours by entering each page at any assumed values of "in-place" resistance R and reactance X.

The crucial second harmonic contours indicate that an optimum resistance of the order of 5 ρc is appropriate. Separate analysis of this requirement indicates that the use of a perforated facing sheet is inappropriate because such a small open area (less than 5%) would be required that its bandwidth and high frequency response would be impaired. Therefore, a more linear, and essentially purely resistive, type of lining was assumed at this point.

Another notable feature of the contour patterns is that, in general, the optimum reactance tends to remain near zero. By contrast, for a rectangular duct, optimum reactances often attain large negative values.

Since the facing is now essentially resistive, the impedance of a simple liner is:

$$R = \text{constant}$$

$$X = -\cot \frac{\omega}{c} \ell$$

where ℓ = airspace depth.

Setting ℓ to a range of values centered on one inch, attenuation spectra were read out of the contour patterns. The pure tone components were treated separately and their attenuation established for each duct length and treatment depth. The attenuations were applied to the source noise spectrum to determine an attenuated noise spectrum. Finally, at each duct length, the attenuated source PNL value was calculated and compared to the design objective source PNL as shown in Figure 52.

The two curves in Figure 52 represent the two extreme assumptions concerning the source of the second harmonic of blade passage frequency. The upper curve is obtained by assuming the tone to be generated by fan blade - compressor inlet guide vane (12 lobe) interaction. The lower curve attributes the tone to interaction between the fan blades and the fan duct OGV's (4 lobes). The precise division of energy between these two sources is not known but, as previously mentioned, experimental evidence indicates a predominance of the fan blade-compressor IGV mechanism.

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RB.211-22

FAN INLET, APPROACH CONDITION

RESULTS OF A SINGLE LAYER LINER

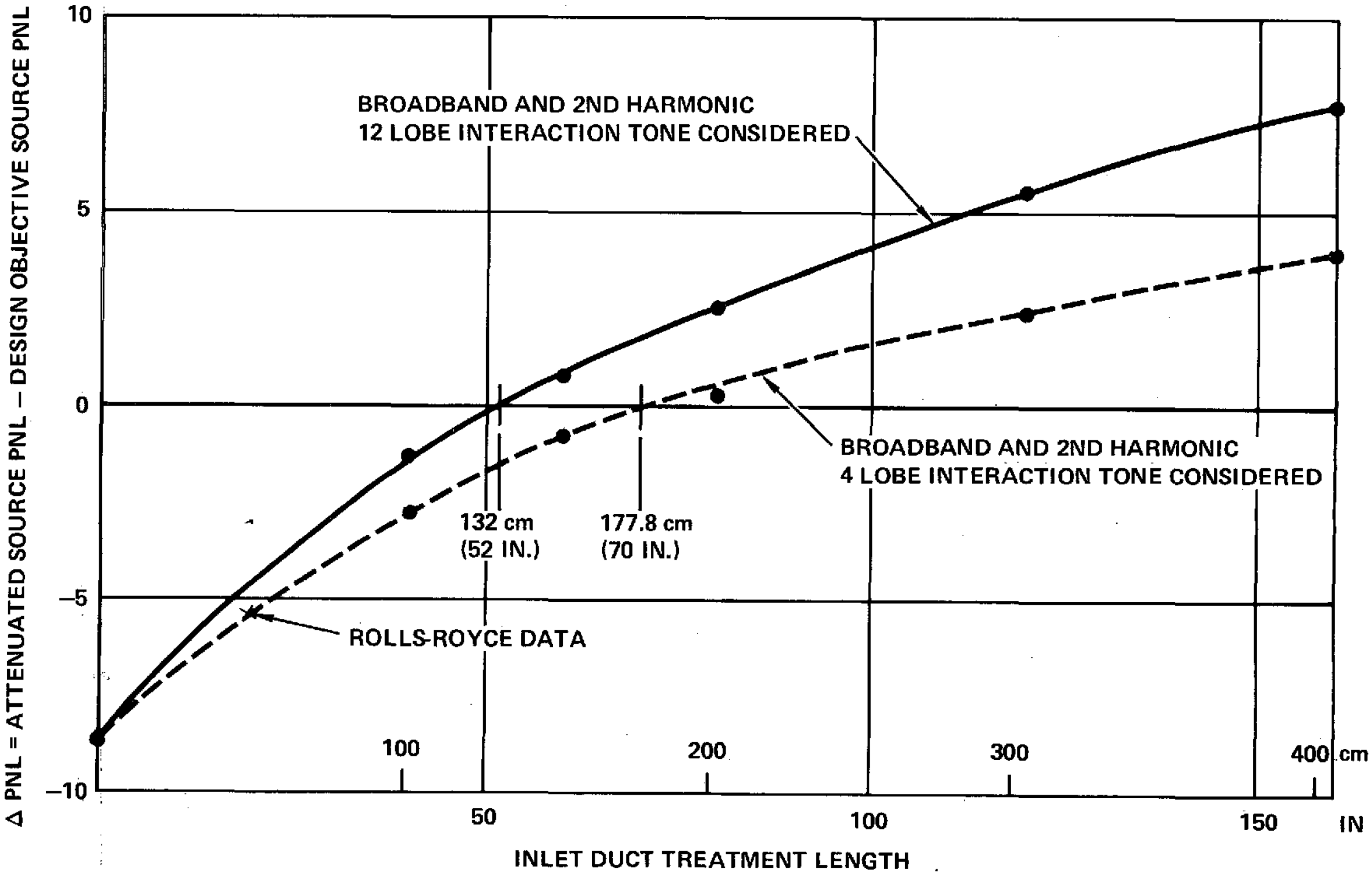

FIGURE 52

As a check, the Rolls-Royce estimate of the attenuation provided by the production inlet silencer also appears on the curve. Detailed consideration of the attenuation spectra for the three air space depths indicates that the bandwidth of the simple liners is a limiting factor. If the liner is tuned to provide optimum reactance at the second harmonic of blade passage, then the low attenuation region (drop-out region) associated with air space depths of a half wavelength ($X \rightarrow \infty$) occurs at a high frequency near the fourth harmonic. At the same time, however, there is a deficiency of lower frequency attenuation because the band width is insufficient. As the depth of treatment is increased to 2.54 cm. (1 in.) and 3.18 cm. (1.25 in.), the lower frequency attenuation below the second harmonic is improved but the second harmonic absorption is no longer optimum and the drop-out region is moving toward a region where attenuation is more important. As a result of these tradeoffs the PNL reduction of the three air space depths is almost the same.

Broadband liners may take many forms, some of which are listed below:

- Bulk fibers and foams
- Multiple layer liners
- Permoblique - Ref. 4 and 7
- Parasone - Ref. 7
- Bicore - Ref. 7

Although there is a considerable variation in the finer details of their loci of impedance as a function of frequency, their common feature is a reactance which more or less follows a cotangent law at low frequency and then, having approached zero, tends to remain there. Thus, for preliminary analysis, broadband liners may be generalized by assuming their low frequency reactance to be:

$$X = -\cot \frac{\omega \ell'}{c}$$

where ℓ' is some equivalent thickness such that $X \rightarrow 0$ at $\ell' = \lambda/4 = c/4f_o$ and $X = 0$ at all frequencies above f_o.

In the presence of broadband noise the resistance may usually be assumed to remain about constant. It is thus possible to make a generalized comparison between simple liners and broadband liners. The results of such a comparison must depend on the shape of the noise spectrum and hence, on the shape of the attenuation requirement spectrum. For the present case the replacement of a thin simple liner by a broadband liner of the same depth produces almost no improvement in PNL. This is because the only significant change is the elimination of the first dropout region but this occurs in a frequency region having only minor significance. The attenuation characteristics for all frequencies below the design frequency are the same. If, however, the broadband treatment is now doubled in depth, its design frequency is placed at the blade passage fundamental. If this is done to the simple absorber the dropout region would center at the crucial second harmonic which is unsatisfactory. The deep broadband liner on the other hand provides near optimum absorption in the frequency region near the second harmonic. Its reactance at the second harmonic and above is near zero which means near optimum, because the optimum reactance in a circular duct with spin mode inputs tends to remain near zero.

The result of using a generalized broadband liner tuned near the blade passage fundamental is shown in Figure 53. It is seen that the length of inlet treatment required to meet the present design objectives is reduced by about 15%. It thus appears that broadband inlet duct liners are advantageous because they can be deeper than simple liners. Conversely deep liners are useful only if they are broadband.

The use of deep broadband inlet liners provides secondary advantages in addition to meeting the present design objective with minimum treatment length. For example, a major reduction in buzz saw noise will occur. Buzz saw noise is not dominant in the formal design objective but subjectively its suppression would provide an improvement.

The official FAR 36 approach condition leads to operation of the RB.211-22 engine at a speed for which the blade passage fundamental is just below cutoff. Under certain landing conditions it may be necessary to operate the engines at a slightly higher rpm with the blade passage fundamental cut on. The advantage of the deeper treatment in this circumstance is clear.

Of the various types of broadband liner available, "Permoblique" about 6.35 cm. (2.5 in.) deep is preferred for this application. Its evolution may be traced through References 4 and 7. As described in Reference 7 prototype aircraft structures have been built and tested. For any given depth Permoblique offers an absorption spectrum similar to that of bulk material, and is readily drainable. Figure 54 shows the

RB.211-22

FAN INLET, APPROACH CONDITION

RESULTS OF A BROAD BAND LINER

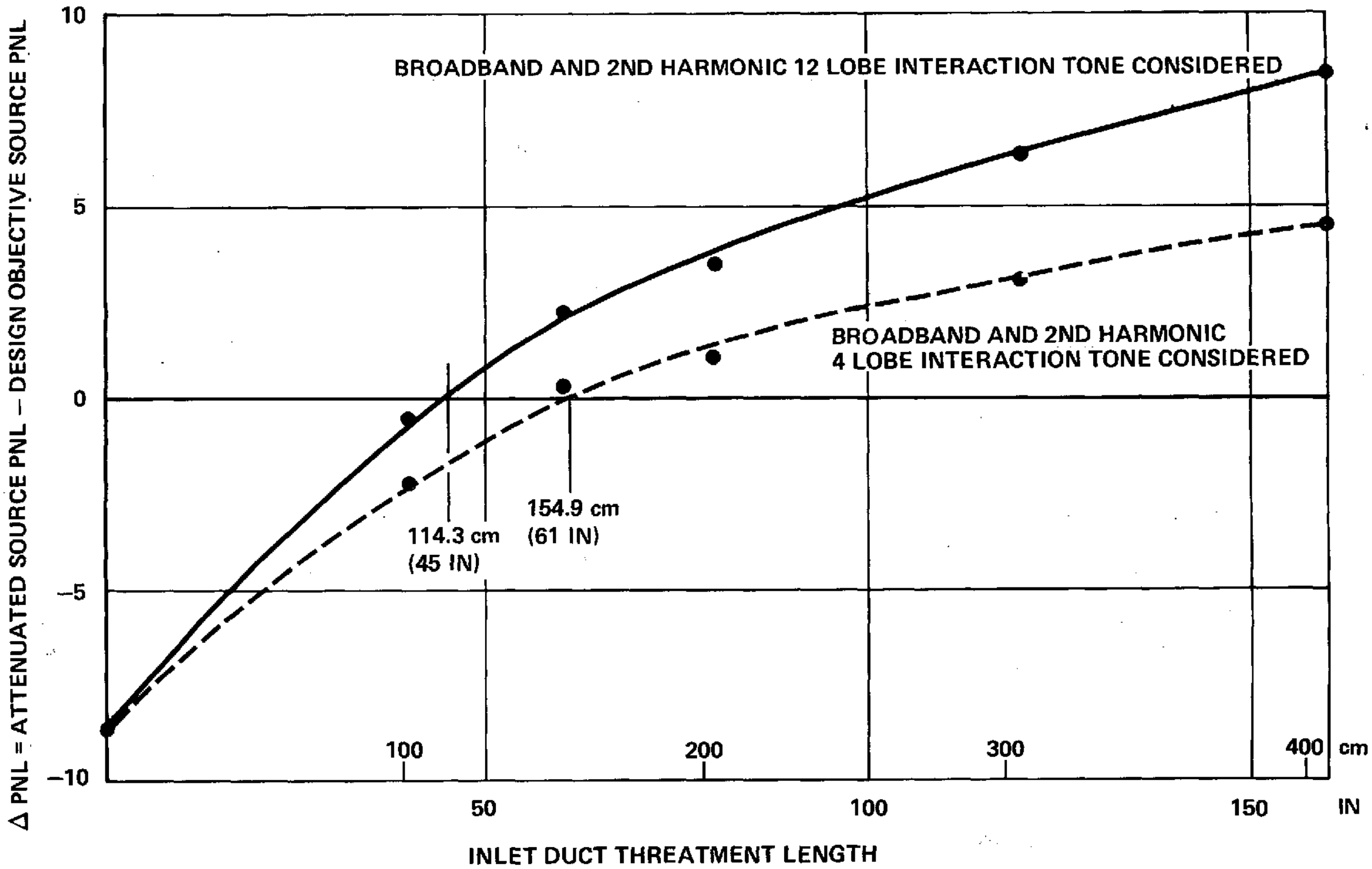

FIGURE 53

C2

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MEASURED AND CALCULATED IMPEDANCE OF PERMOBLIQUE 2" DEEP

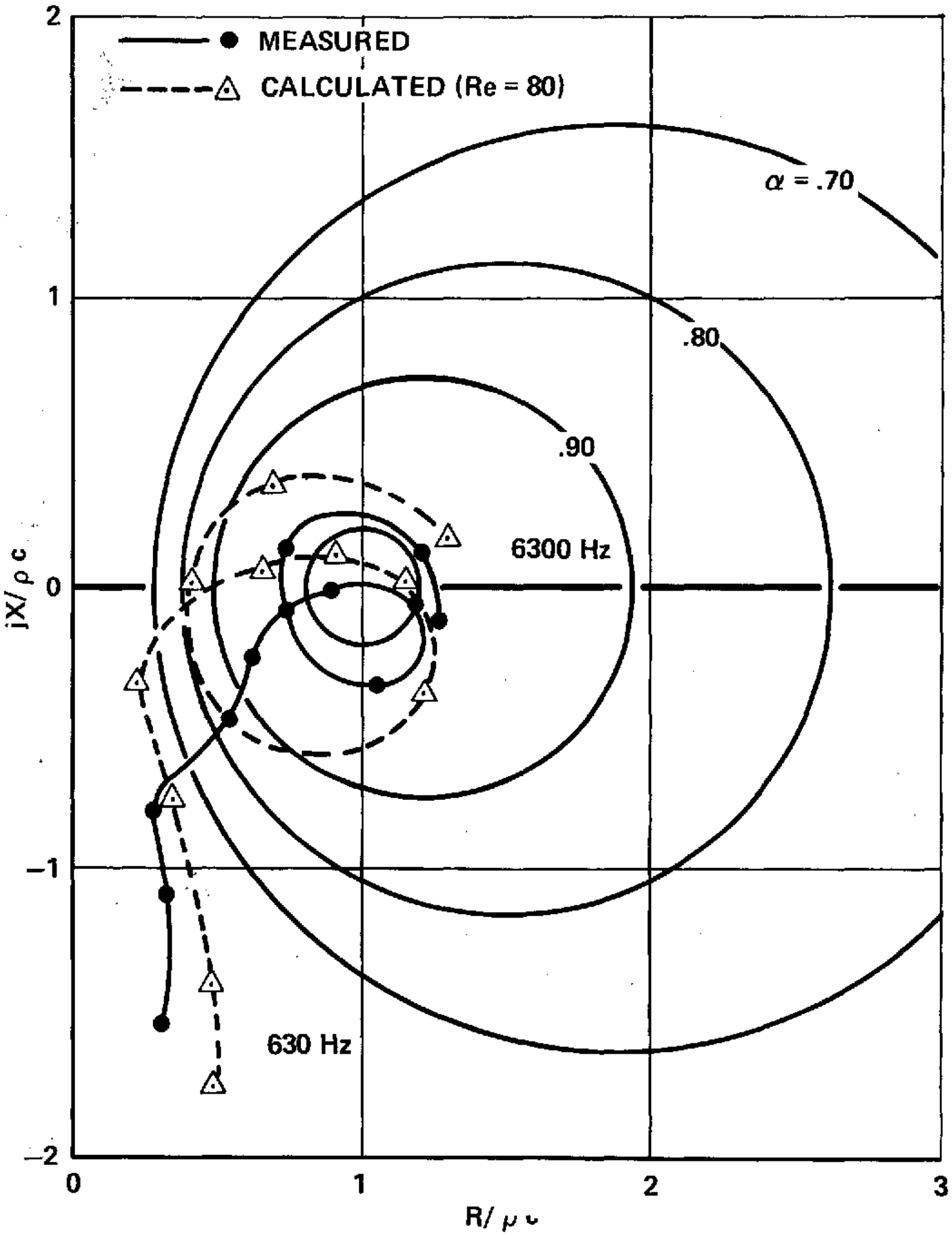

FIGURE 54

measured impedance of unfaced Permoblique 5.08 cm. (2.0 in.) deep. The lumped impedance of any facing sheet is series additive. Thus, by use of a purely resistive facing the impedance may be shifted to the right by any desired amount.

Several possibly relevant factors have not been taken into account in this analysis. These include flow noise generation, sheared flow effects and directivity effects. According to Reference 8, the use of a fine surfaced duct liner facing sheet instead of a perforate should inhibit flow noise generation of the distributed source type. The effect of a sheared flow layer which is very thin compared to the diameter of the duct is expected to have little effect on the attenuation of the average mode but to shift optimum resistance towards lower values. Eversman, Reference 9, has shown that as the sheared flow region becomes thinner, the shear flow and plug flow solutions coalesce. The shape of the contour patterns is such that selection of a resistance which is slightly higher than the indicated optimum at the design frequency is a more conservative or 'safer' design than the optimum because the roll-off of attenuation is much more rapid for resistance below optimum than it is above optimum.

It is well known that generally the use of duct treatment reduces the directivity of a noise source. This inherent advantage has not been taken into account and serves to provide a measure of conservatism in the duct design procedure.

On the basis of the foregoing analysis it is concluded that the inlet noise reduction requirements can be met. Ideally, the liner facing sheet material employed should provide a degree of linearity which in practical constructions has been realized only in felted metals incorporating very fine fibers. A potential alternative which is considerably more attractive when cost and weight are considered, are woven materials constructed from non-metallic fibers. Although much less linear than the fine fibered felt metals, they are considerably more linear than perforated metals. With adequate experimental evaluation it may be possible to overcome possible problems arising from liners which exhibit moderate non-linearity.

6.4.2.2 Fan Duct

In addition to more than compensating for the performance losses associated with fully extended, acoustically treated fan ducts, the exhaust mixing concept offers certain acoustical advantages and challenges.

First of all, the large duct wall area upstream of the mixer exhaust provides space for an acoustical wall treatment which will be more than adequate for attaining the noise suppression requirement, if flow noise does not prove to be a major problem. This conclusion was derived from attenuation contours, examples of which are given in Figure 55 through 57. Using the second harmonic of the blade passage frequency as the primary design frequency, and assuming that four lobed circumferential modes due to fan blade/OGV interaction are present, the optimum face sheet resistance is found to be approximately 2.5 ρc. It should be noted that in discharge, as in inlet ducts, there is a tendency for the optimum resistance to increase with duct length. This results from the fact that the modes which attenuate most slowly approach grazing incidence. A review of the attenuation provided by several liner depths indicated optimum performance at a depth of 2.03 cm (0.8 in.) The required treatment length is 320 cm. (126 in.). A degree of "broadbanding" is achieved with simple single layer lining configurations due to the necessity of providing local variations in treatment depths to allow space for various types of accessories located within the cowl. Additional design conservatism is provided by the presence of gentle turns in the flow passage which tends to increase the level of noise reduction over that attained with the straight duct assumed in the anaytical model.

Figure 58 summarizes the ΔPNL relative to the design objective. Also indicated is a comparison of the analytical prediction and test data derived from an RB.211-22 engine with a treated duct and a highly suppressed primary exhaust.

No deleterious effects of sheared flow on attenuation are to be expected in a discharge duct since the refraction effects are into the liners. No advantage has been taken of either helpful changes in directivity or of any high frequency attenuation occurring in the cowl extensions. The design is, therefore, regarded as conservative and backed by the remaining option of deeper broadband treatment in limited areas.

6.4.2.3 Turbine and Engine Core

To accomplish the mixing in minimum length, the tailpipe makes a rapid transition from round to a deep, multilobed shape. To provide a mixing section, the outer cowl is extended past the end of the tail pipe by one cowl radius. The necessity for the free flow of fan air between the lobes makes thin wall lobe structure very desirable, and the complexity of shape makes use of a simple lining structure very desirable.

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RB. 211-22 FAN DUCT, ATTENUATION CONTOUR FOR L = 2 DIA.

(2000 Hz, 1/3 O.B. BROADBAND NOISE)

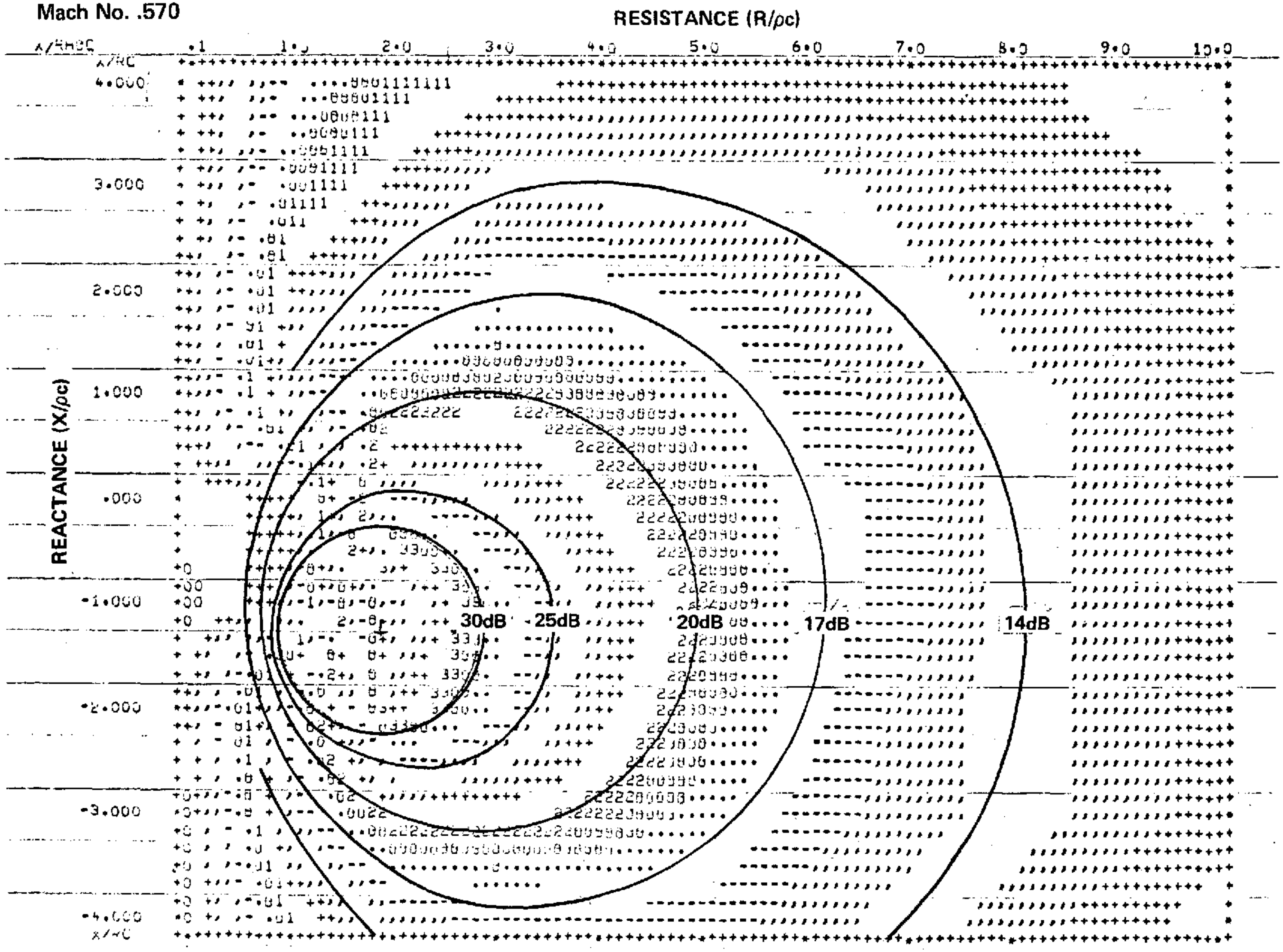

FIGURE 55

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RB. 211-22 FAN DUCT, ATTENUATION CONTOUR FOR L = 2 DIA.

(2500 Hz, 1/3 O.B. BROADBAND NOISE)

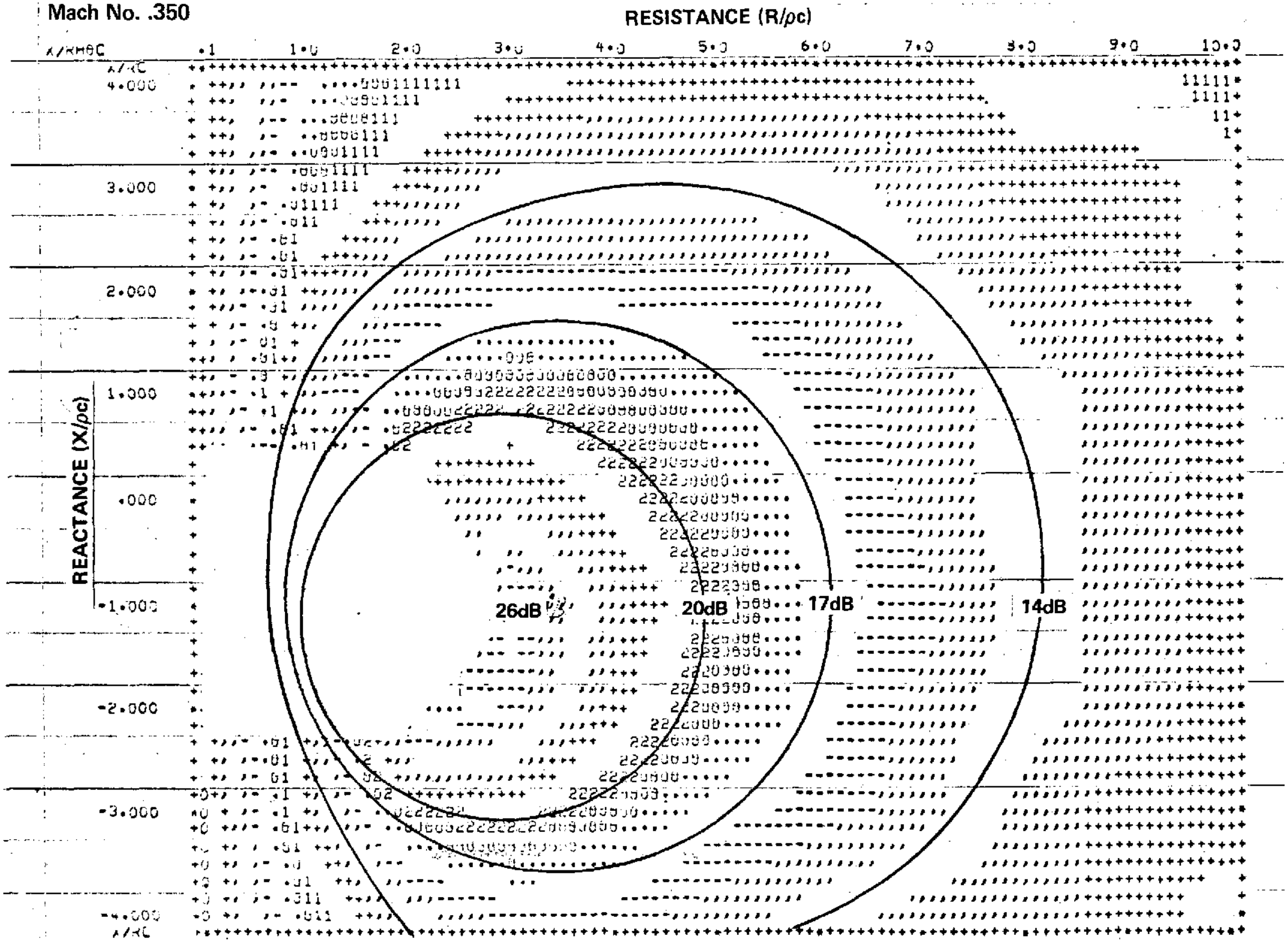

FIGURE 56

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RB. 211-22 FAN DUCT, ATTENUATION CONTOUR, L = 2 DIA.

(3150 Hz, 1/3 O.B. BROADBAND NOISE)

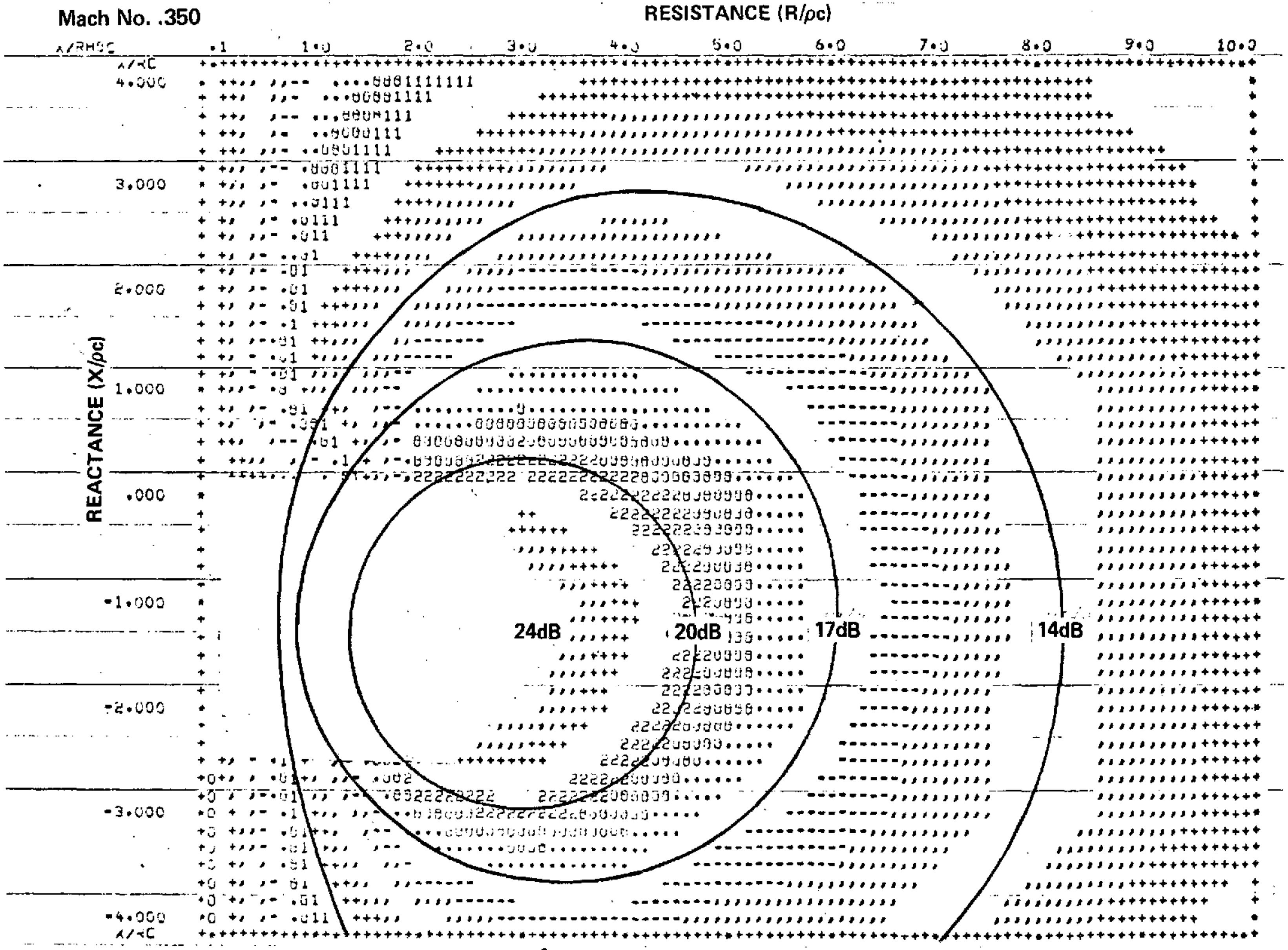

FIGURE 57

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RB. 211 FAN DUCT, APPROACH COND., RESULTS OF A SINGLE LAYER LINER

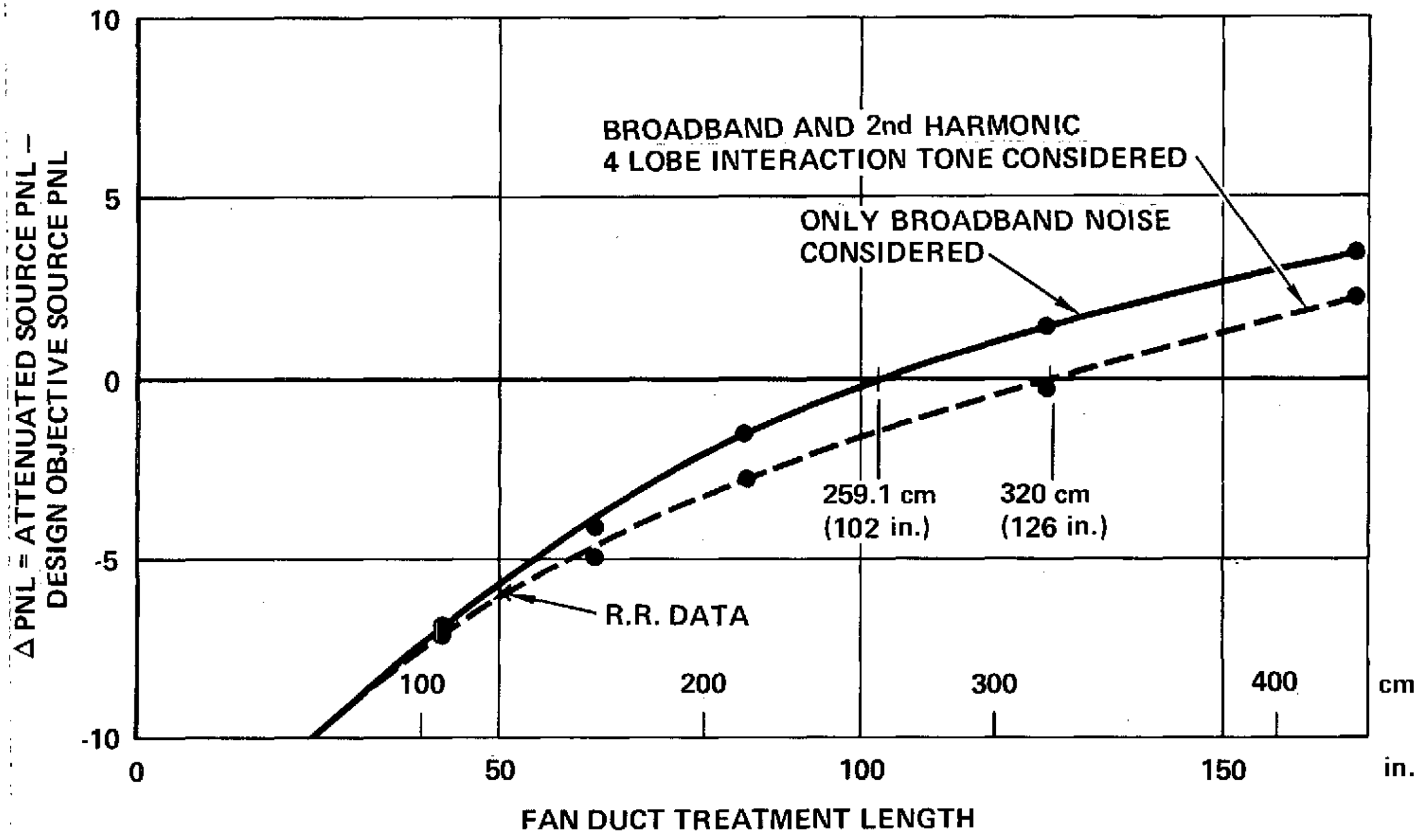

FIGURE 58

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The design approach chosen consists of addressing primary tailpipe treatment to turbine noise only and treating the cowl extension for suppression of core noise. Both the tailpipe and cowl extension are limited in length by mechanical and aerodynamic factors such that highly efficient designs are required. Furthermore, the lobed tailpipe geometry is too complex to be readily amenable to simple lined duct analysis. If a single tailpipe segment containing one lobe is considered, the geometry is suggestive of a duct silencer type developed and tested by Lockheed as part of a prior Independent Research program.

The efficient acoustical performance obtained with the referenced silencer can perhaps be best understood by first considering a hypothetical simple rectangular duct of unit length that is conceptually divided into consecutive segments of lengths 1/2, 1/4, 1/8, 1/16 .... 1/∞. If the first segment (length - 1/2) is acoustically treated on two of its opposite walls with a liner tuned to provide optimum attenuation at a given frequency, the next segment can be given an optimized attenuation at a frequency one octave higher by introducing a central splitter (treated on both sides) and employing wall and splitter linings that are one half the depth used on the first segment. By doubling the number of flow passages (using treated splitters) for each successively shorter segment and reducing the corresponding lining depth by a factor of one-half, the treated area for each segment remains the same, the total flow passage area is held at a constant value and the attenuation is optimized over bands whose center frequencies are spaced one octave apart. Since there is theoretically no limit to the total number of such hypothetical segments, the concept bears a resemblance to Zeno's paradox and has been named the "Zeno Duct."

A practical version of the hypothetical duct described above can be achieved by avoiding the introduction of splitters and increasing the duct width in inverse proportion to the decreasing height, while tapering the treatment depth as the height lessens. The cross-sectional area is maintained constant. A Zeno duct of this type has been built (see Figure 59) and tested and found to provide acoustical performance that is in agreement with predictions (shown in Figure 60).

Each lobe of the RB.211-22 tailpipe exhaust mixer embodies tapering and flaring in orthogonal planes, thereby suggesting the Zeno duct treatment approach described above. Predicted attenuations, based on an implementation of this scheme, are shown in Figure 61 for single degree of freedom liners 4.57 cm. (1.8 in.) tapered to 1.78 cm. (0.7 in.) and 3.56 cm. (1.4 in.) tapered to 1.52 cm. (0.6 in.).

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ZENO DUCT MODEL

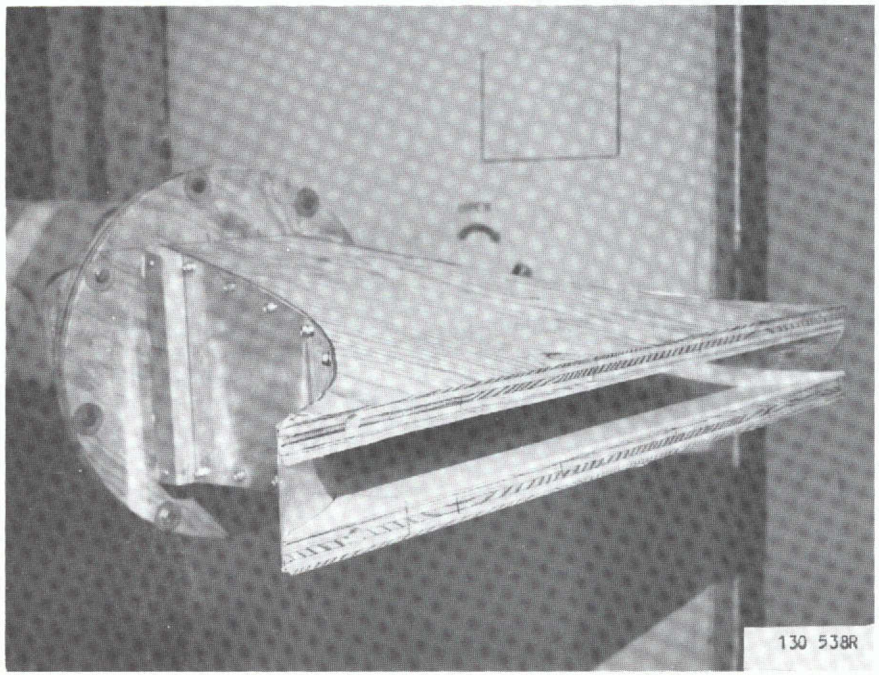

FIGURE 59

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COMPARISON OF MEASURED AND PREDICTED PERFORMANCE OF A "ZENO" DUCT

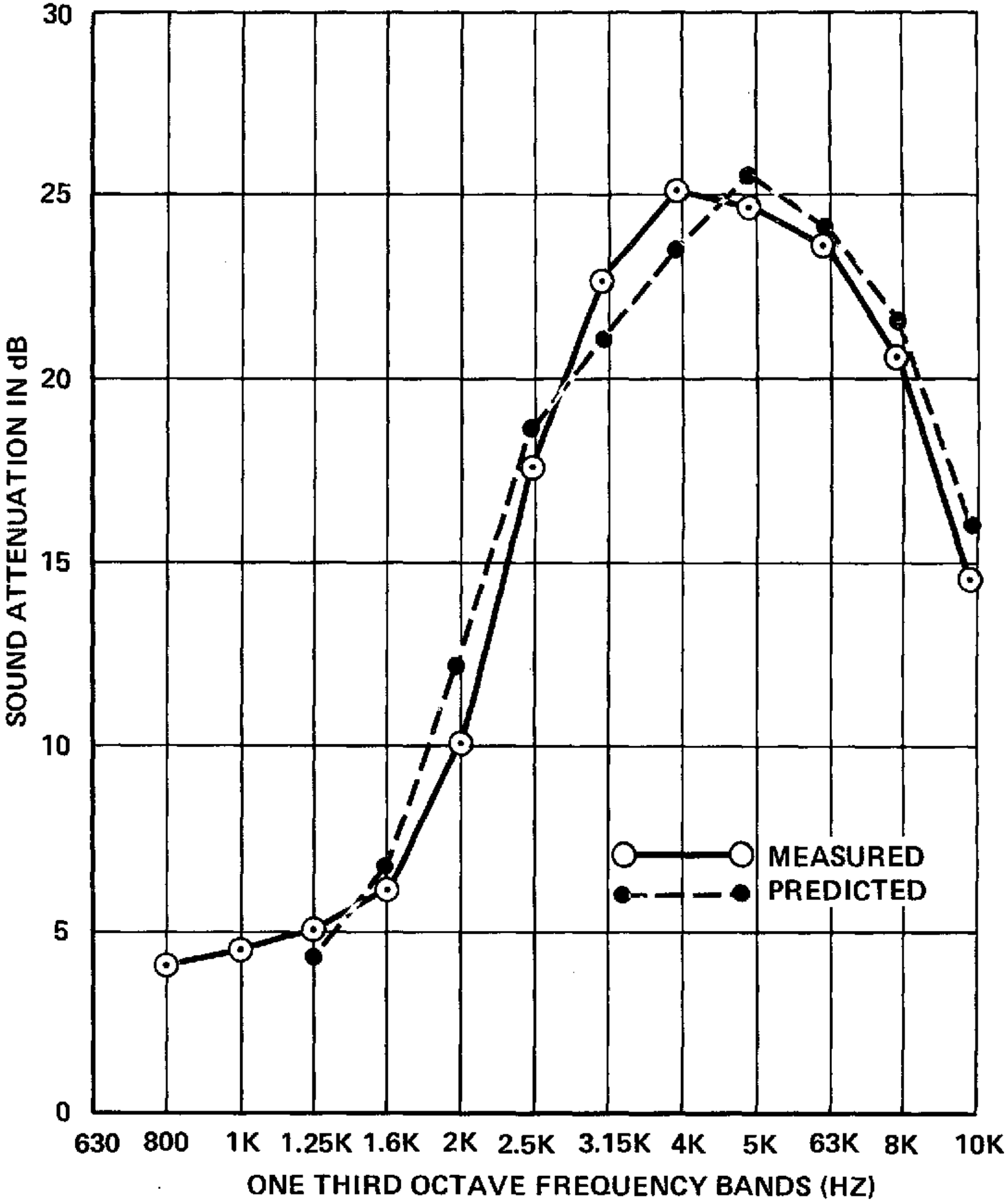

FIGURE 60

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PREDICTED HIGH FREQUENCY SOUND ATTENUATION OF THE RB. 211-22 TAILPIPE EXHAUST MIXER

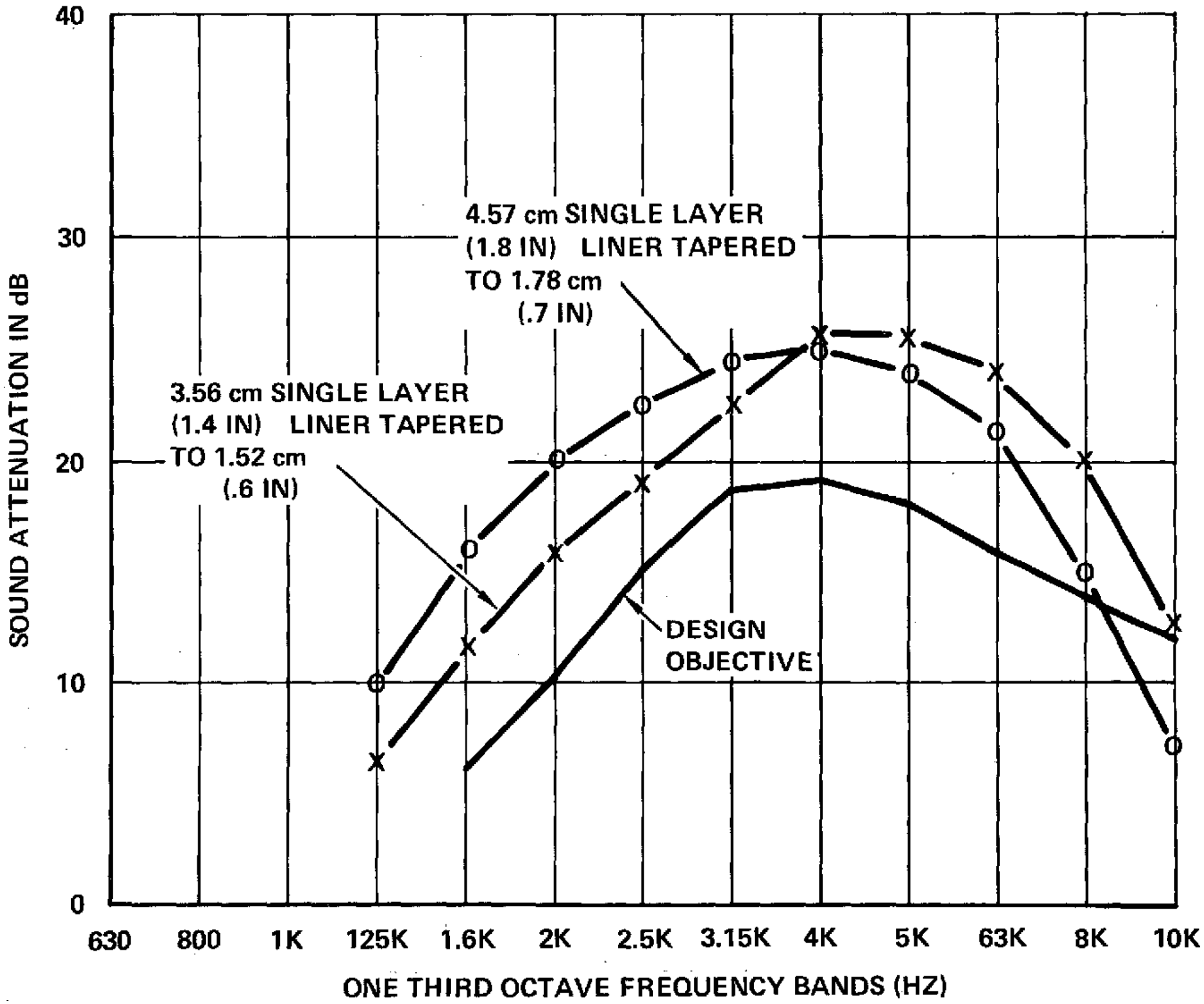

FIGURE 61

Each prediction substantially meets the design objective as shown. Note that the bandwidth provided by the Zeno duct approach is well suited to the shape of the turbine noise spectrum. The thinness of the treatment, which is 0.6" deep at the trailing edge, is also advantageous to the mixing process. It is noted, however, that the attenuation of the lobed section is very difficult to predict analytically, and for this reason the need for a scaled model test program is strongly indicated.

In its mixed flow design, the attenuation of the core noise is relegated to the cowl extension. This extension is considered as a duct 193 cm. (76 in.) in diameter and no more than 96.5 cm. (38 in.) long. In order to preserve minimum cowl wall thickness, the prescribed treatment is Schizophonium (see Appendix C) 6.35 cm. (2.5 in.) deep. Attenuation is optimized for the core noise by selecting the resistance as optimum at 500 Hz at the possible expense of the high frequency range. The residual high frequency absorption of the cowl extension is considered to provide a measure of conservatism on the fan noise and turbine noise design. Figure 62 presents the attenuation contours for 500 Hz broadband noise in a cowl extension 1 radius long.

6.4.3 ATT

Fan Inlet - The considerable difference between the fan designs in the wide bodied and ATT engines resulted in significant differences in target attenuation spectra. It is noted however that there does not exist a "one to one" correspondence between the attenuation spectra and a corresponding PNL reduction; i.e., there are actually an infinite number of spectra that could achieve a target PNL reduction. As shown in Figure 63, the ATT engine requires somewhat greater attenuation at 1600 Hz but somewhat less than the wide bodied above 2500 Hz. This increased need for attenuation at lower frequency tends to make the use of a deep, broadband inlet treatment even more advantageous than in the wide bodied inlet. As a result the recommended lining design is the same for the STF 433 nacelle as for the RB.211-22 inlet: namely, Permoblique, 6.35 cm. (2.5 in.) deep. The required treatment length is 107 cm (42 in.).

Fan Discharge Duct - Fan discharge duct attenuation problems for the ATT and wide bodied aircraft nacelles are very similar in spite of fan design differences. As a result, the prescribed acoustical treatments are the same; namely, treatment of both walls of the annular duct with a simple single layer liner for a length of 266.7 cm. (105 in.). The required "in place" acoustic resistance is 2.5 ρc, which reflects the considerable length of the duct.

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RB. 211-22 COWL EXTENSION, ATTENUATION CONTOUR, L = 5 DIA.

(500 Hz 1/3 O.B. BROADBAND NOISE)

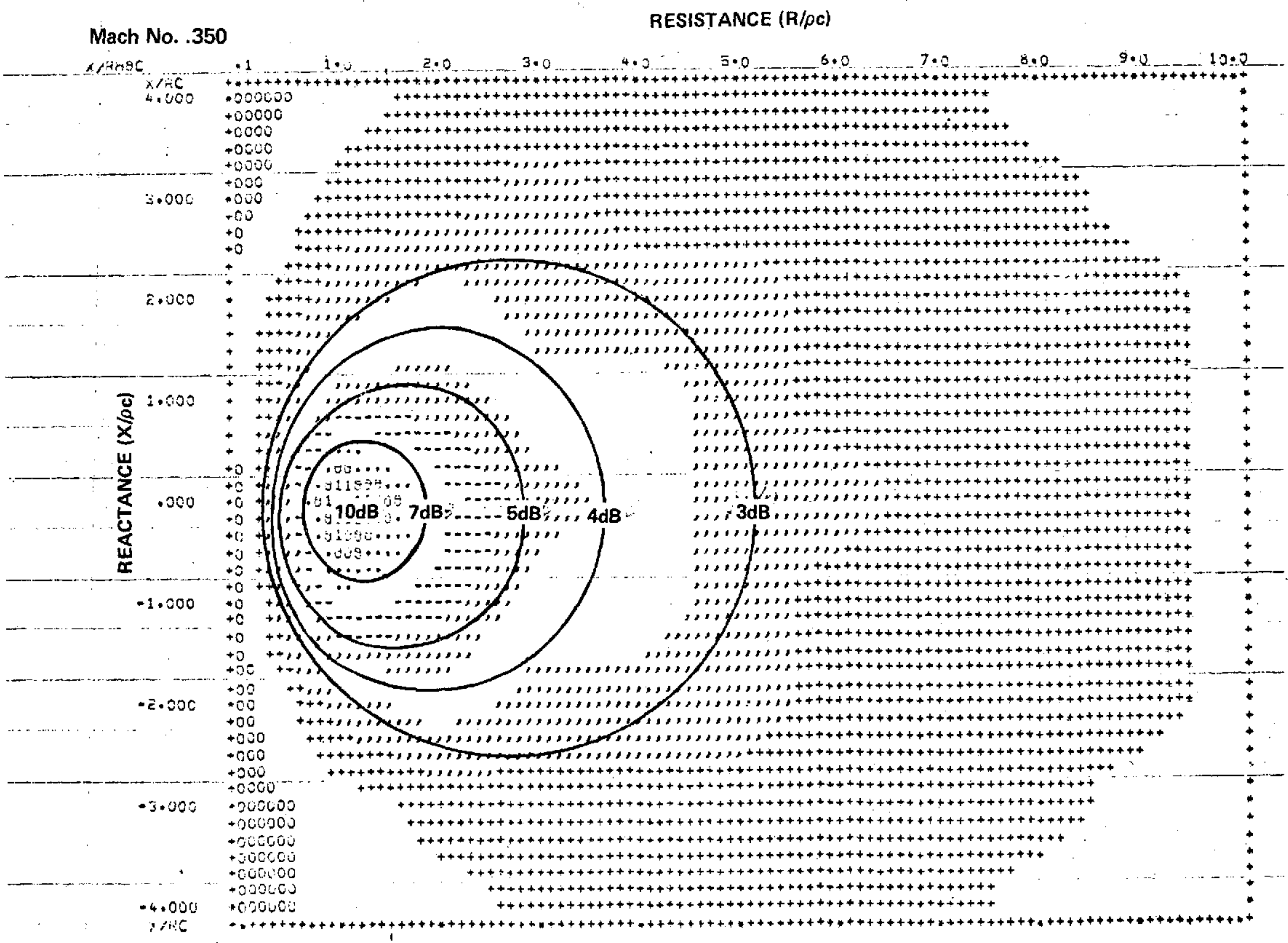

FIGURE 62

COMPARISON OF WIDE BODY AND ATT REQUIRED ATTENUATION FOR THE FAN INLET

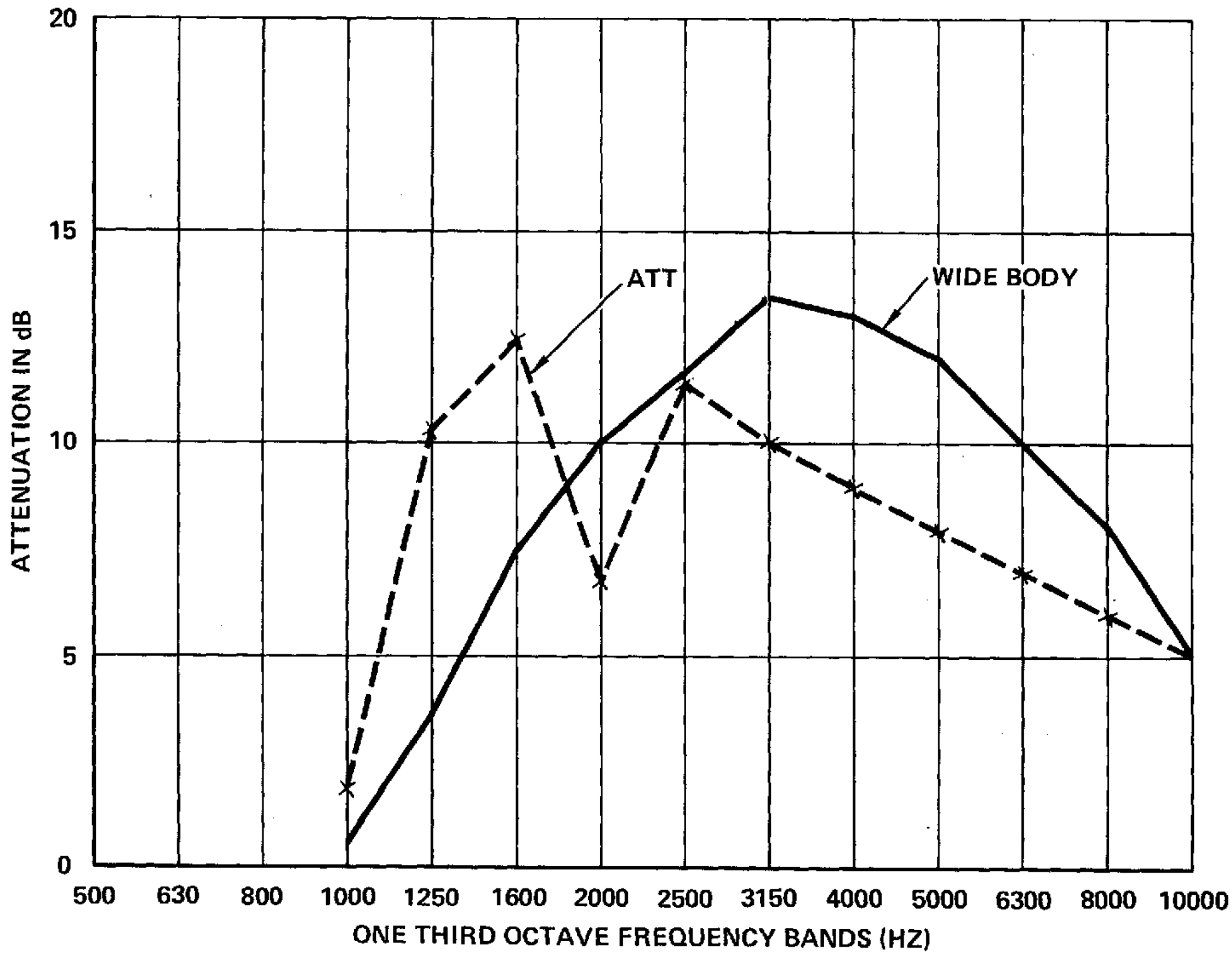

FIGURE 63

Figure 64 indicates that there is a slightly greater need for high frequency attenuation in the ATT fan discharge as compared to the wide bodied nacelle. This in part is due to the fact that the noise floor is lower for the ATT airplane. The indicated 2.5 ρc facing sheet resistance is attained with either fine holed perforated metal or woven structure facings.

Tailpipe - Since the STF 433 engine exhaust flows are not mixed, the acoustical design problems are quite different from those encountered with the RB.211-22.

Two types of noise emanate from the primary exhaust duct. The first, called low frequency core engine noise, consists mainly of a "haystack" of broadband noise centered at about 500 Hz. The second is turbine noise which occurs as a broad peak near 5000 Hz. This noise contains significant pitched tone energy from the blading of the low pressure turbine wheels.

The attenuation requirement spectrum for approach operation suggests two design points: 10 dB reduction at 500 Hz and 20 dB at 5000 Hz.

Two sets of constant attenuation contours were generated, covering broadband noise from 100 Hz to 6300 Hz for cylindrical and annular ducts for lengths ranging from 1/2 to 4 radii. These may be read for either the RB.211-22 or STF 433 exhausts by frequency scaling about 1/3 octave and were, in fact, first used for the RB.211-22 prior to the adoption of the mixed flow design. The turbine pure tones in the STF 433 were assumed to attenuate at least as rapidly as the broadband noise and were lumped with it.

To establish convenient bench marks two simple single layered liners were designed for the cylindrical duct. The first was addressed to the core noise design frequency of 500 Hz and the second to the turbine noise spectrum. The first required a depth of 22.86 cm. (9 in.) and a length of 114.3 cm. (45 in.) and provided negligible attenuation of turbine noise. The second, which was designed to suppress turbine noise only, required a depth and treated length of 2.79 cm. (1.1 in.) and 152.4 cm. (60 in.) respectively. It was clear that a series combination of these two duct sections would be prohibitive in respect to both length and diameter. This led to the consideration of the doubly tuned Schizophonium liner concept. Accordingly a liner of this type was tailored to the two design frequencies of 500 Hz and 5000 Hz by the procedures outlined in Reference 7. This procedure led to a prescription of horn elements 6.6 cm. (2.6 in.) deep with a hyperbolic family parameter

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COMPARISON OF WIDE BODY & ATT REQUIRED ATTENUATION FOR THE FAN DUCT

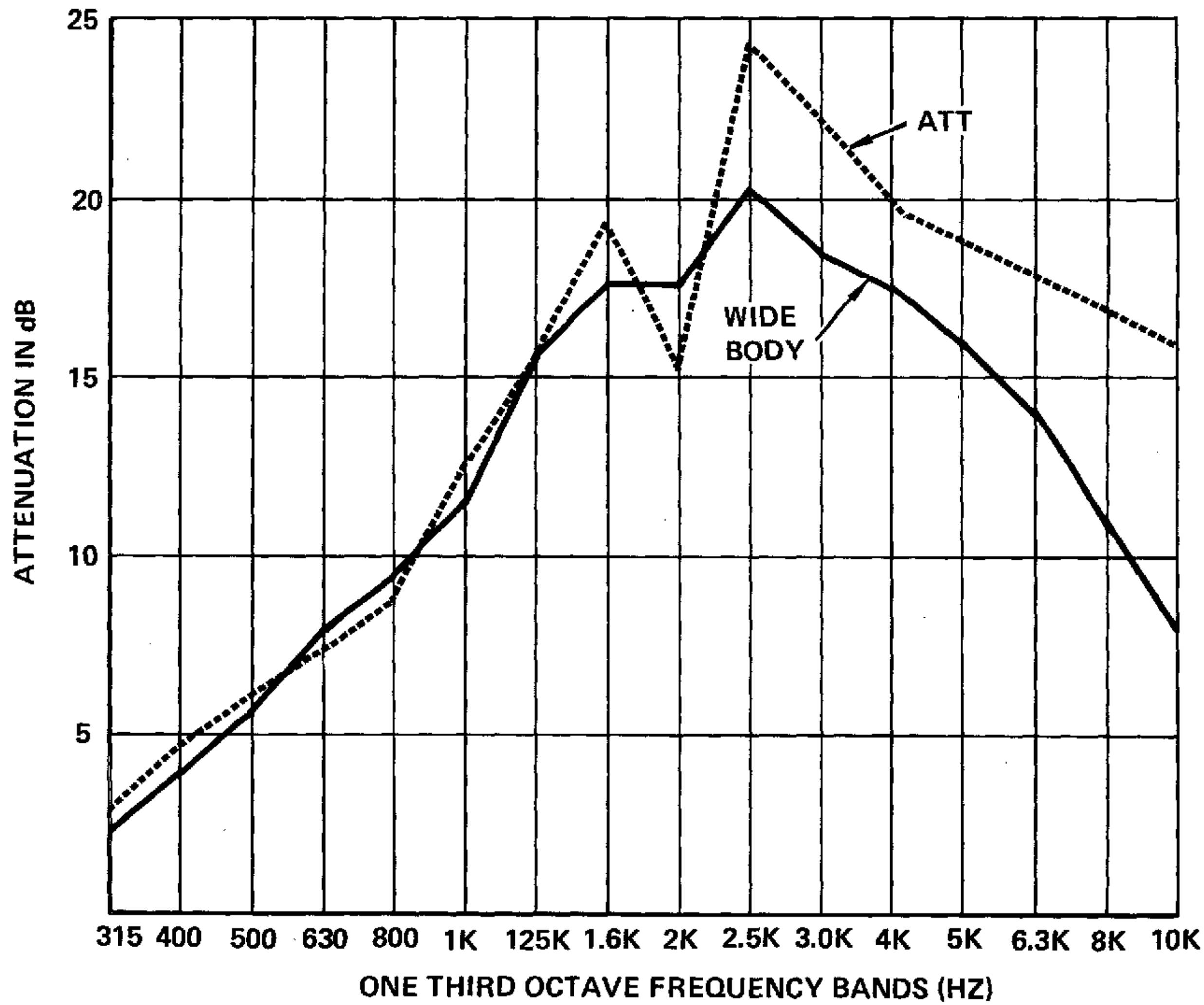

FIGURE 64

of zero. Since it is impossible to provide optimum resistance at both design frequencies, a resistance of 2 ρc was selected to favor the turbine noise, leaving the core noise treatment slightly overdamped.

Insertion of the Schizophonium liner impedance characteristics into the constant attenuation contour patterns revealed the need for including a lined centerbody if the total duct length were not to exceed four outer radii. However, even with the centerbody, the objectives could be met at the two design frequencies but an unacceptable deficiency in attenuation was found to exist at intermediate frequencies.

To correct this, a simplifying change was made. By deleting the horn elements from a certain percentage of the duct, the compartments involved revert to single degree of freedom cells tuned to one-half of the upper design frequency. For the purpose of analysis the two duct sections are cascaded and their attenuations combined by a very conservative method that avoids overestimation by utilizing only the flattest attenuation versus length slope for the second section. It was found that a 25% simple liner combined with 75% Schizophonium produced the desired attenuation. In actual practice the horn deletions would be distributed systematically through the duct liner to provide the additional benefits known to result from such dispersion of treatment.

In summary, the core noise and turbine noise objectives can be substantially met by an annular duct 165.1 cm. (65 in.) long utilizing a 75% Schizophonium treatment and 25% single degree of freedom system, both of which are about 7 cm (2.8 in.) deep. The mixture of the two treatment types is accomplished by the distributed deletion of horn elements, thus providing a convenient means of varying the spectrum shape of the overall attenuation.

6.5 NOISE SUPPRESSION SUMMARY

The remaining part of this section provides a summary of the subjective noise levels predicted for the optimum nacelle design configurations shown in Section 5.

6.5.1 Wide Body Nacelle

Estimates of free field perceived noise for the various treated sources are given in Figures 65 and 66 for approach and take-off operation respectively. It is of interest to compare these levels with the PNL goals provided in Figures 44 and 45. Table 6 gives a summary of predicted EPNL levels as they

NOISE SUPPRESSION

WIDE-BODY AIRCRAFT-APPROACH - 113M (370 FT) ALTITUDE

(FREE FIELD)

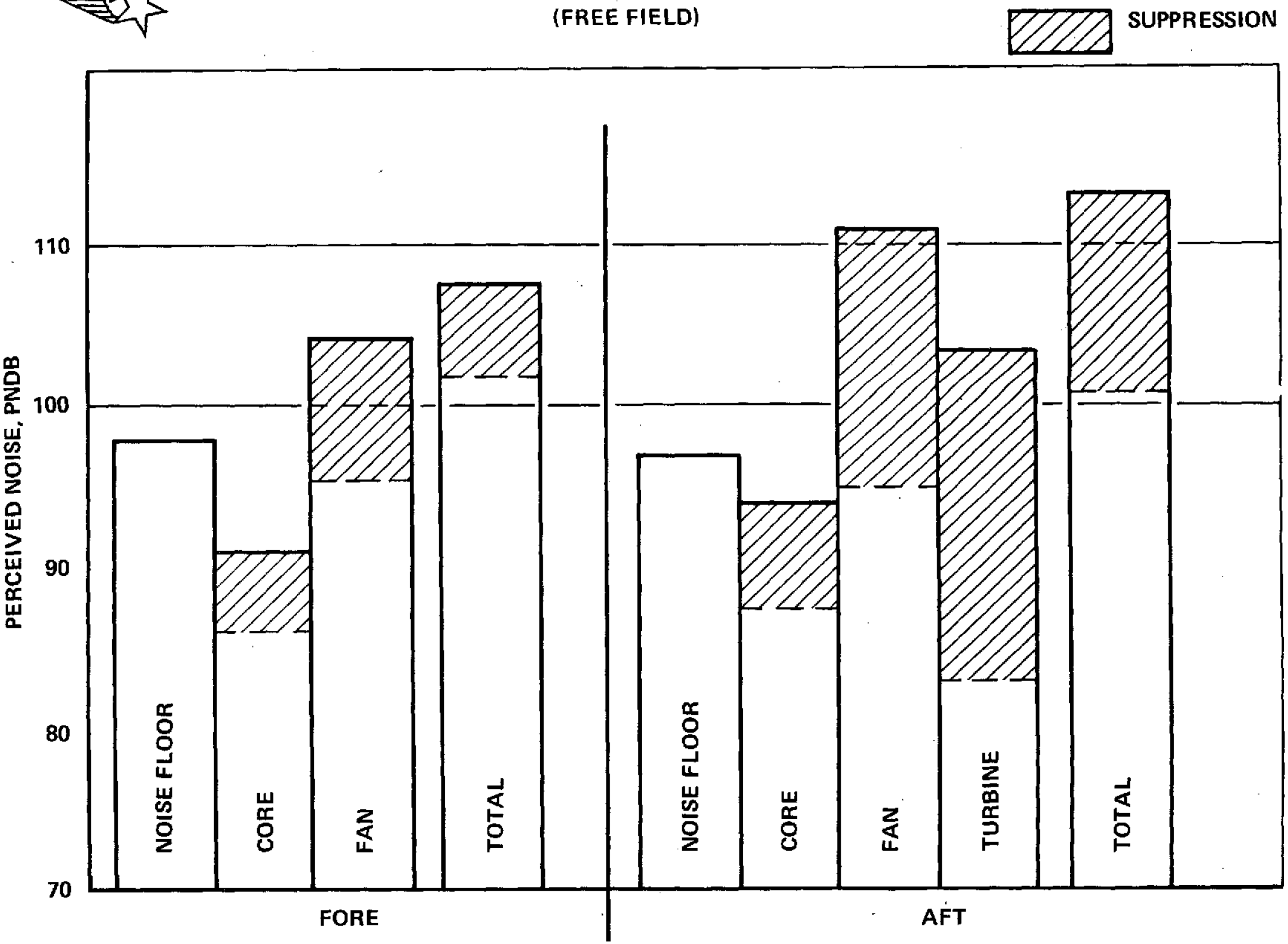

FIGURE 65

NOISE SUPPRESSION

WIDE BODY AIRCRAFT-TAKEOFF 457M (1500 FT) ALTITUDE

(FREE FIELD)

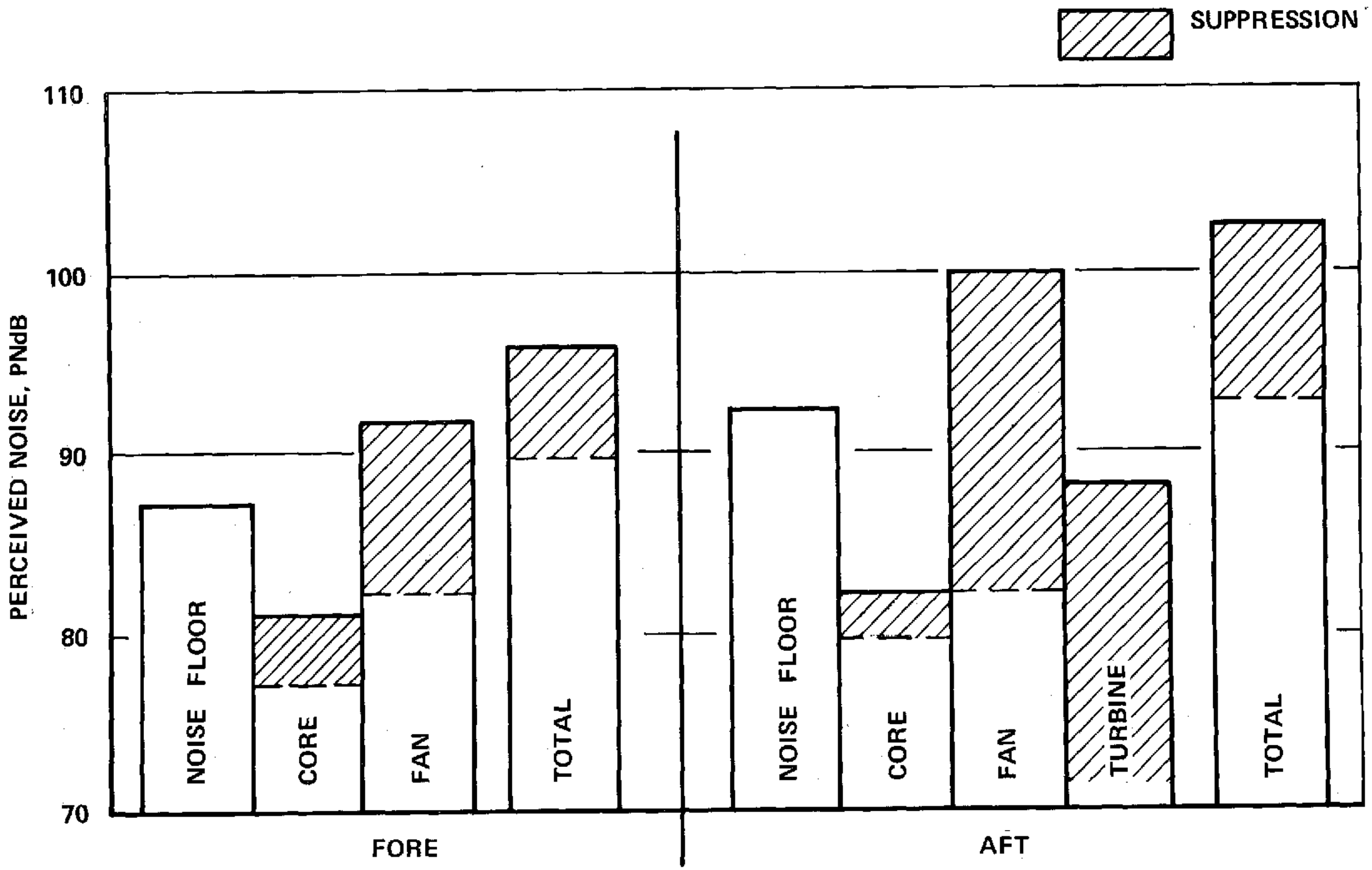

FIGURE 66

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NOISE SUPPRESSION SUMMARY

EPNL

	WIDE BODY			ATT	
	FAR PART 36 LIMIT	CERTIFIED LEVELS	WITH QUIET COMPOSITE NACELLE	FAR PART 36 LIMIT	WITH QUIET COMPOSITE NACELLE
TAKE OFF	105.6	96.2	93.3	103	94.2
APPROACH	107.0	102.9	97.6	106	95.7
SIDELINE	107.0	95.0	92.1	106	92.8

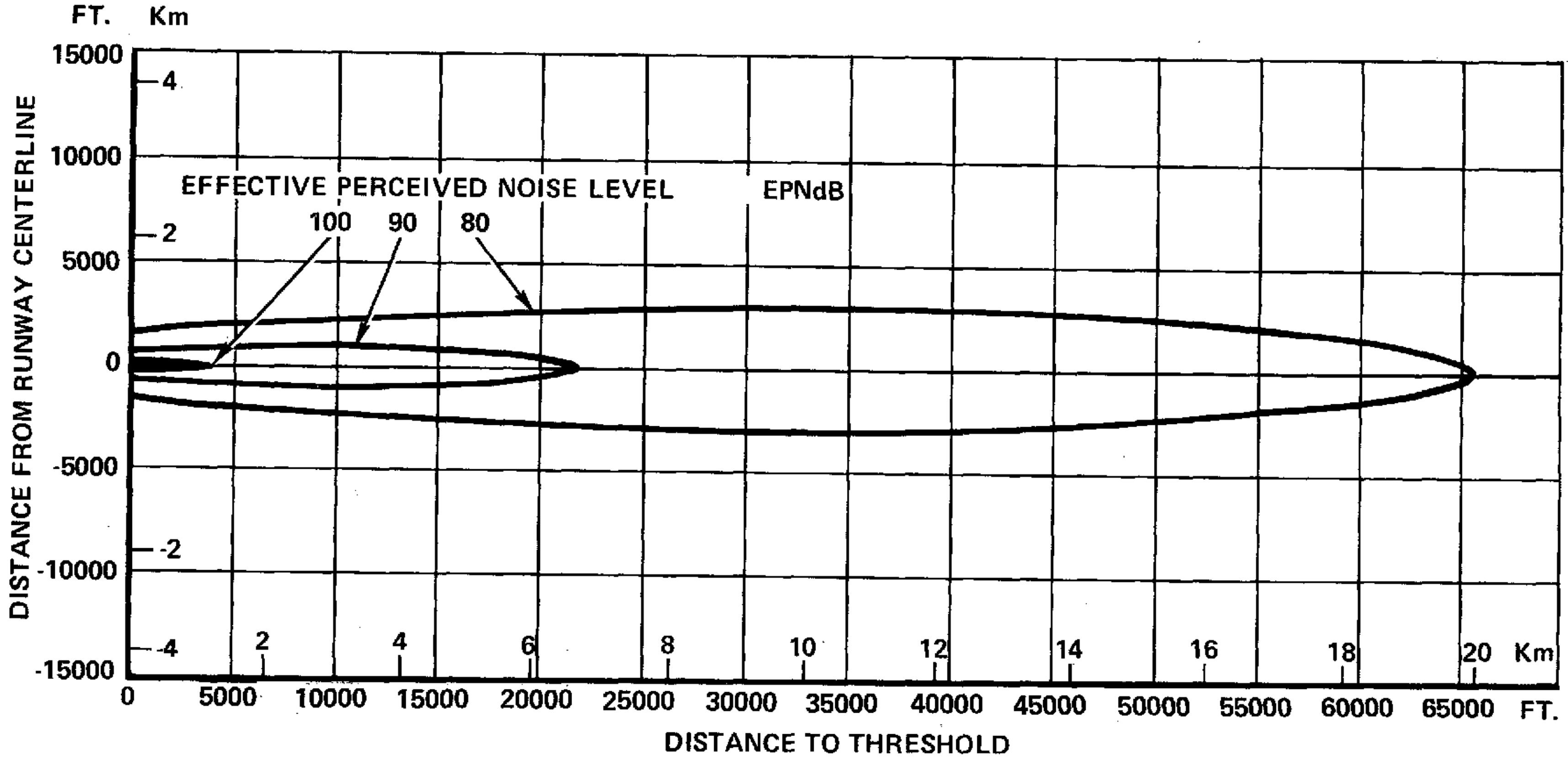
TABLE 6

relate to FAR Part 36 noise limits. Corresponding noise contour footprints for approach and take-off operation respectively are shown in Figures 67 and 68. Footprint areas for the same operating conditions are indicated in Table 7.

6.5.2 ATT Nacelle

Estimates of free field perceived noise for the treated sources are given in Figures 69 and 70 for approach and take-off respectively. Table 6 gives a summary of predicted EPNL levels. Noise contour footprints for approach and take-off are shown in Figures 71 and 72 respectively. Footprint areas for the same operating conditions are indicated in Table 7.

WIDE-BODY NOISE CONTOURS
APPROACH



CONTOUR PLOTS
L-1011-1/RB.211-228 WITH COMPOSITE NACELLE
SEA LEVEL, 25 DEG. C., 70% RELATIVE HUMIDITY
162385 Kg (358000 LB) LANDING WEIGHT, 42 DEG. FLAPS. 1.3V STALL + 10 KNOTS

FIGURE 67

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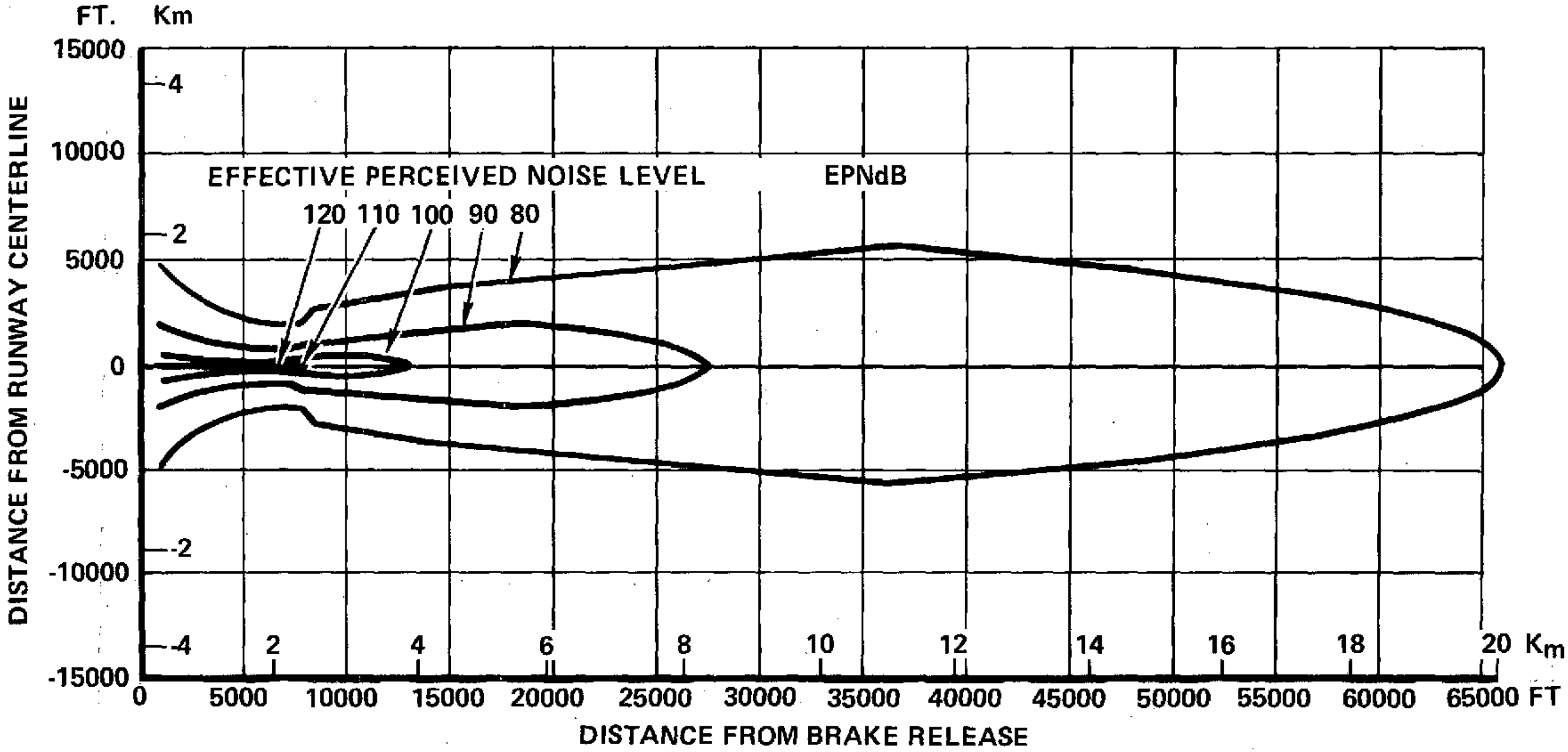
WIDE BODY NOISE CONTOURS
TAKE-OFF



CONTOUR PLOTS
L-1011-1/RB.211-22B WITH COMPOSITE NACELLE
SEA LEVEL, 25 DEG. C., 70% RELATIVE HUMIDITY
195044 Kg (430000 LB.) TAKEOFF GROSS WEIGHT, 10 DEG. FLAPS, V2+10 KNOT CLIMB SPEED

FIGURE 68

ENCLOSED AREAS OF NOISE CONTOURS

SQ Km (SQ. STATUTE MILE)

	EPN dB 80	90	100	110	120
L-1011-1/RB.211-22B BASELINE					
TAKEOFF (FROM ROTATION)	51.18 (19.76)	8.52 (3.29)	1.11 (0.43)	0.18 (0.07)	0.00*
APPROACH	60.55 (23.38)	7.72 (2.98)	0.67 (0.26)	0.00	–
L-1011-1/RB.211-22B WITH COMPOSITE NACELLE					
TAKEOFF	44.60 (17.22)	5.62 (2.17)	0.41 (0.16)	0.02 (0.01)	0.00*
APPROACH	28.75 (11.10)	3.34 (1.29)	0.13 (0.05)	–	–
ADVANCED TECHNOLOGY TRANSPORT					
TAKEOFF	47.71 (18.42)	6.42 (2.48)	0.62 (0.24)	0.02 (0.01)	0.00*
APPROACH	26.16 (10.10)	2.05 (0.79)	0.05 (0.02)	–	–

TABLE 7

NOISE SUPPRESSION

ATT–APPROACH – 113m (370 FT) ALTITUDE
(FREE FIELD)

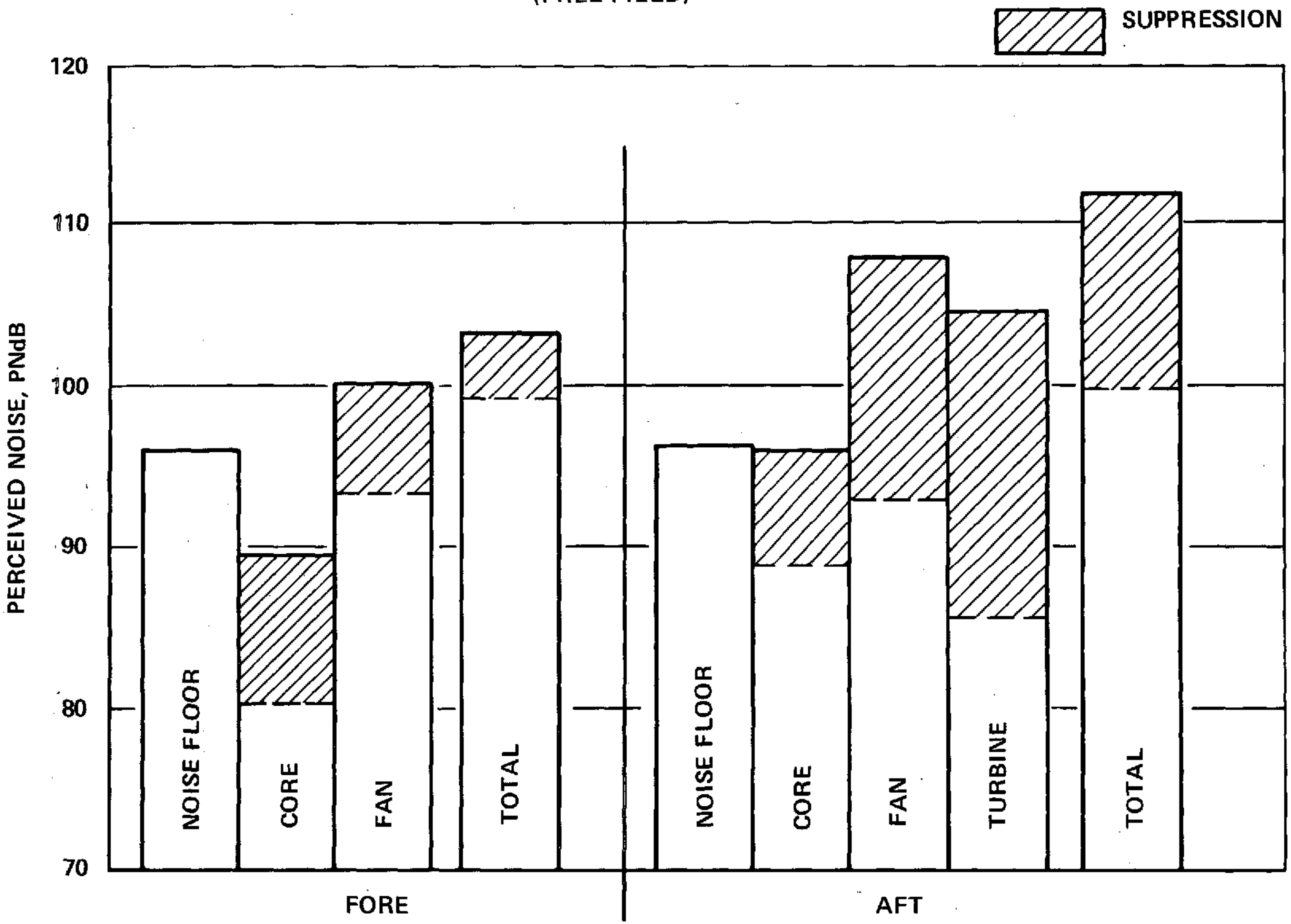


FIGURE 69

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NOISE SUPPRESSION

ATT–TAKEOFF – 449m (1470 FT) ALTITUDE
(FREE FIELD)

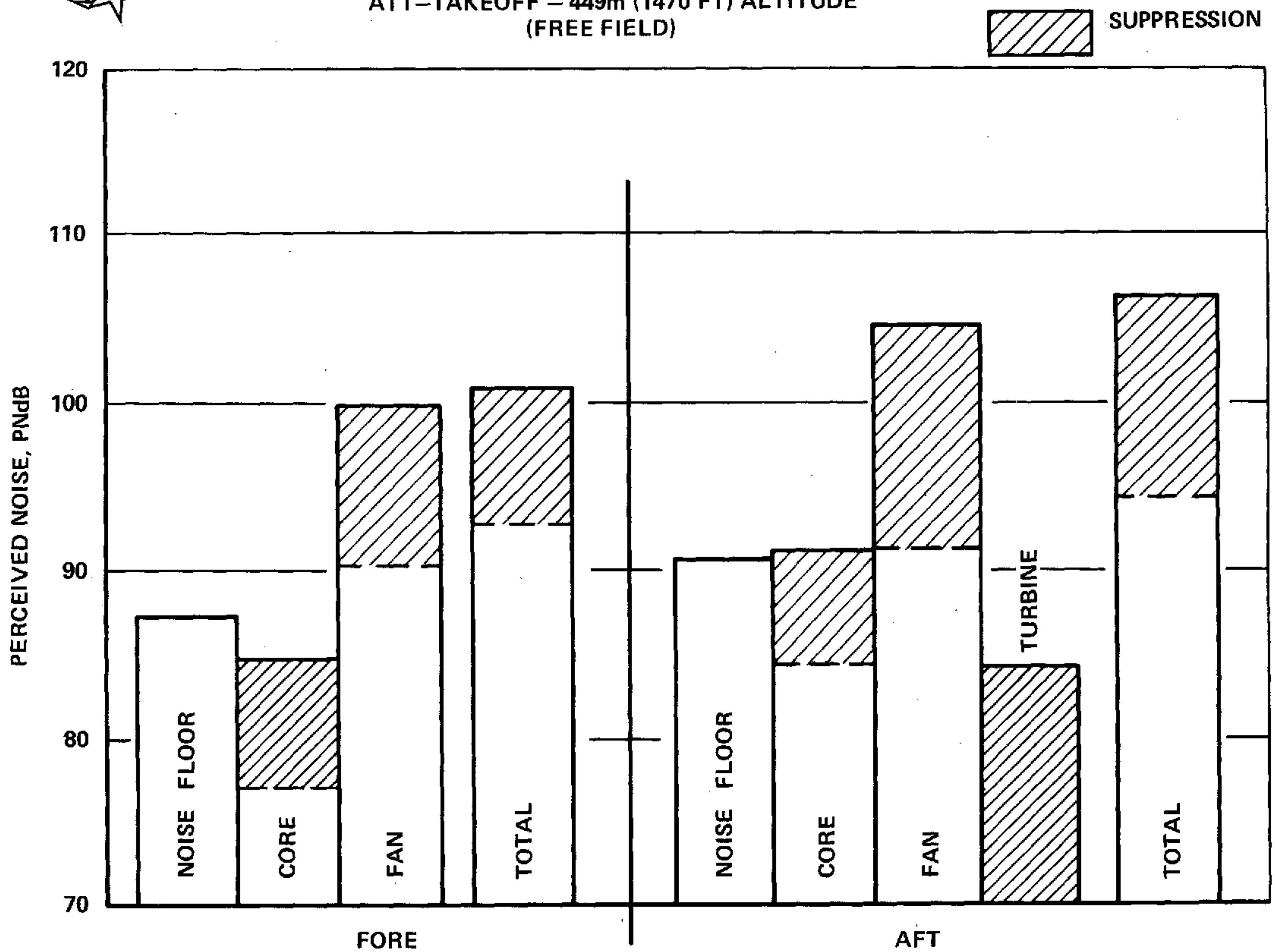
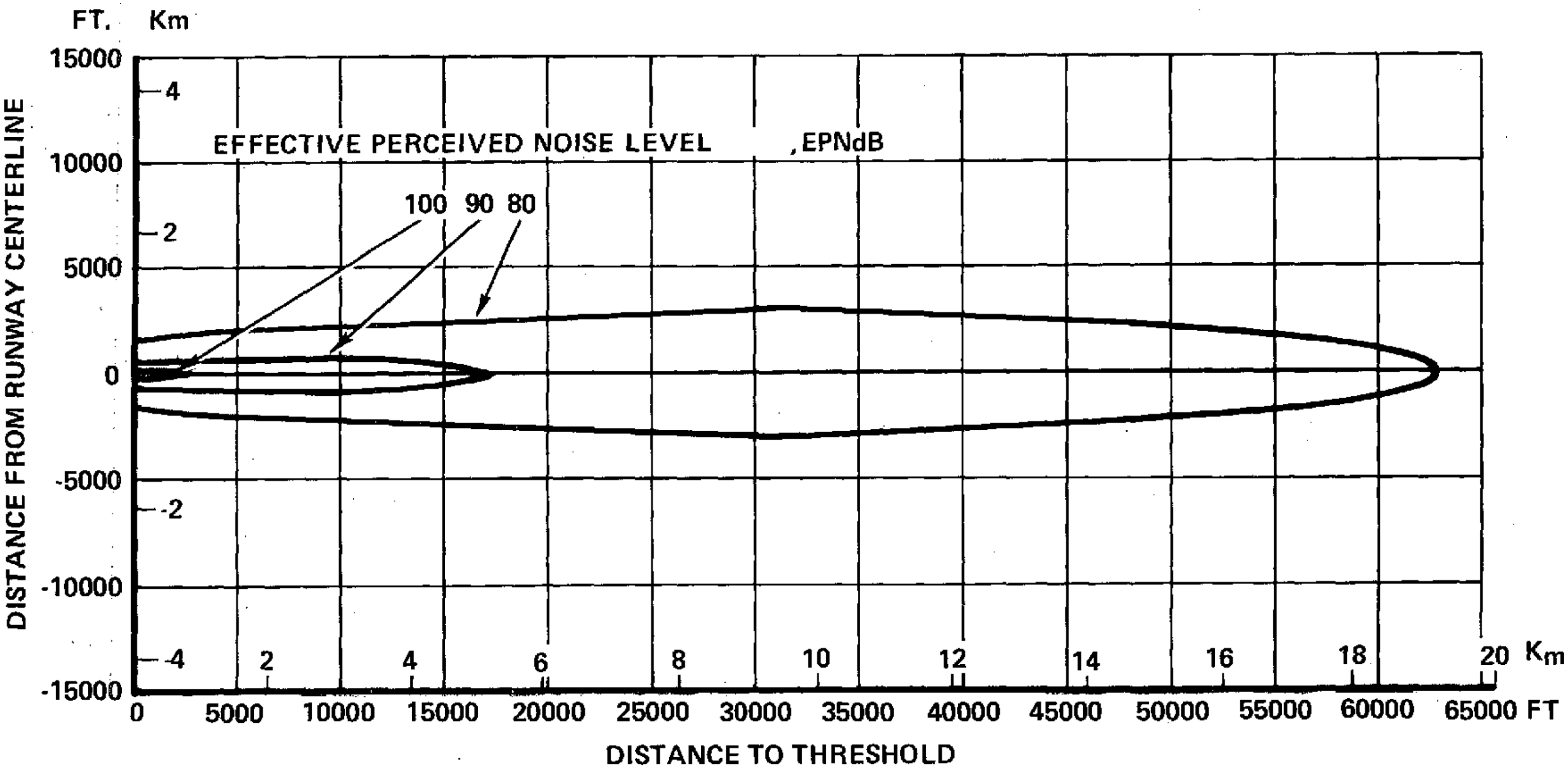


FIGURE 70

ATT NOISE CONTOURS
APPROACH



CONTOUR PLOTS
ADVANCED TECHNOLOGY TRANSPORT WITH PRATT AND WHITNEY STF433
SEA LEVEL, 25 DEG., C., 70% RELATIVE HUMIDITY
95026 Kg (209492 LB) LANDING WEIGHT, 42 DEG. FLAPS, 1.3V STALL + 10 KNOTS

FIGURE 71

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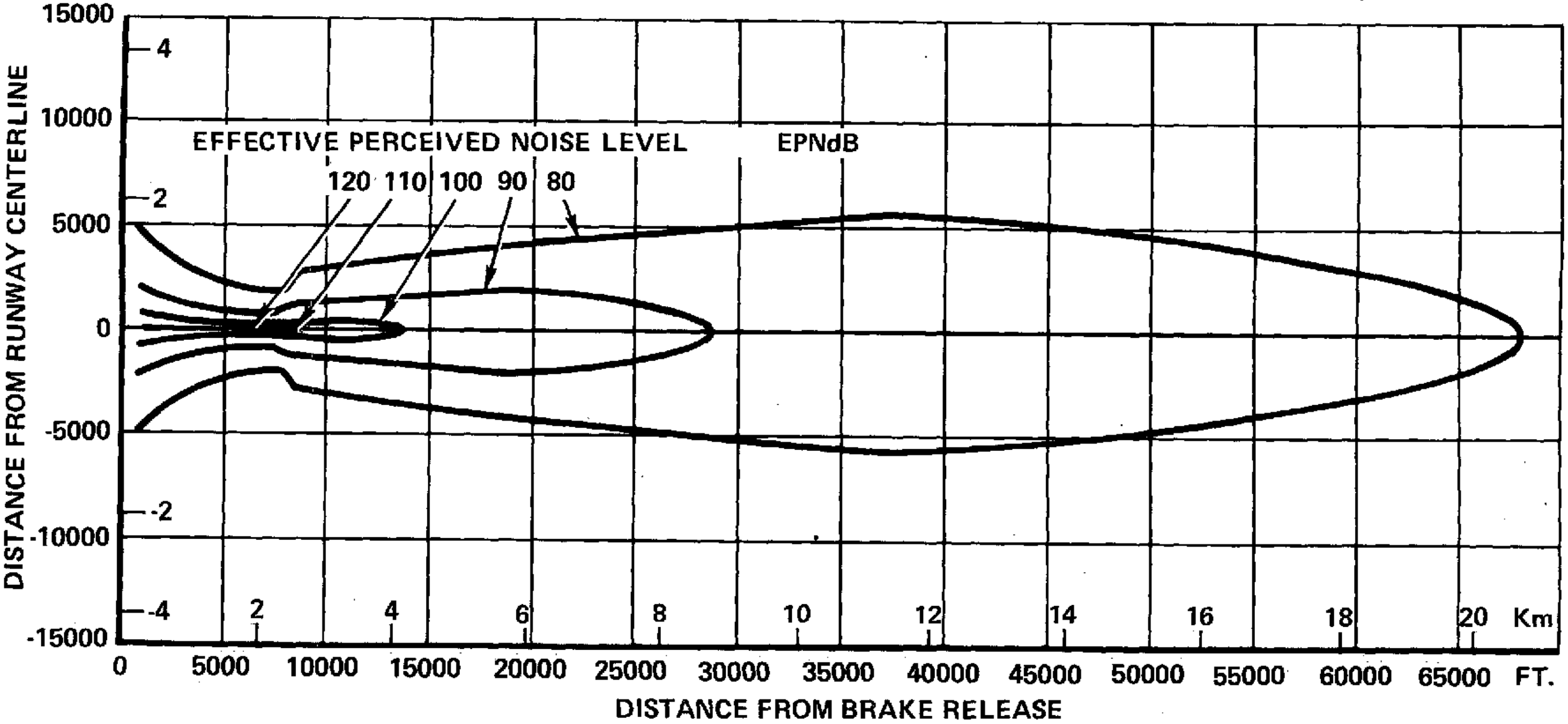
ATT NOISE CONTOURS
TAKE-OFF



CONTOUR PLOTS
ADVANCED TECHNOLOGY TRANSPORT WITH PRATT AND WHITNEY STF433
SEA LEVEL, 25 DEG., C., 70% RELATIVE HUMIDITY
129094 Kg (284599 LB.) TAKEOFF GROSS WEIGHT, 10 DEG. FLAPS, V2+10 KNOT CLIMB SPEED

FIGURE 72

SECTION 7

PROPULSION

7.1 INTRODUCTION

The thrust and drag characteristics of each of the engine nacelle configurations examined in this study were estimated in order to establish their relative installed specific fuel consumption levels. This performance was then compared with the performance of the wide body and ATT baseline configurations. As previously noted, the wide body aircraft baseline nacelle configuration incorporates an improved aftbody (15°) version of the L-1011's RB.211-22B wing pod design. This configuration is illustrated in Figure 17. The ATT baseline nacelle configuration is conceptually similar to the wide body except that it is designed for the Pratt and Whitney STF 433 engine. The ATT configuration, however, has a higher fineness ratio nacelle since it is designed for a higher cruise Mach No. than the wide body transport.

The initial wide body nacelle configurations examined incorporated coplanar nozzles, see Figures 20 through 24. Performance analyses conducted for these configurations showed that they all incurred an SFC penalty of from 1 to 2 percent due to increased internal flow losses and external nacelle drag. Table 1 in Appendix A presents a tabulation of the weight and SFC penalties associated with these configurations. In an effort to improve the performance, a configuration employing a mixed flow exhaust system was developed (see Figure 25). This configuration was selected for performance evaluation in the preliminary design study and later evolved into the minimum fuel consumption design.

Initial ATT configurations examined are shown in Figures 27 and 28. These configurations resulted in approximately a 2 percent cruise SFC penalty as shown in Table 2 of Appendix A. A mixed flow exhaust system was not examined for this installation because the engine exhaust velocities had already been optimized for performance and noise and, therefore, mixing would not be advantageous for this configuration.

This section presents in the following paragraphs a discussion of the analytical methods used to compute engine performance levels and details of the relative performance of nacelles examined in the conceptual design phase and those selected for the preliminary design evaluation.

7.2 ANALYSIS TECHNIQUES

The various nacelle configurations noted above were analyzed to determine the effects of varying amounts of acoustic treatment on inlet, fan duct and exhaust nozzle performance. The engine and inlet internal loss increments were computed using skin friction coefficients consistent with effective roughness of the various types of internal surfaces employed in the engine nacelle. These coefficients varied from 0.0024 to 0.0030 for hardwall surfaces and from 0.0045 to 0.0050 for the acoustically treated surfaces. Engine manufacturer supplied cycle decks were used to determine sensitivities of SFC and thrust to inlet recovery, duct pressure loss and nozzle performance. These sensitivities were then multiplied by the respective loss increments to obtain the total internal performance increment, e.g.,

$$\%\Delta SFC_{int.} = \frac{\Delta SFC}{\%\eta_{Inlet}}(\Delta\eta) + \frac{\% SFC}{\%\Delta P_{\substack{Fan\\Duct\\Loss}}}(\Delta P_{t_{Duct}}) + \frac{\% SFC}{\%\Delta F_{n_{\substack{Nozzle\\Loss}}}}(\Delta F_{N_{Nozzle}})$$

In addition to these internal losses external drag differences were also accounted for using standard skin friction coefficient correlations in determining the total overall performance increment. The incremental SFC differences associated with each configuration in the preliminary concept evaluation phase are presented in Appendix A, Tables 1 and 2. The SFC differences shown for both the wide body and advanced technology transport reflect only installed propulsion system performance levels and do not account for aircraft performance variations resulting from nacelle weight differences. The Δ fuel used values include both SFC and weight effects. As can be seen, only the configuration with a mixed flow exhaust nozzle system is capable of offsetting performance penalties of a long nacelle.

Mixed flow performance was computed using a methodology developed by Lockheed based on an extension of Marbert's work and a correlation derived to match the data of Frost and Hartmann. These calculations showed that the mixed flow version of the long inlet nacelle has a cruise SFC approximately 1.7 percent better than the acoustically equivalent coplaner nozzle configuration Table 1, Appendix A). As a result of the conceptual design study (CDS) it was decided to concentrate preliminary design efforts on the mixed flow exhaust configuration. Table 8 summarizes the various nacelle design refinements and related performance improvements beginning with the CDS mixed flow configuration (Figure 25). Acoustic considerations permit the inlet length to be reduced (to an intermediate length) improving the performance by 0.2 percent, and allows replacement of perforate material in the inlet and fan duct with aerodynamically smooth acoustic liners having comparable suppression capability. This results in a configuration (Shown in Figure 30) having an SFC 0.7 percent better than the baseline.

The minimum fuel configuration incorporates a short inlet similar to the baseline and removes the perforate material from the mixer and tail pipe. This configuration (shown in Figure 36) has an estimated SFC 1.2 percent better than the baseline. Differences in fuel used to maintain the same payload/range as the baseline widebody aircraft are presented in Table 9 for the final configurations analyzed. Also shown are the installed SFC and weight increments which contribute to the aircraft fuel used differences. Comparable ATT results are shown in Table 10 for the resized airplane.

It is again noted that the baseline configuration employed in this study incorporates the improved aftbody (15°) design relative to the original production aftbody on RB.211-22B engines. This aftbody was flight tested and shown to have approximately 3 percent improvement in cruise performance relative to the original production configuration. Had the original production aftbody been used as the baseline in the acoustic nacelle study, the indicated mixed exhaust performance improvement would have been 3.7 to 4.2 percent. It is emphasized, however, that the 15° aftbody is used as the baseline because it provides a more realistic assessment of mixed flow exhaust potential (approximately 1 percent) relative to a developed, high performance aftbody.

Finally, the mixed exhaust performance represents an estimate, based on correlations of model test data. Full scale data are required before the gain can be established.

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CRUISE SFC SUMMARY WIDEBODY NACELLES

CONFIGURATION	Δ SFC ~ % RELATIVE TO BASELINE
• BASELINE ~ (FIG. 3-3) SHORT INLET, SEPARATE EXHAUST NOZZLES	-
• MIXED FLOW ~ (FIG. 4-6) LONG INLET, MIXED EXHAUST	-0.2
• MIXED FLOW ~ (FIG. 5-1) INTERMEDIATE LENGTH INLET	-0.4
• MIXED FLOW ~ (FIG. 5-1) AERODYNAMICALLY IMPROVED ACOUSTIC TREATMENT IN INLET AND FAN DUCT	-0.7
• MINIMUM FUEL ~ (FIG. 5-6A) SHORT INLET (SAME AS BASELINE) REMOVE PERFORATE LINER FROM MIXER AND MIXED EXHAUST NOZZLE	-1.2

TABLE 8

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NACELLE DESIGN EFFECT ON AIRPLANE PERFORMANCE

WIDEBODY TRANSPORT

MATERIAL	CONFIGURATION	ΔWT PER AIRPLANE kg (lb)	Δ SFC %	Δ FUEL USED % (SAME P/L RANGE)
COMPOSITE	BASE	- 538 (-1187)	0	-0.35
METAL	MIXED FLOW	+1422 (+3135)	-0.70*	+0.23
COMPOSITE	MIXED FLOW	+ 694 (+1530)	-0.70*	-0.25
COMPOSITE	MINIMUM FUEL	395 (871)	-1.2**	-0.94

*SMOOTH FAN DUCT, PERFORATE TAIL PIPE
**SMOOTH DUCT AND TAIL PIPE

TABLE 9

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NACELLE DESIGN EFFECTS ON AIRPLANE PERFORMANCE

ADVANCED TECHNOLOGY TRANSPORT

MATERIAL	CONFIGURATION	Δ NACELLE WT PER AIRPLANE kg (LB)	Δ TOGW PER AIRPLANE kg (LB)	Δ SFC %	Δ FUEL USED (SAME P/L RANGE)
METAL	3/4 FAN DUCT				
COMPOSITE	INTERMEDIATE LENGTH INLET, LONG FAN DUCT, ACOUSTIC TREATMENT	+708 (+1561)	+3010 (+6635)	+1.7%	+3.5%

TABLE 10

SECTION 8

STRUCTURES

The role of the nacelle in providing the structure, services, and air passage requirements of the propulsion system imposes a different emphasis in applying structural criteria than that employed for the bulk of the aircraft structure. The use of composites likewise requires particular attention to certain aspects of design. In this section, these nacelle-peculiar and composite-peculiar considerations are discussed for each component of the structure and related to the current and to the projected state of the art in composites.

8.1 DESIGN CRITERIA

8.1.1 Static Loads

Static strength is required for inertia loads, air loads on the cowl, and internal pressures. From a review of the L-1011 design criteria and stress analysis, the following conditions are selected to obtain representative member sizing for preliminary design:

Inertia load factors:

$n_z = -7.47$ ultimate

$n_x = 1.74$

$n_y = 1.125$

Internal pressure:

Aft of fan 138 kPa (20 psi) ult.

Inlet 20.7 kPa (+3 psi)
-20.7 kPa (-3 psi)

Air loads on cowl:

Shear at fan case attach. = 76,950 N (17,300 lb) ult.

Bending moment at fan case attach. = 133,400 Nm (1,180,000 in. lb) ult.

8.1.2 Durability

Fatigue - Although the maximum internal pressures occur at the extremes of the operating envelope and so do not occur on every flight, normal operations do involve pressures which are of significant magnitude. Frequent high loads of this nature present a potential fatigue critical design. The high intensity acoustic environment also presents a potential fatigue problem that is unique to the nacelle. As a fatigue analysis requires more detailed data than is available at the preliminary design state, the criterion used in this study is to proportion the composite members to work at the same ratio of limit stress to allowable stress as the existing design. Un-notched composite specimens typically exhibit higher ratios of fatigue to ultimate stress than metals, so this approach is inherently conservative. Notch effects can be severe in composites, and the detail design must recognize stress raisers and provide suitable doublers or softening strips.

Damage Sensitivity - The criterion employed is that the composite structure should be as rugged as the metal. As definite methods of analysis for damage sensitivity are not available, comparative tests (see Section 10) of metal and composite panels are used to evaluate alternate designs.

8.1.3 Fail-Safe

Particular hazards for which a fail-safe capability is provided are a burst anti-icing air duct and a failed member in the inlet.

8.1.4 Smoothness and Panel Flutter

Smoothness under pressure and panel flutter are both functions of surface stiffness. Performance equivalent to the metal baseline is assured by maintaining the span to stiffness ratio (b/t_{eff}) of composite panels equivalent to that of the metal baseline. The span, b, is the ring spacing, the effective thickness, t_{eff}, is chosen to match the bending stiffness, EI, values of composite and metal skins.

8.2 MATERIALS AND ALLOWABLES

Fibers considered are graphite, Kevlar 49, and boron; resins considered are epoxy and polyimide types. Boron-aluminum is considered for parts requiring erosion resistance and elevated temperature capability.

Material properties are taken from Ref. 14. The design properties of fibers and resins supplied by various vendors differ from these values, and are expected to improve in the next few years. No attempt is made to anticipate improved properties or to prepare material specifications.

Epoxy resins are considered applicable to parts encountering temperatures about 480 K with suitable allowance for the effect of temperature and humidity on the properties. It is considered that resins suitable for use at a temperature of 600 K will be available. The polyimides are taken to be typical of such resins and it is anticipated that processing techniques for producing quality parts will be developed.

There are several categories of polyimides available which vary significantly in thermal stability and processing characteristics. For temperatures in the 480 K - 500 K range, a recently developed addition - polyimide is being evaluated with graphite by Lockheed for processing characteristics and resistance to elevated temperature and humidity. This polyimide type (represented by Kerimid 353, Phodia Corp., and F-178, Hexcel Corp.) is easier to process but less thermally stable than other polyimides.

For higher temperatures, (500 - 600 K), other polyimide systems are required which are more difficult to process. Condensation polyimides have been available for a number of years, but are extremely difficult to process because volatile by-products are produced during cure. Any hardware application of these materials will require processing development to ensure a quality part. Other polyimides are available for use at 500 K and above which do not produce volatiles, but these have the problem of extremely high processing temperatures (up to 700 K), which also would require process development.

The behavior of composites after lengthy exposure to the operating environment remains to be demonstrated. However, military experience and laboratory tests to date indicate that with certain precautions satisfactory service can be expected. Specific hazards and the design precaution taken are:

Lightning and Static Charge - A layer of aluminum wire mesh over the exterior surface and grounded to the airplane metallic structure is used to conduct lightning strikes away from the composite and to discharge static electricity.

Galvanic Corrosion - Contact between graphite and metal is prevented by using glass or Kevlar plies at faying surfaces and installing metallic fasteners wet with corrosion-inhibiting sealant.

Humidity - The edges of laminates and sandwich panels are sealed to minimize the entry of moisture to the bond line.

8.3 STRUCTURAL ARRANGEMENT

The fan case of the engine serves as the foundation of the nacelle structure as indicated in Figure 73. Nacelle loads are transmitted to the fan case which transmits them to the engine and thence to the engine mounts and pylon. The inlet is a short deep beam cantilevered from the forward face of the fan case to which it is attached by a circumferential row of tension bolts. As the fan case forms the flow passage surface, the inlet attach angle is close to the inner wall; the inner wall of the inlet is therefore made the primary load path to the fan case. The outer shell of the inlet is attached to the inner by the rings at the forward and aft end. Each shell is designed for the local pressures resulting from external air flow and flow through the inlet.

The fan case carries the engine accessories, and the nacelle structure in this region consists of a door support member at the top to which is hinged a full depth door on each side of the nacelle.

The nacelle structure immediately aft of the fan case is the thrust reverser frame which consists of a forward ring, six longitudinal beams, and an aft ring. The spaces between the beams are occupied by the cascades which turn the fan flow in the reverse thrust mode. The beams transmit the inertia and pressure loads from the nozzle to the forward ring and support the six actuators that operate the blocker doors and the translating cowl. The general arrangement of this mechanism is shown in Figure 74.

The nozzle aft of the thrust reverser consists of an inner and an outer shell; the inner forms the fan duct, the outer the nacelle contour. A service joint which makes the transition from the composite nozzle structure to the high temperature tail cone is provided just forward of the primary nozzle exit plane.

8.4 COMPONENT DESIGN

8.4.1 Cowl Lip

The cowl lip is shown on the inlet drawing, Figure 75. The governing criteria for the cowl lip are resistance to hail and provision for hot air anti-icing. Operating temperatures at some points reach 403 K, and short time exposures up to 495 K may occur with a burst duct. The baseline nose is 1.62 mm (.064 in.) aluminum to meet these conditions. Candidate composite materials are: graphite and Kevlar polyimide with a protective coating, and boron-aluminum. As the boron aluminum is

STRUCTURAL ARRANGEMENT

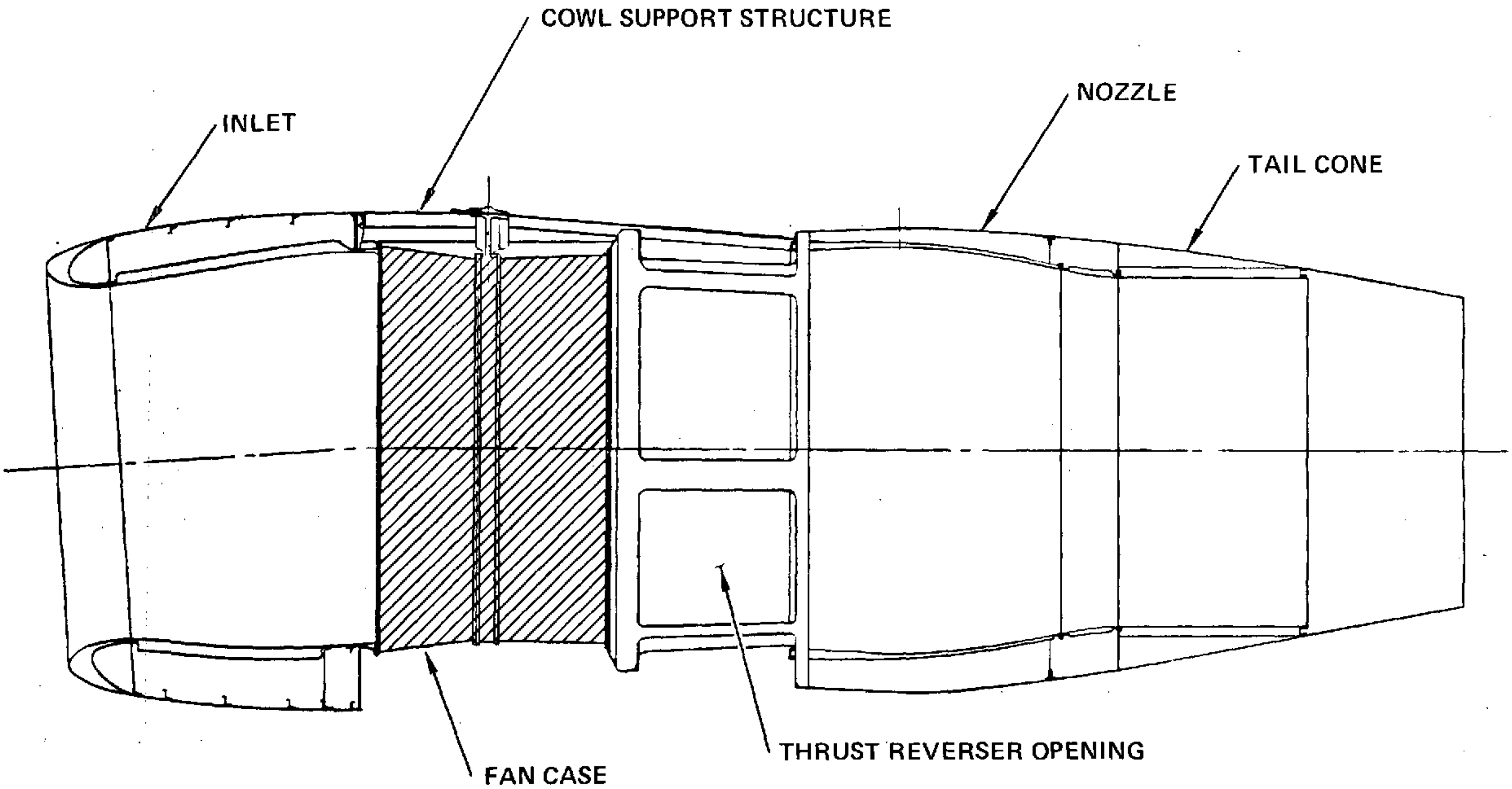

FIGURE 73

COLD STREAM THRUST REVERSER

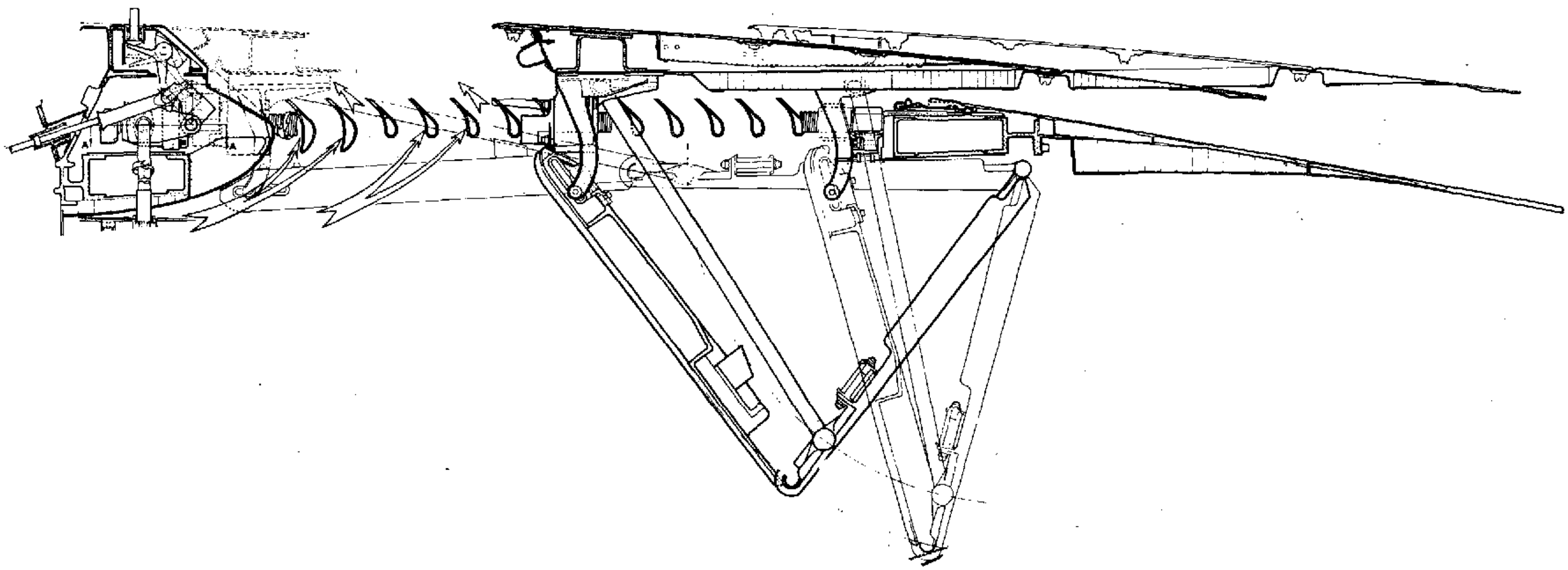

FIGURE 74

ORIGINAL PAGE IS OF POOR QUALITY

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INLET - ACOUSTIC COMPOSITE NACELLE

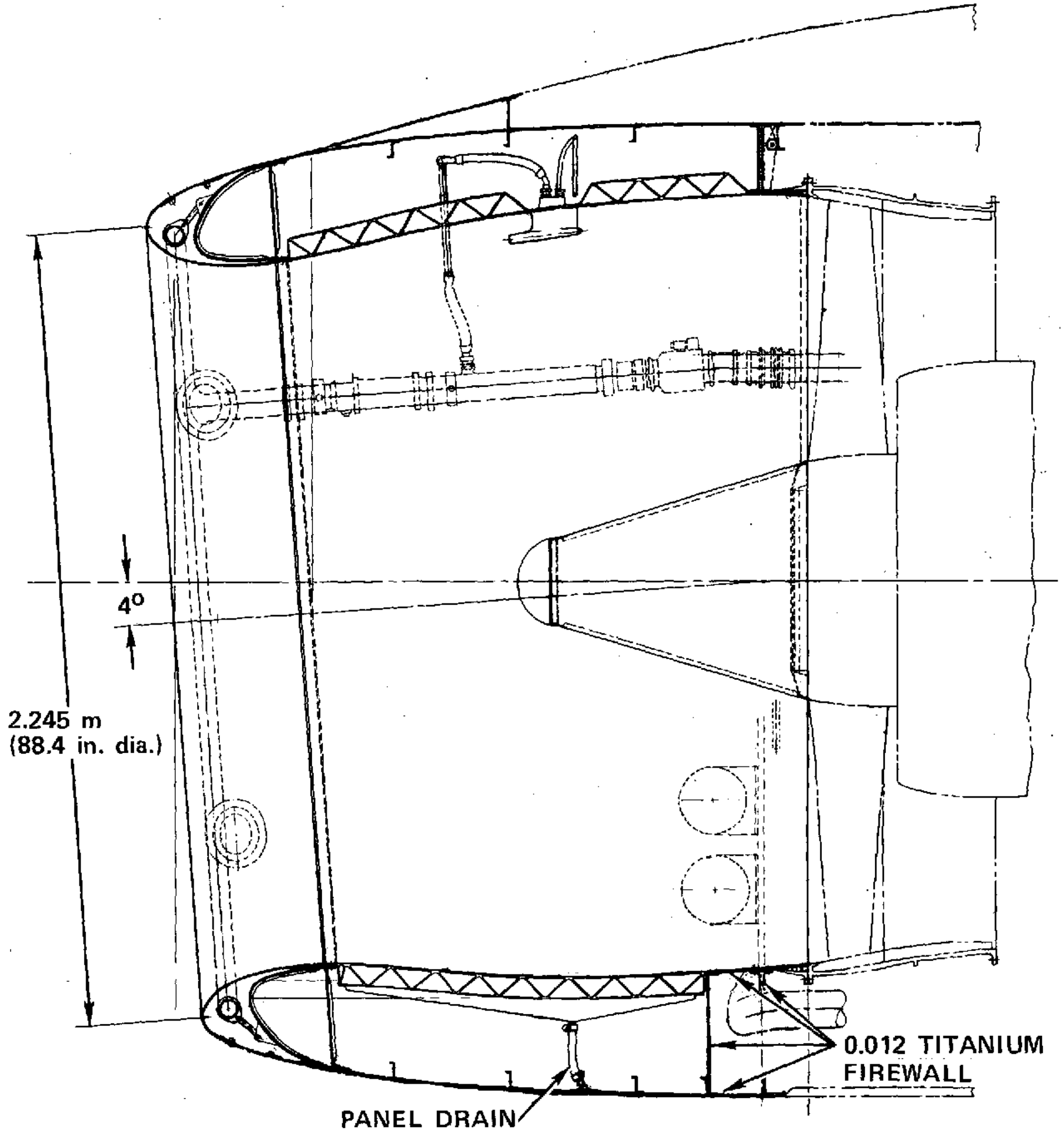

FIGURE 75

nearly as dense as aluminum and as thinner gages are not as resistant to impact, no advantage is seen for this material. With the present state of the art, composites are not recommended for this part. Projecting an improvement in polyimide toughness and processing combined with a suitable surface coating, a weight saving of 8.2 kg (18 lb) is anticipated. The weight saving is calculated using the weight of .25 mm (.01 in.) titanium as the protective coating.

8.4.2 Inlet Outer Skin

The critical static load condition is a collapsing pressure of 20.6 kPa (3 psi). The ability of sandwiches 7.62 mm (.3 in.) thick with minimum gage graphite or graphite-Kevlar to match the durability of the standard 1.0 mm (.040) aluminum skin was doubtful, so the tests described in Section 10 were made. On the basis of these tests the skin-ring arrangement shown in Figure 76 is selected. This skin-ring structure weighs 2.72 kg/m^2 (.558 psf) compared to 4.46 kg/m^2 (.914 psf) for the basic aluminum structure, a saving of 20 kg (44 lb) per inlet on basic structure of 50.8 kg (112 lb) in metal. This structure is current state of the art; the major improvement foreseen is the development of more damage tolerant arrangements.

8.4.3 Forward Bulkhead - Inlet

The forward ring is subjected to 69 kPa (10 psi) ultimate pressure and operating temperatures up to 453 K from anti-icing operation. Burst duct temperatures approach 533 K at some points. A corrugated web laid up integrally with cap strips is used to take the pressure; graphite cloth with polyimide resin to meet the temperature requirements is used. A weight saving of 6.5 kg (14 lb), 56% of the aluminum-titanium baseline is expected.

8.4.4 Aft Bulkhead - Inlet

The aft ring of this inlet serves as a firewall and is made of titanium in the baseline nacelle. Operating temperatures are 383 K. A composite sandwich web using graphite for the forward face and attach angles and .33 mm (.012 in.) titanium for the aft face and attach angles to provide the fire resistance is used. A weight saving of 3.2 kg (7 lb), 28% of the metal is expected. As the operating temperatures are within the epoxy range and titanium-graphite sandwiches have been made for experimental floor boards, this ring is considered current state of the art.

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NOSE
COWL OUTER SHELL

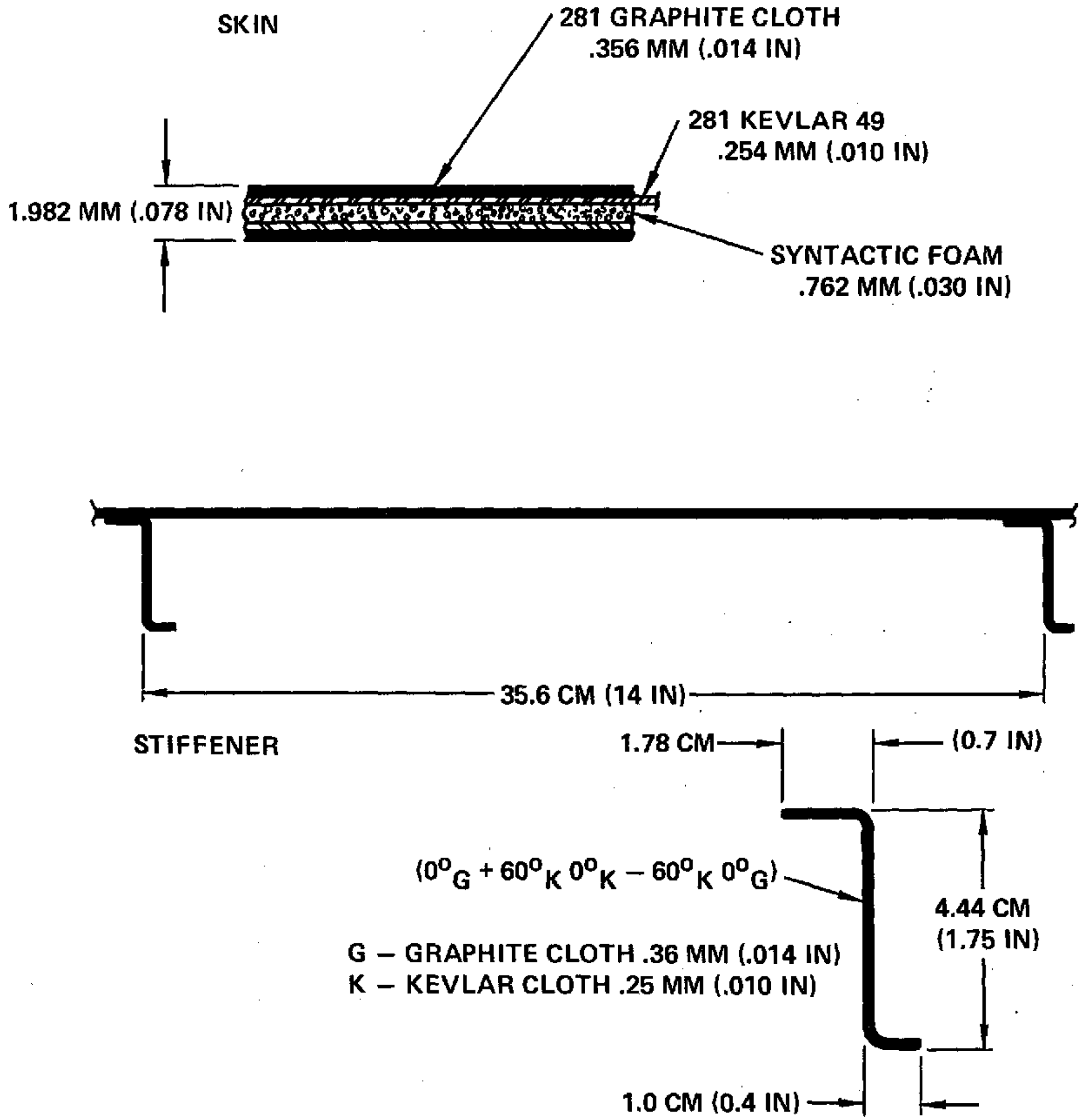

FIGURE 76

8.4.5 Inlet Inner Skin

The inner skin is the primary structural shell as well as the acoustic suppression panel. The bending moment of 133,400 Nm (1,180,000 in. lb) produces a load intensity of 35 kN/m (200 lb/in.), which is within the capability of reasonably stabilized skins. The acoustic requirements therefore dominate the design. To achieve the broadband characteristics over the frequency range desired, the "Permoblique" configuration 6.3 cm (2.5 in.) deep is required. The alternate configurations are shown in Figure 77. Both are characterized by the porous diagonals and the high acoustic resistance of the faces and diagonals. Compartmentation of the acoustic passages formed by the diagonals and walls is required; this is formed by the honeycomb in the built-up version, and by the ribbed inserts in the second. A sample of the woven type, 1.90 cm (.75 in.) deep, incorporating the desired acoustic resistances has been supplied by the Woven Structures Division of HITCO. It appears that with a reasonable development effort, the woven type could meet the acoustic, structural, and smoothness requirements at an appreciable saving in material and assembly costs. Because of the mechanical attachment of the core members to the faces and potential cost savings, the woven type is used in this study.

8.4.6 Attach Ring

The inlet is attached to the fan case by a forged aluminum angle. The same basic geometry, strength and stiffness are provided in the composite version. Graphite cloth has been found adaptable to the layup of curved angles so this is regarded as current state of the art. The weight saving is 5.9 kg (13 lb).

8.4.7 Cowl Doors

The cowl doors on the baseline are sandwich panels with aluminum faces. As the upper halves of the doors serve as fire walls to protect the wing, the inner face is protected by a titanium shield on the upper half. As the doors are subjected to bending and torsion when open in high winds, the sandwich structure is retained. The skin gages required, .76 mm (.03 in.), are sufficiently rugged. The aluminum skins, 29 kg (65 lb), are changed to graphite with a weight saving of 10 kg (23 lb) per nacelle using current state of the art.

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ADVANCED LINERS

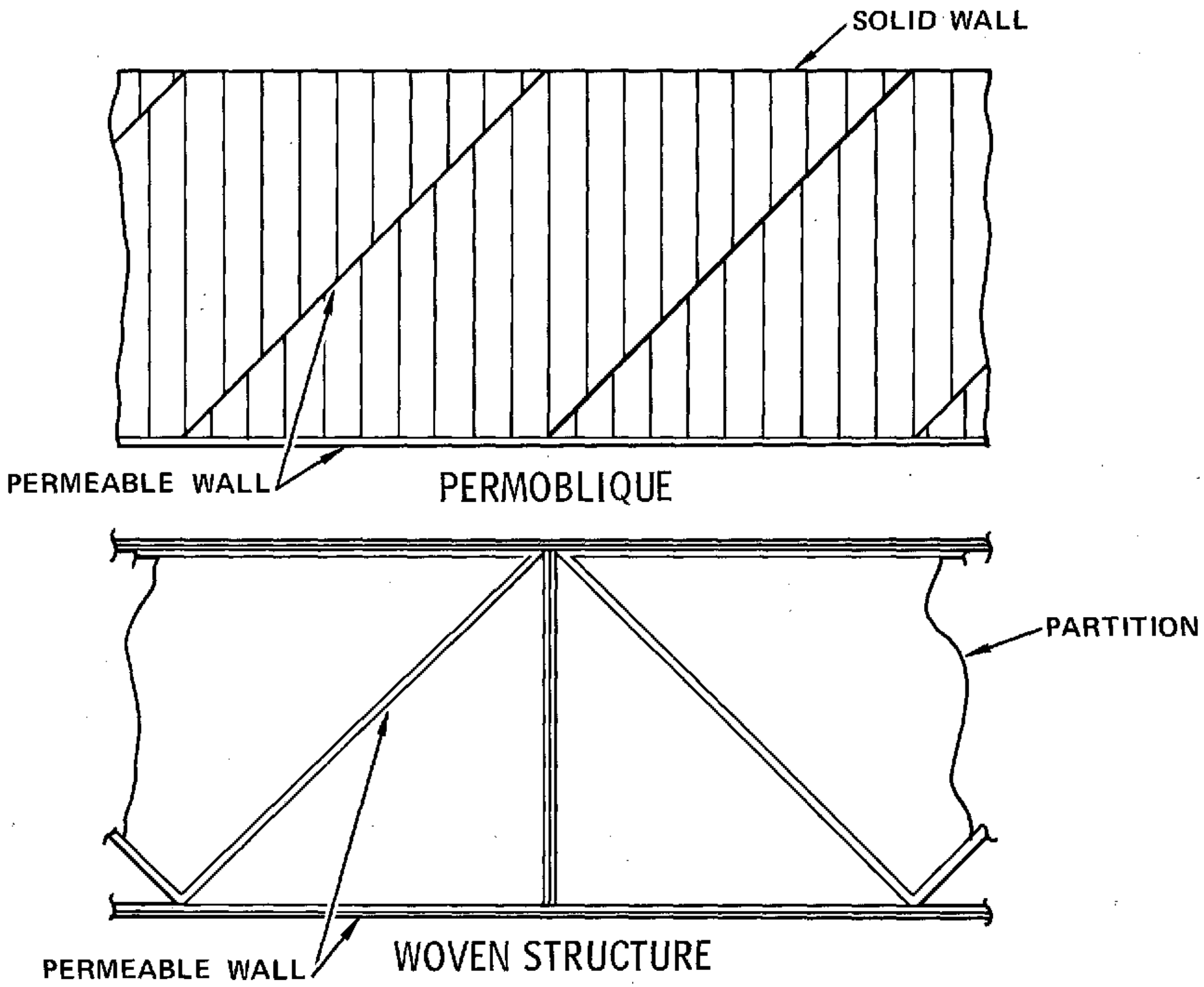

FIGURE 77

8.4.8 Side Panel Support Structure

The door support structure is a built-up titanium structure in the baseline as shown in Figure 78. Using a similar configuration to suit the established hinge points, the weight saving is 1 kg (2 lb) in graphite epoxy; a cost saving is also expected over the titanium with present state of the art composite techniques.

8.4.9 Thrust Reverser Support Structure

The composite thrust reverser support structure is an integral unit with the nozzle as shown in Figure 79. The six longitudinal beams are built into the nozzle shell thereby forming a rigid frame for carrying vertical and lateral inertia loads to the forward ring which is attached to the fan case by a circumferential row of tension bolts. These beams pick up the tension load produced by gas pressure on the nozzle thru tapered doublers on the nozzle. The unidirectional beam caps (Sect FF) are likewise tapered into the nozzle faces. The concentrated loads on the forward ring are distributed to the fan case by the forward ring which is stiffened about its radial axis by unidirectional fibers in the forward and aft walls of the box section. The nozzle wall is basically a sandwich 2.54 cm (1 in.) deep which also serves as acoustic suppression. The forward portion of this sandwich is thickened to form the aft ring of the thrust reverser frame. The forward closure of this ring is a channel which provides attachment flanges for the cascade supports and actuator screw bearings. Longitudinal channels are inserted to provide local support for the blocker door hinge fittings.

As the structure is indeterminate and deflections are of primary interest because of the mechanisms involved, a NASTRAN model using the elements shown in Figure 80 was used to check the proportions used. Reasonable stresses and deflections were found at all points.

The weight of the idealized forward and aft rings and six beams used in the analysis is 63.5 kg (140 lb). The equivalent aluminum ideal weight is 104 kg (230 lb), and the actual baseline weight is 157 kg (347 lb). It is expected that the 41 kg (90 lb) saving in ideal weight can be realized, amounting to 26% of the baseline weight. The elements of this structure are considered to be current state of the art; however, an extensive sub-element test program is necessary to verify all design details, and a tooling development program is required for the assembly.

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COWL SUPPORT STRUCTURE COMPOSITE NACELLE

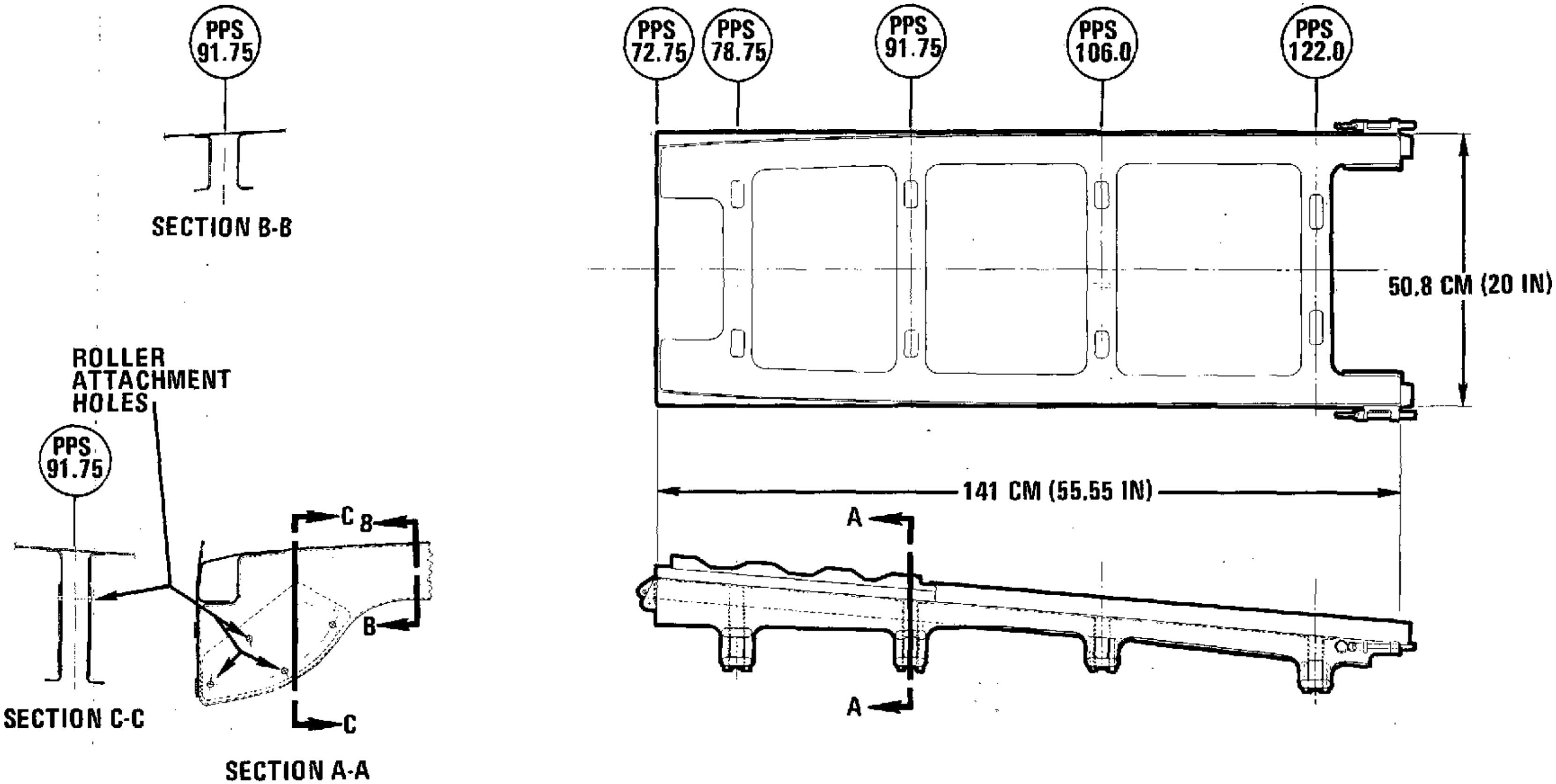

FIGURE 78

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AFT FAN DUCT & THRUST REVERSER STRUCTURE

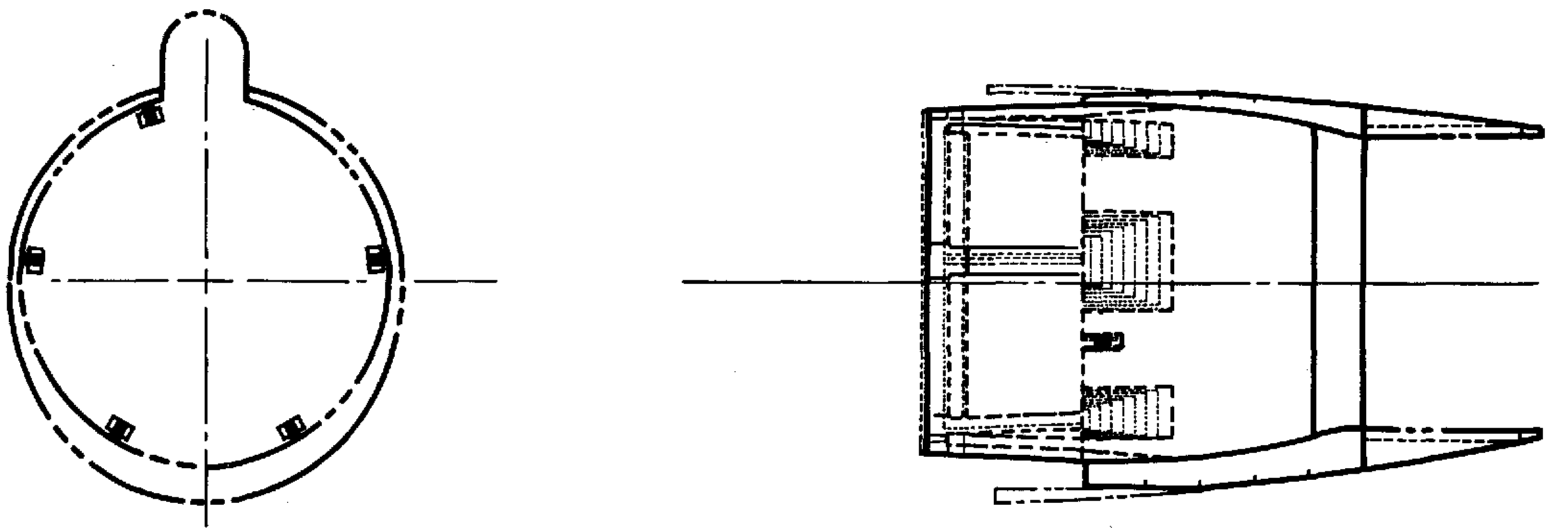


FIGURE 79

AFT FAN DUCT & THRUST REVERSER STRUCTURE DETAILS

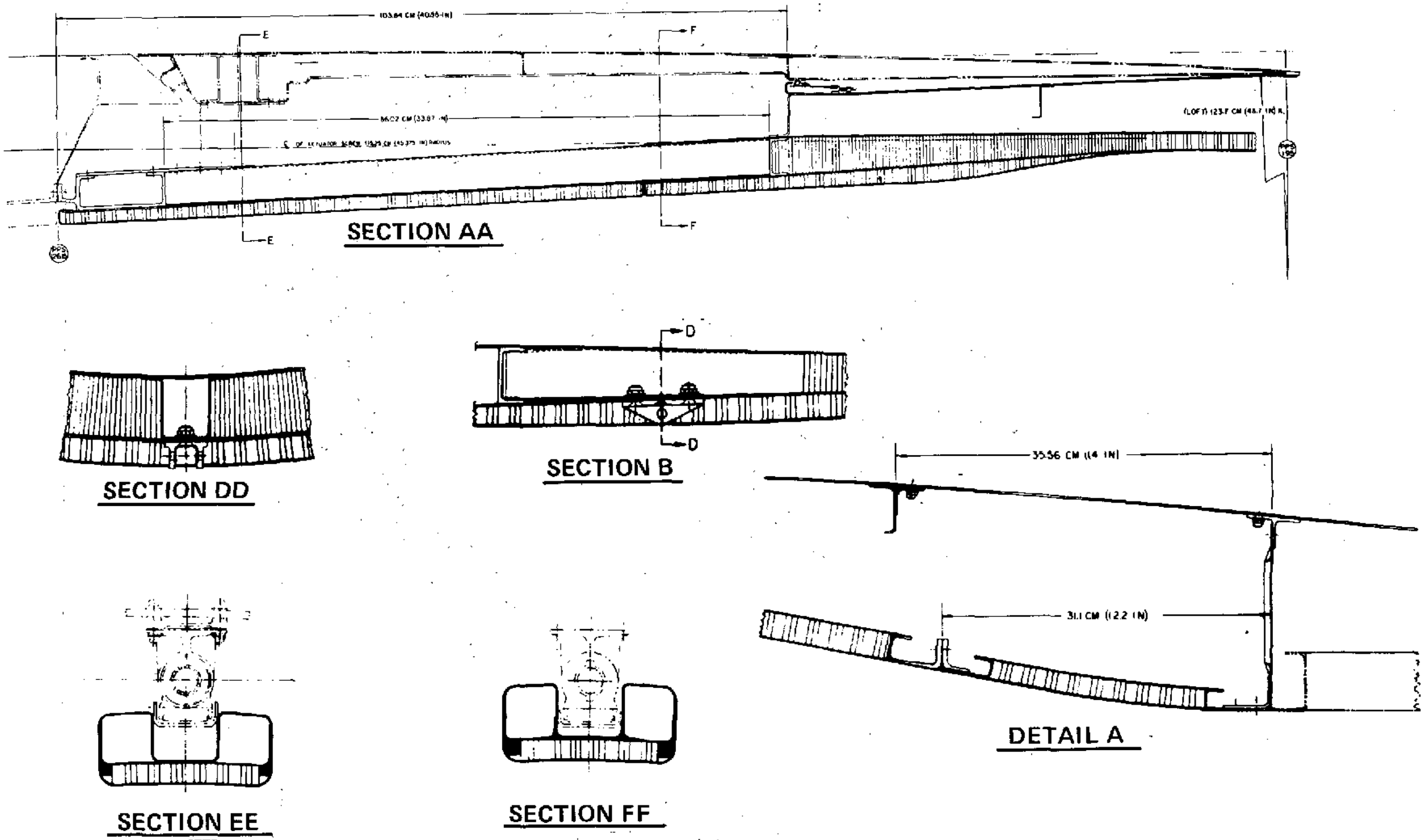


FIGURE 79 (CONTINUED)

COMPOSITE REVERSER, RB211 STUDY FIRST VERSION
UNDEFORMED SHAPE

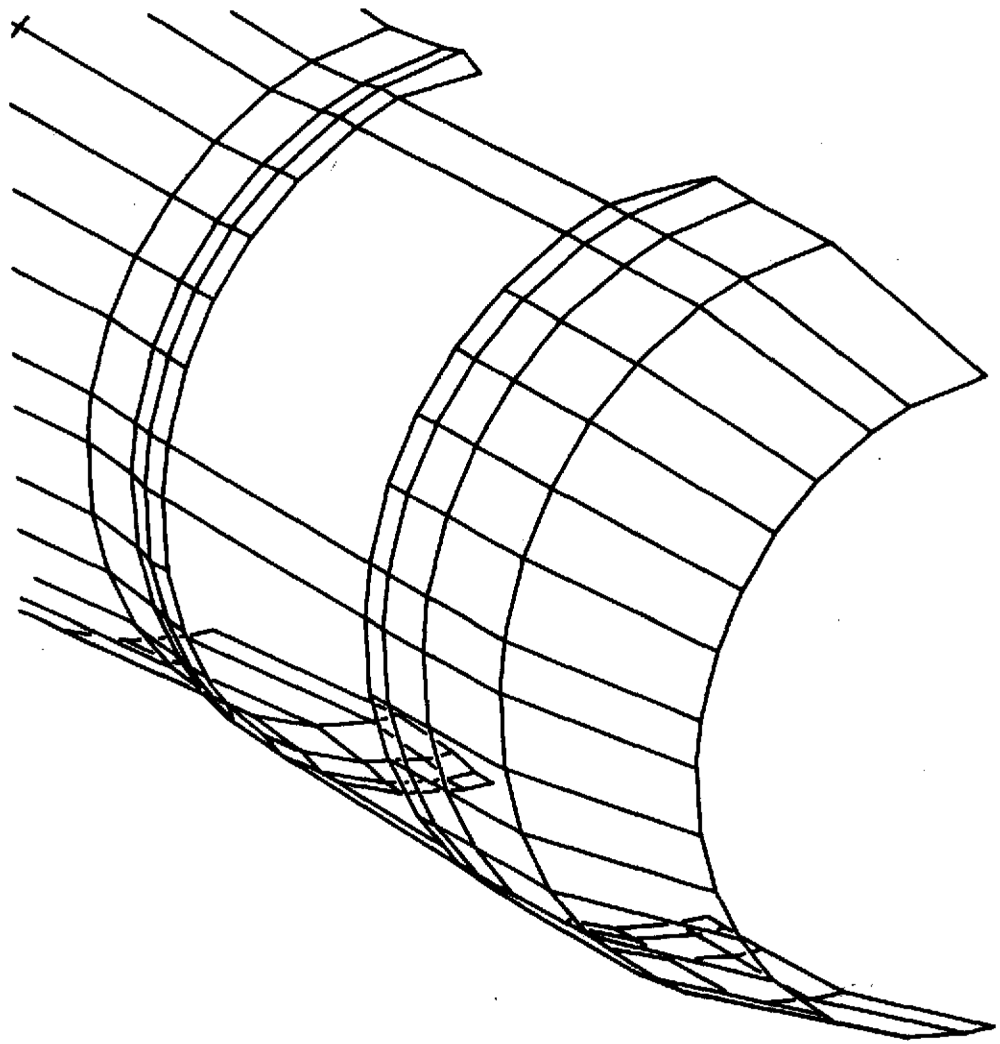


FIGURE 80

Nozzle Structure - The nozzle structure consists of the inner shell which is a honeycomb sandwich to serve both acoustical and structural functions. The graphite faced liners weigh 6.49 kg/m^2 (1.33 psf); corresponding metal liners are 10 kg/m^2 (2 psf), a saving of 33 kg (73 lb). The outer shell is the ring stiffened graphite Kevlar-syntactic resin structure selected for the inlet; the weight saving over 1. mm (.040) stiffened aluminum is 22 kg (49 lb).

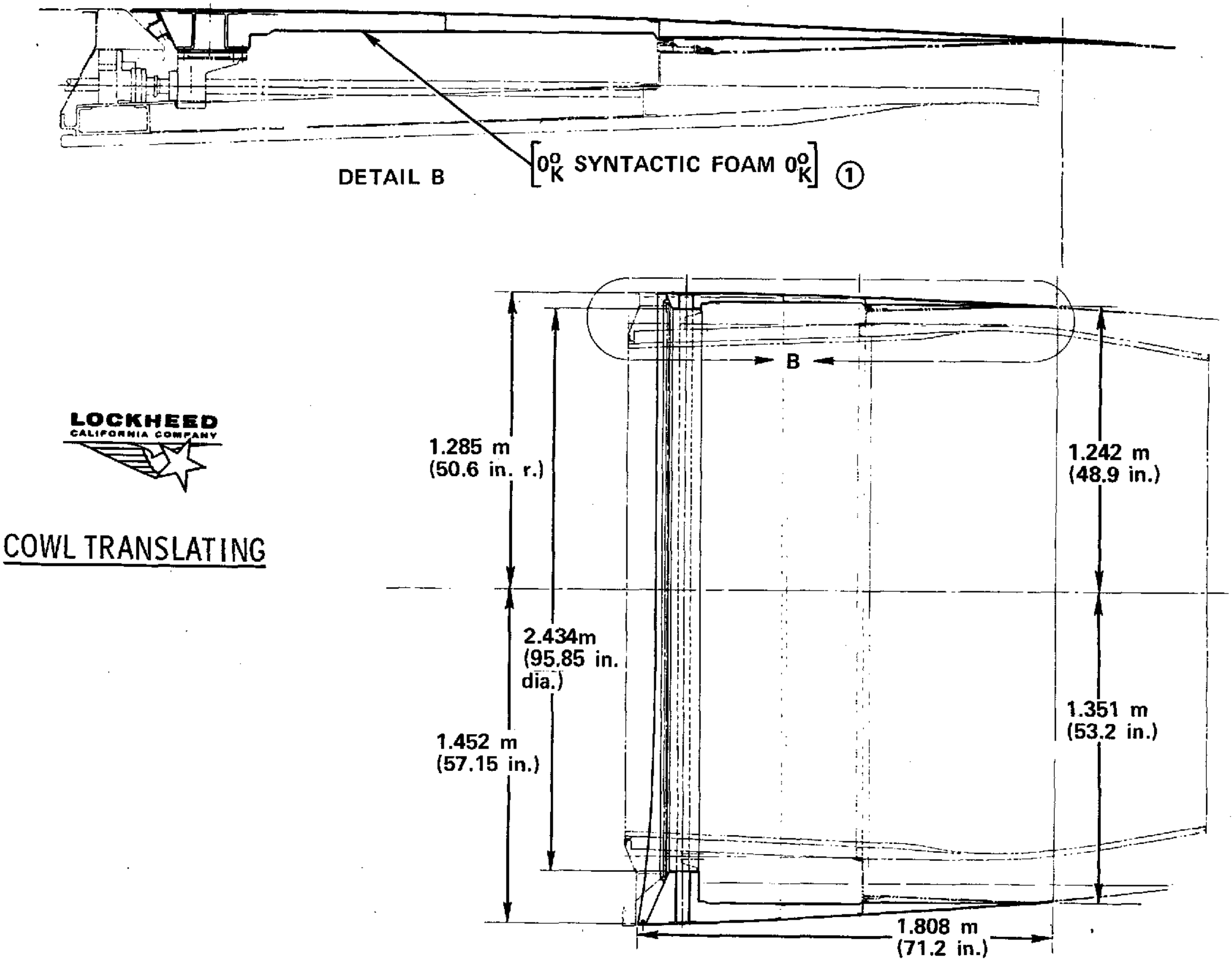
A ring at the forward end of the nozzle supports the outer shell and seal. The ring is laid up with integral beads using graphite and Kevlar cloth, 1.3 mm (.05) total thickness. The weight saving over equivalent aluminum is 4.5 kg (10 lb).

8.4.10 Translating Cowl (Figure 81)

The translating cowl on the mixed flow nacelle is considerably longer and shallower than the baseline, but retains the essential structural features — a strong ring at the forward end to which the actuators and links to the blocker doors are attached, an outer skin and an inner skin connected by rings. The main ring is changed to graphite retaining the baseline geometry, stiffness and strength. The outer skin uses the graphite-Kevlar-syntactic resin layup selected for the inlet; the inner skin being less exposed omits the graphite. The corresponding metallic skins are 1 mm (.040) outside and .8 mm (.032) inside. The primary structural elements in composites weigh 72 kg (158 lb), in aluminum 99 kg (219 lb). The saving is 28 kg (61 lb), 28%. This assembly is current state of the art.

8.4.11 Tail Cone (Figure 82)

The tail cone is exposed to the hot core gases without the cooling fan flow during reverse thrust operation. The inner wall is therefore made of steel. The treated portion uses an assembly of small horns to attenuate the low frequency core noise; although complex, this section is similar in construction to other applications of "Schizophonium" that have been built at Lockheed. The outer fairing of the tail cone, including the removable panel providing access to the tail cone attaching bolts, uses the stiffened skin selected for the inlet. The panel area is 5.1 m^2 (55 square feet); stiffened 1 mm (.040) aluminum weighs 23 kg (50 lb), the composite 17 kg (37 lb).



DETAIL B
[0°K SYNTACTIC FOAM 0°K] ①
B
LOCKHEED
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COWL TRANSLATING
1.285 m
(50.6 in. r.)
2.434m
(95.85 in.
dia.)
1.452 m
(57.15 in.)
1.242 m
(48.9 in.)
1.351 m
(53.2 in.)
1.808 m
(71.2 in.)

FIGURE 81

TAILCONE

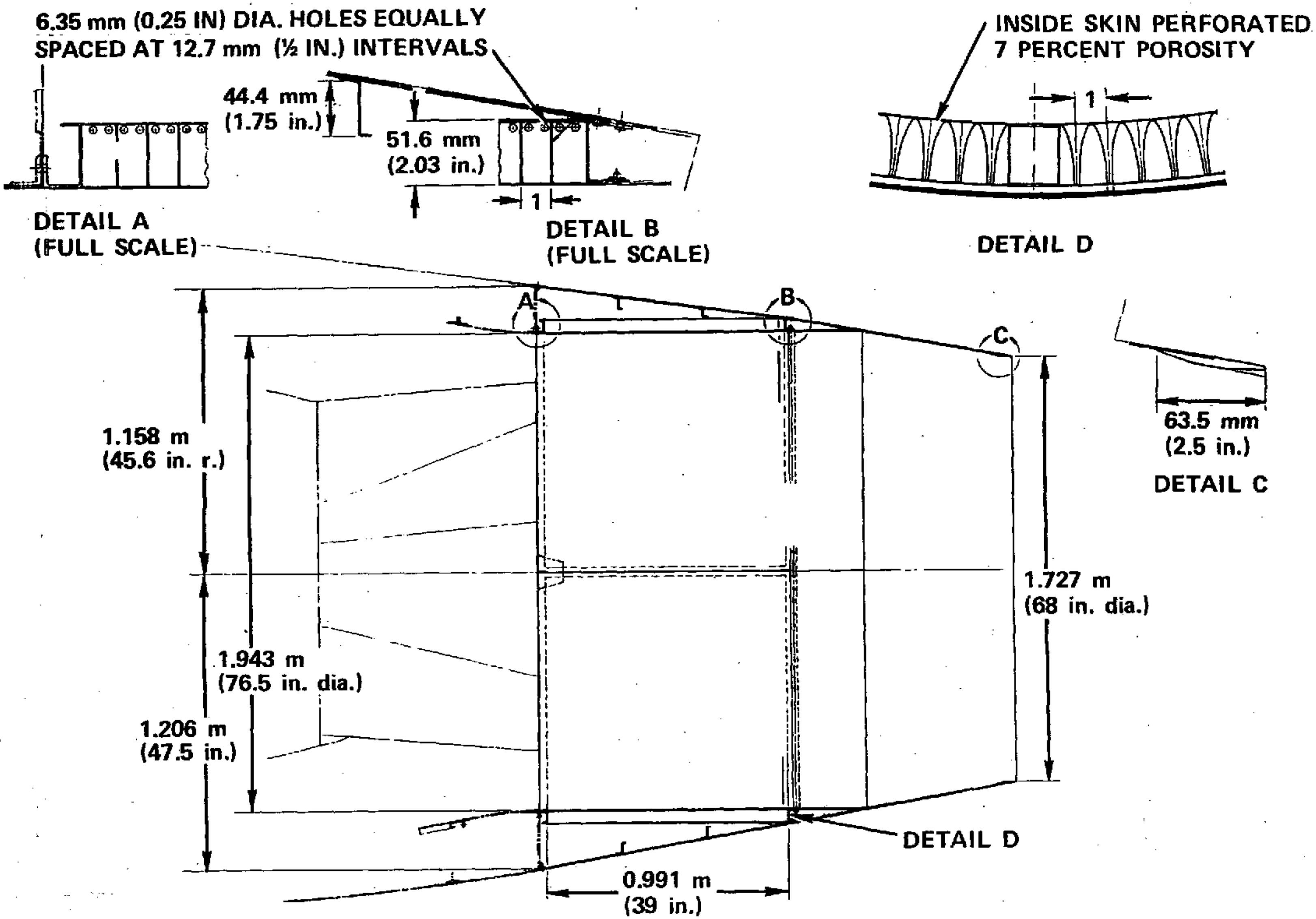

FIGURE 82

8.4.12 Gas Generator Cowl

The cowling is subjected to fan pressure and elevated temperature from the engine. A five percent weight saving is estimated by the use of graphite-polyimide backing sheets, a saving of 7.7 kg (17 lb). Verification testing for this application is necessary.

8.4.13 Blocker Doors

The blocker doors are aluminum forgings with lugs for the hinges and link attachments and a pan for the acoustical treatment. Chopped fiber moldings seem to be the most likely technique for applying composites to these parts. A weight saving of 15%, 16 kg (36 lb), is estimated with the development of an economical process.

8.4.14 Cascades

The cascades for turning the fan flow are cast magnesium. A weight saving of approximately the density difference of graphite epoxy and magnesium is expected with the development of economical molding techniques. A 10% weight saving yields 7.2 kg (16 lb).

8.4.15 Hoop Plate

The hoop plate provides continuity across the pylon area. By comparison with the cowl supports, a weight saving of 25%, 7.2 kg (16 lb), is estimated.

8.4.16 Fairings

The fairings around the engine mounts, plumbing, and equipment in the fan duct are similar to the outer shell. A saving of 30%, 22 kg (48 lb), in the skin and supports is estimated.

8.4.17 Actuators, Ducts, Tail Pipe, Firewall

The actuators are mechanical parts, the ducts and tailpipe operate at high temperatures. No specific composite developments that might save a significant amount of weight are foreseen for these parts. The mixer construction is shown in Figure 83. The bulkhead at the aft end of the fan case serves as a fire wall and is loaded by the thrust reverser. The thrust reverser supports, para 8.4.9, are composite, but the titanium firewall is retained.

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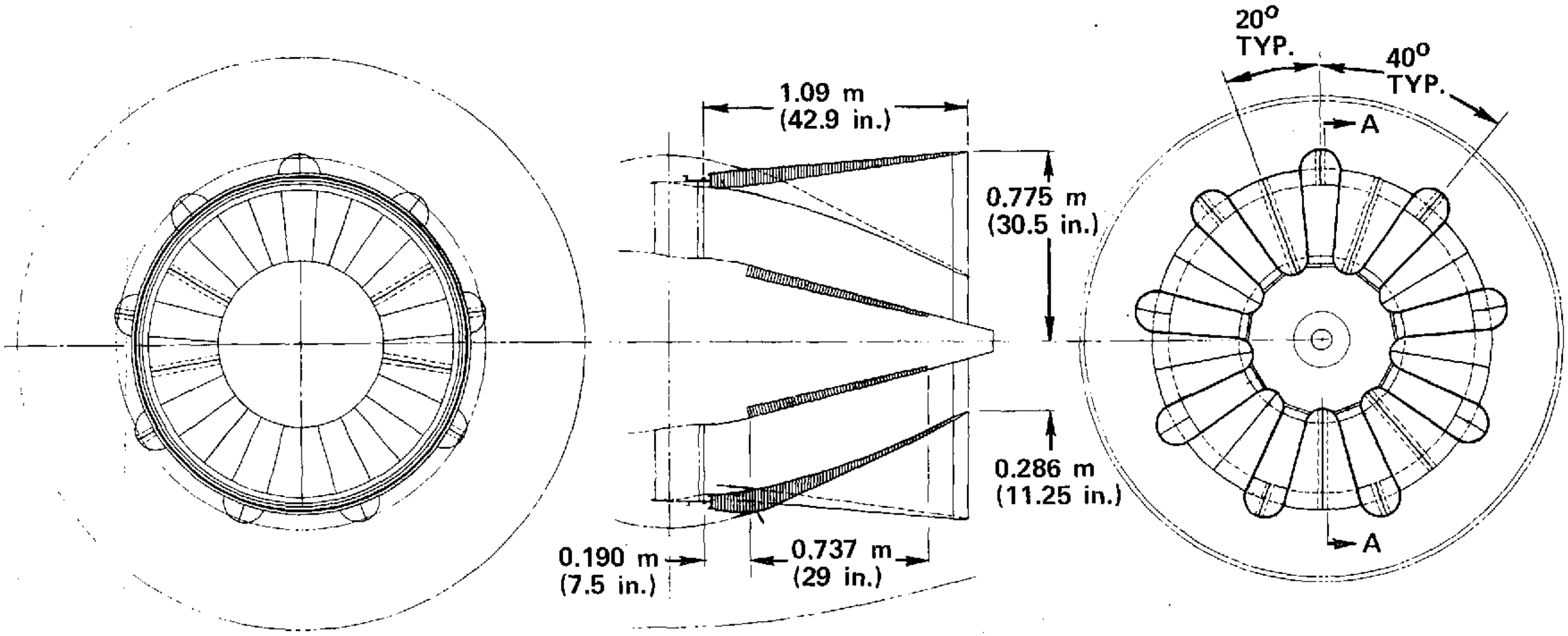
MIXER NOZZLE



VIEW LOOKING AFT SECTION A–A VIEW LOOKING FORWARD

FIGURE 83

SECTION 9

WEIGHT

The nacelle weights used in the economic comparisons are compiled in this section. The wide-body baseline weights are extracted from L-1011 data and are presented in Table 11. The weight savings shown for converting to composites are derived from the analyses discussed in Section 8 for the primary structural components and, for the many small components, are estimated by comparison with the primary parts and with previous studies. The asterisk indicates parts which require some additional development to be technically or economically practical. In general, small parts of complex shape are regarded as economically impractical at present because the tooling and qualification testing required for each part are large compared to the weight involved.

The component weights for the acoustic-composite mixed flow nacelle are given in Table 12. The weights are based on the preliminary design study for the major components; weights of detail parts are estimated by comparison with the L-1011 data.

Table 13 summarizes the weights of the ATT preliminary design nacelle.

A summary of the nacelle weights used in the concept selection study discussed in Section 4 is shown in Appendix A.

WEIGHT BASELINE WIDE BODY

PART	METAL		SAVING			COMPOSITE	
	KG	LB	%	KG	LB	KG	LB
Cowl Lip	28	62	29	8	*18	20	44
Cowl Outer Panel	41	90	39	16	35	25	55
Fwd Bulkhead	11	25	56	6	*14	5	11
Rear Bulkhead	11	25	28	3	7	8	18
Liners	64	140	21	13	29	51	111
Attach Ring	13	29	45	6	13	7	16
Brackets and Clips	20	45	30	6	*14	14	31
Fasteners	14	30	0	0	0	14	30
Inlet Total	(202)	(446)	(29)	(58)	(130)	(144)	(316)
Cowl Door Skins	39	85	35	10	23	29	62
Core	25	54	0	0	0	25	54
Latch Channels	12	27	20	2	*5	10	22
Channel Ribs	9	20	20	2	*4	7	16
Access Doors	12	26	30	4	8	8	18
Hinges	15	34	0	0	0	15	34
Latches	9	20	0	0	0	9	20
Struts - Open	6	14	0	0	0	6	14
Fasteners	6	13	0	0	0	6	13
Supports	5	12	16	1	2	4	10
Doors and Supt Total	(138)	(305)	(14)	(19)	(42)	(119)	(263)
Trans Cowl Skins	33	72	32	10	23	23	49
Webs	25	55	30	7	16	18	39
Angle and Supt	7	16	30	2	5	5	11
Strap Cap	4	10	23	1	2	3	8
Channel, Hoop	6	13	23	1	3	5	10
Skin Lands	4	9	32	1	3	3	6
Angle Rear	6	14	0	0	0	6	14

*Indicates further development required

TABLE 11

WEIGHT BASELINE WIDE BODY

PART	METAL		SAVING			COMPOSITE	
	KG	LB	%	KG	LB	KG	LB
Misc Stiff.	13	29	20	3	*6	10	23
Fasteners	5	11	0	0	0	5	11
Trans Cowl Total	(103)	(229)	(25)	(25)	(58)	(78)	(171)
Fan Nozzle	(34)	(74)	0	0	0	(34)	(74)
Gas Gen Cowl	(157)	(347)	(5)	(7)	*(17)	(150)	(330)
Blocker Doors	110	243	15	16	*36	94	207
Cascades	73	161	10	7	*16	66	145
Cascade Supts	157	347	26	41	*90	116	257
Hoop Plate	29	64	25	7	16	22	48
Fairings	73	161	30	22	48	51	113
Firewall	73	160	0	0	0	73	160
Actuators, Ducts	89	197	0	0	0	89	197
Reverser Total	(604)	(1333)	(15)	(93)	(206)	(511)	(1127)
Tail Pipe Total	(87)	(193)	0		0	(87)	(193)
Total Fwd	341	751	23	78	172	263	579
Total Aft	987	2176	13	127	281	860	1895
Total/Wing Pod	1328	2927	15	205	453	1123	2474
Total/Airplane	3643	8030	15	538	1187	3105	6843

*Indicates further development is required

Considering only current state of art:

PART	METAL KG	METAL LB	SAVING %	SAVING KG	SAVING LB	COMPOSITE KG	COMPOSITE LB
Total Fwd	341	751	16	53	117	288	634
Total Aft	987	2176	5	53	116	934	2060
Total/Wing Pod	1328	2927	8	106	233	1222	2694
Total/Airplane	3643	8030	7	264	582	3379	7448

TABLE 11 (CONTINUED)

WEIGHT MIXED FLOW WIDE BODY

PART	METAL		SAVING			COMPOSITE	
	KG	LB	%	KG	LB	KG	LB
Cowl Lip	28	62	29	8	18	20	44
Cowl Outer Panel	51	112	39	20	44	31	68
Fwd Bulkhead	11	25	56	6	14	5	11
Rear Bulkhead	11	25	28	3	7	8	18
Liners (Comp)	122	270	0	0	0	122	270
Attach Ring	13	29	45	6	13	7	16
Brackets, Clips	20	45	30	6	14	14	31
Fasteners	14	30	0	0	0	14	30
Diffuser Ring	17	37	19	3	7	14	30
Inlet Total	(287)	(635)	(18)	(52)	(117)	(235)	(518)
Cowl Door Skins	39	85	35	10	23	29	62
Core	24	54	0	0	0	24	54
Hardware and Supts	75	166	11	9	19	66	147
Doors and Supt Total	(138)	(305)	(14)	(19)	(42)	(119)	(263)
Trans Cowl Skins	73	160	32	23	50	50	110
Main Ring	19	41	24	3	7	16	34
Rings	8	18	33	2	4	6	14
Fasten, Misc	48	107	0	0	0	48	107
Trans Cowl Total	(148)	(326)	(19)	(28)	(61)	(120)	(265)
Fan Nozzle Liners	99	218	33	33	73	66	145
Fan Nozzle Out Shell	57	125	39	22	49	35	76
Fan Nozzle Ring	10	22	45	5	10	5	12
Fan Nozzle Total	(166)	(365)	(36)	(60)	(132)	(106)	(233)

TABLE 12

WEIGHT MIXED FLOW WIDE BODY

PART	METAL		SAVING			COMPOSITE	
	KG	LB	%	KG	LB	KG	LB
Tail Cone Out Shell	23	50	26	6	13	17	37
Acoustic Treat	162	358	0	0	0	162	358
Aft Cone	51	112	0	0	0	51	112
Tail Cone Total	(236)	(520)		(6)	(13)	(230)	(507)
Gas Gen Cowl	157	(347)	5	(7)	(17)	150	(330)
Reverser Structure	157	347	26	41	90	116	257
Blocker Doors	110	243	15	16	36	94	207
Cascades	73	161	10	7	16	66	145
Hoop Plate	29	64	25	7	16	22	48
Fairings	73	161	30	22	48	51	113
Firewall	73	160	0	0	0	73	160
Actuators, Ducts	87	197	0	0	0	89	197
Reverser Total	(604)	(1333)	(15)	(93)	(206)	(511)	(1127)
Tail Pipe	(92)	(204)	0	0	0	(92)	(204)
Total Fwd	426	940	17	72	159	349	781
Total Aft	1403	3095	14	195	429	1208	2666
Total/Wing Pod	1830	4035	15	267	588	1563	3447
Total/Airplane	5062	11165	14	728	1605	4334	9560
ΔWt/Airplane Refer Base	1421	+3135				694	+1530

TABLE 12 (CONTINUED)

ATT PRELIMINARY DESIGN WEIGHT SUMMARY

ITEM	METAL KG (LB)	% SAVED	COMPOSITE KG (LB)
Inlet	297 (654)	29	210 (464)
Cowl Door and Supt	102 (225)	14	88 (194)
Translating Cowl	91 (200)	25	68 (150)
Fan Nozzle	213 (470)	0	213 (470)
Thrust Rev, Fair, Gas Gen Cowl, Misc.	576 (1270)	15	490 (1080)
Tail Pipe	213 (470)	0	213 (470)
Total Fwd	399 (879)	25	298 (658)
Total Aft	1093 (2410)	10	984 (2170)
Total/Nacelle	1492 (3289)	14	1282 (2828)
Total/Airplane	4077 (8988)	13	3550 (7826)
Change from Baseline	1235 (2723)		708 (1561)

TABLE 13

SECTION 10

MANUFACTURING & REPAIR

Composite materials are more expensive than metal and require different tools and processes. The effects of these factors on the cost of manufacturing the structural elements and the suppression panels are examined in this section. The same factors affect the cost of making repairs, as does the frequency with which repairs are required. Some test data leading to design suggestions to minimize the need for repairs is presented.

10.1 MANUFACTURING COSTS

10.1.1 Primary Structure

Evaluating the labor costs involved in manufacturing requires identifying the operations involved and estimating the time required for each. This in turn requires a detail design and a definition of each step in the process. As such detail cannot be obtained for the complete nacelle in a preliminary design study, a representative set of parts is selected for analysis. The parts chosen comprise most of the inlet structure and include stiffened skin, built up bulkheads, the attach ring which is machined from a forging, and the cowl doors which are aluminum-faced sandwiches in the baseline design. The characteristics of each part are summarized in Table 14.

The results of this study are shown in Figure 84 in which the changes in weight are plotted against the changes in cost produced by changing to composites. The parts are ranked in order of increasing ΔCost/ΔWt ratio and the cumulative values plotted. All parts yield a weight saving and some a cost saving as well. In general, those parts which require many mechanical fasteners in metal are likely to be less expensive in composites. Parts for which the operations are similar in metal and composites are more expensive in composites, reflecting the higher material costs, e.g. the cowl doors which are sandwiches in both materials. By selecting parts to change, one can minimize manufacturing cost or maximize weight

COST ANALYSIS

1) Outer Skin

Design #1 present design made from .064 skin chem-milled to .040. Four "Z" type aluminum stiffeners, riveted to outer skin.

Design #2 consist of sandwich aluminum core .96 inch thick with .035 outer facing and .020 inner facing made of graphite composite.

Study assumes all access door openings and assembly into nacelle comparable.

2) Cowl Doors

Design #1 present design made from honeycomb sandwich with aluminum face skins and honeycomb core.

Design #2 change face skins to graphite composite of equal thickness as Design #1.

Cost for edge members, access door openings and honeycomb core considered comparable.

3) Forward Bulkhead

Design #1 consists of four (4) assemblies comprising two (2) outer angles made from aluminum, two (2) inner angles made from titanium, with a titanium web, four (4) titanium splice plates, and thirty-five (35) hat stiffeners made from titanium.

Design #2 consists of a .96 HRH 327 3/8 cell honeycomb core with .020 graphite facings. Four (4) .040 graphite angles bonded to honeycomb sandwich. Assumes one (1) complete assembly.

Attachment of assembly into nacelle comparable.

4) Engine Attach Ring

Design #1 fabricated from an aluminum forging. Study assumes machining on vertical turret lathe.

Design #2 fabricated from 30 layers of graphite cloth .010 thick. Assume lay-up in one piece.

5) Cowl Support Structure

Design #1 two (2) titanium beams (R&L) fabricated from sheet metal bonded and spotwelded together and riveted to an upper plate. Eight frames for cowl door attach are riveted to assembly.

Design #2 made from .050 and .030 graphite parts. End supports and attach fittings not included in this study.

#1 = Baseline
#2 = Composite

TABLE 14

6) Rear Bulkhead

Design #1 fabricated from two (2) webs, twenty-two (22) hat sections, sixteen (16) "Z" stiffeners made of titanium and four (4) coaming angels made from aluminum.

Design #2 honeycomb sandwich .96 HRH 327 honeycomb 3/8" cell with .020 graphite face sheets coaming fabricated from .040 thick graphite cloth.

Area between 30°, 0°, 330° and approximately 150° thru 210° and attach points was not costed.

7) Transverse Cowl

Design #1 assumed to be made of four (4) assemblies consisting of one (1) inner and one (1) outer skin, three (3) sheet metal sections bonded together. This assembly is riveted to five (5) webs, eight (8) angles and one (1) close out.

Design #2 made from one (1) 7" thick piece MRP type honeycomb core with .050 facing skins (graphite) and one (1) close out ribs.

Installation of four (4) assemblies considered the same in both designs.

Additional Premises and Assumptions

- Delta labor costs factored by 1.20 to allow for contingency and scrap.
- Delta material costs factored by 1.35 to allow for contingency and scrap.
- Graphite linear tape estimated $20/lb.
- Graphite cloth estimated at $23/lb.
- Labor costs for graphite based on ECH data. Material costs based on Procurement tapes and Timet Price List.
- All costs are rough order of magnitude.

#1 = Baseline
#2 = Composite

TABLE 14 (CONTINUED)

COMPOSITE STRUCTURE-COST VS WEIGHT

(RECURRING COSTS)

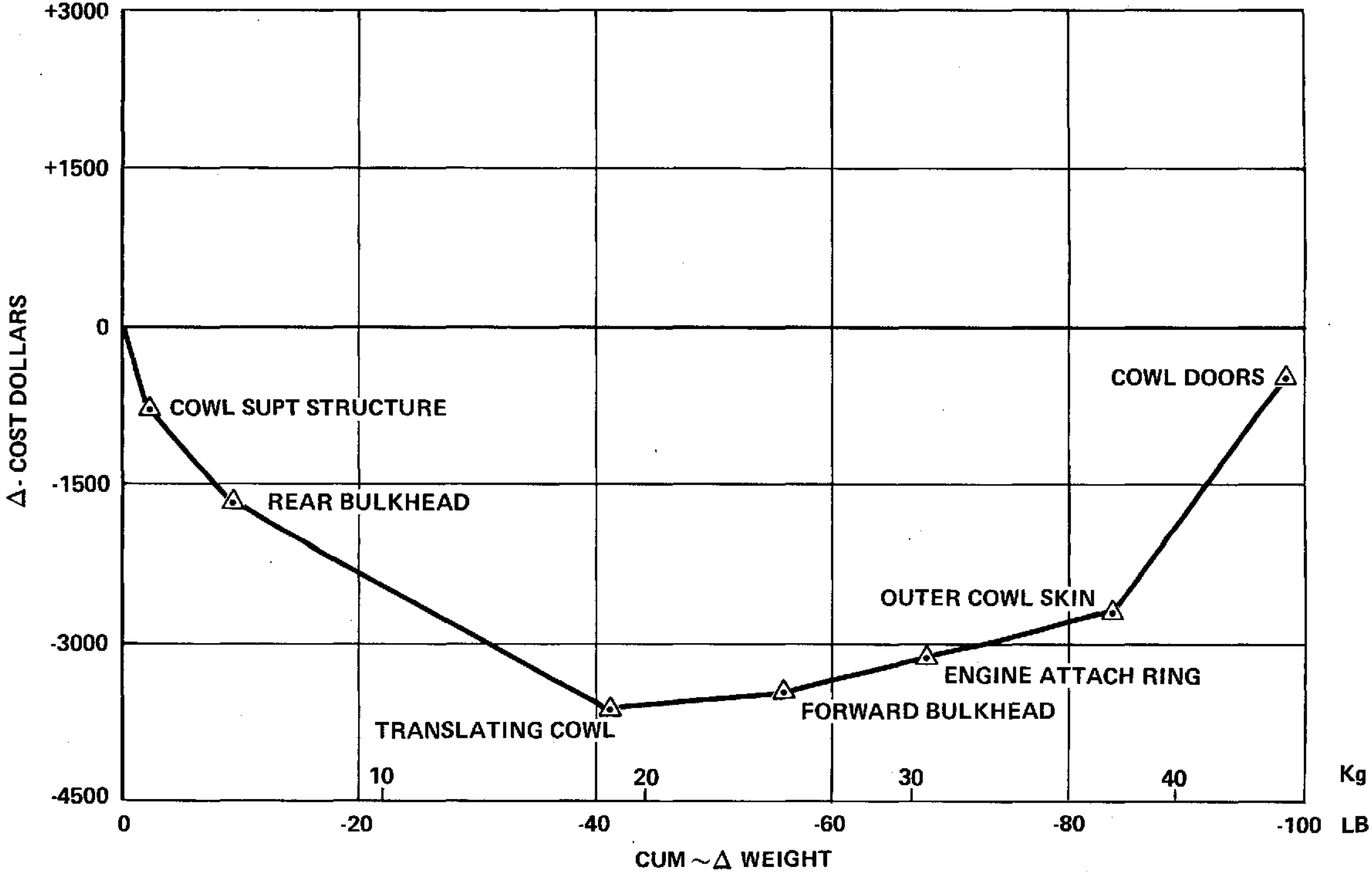


FIGURE 84

savings. It is concluded that maximum weight savings are possible with no significant effect on manufacturing cost.

10.1.2 Suppression Panels

The inlet liners designed for broadband attenuation incorporate two features that, with present technology, are more costly than the baseline honeycomb core with perforated face sheets. The "Permoblique" liner, Figure 76, derives its characteristics, and name, from the oblique core members; inserting these members require additional shop operations. Both the oblique members and the face sheets must have high acoustic resistance and linearity for this application and the felted metal materials with these characteristics are expensive. It is estimated that the basic Permoblique liner without provision for edge attachments would cost $150 per square foot, about five times the baseline value. The bulk of the increase is in material cost.

Sample liners supplied by Woven Structures Division of HITCO have exhibited the desired resistance and a degree of linearity better than perforates, but not as good as felted metal. It is anticipated that with a reasonable development effort, liners with the desired characteristics can be available at competitive prices.

10.2 REPAIR

Major sources of damage requiring repairs in static metal structure are corrosion, fatigue cracks, impact damage from rocks and hail, and accidental damage. Composites show good resistance to "corrosion," reaction to chemicals in the aircraft environment, although this remains to be demonstrated in service. Resistance to fatigue cracks is also typically good for composites in the laboratory, but remains to be demonstrated in service for the acoustic environment of the nacelle. Definitive laboratory tests for the durability of composites under impact and accidental damage are more difficult to define, and some published data indicates sensitivity to a number of failure modes. As the static load requirements for the nacelle result in minimum gages for many members, design for durability becomes the governing criterion. To ensure that the composite structure would attain the durability levels of the metal structure, the panels described in Figure 85 were subjected to impact tests. Both blunt and sharp objects were dropped through cardboard tubes to control the impact point. A 1.9 pound steel weight with a nose

TEST PANELS

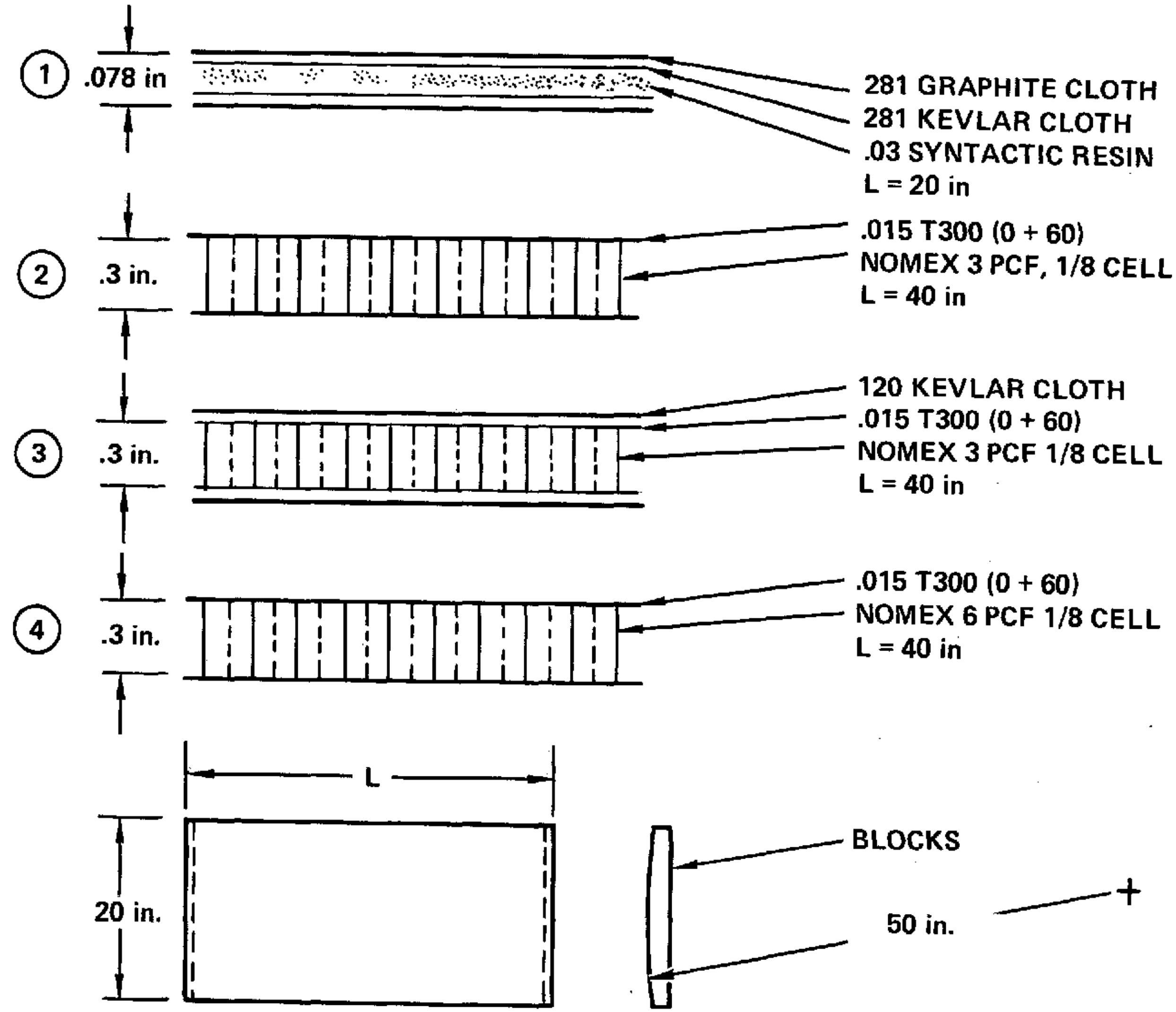


FIGURE 85

radius of .75 inch was the "blunt" object; a 4 oz screw driver the "sharp" object. The wooden clamps used to support the panels were set at the length L to represent the ring spacing anticipated for each panel. The response of the panel is a function of its stiffness; impacts in the center of a panel are less damaging than impacts close to a support. All panels were first subjected to center impacts, the only composite panel undamaged by impacts in the center was subjected to impact at the edge.

The results of the blunt object drops are summarized in Figure 86. The ordinate shows the depth of the local depression at the point of impacts. The aluminum panels were supported by clamps spaced 20 cm (8 in) apart to simulate the ring spacing. Both aluminum panels were permanently buckled over the 20 cm (8 in) span, and this buckle was pronounced in the .64 mm panel. The energy absorbed by forming the large buckle is believed to account for the smaller local deformation observed in the .64 mm as compared to the 1 mm. Panel #1 was not perceptibly damaged by the center drops up to 17 Nm (150 in.lb.) energy. The edge drop of 5.2 Nm (46 in.lb.) left a slight mark, but no delamination could be detected by a tap test. Higher energy edge impacts produced visible damage and delamination. This panel is shown in Figure 87. All of the sandwich panels indicated delamination at the 2.6 Nm (23 in.lb.) impact, but the damage was difficult to detect visually.

The screw driver dropped from 1.5 m (5 ft) produced slight scratches on the aluminum panels, and no visible damage on panel #1. On the sandwich panels, the screw driver penetrated the face sheet when dropped from 1.5 m (5 ft). Dropped from 0.6 m (2 ft), the screw driver punctured panel #2 and produced scratches on #3 and #4.

The tests indicate that panels of type #1 are equivalent to the 1 mm (0.040 in) aluminum in likelihood of encountering damage that requires repair. The nature of the damage is quite different, however. A dent in aluminum is visible but not structurally critical. A local delamination in composites may be difficult to locate, and its propensity to spread is unknown at this time. In this respect the sandwich panels appear to be more sensitive than the solid type.

The tests suggest:

- Panels of type #1 should be used on nacelle outer surfaces.
- Rapid reliable inspection techniques are required.
- Rapid on airplane repair techniques should be available for local damage.
- A fail-safe s-ructure is desirable.

PANEL IMPACT TESTS

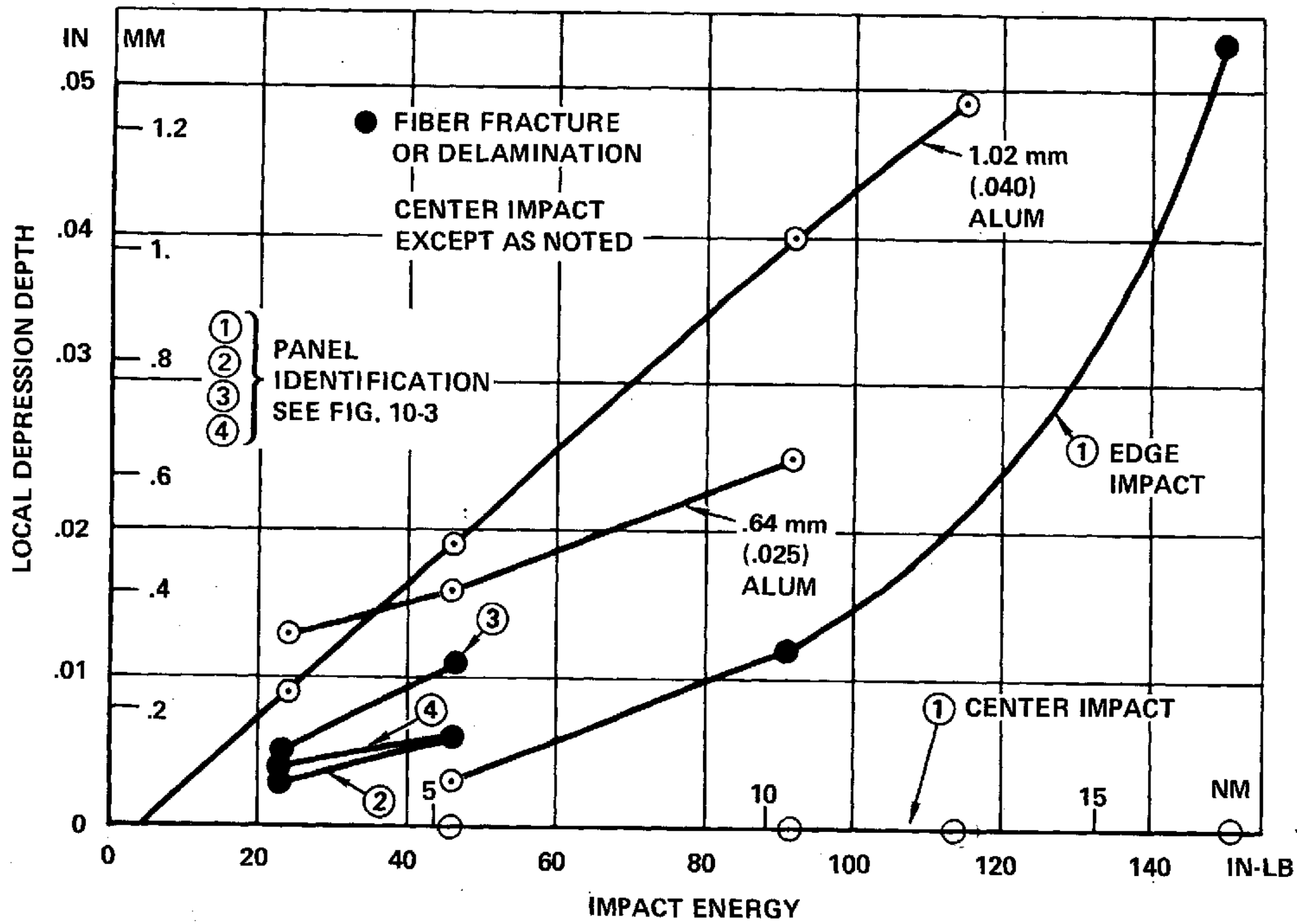


FIGURE 86

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TEST PANEL NO. 1

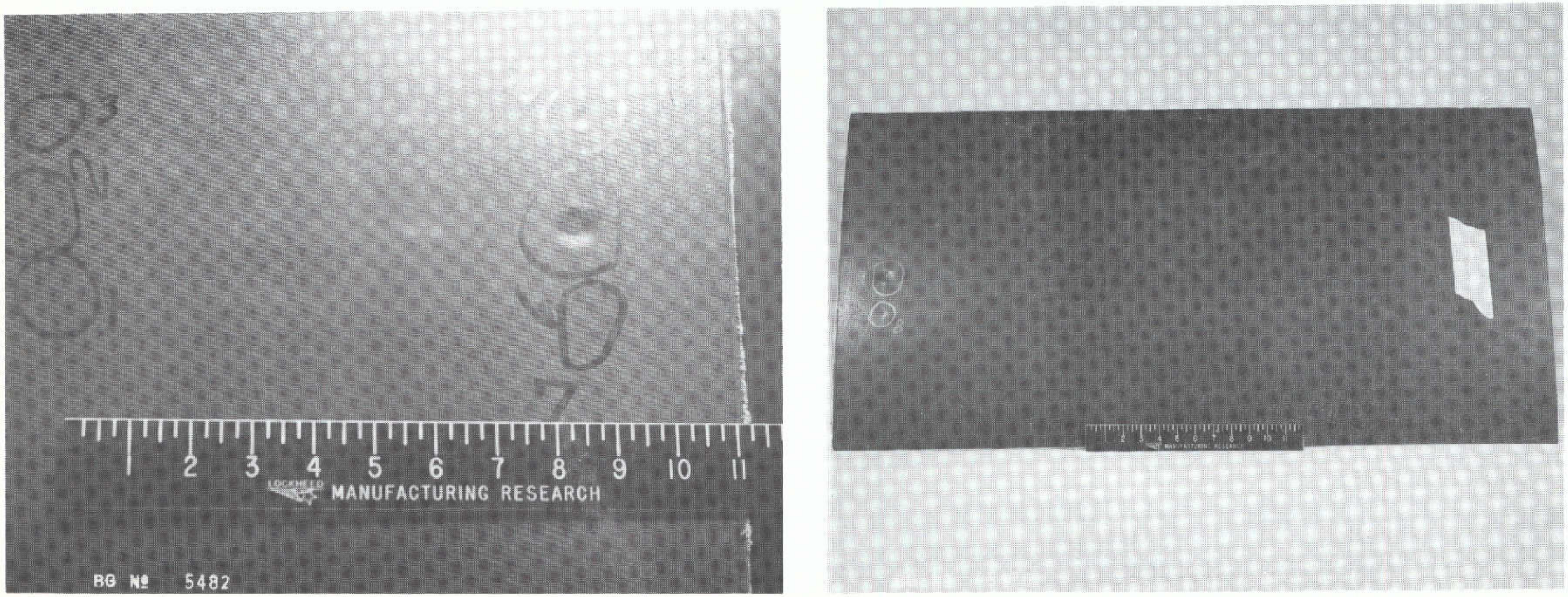

FIGURE 87

SECTION 11

ECONOMIC EVALUATION

The effects on direct operating cost (DOC) and on return on investment (ROI) are used to evaluate alternate component designs, nacelle configurations, and finally to indicate the price of noise reduction. As the application of the acoustic-composite nacelle to the wide body transport is treated as a production change to an existing aircraft without change to the basic airframe, while the ATT application is treated as a design change influencing all components, the costing techniques differ. This section first presents the techniques and input data used for each aircraft. The sensitivity of DOC to each of the major design variables and trade-off relationships which may be used as a basis for design decisions are derived. The DOC and ROI of the acoustic composite nacelles configured in metal, in composites, and for maximum fuel saving are then compared with the baseline value.

The comparisons of DOC and ROI are shown for fuel prices of 3.44, 6.87, 10.3 and 13.7¢/liter (13, 26, 39 and 52¢/gallon). The sensitivity factors used for design decisions are shown for 10.3¢/liter (26¢/gallon) fuel only as this is considered to be closest to the probable price of fuel in the early 1980's. The cost factors are shown for both the design range of 5556 km (3000 n mi) and 1852 km (1000 n mi).

11.1 ANALYSIS METHOD

11.1.1 Basic Cost Data

The cost factors used in the calculation of DOC are listed in Table 15. These factors are obtained from airline experience through the reported CAB data on wide body aircraft and the United Airline assessment of the ATT study (Reference 15). The first step in deriving the DOC factors was to check the ATA DOC formulas against the CAB reported data on wide body aircraft. With the application of the factors listed in Table 15 the calculated DOC for the wide body aircraft comes reasonably close

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DOC COST FACTORS

	CURRENT WIDEBODY	ATT BASELINE STANDARD NACELLES)	QUIET NACELLE ATT
CREW INFLATION RATE	11.5% PER YEAR	11.5% PER YEAR	11.5% PER YEAR
INSURANCE RATE (% OF AIRPLANE PRICE)	1%	0.9%	0.9%
DEPRECIATION	15 YEAR, 10% RES.	15 YEAR, 10% RES.	15 YEAR, 10% RES.
SPARES (% OF AIRFRAME & ENG. PRICE)	10% AIRFRAME, 35% ENG.	10% AIRFRAME, 35% ENG.	10% AIRFRAME, 35% ENG.
FUEL (CENTS/LITER)	3.44, 6.87, 10.3, 13.7	3.44, 6.87, 10.3, 13.7	3.44, 6.87, 10.3, 13.7
(CENTS/GALLON)	13, 26, 39, 52	13, 26, 39, 52	13, 26, 39, 52
UTILIZATION (HRS/YEAR)			
5556 km (3000 N.MI.)	3285	3600	3600
1852 km (1000 N.MI.)	–	3000	3000
MAINTENANCE BURDEN	1.8	1.8	1.8
MAINTENANCE LABOR	$6.00/HOUR	$6.00/HOUR	$6.00/HOUR
MAINTENANCE FACTORS			
ENGINE			
CYCLE	60% OF ATA	ATA	120% OF ATA
HOURLY	75% OF ATA	ATA	120% OF ATA
AIRFRAME			
CYCLE	60% OF ATA	120% OF ATA	120% OF ATA
HOURLY	75% OF ATA	120% OF ATA	120% OF ATA

TABLE 15

to the reported data. The maintenance adjustment factors for the widebody aircraft are a result of an in-house maintenance analysis augmented by maintenance data received through a maintenance monitoring system established with the airlines. The maintenance factors are applied to the results as obtained from the standard ATA maintenance equations to bring the maintenance cost in line with airline experience. The primary concern with the ATT configuration, in terms of maintenance, is the influence of the composites on maintenance techniques, and costs. The recommendations of United Airlines as outlined in the ATT assessment study are used to derive the factors shown in Table 17 The baseline ATT has standard nacelles without the materials for quieting and the maintenance factors are increased to lesser values than those for the quiet nacelles.

The Indirect Operating Cost (IOC) is calculated by a set of equations which relate the indirect expense of the system to several system parameters. The IOC model is a culmination of effort by Boeing and Lockheed and is described in Reference 16. The indirect expense factors that are applied to the system parameter to arrive at the indirect expense are derived from the indirect expense accounts for the domestic airlines. The indirect expense factors used in this study are weighted averages for the eleven domestic airlines. The method for deriving these expense factors is described in Reference 17.

The IOC elements, system parameters and expense factors are shown in Table 16. The return on investment (ROI) is determined by the following formula:

$$ROI = \frac{(TOTREV - TOTEXP - INT)(1-TAXR) + INT}{BVINV}$$

where:

TOTREV	=	total revenue
TOTEXP	=	total expense (DOC + IOC)
INT	=	interest paid on load (12%)
TAXR	=	tax rate (48%)
BVINV	=	book value of investment

The amound of interest paid is determined from the debt to equity ratio assumed for the airline, (60/40), the interest rate, and the purchase cost for the equipment plus spares and ground equipment. The book value for the investment is defined as the purchase cost of the investment less the depreciation. The amount of depreciation for each vehicle is determined from the depreciation period and the number of

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IOC MODEL

IOC ELEMENTS	SYSTEM PARAMETERS	EXPENSE FACTORS
SYSTEM EXPENSE	DIRECT MAINTENANCE LABOR DOLLAR	0.53
LOCAL EXPENSE	DEPARTURES & TOGW	1.45
AIRCRAFT CONTROL	DEPARTURES	20.0
HOSTESS ACTIVITY	CABIN CREW BLOCK HOURS	22.0
FOOD AND BEVERAGE	PASSENGER BLOCK HOURS	0.85
PASSENGER SERVICE	PER ENPLANED PASSENGER	5.0
CARGO HANDLING	PER TON OF CARGO	67.0
OTHER PASSENGER EXPENSE	REVENUE PASSENGER MILE	0.0045
OTHER CARGO EXPENSE	FREIGHT TON MILE	0.0072
G & A	TOTAL OPERATIONS COST LESS DEPRECIATION & INSURANCE	0.055

TABLE 16

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COST PREMISES

PRODUCTION COST

- MID 1974 DOLLARS
- PRODUCTION QUANTITY - 400 AIRPLANES
- AVIONICS COST - $600,000
- COMPOSITE MATERIAL $44.1/kg ($20/LB)

OPERATIONS COSTS

- DOC - ATA METHOD, AIRLINE DATA, UAL STUDY
- IOC - AIRLINE DATA

TABLE 17

depreciating years as calculated from the delivery schedule and the span of years (10) used in the ROI calculation.

The cost premises used are summarized in Table 17.

11.1.2 Widebody Aircraft Cost Increments

The DOC increments for the widebody transport are calculated from the increments in airplane weight, cost, and specific fuel consumption resulting from nacelle changes as no adjustments in basic airplane characteristics are considered for a production change. As changes in airplane weight and drag require corresponding changes in wing, thrust and fuel to just maintain the design performance, the procedure used is tantamount to assuming that the aircraft is not operated exactly at its design point. The assumed condition is representative of practical operations, since the weight and drag increments being considered are small compared to the total aircraft values.

The elements of the DOC for the two ranges considered are shown in Table 18. The effect of various fuel prices is also shown. The other elements are not affected by fuel cost. For each nacelle, the effect of changes in specific fuel consumption and the change in fuel required by weight changes are both applied to the fuel cost. Insurance and depreciation are function of cost, and nacelles of conventional technology are costed at \$80/lb. Maintenance includes both labor and materials. Nacelles of comparable material but differing in size are charged with maintenance costs in proportion to their weight.

The change in ROI is found from the percentage change in DOC by the factors:

Fuel Cost ¢/kg (¢/Gal)	3.44 (13)	6.87 (26)	10.3 (39)	13.7 (52)
$\frac{\Delta ROI}{\Delta DOC\%}$	-0.13	-0.16	-0.19	-0.22

11.1.3 ATT Aircraft Cost Increments

The effects of alternate nacelles on the DOC and ROI of the ATT aircraft are calculated by the Lockheed Advanced Systems Synthesis and Evaluation Techniques (ASSET) program. ASSET is a computer program with coupled airplane performance, weight, engine performance and costing routines. Given the basic airplane and engine characteristics and the mission constraints, the program sizes the airplane to perform the mission and calculates the airplane component weights, costs, fuel

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WIDEBODY BASELINE DOC

		DOC $/KM ($/N MI)							
RANGE KM (N MI)		5556 (3000)				1852 (1000)			
FUEL COST	¢/LITER	3.44	6.87	10.3	13.7	3.44	6.87	10.3	13.7
	¢/GAL	13	26	39	52	13	26	39	52
Crew		.369 (.685	→	→	→	.408 (.756)	→	→	→
Fuel		.371 (.688)	.743 (1.376)	1.114 (2.064)	1.486 (2.752)	.385 (.713)	.770 (1.426)	1.155 (2.139)	1.540 (2.852)
Insurance		.0696 (.129)	→	→	→	.0837 (.155)	→	→	→
Depreciation		.500 (.927)	→	→	→	.604 (1.119)	→	→	→
Maintenance		.377 (.699)	→	→	→	.500 (.926)	→	→	→
Total $/km ($/n mi)		1.689 (3.128)	2.060 (3.816)	2.432 (4.504)	2.803 (5.192)	1.981 (3.669)	2.366 (4.382)	2.751 (5.095)	3.136 (5.808)

TABLE 18

consumption, and DOC. The basic data used is tabulated in Tables 19 and 20. The summary printouts are reproduced in Appendix D.

11.2 DOC SENSITIVITY

The typical design problem requires achieving a proper balance of such conflicting requirements as aerodynamic shape and smoothness, weight, cost, and accessibility. One technique for making rational choices is to determine the effect of each parameter on cost and to seek a combination that minimizes DOC. The sensitivities used for this purpose are developed from the DOC calculations and relate specific fuel consumption (SFC), weight, cost and maintenance to DOC. The DOC sensitivities are used to develop the weight-SFC, weight-cost, and weight maintenance relationships. The range in parameters considered is representative of the range encountered in the various versions of the mixed flow acoustic-composite nacelle.

Fuel Consumption Sensitivity

The cost of fuel is a major element of the DOC, so the sensitivity of fuel consumption to changes in weight and SFC is an important factor in evaluating various nacelle configurations. The objective is to obtain sensitivity factors that may be used in trade-off studies to obviate making a mission analysis for each set of circumstances. To select suitable sensitivity factors, mission analyses are made for some of the most likely situations and the effects on fuel evaluated. The situations considered are:

- A: Baseline airplane with a takeoff gross weight (TOGW) of 195,048 kg (430,000 lb).
- B: An increase in SFC of 1% with TOGW held at the baseline value. The empty weight is reduced to accommodate the increase in fuel weight.
- C: An increase in SFC of 1% with the empty weight and payload held at the baseline value. The TOGW is increased to accommodate the increased fuel, but no provision is made for increased structure or thrust.
- D: A reduction in empty weight of 454 kg (1000 lb). The TOGW is reduced by both the change in empty weight and the change in fuel required.
- E: An increase in SFC of 1% combined with an increase in empty weight of 454 kg (1000 lb). The TOGW is increased by the change in empty weight and by the increased fuel, but no increase in structure or in engine weight is provided.

SPECIFIED DATA - ATT

NUMBER OF PASSENGERS	200
CRUISE MACH NO.	.9
DESIGN RANGE	5556 km (3000 nm)
CRUISE ALTITUDE	10973 m (36000 ft)
TAKEOFF FIELD LENGTH	2530 m (8300 ft)
APPROACH SPEED - MAX LAND WT	74.6 m/sec (145 kts)
APPROACH SPEED - END OF MISSION	69.4 m/sec (135 kts)
MAX TAKEOFF WING LOADING PSF	659 kg/m^2 (135 psf)
WING SWEEP 1/4 C	36.5^o
WING ASPECT RATIO	7.6
CRUISE L/D	13.9
STRUCTURE TECHNOLOGY	~10%
AERO TECHNOLOGY	SUPER CRITICAL
ENGINE	STF 433

TABLE 19

MISSION

SEGMENT	SI UNITS	ENGLISH UNITS
WARM UP		.15 HR
CLIMB	129 m/sec TO 3048 m	250 KEAS TO 10,000 FT
ACCELERATE TO	154 m/sec TO 3048 m	300 KEAS 10,000 FT
CLIMB	154 m/sec TO .9M	300 KEAS TO .9M
CLIMB	.9M TO 10973 m	.9M TO 36,000 FT
START CRUISE CLIMB	10973 m	36,000 FT
DESCEND BY REVERSE OF CLIMB PATH		
LANDING ALLOWANCE	.05 HR 457 m	.05 HR 1500 FT.
DOMESTIC RESERVES	370 km + .75 hr LOITER	-200 NM + 45 MIN. LOITER

TABLE 20

In each case the range is 5556 km (3000 n.mi.), the cruise Mach number is .85, and a step-climb cruise beginning at 9449 m (31,000 ft) and ending at 10,668 m (35,000 ft.) is used. The results are summarized in Table 21.

Considering cases A & B, the sensitivity to a 1% change in SFC is affected by the gross weight constraints imposed; however, using the nominal value of 1% of the baseline fuel used, i.e., 490 kg (1080 lb) per 1% change in SFC is reasonably accurate.

Case D indicates that a 454 kg (1000 lb) decrease in OWE results in a 91 kg (200 lb) saving in fuel burned. Considering case E in which both OWE and SFC are increased, the increase in fuel burned is 658 kg (1450 lb). Charging 490 kg (1080 lb) of this increase to the SFC change leaves 168 kg (370 lb) to be charged to the change in OWE. Noting that the fuel sensitivity corresponding to a constant fuel fraction* is .335 (Δwt), which is between the extremes of examples D and E, suggests the use of this value for tradeoff purposes.

The DOC vs SFC and DOC vs weight sensitivities plotted in Figure 88 are based on the sensitivities:

$$\text{SFC:} \qquad \frac{\Delta \text{ Fuel } \%}{\Delta \text{ SFC } \%} = 1$$

$$\text{Weight:} \qquad \frac{\Delta \text{ Fuel}}{\Delta \text{ Wt}} = .335$$

<u>ΔSFC vs DOC</u> - The SFC for the optimized mixer, smooth walls, and advantageous cruise power could decrease 3% from the baseline value. At 6.87¢/liter (26¢/gal) the fuel cost is 0.743$/km ($1.376/n mi); and the possible change is .0223 $/km (0.04128$/n mi) which is 1.082% of the baseline value.

<u>ΔWeight vs DOC</u> - The weight increment per airplane is approximately 1361 kg (3000 lbs) for a metal version of the mixed flow nacelle. The increment in DOC due to the fuel required to carry this weight is 0.00689$/kg (0.012759$/n mi).

$$\text{*Fuel fraction} = \frac{\text{Fuel burned}}{\text{TOGW-Fuel burned}}$$

$$= \frac{48{,}989}{195{,}048-48{,}989} = .335$$

FUEL SENSITIVITY

RANGE 5556 km (3000 nm) M .85 CRUISE

AIRCRAFT		A BASE LINE	B +1% SFC CONSTANT TOGW	C +1% SFC CONSTANT OWE	D -454 kg (-1000 lb) OWE	E +1% SFC +454 kg (1000 lb) OWE
TOGW	kg	195,048	195,048	195,683	194,481	196,273
	lb	430,000	430,000	431,400	428,750	432,700
OWE	kg	108,864	108,365	108,864	108,410	109,318
	lb	240,000	238,900	240,000	239,000	241,000
PAYLOAD	kg	28,214	28,214	28,214	28,214	28,214
	lb	62,200	62,200	62,200	62,200	62,200
RESERVE FUEL	kg	8,981	9,027	9,072	8,959	9,095
	lb	19,800	19,900	20,000	19,750	20,050
FUEL BURNED	kg	48,989	49,443	49,533	48,898	49,647
	lb	108,000	109,000	109,200	107,800	109,450
ΔFUEL BURNED RE BASELINE	kg	0	+454	+ 544	- 91	+ 658
	lb	0	+1000	+1200	-200	+1450

TABLE 21

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DOC SENSITIVITY
WIDE BODY

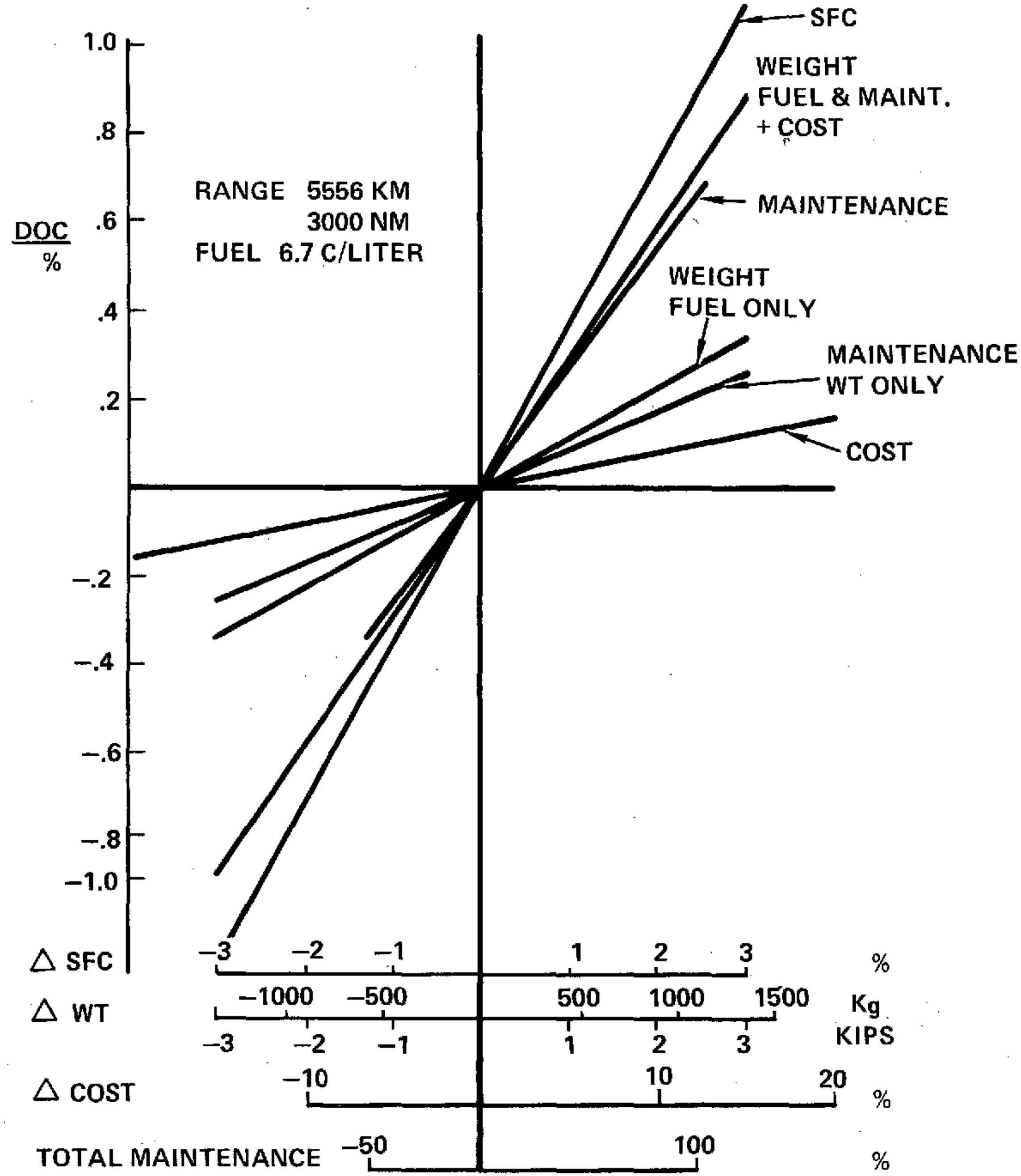

FIGURE 88

This is 0.3343% for 1361 kg (3000 lbs.)

If the weight increment is due to change in size rather than a change in technology, the increased size incurs additional costs. At an average cost for conventional structure of \$176/kg (\$80/lb), the changes in depreciation and insurance for an increase in size of 3000 lbs are:

Depreciation ΔDOC = 0.00518\$/km (0.0096\$/n mi)

Insurance ΔDOC = 0.000740\$/km (0.00137\$/n mi)

TOTAL = 0.00592\$/km (0.01097\$/n mi)

$$\Delta \text{DOC } \% = \frac{0.01097}{3.816} \times 100 = 0.2874$$

<u>ΔMaintenance vs DOC</u> - A change in size with no change in technology incurs changes in both maintenance labor and material. Using the 1361 kg (3000-lb) weight increments as a possible excursion and \$176/kg (\$80/lb) as the cost basis to which the DOC calculations are related:

DOC due to maintenance labor = 0.00269\$/km (0.00498\$/n mi)

DOC due to material = 0.00259\$/km (0.0048\$/n mi)

TOTAL = 0.00528\$/km (0.00978\$/n mi)

which is 0.2563% of the DOC at a fuel price of 6.87¢/liter (26¢/gal)

A similar calculation using the baseline nacelle weight per airplane of 3643 kg (8030 lb) gives the total maintenance charged to the nacelles as .686%. This sensitivity is plotted against per cent in Figure 88 with an excursion from -50% (halving maintenance) to +100% (doubling maintenance).

<u>ΔCost vs DOC</u> - A 20% reduction in cost by the use of composites has been reported in other studies. Using this 20% as a possible excursion and applying it to a cost of \$640,000 per ship set, the depreciation and insurance components of DOC are affected by:

ΔDepreciation = 0.00276\$/km (0.00512\$n mi)

ΔInsurance = 0.000394\$/km (0.0007296\$/n mi)

Total = 0.00316\$/km (0.0058496\$/n mi)

This is 0.1533% @ 6.87 ¢/liter (26¢/gallon)

At \$176/kg(\$80/lb,) a 20% change corresponds to a \$35.3/kg (\$16/lb) change in cost.

Increase in Size vs DOC - An increase in size without a change in technology affects DOC through changes in fuel, cost, and maintenance as calculated above.

$$\Delta \text{DOC due to size} = 0.3343 + 0.2874 + 0.2563 = 0.878\%$$

Design Trades - Tradeoffs between weight, SFC, cost, and maintenance cost are plotted on Figure 89. The trade data are obtained by cross plotting the sensitivities of Figure 88. Only the cost of the fuel used to carry the weight is included, as the purpose is to evaluate alternate materials without changing configuration.

11.2.1 ATT Sensitivities

The sensitivity of ATT direct operating cost to variations in weight, cost, and SFC are determined by running the ASSET program for the baseline with increment changes in each parameter. This calculation gives:

$$\frac{\Delta \text{DOC } \%}{\Delta \text{WT.}} = 0.0003266\% \text{ per kg } (0.72\% \text{ per 1000 lb weight change})$$

$$\frac{\Delta \text{DOC } \%}{\Delta \$} = 0.0033\% \text{ per \$1000 cost change}$$

$$\frac{\Delta \text{DOC } \%}{\Delta \text{SFC}} = 1.8\% \text{ per } \% \text{ SFC change}$$

To illustrate the effect of resizing the airplane to meet the design point, the corresponding weight sensitivity for the wide-body from Table 20 is 0.29% DOC for a 1000 lb weight change. The ratio of 0.72/0.29 reflects a "growth factor" of approximately 2.5.

11.3 COMPLETE NACELLE IMPACT ON DOC AND ROI

11.3.1 Wide Body Nacelles

The total impact of applying composite structures, of reducing noise, and of selecting features to minimize fuel consumption are evaluated by calculating the DOC and ROI for each of five configurations:

- Baseline - metal structure
- Baseline configuration - composite structure
- Mixed flow - metal structure

- Mixed flow - composite
- Minimum fuel

The minimum fuel configuration subordinates noise reduction to minimizing fuel consumption by using the standard length inlet and omitting any acoustic treatment that is not as smooth as a hardwall duct. The high resistance facings used in the cool ducts are smooth, but the mixer and nozzle treatments in the hot regions require perforates, and these perforates are replaced by hard walls for the minimum fuel configuration. The perforated treatment on the center body are retained as the loss is negligible and turbine noise suppression is desired.

The DOC model used in the ASSET model recognizes the influence of airplane size on operating cost by relating maintenance labor to airplane weight and maintenance material costs to airplane costs. In comparing the larger mixed flow metal nacelle to the metal baseline, the larger nacelle presents more area to inspect, more potential trouble spots, and therefore greater maintenance costs. The standard DOC model is, therefore, used to evaluate these costs. In comparing the composite versions of the baseline and mixed flow nacelles with their metal counterparts, however, the nacelle geometry is not changed and composite design details are chosen to preserve the metal standards of durability and accessibility; therefore, the maintenance costs are not changed. The producibility studies indicate that for a broad application of composites the net effect on costs is small, so both metal and composite nacelles are priced at the same cost per pound ($80). As the composite nacelles are lighter, the production cost is lower at the same cost per pound. The characteristics of each nacelle relative to the baseline and to each other are summarized in Table 22. The increment in DOC and the % change from the baseline area summarized in Table 23 for each configuration. The effects of these cost changes on return on investment are summarized in Table 24. The effect of fuel cost is shown on Figure 90.

11.3.2 ATT Nacelles

The effects of the preliminary design nacelle on the direct operating cost and return on investment of the advanced technology transport are determined by resizing the baseline aircraft to account for the changes in specific fuel consumption and nacelle weight. These calculations are performed by the ASSET program described earlier in this section and the summary printouts are collected in Appendix D. The basic inputs and results are summarized in Table 25.

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WIDE BODY DESIGN TRADES

RANGE 5556 Km (3000 NM)
6.87 ¢/liter (26¢/GAL) FUEL

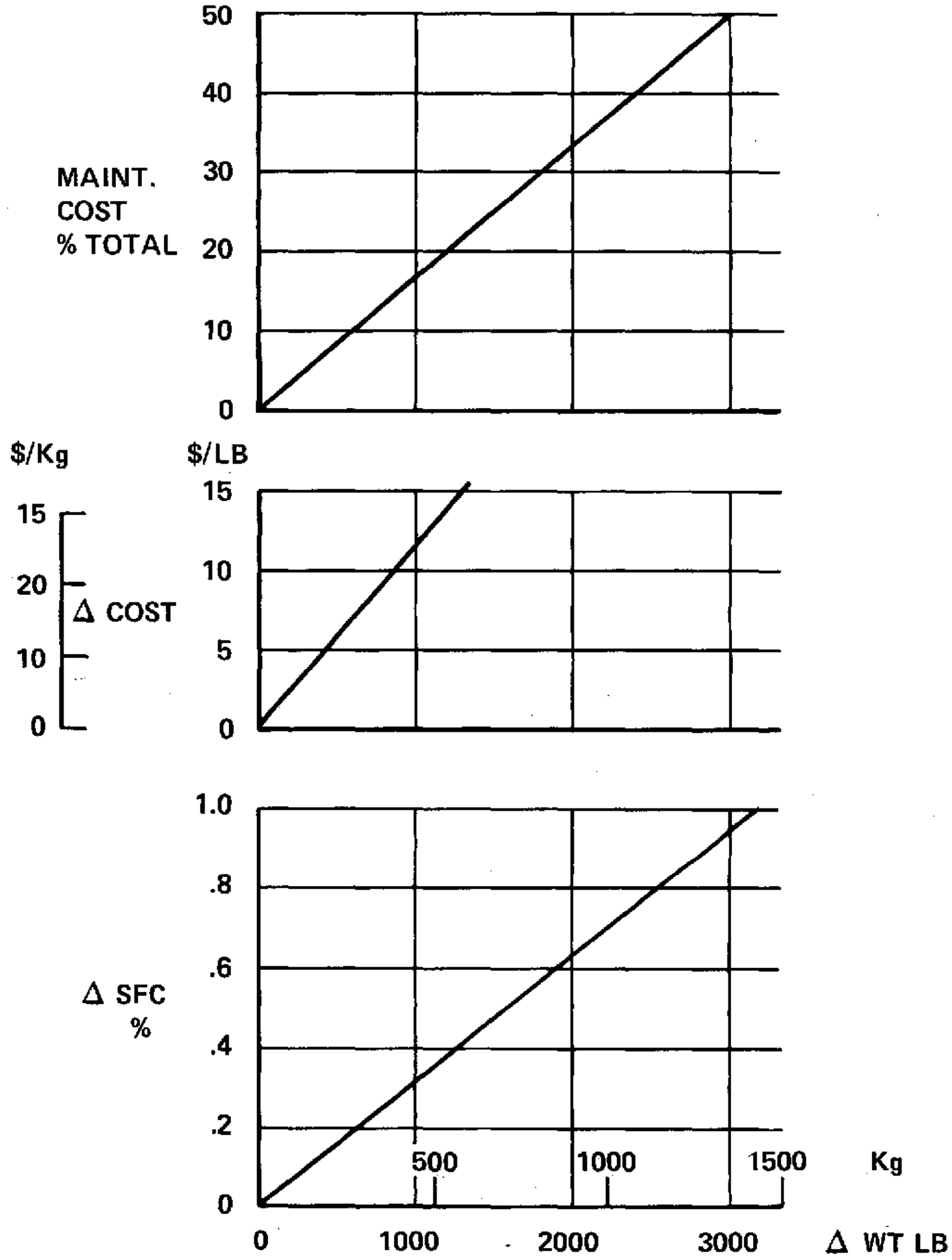

FIGURE 89

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WIDEBODY NACELLES FOR COST COMPARISON

CONFIGURATION	ΔWT PER AIRPLANE KG (LB)	ΔSFC %	ΔCOST $	
Base-Composite	-538.4 (-1187)	0	-94,960	Same size as base. ΔDOC due to fuel saved. ΔCost based on same $/lb, 15% Wt saved.
Mixed-Metal	1422 (+3135)	-.70*	+250,800	Wt due to size increase. ΔDOC include: Fuel, Maint., Cost
Mixed Composite	694 (+1530)	-.70*	+122,400	Wt is 728 kg (1605) less than mix metal. ΔCost is mix metal Δcost less 1605 x 80 = $128,400.
Minimum Fuel	395 (+871)	-1.2**	69,680	Wt is 299 kg (659 lb) less than mix-composite. ΔCost is mix-composite Δcost less 659 x 80 = $52,720

*Smooth fan duct, perforate tail pipe
**Smooth duct and tail pipe

TABLE 22

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WIDE-BODY DIRECT OPERATING COST SUMMARY

DOC IN $/KM ($/NM)

FUEL ¢/LITER COST ¢/GAL		3.44 13	6.87 26	10.3 39	13.7 52
RANGE 5556 KM (3000 NM)					
Baseline	DOC	1.689(3.128)	2.060(3.816)	2.432(4.504)	2.803(5.192)
Base Config Composite	ΔDOC %	-.00367(-.0068) -.2174	-.00502(-.0093) -.2437	-.00637(-.0118) -.2620	-.00777(-.0144) -.2773
Mixed Flow Metal	ΔDOC %	.0127(.0235) .7500	.0137(.0253) .6630	.0146(.0271) .6020	.0157(.029) .5590
Mixed Flow Composite	ΔDOC %	.0077(.0143) .4572	.0068(.0127) .3328	.0060(.0111) .2464	.0052(.0096) .1848
Min. Fuel	ΔDOC %	.0037(.0070) .227	+.0003(+.0006) +.016	-.0023(-.0058) -.129	-.0065(-.0121) .233
RANGE 1852 KM (1000 NM)					
Baseline	DOC	1.981(3.6690)	2.366(4.3820)	2.751(5.095)	3.1361(5.8080)
Base Config Composite	ΔDOC %	-.0037(-.0070) -.1908	-.0052(-.0097) -.2214	-.0067(-.0124) -.2434	-.0081(-.0150) -.2583
Mixed Flow Metal	ΔDOC %	.0128(.0237) .6459	.0139(.0258) .5888	.0151(.0279) .5476	.0162(.0300) .5165
Mixed Flow Composite	ΔDOC %	.0077(.0143) .3898	.0069(.0127) .2898	.0060(.0112) .2198	.0052(.0097) .1670
Min Fuel	ΔDOC %	.0032(.0068) .1853	+.0001(+.0002) .0046	-.0034(-.0064) -.1256	-.0069(-.013) -.2238

TABLE 23

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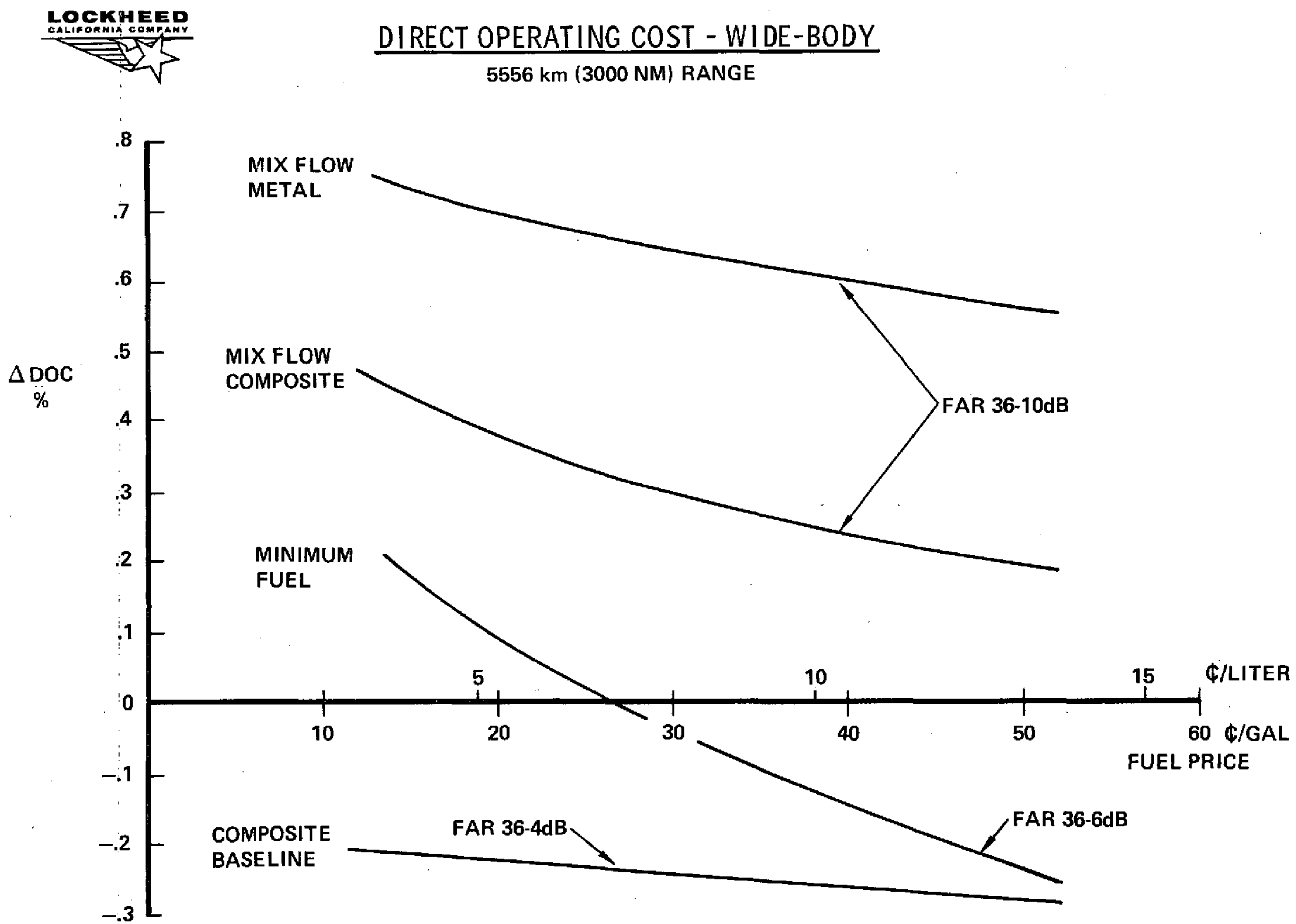
ECONOMIC EFFECT

RANGE 5556 km (3000 NM) – FUEL @ 6.9 c/LITER (26 c/GAL)
BASELINE EPNL FAR 36–4dB
WIDE BODY

		CHANGE FROM METAL BASELINE		
CONFIGURATION	BASELINE	MINIMUM FUEL	MIX FLOW	MIX FLOW
MATERIAL	COMP	COMP	COMP	METAL
EPNL △ dB	0	-2	-6	-6
SFC %	0	-1.2	-0.70	-0.70
NACELLE WEIGHT/AIRPLANE kg	-538	395	694	1422
NACELLE WEIGHT/AIRPLANE LB	-1187	871	1530	3135
FUEL FLOW %	-0.35	-0.94	-0.25	+0.23
DIRECT OPERATING COST $/km	-0.0050	-0.00032	0.00686	0.0136
DIRECT OPERATING COST $/NM	-0.0093	+0.0006	0.0127	0 0253
DIRECT OPERATING COST %	-0.244	+0.016	0.333	0.663
RETURN ON INVESTMENT △ %	0.0390	-0.0025	-0.0532	-0.1061

TABLE 24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DIRECT OPERATING COST - WIDE-BODY
5556 km (3000 NM) RANGE
Δ DOC %
.8
.7
.6
.5
.4
.3
.2
.1
0
-.1
-.2
-.3
MIX FLOW METAL
MIX FLOW COMPOSITE
MINIMUM FUEL
COMPOSITE BASELINE
FAR 36-10dB
FAR 36-6dB
FAR 36-4dB
5
10
15
¢/LITER
10
20
30
40
50
60 ¢/GAL
FUEL PRICE

FIGURE 90

EFFECT ON COST & RETURN ON INVESTMENT - ATT

RANGE 3000 NM FUEL @ 26 c/GAL

	CHANGE FROM BASELINE
SPECIFIC FUEL CONSUMPTION	1.7%
NACELLE WEIGHT PER AIRPLANE	708 kg(1561 LB)
AIRPLANE GROSS WEIGHT	3010 kg(6635 LB)
DIRECT OPERATING COST	0.033$/kg(0.062 $/NM)
DIRECT OPERATING COST	2.0%
RETURN ON INVESTMENT (Δ %)	-0.38%

TABLE 25

SECTION 12

TECHNICAL DEVELOPMENT

The technology developments required to provide a firm basis for the initiation of production designs realizing the cost, fuel and noise reductions indicated above consist of refinements and extensions of the present state of the art in acoustics, propulsion and structural areas. Neither breakthroughs nor fundamental research is required. The specific items requiring further development are discussed below.

12.1 ACOUSTICS TECHNICAL DEVELOPMENT REQUIREMENTS

The specific noise reduction analyses and tests that should be performed before finalizing the production acoustic-composite nacelle designs for the wide-body and ATT aircraft include consideration of fan inlet, fan duct and turbine noise.

12.1.1 Fan Inlet Noise

The recommended acoustical treatment is a deep broadband liner with a linear facing sheet and a resistance of approximately 5 ρc. The present analysis of this treatment has the following uncertainties:

1. A liner with the noted characteristics has not been experimentally demonstrated.

2. If the recommended acoustical treatment liner incorporating the best linear material (fine fibered felt metal) performs satisfactorily in an experimental demonstration, then it is highly desirable to demonstrate whether a more practical material (woven non-metallic fiber) of somewhat less linearity can give satisfactory performance at less weight.

3. The recommended inlet liner is based on a solution to the convected wave equation which does not include the presence of sheared flow. However, a very recent extension of the associated computer program to include boundary layer effects indicates that when the noise attenuation is averaged over all modes (on an equipartition of energy basis) the optimum impedance is only slightly less than that predicted for a zero thickness boundary layer.

4. Hard to attenuate (low order) modes may be present. Such modes were considered but not included in the mathematical model.

5. Effect of grazing a flow on acoustical impedance of high resistance liners may differ from that predicted.

6. Contamination by dust, oil, etc, may modify the acoustical impedance.

The following are the actions recommended to reduce the noted acoustical performance risks.

1. An item of first priority is to demonstrate that an engine inlet liner of the type recommended (with the most linear facing sheet material available) will perform as predicted. The experimental test facility must make provisions for eliminating the distortion noise problems that are present with static engine tests. Possible means are indicated in paragraph 12.1.1.1.

2. Flow bench tests are adequate for determining linearity per se, but what must be determined for non-metallic liners is the amount of deviation from linearity which can be tolerated. This can be done only by performing tests such as indicated in (1) and possibly evaluating woven material of differing porosity.

3. Analytical work on sheared flow should continue but experimental demonstrations should also be conducted. For more fundamental studies, a mode synthesizer could be employed to examine behavior of individual modes as a function of boundary layer thickness. Experiments of greatest practical value would employ a scaled model fan or full-scale engine with static test effects removed. A long experimental inlet should be used. Boundary layer at the liner face can be varied by locating an inlet liner segment (which is perhaps 1/4 as long as total inlet length) at various axial positions. Other possibilities for varying boundary layer depth include upstream wall roughening with grit or using boundary layer bleed.

4. Analytical studies should continue with the goal of estimating the strength of various modes excited by blade/vane interactions. Model studies, such as described in paragraph 12.1.1.1 should be performed to verify predictions.

5. Grazing flow effects can be investigated by using flow duct facility and impedance tube tests. Studies of this type have been in progress at Calac for several years. The approach involves first measuring the acoustical impedance of materials with standing wave apparatus and a flow bench, and then predicting the performance in a flow duct by wave equation solution. Comparisons between flow duct measurements and predictions provide a means for determining grazing flow effects on impedance (see Appendix B).

6. Contamination effects can be best evaluated by testing material in the intended service environment. It is, of course, possible to subject materials to dirty environments in the laboratory, evaluate, clean, evaluate, but correlation with service conditions is difficult.

12.1.1.1 Inlet Noise Suppression Validation Tests

A common requirement for most of the studies recommended for development and evaluation of the proposed inlet noise suppression systems is that the experimental approach be designed to produce the types of noise sources that occur during flight and to avoid the introduction of spurious sources associated with static testing. The importance of this requirement can hardly be over emphasized. Virtually all previously conducted quiet nacelle programs have failed to accomplish an adequate simulation of the aerodynamic and acoustical conditions that exist in flight. As a result the usefulness of the test results has been seriously diminished.

A consideration of current and projected state of the art in providing the required experimental capability and of the potential costs involved has led to the recommendation of a two phase program, designed to provide a validation of the inlet suppression concept that has evolved from this study. Phase I would involve the use of a scale model powered nacelle installed in the test section of the Acoustic Research Tunnel (ART) at the United Aircraft Research Laboratories. This will provide, at very low cost, a means for simulating the in-flight environment. These test results can be used to validate the analytical approach developed at Pratt and Whitney for predicting the strength of various important duct modes. Furthermore, it will be possible to introduce scale model linings in the flow passage(s) of the model nacelle. These linings will provide linear performance, a broadband absorption characteristic, and can be tailored to provide the required resistive and reactive impedance. Confidence in the successful application of scaled linings to the model nacelle is based on their use in many previous scale model studies at Lockheed where the requirements were similar.

At the successful completion of Phase I, a full-scale experimental program, based on a survey of potential approaches will be initiated.

A detailed discussion of the studies recommended follows.

Phase I - Scale Model Study

The analytical acoustic treatment models developed at Lockheed-California indicate that, in general, higher order circumferential modes are more efficiently attenuated than low order modes. Preliminary interaction tone noise generation studies at P&W Aircraft, however, demonstrate that changing the numbers of blades and vanes in a fan design (so as to increase the order of the circumferential modes)

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can significantly alter the level of generated noise. It is very desirable, therefore, to combine the two analyses so that the most effective fan and nacelle system can be designed that will achieve low noise goals.

In order to achieve a reliable combined model, the component parts of the model need to be further improved and experimentally validated. We are proposing that the existing two dimensional interaction tone noise generation analysis be extended to three dimensional, cylindrical geometries. In this way, more accurate estimates of the acoustic energy in the propagating circumferential and radial duct modes would be obtained. The analysis should also be extended to consider noise generation in multistage fans by incorporating the effects of acoustic transmission loss through the various blade rows, using one of the current simplified analytical propagation models. Although, in theory, these models would not be expected to be accurate in the range of wave lengths associated with interaction tone noise propagation, they do appear to give reasonable results when compared to the more complicated analyses.

It is recommended that the analytical model be checked out using a powered nacelle model in the Acoustic Research Tunnel (ART) at the United Aircraft Research Laboratories. This model has a design tip speed and pressure ratio typical of modern high bypass ratio turbofan engines. The fan noise generated by this model is similar to that generated by full scale engines and when run in the ART allows operation in a simulated flight environment free from distortions that normally exist during static testing. It is recommended that a new nacelle model (currently being designed and fabricated) be used to check the noise generation model. This new nacelle model features the capability of changing vane number and rotor-stator axial spacing. Thus the predicted effects of changing the lobe number of a propagating circumferential mode can be checked out experimentally.

Lockheed refined its analytical acoustic treatment model to allow for the inlet boundary layer effects just prior to the publication of this report. The resulting predictions can be checked out by designing acoustic treatment for the specific model structure of the powered nacelle. Suitable check out testing can be accomplished in the UARL ART after installing the acoustic treatment in the powered nacelle model. To do this requires an ability to scale acoustic treatment by factors on the order of 25:1.

Previous experience at Lockheed in the fabrication and use of scale model liners provides a high level of confidence in their application to this requirement. In designing and building such liners, it is necessary that the acoustical resistive impedance be the same as that of the full scale liner. Fine pored, chemically reticulated, urethane foam is particularly useful for the construction of model liners. This material can be readily molded into complex shapes by heating a preshaped blank constrained in a mold. Local acoustical resistance and reactance are controlled to their prescribed values by local thickness and density.

These techniques are well established at Lockheed. For example, the experimental liners employed for evaluating the performance of the Zeno ducts shown in Figure 6-36 were of the above type. In this particular application the resistive impedance was held at the desired value of ρc even though the liner depth varied. In its compressed state, the foam is tough and leathery, can be readily bonded to rigid materials and its dimensional control is a function of constraining mold tolerances. The surface is fine textured and smooth.

After the generation and acoustical treatment models have been improved and experimentally evaluated, any necessary modifications to the analytical models can be carried out. The two models will then be combined to form a complete fan and nacelle design procedure. The combined design procedure can then be used to conduct parametric studies to define general fan and nacelle design criteria and also to determine an optimum low noise configuration for the powered nacelle within performance and structural limitations. This optimum configuration can be checked out as before in the UARL Acoustic Research Tunnel.

Phase II - Full Scale Study

Following completion of the scaled model study, a full scale test program should be undertaken for the purpose of demonstrating the acoustical performance of an approximately "matched" fan/treated nacelle combination derived from the scaled model program. As with scale model studies, the key requirement of such an experimental program is the satisfactory removal of the spurious noise generating mechanism normally associated with static testing which include distortions attributed to changes in the boundary layer at the fan inlet face, ingestion of the ground vortex, and atmospheric turbulence.

A number of approaches have been employed or attempted as means for avoiding these problems. The most straightforward is probably an airplane flyover test.

However, this approach is expensive and not well suited for diagnostic work due to "non-stationary" problems and anomalous atmospheric effects. Another method involves the use of a flying test bed with the microphones located within the flow passage or at suitable locations on the airplane external structure. The forward flight environment has also been produced by fast taxying. The use of wind tunnels for producing relative airflow is a possibility but is probably limited to noise measurements within the duct due to "signal-to-noise" problems unless special means are employed for reducing background noise. This is a practical possibility only in facilities designed for noise testing.

Although all of the above methods (singly or in combination) should be considered as candidates for providing a "full scale" validation of the noise reduction achieved, there is yet another approach currently under development at Rolls-Royce which shows considerable promise.

This method, which is described by Lowrie in Reference 13, is based on the premise that the static simulation of in-flight tone generation requires the following: (1) an adequate reduction in the level of atmospheric turbulence, (2) control of the boundary layer and mean flow conditions, and (3) the production of the (in-flight) Mach number gradient field in the vicinity of the fan and inlet. The latter two requirements have been attained at Rolls-Royce with the development of a "flight-simulation-flare" on the inlet. Studies devoted to the elimination of the remaining problem (atmospheric turbulence) are continuing. The benefits derived from "conditioning" the air flow and passing the air through a gauze screen have been encouraging and the author concludes that "straight-forward development of techniques already tried will lead to acceptable means of simulating in-flight tone noise generation on static tests."

On the basis of the above considerations, it would appear desirable to review the state of the art in large scale testing at the completion of the scaled model study and select the most promising approach at that time for the Phase II engine test program.

12.1.2 Fan Duct Noise

The recommended acoustical treatment is a simple single layer liner with perforate or equivalent woven material. The acoustical performance risk for the RB.211-22B mixed flow exhaust engine and nacelle is low due to the large available noise treatment area. The ATT installation may be slightly higher in acoustical

c3

performance risk than the wide-body installation due to the proportionately smaller area available for acoustic treatment. On the basis of unpublished experimental studies on flow generated noise which became available just prior to publication of this report, it now appears that this source of noise does not make a significant contribution to the total noise radiated from the fan duct.

12.1.3 Turbine Noise

The recommended acoustical treatment is a simple single layer, tapered depth liner on the engine exhaust mixer chutes. Although the achieved noise reduction derived from the analytical model is adequate, the validity of the model is in question due to the complex geometry of the exhaust flow mixer. Space for acoustical treatment is very limited. The possibility exists that the turbine outlet duct will have to be extended upstream of the mixer to provide additional treatment area. Due to the more simple geometry of the ATT tailpipe section, the turbine noise suppression problem is more amendable to acoustic treatment than the mixed flow nozzle. Scale model tail pipe tests for checking the analytical model are recommended.

12.1.3.1 Scale Model Tail Pipe Tests

The analysis of acoustically lined ducts by wave equation theory is presently limited to only the simplest of geometric cases. For the many cases where the geometry is too complex, the testing of acoustically scaled models is often a very useful substitute.

The fluted mixing tail pipe, acoustically treated to attenuate the turbine noise, is an excellent example of such a complex structure. When treated with a liner having a tapered airspace depth, the similarity to a simple rectangular Zeno duct is obvious. The only analysis of the mixing duct that is possible is by analogy to the much simpler rectangular case. Since this component of the engine attenuation system is quite important, scaled model tests are required in order to verify the analogy and modify it as needed.

The success of the acoustical scaling of the absorptive structures depends critically upon the case with which the boundary impedance is scaled. The general procedures for fabricating model liners have been discussed in Paragraph 12.1.4.

The following scale model tests are proposed:

1. Design and construct one acoustically treated lobed mixing nozzle and one equivalent Zeno duct. Both are to be designed and built to the same scale factor (of the order of ¼ to ½).

2. Test both models using a broadband noise and a range of flow velocities. These tests can be performed in the quiet jet facility located in an anechoic chamber at the Lockheed acoustic laboratory. Measurements will include acoustic-power-level insertion loss and directivity.

3. Data will be interpreted in terms of the theoretical prediction of rectangular duct results and the correlation between rectangular and lobed duct results, the end objective being the attainment of a means for predicting the attenuation of a lobed mixing duct with tapered linings.

12.2 PROPULSION TECHNICAL DEVELOPMENT REQUIREMENTS

It is likely that any application of the acoustic-composite nacelle to current aircraft will be configured with a mixed flow exhaust system. The reasons for this are related to the need to recover the losses in engine performance which result from the installation of acoustic treatment. Initial estimates have shown that by mixing the hot and cold streams on a turbofan engine, performance improvements of at least the magnitude of the acoustic suppression treatment losses can be achieved with only a small increase in nacelle weight relative to the typical acoustically treated long cowl nacelle. For this reason it appears that investigation of the application of the mixed flow concept to the current family of high bypass ratio engines would be of significant interest and importance.

The investigation would involve tradeoffs between engine cycle parameters, mixing efficiency, mixing length, internal losses, noise, external drag, and system weight to yield an optimum mixed flow exhaust system from an energy conservation point of view. As an example, initial studies have shown that the maximum gain of mixed flow exhaust systems, when applied to the current family of high bypass ratio engines, tends to occur at the maximum cruise thrust. On the other hand, experience indicates that the average cruise thrust during airline operational service is of the order of 15 to 20 percent below the maximum cruise thrust. Therefore, in order to make practical use of the full mixed flow exhaust fuel savings potential it will be necessary to determine what practical modifications could be made to the current high bypass ratio engines to make these engines more compatible with mixed flow exhaust systems at representative part power cruise thrust levels.

A recommended program to identify the optimum mixed flow exhaust system for current (or growth) versions of the wide-body high bypass ratio engines is outlined in the following section.

12.2.1 Recommended Propulsion Research and Test Program

PHASE I

Conduct analytical systems studies, in combination with an appropriate engine manufacturer, to identify the configuration of mixed flow exhaust system which will provide the best combined acoustics and fuel savings performance. These studies would use existing analytical methods to conduct tradeoffs between engine cycle parameters, mixing efficiency, mixing length, system weight, engine design changes, performance, and acoustics improvements. This analysis would identify (1) the optimum mixed flow exhaust system, (2) necessary component tests to be conducted prior to production go ahead, and (3) engine modifications necessary to fully realize the mixed flow exhaust system performance.

PHASE II

Conduct testing of the optimum mixed flow exhaust system identified in Phase I. This would include testing a scale model baseline configuration to confirm the net mixing gain. In addition, a systematic variation of key geometric and flow parameters around the baseline would be tested. Also a back-to-back test with a three-quarter cowl separate exhaust model would be conducted to confirm the calculated performance incremental improvement between configurations. These would be static (Mach 0) tests in an altitude facility and, again, would be conducted jointly with an engine manufacturer.

PHASE III

Conduct full scale engine tests on a sea level static test bed and in an altitude facility to obtain quantitative performance data prior to formulation of engine and aircraft firm performance. The full scale test phase would be primarily the responsibility of the engine manufacturer. Inasmuch as the design and analytical effort by this time is primarily application-oriented and unique to the particular engine and airframe, this phase would properly be funded by industry rather than NASA.

12.3 STRUCTURES TECHNICAL DEVELOPMENT - REQUIREMENTS

A number of composite development and flight demonstration programs are active and will provide data helpful to the nacelle program. The nacelle application, however, presents some unique problems. The acoustic environment is more severe than that of any other part of the airplane; this, coupled with the lightly loaded basic structure, makes the nacelle vulnerable to acoustic fatigue problems. The design of noise suppression panels imposes geometric and material constraints on the structural design that are not found elsewhere in the airplane. Some parts are exposed to higher temperatures than any other structural components, and some serve as firewalls.

The technology development required for the application of composites to production nacelle fall into three areas. The first is attaining experience necessary to provide the necessary confidence in the durability of the materials in the nacelle environment. The second is the development of efficient manufacturing techniques for the many complex parts that comprise the nacelle structure and its mechanisms, and the third is the reduction of cost of the basic material and its processing. Material costs are expected to come down as usage increases and some dramatic reductions in the cost of both graphite and boron fibers may be possible by breakthroughs in the precursers and processing employed in producing the basic fiber. However, neither of these are considered in this study.

Therefore, the technology development program for application of composites to nacelle design is tailored to obtain data peculiar to nacelle structures that will supplement but not duplicate the data being obtained in the basic airframe structure programs.

12.3.1 Acoustic/Composite Structures Service Life Tests

Objective: To assess the service life of typical acoustic composite structures in a nacelle under airline service conditions.

Scope: Service characteristics will be monitored for a period of 3 years prior to production incorporation, and for 7 years thereafter, with special emphasis on exposure to the elements, operational hazards, operation loads, inspectability, maintainability, and acoustic performance.

Approach: One L-1011 inlet lower acoustic panel, one inlet upper outer skin, and one inlet lower outer skin will be fabricated from advanced composite materials. Following laboratory qualification tests, the composite items will be installed in selected production airplanes with the concurrence of participating airlines for service evaluation. These items have been selected on the basis of ease of substitution of composite for metal; accessibility for inspection and maintenance, and representativeness of the key critical design considerations unique to nacelles. The inlet acoustic panel is designed for 350 K in normal operation. The acoustic facing sheet may be a high resistance linear woven graphite/Kevlar/polyimide structure newly developed for this application. A lower acoustic panel is selected as more critical for durability than an upper panel owing to susceptibility to impact from falling objects, foot pressure, and scuffing during maintenance operations. The inlet lower outer skin is selected because it is close to the ground and is therefore most susceptible to impact from ground objects. The inlet upper outer skin is selected because of susceptibility to impact from falling objects and work stands, body pressure, scuffing, etc. during maintenance operations. Taken together, these three assemblies typify the most critical materials applications for composites on an engine nacelle.

Results and Potential Benefits: By assessing the application of acoustic/composite structures in a nacelle over a period of several years in actual airline service, the effects of sonic fatigue, weathering, foreign object impact, and miscellaneous hangar mishaps will become better known. Tests will be performed periodically to determine degradation of acoustic performance with time, if any. Additionally, special inspection techniques and rapid field repair techniques will be developed to maintain the customarily required high fleet utilization rates with the new acoustic/composite nacelles.

12.4 MANUFACTURING TECHNICAL DEVELOPMENT REQUIREMENTS

In addition to a development program for developing confidence in the airline service suitability and durability of composite structures and materials for application to acoustic-composite nacelles as indicated in Section 12.3; a modest amount of work in composite materials research and development should be programmed specifically oriented toward the acoustic-composite nacelle. Such programs would primarily address fabrication methods and cost reduction. The impact of this development work on the anticipated weight saving is shown in Figure 91 which reflects the weight data of Section 9.

Several graphite and boron manufacturing techniques require further development before they can be economically used for the production of the various components of the nacelle. The presence of numerous doors for access and inspection

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COMPOSITE DEVELOPMENT VS WEIGHT BASELINE

kg (lb)

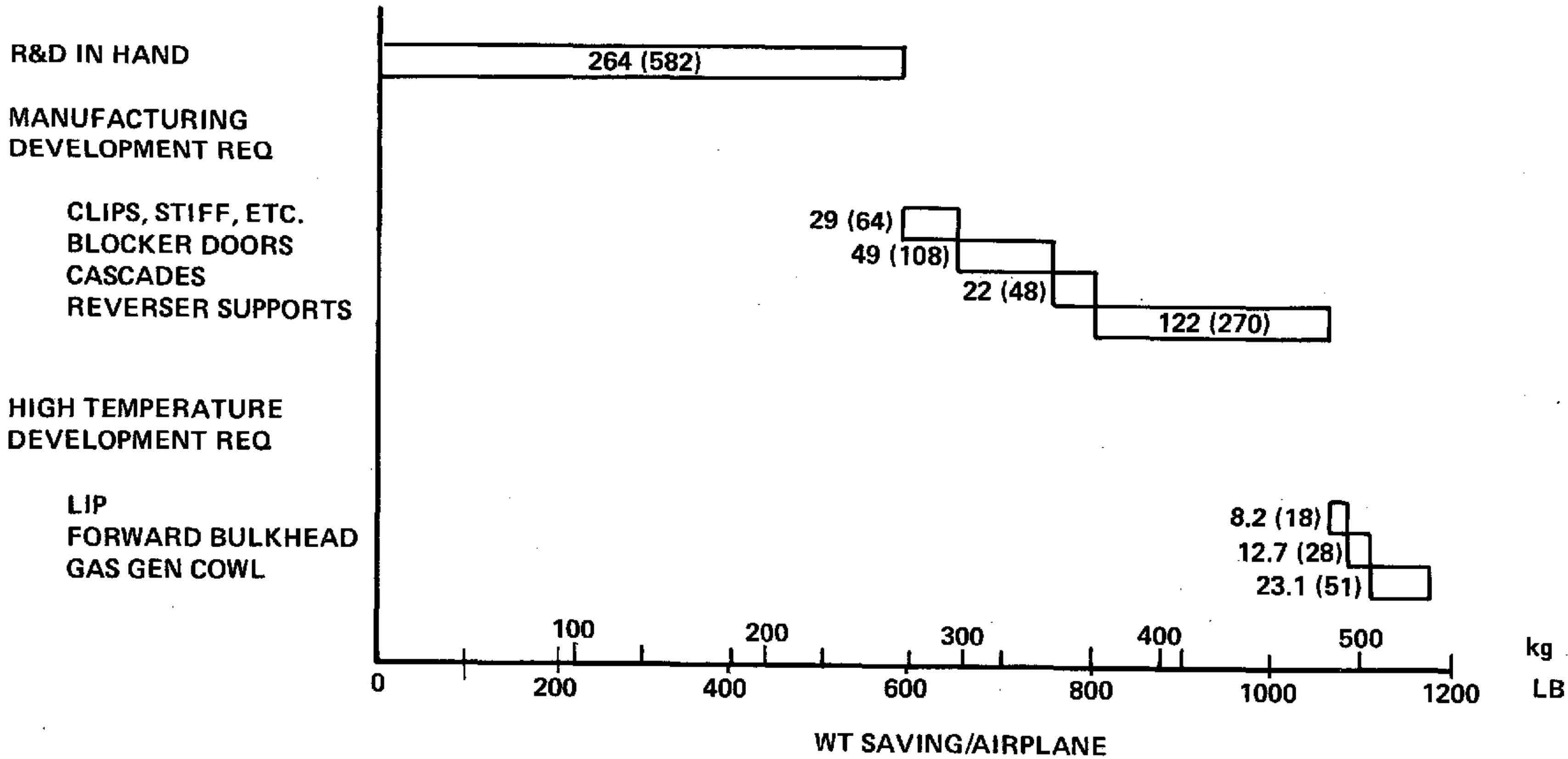

FIGURE 91

and the need for the thrust reverser involving actuators and translating cowl results in a large portion of nacelle weight being devoted to mechanical items such as links, hinges, latches, actuator supports, and blocker doors. The techniques developed in some experimental programs in which landing gear parts were manufactured of composites is applicable to many of these parts. But as yet, the application of chopped fiber moldings or chopped fiber moldings reinforced with tape requires the use of expensive steel dies and several separate operations to produce the final part, resulting in a high fabrication cost and a high tooling cost. An economical technique for fabricating such parts would be beneficial to the nacelle development as well as other components.

The tooling and processing techniques for producing the complex integral structures typified by the thrust reverser support-nozzle assembly require further development. Some of the major problems involved are the design of joints at the ring-beam intersections, developing the cure cycle for assemblies containing both thin and thick members, and dimensional control of large three-dimensional structures. A progressive development program attacking each problem area with subcomponent test specimens and culminating in a complete structure for static and fatigue tests is suggested.

A number of resins have been developed which have useful properties up to $600^{\circ}F$. To date, however, these resins are relatively difficult to process, requiring a very close control to produce void-free parts. Further development of these materials and of the processes required to use them is recommended.

The rear bulk head, fire wall, and the cowl doors must be fire proof. This involves a 15-minute exposure of $2000^{\circ}F$ flames. For this occasional exposure, intumescent coatings might be used in conjunction with the epoxy or polyimide resins. As this potential weight saving is a small part of the total potential saving, this is recommended as a low priority development.

A great portion of the nacelle weight is involved in those parts subjected to continuous operating temperatures of over 1000° such as a nozzle and mixer chute. Organic matrices seem to be out of the question for these parts. Some development work has been done on metal matrix composites which have the potential of having very high strength to weight ratios at elevated temperatures. This type of material does not seem applicable to the nozzle and chute which operate a fairly low stresses. The high strength characteristics, therefore, could not be exploited, and the presence of metal suggests that the weight saving would be small over the current titanium and steel designs. Further work on these materials for this application is therefore not recommended.

SECTION 13

PROGRAM PLAN

This section discusses the schedule and funding anticipated to implement the technology development described in Section 12.

13.1 SCOPE

The technology development activities defined in Section 12 are in addition to the work required to develop, qualify, and place in production a new nacelle using available state-of-the-art technology. Upon the completion of the specified technology development it is presumed that adequate data will be available to regard the acoustic-composite nacelle as 'current state-of-the-art', and that a normal nacelle development program can be undertaken with confidence. The technology development program is designed to produce data of general applicability rather than a specific design; the schedule and funding estimates given in this section apply only to this general program, the normal development activities would follow successful attainment of the objectives of the general technology development program.

The specific tests identified in Section 12 are listed in Table 26. The first three acoustic items deal with the various aspects of inlet and fan duct development, the last acoustic item is for tests of the convoluted mixing nozzle. The service test of acoustic liners are included in the composite structure service test program in the following schedule and costs.

13.2 SCHEDULE

A schedule for accomplishing the tests and analyses defined in Section 12 is shown in Figure 92. In the interest of compressing the total calendar time, concurrent programs are suggested wherever feasible. The inlet noise suppression program, which culminates in a full scale test, is planned to utilize model data to guide the full scale program. It is premised that the components chosen for the service demonstration of composite materials can be made with present techniques and that they can be installed on existing nacelles without extensive re-design.

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TECHNOLOGY DEVELOPMENT PROGRAM

ACOUSTICS

- SCALE MODEL INLET TESTS & ANALYSIS
- FULL SCALE INLET TESTS
- FLOW DUCT & IMPEDANCE TUBE STUDIES OF GRAZING FLOW
- SERVICE TESTS FOR CONTAMINATION
- SCALE MODEL TAIL PIPE TESTS

PROPULSION
MIXED FLOW
NACELLE

- SYSTEM STUDY TO TRADE OFF ENGINE CYCLE, MIXING EFFICIENCY, MIXING LENGTH, WEIGHT, COST, PERFORMANCE
- VERIFY PERFORMANCE OF OPTIMUM DESIGN BY MODEL TESTS

COMPOSITE STRUCTURE

- DEVELOP DAMAGE CONTROL - INSPECTION, REPAIR, FAILSAFE
- DEVELOP ECONOMICAL MANUFACTURING METHODS
  - LARGE SPACE FRAMES
  - MECHANISMS
- SERVICE TEST OF MATERIAL ON OPERATIONAL NACELLE

TABLE 26

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NACELLE DEVELOPMENT SCHEDULE

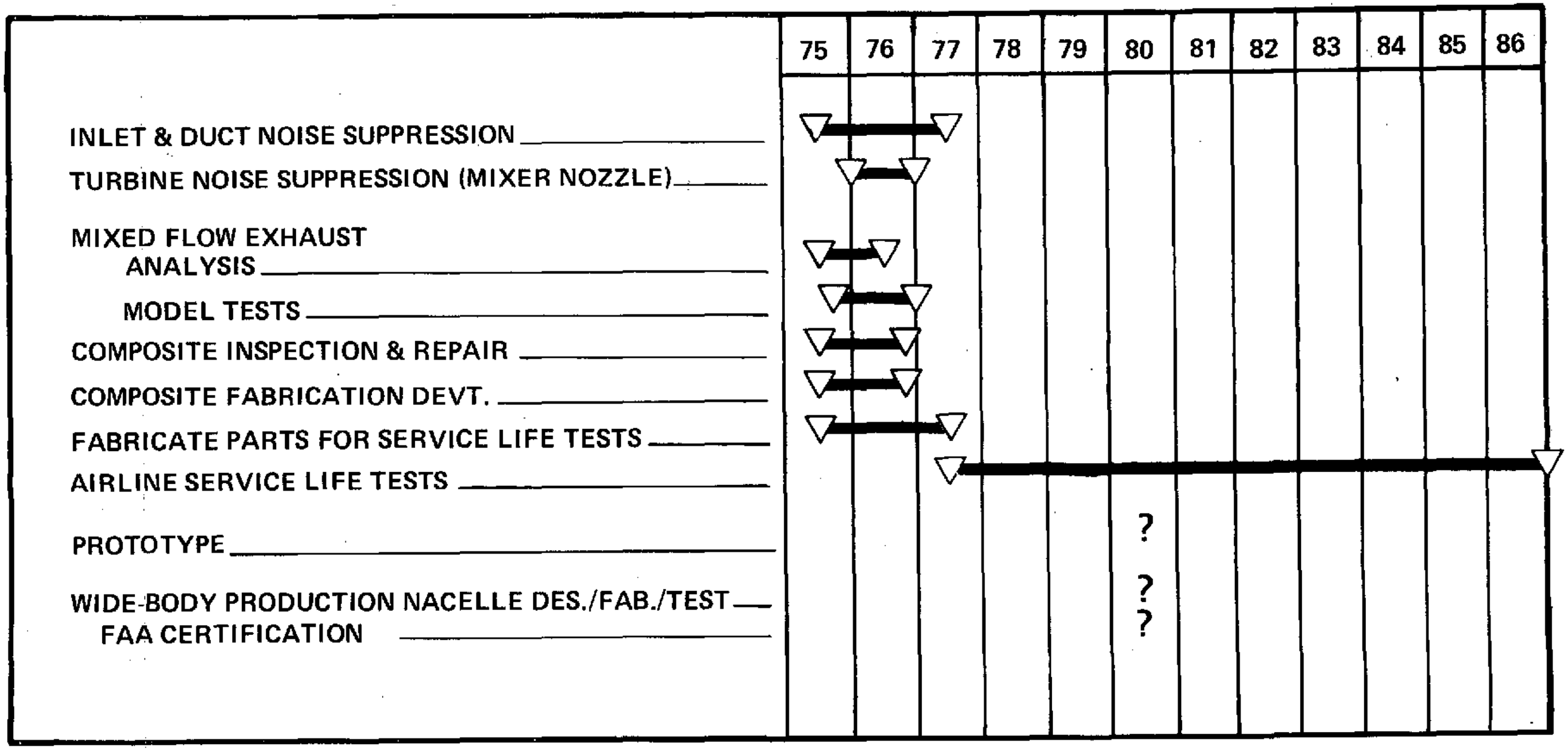

FIGURE 92

Although a lengthy service life test is indicated, it is anticipated that a favorable performance in the early years combined with environmental exposure data from other programs could reduce the risk of an early commitment to acceptable levels.

13.3 PROGRAM FUNDING

13.3.1 Widebody Program

The anticipated budgetary requirements to implement the development program are summarized in Table 27. Both the model and the full scale acoustic test program costs are estimated on the basis of using existing test equipment and specimens. The full scale tests include the costs for design, fabrication and installation of the advanced liners in an existing inlet. The service test of composite materials is based on the plan of Section 12 which includes upper and lower outer skins as well as acoustic liners for one airplane. By limiting the program to outer shell parts, e.g., a cowl door, the cost could be reduced to $500,000 for one demonstration part. Once qualified, installing like parts on more aircraft could provide a greater exposure at relatively small additional cost.

The yearly funding for development work required prior to a commitment to production is shown in Figure 93.

13.3.2 ATT PROGRAM

As shown on Table 26, the ATT is expected to benefit from the wide body program and the only specific ATT development is to apply the fan-inlet study results to the ATT engine-nacelle design. This study is estimated to require $200,000.

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NACELLE DEVELOPMENT FUNDING

(DOLLARS IN THOUSANDS)

- TECHNOLOGY

ACOUSTICS	• INLET	1000
	• TURBINE	300
MIXED FLOW	• ANALYSIS	180
	• MODEL TESTS	500
COMPOSITES	• DAMAGE CONTROL	1000
	• MANUFACTURING	1000
	• SERVICE TEST	1500
		5480

TABLE 27

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TECHNOLOGY FUNDING SCHEDULE

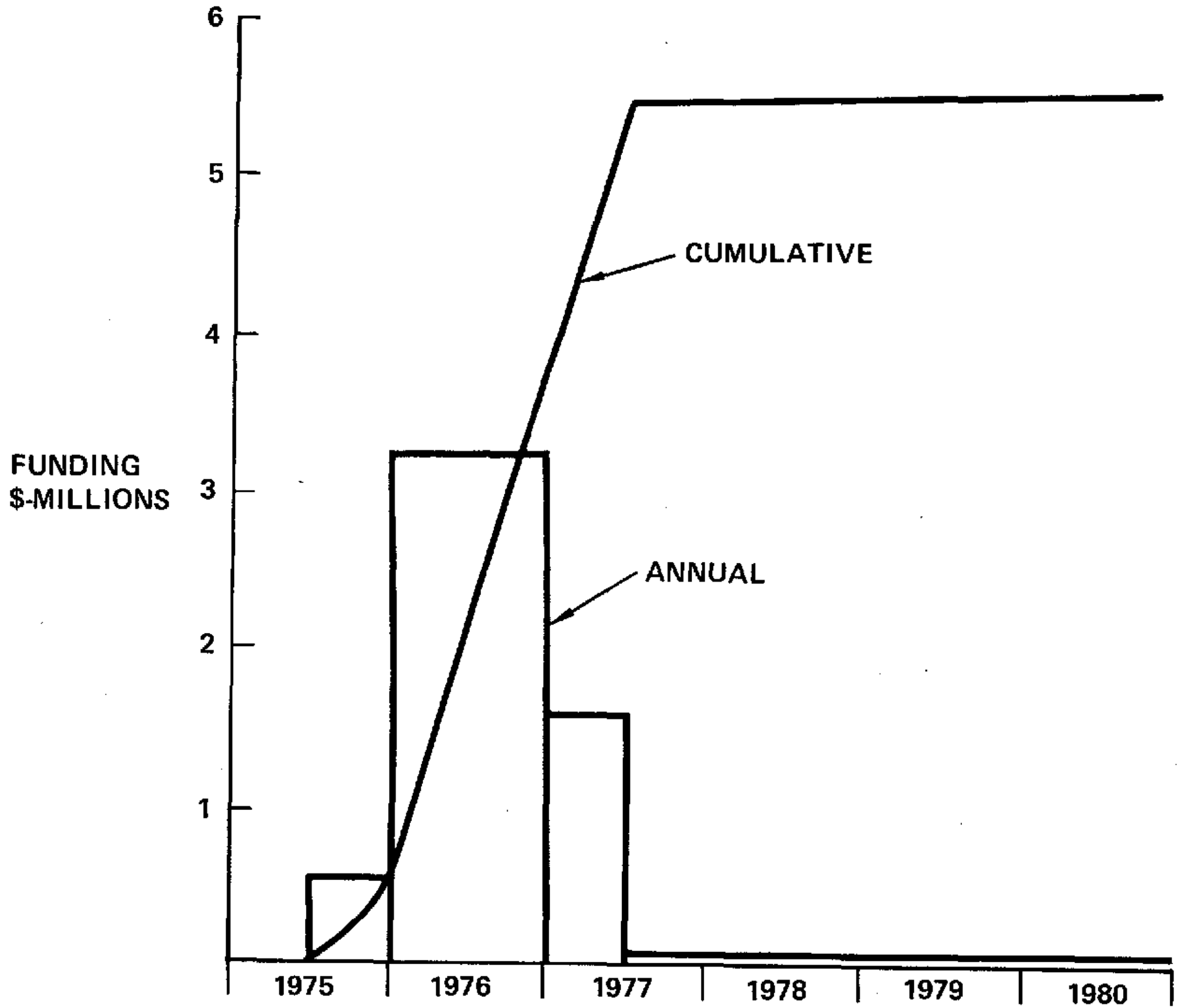

FIGURE 93

APPENDIX A

CONCEPT EVALUATION DATA

The data used in the concept evaluation phase of the study is summarized in this appendix. The preliminary design study discussed in Section 5 produced major modifications of the original concept; this appendix merely records the comparative data for the concepts evaluated.

A.1 WIDE-BODY CONFIGURATION COMPARISON

The impacts of each of the configurations considered on airplane characteristics are summarized in Figure A-1. The values shown are increments over the baseline in each case. The weight increment per airplane includes the weight difference for two wing inlets and for the fan duct and tail pipe installations for all three engines. Note that the configuration with the long inlet, long duct, and the ring tail pipe is very close in weight to that of the mixed flow nozzle and that the near sonic inlet is somewhat heavier than any of the other configurations. The increment in external wetted area per airplane is shown for reference, although the values for changes in specific fuel consumption include both the effects of the external drag and the internal losses.

A.2 ATT CANDIDATE CONFIGURATIONS

The impact on the airplane characteristics for the two configurations is shown in Figure A-2. Again the large increase in weight and wetted area and increment in specifid fuel consumption attributable to the near sonic inlet is evident.

A.3 WEIGHT SUMMARY

A summary of the nacelle weights used in the concept selection study discussed in Section 4 is shown in Figure A-3 for the wide-body and in Figure A-4 for the ATT.

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NACELLE EFFECT ON AIRPLANE WIDEBODY

INLET	DUCT	TAIL PIPE	MATERIAL	Δ WT* kg (LB) AIRP	Δ EXTERNAL WET AREA m^2 (FT^2)/AIRP	Δ SFC %	Δ FUEL USED %
BASELINE –	LINED		METAL	–	–	–	
"	"		COMP	–83.5 (–184)	–	–	–.04
LONG	LONG	STD	"	797 (1756)	39.2 (422)	1.08	+1.4
"	"	RAD. SPLIT.	"	1063 (2344)	44.4 (478)	1.35	+1.8
"	"	RING	"	1256 (2770)	44.4 (478)	1.48	+2.03
RING	"	"	"	976 (2152)	23.2 (250)	1.28	+1.7
NEAR SONIC	"	"	"	1614 (3558)	63.5 (684)	2.10	+2.8
LONG	MIXED	FLOW	"	1315 (2899)	57.8 (622)	-.20	+.38

FIGURE A-1

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ATT NACELLE EFFECT ON AIRPLANE

	ΔWT * kg (LB)/AIRP	Δ WET AREA m^2 (FT^2)/AIRP	Δ SFC %
BASELINE METAL HARDWARE	–	–	–
BASELINE COMPOSITE HARDWARE	–69.8 (–154)	–	–
LONG NACELLE – METAL	1314 (2898)	38.3 (412)	2.1
LONG NACELLE – COMPOSITE	1019 (2246)	38.3 (412)	2.1
NEAR SONIC INLET PLUS LONG DUCT COMPOSITE	1331 (2934)	50.2 (540)	2.4

FIGURE A-2

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L-1011 NACELLE WEIGHTS

INLET CONFIGURATION FAN DUCT CONFIGURATION TAIL PIPE CONFIGURATION	LONG LONG STD.		LONG LONG RAD. SPLIT		LONG LONG RING		RING LONG RING		SONIC LONG RING	
MATERIAL	M	C	M	C	M	C	M	C	M	C
	KG (LB)	KG (LB)	KG (LB)	KG (LB)	KG (LB)	KG (LB)	KG (LB)	KG (LB)	KG (LB)	KG (LB)
Fwd: Inlet	406 (895)	356 (785)	406 (895)	356 (785)	406 (895)	356 (785)	247 (545)	220 (485)	649 (1430)	535 (1180)
Fwd: Cowl Door and Support	138 (305)	138 (305)	138 (305)	138 (305)	138 (305)	138 (305)	138 (305)	138 (305)	138 (305)	138 (305)
Aft: Translating Cowl	150 (330)	132 (290)	150 (330)	132 (290)	150 (300)	132 (290)	150 (330)	132 (290)	150 (330)	132 (290)
Aft: Fan Nozzle	163 (360)	136 (300)	163 (360)	136 (300)	163 (360)	136 (300)	163 (360)	136 (300)	163 (360)	136 (300)
Aft: Fan Thrust Reverser	542 (1195)				← No Change →					542 (1195)
Aft: Splitter Fairing	63 (138)				← No Change →					63 (138)
Aft: Gas Generator Cowl	157 (347)				← No Change →					157 (347)
Aft: Tail Pipe	88 (195)	88 (195)	177 (390)	177 (390)	240 (530)	240 (530)	240 (530)	240 (530)	240 (530)	240 (530)
Aft: Engine Reinforcement	32 (70)	32 (70)	32 (70)	32 (70)	32 (70)	32 (70)	32 (70)	32 (70)	32 (70)	32 (70)
Total - Fwd	544 (1200)	494 (1090)	544 (1200)	494 (1090)	544 (1200)	494 (1090)	386 (850)	358 (790)	787 (1735)	574 (1485)
Total - Aft	1195 (2635)	1150 (2535)	1284 (2830)	1238 (2730)	1347 (2970)	1302 (2870)	1347 (2970)	1302 (2870)	1347 (2970)	1302 (2870)
Total per Nacelle	1740 (3835)	1644 (3625)	1828 (4030)	1733 (3820)	1892 (4170)	1796 (3960)	1733 (3820)	1660 (3660)	2134 (4705)	1975 (4355)
Total per Airplane (2 x Fwd + 3 x Aft)	4674 (10305)	4438 (9785)	4940 (10890)	4704 (10370)	5130 (11310)	4894 (10790)	4813 (10610)	4622 10190)	5616 (12380)	5253 (11580)
Change from Baseline	1030 (2275)	794 (1751)	1295 (2856)	1060 (2336)	1486 (3276)	1250 (2756)	1168 (2576)	978 (2156)	1971 (4346)	1608 (3546)

M = Metal; C = Composite

FIGURE A-3

LOCKHEED CALIFORNIA COMPANY

ATT NACELLE WEIGHTS

		BASELINE		LONG		SONIC INLET	
		METAL	COMP	METAL	COMP	METAL	COMP
		KG (LB)	KG (LB)	KG (LB)	KG (LB)	KG (LB)	KG (LB)
Fwd	Inlet	188 (414)	171 (376)	336 (740)	281 (620)	526 (1160)	440 (970)
	Cowl Door and Supt	102 (224)	102 (224)	102 (225)	102 (225)	102 (225)	102 (225)
Aft	Translating Cowl	76 (167)	64 (141)	91 (200)	73 (160)	91 (200)	73 (160)
	Fan Nozzle	26 (58)	26 (58)	213 (470)	168 (370)	213 (470)	168 (370)
	Thrust Rev., Fairing, Gas Gen. Cowl, Etc.	576 (1271)	576 (1271)	576 (1270)	576 (1270)	576 (1270)	576 (1270)
	Tail Pipe	76 (167)	76 (167)	213 (470)	213 (470)	213 (470)	213 (470)
	Total - Fwd	289 (638)	272 (600)	438 (965)	383 (845)	628 (1385)	542 (1195)
	Total - Aft	754 (1663)	743 (1637)	1093 (2410)	1030 (2270)	1093 (2410)	1030 (2270)
	Total - Per Nacelle	1044 (2301)	1015 (2237)	1531 (3375)	1413 (3115)	1721 (3795)	1572 (3465)
	Total - Airplane	2842 (6265)	2772 (6111)	4155 (9160)	3856 (8500)	4536 (10000)	4173 (9200)
	Change From Baseline	-	-70 (-154)	1313 (2895)	1014 (2235)	1694 (3735)	1331 (2935)

FIGURE A-4

APPENDIX B

THE PROPAGATION OF SOUND IN CIRCULAR AND ANNULAR DUCTS

A. THE CONVECTED WAVE EQUATION

For the case of plug flow, the applicable form of the convected wave equation may be written:

$$\nabla^2 p = \frac{1}{c^2} D^2 p \qquad \text{(Eq. 1-A)}$$

where D represents the operator

$$\frac{\partial}{\partial t} + \vec{V} \cdot \nabla$$

or if the flow is axial (z axis)

$$D = \left(\frac{\partial}{\partial t} + V_z \frac{\partial}{\partial z}\right)$$

Conversion to cylindrical coordinates (r, θ, z), separation of variables and application of a continuity of particle displacement boundary condition leads to the equation set:

$$K_z = \frac{-MK + \sqrt{K^2 - (1 - M^2)\, K_r^{\,2}}}{1 - M^2}$$

$$jK\left(1 - M\frac{K_z}{K}\right)^2 \frac{\rho c}{Z_b} = -K_r \frac{E_m'(K_r)}{E_m(K_r)}$$

$$jK\left(1 - M\frac{K_z}{K}\right)^2 \frac{\rho c}{Z_a} = +K_r \frac{E'_m(\delta K_r)}{E_m(\delta K_r)}$$

where

$$E_m(x) = J_m(x) + Q\,Y_m(x)$$

$$\delta = \frac{a}{b}$$

This equation set may be solved for a double infinity of solution sets

$$K_{rm\mu},\ K_{zm\mu},\ Q_{m\mu}$$

wherein m is the circumferential lobe count and μ is the radial index number of a solution mode.

The insertion loss of a duct relative to a hard wall duct is

$$I = -10\log_{10}\frac{\sum_m \sum_\mu \left|A_{m\mu}\right|^2 \exp(2\beta_{m\mu}L)}{\sum_m \sum_\mu \left|A_{m\mu}\right|^2 \exp(2\overline{\beta}_{m\mu}L)} \qquad \text{(Eq. 2-A)}$$

where $\beta_{m\mu} = \operatorname{Im} K_{zm\mu}$ and $\overline{\beta}$ means as calculated for the hard wall case.

The lobe count and radial index number m and μ are chosen such that only modes which propagate in a hard wall duct are considered. Thus

$$A_{m\mu} = 0 \quad \text{if} \quad \overline{\beta}_{m\mu} \neq 0$$

The lobe count m is also limited to values which satisfy the selection rule:

$$m = nB + dV \qquad \text{(Eq. 3-A)}$$

For the calculation of the attenuation of blade passage tones and their harmonics, the wave number K is introduced in terms of blade tip Mach number M_t

$$K = nB\, M_t$$

in conjunction with the proper values of

$$n,\ B,\ M,\ \text{and}\ V$$

Broadband noise is represented as being composed of all possible propagating modes:

$$\text{by choosing } B = 0,\ V = 1 \quad \text{and } K = \frac{2\pi bf}{c}$$

where f is the center frequency of a 1/3 octave band of noise. Buzz-saw tones may be introduced simply by setting V = 0.

Attenuation is found to increase monotonically with increasing m and also with increasing μ. This permits the use of systematic mode sampling to reduce the magnitude of the calculations in the broadband case.

In summary, the computer implemented solution to the convected wave equation has been formulated in such a way that spinning modes (both rotor generated and interaction generated), broadband noise, or buzz-saw tones are handled with equal facility.

The Computer Output Format

The printout of the solutions to the convected wave equation consists of contours of equal duct attenuation in the complex plane R + jX which represents the "in place" duct wall impedance. Each sheet represents a particular buzz-saw order, blade passage harmonic or 1/3 octave band of broadband noise. All values of $\beta_{m\mu}$ are in storage such that the results for a range of duct lengths L may be readily obtained from one basic solution set.

Once a set of attenuation contours (see for instance, Figure 6-11) are available, then any number of attenuation predictions may be read off by simply entering each page at the appropriate values of R and X. No assumptions concerning the design of the liner have entered into the solutions of the wave equation.

The crucial factor governing the accuracy of insertion loss predictions is the assignment of the energy weighting factors $\left|A_{m\mu}\right|^2$.

Knowledge of the actual energy distribution among the propagation modes is always scant. Improved knowledge of modal energy distribution is the key to improved predictability of duct liner attenuation but its attainment is a formidable task.

In the absence of any solid evidence to the contrary, the following working assumptions have proven useful:

- For any given blade passage harmonic, the energy is divided equally among the allowed lobe counts m. For any given value of m, the energy is subdivided equally among the radial modes.
- Within any given band of broadband noise, the energy is divided equally among all allowed lobe counts m. For any given value of m, the energy is subdivided equally among the radial modes.
- Within any 1/3 O.B. containing both broadband noise and perceptible pure tones, the total energy is distributed equally between the broadband and the pure tones.

These assumptions can only be roughly justified. It is normally true that a pure tone only causes a minor proturberance (of the order of 3 dB) in a 1/3 O.B. spectrum of fan jet engine noise, inferring that the broadband and pure tone energies are about the same. Broadband noise by its very nature and multiplicity of sources is modally very rich.

The importance of the modal distribution of the energy can scarcely be overstated. As an example, consider the second harmonic if a 33 blade fan operating with 70 OGVs in its fan duct and 54 OGVs in its compressor inlet, and rotating at slightly above 70 percent of rated speed such that the rotor generated mode m = 66 is just cut on. The allowable modes are:

1. m = 66 - 0 (rotor only)
2. m = 66 - 70 = -4 (rotor - OGV_1 interaction)
3. m = 66 - 54 = 12 (rotor - OGV_2 interaction)
4. m = 66 - 108 = -42 (rotor - 2K OGV_2 interaction)

The calculated attenuation rates for cases 1 and 4 are very great and these modes may be completely disregarded. The four lobe pattern in case 2 decays much more slowly than the broadband noise and is the limiting factor.

The 12 lobe pattern in case 3 decays at about the same rate as the broadband noise and so is not a limiting factor. As is shown in Figure 6-15, the required inlet treatment is about 16 inches shorter if the 12 lobe pattern is dominant, as compared to the treatment length required if the 4 lobe pattern dominates the second harmonic. The analysis has been conducted separately for these two extreme cases (4 lobe or 12 lobe completely dominant). Experimental evidence, based on the interpretation of directivity patterns indicates that the 12 lobe mechanism is dominant.

It is a curious fact that several engines suitable for propelling a wide-body transport contain a 4 lobe spinning mode, as shown in the table below:

TABLE 1

ENGINE	B	V	m = n B + dV
RB211	33	70	m = (2) 33 - (1) 70 = -4
G.E. CF6	38	80	m = (2) 38 - (1) 80 = -4
STF 433*	40	58	m = (3) 40 - (2) 58 = +4

The preceding sections have sketched the utilitarian solution to the convected wave equation. The selection of modal energy assumptions and the printout of the solutions as equal attenuation contours in the complex plane representing the "in place" impedance of the duct liner. These contours serve to permit attenuation predictions and also serve to prescribe the most desirable "in place" impedance as a function of frequency. The final step is to attempt to fill these prescriptions with actual liner designs.

This requires correction for the effect of sound pressure on any nonlinearity of this liner and also correction for the biasing effects of grazing flow. Usually the conditions in engine ducts are such that these two effects are of the same order of magnitude of importance such that neither should be neglected.

It is well known that the throughflow resistance to steady flow for virtually any acoustical material may be well represented in the form

*Original configuration

$$\frac{\Delta P}{U} = R = R_o + R_1 U \qquad \text{(Eq. 4-A)}$$

where R_o represents the purely viscous component of resistance and R_1U the kinetic resistance, where U is the approach velocity. It is clear that any acoustical sheet material can be conveniently described by the two constants R_o and R_1 which may be easily determined by a few flow bench measurements at different values of U. This procedure is routinely followed in the Lockheed acoustical materials laboratory and the constants R_o and R_1 have been found to be more useful than the unfortunate nomenclature "nominal flow resistance," and "nonlinearity factor."

It is plausible to associate the flow bench approach velocity U with the acoustical approach velocity. The usefulness of this association is, however, reduced by the fact that there are no common instruments available for the easy measurement of acoustical approach velocity near engine liners. Our knowledge of environmental conditions near ducts is in terms of SPL spectra (usually from flush microphones in locally hard surfaces). We should, therefore, attempt to relate SPL and ΔP.

Equation 1 may be manipulated into the forms.

$$R = \frac{R_o + \sqrt{R_o^2 + 4R_1 \Delta P}}{2} \qquad \text{(Eq. 5-A)}$$

$$\Delta P = \frac{R(R - R_o)}{R_1} \qquad \text{(Eq. 6-A)}$$

It may also be shown that

$$U \text{ (acoustical)} = \sqrt{\sum_n \frac{P_n^2}{(R + \rho c)^2 + X_n^2}} \qquad \text{(Eq. 7-A)}$$

where P_n is the sound pressure in the nth 1/3 O.B. as measured by a flush microphone in a hard wall (pressure doubled). By associating U steady state and U (acoustical) we may write

$$R = R_o + R_1 \left[\sum_n \frac{P_n^{\;2}}{(R + \rho c)^2 + X_n^{\;2}} \right]^{1/2} \qquad \text{(Eq. 8-A)}$$

and both P_n and X_n may be measured directly.

Equation 8-A may be solved for implicit R by iteration. This value of R inserted in Equation 6-A may be used to determine an appropriate value for equivalent ΔP, i.e., the flow bench differential pressure corresponding to the conditions in the engine duct.

Note that equivalent ΔP is a function not only of the material constants R_o and R_1 but also of both the spectrum level and shape of the sound and also of the reactance spectrum of the liner.

The usefulness of these sections have been extensively verified by tests on a variety of materials in a high intensity standing wave tube using the broadband bias noise method described in Reference 3.

Grazing flow also increases the acoustics resistance of duct liner facing sheets and to some extent affects their inertance. Only limited data concerning this effect is found in the literature. The most notable of this is found in Reference 4. It was found that the results of Reference 4 could be represented by an additive term ΔR which is a function of R_1 and the mean flow Mach number M

$$R = \frac{R_o + \sqrt{R_o^{\;2} + 4R_1 \Delta P}}{2} + F(R_1, M) \qquad \text{(Eq. 9-A)}$$

These results have been systematized into a facing sheet selection handbook covering all values of R_o, R_1, ΔP, and M of interest. Similarly, the inertance of facing sheets may be expressed as a function of R_1 and the effect of grazing flow as a function of M. This effect and its consequences on air space depth selection have been systematized into a selection handbook covering all cases of interest.

Analyses of this type reveal clearly that acoustical resistances that are either very large or very small are difficult to attain using perforated facing sheets. The convected wave equation solutions indicate that for spinning modes very near cutoff (as is always the case for low orders of buzz-saw) optimum resistances are extremely low, at limits of the order of .1 ρc. In the presence of substantial grazing flow (say M = 0.4) it is difficult to attain a resistance as low as 0.5 ρc.

The present analysis shows that optimum wall resistance for inlet ducts to be of the order of 5 ρc. Such a resistance requires the use of perforated facing sheets where open area is only of the order of 3 percent. The nonlinearity of such a sheet is extreme. Figure 22 in Reference 3 shows that a 4 percent open perforate changes its resistance by a factor of 9 to 1 as sound pressure increases 60 dB. The inertance of such a sheet is also large which will lead to a significant narrowing of the first absorption peak and a loss of high frequency response. For these reasons, the use of more purely resistive facing sheets such as fine fibered felt metals bonded to open perforate is strongly indicated.

List of Symbols

a = Radius of center body

b = Radius of outer duct

c = Velocity of sound

d = integer

j = $\sqrt{-1}$

k = wave number $\left(\frac{\omega}{c}\right)$

k_z = axial wave number

k_r = radial wave number

ℓ = duct length

n = integer

p = sound pressure

B = blade count

$F(x,y)$ = Function of x and y

$J_m(x)$ = Bessel function of first kind and order m

K = kb, $Kr = k_{rb}$, $Kz = k_z b$

l = $\frac{\ell}{b}$

M = Mach number

Q = Constant

V = Vane count

$\vec{V}$ = Flow velocity vector

V_z = Flow velocity axial

$Y_m(x)$ = Bessel function of the second kind of order m

Z_a = Acoustic impedance at $r = a$

Z_b = Acoustic impedance at $r = b$

ρ = Air density

Δ = $\frac{\partial}{\partial x} + \frac{\partial}{\partial y} + \frac{\partial}{\partial z}$

APPENDIX C

SCHIZOPHONIUM

The inexorable laws of acoustical scaling lead to the most formidable problem in aircraft noise control, a need for substantial low frequency absorption in very limited space. The only known approach to passive low frequency absorption in limited space has been some form of resonator. These are characteristically difficult to apply because of their narrow response and nonlinearity.

The Helmholtz resonator is a series element device. A constant inertance I, and hence constantly increasing positive reactance ωI, is placed in series with an air spring whose capacitance may be regarded as constant at low frequencies but becomes a function of cavity geometry at high frequencies. Series damping is either provided by the nonlinear resistance inherent in the throat or by a supplemental and rather critical permeable insert.

The general characteristics of such a series device could be drastically altered only if new elements could be found having intrinsically different characteristics, for example, inertance which is not constant. Miniature acoustical horns may be regarded as elements whose characteristics might be expected to change considerably according to whether they were operating below or above their cutoff frequency.

Suppose the throat of an acoustical horn is coupled to a closed cavity. The air cavity may be conveniently provided by the space between the horn exterior and a cylinder having the same cross-section as the horn mouth. Although not strictly accurate, for the purposes of visualization, attribute the properties of the infinite acoustical horn to the horn element. Then below cutoff frequency, if there is an axial oscillation of the air in the horn, all the air moves in phase. This corresponds to a substantial inertance. This inertance is in series with the air spring and so the system constitutes a resonator. Above the cutoff frequency of the horn, sound propagates with the usual phase shift much as it would be in a tube.

The abrupt discontinuity of cross-section at the juncture of the throat and air cavity is a very reflective situation such that the horn becomes a resonant air column at each frequency for which its length equals an integral number of half wave lengths. This is exactly analogous to the behavior of an air column closed at one end and half as deep. Finally, closely controllable linear damping for both modes of operation may be provided by a permeable flow resistive sheet covering the mouth of the horn. Thus, below cutoff frequency, the system provides a fairly broad "haystack" of low frequency absorption. Above cutoff frequency, the device behaves as a single layer absorber. This duality of frequency range, split by the cutoff frequency of the horn, suggested the name "Schizophonium."

APPENDIX D

ASSET PARAMETRIC ANALYSIS - ATT

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A S S L T   P A R A M E T R I C   A N A L Y S I S

SUMMARY ID NO. 100
OCTOBER 14 1974

AIRCRAFT MODEL --1522-7-1-200
I.O.C. DATE --1974
DESIGN SPEED --SUBSONIC

ENGINE I.D. -- 200000
SLS SCALE 1.0 = 30700
NUMBER OF ENGINES = 3.

WING QUARTER CHORD SWEEP = 36.50 DEG
WING TAPER RATIO = 0.400

1 W/S	135.0	135.0	135.0	135.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2 T/W	0.35	0.32	0.31	0.31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 AR	7.60	7.60	7.60	7.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 T/C	9.40	9.40	9.40	9.40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 RADIUS N. MI	3000	3000	3000	16[illegible]	0	0	0	0	0	0	0	0	0	0	0	0
6 GROSS WEIGHT	275519	276314	274484	******	0	0	0	0	0	0	0	0	0	0	0	0
7 FUEL WEIGHT	85565	85043	84265	85078	0	0	0	0	0	0	0	0	0	0	0	0
8 OP. WT. EMPTY	153054	151271	150221	149921	0	0	0	0	0	0	0	0	0	0	0	0
9 ZERO FUEL WT.	193054	191271	190221	189921	0	0	0	0	0	0	0	0	0	0	0	0
10 THRUST/ENGINE	30681	29473	28820	28416	0	0	0	0	0	0	0	0	0	0	0	0
11 ENGINE SCALE	0.999	0.960	0.939	0.926	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12 WING AREA	2066.	2047.	2033.	2037.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
13 WING SPAN	125.3	124.7	124.3	124.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14 H. TAIL AREA	459.	453.	448.	449.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
15 V. TAIL AREA	393.	387.	383.	384.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
16 BODY LENGTH	161.2	161.2	161.2	161.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COST DATA--MILLION DOLLARS/AIRCRAFT																
17 FLYAWAY COST	17.961	17.708	17.560	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18 AIRFRAME COST	14.139	14.014	13.937	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19 ENGINE COST	3.051	2.948	2.892	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20 AVIONICS COST	0.600	0.600	0.600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COST DATA--DIRECT OPERATING COST																
21 $ PER MILE	3.141	3.106	3.086	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22 CENTS/A S MILE	1.570	1.553	1.543	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FLIGHT PATH MISSION CHARACTERISTICS																
23 MISSION SYM(1)	36000	36000	36000	0	0	0	0	0	0	0	0	0	0	0	0	0
CONSTRAINT OUTPUT																
24 TAKEOFF DST(1)	7021	7309	7459	0	0	0	0	0	0	0	0	0	0	0	0	0
25 CLIMB GRAD(1)	0.1434	0.1356	0.1318	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26 TAKEOFF DST(2)	7155	7420	7564	0	0	0	0	0	0	0	0	0	0	0	0	0
27 CLIMB GRAD(2)	0.0474	0.0426	0.0401	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28 AP SPEED-KT(1)	132.8	132.9	132.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29 CTOL LNDG D(1)	5589	5566	5513	0	0	0	0	0	0	0	0	0	0	0	0	0
30 AP SPEED-KT(2)	140.7	140.8	140.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31 CTOL LNDG D(2)	6037	6038	6039	0	0	0	0	0	0	0	0	0	0	0	0	0
32 AP SPEED-KT(3)	148.1	148.2	148.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33 CTOL LNDG D(3)	6485	6490	6494	0	0	0	0	0	0	0	0	0	0	0	0	0

SELECTED
CONFIGURATION

ATT CONCEPT EVALUATION
BASE LINE METAL

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CALIFORNIA COMPANY

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COST SUMMARY

WING		1090157.00		
TAIL		410755.25		
BODY		1169100.00		
LANDING GEAR		299067.94		
FLIGHT CONTROLS		256614.63		
NACELLES		571286.00		
PROPULSION				
ENGINE	21002.57			
AIR INDUCTION	265955.63			
FUEL SYSTEM	230813.44			
START SYSTEM	4625.39			
ENGINE CONTROLS	2219.17			
EXH/THRUST REV.	5026.96			
LUBE SYSTEM	2395.23			
TOTAL PROPULSION		464459.06		
INSTRUMENTS		99516.31		
HYDRAULICS		147045.86		
ELECTRICAL		506519.31		
ELECTRONIC RACKS		141123.44		
FURNISHING		911625.31		
AIR CONDITIONING		391513.19		
ANTI ICING		22219.97		
APU		115601.25		
SYS. INTEGRATION		196949.19		
TOTAL EMPTY MFG. COST			7993726.00	
SUSTAINING ENGINEERI	577845.75			
TECHNICAL DATA	0.0			
PROD. TOOLING MAINT.	698109.75			
MISC.	201090.31			
ENG. CHANGE ORDER	0.0			
QUALITY ASSURANCE	739815.94			
AIRFRAME WARRANTY		510529.31		
AIRFRAME FEE		1608167.00		
AIRFRAME COST			12329283.00	
ENGINE WARRANTY		122974.44		
ENGINE FEE		309895.50		
ENGINE COST			2992359.00	
AVIONICS COST			600000.00	
RESEARCH AND DEVELOPMENT			1738719.00	
TOTAL FLY AWAY COST				17560352.00

ATT CONCEPT EVALUATION
BASE LINE METAL

R AND D	
DEVELOPMENT TECHNICAL DATA	15780498.
DESIGN ENGINEERING	350677760.
DEVELOPMENT TOOLING	213433616.
DEVELOPMENT TEST ARTICLE	42309584.
FLIGHT TEST	35510128.
SPECIAL SUPPORT EQUIPMENT	4208132.
DEVELOPMENT SPARES	33568624.
ENGINE DEVLEOPMENT	0.
AVIONICS DEVLEOPMENT	0.
TOTAL R AND D	695487488.

DIRECT OPERATING COST-DOLLARS/N. MILE		0/0
CREW	0.6220	20.16
AIRFRAME LABOR AND BURDEN MAINT.	0.2366	7.67
ENGINE LABOR AND BURDEN MAINT.	0.1622	5.26
AIRFRAME MATERIAL MAINT.	0.1030	3.34
ENGINE MATERIAL MAINT.	0.1712	5.55
FUEL AND OIL	0.9390	30.43
INSURANCE	0.0901	2.92
DEPRECIATION (INCLUDING SPARES)	0.7619	24.69
TOTAL DOC $/N. MILE	3.0660	100.00

RANGE N. MI	660.	1050.	1440.	1830.	2220.	2610.	3000.
DOC C/ASM	2.0298	1.7979	1.6917	1.6307	1.5912	1.5635	1.5430
TB-HR	1.6289	2.3840	3.1390	3.8941	4.6492	5.4043	6.1593
$/TRP	2678.	3775.	4871.	5968.	7065.	8161.	9258.

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A S S E T   P A R A M E T R I C   A N A L Y S I S

SUMMARY ID NO. 101
OCTOBER 14 1974

AIRCRAFT MODEL --1322-2-1-201
I.O.C. DATE --1974
DESIGN SPEED --SUBSONIC

ENGINE I.D. -- 200000
SLS SCALE 1.0 = 30700
NUMBER OF ENGINES = 3.

WING QUARTER CHORD SWEEP = 36.50 DEG
WING TAPER RATIO = 0.400

1 W/S	135.0	135.0	135.0	135.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2 T/W	0.33	0.32	0.31	0.31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 AR	7.60	7.60	7.60	7.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 T/C	9.40	9.40	9.40	9.40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 RADIUS N. MI	3000	3000	3000	169	0	0	0	0	0	0	0	0	0	0	0	0
6 GROSS WEIGHT	277285	274276	273103	******	0	0	0	0	0	0	0	0	0	0	0	0
7 FUEL WEIGHT	85463	84333	83982	85732	0	0	0	0	0	0	0	0	0	0	0	0
8 OP. WT. EMPTY	151816	149943	149121	149267	0	0	0	0	0	0	0	0	0	0	0	0
9 ZERO FUEL WT.	191816	189943	189121	189267	0	0	0	0	0	0	0	0	0	0	0	0
10 THRUST/ENGINE	30501	29256	28675	28416	0	0	0	0	0	0	0	0	0	0	0	0
11 ENGINE SCALE	0.994	0.953	0.934	0.926	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12 WING AREA	2054.	2032.	2025.	2037.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
13 WING SPAN	124.9	124.3	124.0	124.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14 H. TAIL AREA	455.	447.	444.	449.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
15 V. TAIL AREA	384.	382.	380.	384.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
16 BODY LENGTH	161.2	161.2	161.2	161.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COST DATA--MILLION DOLLARS/AIRCRAFT																
17 FLYAWAY COST	17.809	17.543	17.425	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18 AIRFRAME COST	13.994	13.863	13.805	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19 ENGINE COST	3.036	2.930	2.880	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20 AVIONICS COST	0.600	0.600	0.600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COST DATA--DIRECT OPERATING COST																
21 $ PER MILE	3.125	3.084	3.073	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22 CENTS/A S MILE	1.563	1.544	1.536	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FLIGHT PATH MISSION CHARACTERISTICS																
23 MISSION SYM(1)	36000	36000	36000	0	0	0	0	0	0	0	0	0	0	0	0	0
CONSTRAINT OUTPUT																
24 TAKEOFF DST(1)	7024	7314	7462	0	0	0	0	0	0	0	0	0	0	0	0	0
25 CLIMB GRAD(1)	0.1434	0.1365	0.1316	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26 TAKEOFF DST(2)	7159	7426	7566	0	0	0	0	0	0	0	0	0	0	0	0	0
27 CLIMB GRAD(2)	0.0474	0.0425	0.0401	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28 AP SPEED-KT(1)	132.8	132.8	132.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29 CTOL LNDG D(1)	5567	5583	5581	0	0	0	0	0	0	0	0	0	0	0	0	0
30 AP SPEED-KT(2)	140.7	140.8	140.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31 CTOL LNDG D(2)	6037	6039	6039	0	0	0	0	0	0	0	0	0	0	0	0	0
32 AP SPEED-KT(3)	148.1	148.3	148.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33 CTOL LNDG D(3)	6485	6464	6496	0	0	0	0	0	0	0	0	0	0	0	0	0

ATT CONCEPT EVALUATION
BASELINE COMPOSITE

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CALIFORNIA COMPANY

COST SUMMARY

WING		1680697.00		
TAIL		412326.44		
BODY		2168555.00		
LANDING GEAR		287593.06		
FLIGHT CONTROLS		255752.68		
NACELLES		369370.69		
PROPULSION				
ENGINE	20896.98			
AIR INDUCTION	152919.44			
FUEL SYSTEM	229520.31			
START SYSTEM	4600.67			
ENGINE CONTROLS	2207.28			
EXH/THRUST REV.	4903.87			
LUBE SYSTEM	2355.94			
TOTAL PROPULSION		417404.31		
INSTRUMENTS		99414.06		
HYDRAULICS		146526.69		
ELECTRICAL		500766.50		
ELECTRONIC RACKS		141129.13		
FURNISHING		511961.00		
AIR CONDITIONING		391624.44		
ANTI ICING		22148.17		
APU		119619.94		
SYS. INTEGRATION		195476.00		
TOTAL EMPTY MFG. COST			7921351.00	
SUSTAINING ENGINEERI	571991.56			
TECHNICAL DATA	0.0			
PROD. TOOLING MAINT.	691037.06			
MISC.	199053.06			
ENG. CHANGE ORDER	0.0			
QUALITY ASSURANCE	732320.69			
AIRFRAME WARRANTY		505707.56		
AIRFRAME FEE		1543230.00		
AIRFRAME COST			12214769.00	
ENGINE WARRANTY		122444.63		
ENGINE FEE		301560.25		
ENGINE COST			2879697.00	
AVIONICS COST			600000.00	
RESEARCH AND DEVELOPMENT			1730254.00	
TOTAL FLY AWAY COST				17424944.00

DIRECT OPERATING COST-DOLLARS/N. MILE		O/O
CREW	0.6219	20.24
AIRFRAME LABOR AND BURDEN MAINT.	0.2361	7.68
ENGINE LABOR AND BURDEN MAINT.	0.1617	5.26
AIRFRAME MATERIAL MAINT.	0.1020	3.32
ENGINE MATERIAL MAINT.	0.1704	5.55
FUEL AND OIL	0.9355	30.45
INSURANCE	0.0894	2.91
DEPRECIATION (INCLUDING SPARES)	0.7561	24.61
TOTAL DOC $/N. MILE	3.0730	100.00

RANGE N. MI	660.	1050.	1440.	1830.	2220.	2610.	3000.
DOC C/ASM	2.0208	1.7902	1.6845	1.6258	1.5845	1.5569	1.5365
TB-HR	1.6296	2.3845	3.1595	3.6944	4.6494	5.4043	6.1593
$/TRP	2668.	3760.	4851.	5943.	7035.	8127.	9219.

ATT CONCEPT EVALUATION
BASELINE COMPOSITE

R AND D	
DEVELOPMENT TECHNICAL DATA	15710629.
DESIGN ENGINEERING	349125120.
DEVELOPMENT TOOLING	212531456.
DEVELOPMENT TEST ARTICLE	41894304.
FLIGHT TEST	35367120.
SPECIAL SUPPORT EQUIPMENT	4169500.
DEVELOPMENT SPARES	33296384.
ENGINE DEVLEOPMENT	0.
AVIONICS DEVLEOPMENT	0.
TOTAL R AND D	692113408.

LOCKHEED
CALIFORNIA COMPANY

A S S E T   P A R A M E T R I C   A N A L Y S I S

SUMMARY ID NO. 100
OCTOBER 11 1974

AIRCRAFT MODEL --1322-2-1-205
I.O.C. DATE --1974
DESIGN SPEED --SUBSONIC

ENGINE I.D. -- 205000
SLS SCALE 1.0 = 30700
NUMBER OF ENGINES = 3.

WING QUARTER CHORD SWEEP = 36.50 DEG
WING TAPER RATIO = 0.400

1 W/S	135.0	135.0	135.0	135.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2 T/W	0.33	0.32	0.31	0.31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 AR	7.60	7.60	7.60	7.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 T/C	9.40	9.40	9.40	9.40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 RADIUS N. MI	3000	3000	170	161	0	0	0	0	0	0	0	0	0	0	0	0
6 GROSS WEIGHT	300792	296547	******	******	0	0	0	0	0	0	0	0	0	0	0	0
7 FUEL WEIGHT	93048	91574	78123	78701	0	0	0	0	0	0	0	0	0	0	0	0
8 OP. WT. EMPTY	167744	164973	156176	156298	0	0	0	0	0	0	0	0	0	0	0	0
9 ZERO FUEL WT.	207744	204973	196676	196298	0	0	0	0	0	0	0	0	0	0	0	0
10 THRUST/ENGINE	33087	31631	28874	28416	0	0	0	0	0	0	0	0	0	0	0	0
11 ENGINE SCALE	1.078	1.030	0.941	0.926	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12 WING AREA	2228.	2197.	2037.	2037.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
13 WING SPAN	130.1	129.2	124.4	124.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14 H. TAIL AREA	517.	506.	449.	449.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
15 V. TAIL AREA	443.	433.	384.	384.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
16 BODY LENGTH	161.2	161.2	161.2	161.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COST DATA--MILLION DOLLARS/AIRCRAFT																
17 FLYAWAY COST	18.958	18.622	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18 AIRFRAME COST	14.887	14.704	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19 ENGINE COST	3.255	3.132	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20 AVIONICS COST	0.600	0.600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COST DATA--DIRECT OPERATING COST																
21 $ PER MILE	3.304	3.257	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22 CENTS/A S MILE	1.652	1.629	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FLIGHT PATH MISSION CHARACTERISTICS																
23 MISSION SYM(1)	36000	36000	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CONSTRAINT OUTPUT																
24 TAKEOFF DST(1)	7136	7421	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25 CLIMB GRAD(1)	0.1395	0.1317	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26 TAKEOFF DST(2)	7245	7516	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27 CLIMB GRAD(2)	0.0449	0.0401	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28 AP SPEED-KT(1)	132.8	132.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29 CTOL LNDG D(1)	5593	5589	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30 AP SPEED-KT(2)	140.1	140.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31 CTOL LNDG D(2)	6009	6011	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 AP SPEED-KT(3)	147.0	147.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33 CTOL LNDG D(3)	6425	6433	0	0	0	0	0	0	0	0	0	0	0	0	0	0

ATT CONCEPT EVALUATION
LONG INLET–LONG DUCT–METAL

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CALIFORNIA COMPANY

ATT CONCEPT EVALUATION
LONG INLET—LONG DUCT—METAL

C O S T   S U M M A R Y

WING		2046633.00		
TAIL		473559.63		
BODY		2179925.00		
LANDING GEAR		311704.44		
FLIGHT CONTROLS		273779.13		
NACELLES		433037.44		
PROPULSION				
ENGINE	23462.32			
AIR INDUCTION	250935.25			
FUEL SYSTEM	254786.44			
START SYSTEM	5185.36			
ENGINE CONTROLS	2488.23			
EXH/THRUST REV.	13809.91			
LUBE SYSTEM	2346.31			
TOTAL PROPULSION		553013.63		
INSTRUMENTS		101220.44		
HYDRAULICS		155405.81		
ELECTRICAL		502045.88		
ELECTRONIC RACKS		141166.44		
FURNISHING		510150.56		
AIR CONDITIONING		390174.75		
ANTI ICING		23382.78		
APU		119365.00		
SYS. INTEGRATION		216624.44		
TOTAL EMPTY MFG. COST			8431175.00	
SUSTAINING ENGINEERI	610291.00			
TECHNICAL DATA	0.0			
PROD. TOOLING MAINT.	737307.50			
MISC.	212381.25			
ENG. CHANGE ORDER	0.0			
QUALITY ASSURANCE	781355.44			
AIRFRAME WARRANTY		538625.38		
AIRFRAME FEE		1656669.00		
AIRFRAME COST			13007803.00	
ENGINE WARRANTY		133171.38		
ENGINE FEE		335591.69		
ENGINE COST			3132191.00	
AVIONICS COST			600000.00	
RESEARCH AND DEVELOPMENT			1881822.00	
TOTAL FLY AWAY COST				18621808.00

R AND D	
DEVELOPMENT TECHNICAL DATA	17255264.
DESIGN ENGINEERING	383450624.
DEVELOPMENT TOOLING	229272800.
DEVELOPMENT TEST ARTICLE	44667536.
FLIGHT TEST	37775728.
SPECIAL SUPPORT EQUIPMENT	4601406.
DEVELOPMENT SPARES	35706480.
ENGINE DEVELOPMENT	0.
AVIONICS DEVELOPMENT	0.
TOTAL R AND D	752728576.

DIRECT OPERATING COST-DOLLARS/N. MILE		O/O
CREW	0.6244	19.17
AIRFRAME LABOR AND BURDEN MAINT.	0.2454	7.53
ENGINE LABOR AND BURDEN MAINT.	0.1715	5.26
AIRFRAME MATERIAL MAINT.	0.1092	3.35
ENGINE MATERIAL MAINT.	0.1854	5.69
FUEL AND OIL	1.0170	31.22
INSURANCE	0.0956	2.93
DEPRECIATION (INCLUDING SPARES)	0.8087	24.83
TOTAL DOC $/N. MILE	3.2570	100.00

RANGE N. MI	655.	1046.	1437.	1828.	2218.	2609.	3000.
DOC C/ASM	2.1477	1.8995	1.7863	1.7216	1.6796	1.6502	1.6285
TB-HR	1.6206	2.3772	3.1338	3.8903	4.6469	5.4034	6.1600
$/TRP	2814.	3973.	5133.	6292.	7452.	8612.	9771.

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A S S E T   P A R A M E T R I C   A N A L Y S I S

SUMMARY ID NO. 101
OCTOBER 14 1974

AIRCRAFT MODEL --1-22-2-1-207
I.O.C. DATE --1974
DESIGN SPEED --SUBSONIC

ENGINE I.D. -- 205000
SLS SCALE 1.0 = 30700
NUMBER OF ENGINES = 3.

WING QUARTER CHORD SWEEP = 36.50 DEG
WING TAPER RATIO = 0.400

1 W/S	135.0	135.0	135.0	135.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2 T/W	0.33	0.32	0.31	0.31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 AR	7.60	7.60	7.60	7.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 T/C	9.40	9.40	9.40	9.40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 RADIUS N. MI	3000	3000	170	161	0	0	0	0	0	0	0	0	0	0	0	0
6 GROSS WEIGHT	288040	286544	******	******	0	0	0	0	0	0	0	0	0	0	0	0
7 FUEL WEIGHT	85609	88426	82496	82997	0	0	0	0	0	0	0	0	0	0	0	0
8 OP. WT. EMPTY	155370	156172	152503	152002	0	0	0	0	0	0	0	0	0	0	0	0
9 ZERO FUEL WT.	195370	196172	192503	192002	0	0	0	0	0	0	0	0	0	0	0	0
10 THRUST/ENGINE	31684	30357	29174	28416	0	0	0	0	0	0	0	0	0	0	0	0
11 ENGINE SCALE	1.032	0.985	0.941	0.926	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12 WING AREA	2134.	2118.	2037.	2037.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
13 WING SPAN	127.3	126.6	124.4	124.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14 H. TAIL AREA	483.	474.	449.	449.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
15 V. TAIL AREA	415.	406.	384.	384.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
16 BODY LENGTH	161.2	161.2	161.2	161.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COST DATA--MILLION DOLLARS/AIRCRAFT																
17 FLYAWAY COST	18.327	18.635	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18 AIRFRAME COST	14.387	14.237	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19 ENGINE COST	3.137	3.024	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20 AVIONICS COST	0.600	0.600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COST DATA--DIRECT OPERATING COST																
21 $ PER MILE	3.216	3.176	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22 CENTS/A S MILE	1.608	1.586	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FLIGHT PATH MISSION CHARACTERISTICS																
23 MISSION SYM(1)	36000	36000	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CONSTRAINT OUTPUT																
24 TAKEOFF DST(1)	7159	7445	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25 CLIMB GRAD(1)	0.1393	0.1315	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26 TAKEOFF DST(2)	7273	7546	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27 CLIMB GRAD(2)	0.0448	0.0400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28 AP SPEED-KT(1)	132.6	132.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29 CTOL LNDG D(1)	5578	5574	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30 AP SPEED-KT(2)	140.2	140.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31 CTOL LNDG D(2)	6012	6014	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 AP SPEED-KT(3)	147.4	147.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33 CTOL LNDG D(3)	6446	6453	0	0	0	0	0	0	0	0	0	0	0	0	0	0

ATT CONCEPT EVALUATION
LONG INLET—LONG DUCT—COMPOSITE

LOCKHEED
CALIFORNIA COMPANY

ATT CONCEPT EVALUATION
LONG INLET–LONG DUCT–COMPOSITE

C O S T   S U M M A R Y

WING		1962644.00		
TAIL		442515.31		
BODY		2174677.00		
LANDING GEAR		299444.94		
FLIGHT CONTROLS		264650.00		
NACELLES		415022.50		
PROPULSION				
ENGINE	22502.75			
AIR INDUCTION	181148.31			
FUEL SYSTEM	243309.44			
START SYSTEM	4962.93			
ENGINE CONTROLS	2381.27			
EXH/THRUST REV.	7858.62			
LUBE SYSTEM	2351.52			
TOTAL PROPULSION		464514.69		
INSTRUMENTS		100324.25		
HYDRAULICS		150906.19		
ELECTRICAL		501479.25		
ELECTRONIC RACKS		141172.00		
FURNISHING		511130.63		
AIR CONDITIONING		390959.50		
ANTI ICING		22757.46		
APU		119503.13		
SYS. INTEGRATION		204894.00		
TOTAL EMPTY MFG. COST			8166581.00	
SUSTAINING ENGINEERI	590014.69			
TECHNICAL DATA	0.0			
PROD. TOOLING MAINT.	712811.38			
MISC.	205325.13			
ENG. CHANGE ORDER	0.0			
QUALITY ASSURANCE	755395.81			
AIRFRAME WARRANTY		521506.25		
AIRFRAME FEE		1642744.00		
AIRFRAME COST			12594376.00	
ENGINE WARRANTY		128564.69		
ENGINE FEE		323967.88		
ENGINE COST			3023842.00	
AVIONICS COST			600000.00	
RESEARCH AND DEVELOPMENT			1816650.00	
TOTAL FLY AWAY COST				18034896.00

R AND D	
DEVELOPMENT TECHNICAL DATA	16641964.
DESIGN ENGINEERING	369821440.
DEVELOPMENT TOOLING	221487792.
DEVELOPMENT TEST ARTICLE	43207600.
FLIGHT TEST	36553136.
SPECIAL SUPPORT EQUIPMENT	4437856.
DEVELOPMENT SPARES	34523408.
ENGINE DEVELOPMENT	0.
AVIONICS DEVELOPMENT	0.
TOTAL R AND D	726671872.

DIRECT OPERATING COST-DOLLARS/N. MILL		O/O
CREW	0.6231	19.62
AIRFRAME LABOR AND BURDEN MAINT.	0.2411	7.59
ENGINE LABOR AND BURDEN MAINT.	0.1672	5.27
AIRFRAME MATERIAL MAINT.	0.1057	3.33
ENGINE MATERIAL MAINT.	0.1790	5.63
FUEL AND OIL	0.9840	30.98
INSURANCE	0.0926	2.92
DEPRECIATION (INCLUDING SPARES)	0.7830	24.66
TOTAL DOC $/N. MILE	3.1757	100.00

RANGE N. MI	658.	1048.	1439.	1829.	2219.	2610.	3000.
DOC C/ASM	2.0907	1.8509	1.7412	1.6783	1.6376	1.6090	1.5879
TB-HR	1.6258	2.3814	3.1371	3.8927	4.6483	5.4040	6.1596
$/TRP	2751.	3881.	5010.	6139.	7269.	8398.	9527.

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A S S E T   P A R A M E T R I C   A N A L Y S I S

SUMMARY ID NO. 100
OCTOBER 15 1974

AIRCRAFT MODEL --1322-7-1-207
I.O.C. DATE --1974
DESIGN SPEED --SUBSONIC

ENGINE I.D. -- 207000
SLS SCALE 1.0 = 30700
NUMBER OF ENGINES = 3.

WING QUARTER CHORD SWEEP = 36.50 DEG
WING TAPER RATIO = 0.400

1 W/S	135.0	135.0	135.0	135.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2 T/W	0.33	0.32	0.31	0.31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 AR	7.60	7.60	7.60	7.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 T/C	9.40	9.40	9.40	9.40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 RADIUS N. MI	3467	3467	172	183	0	0	0	0	0	0	0	0	0	0	0	0
6 GROSS WEIGHT	352863	347341	******	******	0	0	0	0	0	0	0	0	0	0	0	0
7 FUEL WEIGHT	131214	128966	81693	82208	0	0	0	0	0	0	0	0	0	0	0	0
8 OP. WT. EMPTY	181649	178374	153306	152791	0	0	0	0	0	0	0	0	0	0	0	0
9 ZERO FUEL WT.	221649	218374	193306	192791	0	0	0	0	0	0	0	0	0	0	0	0
10 THRUST/ENGINE	38814	37049	28874	28416	0	0	0	0	0	0	0	0	0	0	0	0
11 ENGINE SCALE	1.264	1.207	0.941	0.926	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12 WING AREA	2614.	2573.	2037.	2037.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
13 WING SPAN	140.9	139.8	124.4	124.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14 H. TAIL AREA	665.	649.	444.	449.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
15 V. TAIL AREA	573.	558.	384.	384.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
16 BODY LENGTH	161.2	161.2	161.2	161.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COST DATA--MILLION DOLLARS/AIRCRAFT																
17 FLYAWAY COST	21.179	20.760	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18 AIRFRAME COST	16.543	16.305	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19 ENGINE COST	3.732	3.566	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20 AVIONICS COST	0.600	0.600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COST DATA--DIRECT OPERATING COST																
21 $ PER MILE	3.675	3.614	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22 CENTS/A S MILE	1.837	1.807	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FLIGHT PATH MISSION CHARACTERISTICS																
23 MISSION SYM(1)	36000	36000	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CONSTRAINT OUTPUT																
24 TAKEOFF DST(1)	7164	7447	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25 CLIMB GRAD(1)	0.1270	0.1252	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26 TAKEOFF DST(2)	7252	7519	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27 CLIMB GRAD(2)	0.0435	0.0387	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28 AP SPEED-KT(1)	129.6	129.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29 CTOL LNDG D(1)	5431	5429	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30 AP SPEED-KT(2)	136.0	136.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31 CTOL LNDG D(2)	5786	5790	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32 AP SPEED-KT(3)	142.1	142.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33 CTOL LNDG D(3)	6142	6152	0	0	0	0	0	0	0	0	0	0	0	0	0	0

ATT CONCEPT EVALUATION
NEAR SONIC INLET – COMPOSITE

LOCKHEED
CALIFORNIA COMPANY

ATT CONCEPT EVALUATION
NEAR SONIC INLET – COMPOSITE

COST SUMMARY

WING		2446904.00		
TAIL		619149.56		
BODY		2217078.00		
LANDING GEAR		364580.31		
FLIGHT CONTROLS		312855.81		
NACELLES		513303.13		
PROPULSION				
ENGINE	27782.40			
AIR INDUCTION	308892.88			
FUEL SYSTEM	306051.75			
START SYSTEM	6158.22			
ENGINE CONTROLS	2555.45			
EXH/THRUST REV.	9702.42			
LUBE SYSTEM	2338.99			
TOTAL PROPULSION		663881.94		
INSTRUMENTS		105338.38		
HYDRAULICS		175301.38		
ELECTRICAL		507000.50		
ELECTRONIC RACKS		142014.00		
FURNISHING		508774.25		
AIR CONDITIONING		389072.75		
ANTI ICING		26161.31		
APU		119170.94		
SYS. INTEGRATION		234305.63		
TOTAL EMPTY MFG. COST			9344876.00	
SUSTAINING ENGINEERI	677769.00			
TECHNICAL DATA	0.0			
PROD. TOOLING MAINT.	818829.44			
MISC.	235863.63			
ENG. CHANGE ORDER	0.0			
QUALITY ASSURANCE	867747.56			
AIRFRAME WARRANTY		597254.25		
AIRFRAME FEE		1881350.00		
AIRFRAME COST			14423690.00	
ENGINE WARRANTY		152470.44		
ENGINE FEE		364225.25		
ENGINE COST			3586104.00	
AVIONICS COST			600000.00	
RESEARCH AND DEVELOPMENT			2150222.00	
TOTAL FLY AWAY COST				20760000.00

R AND D	
DEVELOPMENT TECHNICAL DATA	19831008.
DESIGN ENGINEERING	440689152.
DEVELOPMENT TOOLING	261835776.
DEVELOPMENT TEST ARTICLE	44577600.
FLIGHT TEST	42868976.
SPECIAL SUPPORT EQUIPMENT	5288269.
DEVELOPMENT SPARES	39998848.
ENGINE DEVELOPMENT	0.
AVIONICS DEVELOPMENT	0.
TOTAL R AND D	860088576.

DIRECT OPERATING COST-DOLLARS/N. MILE		O/O
CREW	0.6410	17.74
AIRFRAME LABOR AND BURDEN MAINT.	0.2602	7.20
ENGINE LABOR AND BURDEN MAINT.	0.1891	5.23
AIRFRAME MATERIAL MAINT.	0.1187	3.28
ENGINE MATERIAL MAINT.	0.2124	5.88
FUEL AND OIL	1.1651	32.24
INSURANCE	0.1085	3.00
DEPRECIATION (INCLUDING SPARES)	0.9188	25.42
TOTAL DOC $/N. MILE	3.6138	100.00

RANGE N. MI	1115.	1507.	1899.	2291.	2683.	3075.	3467.
DOC C/ASM	2.1736	2.0330	1.9505	1.8961	1.8577	1.8291	1.8069
TB-HR	2.6945	3.4534	4.2122	4.9711	5.7300	6.4889	7.2477
$/TRP	4847.	6127.	7407.	8688.	9968.	11249.	12529.

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CALIFORNIA COMPANY

A S S E T   P A R A M E T R I C   A N A L Y S I S

SUMMARY ID NO. 100
MARCH 18 1975

AIRCRAFT MODEL --1322-2-1-200
I.O.C. DATE --1974
DESIGN SPEED --SUBSONIC

ENGINE I.D. -- 200000
SLS SCALE 1.0 = 30700
NUMBER OF ENGINES = 3.

WING QUARTER CHORD SWEEP = 36.50 DEG
WING TAPER RATIO = 0.400

1 W/S	135.0	135.0	135.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2 T/W	0.33	0.32	0.31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 AR	7.60	7.60	7.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 T/C	9.40	9.40	9.40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 RADIUS N. MI	3000	3000	3000	0	0	0	0	0	0	0	0	0	0	0	0	0
6 GROSS WEIGHT	278919	276314	274484	0	0	0	0	0	0	0	0	0	0	0	0	0
7 FUEL WEIGHT	85865	85043	84263	0	0	0	0	0	0	0	0	0	0	0	0	0
8 OP. WT. EMPTY	153054	151271	150221	0	0	0	0	0	0	0	0	0	0	0	0	0
9 ZERO FUEL WT.	193054	191271	190221	0	0	0	0	0	0	0	0	0	0	0	0	0
10 THRUST/ENGINE	30681	29473	28820	0	0	0	0	0	0	0	0	0	0	0	0	0
11 ENGINE SCALE	0.999	0.960	0.939	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12 WING AREA	2066.	2047.	2033.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
13 WING SPAN	125.3	124.7	124.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14 H. TAIL AREA	459.	453.	448.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
15 V. TAIL AREA	393.	387.	383.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
16 BODY LENGTH	161.2	161.2	161.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17 WING FUEL LIMIT	0.628	0.624	0.623	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COST DATA--MILLION DOLLARS/AIRCRAFT																
18 FLYAWAY COST	17.961	17.708	17.560	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19 AIRFRAME COST	14.310	14.159	14.068	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20 ENGINE COST	3.051	2.948	2.892	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21 AVIONICS COST	0.600	0.600	0.600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COST DATA--DIRECT OPERATING COST																
22 $ PER MILE	3.127	3.092	3.072	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23 CENTS/A S MILE	1.563	1.546	1.536	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FLIGHT PATH MISSION CHARACTERISTICS																
24 MISSION SYM(1)	36000	36000	36000	0	0	0	0	0	0	0	0	0	0	0	0	0
CONSTRAINT OUTPUT																
25 TAKEOFF DST(1)	7021	7309	7459	0	0	0	0	0	0	0	0	0	0	0	0	0
26 CLIMB GRAD(1)	0.1434	0.1356	0.1316	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27 TAKEOFF DST(2)	7155	7420	7564	0	0	0	0	0	0	0	0	0	0	0	0	0
28 CLIMB GRAD(2)	0.0474	0.0426	0.0401	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29 AP SPEED-KT(1)	132.8	132.9	132.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30 CTOL LNDG D(1)	5589	5586	5583	0	0	0	0	0	0	0	0	0	0	0	0	0
31 AP SPEED-KT(2)	140.7	140.8	140.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32 CTOL LNDG D(2)	6037	6038	6039	0	0	0	0	0	0	0	0	0	0	0	0	0
33 AP SPEED-KT(3)	148.1	148.2	148.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34 CTOL LNDG D(3)	6485	6490	6494	0	0	0	0	0	0	0	0	0	0	0	0	0

ATT PRELIMINARY DESIGN (IMPROVED COST MODEL)
BASE LINE METAL

LOCKHEED
CALIFORNIA COMPANY

COST SUMMARY

WING		1890159.00		
TAIL		416755.25		
BODY		2169100.00		
LANDING GEAR		289007.94		
FLIGHT CONTROLS		256814.63		
NACELLES		371286.00		
PROPULSION				
ENGINE	21603.37			
AIR INDUCTION	203955.63			
FUEL SYSTEM	230813.44			
START SYSTEM	4625.39			
ENGINE CONTROLS	2219.17			
EXH/THRUST REV.	5026.96			
LUBE SYSTEM	2355.23			
TOTAL PROPULSION		469999.00		
INSTRUMENTS		99518.31		
HYDRAULICS		147043.88		
ELECTRICAL		500819.31		
ELECTRONIC RACKS		141123.44		
FURNISHING		511828.31		
AIR CONDITIONING		391518.19		
ANTI ICING		22219.97		
APU		119601.25		
SYS. INTEGRATION		196949.31		
TOTAL EMPTY MFG. COST			7993729.00	
SUSTAINING ENGINEERI	577845.94			
TECHNICAL DATA	0.0			
PROD. TOOLING MAINT.	698109.88			
MISC.	201090.38			
ENG. CHANGE ORDER	0.0			
QUALITY ASSURANCE	739816.06			
AIRFRAME WARRANTY		510529.38		
AIRFRAME FEE		1608167.00		
AIRFRAME COST			12329285.00	
ENGINE WARRANTY		122974.44		
ENGINE FEE		309895.50		
ENGINE COST			2892359.00	
AVIONICS COST			600000.00	
RESEARCH AND DEVELOPMENT			1738719.00	
TOTAL FLY AWAY COST				17560352.00

ATT PRELIMINARY DESIGN
(IMPROVED COST MODEL)
BASE LINE METAL

R AND D	
DEVELOPMENT TECHNICAL DATA	15780498.
DESIGN ENGINEERING	350677760.
DEVELOPMENT TOOLING	213433616.
DEVELOPMENT TEST ARTICLE	42309600.
FLIGHT TEST	35510128.
SPECIAL SUPPORT EQUIPMENT	4208132.
DEVELOPMENT SPARES	33568624.
ENGINE DEVLEOPMENT	0.
AVIONICS DEVLEOPMENT	0.
TOTAL R AND D	695487488.

DIRECT OPERATING COST-DOLLARS/N. MILE		0/0
CREW	0.6220	20.25
AIRFRAME LABOR AND BURDEN MAINT.	0.2321	7.55
ENGINE LABOR AND BURDEN MAINT.	0.1587	5.17
AIRFRAME MATERIAL MAINT.	0.1011	3.29
ENGINE MATERIAL MAINT.	0.1675	5.45
FUEL AND OIL	0.9390	30.56
INSURANCE	0.0901	2.93
DEPRECIATION (INCLUDING SPARES)	0.7619	24.80
TOTAL DOC $/N. MILE	3.0724	100.00

RANGE N. MI	660.	1050.	1440.	1830.	2220.	2610.	3000.
DOC C/ASM	1.9990	1.7786	1.6776	1.6196	1.5820	1.5557	1.5362
TB-HR	1.6289	2.3840	3.1390	3.8941	4.6492	5.4043	6.1593
$/TRP	2637.	3734.	4831.	5927.	7024.	8121.	9217.

LOCKHEED
CALIFORNIA COMPANY

ASSET PARAMETRIC ANALYSIS

SUMMARY ID NO. 101
MARCH 16 1975

AIRCRAFT MODEL --1322-2-1-200
I.O.C. DATE --1974
DESIGN SPEED --SUBSONIC

ENGINE I.D. -- 200000
SLS SCALE 1.0 = 30700
NUMBER OF ENGINES = 3.

WING QUARTER CHORD SWEEP = 36.50 DEG
WING TAPER RATIO = 0.400

1 W/S	135.0	135.0	135.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2 T/W	0.33	0.32	0.31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 AR	7.60	7.60	7.60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 T/C	9.40	9.40	9.40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 RADIUS N. MI	3000	3000	3000	0	0	0	0	0	0	0	0	0	0	0	0	0
6 GROSS WEIGHT	285712	282606	281119	0	0	0	0	0	0	0	0	0	0	0	0	0
7 FUEL WEIGHT	88903	87769	87237	0	0	0	0	0	0	0	0	0	0	0	0	0
8 OP. WT. EMPTY	156809	154836	153882	0	0	0	0	0	0	0	0	0	0	0	0	0
9 ZERO FUEL WT.	196809	194836	193882	0	0	0	0	0	0	0	0	0	0	0	0	0
10 THRUST/ENGINE	31428	30144	29517	0	0	0	0	0	0	0	0	0	0	0	0	0
11 ENGINE SCALE	1.024	0.982	0.961	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12 WING AREA	2116.	2093.	2082.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
13 WING SPAN	126.8	126.1	125.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14 H. TAIL AREA	477.	469.	465.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
15 V. TAIL AREA	408.	401.	398.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
16 BODY LENGTH	161.2	161.2	161.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17 WING FUEL LIMIT	0.632	0.628	0.627	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COST DATA--MILLION DOLLARS/AIRCRAFT																
18 FLYAWAY COST	18.329	18.051	17.916	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19 AIRFRAME COST	14.614	14.446	14.364	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20 ENGINE COST	3.115	3.006	2.952	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21 AVIONICS COST	0.600	0.600	0.600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COST DATA--DIRECT OPERATING COST																
22 $ PER MILE	3.190	3.152	3.134	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23 CENTS/A S MILE	1.595	1.576	1.567	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FLIGHT PATH MISSION CHARACTERISTICS																
24 MISSION SYM(1)	36000	36000	36000	0	0	0	0	0	0	0	0	0	0	0	0	0
CONSTRAINT OUTPUT																
25 TAKEOFF DST(1)	7011	7296	7444	0	0	0	0	0	0	0	0	0	0	0	0	0
26 CLIMB GRAD(1)	0.1435	0.1356	0.1317	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27 TAKEOFF DST(2)	7140	7404	7545	0	0	0	0	0	0	0	0	0	0	0	0	0
28 CLIMB GRAD(2)	0.0475	0.0426	0.0402	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29 AP SPEED-KT(1)	132.6	132.6	132.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30 CTOL LNDG D(1)	5578	5574	5572	0	0	0	0	0	0	0	0	0	0	0	0	0
31 AP SPEED-KT(2)	140.3	140.4	140.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32 CTOL LNDG D(2)	6015	6017	6017	0	0	0	0	0	0	0	0	0	0	0	0	0
33 AP SPEED-KT(3)	147.5	147.7	147.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34 CTOL LNDG D(3)	6453	6459	6462	0	0	0	0	0	0	0	0	0	0	0	0	0

ATT PRELIMINARY DESIGN
LONG INLET–LONG DUCT–COMPOSITE

LOCKHEED
CALIFORNIA COMPANY

ATT PRELIMINARY DESIGN
LONG INLET—LONG DUCT—COMPOSITE

COST SUMMARY

WING		1937956.00		
TAIL		433609.81		
BODY		2172940.00		
LANDING GEAR		295863.50		
FLIGHT CONTROLS		261968.94		
NACELLES		431870.00		
PROPULSION				
ENGINE	21529.48			
AIR INDUCTION	212473.25			
FUEL SYSTEM	237142.38			
START SYSTEM	4745.61			
ENGINE CONTROLS	2276.94			
EXH/THRUST REV.	6399.94			
LUBE SYSTEM	2352.93			
TOTAL PROPULSION		486920.38		
INSTRUMENTS		100054.00		
HYDRAULICS		149586.06		
ELECTRICAL		501262.63		
ELECTRONIC RACKS		141164.69		
FURNISHING		511395.19		
AIR CONDITIONING		391171.38		
ANTI ICING		22573.88		
APU		119540.31		
SYS. INTEGRATION		201839.94		
TOTAL EMPTY MFG. COST			8159722.00	
SUSTAINING ENGINEERI	590681.06			
TECHNICAL DATA	0.0			
PROD. TOOLING MAINT.	713616.38			
MISC.	205557.00			
ENG. CHANGE ORDER	0.0			
QUALITY ASSURANCE	756248.94			
AIRFRAME WARRANTY		521291.13		
AIRFRAME FEE		1642066.00		
AIRFRAME COST			12589181.00	
ENGINE WARRANTY		125514.50		
ENGINE FEE		316296.44		
ENGINE COST			2952101.00	
AVIONICS COST			600000.00	
RESEARCH AND DEVELOPMENT			1775025.00	
TOTAL FLY AWAY COST				17916304.00

R AND D	
DEVELOPMENT TECHNICAL DATA	16115707.
DESIGN ENGINEERING	358126848.
DEVELOPMENT TOOLING	217759296.
DEVELOPMENT TEST ARTICLE	43231440.
FLIGHT TEST	36195152.
SPECIAL SUPPORT EQUIPMENT	4297521.
DEVELOPMENT SPARES	34285296.
ENGINE DEVLEOPMENT	0.
AVIONICS DEVLEOPMENT	0.
TOTAL R AND D	710009856.

DIRECT OPERATING COST-DOLLARS/N. MILE		0/0
CREW	0.6227	19.87
AIRFRAME LABOR AND BURDEN MAINT.	0.2354	7.51
ENGINE LABOR AND BURDEN MAINT.	0.1610	5.14
AIRFRAME MATERIAL MAINT.	0.1032	3.29
ENGINE MATERIAL MAINT.	0.1709	5.45
FUEL AND OIL	0.9713	30.99
INSURANCE	0.0920	2.93
DEPRECIATION (INCLUDING SPARES)	0.7774	24.81
TOTAL DOC $/N. MILE	3.1338	100.00

RANGE N. MI	658.	1048.	1438.	1829.	2219.	2610.	3000.
DOC C/ASM	2.0408	1.8147	1.7113	1.6521	1.6137	1.5868	1.5669
TB-HR	1.6250	2.3807	3.1365	3.8922	4.6479	5.4036	6.1594
$/TRP	2684.	3804.	4923.	6043.	7162.	8282.	9401.

REFERENCES

1. Revell, J.D.; Healy, G.J.; and Gibson, J.S.: Methods for Prediction of Airframe Aerodynamic Noise Paper. 75-539, AIAA, March 24 - 26, 1975.

2. Softrin, T.G.: Experience in Compressor Noise Reduction. Pratt and Whitney Company Report, 1966.

3. Tyler, J.M.; and Sofrin, T.G.: Axial Flow Compressor Noise Studies. S.A.E. 345D, 1961.

4. Wirt, L.S.: Design, Testing, and Analysis of Lined Ducts. J. Acoust. Soc. Am. Vol 51 #5 part 1, May 1972.

5. Feder, E.; and Dean, L.W.: Analytical and Experimental studies for Predicting Noise Attenuation in Acoustically Treated Ducts for Turbofan Engines. NASA CR 1373, Sept. 1969.

6. Feiler, C.E.; and Merriman, J.E.: Effects of Forward Velocity and Acoustic Treatment on Inlet Fan Noise. Paper 74-946, AIAA, Aug. 12 - 14, 1974.

7. Wirt, L.S.: Sound AbsorPtive Materials to Meet Special Requirements. J. Acoust. Soc. Am. Vol 57 #1, Jan. 1975.

8. Ffowcs - Williams, J.E.: The Acoustics of Turbulence Near Sound - Absorbent Liners. J. Fluid Mech. Vol 51 part 4 1972.

9. Eversman W.; and Beckmeyer, R.J.: Transmission of Sound in Ducts with Thin Shear Layers - Convergence to the Uniform Flow Case. J. Acoust. Soc. Am. Vol 52 #1 part 2 July 1972.

10. Pickett, G.F.: Core Engine Noise Due to Temperature fluctuations Convecting Through Turbine Blade Rows. Paper 75-528, AIAA, March, 1975.

11. Balombin, J.R.; and Stakolich, E.G.: Effect of Rotor to Stator Spacing on Acoustic Performance of a Full Scale Fan (QF-5) for Turbofan Engines. NASA TMX - 3103.

12. Healy, G.J.: Measurement and Analysis of Aircraft Far-Field Aerodynamic Noise. NASA CR-2377, Dec. 1974.

13. Lowrie, B.W.: Simulation of Flight Effects on Aero Engine Fan Noise. Paper 75-463, AIAA, March, 1975.

14. Advanced Composites Design Guide: Advanced Development Division, Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio, Air Force Systems Command.

15. Assessment of the Application of Advanced Technologies to Subsonic CTOL Transport Aircraft, United Airlines, Inc., San Francisco, California. (NAS 1-11751)

16. Revision to 1969 Lockheed/Boeing Indirect Operating Expense Method, Lockheed-California Company, COA 2061, July 1974

17. Indirect Operating Expense Coefficients, Lockheed-California Company, June 1973, COA/1277.