NASA CR-134797
BCAC D6-42440-1

PHASE II PROGRAM ON GROUND TEST OF REFANNED JT8D TURBOFAN ENGINES AND NACELLES FOR THE 727 AIRPLANE

Final Report

VOLUME I
SUMMARY

December 1975

Boeing Commercial Airplane Company
Seattle, Washington 98124

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA Lewis Research Center
Contract NAS3-17842

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CR-134797		
4. Title and Subtitle PHASE II PROGRAM ON GROUND TEST OF REFANNED JT8D TURBOFAN ENGINES AND NACELLES FOR THE 727 AIRPLANE-FINAL REPORT–VOLUME I, SUMMARY		5. Report Date December 1975
		6. Performing Organization Code
7. Author(s)		8. Performing Organization Report No. D6-42440-1
		10. Work Unit No.
9. Performing Organization Name and Address Boeing Commercial Airplane Company P.O. Box 3707 Seattle, Washington 98124		11. Contract or Grant No. NAS3-17842
		13. Type of Report and Period Covered Contractor Report
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

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16. Abstract

This report summarizes the investigative efforts required to evaluate the propulsion performance, acoustic, structural, and systems changes to a 727-200 airplane retrofitted with a refan modification of the JT8D turbofan engine. The program included: model tests; design of certifiable airplane retrofit kit hardware; manufacture of test hardware; ground test of a current production JT8D engine, followed by test of the same engine modified to the refan configuration; detailed analyses of the retrofit impact on airplane airworthiness, performance, and noise; and a preliminary analysis of retrofit costs.

The program results indicate that the refan retrofit of the 727-200 would be certifiable and would result in a 6- to 8-EPNdB reduction in effective perceived noise level (EPNL) at the FAR 36 measuring points and an annoyance-weighted footprint area reduction of 68% to 83%. The installed refan engine is estimated to provide 14% greater takeoff thrust at zero velocity and 10% greater thrust at 100 kn (51.4 m/s). There would be an approximate 0.6% increase in cruise specific fuel consumption (SFC). The refan engine performance in conjunction with the increase in installed weight results in a range reduction of approximately 15% over the unmodified airplane at the same brake release gross weight (BRGW), with a block fuel increase of 1.5% to 3%. With the particular model 727 that was studied, however, it is possible to operate the airplane (with minor structural modifications) at a higher BRGW and increase the range up to approximately 15% relative to the non-refanned airplane (with equal or slightly increased noise levels). The JT8D refan engine also improves the limited-field range of the airplane. The cost of the refan retrofit is estimated to be approximately $2 million per airplane in 1974 dollars.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
JT8D refan Community noise 727-200 refan retrofit	Unclassified–unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	54	

* For sale by the National Technical Information Service, Springfield, Virginia 22151

NASA-C-168 (Rev. 6-71)

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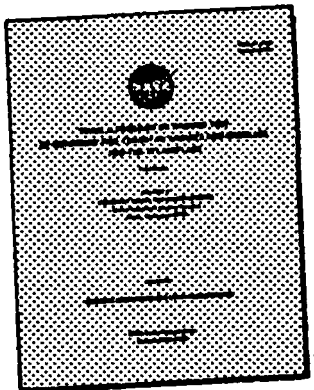
OVERALL REPORT ORGANIZATION



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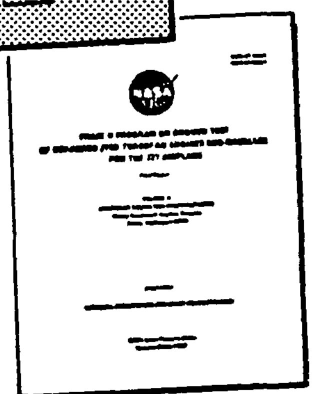

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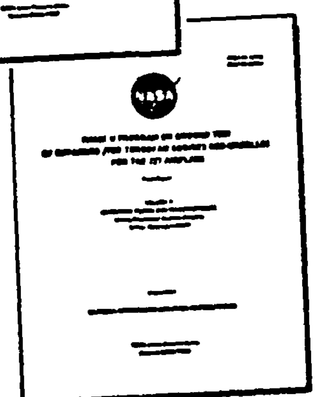

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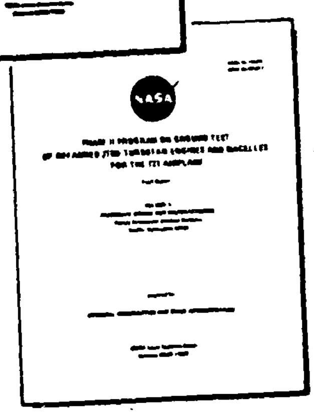

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1.0 SUMMARY

The objective of Phase II of the NASA-sponsored Refan Program was to evaluate the technical feasibility of retrofitting JT8D refan engines on a 727-200 airplane in terms of airworthiness, performance, noise, and modification cost. The scope of work included the design and analysis of an acoustically treated, certifiable, refan engine installation for the 727, together with manufacture and ground testing of the essential hardware. This document, Volume I, presents a summary of the work completed during Phase II of the Refan Program (NASA contract NAS3-17842).

The retrofit installation of the JT8D refan engine on the 727-200 was designed to minimize changes to the existing airframe and to provide for the requirements of airplane safety, reliability, durability, maintainability, and fleet operational suitability. Because of the increased size and weight of the JT8D refan engine, special attention was given to the use of advanced structural design and materials to minimize the weight of the installation. The following list identifies the major hardware included in the design effort:

1. Side-engine nacelle including inlet, cowls, exhaust system, thrust reverser, engine mounts, and engine installation hardware details within the nacelle

2. Center-engine inlet duct, aircraft structure modifications to accommodate the new larger duct, engine mounts, supporting structure, aft-body fairings, center-engine cowls, and tail-skid revision

3. Engine and thrust-reverser control adaptation and instrumentation adjustments

The design, model tests, associated studies, and reviews substantiated the technical credibility of the refan retrofit concept, and the manufacturing of the test components demonstrated the producibility of the design and the manufacturing techniques required for production of refan unique materials usage. The use of titanium for the exhaust system for example, would yield approximately a 1000-lb (4536-kg) saving per airplane in weight as compared to Inconel which is a typical production material. The capability of the design to be certified could only be partially demonstrated through analysis and test because of the scope of the program; however, it was judged that the refan engine installation and airplane would be certifiable based on Contractor data generated outside of this program. The major components fabricated for this program included a flightworthy center-engine inlet duct and exhaust system, and a non-flightworthy (ground test only) side-engine inlet.

Full-scale static ground tests were conducted to determine and compare JT8D (baseline) and JT8D refan engine performance and noise characteristics. Data were taken to determine (1) the installed JT8D refan engine performance, including the performance increments for the inlets and exhaust systems, and (2) the component noise differences between the two engines in order to develop (through analytical methods) predicted in-flight performance and noise increments that were subsequently applied to a known flight data base. In addition, data were

acquired for evaluation of the nacelle acoustic treatment effectiveness of the refan engine installation, to define the compatibility of the inlets with the JT8D refan engine in terms of engine surge margin, and to evaluate the design loads for the JT8D refan center-engine inlet duct, exhaust duct, and fan/primary flow divider.

The baseline engine for this test program was a model JT8D-15, and testing included basic engine performance calibrations with reference hardware and engine performance with production hardware with bellmouth inlet lips. The acoustic testing included acquisition of far-field component noise data using baffles to isolate noise sources.

Testing of the JT8D-115 engine (the refan version of the baseline engine) included acquisition of data to evaluate the performance and noise characteristics associated with flight-type engine installations including: the side-engine inlet both with and without an acoustically treated inlet ring; the center-engine inlet; and two exhaust system configurations (differing only in the fan/primary flow divider design which varied the amount of acoustic treatment). Inlet pressure surveys and crosswind testing were conducted to measure inlet recovery, inlet pressure distortion, and engine surge margin characteristics. In addition, the static (zero crosswind) engine surge margins were determined with the side inlet (without a ring) and the center-engine inlet. Acoustic testing included acquisition of far-field component noise data (using baffles to isolate noise sources) and near-field noise data (through use of flush-mounted microphones) in the inlet and exhaust system.

To evaluate some of the structural design criteria, the center-engine inlet duct was instrumented to measure skin stresses, duct wall and engine seal deflections, and internal pressures. Exhaust duct and fan/primary flow divider surface temperatures were also measured during cold start, maximum acceleration to takeoff power, and engine shutdown.

Analysis of propulsion data recorded during the ground test indicated that the JT8D-115 engine, as compared to the JT8D-15 engine, demonstrated a 12.5% to 13.2% reduction in static specific fuel consumption (SFC) for the side-engine inlets, with and without acoustic ring, at takeoff thrust.

Analysis of component noise data showed that the fully treated JT8D-115 engine (and nacelle) produced a reduction of 6 to 7 PNdB in a weighted average value of tone-corrected perceived noise level (PNLTW), relative to the JT8D-15 hardwall engine compared at equal static thrust. Separated into noise components, the JT8D-115 showed significant noise reduction in inlet fan noise, aft fan noise, exhaust duct flow noise, turbine noise, and jet noise relative to the JT8D-15; however, core noise was increased.

Analysis of center-engine inlet-duct wall pressure data indicated up to 3% lower stabilized static pressures and up to 19% higher surge pressures (extrapolated to altitude conditions) than predicted by model tests and duct flow analyses. All temperatures measured in the exhaust system were within the maximum design allowable temperature limitations (for the Inconel and titanium assemblies).

Extensive analyses were conducted using the full-scale test results to predict the 727 refan airplane noise and performance characteristics relative to a baseline 727-200 at a brake release gross weight (BRGW) of 172 500 lb (78 245 kg). The 727 refan was evaluated at this BRGW and at a practical weight growth limit to assess the maximum range potential of this particular model 727-200.

The 727 refan at a BRGW of 172 500 lb (78 245 kg) loses about 15% in range performance relative to the 727-200 at sea level (SL) takeoff and an unlimited field length. It was estimated that a 727 refan at the higher BRGW of 182 500 lb (82 781 kg) would provide a 15% *increase* in range relative to the baseline 727-200. The refan airplane block fuel, however, is estimated to be 1.5% to 3% higher than the 727-200 airplane for the various range-payload missions studied.

The 727 refan noise levels for a BRGW of 172 500 lb (78 245 kg) were estimated to be 6 to 8 EPNdB lower than for the 727-200. At cutback and sideline conditions, the 727 refan noise levels would be significantly below Federal Aviation Regulation (FAR) Part 36, and the refan airplane would be expected to meet the FAR 36 certification requirements without resorting to thrust cutback on takeoff. The 727 refan would also reduce a takeoff and landing annoyance-weighted footprint area by 68% to 83% relative to the 727-200.

It is estimated that the JT8D refan engine thrust reverser (a target type scaled from the 737 airplane) would provide a stopping capability comparable to the baseline 727-200 airplane. Additional analyses and tests would be required to completely evaluate rudder effectiveness during thrust reverser operation.

The installed takeoff thrust capability of the JT8D refan was estimated to be 14% higher at zero forward velocity and 10% greater at 100 kn (51.4 m/s) than the installed baseline engine. The 727 refan three-engine installed SFC at Mach 0.84 and 30 000 ft (9144 m) at a nominal cruise thrust of 4050 lb (18 015 N) was estimated to be 0.6% higher than the comparable value for the installed baseline engine.

Structural strength and fatigue requirements for the refan installation hardware were analyzed, and materials (type, size, and geometry) used in the design were selected to meet those requirements. All hardware for which the design was finalized would meet certification requirements.

Airplane weight and balance requirements were assessed, and fixed ballast was chosen as the most logical technique to correct the center-of-gravity (c.g.) changes that would result from the JT8D refan engine installation.

The 727 refan stability and control requirements were analyzed, and it is estimated that the longitudinal and lateral-directional stability and control characteristics would be similar to those of the 727-200 and would meet airworthiness requirements.

A preliminary cost estimate for refan modification including engine and airplane retrofit hardware and installation would approximate $2 million per airplane in 1974 dollars for an assumed U.S. 727 fleet size of 669 airplanes including both -100 and -200 series.

2.0 INTRODUCTION

The NASA Refan Program was initiated in August 1972 with the objective of evaluating the technical feasibility of JT3D and JT8D refanned engine installations on the appropriate 707, DC-8, 727, 737, and DC-9 airplanes to reduce aircraft noise with minimum total cost. The refan concept consists of (1) modifications of the JT3D and JT8D engines to reduce the jet noise, (2) application of nacelle noise suppression treatment, and (3) modification to existing airplanes to accept the redesigned engines and nacelles. The major feature of the engine modification is the replacement of the two-stage fan of the existing engines with a single-stage fan of larger diameter, thereby providing both an increase in engine performance (through increase in bypass ratio) and a reduction in jet noise (through lower jet velocity). Participants in the program were the Boeing Commercial Airplane Company, Douglas Aircraft Company, Pratt & Whitney Aircraft (P&WA), United Air Lines, and American Airlines. Each contractor operated under separate contract from NASA.

The Boeing Company Phase I work was conducted under NASA contract NAS3-16815, which resulted in a definition of engine, nacelle, and airplane modifications for the JT3D and JT8D refan enfine installations on the 707, 727, and 737 airplanes. In January 1973, program funding curtailment forced limitation of the scope of the program to only one model of engine. The decision was made to proceed with the JT8D engine rather than the JT3D, although there was no technical reason for discontinuing further work on the JT3D engine. Rather, the JT8D engine was selected because the aircraft it powers accounted for about 60% of the domestic airline fleet and for over 70% of the takeoffs and landings. Budget constraints also required cancellation of the 737 airplane portion of the remaining JT8D program. Work accomplished during Phase I is reported in reference 1.

The Contractor's Phase II work was conducted under NASA contract NAS3-17842, which was a direct follow-on to the Phase I contract. Phase II provided for the design, manufacture, ground test, and analysis of full-scale flightworthy hardware to assess the technical feasibility of the 727/JT8D refan configuration selected for development in the Phase I program.

The final report for Phase II has been prepared in four volumes, reporting the results of the work accomplished during the contract period of performance from July 12, 1973 to November 30, 1975.

Volume I, *Summary* provides an overview of the work completed, including summary discussions on hardware design with reference to the model tests, manufacturing, ground tests, airplane evaluation and analysis, and preliminary estimates of retrofit kit costs in 1974 dollars.

Volume II, *Hardware Design and Manufacturing* (ref. 2) provides a technical description of the flightworthy design and describes the manufacture of hardware built to support full-scale ground tests.

Volume III, *Ground Tests* (ref. 3) provides the propulsion, noise, and structural results of full-scale ground tests of the JT8D-15 and JT8D-115 engines including inlet and exhaust system hardware.

Volume IV, *Airplane Evaluation and Analysis* (ref. 4) presents the performance, noise, and airworthiness evaluations of the 727-200/JT8D refan airplane.

A typical version of the current production model 727-200 airplane was selected as the baseline model in the evaluation of the refan concept. Likewise, the current production P&WA JT8D-9 and -15 engines were used as baseline models. The corresponding derivatives were the JT8D-109 and -115 engines. The JT8D-9 was selected as the baseline in the analysis of the 727 refan airplane because of its wide usage in the current airplane fleet. A new JT8D-15 engine was used as the baseline in the full-scale ground tests because of availability of this engine from the Contractor's inventory at greatly reduced program costs compared to obtaining a JT8D-9 engine. The JT8D-109 performance and noise characteristics were analytically derived from the JT8D-115 ground test data.

Two side-engine nacelles with different acoustic treatment configurations were designed, manufactured, and tested. The maximum treatment nacelle was chosen by NASA as a basis for analyzing the detailed performance and noise increments of the 727 refan from the 727-200. This maximum treatment nacelle is characterized by an inlet with peripheral lining and a treated ring, a peripheral lining in the exhaust duct, and a treated splitter between the fan and primary exhaust flows. While this configuration would provide the greatest noise reduction, further studies would be required to assess the cost effectiveness of a ring in the inlet and the amount and type of treatment in the remainder of the nacelle. The minimum treatment configuration differed only in the deletion of the inlet ring and a hardwall version of the fan/primary flow divider.

The center-engine nacelle installation had an acoustically treated inlet duct (without ring) with the same exhaust system treatment as the side engine.

The Phase II program used the English system of measurements, with conversion to the International System of Units (SI) (ref. 5) for this report where applicable. The SI units will be found in parentheses following the English units, in additional columns, or as secondary scales where appropriate.

3.0 DISCUSSION

The Phase II Refan Program included:

- The design of flightworthy certifiable hardware associated with the installation of JT8D refan engines on a 727-200 airplane, and the performance of a number of model and structural tests in support of this design
- The manufacture of hardware in support of the full-scale ground tests
- Full-scale ground tests involving a JT8D-15 (baseline) and a JT8D-115 (refan) engine
- The performance and noise evaluation of a 727-200 airplane equipped with JT8D-109 (refan) engines (derived through analyses of full-scale ground test results)
- Preliminary Retrofit Kit Cost estimate in 1974 dollars

The following subsections present discussions of these subjects.

3.1 HARDWARE DESIGN AND MANUFACTURING

The design effort to support the installation of a refan engine on the 727-200 encompassed engine-associated hardware, airplane systems, and structure. There was no direct effect on the wing structure, but several modifications were required in the body and vertical fin, as well as to the airplane hydraulic, electrical, and control systems (fig. 1).

The primary design effort was expended in the powerplant installation. Complete production design was accomplished on the side-engine installation (fig. 2) and center-engine inlet and duct (fig. 3), and partial design for the remaining airplane modifications. The partial design effort was carried to the point that the technical feasibility of the required changes was assured; such changes were judged certifiable based on Contractor data generated outside of this program.

A full-scale mockup (figs. 4 and 5) of a side-engine installation was constructed as an aid in the installation design process to display relative locations of the nacelle components.

The objective of the manufacturing effort was to fabricate flightworthy, certifiable hardware to production engineering requirements using normal production practices and facilities while minimizing cost where feasible by the use of soft or expendable tools. The flightworthy, certifiable components fabricated for this program were an exhaust system and a center-engine inlet-duct assembly. To reduce costs, a nonflightworthy side-engine inlet assembly was manufactured. Work on the side-engine side cowls and the thrust reverser was not completed due to funding limitations.

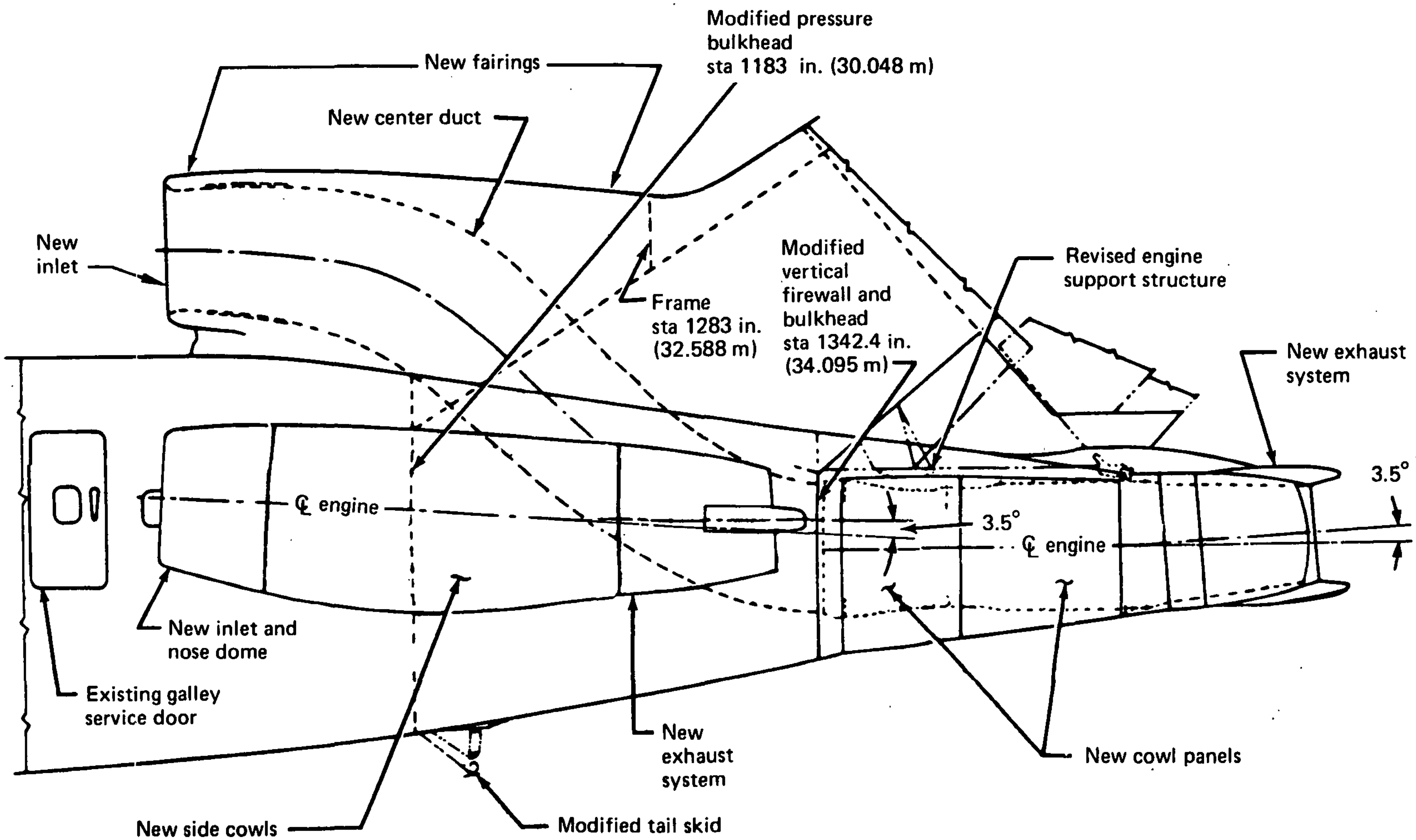

Figure 1. —727 JT8D Refan Engine Installation—Side- and Center-Engine Nacelles

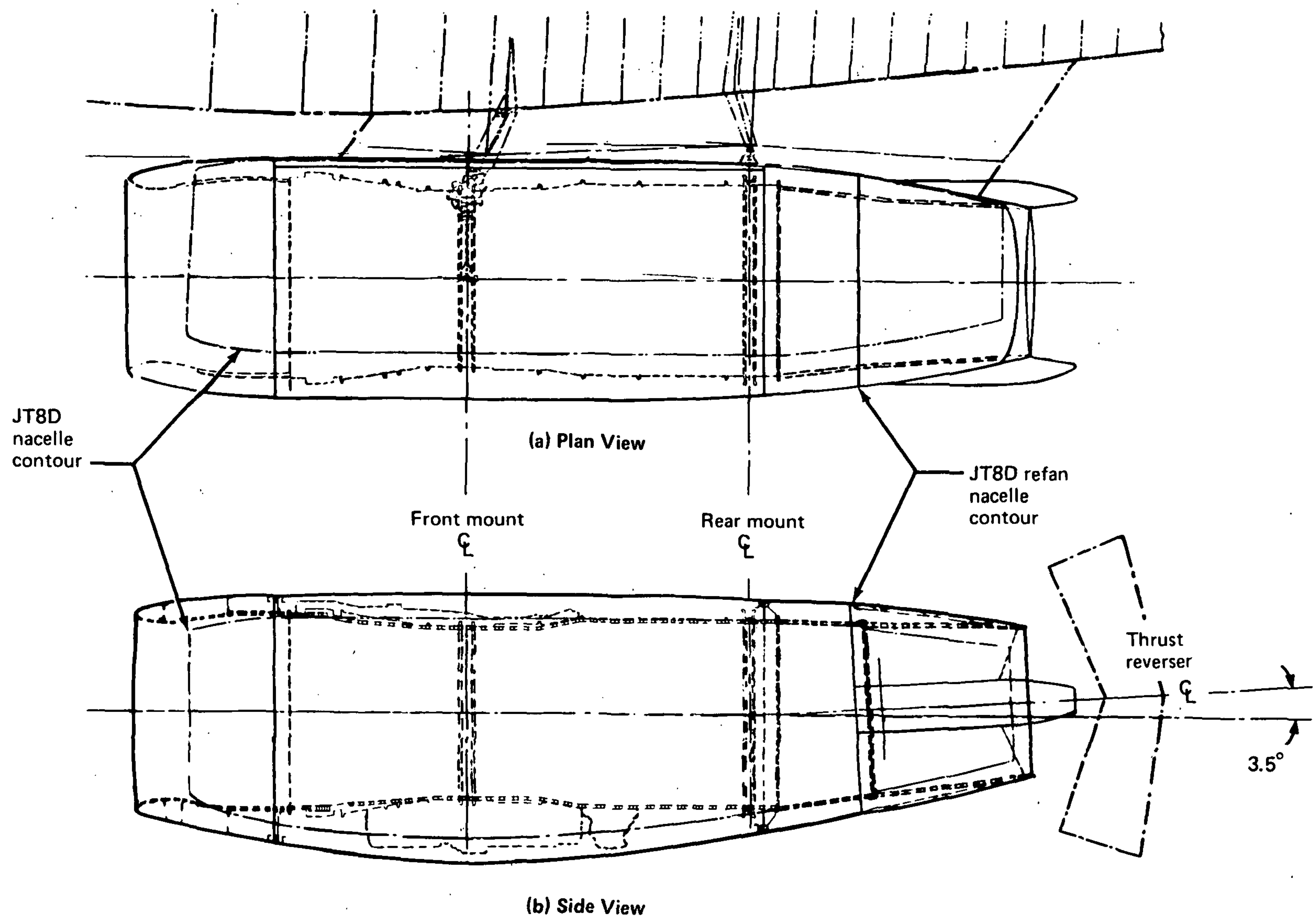

Figure 2.—Comparison of Side-Engine Nacelle Installation for JT8D and JT8D Refan Engines

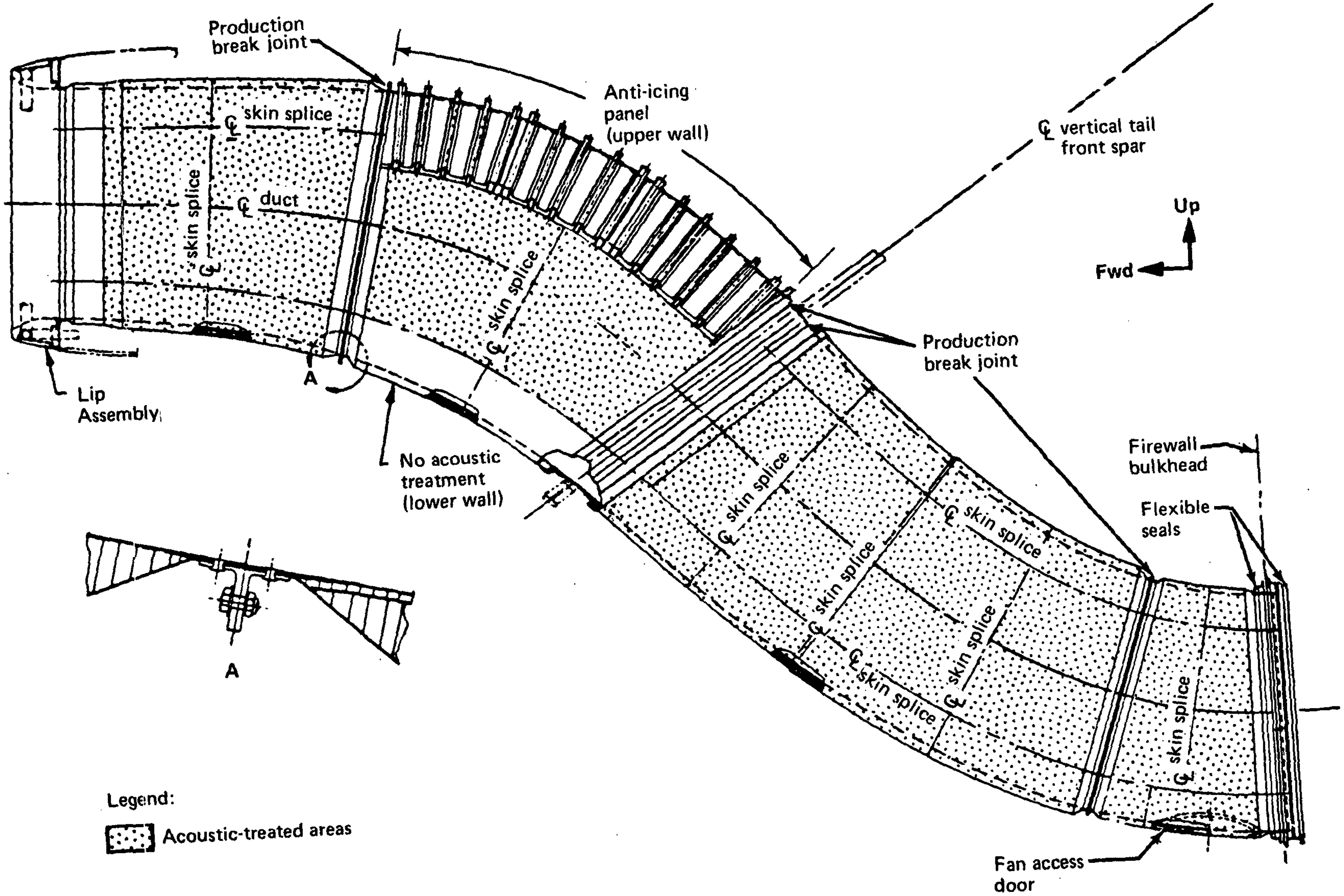

Figure 3.—JT8D Refan Center-Engine Inlet Duct

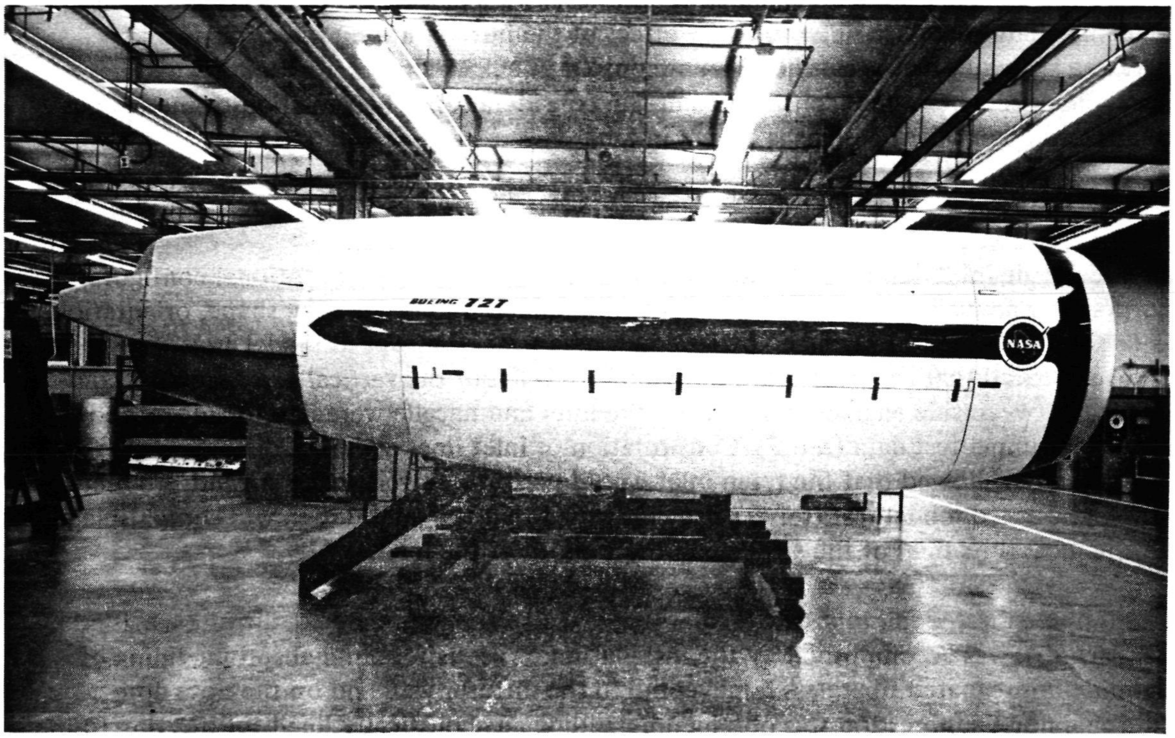

Figure 4.—Refan Side-Engine Nacelle Mockup

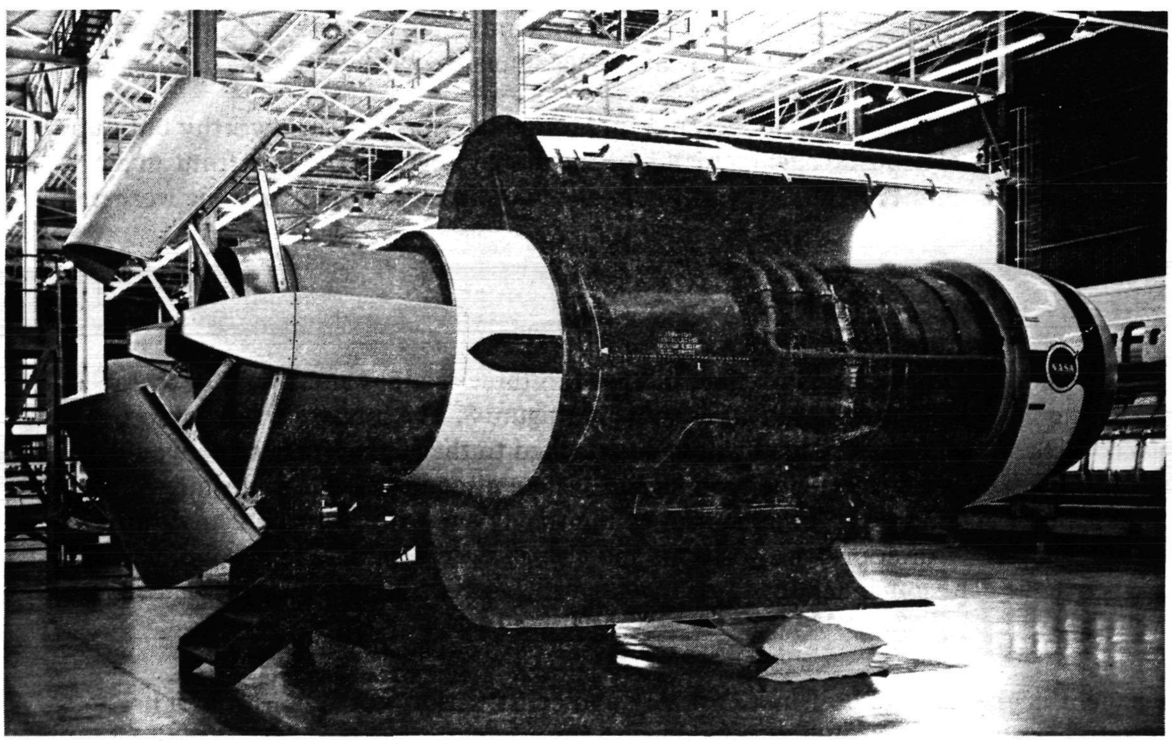

Figure 5.—Refan Side-Engine Nacelle Mockup With Side Cowls Open

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During the design period, model and structural tests were performed to define the refan engine installation and to determine the effect of the installation on the airplane and associated systems. These tests have been reported in NASA Contractor Reports and have been referenced where they constitute a design consideration. Their relation to the various airplane and component designs is shown in table 1.

3.1.1 SIDE-ENGINE INLET

The side-engine inlet designed for the refan engine (fig. 6) was of conventional configuration incorporating acoustic panels to reduce forward-radiated noise. The inlet shape, orientation, and configuration were influenced by several model tests. High-speed model scale drag tests (ref. 6) indicated that the inlet could be symmetrical about the vertical axis, allowing commonality between side engines. Airloads on the inlet and nacelle were developed from low-speed wind tunnel test data (ref. 7). Confirmation of inlet lines and inlet distortion characteristics (ref. 8) showed that the refan inlet would perform as well as the current production inlet. A low-speed model test (ref. 9) also confirmed that the inlet design was compatible with the local flow field of the airplane in the vicinity of the inlet.

Noise suppression for fan tones, particularly at the airplane approach condition (specified by FAR Part 36), was accomplished by the installation of acoustic sound-absorbing lining of polyimide-impregnated fiberglass honeycomb in the diffuser wall and on the nose dome. Additional noise suppression was obtained by adding an acoustically lined splitter ring to the side-engine inlet (fig. 7). The inlet was configured to permit operation with and without the ring installed.

The length-to-diameter ratio of the inlet is 0.80 and was constrained by considerations of weight and proximity to the airplane aft service door. Hot air anti-icing for the inlet lip, nose dome, and ring is provided by engine-bleed air in a manner similar to the current 727-200 inlet.

The side engine inlet that was manufactured for ground test was not flightworthy but duplicated propulsion and acoustic characteristics of the design judged certifiable from an air worthiness view point. Provisions for anti-icing the inlet lip, nose dome, and ring were not provided.

3.1.2 COWL PANELS

The cowl panels on the side engines were designed in three sections and would be installed between the inlet and exhaust systems as shown in figure 8. The inboard fixed section adjacent to the engine support strut would be attached to the engine frames and would include access panels for the engine mounts and system disconnects. The remaining sections were designed to be hinged together and/or to the fixed cowl with removable hinge pins that allowed for a variety of door open positions and also allowed complete removal of panels from the engine. The upper and lower removable panels would be interchangeable between side engines.

The panel thickness would be 1 in. (2.54 cm), and construction would consist of a heat-resistant phenolic honeycomb core bonded with inner and outer skins of 0.02-in. (0.58-mm) 2-ply structural glass fabric. A stainless steel wire mesh fire barrier was designed to be

Table 1.—Model and Component Test Influence on Design

Test report	Test scope			Side-engine inlet	Side-engine side cowls	Exhaust duct	Thrust reverser	Center-engine inlet duct	Engine location
	Purpose	Type	Scale						
Ref. 6	Drag evaluation	High-speed wind tunnel	Model	◆	◆				◆
Ref. 7	Airload development	Low-speed wind tunnel	Model	◆	◆				
Ref. 8	Inlet performance	Low-speed wind tunnel	Model	◆					
Ref. 9	Inlet flow field evaluation	Low-speed wind tunnel	Model	◆				◆	
Ref. 10	Nozzle performance	Thrust measurement	Model			◆			
Ref. 11	Nozzle acoustic performance	Noise measurement	Model			◆			
Ref. 12	Thrust reverser static performance	Thrust measurement	Model			◆	◆		
Ref. 13	Structures material evaluation	Load and fatigue	Full-scale samples			◆			
Ref. 14	Thrust reverser effect on stability and control	Low-speed wind tunnel	Model				◆		
Ref. 15	Thrust reverser reingestion limit	Low-speed wind tunnel	Model				◆		
Ref. 16	Center engine inlet performance	Low-speed wind tunnel	Model					◆	
Ref. 17	Low speed stability and control	Low-speed wind tunnel	Model						◆
Ref. 18	High-speed stability and control	High-speed wind tunnel	Model						◆

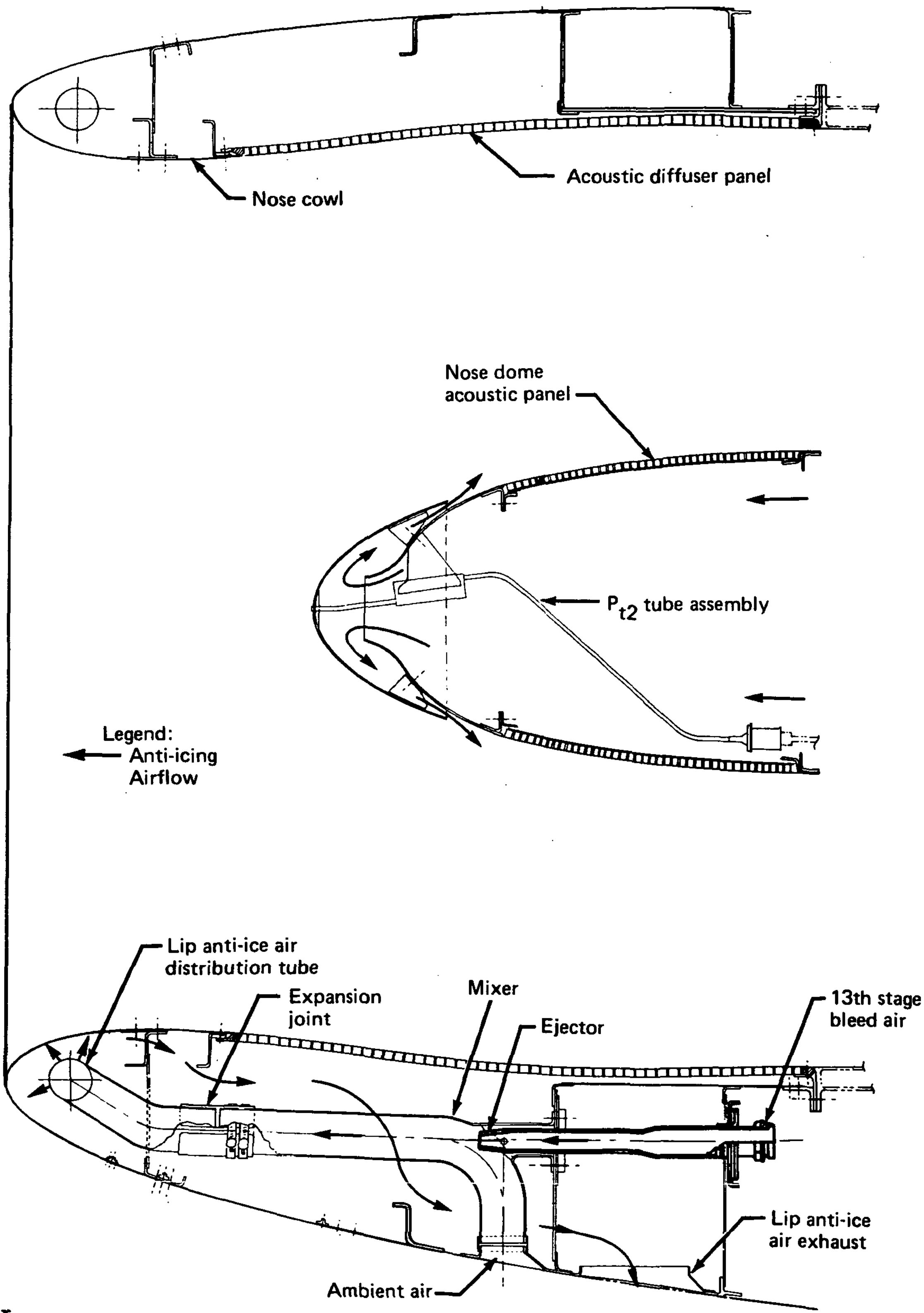


Figure 6.—JT8D Refan Side-Engine Inlet Construction

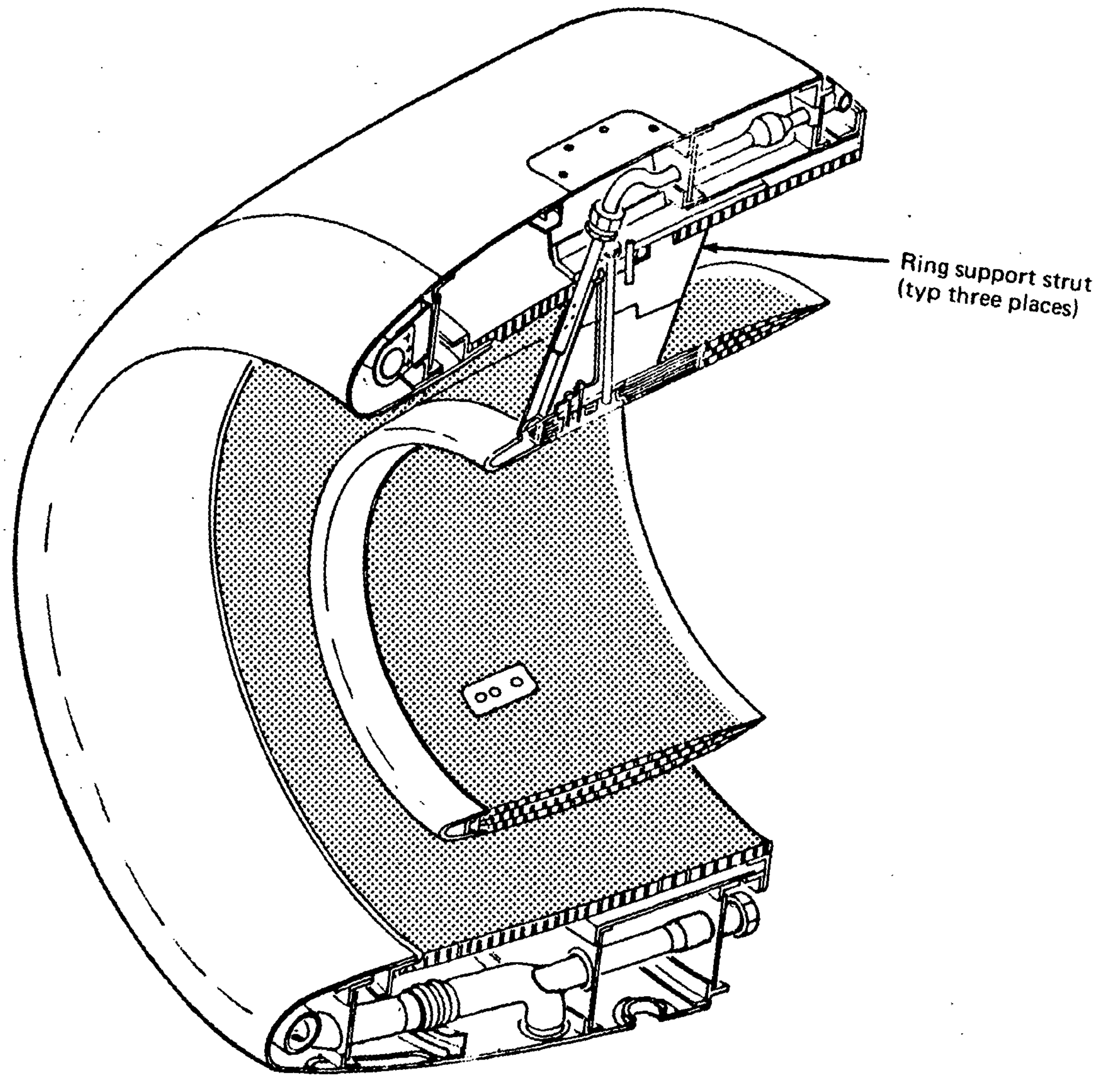
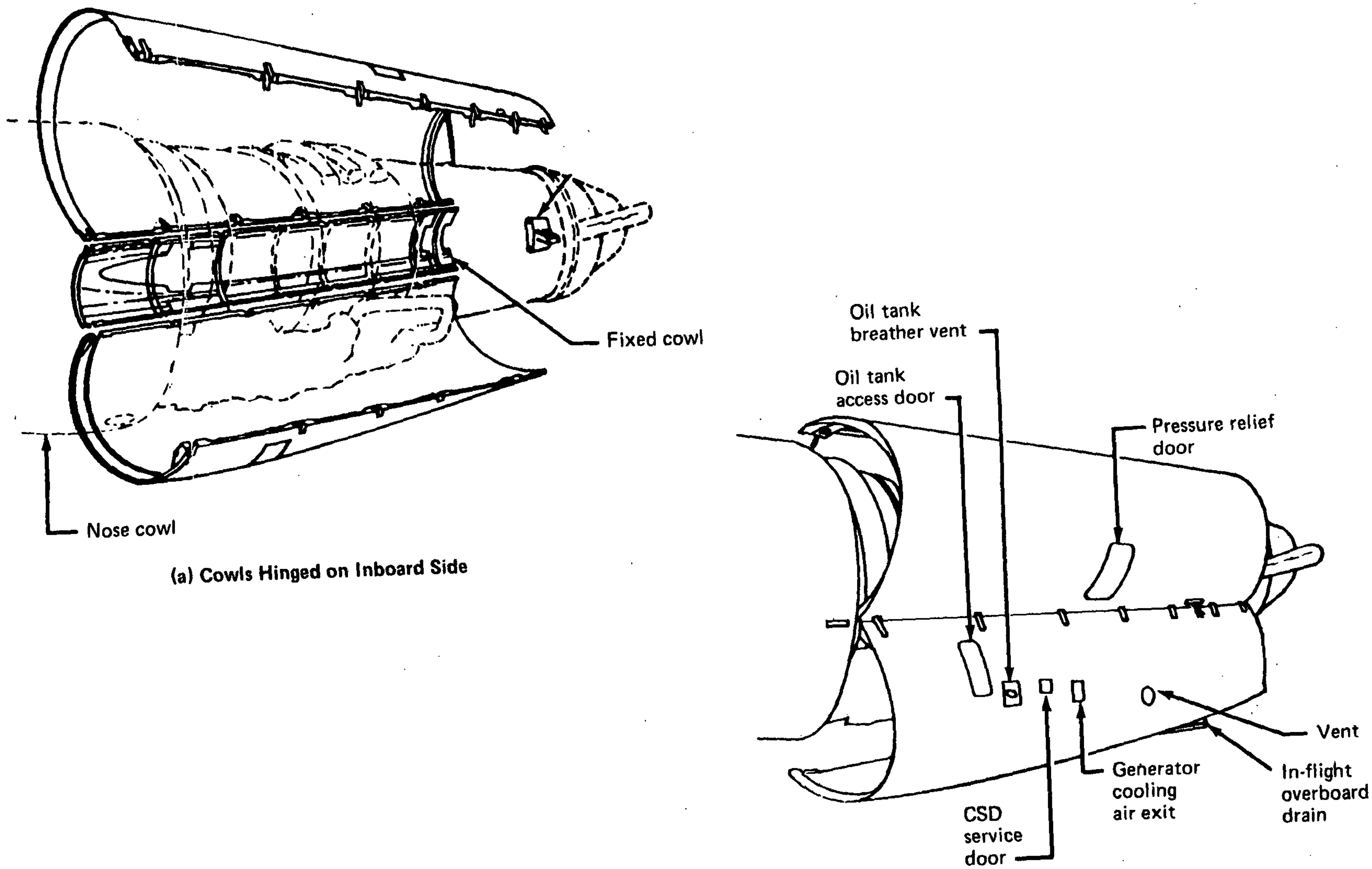


Figure 7.—JT8D Refan Side-Engine Inlet Cross Section With Acoustic Ring Installation Option



(a) Cowls Hinged on Inboard Side

(b) Cowls Hinged on Outboard Side

Figure 8.—JT8D Refan Side-Engine Cowl Panels

sandwiched in the inner skin laminate. The ability of the fire barrier to meet Civil Air Regulation (CAR) standards was proven by test and is discussed in reference 4. The wire mesh would also serve as an electrical shroud around the engine.

The cowl panel configuration was influenced by two model tests. The high-speed drag model test (ref. 6) confirmed that cylindrical cowls could be used without drag penalty, thus, allowing interchangeability of cowls between side engines. Airloads developed in reference 7 were used to size the structure of the cowl. The center-engine cowl panels were designed to the same standards used for the side engine and were of the same basic construction.

The side-engine side cowls were partially manufactured but were ultimately terminated because of budgetary constraints.

3.1.3 EXHAUST SYSTEM

The exhaust system of the JT8D refan engine design consisted of a two-piece exhaust duct (wedge duct and nozzle), a fan/primary flow divider (splitter), an engine center-body exit plug, and the exhaust duct external aerodynamic fairings (fig. 9). The exhaust duct acts as a mixing chamber for the hot primary and cold secondary flows discharging through a common nozzle.

In the design of the exhaust system, the engine/nozzle area match, acoustic treatment, thrust reverser support and aerodynamic loads were the primary items influencing the design. The final design was the result of the integration of requirements associated with these four items. The nozzle configuration that provided the required fan/primary area match and nozzle geometry was developed in conjunction with the data from the exhaust-system propulsion and acoustic model tests (refs. 10 and 11). The acoustic treatment design was predicated on attenuation of the aft fan and turbine fundamental tones making use of a prediction of the spectral characteristics and level of the acoustic energy. The loads imposed on the exhaust system by the thrust reverser were developed from static thrust reverser model test data (ref. 12). The loads data from the test were used in conjunction with the results of structural testing of brazed honeycomb (ref. 13) to determine material skin gages and other structural criteria for satisfying appropriate airworthiness requirements.

All of the exhaust system components were manufactured from brazed honeycomb sandwich except for the center-body plug which was Inconel 625 sheet metal. The exhaust duct and the fan-flow side of the flow divider were made in a circumferentially continuous brazement of aluminum-brazed titanium (ABTi), which had the acoustic treatment requirements integrated into it. The primary flow side of the flow divider was of similar construction made from Inconel 625.

3.1.4 THRUST REVERSER

The thrust reverser designed for the refan was a hydraulically actuated target type that was basically a scaled-up version of the reverser currently in use on the 737 airplane, as shown in figure 10. The identical reverser unit would be used on all three 727 refan engine positions and would be rotated (clocked) relative to the vertical centerline of the airplane to obtain the appropriate exhaust efflux pattern consistent with airplane compatibility and stopping distance.

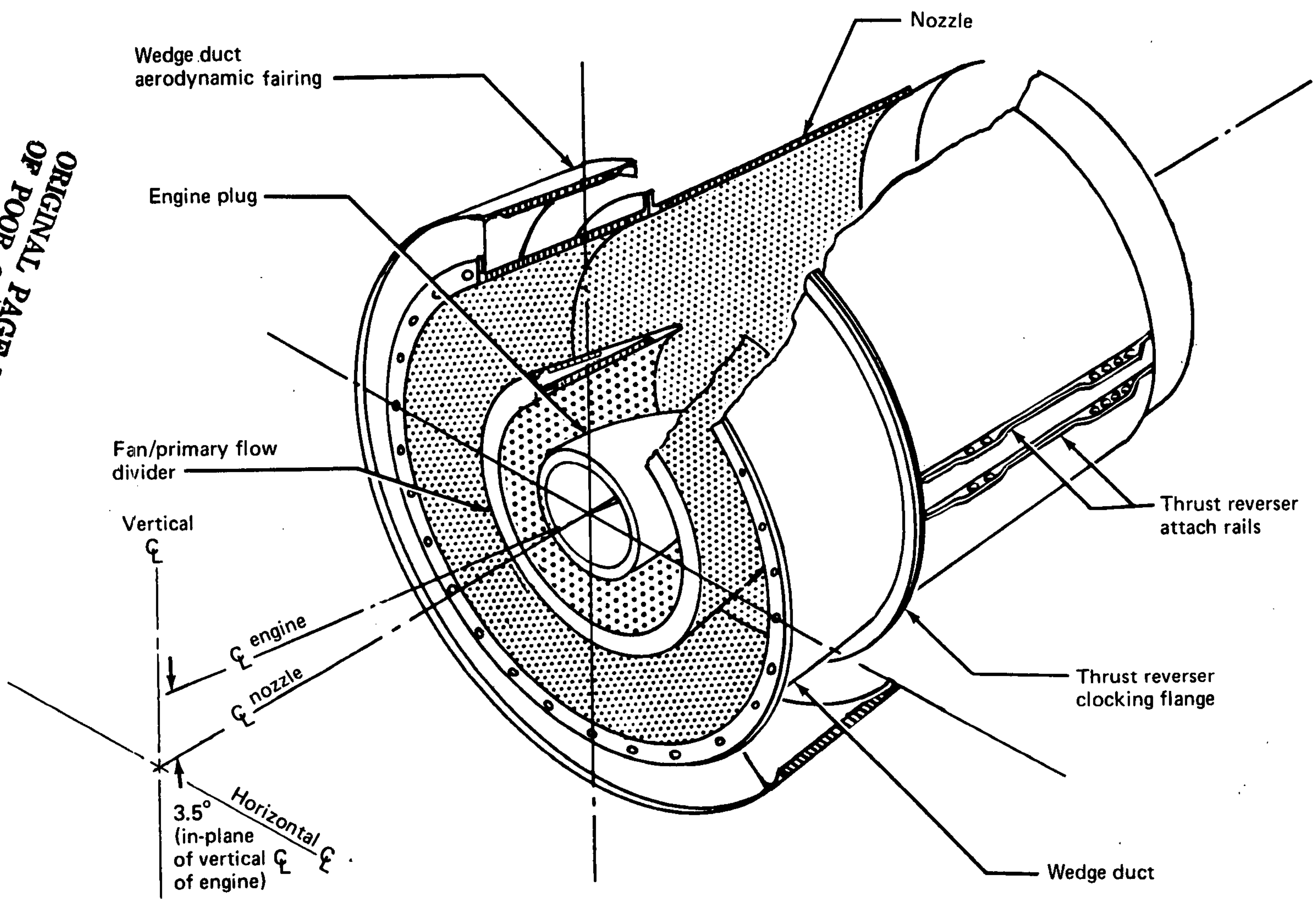


Figure 9.—JT8D Refan Exhaust System

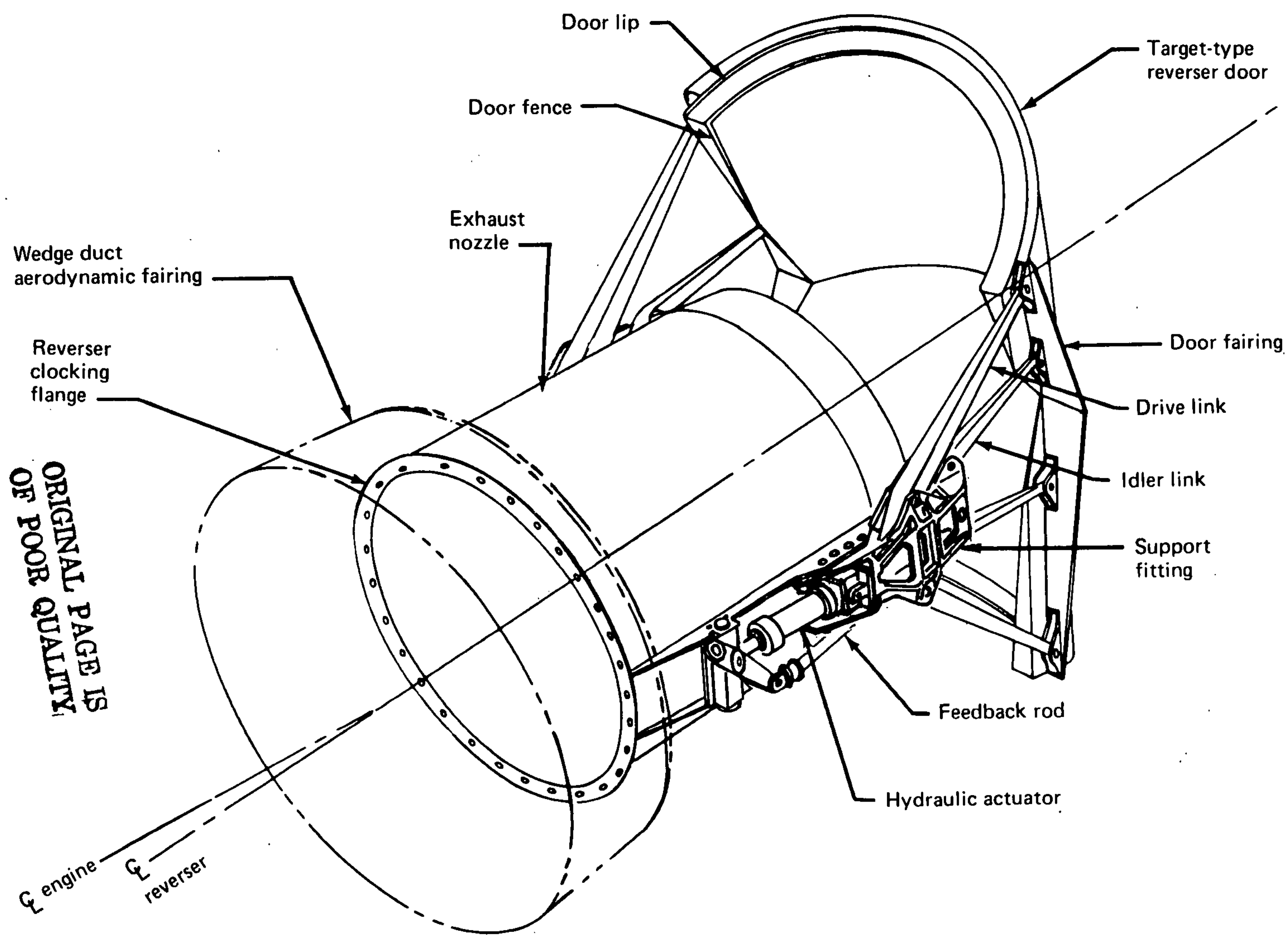


Figure 10.—JT8D Refan Thrust Reverser—Hydraulically Actuated

The design of the thrust reverser employed the results of four different model tests to define the reverser configuration. The static thrust reverser model performance test (ref. 12) was used in conjunction with analytical methods to define the structural requirements and engine/thrust reverser compatibility (effective nozzle area match with the reverser operating). A low-speed wind tunnel test (ref. 14) was run to determine the effect of clocking position on the airplane stability and control characteristics. Another low-speed wind tunnel test (ref. 15) was conducted to determine the reingestion, fuselage heating, and aerodynamic interference characteristics of the reverser doors as related to reverser-clocking position, door fence and lip geometry, and engine power setting.

The combined results of these tests identified reverser door geometries that were acceptable (in model scale) relative to the constraints of reingestion, engine match, body heating, and stability and control. These candidates were evaluated for adaptability to the installation within aerodynamic constraints for minimum cruise drag. Finally, the configuration candidates were subjected to a landing roll analysis to select the refan reverser configuration. Confirmation of the design, however, would be subject to further analysis and model- and full-scale operational tests.

Weight was the other major influence on the thrust reverser design. With the engines installed at the aft end of the airplane, any weight increase in the nacelle results in an airplane weight increase in the ratio of approximately 4.8 to 1 (instead of the present ratio of 3 to 1 for the production airplane) because of the ballast required to restore airplane balance (c.g. location). The increase in weight of the engine installation strongly influenced the design toward the use of titanium. A titanium casting would be used for the thrust-reverser linkage support. All of the linkage, door inner skin, and door frames were designed to be made from titanium bar and sheet. The refan reverser door would be made of formed titanium frames, a titanium interior skin, and an aluminum outer skin.

The refan thrust reverser was only partially manufactured due to funding limitations.

3.1.5 CENTER-ENGINE INLET DUCT

The air inlet duct for the center engine (fig. 3) was designed to accommodate the larger mass flow of the refan engine, 480 lb/sec (217.73 kg/sec) compared to 334 lb/sec (151.5 kg/sec) for the existing JT8D engine, without increasing duct loss and flow distortion. The flow geometry was developed as reported in reference 16 within the constraints of the existing opening in the vertical tail front spar forging. Bonded aluminum/fiberglass honeycomb construction, which is structural and acoustic, was selected to minimize weight and cost while making optimum use of the available space. The length of the duct permitted acoustic lining sections to be tailored to a wide range of frequencies, including buzzsaw and the fan tone fundamental. The inlet lip was designed to perform in the local flow field of the airplane as reported in reference 9.

The flightworthy center-engine inlet-duct assembly has a complex internal shape that is a continuous transition from circular at the forward end to elliptical at the vertical tail front spar to circular at the engine inlet. The inlet-duct assembly was manufactured in four major sections. Three of the sections were of circumferentially continuous bonded construction with perforated-aluminum inner skin backed by phenolic-impregnated fiberglass-honeycomb and epoxy/fiberglass outer skin. The fourth section, the forward elbow containing the rain impingement thermal anti-icing panel, was a combination of bonded honeycomb and riveted sheet metal.

3.1.6 AIRFRAME MODIFICATION DESCRIPTION

The major portion of the required structural changes affected the aft-body section in the area of attachment of the new engines. There would be no major changes to the forward body or to the wing structure. However, minor reinforcement of body structure would be required to support the ballast that is necessary for airplane balance to compensate for the additional weight of the refan engine installation.

The body bulkhead at station 1342.4 in. (34.095 m) (fin rear spar attachment) would be reworked to permit passage of the larger inlet duct for the center engine, as shown in figure 1.

A recess would be required at the intersection of the body crown with the pressure bulkhead, body station 1183 in. (30.048 m), to clear the larger center duct. The bulkhead would be lowered at the top centerline, and a contoured skin panel would be added to the pressure bulkhead to close off the opening in the upper body skin. Reinforcing would be added to the pressure bulkhead to restore the original strength. The aft-body structure would be exposed to the same loads as the existing airplane with a slight modification to account for increased nacelle weights and new c.g. location.

No change to the rudder would be required. Wind tunnel data (ref. 17) indicated that rudder effectiveness would not be affected by the nacelle installation.

All of the vertical tail leading edge structure forward of body station 1283 in. (32.588 m) was redesigned to accommodate the larger inlet. The outer surface of the new fairing structure would consist of contoured, fiberglass epoxy honeycomb paneling.

The tail skid was redesigned to make ground contact at a 9.6° aircraft ground rotation attitude by lowering the mechanism pivot points and retaining the existing door and tail-skid tip assembly. This design change was required to prevent exhaust duct contact with the runway during airplane rotation in view of the downward relocation and increased length and diameter of the center engine.

3.2 GROUND TESTS

The objectives of the full-scale ground tests were to determine:

- Installed JT8D refan engine performance
- Performance increments for the inlets and exhaust system
- Component noise differences, as related to propulsion cycle parameters, between the JT8D (baseline) and the JT8D refan engines (in order to develop, through analytical methods, predicted in-flight noise increments that would be applied to a known flight data base)

- JT8D refan acoustic treatment effectiveness and internal sound pressure levels (SPL)
- Structural loads and deflections for the center-engine inlet duct; thermal environment for the exhaust duct and fan/primary flow divider
- Compatibility of the JT8D refan engines with flight-type inlets and exhaust system

The tests were conducted on the B-2 test stand at the Contractor's Boardman, Oregon test facility. The baseline test was conducted on a new JT8D-15 engine during the time period August 28, 1974 to September 13, 1974. On completion of the baseline test, the JT8D-15 was shipped to P&WA for conversion to a JT8D-115; this refanned engine was returned to Boardman for testing in the time period January 7, 1975 to March 28, 1975. Typical JT8D-115 side- and center-engine test setups are shown in figures 11 and 12.

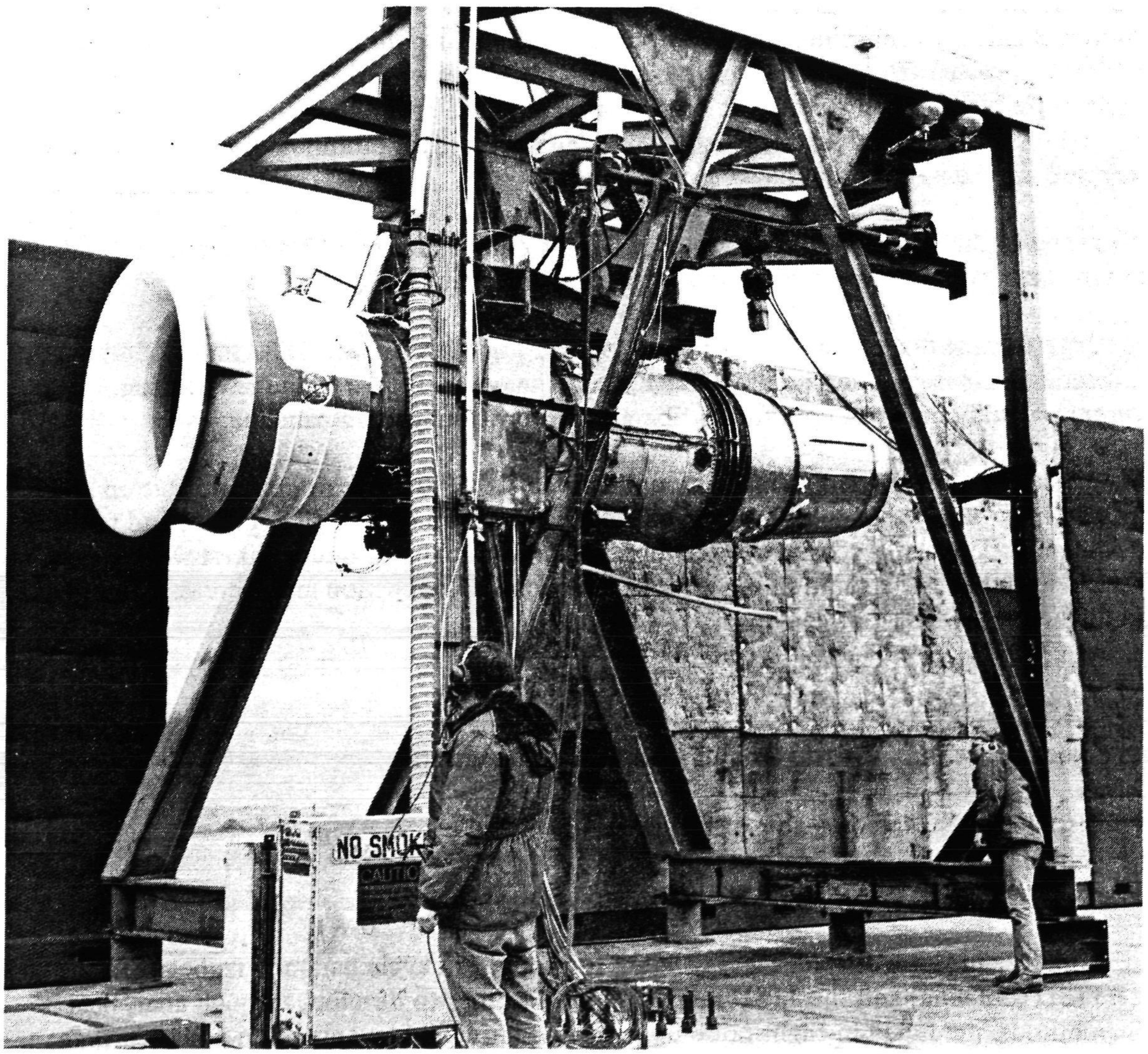


Figure 11.—JT8D-115 Side-Engine—Typical Test Setup

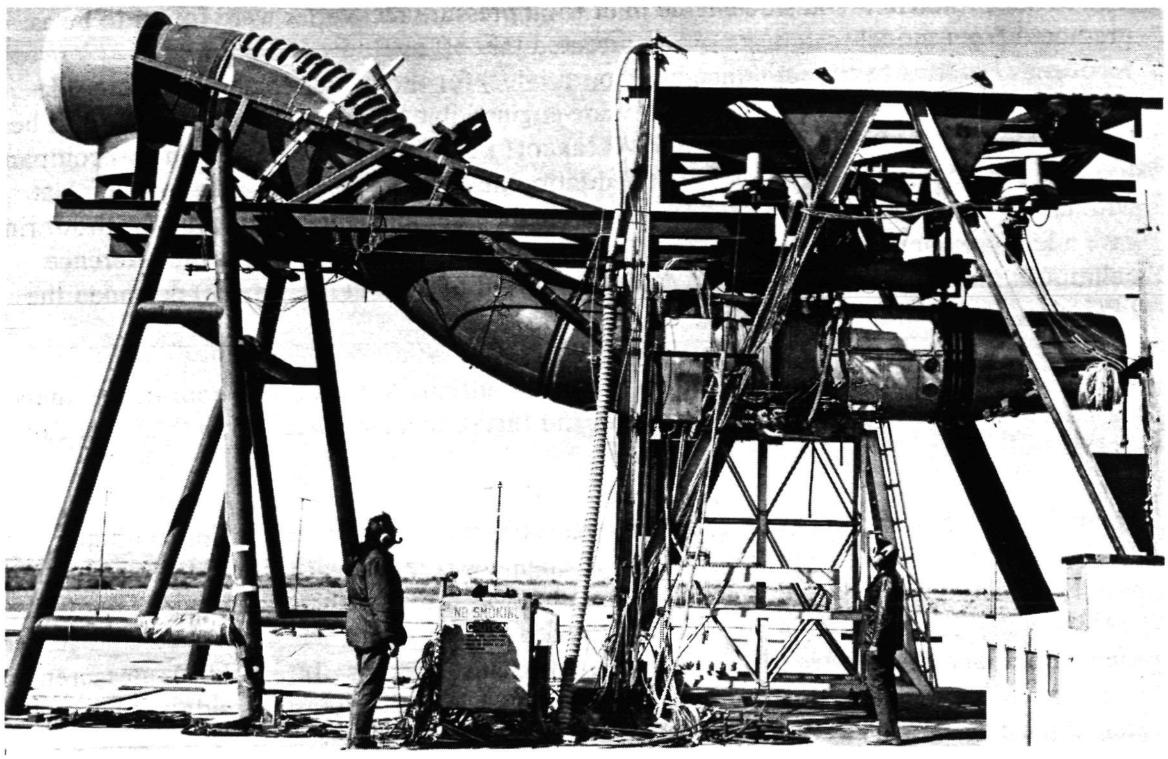


Figure 12.—JT8D-115 Center-Engine—Typical Test Setup

The propulsion testing of the JT8D-15 engine included both engine calibration with reference hardware and engine performance evaluation with production nacelle hardware with bell-mouth inlet lips. Propulsion testing of the JT8D-115 engine included test configurations to evaluate the performance characteristics associated with flight-type nacelle hardware elements; i.e., the side-engine inlet both with and without an acoustically treated inlet ring, the center-engine inlet, and two exhaust system configurations (differing in the fan/primary flow divider design which varied the amount of acoustic treatment). Inlet pressure surveys and crosswind testing were conducted to measure inlet recovery, inlet pressure distortion, and engine surge margin characteristics. In addition, the static (zero crosswind) surge margins were determined for the side-engine inlet (without ring) and the center-engine inlet. Surge margin characteristics were determined using the P&WA cross-bleed system. During the center-engine inlet testing, two vortex generator configurations were evaluated. Inlet duct deflections were measured at critical structural and aerodynamic areas. Normal engine instrumentation was utilized to monitor engine cycle parameters for both performance and acoustic tests.

The flight-type exhaust system was matched at the upper limit (+0.5%) of P&WA's allowable effective area tolerance. The flight-type exhaust system and the reference exhaust system were found to have identical gross thrust coefficients over the full range of nozzle pressure ratios from 1.2 to 1.95. The flow coefficient of the flight-type nozzle was found to be 0.0035 higher than that of the reference nozzle. This result implies that a reduction in nozzle exit area of 0.35% would produce the engine manufacturers recommended engine match.

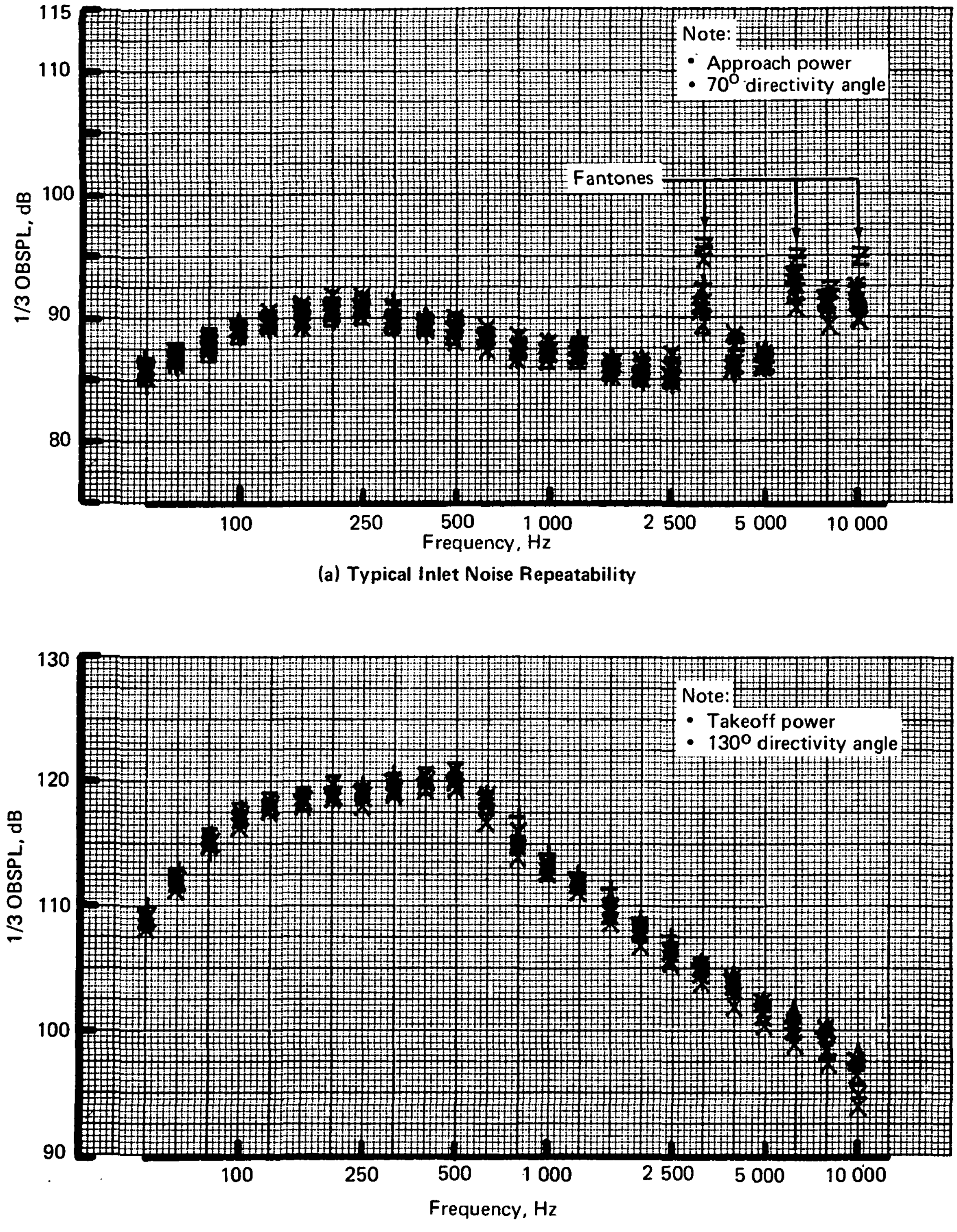
The JT8D-115 center- and side-engine inlet total pressure recoveries were found to be as predicted from model-scale tests. At a corrected takeoff airflow of 470 lb/sec (213 kg/sec), recoveries (relative to the reference bellmouth inlet) for the center-engine inlet, the side-engine inlet (with acoustic ring), and the side-engine inlet (without ring) were found to be 0.984, 0.9925, and 0.995, respectively. At takeoff thrust the JT8D-115 engine, as compared to the JT8D-15, shows 12.5% to 13.2% reduction in static SFC for the side-engine inlets with and without ring. The JT8D-115 center-engine inlet and side-engine inlet (without ring) gave a low pressure compressor (LPC) surge margin nearly the same as for the reference bellmouth inlet at static conditions. A 90° crosswind of 20 kn (16.3 m/sec) degraded the LPC surge margin 4% relative to static conditions.

Propulsion data accuracy and repeatability were as anticipated with 95% confidence, mass flow accuracy was within 0.5% of full scale, and thrust accuracy was within 0.25% of full scale.

Acoustic testing of the JT8D-15 and -115 engines included the use of baffles to obtain far-field component noise data. The JT8D-15 engine was tested with a hardwall production nacelle. The as-delivered treated JT8D-115 engine was tested with various nacelle hardware: hardwall inlet, treated side-engine inlet (both with and without treated ring); treated center-engine duct; and one hardwall, and two treated exhaust systems. Internal SPL measurements were taken that included flush-mounted microphones in the center duct, side-engine inlet, and exhaust system, as well as a side-engine inlet radial SPL survey.

Analyses of acoustic data showed that good acoustic repeatability was achieved for all noise components except inlet fan tones (fig. 13) and buzzsaw; provided testing was restricted to accepted weather limits. The large variation in measured inlet fan tone levels is compatible with the Contractor's earlier test experience and is attributed to fluctuations in atmospheric turbulence ingested by the engine in a static mode. Studies of factors that affect inlet tone data scatter should have high priority for future ground test work.

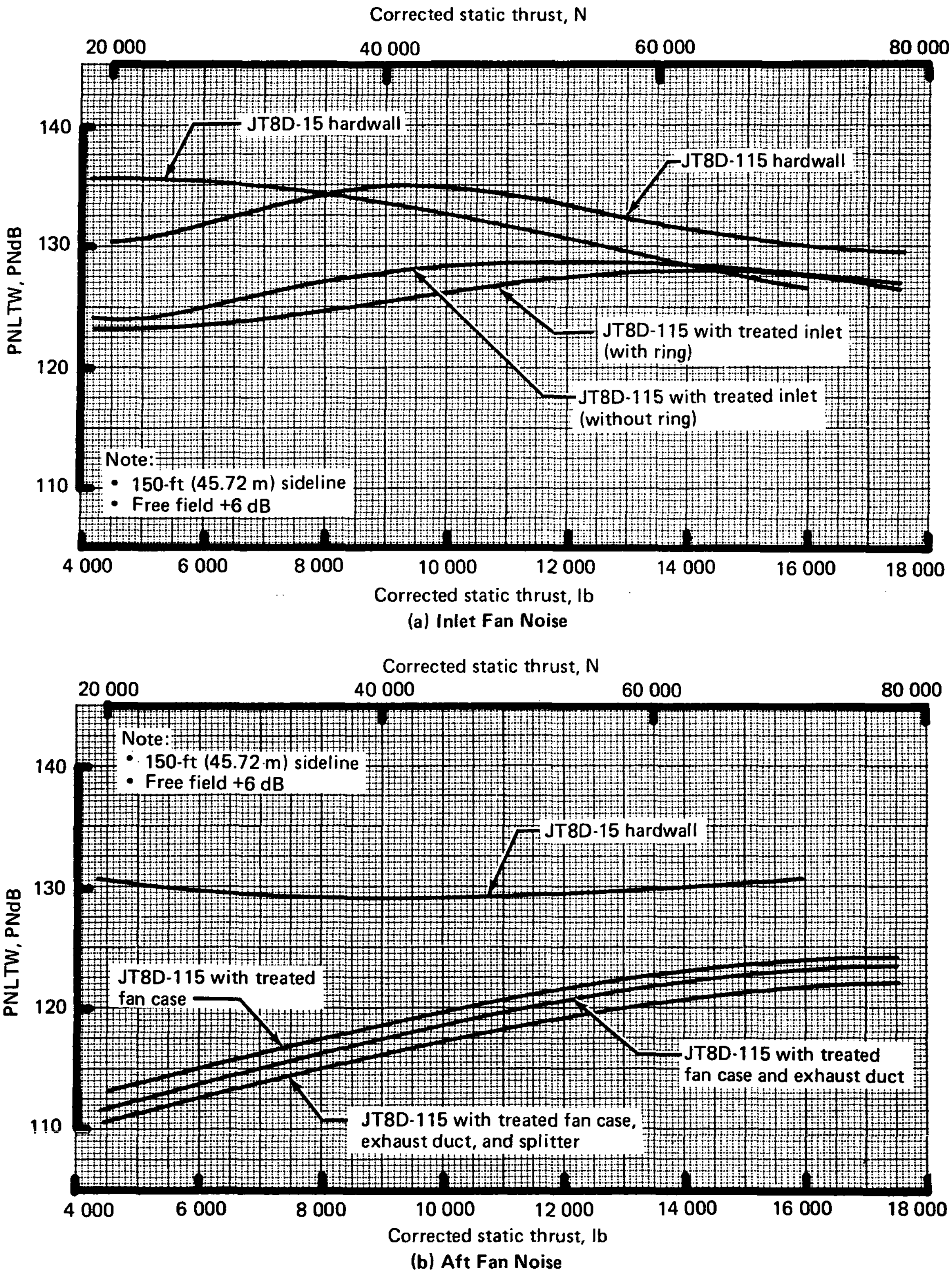
Analyses of component noise data showed that the fully treated JT8D-115 engine (and nacelle) produced a reduction of 5 to 11 PNdB in a weighted average value of tone corrected perceived noise level (PNLTW), relative to the JT8D-15 hardwall engine compared at equal static thrust. Separated into noise components, the JT8D-115 engine showed significant noise reduction in inlet fan noise, aft fan noise, exhaust duct flow noise, turbine noise, and jet noise relative to the JT8D-15; however, core noise was increased. The gross results, expressed in terms of a PNLTW, are shown in figure 14 for (1) the JT8D-15 hardwall, (2) the JT8D-115 with hardwall nacelle, (3) the JT8D-115 with treated side-engine inlet (without ring) and treated exhaust duct, and (4) the JT8D-115 with a treated side-engine inlet (with ring) and exhaust system with treated exhaust duct and splitter. Application of these results to an airplane flyover situation requires proper interpretation of these results in terms of detailed in-flight propulsion performance parameters; such an analysis for the JT8D-9 and JT8D-109 engines installed on the 727-200 airplane is the subject of Volume IV of this final report (ref. 4).



(a) Typical Inlet Noise Repeatability

(b) Typical Aft Noise Repeatability

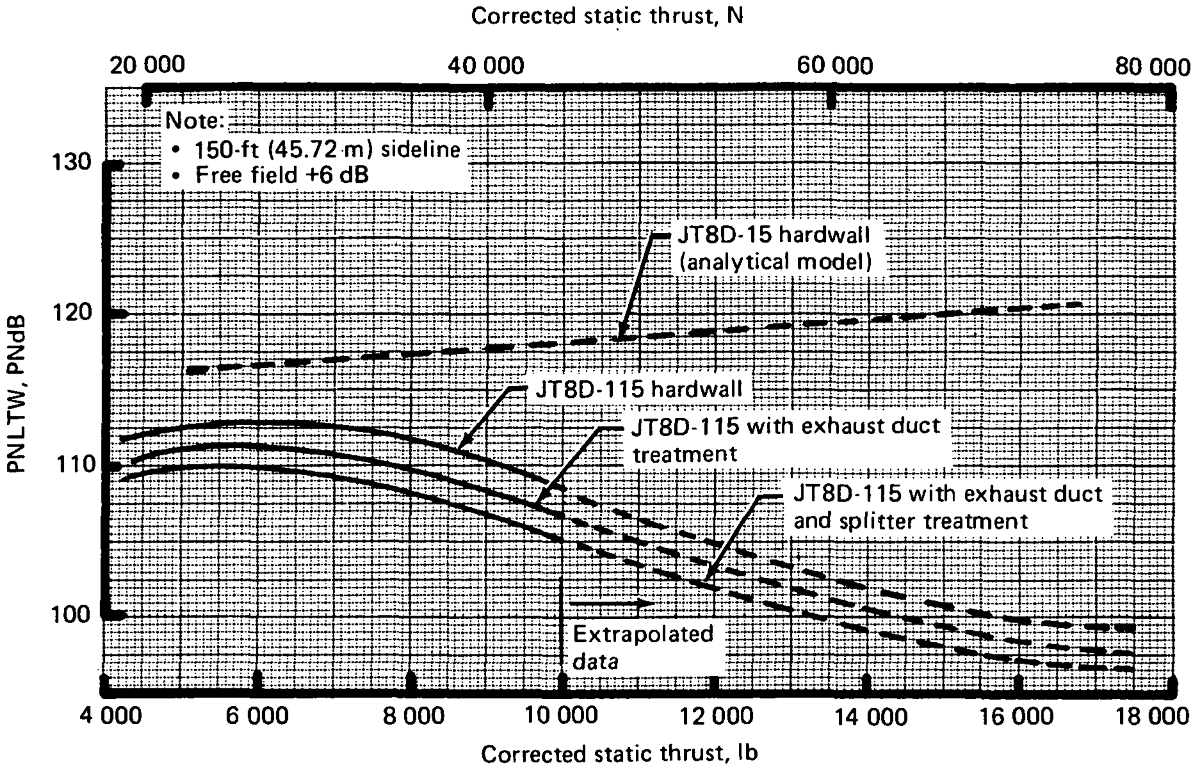
Figure 13.—JT8D-115 Ground Test—Typical Inlet and Aft Noise Repeatability



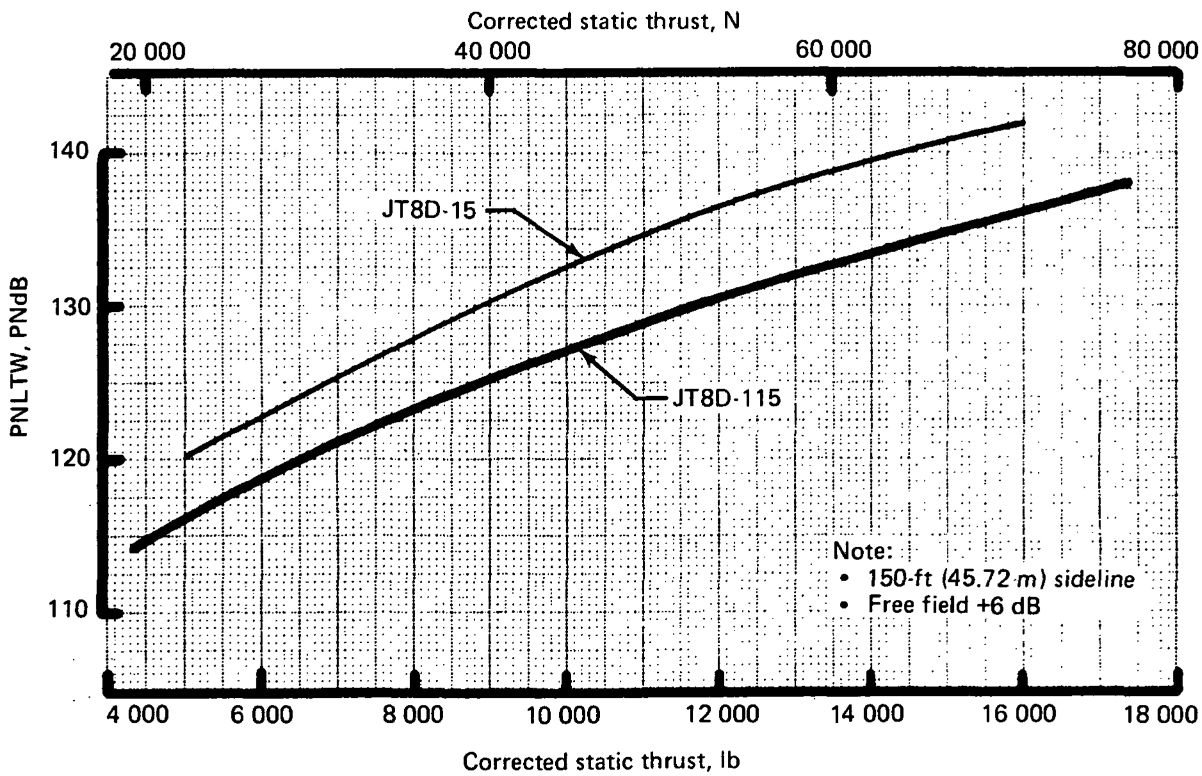
(a) Inlet Fan Noise

(b) Aft Fan Noise

Figure 14.—JT8D-15 and -115 Component Noise Comparison at Ground Static Conditions

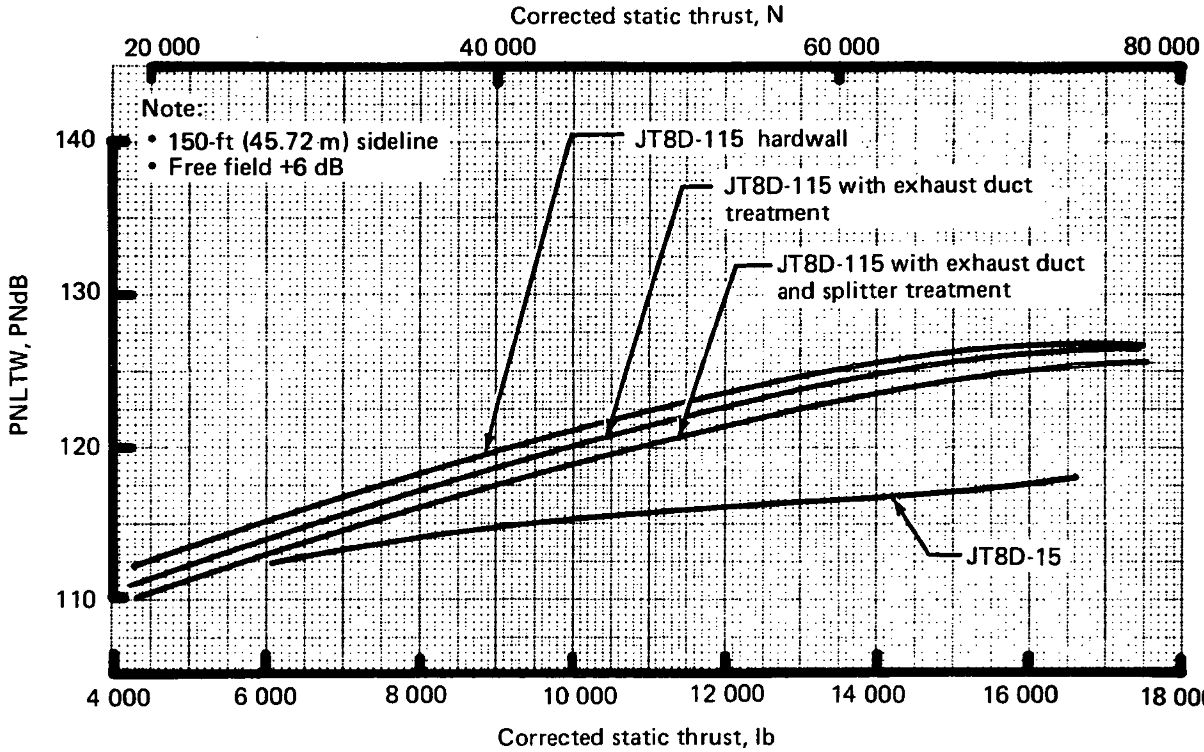


(c) Turbine Noise

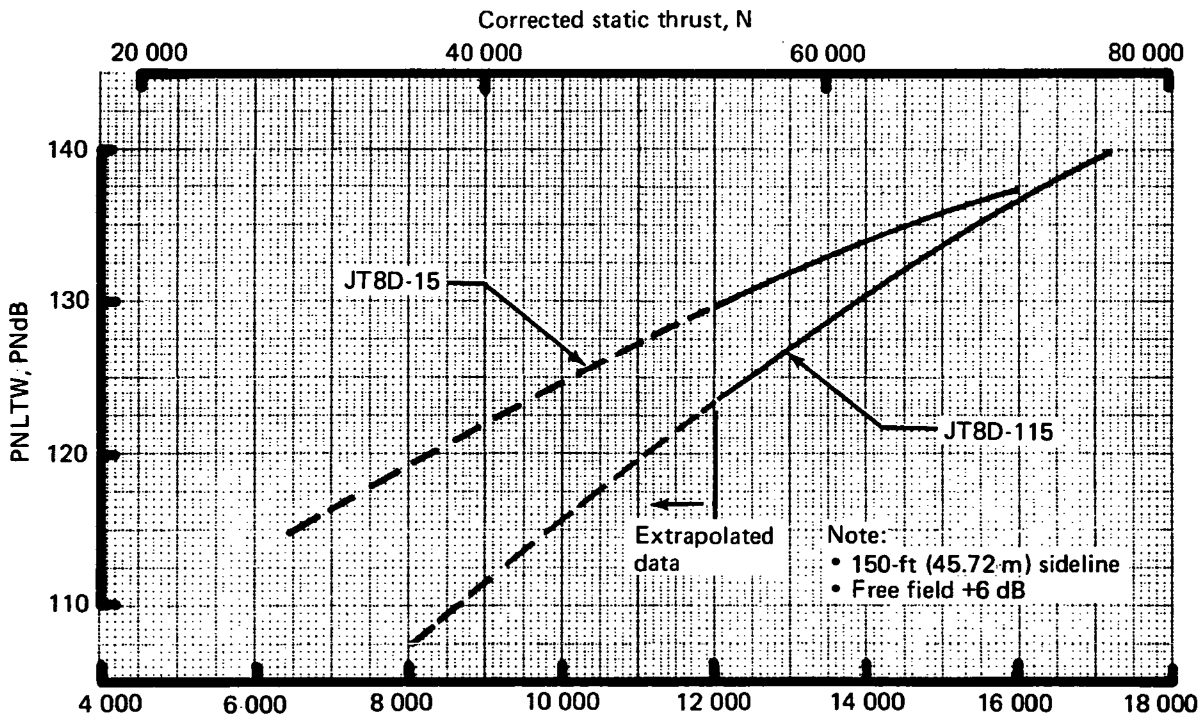


(d) Jet Noise

Figure 14.—(Continued)

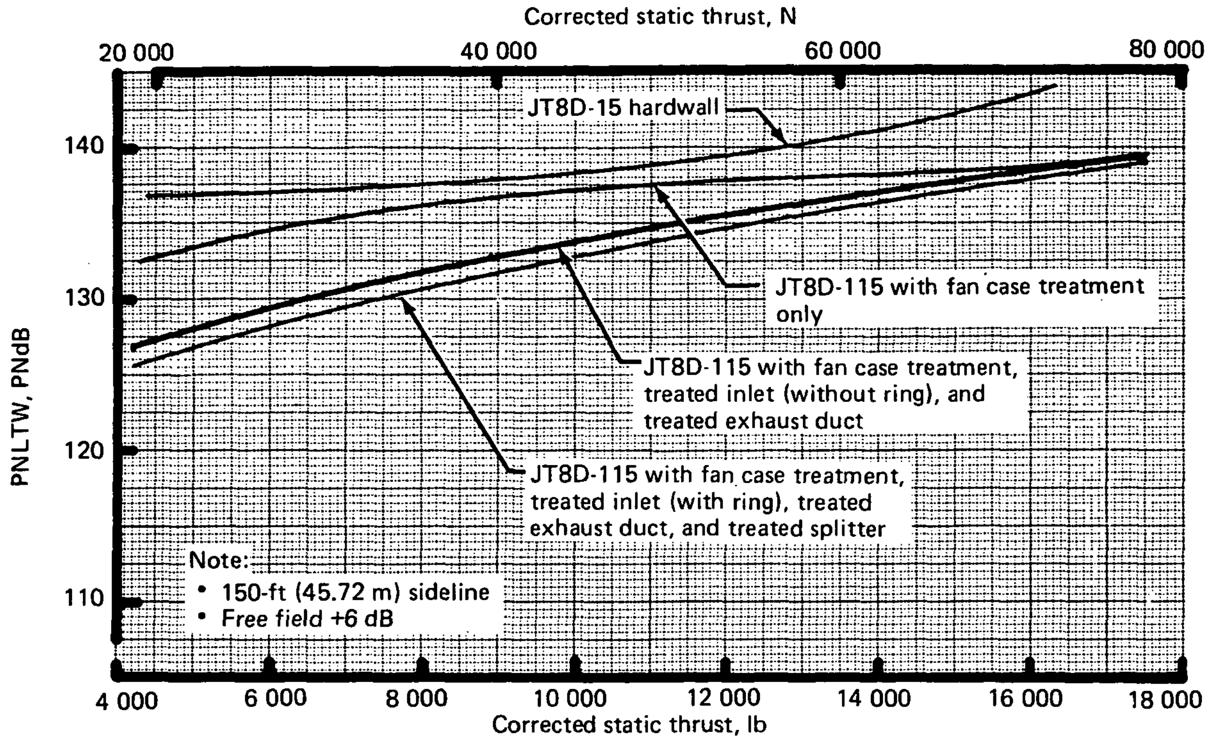


(e) Core Noise



(f) Exhaust Duct Flow Noise

Figure 14.—(Continued)

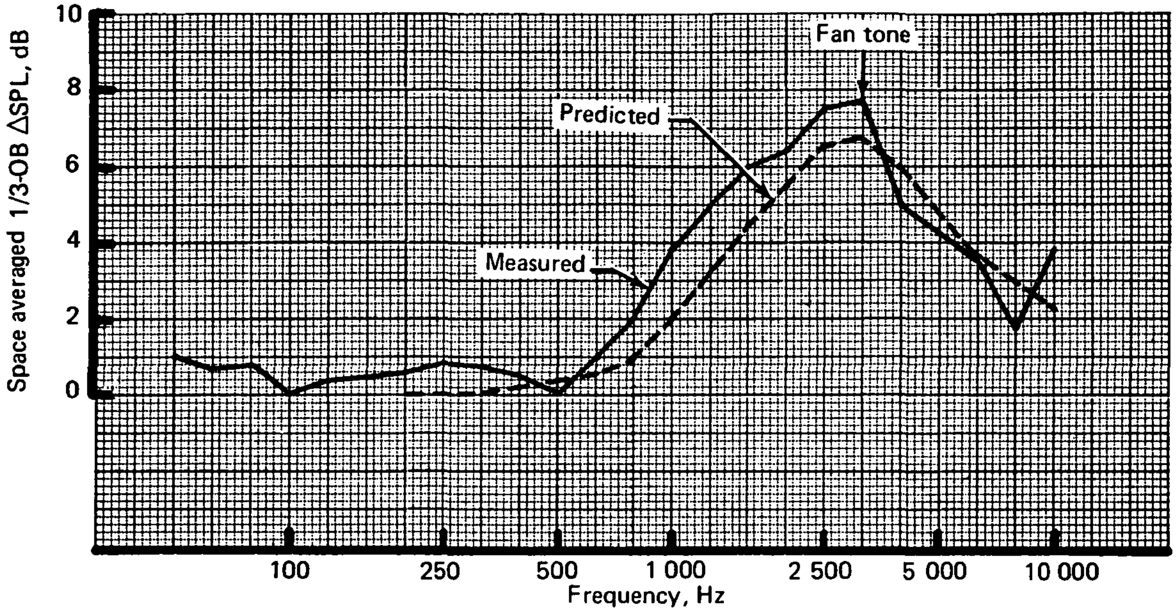


(g) Total Noise

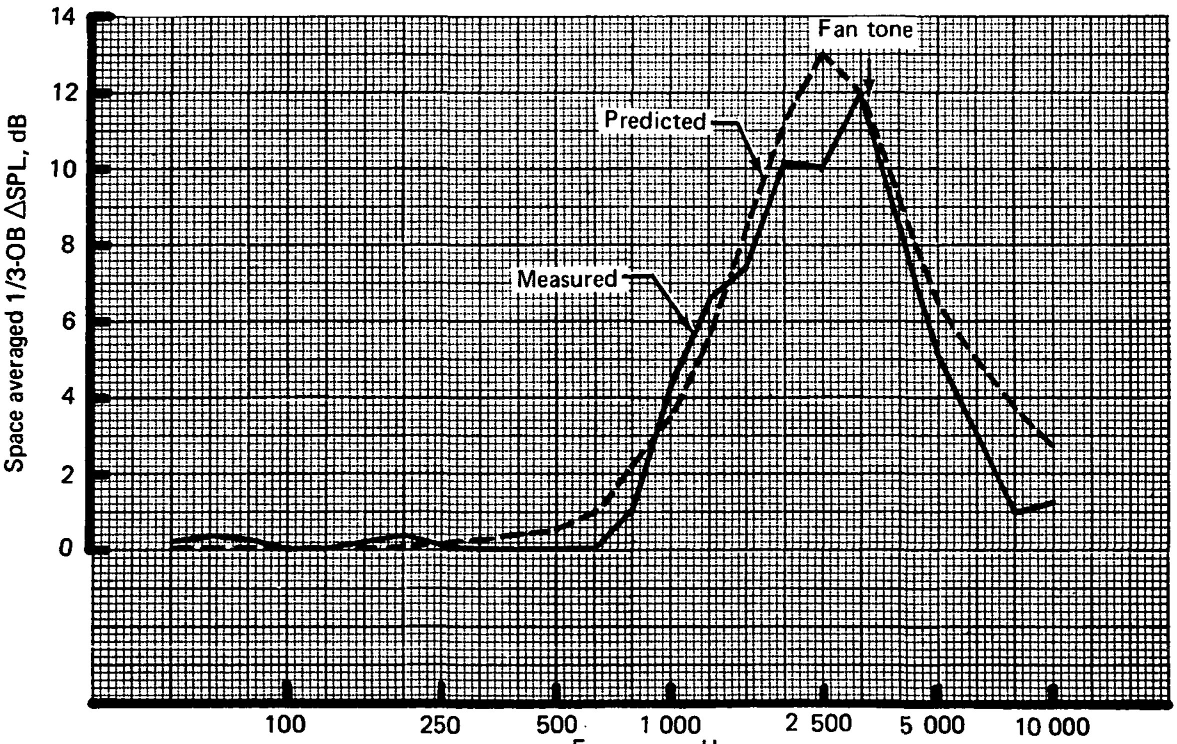
Figure 14.—(Concluded)

The side-engine inlet lining attenuations agreed well with pretest predictions (fig. 15); the center-engine inlet noise was reduced to a low SPL level relative to the side-engine inlet noise (fig. 16a); and the exhaust treatment suppression was not as large as predicted (fig. 16b). Internal SPL measurements provide a basis for possible improvements in inlet splitter locations and lining designs for both the inlet and exhaust system.

The test techniques employed in the JT8D-15 and -115 ground tests for acquisition of component noise information proved generally successful; indeed, these tests provided component noise information to a greater degree of detail than any existing JT8D acoustic data. The use of acoustic barriers for segregation of inlet and aft noise components provided essential information that could not have been obtained otherwise, and the use of ground level microphones at all directivity angles substantially improved the resolution of low frequency acoustic data. The microphones mounted in the inlets and exhaust system of the JT8D-115 engine provided essential lining design information and yielded the clue that led to the definition of a new noise source: *exhaust duct flow* noise. The exhaust duct flow noise component was discovered with the aid of improved data acquisition and analyses techniques. It is a low frequency broadband noise and, although the exact mechanics of generation are conjecture at this point, it quite possibly results from the mixing of the fan and primary flows. The analysis of this noise source has thus far only been superficial. Both analytical and experimental work are needed to clearly define this noise component.

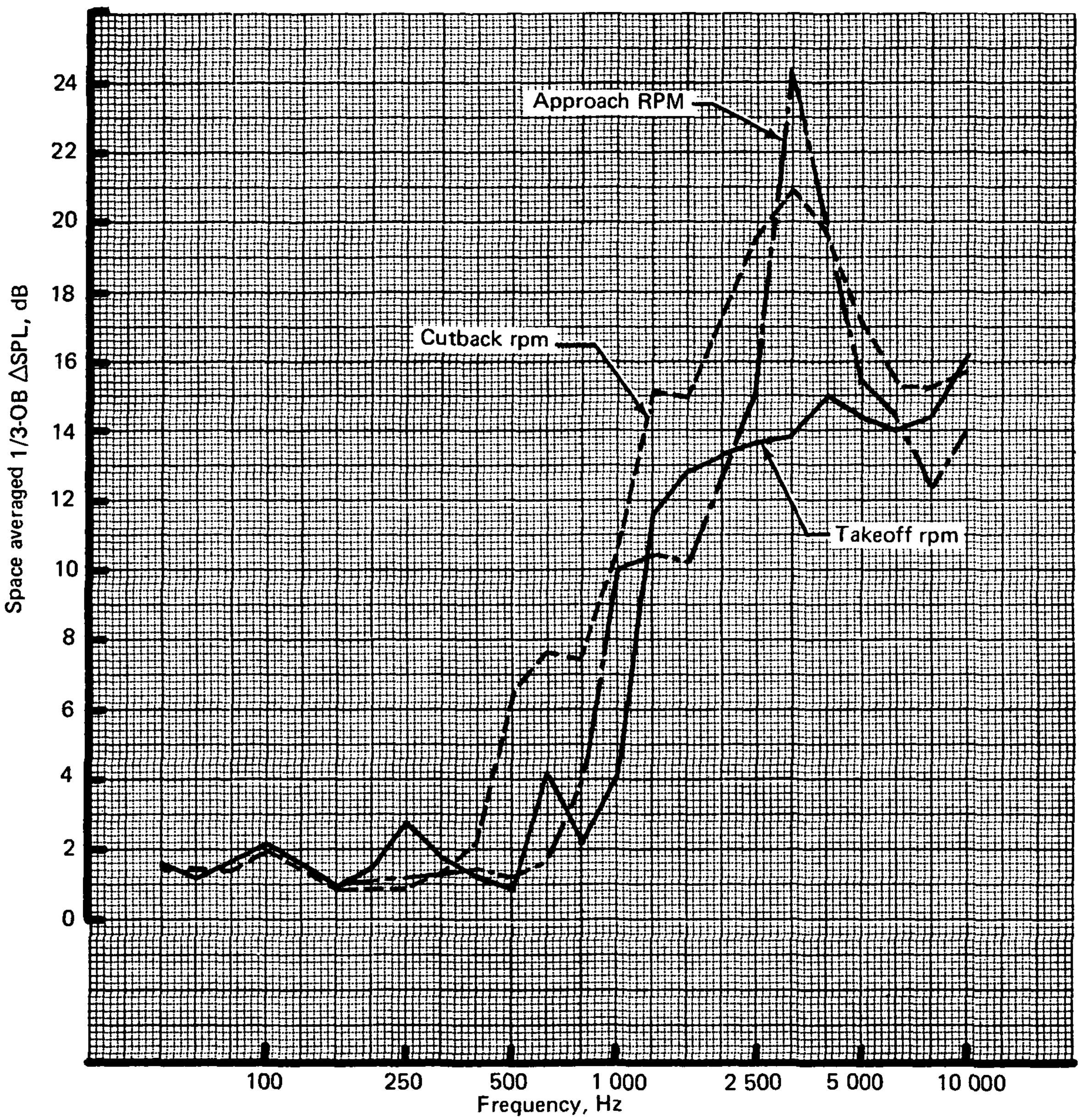


(a) Inlet Without Ring



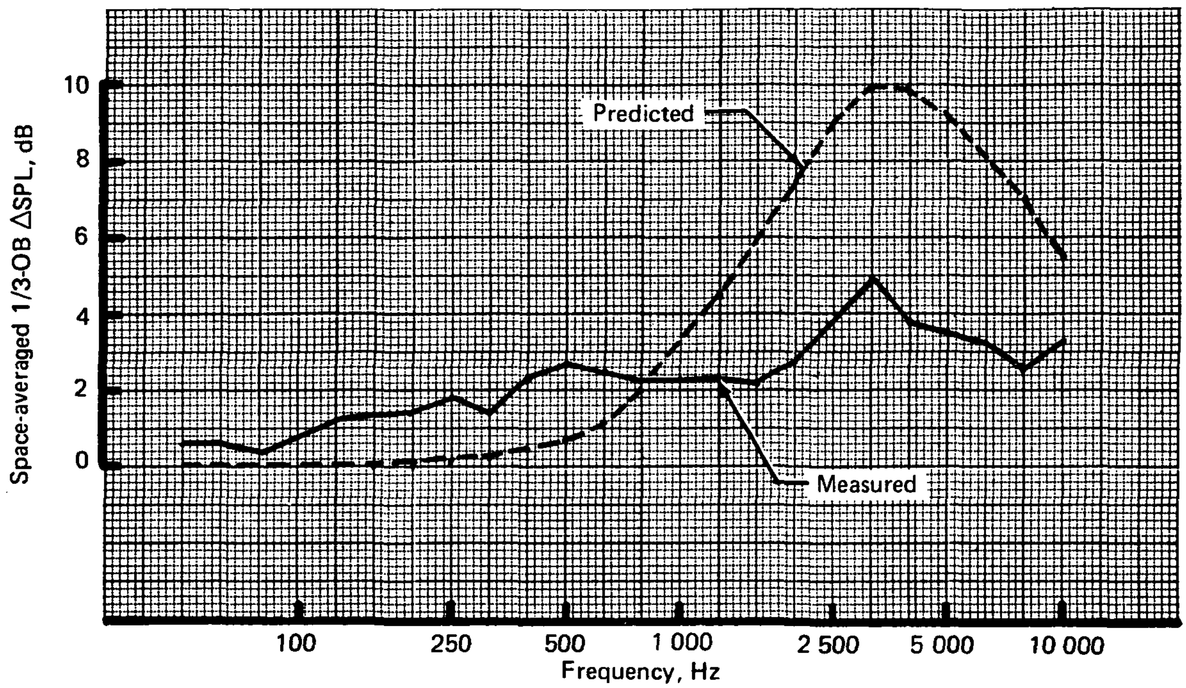
(b) Inlet With Ring

Figure 15.—Measured Versus Predicted Lining Attenuation for JT8D-115 Side-Engine Inlet Linings—Approach RPM



(a) Treated Center-Engine Inlet Minus Hardwall Side-Engine Inlet Without Ring

Figure 16.—JT8D-115 Center-Engine Inlet and Exhaust System Lining Attenuation Characteristics



(b) Treated Exhaust Duct and Splitter—Approach RPM

Figure 16.—(Concluded)

One of the most interesting aspects of the ground tests resulted from the comparison of Contractor-conducted acoustic ground tests on a JT8D-115 engine, with P&WA acoustic tests on a JT8D-109 engine. These two engines are identical throughout, except for the exhaust system hardware and hot rematch. Curiously the largest noise difference between the two engines was in the inlet fan noise component when correlated on fan pressure rise (the traditional fan noise parameter). However, when correlated on corrected rpm, the two sets of data agree quite well. From this cursory information, it appears that a detailed study is needed of the relationship between fan noise and the fan-operating map in order to better understand inlet-guide-vane fan noise.

The center-engine inlet duct was instrumented to measure skin stresses, duct wall and engine seal deflections, and internal pressures. The structural test data were recorded for both stabilized and surge conditions concurrently with the center-engine inlet-duct surge margin evaluation testing. The exhaust duct and fan/primary flow divider surface temperatures were measured during cold start, maximum acceleration to takeoff power, and engine shutdown.

Analyses of center-engine inlet-duct wall pressure data indicated up to 3% lower stabilized pressures and up to 19% higher surge pressures (extrapolated to altitude conditions) than predicted by model tests and duct flow analyses. Measured exhaust system hardware temperatures were within the design structural limits. The partial loss of test data for the Inconel honeycomb assembly on the fan/primary flow divider rendered the analyses of the flow divider thermal stresses as qualitative. However, the ABTi portion of the flow divider would have acceptable durability relative to the predicted thermal stresses, while the brazed Inconel honeycomb portion is judged to have marginal durability. Additional testing would be required for verification of this judgement.

3.3 AIRPLANE EVALUATION AND ANALYSIS

The objectives of these analyses were to predict 727 refan airplane performance and community noise characteristics. Analyses were conducted to determine the effect of the installation of the JT8D-109 (refan) engine on the 727-200 airplane design, operating characteristics, and performance. These analyses included the evaluation of:

- 727 refan aerodynamic performance
- Noise characteristics of the 727 refan at FAR 36 measuring points, and the outlying community
- Installed propulsion performance and installation characteristics at pertinent points throughout the 727-200 mission envelope
- Airplane structural modifications integral to the JT8D-109 engine retrofit and new structure used on the engine nacelle
- The weight change
- Changes that would occur to the 727 refan stability and control characteristics
- Electrical and mechanical system changes

Table 2 summarizes the major results of these analyses. The following subsections present a discussion of the subjects listed.

3.3.1 AIRPLANE PERFORMANCE

Table 3 describes the baseline 727-200 airplane characteristics at a BRGW of 172 500 lb (78 245 kg) along with the estimated refan airplane characteristics that would result from retrofit of the JT8D-109 engine on the baseline airplane. Two refan airplanes are shown: one at the same BRGW as the baseline airplane and the other at the practical growth weight limit of the baseline airplane.

It was found that the 727 refan would lose about 15% in range performance for a 172 500-lb (78 245-kg) BRGW takeoff relative to the baseline 727-200 at the same BRGW (table 2). This range loss would primarily be caused by the large increase in operational empty weight (OEW) of the airplane and the required reduction in on-board fuel to maintain 172 500-lb (78 245-kg) BRGW. Small drag and SFC penalties also contribute to the loss.

A retrofit option that would be available with this particular model of the baseline 727 is to make minor additional hardware changes that would increase the structurally limited BRGW to 182 500 lb (82 781 kg), as well as increase the OEW by 160 lb (72.6 kg) and the fuel capacity by 100 gal (0.379 m^3) through volumetric top-off. This change could be accomplished in association with the retrofit of the JT8D-109 engine. The net effect of these changes is to increase the onboard fuel to the capacity limit of the airplane. In taking advantage of

Table 2.—727-200/727 Refan Noise/Performance Summary

	FAR 36 limits	727-200	727 REFAN: Increment from -200	727 REFAN
Noise [1]				
FAR 36 EPNL, EPNdB				
Approach at 40° flaps	104.4	109.5	-6.8	102.7
Approach at 30° flaps	104.4	108.2	-7.5	100.7
Takeoff/cutback at 5° flaps	99.0	100.0	-6.3	93.7
Full-power takeoff at 5° flaps	99.0	107.4	-7.7	99.7
Sideline at 5° flaps	104.4	99.9	-6.4	93.5
Percent reduction in annoyance - weighted area			68% to 83%	
Performance			Increment from -200	
Uninstalled SL static thrust, lb (N)		14 500 (64 499)	+14.5%	
Takeoff thrust at 100 kn (51.4 m/s), 84°F (302 K), lb (N)		12 700 (56 492)	+9.1%	
Maximum cruise thrust, lb (N)/engine [2]		4 325 (19 239)	+6.0%	
Cruise SFC, lb/hr/lb (kg/hr/daN) [3]		0.833 (0.849)	+0.6%	
Range, nmi (km) [1]		1 405 (2 602)	-205 (-380)	
Takeoff field length, SL, 84°F (302 K), ft (m) [1]		8 370 (2 551)	-1450 (-442)	
Range from 6900 ft (2103 m) field, nmi (km) [4]		1 000 (1 852)	+180 (+334)	
Weight				
Maximum brake release gross weight, lb (kg)		172 500 (78 245)		
Maximum landing weight (30° flaps), lb (kg)		150 000 (68 040)		
Maximum landing weight (40° flaps), lb (kg)		142 500 (64 638)		
Operational empty weight, lb (kg)		99 000 (44 906)	Increment from -200 +3839 (+1741)	
Nacelle and structure, lb (kg)		15 760 (7 149)	+2849 (+1292)	
Ballast, lb (kg)		0	+990 (+449)	

[1] Brake release gross weight = 172 500 lb (78 245 kg)
[2] Standard day, 30 000 ft (9144 m), $M_\infty = 0.84$
[3] Standard day, 30 000 ft (9144 m), $M_\infty = 0.84$, midcruise weight = 155 000 lb (70 307 kg)
[4] SL, 84° (302 K) takeoff, $M_\infty = 0.84$ at 30 000 ft (9144 m) cruise, standard day, zero wind, payload of 134 passengers at 205 lb (93 kg)/passenger = 27 470 lb (12 460 kg)

Table 3.—Airplane Characteristics

	727-200 (Baseline)	727 refan	727 refan at practical weight growth limit
Maximum taxi weight	173 000 lb (78 471 kg)	173 000 lb (78 471 kg)	183 000 lb (83 008 kg)
Maximum brake release gross weight	172 500 lb (78 245 kg)	172 500 lb (78 245 kg)	182 500 lb (82 781 kg)
Maximum landing weight			
30° flaps	150 000 lb (68 040 kg)	150 000 lb (68 040 kg)	154 500 lb (70 081 kg)
40° flaps	142 500 lb (64 638 kg)	142 500 lb (64 638 kg)	142 500 lb (64 638 kg)
Maximum zero fuel weight	136 000 lb (61 689 kg)	136 000 lb (61 689 kg)	138 000 lb (62 596 kg)
Fuel capacity	7 680 gal (29.071 m^3)	7 680 gal (29.071 m^3)	7 780 gal (29.449 m^3)[a]
Engine	JT8D-9	JT8D-109	JT8D-109
Operating empty weight	99 000 lb (44 906 kg)	102 840 lb (46 647 kg)	103 000 lb (46 720 kg)
C.G. at operating empty weight	40%	42%	42%

[a]Added capacity utilizing volumetric topoff.

this option, the resulting 727 refan airplane at the practical weight growth limit (table 3) could recover the lost range and provide a 15% *increase* in range improvement relative to the 727-200. The increased range (fig. 17) can be accomplished along with a takeoff field length improvement (fig. 18) because of the substantial takeoff thrust increase of the JT8D-109 engine. For the refan airplane, the block fuel (required to fly the same mission as the 727-200) is increased 1-1/2% to 3% depending on payload.

The JT8D-109 in-flight idle thrust would be increased over that of the JT8D-9 engine. This would result in the loss of the 727 refan capability to fly a $6^{o}/3^{o}$ multigradient glide slope approach for noise abatement. Normal 3^{o} approaches would be attainable.

3.3.2 ACOUSTIC CHARACTERISTICS

The acoustic characteristics of the 727-200 and 727 refan were analyzed with a method that combined the JT8D-15 and -115 ground test data with existing 727-200/JT8D-9 flight test data. The keynote of the analysis method was the evaluation and in-flight prediction of five major engine noise components: inlet fan noise including buzzsaw noise, aft fan noise emitted from the fan discharge duct, low frequency core noise emitted from the primary duct, turbine noise emitted from the primary duct, and jet noise including exhaust duct flow noise.

Table 2 presents a summary of the FAR Part 36 community noise levels predicted for the 727 refan. These are seen to be 6 to 8 EPNdB lower than for the 727-200. At cutback and sideline conditions, the 727 refan noise levels would be significantly below FAR Part 36. The 727 refan would meet the FAR Part 36 certification requirements without resorting to thrust cutback on takeoff.

Level flyby noise characteristics were predicted as a function of corrected net thrust and altitude. Figure 19 shows typical comparisons at altitudes of 400 ft (122 m) and 2000 ft (610 m). At high power settings, the 727 refan jet noise reduction due to the engine cycle change results in a significant noise improvement, as seen by comparing the 727-200 and 727 refan with a hardwall nacelle. At the lower power settings, other noise sources dominate the total; the noise reduction is primarily caused by the effectiveness of the acoustic linings, as seen from the comparison of the 727 refan with hardwall and treated nacelles. Over the complete matrix of thrusts and altitudes, the combined noise reduction is 3 to 9 EPNdB, while at FAR conditions it is 6 to 8 EPNdB.

The footprint contour area study (ref. 4) considered the community noise exposure of both the 727-200 and 727 refan for a variety of takeoff and landing gross weights and operational procedures. A comparison of different takeoff profile results for both airplanes (fig. 20) showed a reduction in annoyance-weighted total area of 68% to 83%, depending on gross weight and flight takeoff profiles. (Approach contour areas have little impact on total community noise exposure when compared to the takeoff contour areas.)

Note:

- M_∞ = 0.84 at 30 000 ft (9144 m)
- ATA domestic reserves
- Standard day
- No wind

Airplane	Engines	Max BRGW, lb (kg)	Fuel capacity, US gal (m^3)	OEW, lb (kg)
727-200	JT8D-9	172 500 (78 245)	7 680 (29.071)	99 000 (44 906)
727 refan	JT8D-109	172 500 (78 245)	7 680 (29.071)	102 840 (46 647)
727 refan growth option	JT8D-109	182 500 (82 781)	7 780 (29.450)	103 000 (46 720)

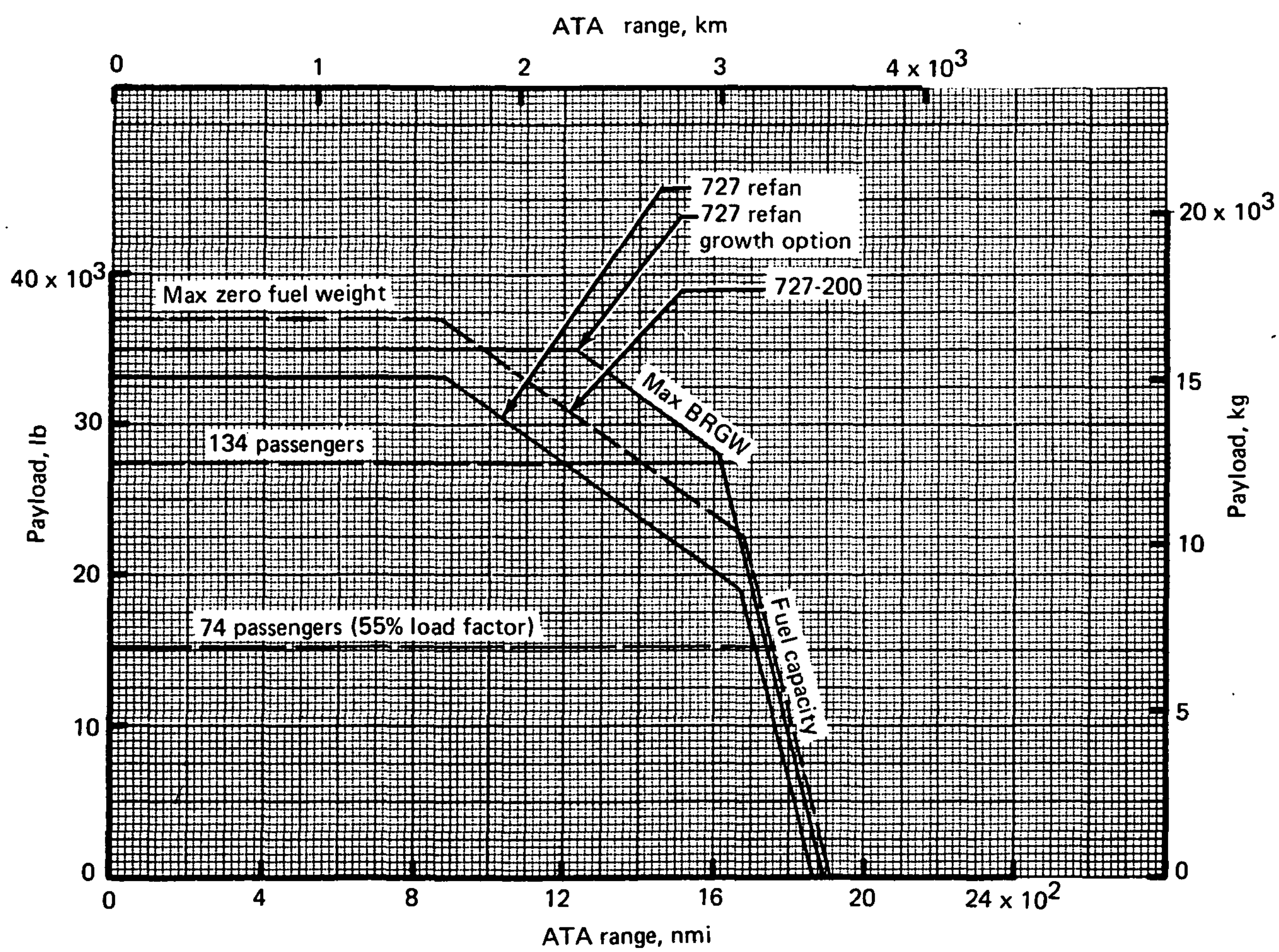


Figure 17.—727-200/727 Refan Performance Comparison—Payload and Range

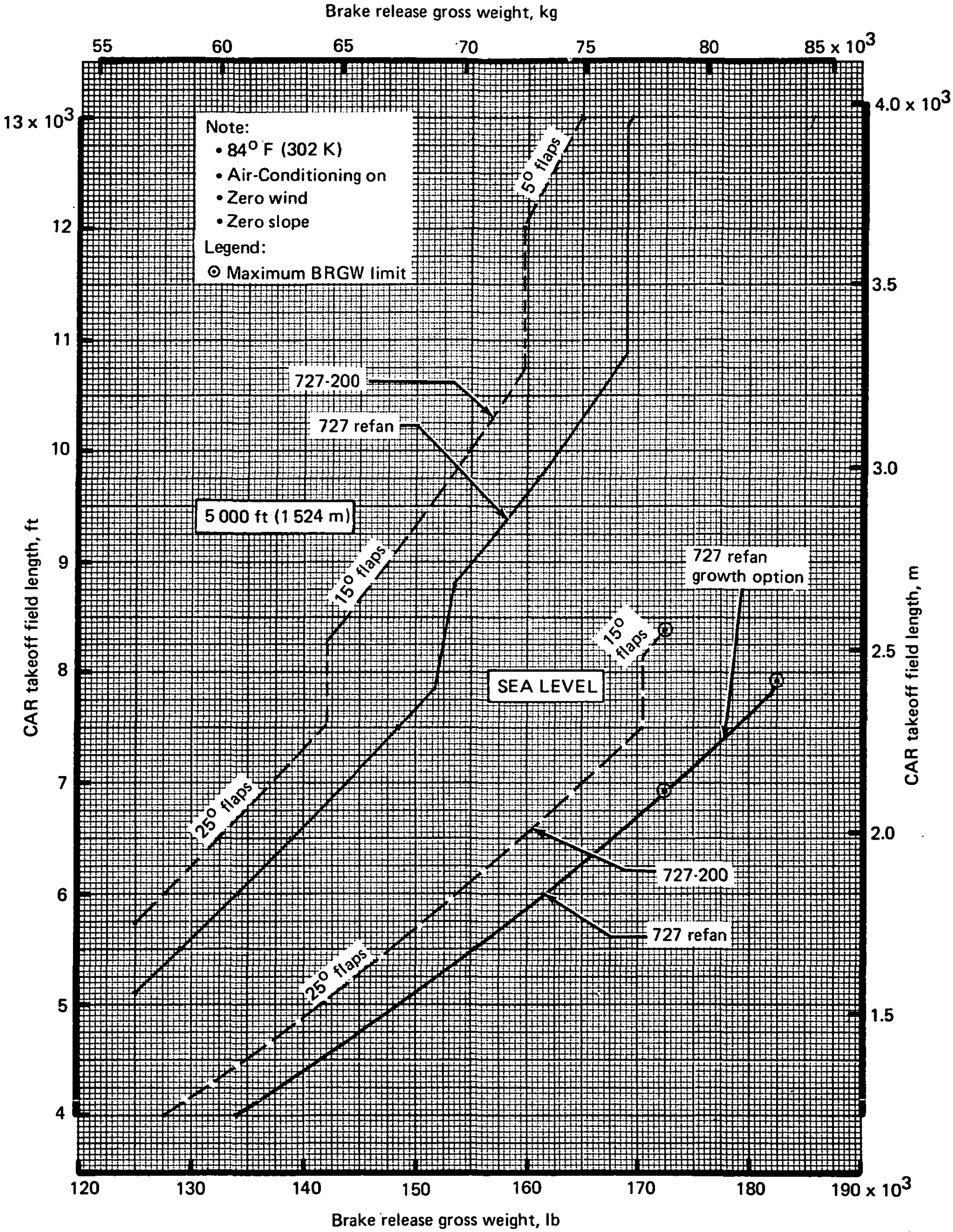


Figure 18. — 727-200/727 Refan Performance Comparison — Takeoff Field Length

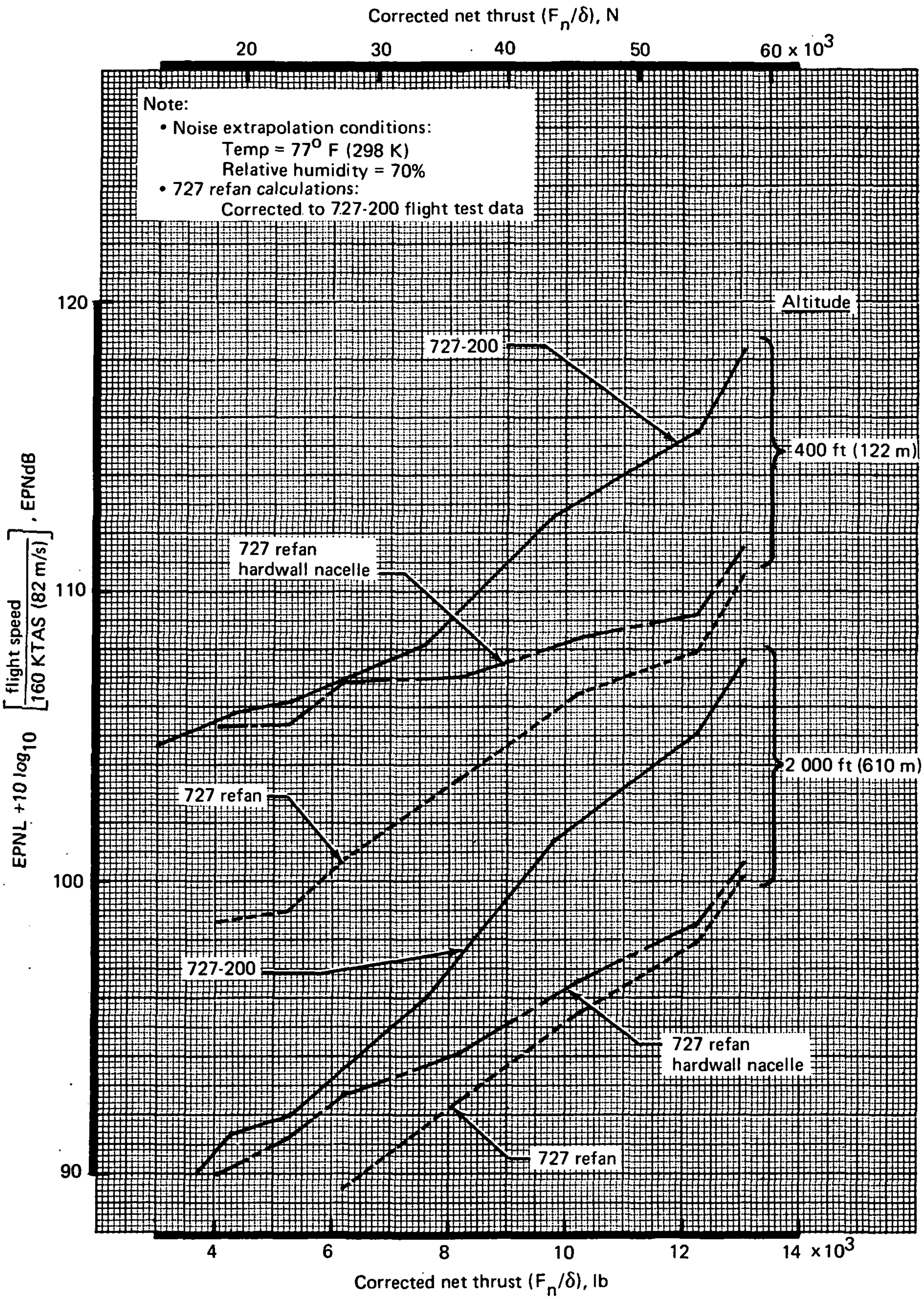


Figure 19.—Effectiveness of the Refan Concept

Note:

- Airplane: 727-200/727 refan
- Takeoff condition: Flap position = 5°
- Approach condition: LGW = 150 000 lb (68 040 kg) or 126 700 lb (57 470 kg)
  Conventional 3° approach
  Flap position = 30°
- Noise extrapolation cond: Temp = 77°F (298 K)
  Relative humidity = 70%
- EPNL calculation: Corrected to 727-200 flight test data
  +5 EPNdB limit on duration correction

Legend:

Takeoff profile designations

- ALPA
- FAR
- MFPOP
- ATA
- CI 1000
- CI 500

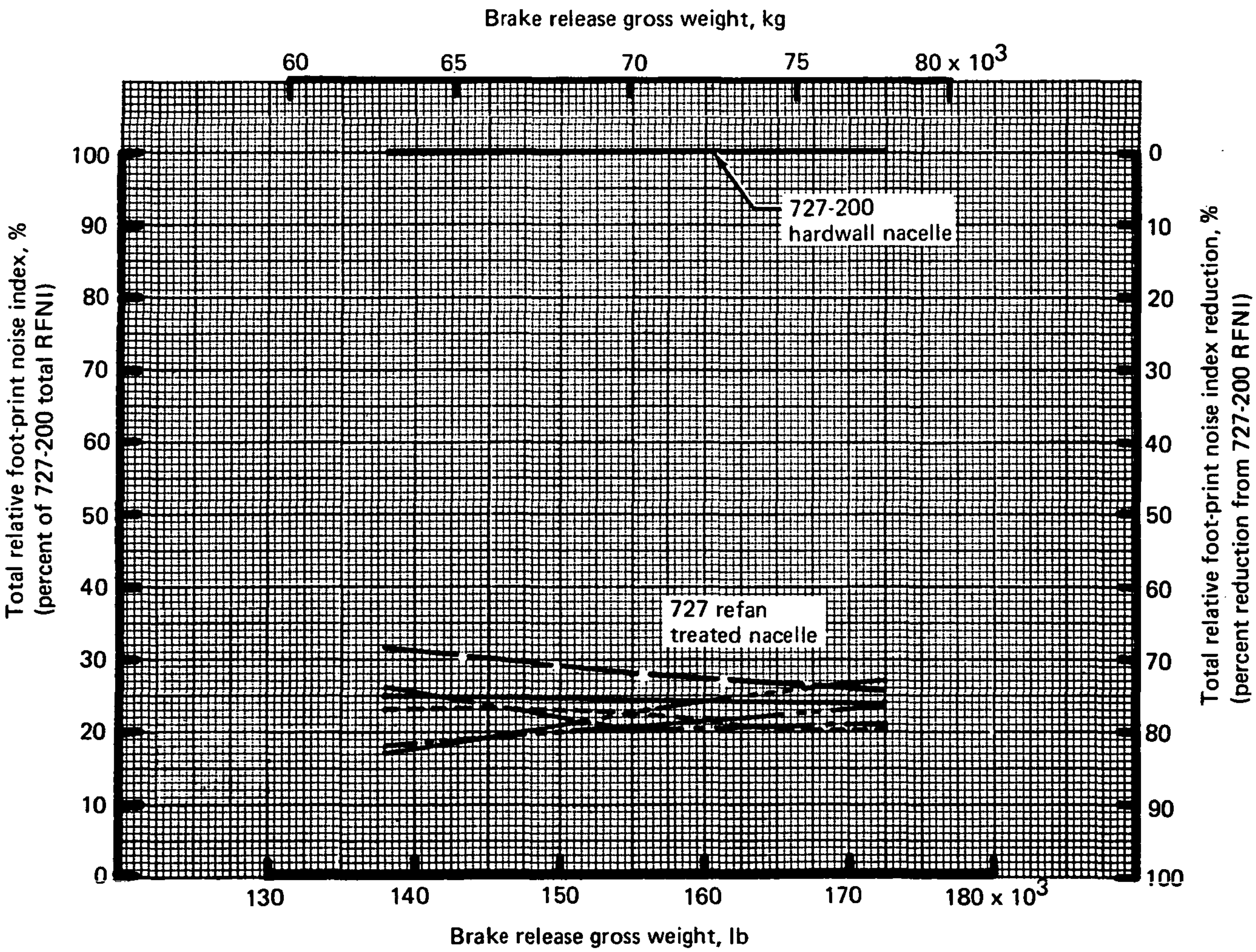


Figure 20.—727-200/727 Refan Total RFNI Reduction

3.3.3 PROPULSION

Figure 21 shows a comparison of the predicted installed JT8D-109 side- and center-engine takeoff thrust lapse rate with that of the JT8D-9 for a standard day at sea level. When compared to the JT8D-9, the total airplane thrust of the JT8D-109 engine is 14% greater at zero velocity and 10% higher at 100 kn (51.4 m/s).

A comparison of JT8D-9 and -109 estimated cruise performance was made at Mach 0.84, 30 000-ft (9144-m) altitude conditions (fig. 22). The average 727 refan SFC for two side engines and the center engine would be approximately 0.6% higher than for the 727-200 SFC at an average midcruise thrust of 4050 lb (18 015 N).

Separate ground and flight idle power settings would be required with the JT8D-109 engine. The flight idle power setting was established so that the certification engine acceleration time requirements for a refused landing could be met. The ground idle power setting would be set to provide adequate engine speed characteristics to satisfy 727-200 generator load requirements and low enough thrust for satisfactory 727 refan ground handling characteristics.

The thrust reverser performance estimates indicated that the refan thrust reverser can provide stopping capability equivalent to that of the 727-200. Since the refan thrust reverser was not evaluated in full-scale ground tests, further development work would be required to finalize the design and performance characteristics.

The nacelle subsystems such as starters, generators, coolers, etc., installed on the JT8D-109 were analyzed to maintain maximum commonality with the 727-200 installation. It was also determined that fire safety consistent with that provided on the 727-200 could be preserved with minor wiring and bracketry modifications.

3.3.4 STRUCTURES

The structural modifications were designed to meet the refan program design objectives for flightworthy and certifiable hardware. Analyses showed that all requirements were met. Positive margins of safety were calculated in all areas where the design was finalized and analyses using definitive loads were completed. A detailed fatigue durability analysis was not attempted, but the fatigue objectives could be met by maintaining low stress levels. Where the structural modifications were reviewed for feasibility only and the designs were not finalized, further structural and fatigue analyses would be required. It was judged that reasonable solutions would exist for the unfinished installation design.

3.3.5 WEIGHT AND BALANCE

The airplane weight and balance analysis showed a 2849-lb (1292-kg) weight increase and an approximate 6% mean aerodynamic chord (MAC) aft c.g. shift for the 727 refan at a BRGW of 172 500 lb (78 245 kg). This aft c.g. shift would be unacceptable. One solution is the addition of 990 lb (449 kg) of ballast, bringing the total weight increase to 3839 lb (1741 kg) (see table 2). The 990 lb (449 kg) of ballast added to the nose radome bulkhead shifts the *as-delivered fleet average* OEW center-of-gravity forward to a recommended 42% MAC for flight considerations.

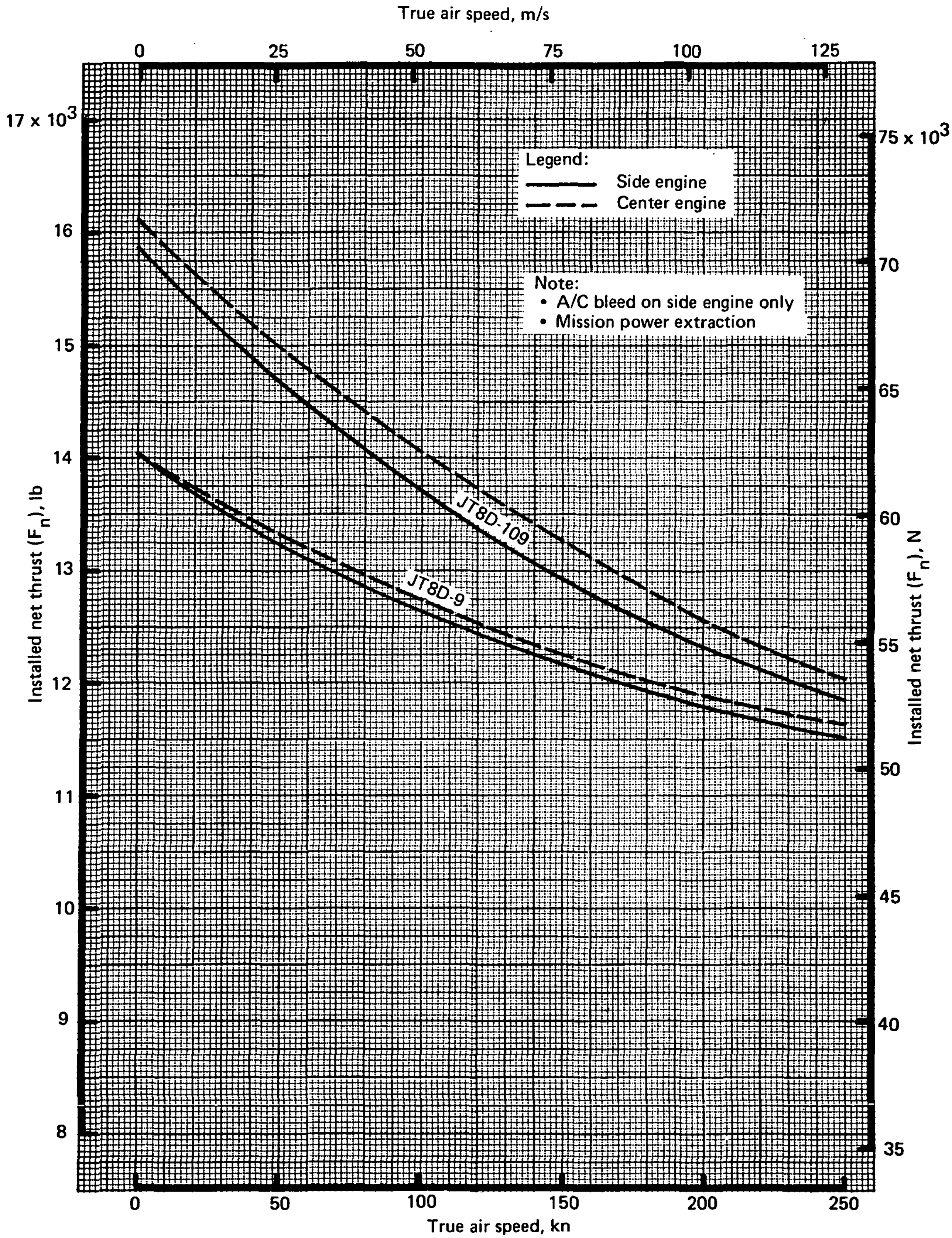
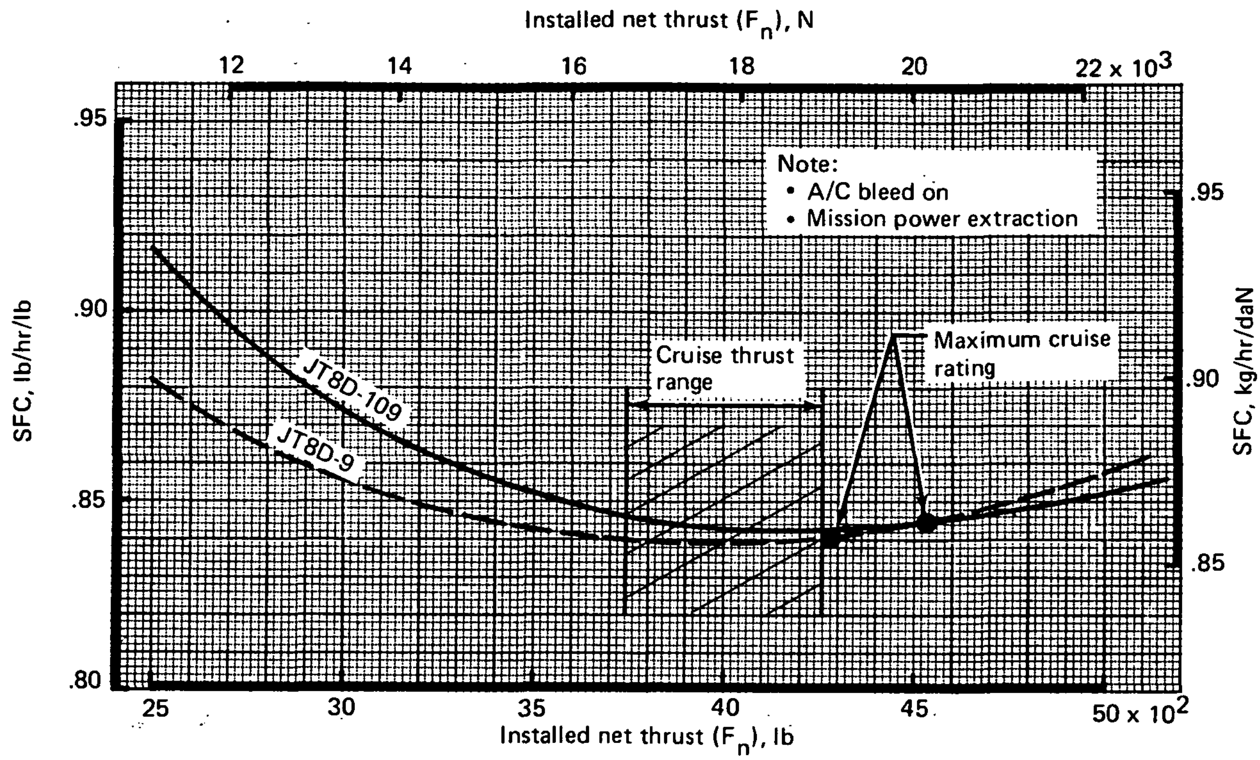
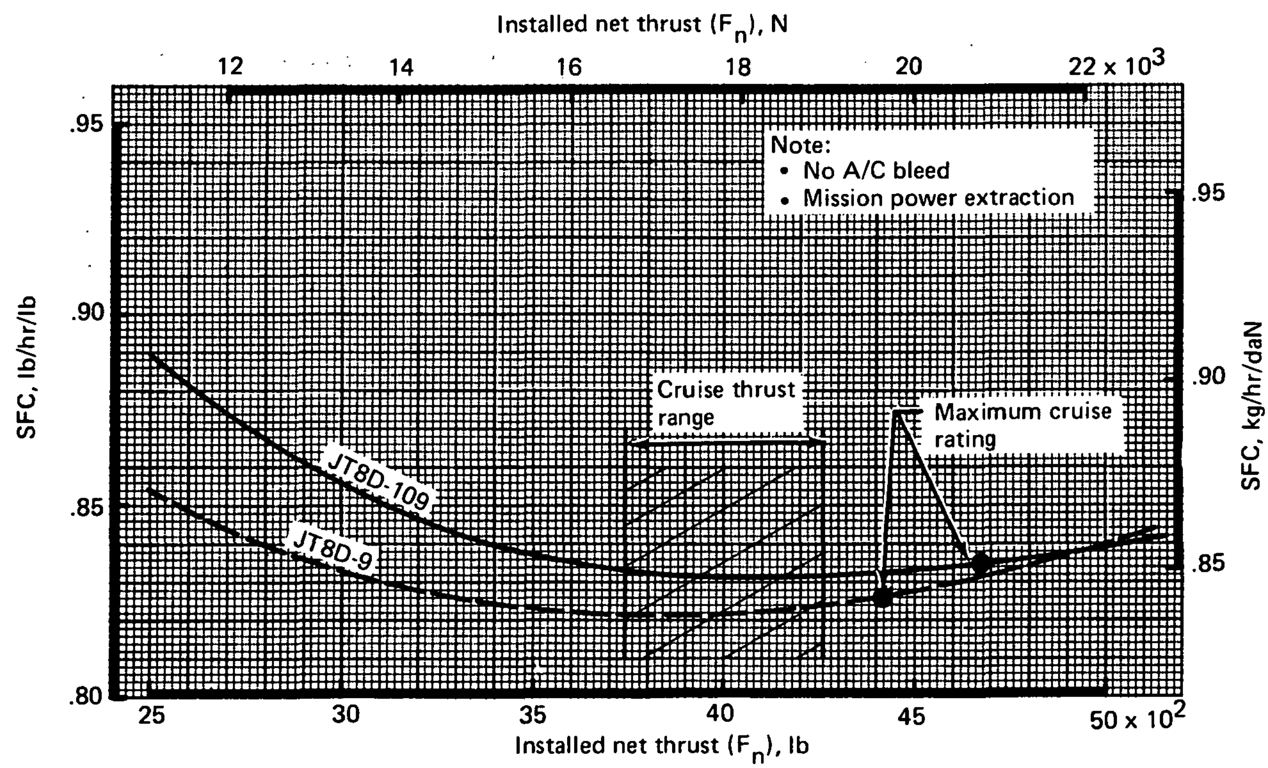


Figure 21.—Installed Takeoff Lapse Rate Comparison: JT8D-9 and -109 Engines—Sea Level, Standard Day, 727-200 Airplane



(a) Side-Engine Installation



(b) Center-Engine Installation

Figure 22.—Installed Cruise Performance Comparison: JT8D-9 and -109 Engines—Mach 0.84 at 30 000 ft (9 144 m), Standard Day, 727-200 Airplane

For ground handling, additional temporary ballast would be required to prevent tipping, since the *ground handling configuration* of the refan airplane (with nose radome ballast only) would be at approximately 47% MAC. The recommended aft c.g. location is 42% MAC with the maximum acceptable aft c.g. location being 46% MAC.

3.3.6 STABILITY AND CONTROL

The longitudinal and lateral-directional stability and control characteristics were analyzed for the 727 refan airplane. The results show that the longitudinal static stability, mistrim dive recovery, trim and stall characteristics, unaugmented Dutch roll damping, and directional control capability during reverse thrust operation would be similar to those of the 727-200 airplane and would meet the applicable airworthiness requirements.

3.3.7 ELECTRICAL AND MECHANICAL SYSTEMS

The hydraulic system for the refan target-type thrust reverser was scaled from the Contractor's 737 airplane. The analysis indicated that a satisfactory actuation system would result.

The ice protection system selected to be used on the 727 refan is a modification of the current 727-200 design. Analysis uncovered no major problems that would prevent adequate ice protection. The 727-200 air-conditioning and brake systems will meet the requirements of the 727 refan with no system modifications.

3.4 RETROFIT KIT COSTS

A preliminary study to determine the approximate cost of incorporating JT8D-109 retrofit kits on the 727 domestic fleet was conducted to aid the FAA in evaluating the cost effectiveness of the refan engine for noise reduction.

For purposes of the study, it was assumed that 669 model 727-100 and -200 airplanes would be subject to modification. This number of airplanes was based on the approximate U.S. fleet of 727's at the end of 1972. The 669 airplanes consisted of 414 727-100's and 255 727-200's; no attempt was made to differentiate between models and age as far as the kit cost estimates were concerned. The base for the kit cost estimate was a 727-200 model with a BRGW of 172 500 lb (78 245 kg) with specification characteristics for the airplane sections to be modified; i.e., a typical new airplane with JT8D-9 engines. The modified airplane would also have a 172 500-lb (78 245-kg) BRGW.

For purposes of this study, nacelle configuration 1 in the following table assumes a treatment configuration consisting of a peripherally lined inlet, a treated exhaust duct, and a hardwall fan/primary flow divider. Nacelle configuration 2 treatment varies from configuration 1 in that a treated inlet ring is added and the fan/primary flow divider is treated. The estimated modification price summary is presented in millions of 1974 dollars.

Plan I:	669	727 airplanes (nacelle configuration 1)	
	Engine parts		\$ 530.1
	Airplane parts		751.7
	Total installation		64.6
	Total Program Price		\$1 346.4
	Unit price		\$ 2.01 Million
Plan II:	414	727-100 (nacelle configuration 1)	
	255	727-200 (nacelle configuration 2)	
	Engine parts		\$ 530.1
	Airplane parts		783.2
	Total installation		64.6
	Total Program Price		\$1 377.9
	Unit price		\$ 2.06 Million

Nacelle configuration 1 will result in approximately the same noise level on the 727-100 as configuration 2 on the 727-200 on approach because of lower landing weights (and lower thrust levels) and larger installation effects (i.e., wing shielding). Takeoff noise with configuration 1 on the 727-100 will be slightly less than for configuration 2 on the 727-200 because of installation effects, lower maximum BRGW's, and resultant higher altitudes and lower cutback thrust levels.

The modification program price estimate assumed that the work was accomplished at a facility with the resources to minimize airplane down time, and that the modified airplane would be certified in accordance with the criteria existing at the time of the original model-type certificate. The costs of spares, changes in direct operating costs, additional maintenance, and out-of-service time during airplane modification have not been included in this preliminary retrofit cost estimate.

4.0 SUMMARY OF RESULTS AND CONCLUSIONS

The *Phase II Program On Ground Test of Refanned JT8D Turbofan Engines and Nacelles for the 727 Airplane* was conducted to evaluate the airplane performance, community noise reduction and airworthiness characteristics of a 727-200 airplane retrofitted with JT8D-109 engines. The technical credibility of such a retrofit concept was successfully demonstrated, and the program resulted in the definition of a refan engine installation design that is certifiable and producible.

The salient performance, noise, and airplane modification cost features follow:

1. For the same brake release gross weight (BRGW) airplane [172 500 lb (78 245 kg)], the refan modification would reduce the airplane range (from a SL unlimited length field) by approximately 15%. The block fuel would increase by 1-1/2% to 3%.

2. For this particular model of 727-200, analyses show that the range could be increased 15% compared to the non-refanned 172 500 lb (78 245 kg) BRGW airplane by making use of the airplanes maximum fuel capacity. The additional fuel would result in a BRGW of 182 500 lb (82 781 kg) and would require some minor structural modifications to the airplane.

3. The noise reduction associated with the refan engine and acoustically treated nacelles is estimated to be 6 to 8 EPNdB lower than the unmodified airplane at the FAR 36 measurement points, with an annoyance-weighted footprint area reduction of 68% to 83%.

4. The retrofit cost is estimated to be approximately $2 million per airplane in 1974 dollars, assuming modification of 669 727's, including both -100 and -200 series airplanes.

APPENDIX

SYMBOLS AND ABBREVIATIONS

A/C	Air-conditioning
ALPA	Airline Pilots Association
ATA	Air Transport Association
BRGW	Brake release gross weight
CAR	Civil Air Regulation
c.g.	Center of gravity
CI 500	Community interface profile, 500 ft/min climb rate
CI 1000	Community interface profile, 1000 ft/min climb rate
℄	Centerline
cm	Centimeter
CSD	Constant speed drive
daN	Dekanewton
dB	Decibel re 0.0002 μbar
deg, ^{o}	Degree (unit of plane angular increment)
^{o}F	Degrees Fahrenheit
EPNdB	Effective perceived noise level in decibels
EPNL	Effective perceived noise level
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
F_n	Net thrust
F_n/δ	Corrected net thrust
ft	Feet

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fwd	Forward
gal	United States gallon
hr	Hour
Hz	Hertz
in.	Inch
K	Degrees Kelvin (absolute)
kg	Kilogram
km	Kilometer
kn	Knot
KTAS	Knot true air speed
lb	Pound
LGW	Landing gross weight
LPC	Low pressure compressor
m	Meter
M_∞	Freestream Mach number
MAC	Mean aerodynamic chord
max	Maximum
MFPOP	Modified full power operational profile
min	Minute
mm	Millimeter
N	Newton
nmi	Nautical mile
OEW	Operational empty weight
P&WA	Pratt & Whitney Aircraft

PNdB	Perceived noise in decibels
PNLTW	Weighted average value of tone-corrected perceived noise level
P_{t2}	Engine compressor-face total pressure
re	Reference value
ref.	Reference
RFNI	Relative footprint noise index
rpm	Revolutions per minute
sec, s	Second
SFC	Specific fuel consumption
SI	International System of Units
SL	Sea level
SPL	Sound pressure level
sta	Body station (longitudinal location)
temp	Temperature
TSFC	Thrust specific fuel consumption
typ	Typical
U.S.	United States
%	Percent

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