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

Final Report

VOLUME II
HARDWARE DESIGN AND MANUFACTURING

December 1975

Boeing Commercial Airplane Company
Seattle, Washington 98124

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NASA Lewis Research Center
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16. Abstract

This report presents a summary of the design and manufacturing effort required to support the Phase II Program on Ground Test of Refanned JT8D Turbofan Engines and Nacelles for the 727 Airplane. This effort was a follow-on to the Phase I effort, which was conducted under contract NAS3-16815. A production oriented design was conducted in Phase II for application of the JT8D-100 series refan engine to the 727-200 airplane with the objective of evaluating retrofit to reduce operating noise levels below those defined in FAR Part 36 while retaining and utilizing as much of the current production hardware, accessories, and subsystems as possible. The design includes changes to all engine-mounted and engine-related components. The design also includes changes to the airplane and airplane systems. The installation of JT8D-100 series engines required a new side-engine inlet, new side-engine side cowls, a new exhaust system, a new center-engine inlet duct, new center-engine side cowls, new accessory installations, and revisions to associated airplane structure and systems. Those components essential to the ground test evaluation of acoustic and propulsion performance were manufactured including a side-engine inlet, a center-engine inlet duct, and an exhaust system without thrust reverser.

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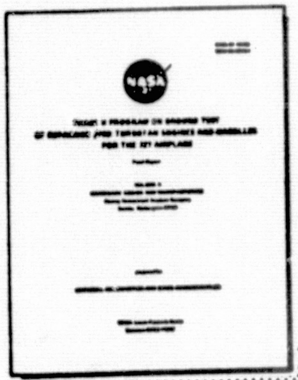
FINAL REPORT

OVERALL REPORT ORGANIZATION



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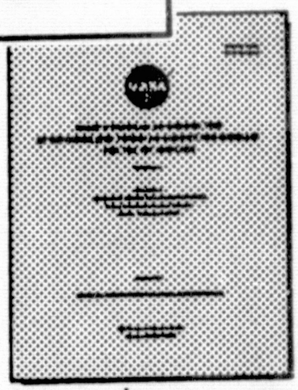

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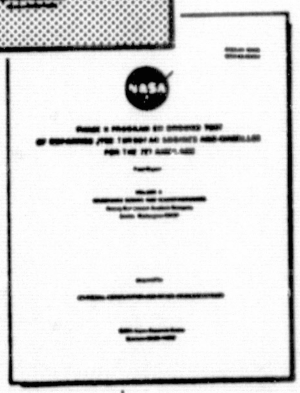

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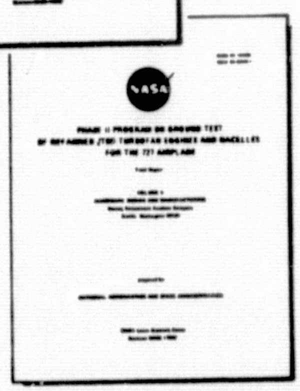

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1.0 SUMMARY

The objective of Phase II of the NASA-sponsored Refan Program was to design, manufacture, and ground test an acoustically treated certifiable and producible JT8D-100 series engine installation for the 727-200 airplane under contract NAS3-17842.

The Phase II design effort began in July of 1973 and ran through October of 1974. The fabrication effort was completed in February of 1975 in time to support the ground test effort.

This document, Volume II, covers the Phase II design and the fabrication of full-scale test hardware for the installation of the Pratt & Whitney Aircraft JT8D-100 series refan engine as a retrofit on the existing Boeing 727-200 airplane.

The JT8D refan series engine is a derivative of the JT8D series engine used to power the 727-200 airplane. The refan engine incorporates a single-stage fan of larger diameter than the two fan stages of the JT8D series, to achieve higher thrust, lower specific fuel consumption, and reduced jet noise. The engine length is increased by 7.3 in. (18.5 cm), the fan tip diameter by 8.7 in. (22.1 cm), and the weight by 570 lb (258 kg).

The retrofit installation of the refan engine in the 727 was designed to minimize impact on the existing airframe. The side-engine strut length and firewall locations were retained, the nacelle centerlines were moved 5.5-in. (13.9-cm) outboard, and the engine mount systems were changed to meet the requirements of nacelle weight and geometry.

The side inlets were redesigned to accommodate the increased airflow and to incorporate acoustic treatment. They are symmetrical, providing commonality between left and right nacelles. The removable side-cowl panels were changed from aluminum skin and stringer to fiberglass-honeycomb construction and are likewise common between right and left nacelles. The exhaust system of aluminum-brazed titanium structural/acoustic honeycomb is common to all three engine locations. A new hydraulically operated target-type thrust reverser (based on the design used on the 737 airplane) is mounted on the exhaust duct. The center-engine installation retains the same vertical and horizontal (overhead) firewall positions, but the engine centerline moved down 4.5 in. (11.4 cm), and the engine mounts moved aft 10.7 in. (27.2 cm), requiring a new support structure.

The center-inlet duct construction was changed from aluminum skin and stringer to perforated aluminum inner skin, bonded to fiberglass structural/acoustic honeycomb. The flowpath was contoured to pass through the existing opening in the vertical-tail front spar forging.

Airframe-furnished equipment required to integrate the engine and related systems into the airplane was changed only where necessary or where reasonable design simplification could be achieved. Engine and seal drains were simplified by the removal of the drain tanks of the side engines. Some changes in the fire barriers occurred as a result of the new cowl construction; but fire detection, fire extinguishing, engine lubrication, and the engine fuel system were essentially unchanged. A new constant-speed-drive oil cooler utilizing fan air was mounted in the fan duct. Because of interference with the larger engine diameter, the center-engine control system was redesigned to use a push-pull cable rather than a lever system from the firewall to the engine control cross-shaft.

Engine dimensional changes also caused a redesign of the airbleed ducting, but no basic changes were made in the thermal anti-ice or air-conditioning systems.

The objective of the manufacturing effort in support of the NASA Refan Program was to fabricate flightworthy certifiable hardware to engineering requirements using normal production practices and facilities and to minimize cost where feasible by the use of soft or expendable tools.

The manufacturing effort was concerned with several basic types of construction, including casting, machining, metal forming, welding, and related processes to fabricate the detail parts. Also included were metal bonding, fiberglass/plastic laminate bonding, brazing, chemical milling, and related assembly processes required to assemble the detail parts.

The major components fabricated for this program were a center-engine inlet duct, an exhaust nozzle system, and a nonflightworthy side-engine inlet.

- The center-engine inlet duct was fabricated as a bonded honeycomb assembly with a perforated aluminum acoustic face and fiberglass core and fiberglass outside skins.

- The exhaust nozzle system made extensive use of aluminum-brazed titanium (ABTi) honeycomb using chemically milled perforated acoustic skins. The components exposed to engine core gas temperatures were made from Inconel 625 honeycomb and sheet metal.

- The nonflightworthy side-engine inlet was manufactured using fiberglass laminates and fiberglass polyimide honeycomb combined with aluminum substructure.

Many benefits including improved production techniques to build light weight acoustic treatment using both bonding and brazing can be derived from the Refan Program. These techniques show promise in reducing both cost and weight of nacelle acoustic components.

2.0 INTRODUCTION

The overall NASA Refan Program was established in mid-1972 with the objective of developing and evaluating JT3D and JT8D refanned engine retrofit installations on 707, DC-8, 727, 737, and DC-9 airplanes to reduce aircraft noise with minimum impact on total cost of ownership. Participants in the program were the Boeing Commercial Airplane Company, McDonnell Douglas Aircraft Division, Pratt & Whitney Aircraft Division, United Air Lines, and American Airlines.

The Boeing Phase I program, contract NAS3-16815, was undertaken in August 1972 with the initial objective of identifying changes in the existing Boeing airplane fleet to retrofit modified higher bypass engines and thus effect a substantial reduction in community noise.

The Phase I work, reported in reference 1, documents studies relating to the model 707, 727, and 737 airplanes. It describes proposed retrofit configurations, projected performance, and estimated economic aspects of each. Those preliminary design studies led to the conclusion that the JT8D refan engine with its increased bypass ratio could be installed with appropriate inlet and exhaust acoustic treatment on the existing 727-200 airplane to provide substantial reduction in community noise.

The Boeing Phase II program, contract NAS3-17842, was undertaken in July of 1973 with the objective of designing, manufacturing, and testing a certifiable JT8D-100 series refanned engine installation for the 727-200 airplane. The Phase II detail design provided the definition of a new side-engine nacelle together with a new center-engine inlet duct to match the larger diameter and higher airflow of the refan engine. Modifications required in the airplane body structure and systems were also defined.

This document is Volume II of the NASA/Boeing Refan Program Phase II Final Report. It provides a technical description of the flightworthy design that is part of the evaluation of retrofit of the Pratt & Whitney Aircraft (P&WA) JT8D refan engine on the Boeing 727-200 airplane. It also describes the manufacture of hardware built to support full-scale ground tests with the engine. This document is not a specification. It describes a design that is representative of typical modification for application of the refan engine. Customer requirements and further evaluation could result in changes or identify desirable alternative construction.

Volume I of this final report series (ref. 2) is a summary of the Phase II activities in the contract. Volumes III and IV of this final report series (refs. 3 and 4), respectively, provide a report of full-scale ground tests of the engine with inlet and exhaust systems and performance evaluation of the 727-200/JT8D refan airplane.

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 adaptation of the Pratt & Whitney Aircraft JT8D refan engine to the 727-200 airplane was evolved to provide a configuration suitable for retrofit in the existing commercial airplane fleet and, accordingly, was constrained by the normal requirements for airplane safety, performance, reliability, durability, maintainability, cost, and fleet operational suitability. With the increased size and weight of the refan engine, special attention was given to the use of advanced structural design and manufacturing techniques to minimize the weight of the installation. The following list identifies the scope of the redesign:

1. Side-engine nacelle including inlet, cowls, exhaust duct 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.

Section 3.3 describes several preliminary trade studies that provided background for the design.

The new exhaust system (common to all three engines in the 727 airplane) and the center-engine inlet duct are typical of the advanced manufacturing approach used in that they were designed with structural/acoustic honeycomb construction. They were fabricated, as described in section 3.2, to the flightworthy design in order to confirm both the acoustic and structural adequacy of this construction in the full-scale ground tests. Alternate designs of the wedge duct, nozzle, and fan/primary flow divider were selected instead of the original design in order to minimize fabrication time and assure maximum potential of achieving acceptable brazements. The Contractor also determined that the multiple skin and bonded doubler construction used in the center-engine inlet duct might pose a service maintenance problem because of possible bonding delamination. For this reason, an alternative design eliminating the bonded joints was completed but not manufactured. This alternative design is certifiable. Fabrication of the side-engine flightworthy inlet, cowls, and thrust-reverser system was undertaken but was terminated prior to completion because of a reduction in program funds. A flightworthy side-engine inlet which could be used with and without a ring was designed. The inlet was replaced by a ground test unit that was built without anti-icing provisions. This unit was not a production flight-weight design, but duplicated the propulsion and acoustic critical requirements.

3.1 DESIGN

This section describes the configuration developed to provide a flightworthy production design for retrofit of existing 727-200 airplanes with the JT8D-100 series refan engine. The following general ground rules were used to guide the design effort:

1. Incorporate noise attenuation treatment in the engine inlet and exhaust systems to provide substantial reduction in emitted fan and turbomachinery noise
2. Utilize commercial design practices, minimize changes to airplane structure and systems, and provide a high degree of commonality of components with existing JT8D engine installations to minimize time and cost of the retrofit

3. Retain or improve existing standards of safety, reliability, and maintainability

4. With the airplane center of gravity at the aft limit, any weight increase in the nacelle results in an airplane weight increase in the ratio of 4.8 to 1, including ballast to restore balance

5. Optimize the installation to retain airplane performance and operational characteristics.

The JT8D-100 series engine is a derivative of the basic JT8D turbofan engine modified to incorporate a new larger-diameter single-stage fan with a bypass ratio of about 2.00 and two supercharging low-pressure compressor stages. Extensive acoustic treatment was included in the -100 series engine fan duct to reduce aft-directed fan noise. The modifications give lower jet noise, increased takeoff and maximum allowable cruise thrust, and lower specific fuel consumption. A comparison of the physical characteristics of the JT8D and the JT8D-100 series engines is shown in figure 1.

The engine selected for modification to the refan configuration was a JT8D-9, but the 727 installation design was based on the JT8D-15 and its counterpart JT8D-115 refan engine for ground test purposes. Requirements of the engine/airplane interface, such as flange loads, pressure limits, flow distortion, and flow areas for the inlet and exhaust system, were established through coordination with the engine manufacturer, as were the functional requirements and limitations of accessories and subsystems. As an aid in the installation design process, a full-scale engineering mockup of a side-engine installation was constructed (figs. 2 and 3) providing physical relationships of the components in the nacelle.

On the existing JT8D installation for the 727 airplane, the side engines are mounted in nacelles on struts from the aft body. The nose cowls have 4° toe-in, and the exhaust duct centerline is directed up $3^{\circ}22'$ relative to the engine centerline. The center engine is suspended from the structure aft of the vertical-tail rear spar. The inlet, located at the forward base of the vertical tail, supplies air to the engine via a center duct that passes through the fin front-spar forging. All three engines are equipped with pneumatically operated internal clamshell thrust reversers.

The basic external dimensional parameters for the JT8D refan side-engine nacelle are compared with the current production JT8D nacelle in figure 4. A comparison of the side-engine nacelle and engine installations is shown in figure 5. The nose cowl toe-in was eliminated, thereby allowing a simplified design that provides nose cowl commonality between left- and right-side engines. The exhaust duct was canted up 3.5° relative to the engine centerline to direct the exhaust parallel to the airplane centerline for the side engines and to provide adequate ground clearance for the center engine during airplane rotation on takeoff and landing. No change was made in the strut-mounted concept of the existing airplane, and only minor alterations to the firewall and strut components were required. The engine mounts on the strut retain the same geometry as the existing airplane, but the engine centerline is moved 5.5 in. (13.9 cm) outboard.

Side-cowl construction was changed from aluminum skin and stringer to epoxy fiberglass-honeycomb sandwich. The thrust reverser was changed from a pneumatically operated internal blocker-door type with external deflection door to a hydraulically operated target type based on the design currently in use on the 737 airplane. Acoustic lining was incorporated

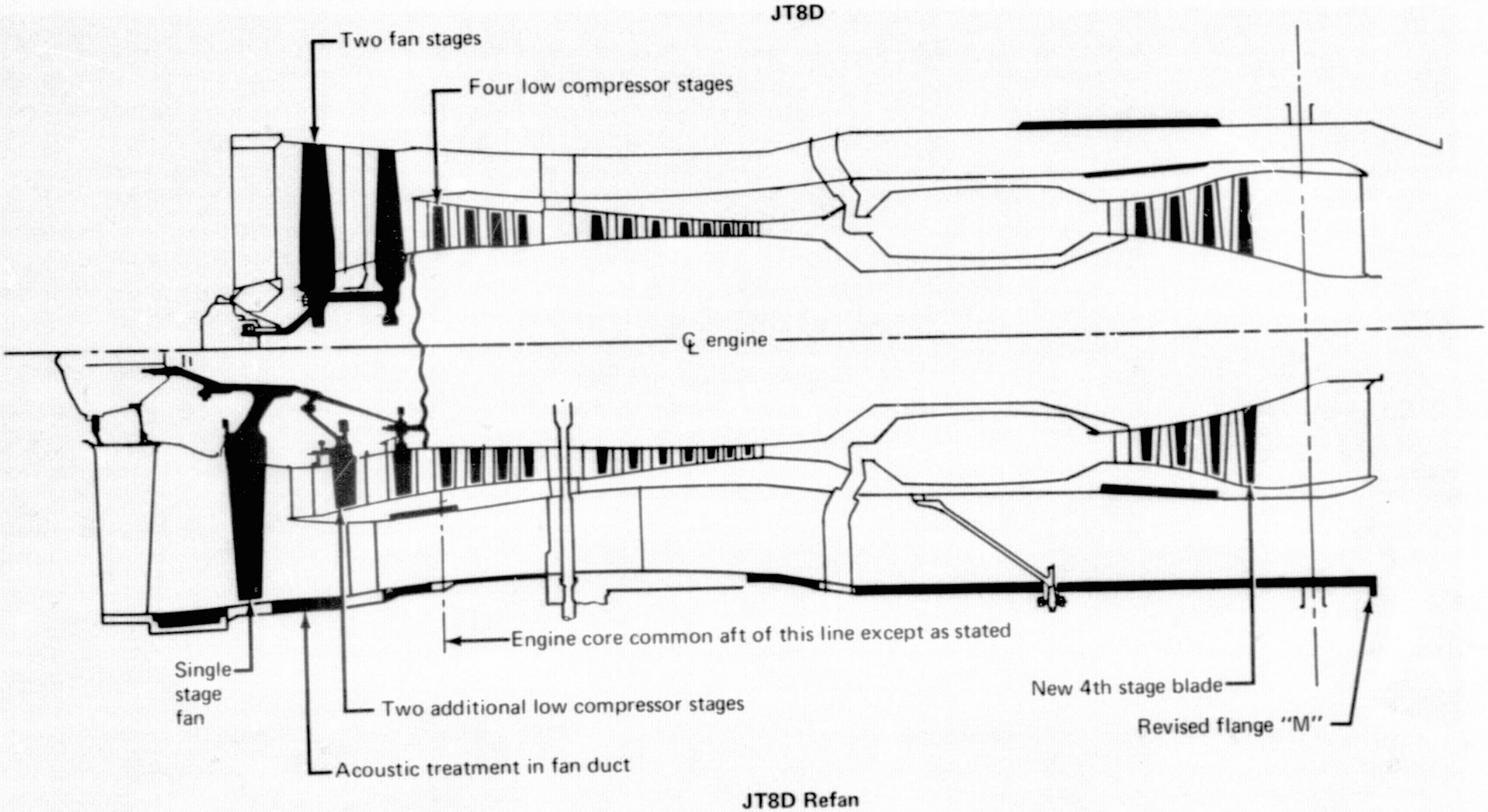


Figure 1.—JT8D/JT8D Refan Engine Physical Characteristics Comparison

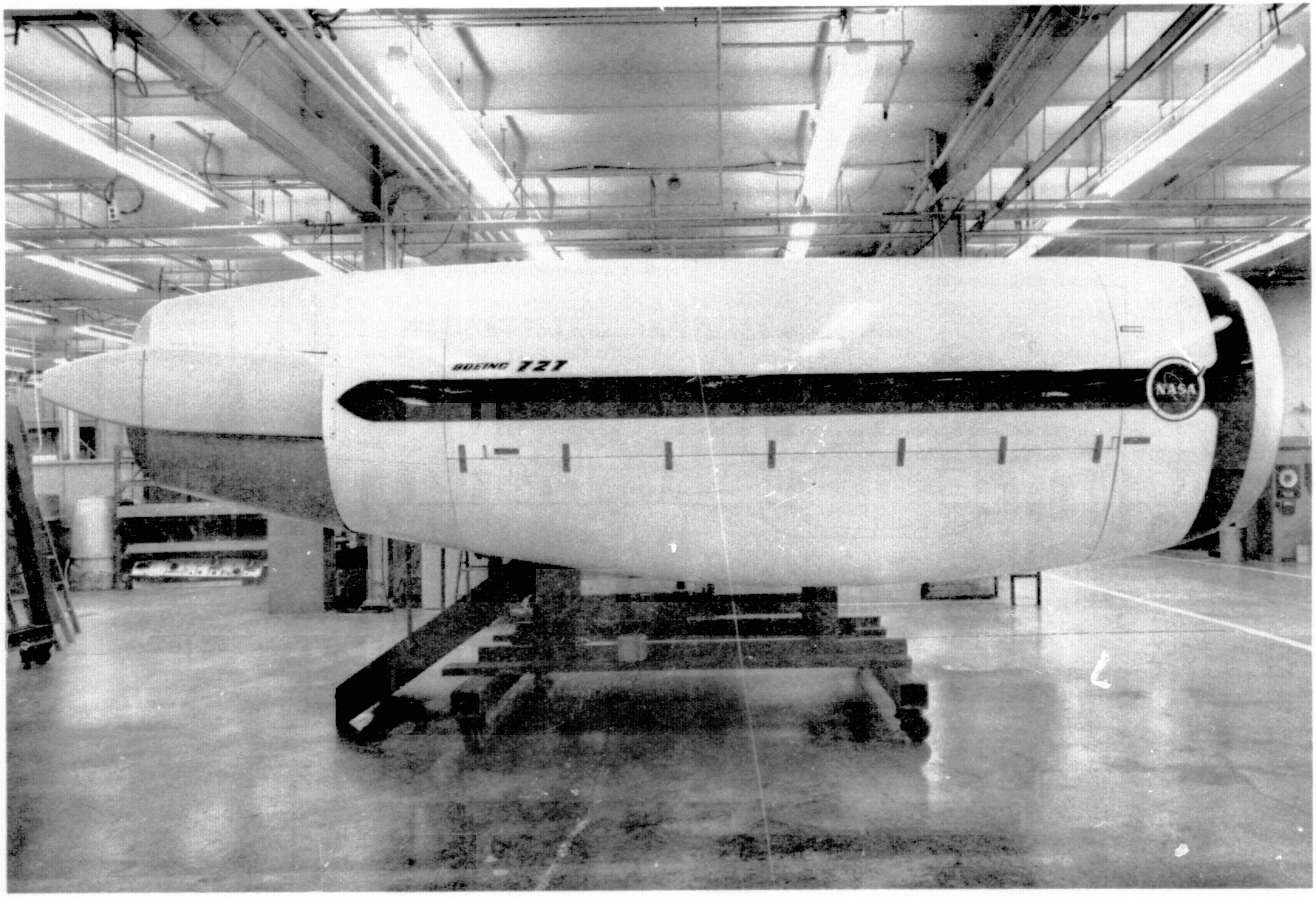


Figure 2.—JT8D Refan Side-Engine Nacelle Mockup

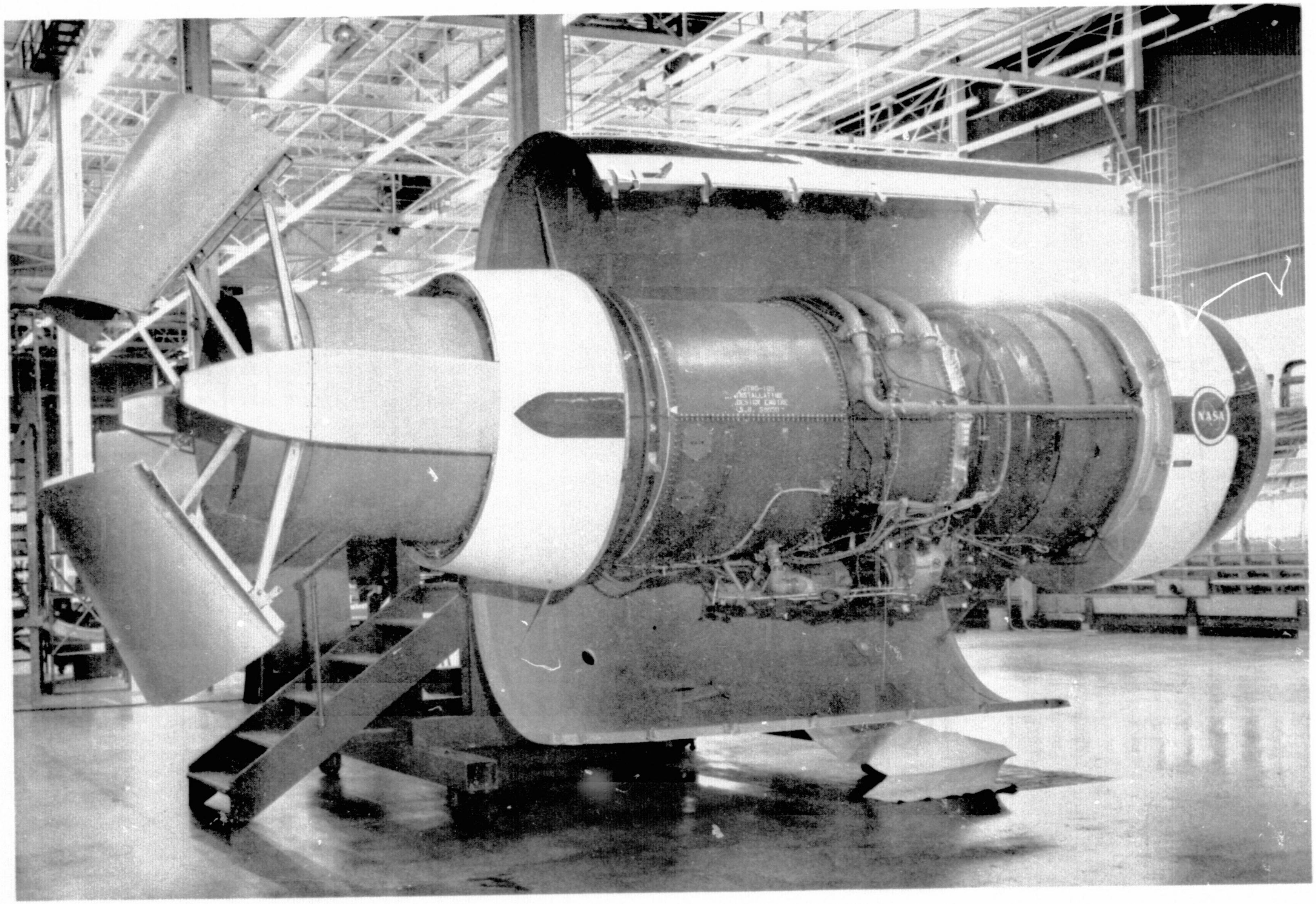
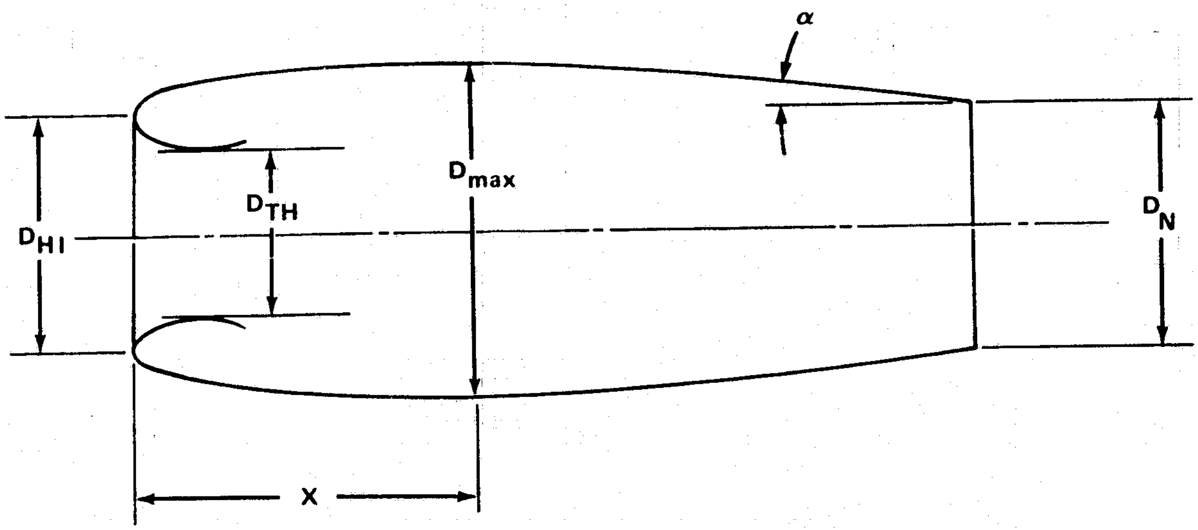


Figure 3.—JT8D Refan Side-Engine Installation Mockup



	JT8D	JT8D refan
Nacelle length, in. (m)	214.50 (5.45)	234.10 (5.95)
Maximum diameter (D_{max}), in. (m)	50.00 (1.27)	62.00 (1.57)
Maximum area (A_{max}), ft^2 (m^2)	15.87 (1.47)	23.00 (2.14)
Nozzle exit diameter (D_N), in. (m)	29.84 (0.76)	39.08 (0.99)
Ratio (D_{HI}/D_{max})	0.78	0.84
Length to maximum section (X), in. (m)	25.0 (0.64)	58.5 (1.48)
Exhaust duct boattail angle α, deg	10.5°	12°
Throat diameter (D_{TH}), in. (m)	37.84 (0.96)	46.70 (1.19)
Highlight diameter (D_{HI}), in. (m)	42.31 (1.07)	52.21 (1.33)

Figure 4.—JT8D/JT8D Refan Nacelle External Dimensional Parameter Comparison

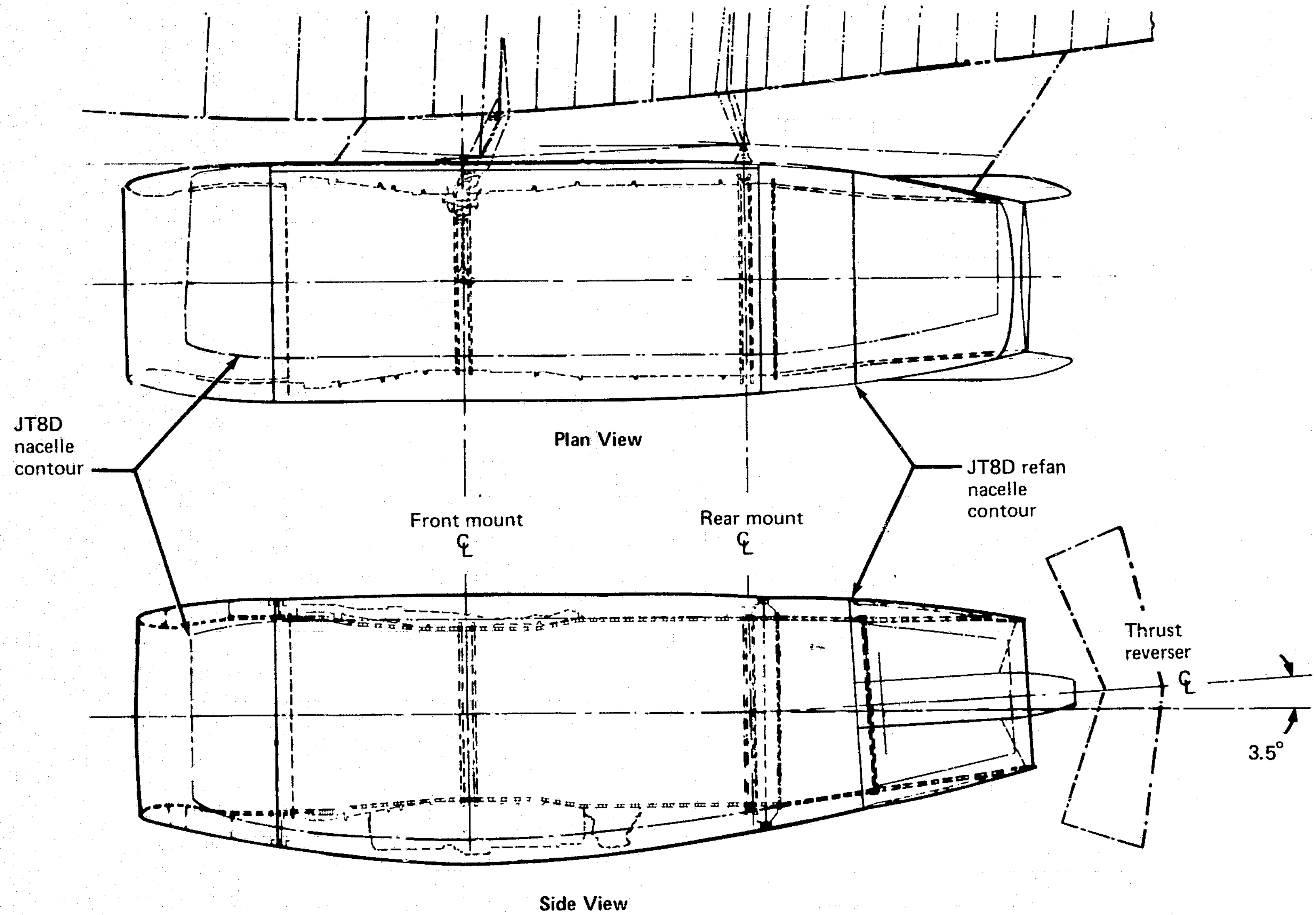


Figure 5.—Comparison of Side-Engine Nacelle Installation for JT8D and JT8D Refan Engines

on the inlet diffuser walls, nose dome, exhaust duct inner wall, and on both sides of the fan/primary exhaust divider duct.

The inlet featured the ability to perform with and without an acoustically treated ring. The exhaust duct was designed to operate with the hardwall flow divider provided by P&WA and with the Contractor-designed acoustically treated flow divider. This provided the ability to test both a maximum and a minimum acoustic configuration.

The 727/JT8D refan engine installation is shown in figure 6.

The center engine attaches to a new mount structure that relocates the engine 10.7 in. (27.2 cm) aft with the centerline 4.5 in. (11.4 cm) below its original position. The exhaust duct is common with the side engines and is also canted up relative to the engine centerline, preserving airplane rotational capability (see table 8, sec. 3.1.7.1). The inlet and center duct were revised with new flowpath geometry accommodating the increased engine air mass flow without changing the opening through the vertical-tail front spar. The construction of the center duct was changed from aluminum skin and frame to perforated-aluminum inner skin and phenolic-fiberglass structural/acoustic honeycomb with fiberglass outer skin.

The nacelles and support structure were designed for the same ultimate load criteria as for the 727-200 installation, accounting for the increased weight and thrust of the engine and the flaps-down aerodynamic loads derived from pressure model test. A comparison of these loads with those used in the existing design is shown both in table 1 and in figure 7. Fatigue criteria used in the design of the refan nacelle and supporting structure are also consistent with the existing installation.

The refan installation exceeds the standard of interchangeability provided by the current 727-200 installations. Several items of engine accessories also retain commonality with the existing installation (see sec. 3.1.6.13). As in the current airplane, the thrust reversers are common to all three engine positions. In addition, the refan side-engine nacelle design provides side-to-side commonality of nose cowls and of upper and lower removable side-cowl panels.

3.1.1 SIDE-ENGINE INLET

The side-engine inlet designed for the JT8D refan engine is of conventional configuration incorporating acoustic panels to reduce forward projected noise. The inlet is symmetric about the vertical axis, allowing commonality between side engines as determined by wind tunnel tests (ref. 6). The throat diameter was increased to 46.7 in. (1.186 m) to accommodate the airflow of the refan engine. A lip contraction ratio of 1.25 results in a lip highlight diameter of 52.2 in. (1.326 m). The length/diameter (L/D) ratio of the inlet is 0.8, constrained by considerations of weight and the proximity of the inlet to the airplane aft service door.

3.1.1.1 Nose Cowl

The nose cowl, shown in cross section in figure 8, is of sheet-metal frame and bulkhead construction with bleed air anti-icing provisions in the inlet lip. The acoustic diffuser panel is a single piece 29-in. (73.6-cm) long panel constructed in continuous 360° polyimide-impregnated fiberglass honeycomb. Details of the panel construction are shown in figure 9.

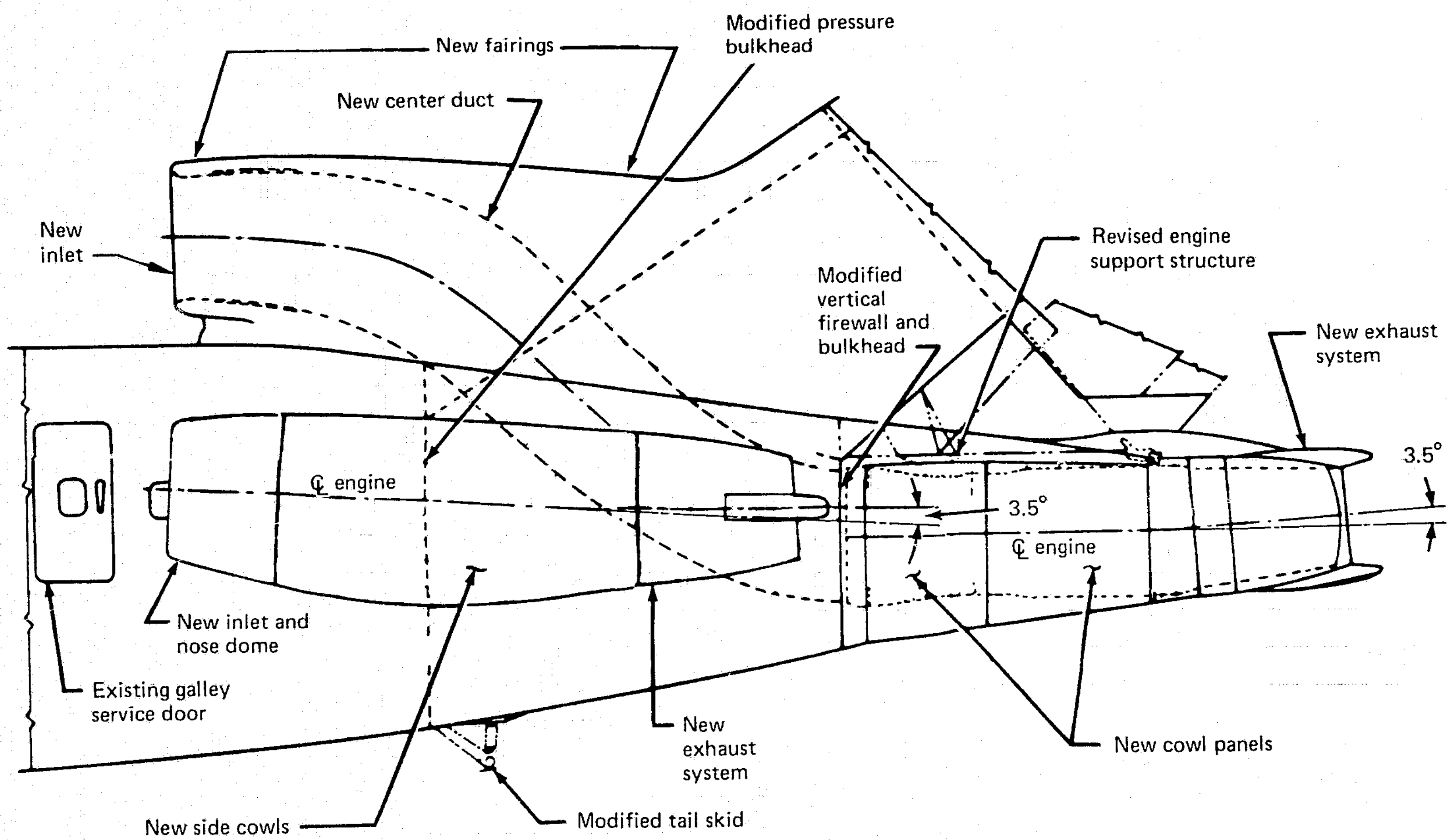


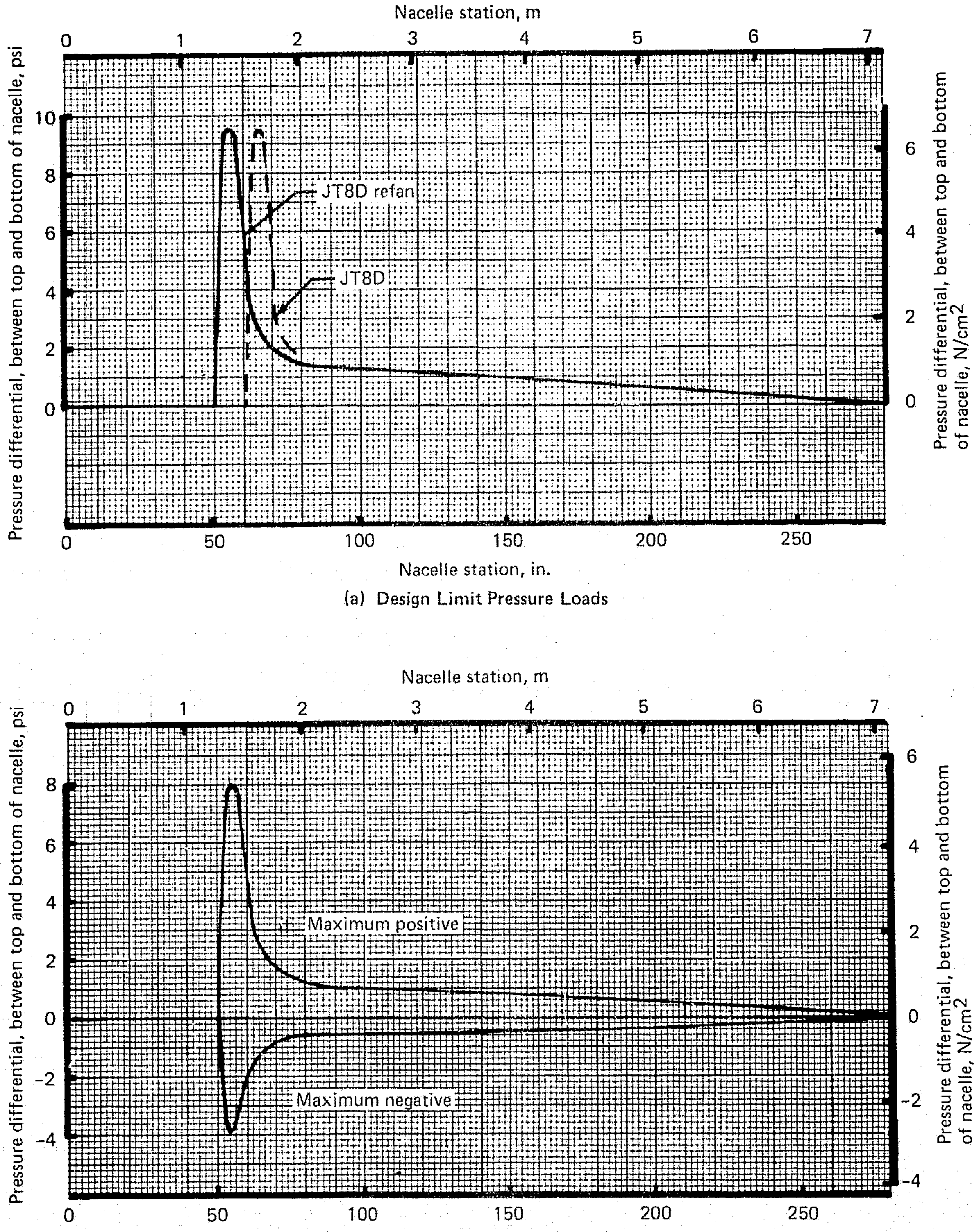
Figure 6.—727 JT8D Refan Engine Installation

Table 1.—JT8D/JT8D Refan Nacelle Loads Comparison

Loads (one factor)	Nacelle	
	JT8D	JT8D refan
Weight, lb (kg)	5065 (2297) side[a] 4312 (1956) center[b]	5797 (2629) side[a] 4948 (2244) center[b]
Thrust, lb (N)	14 500 (64 496)	16 600 (73 837)
Aerodynamic Limit Fatigue	 See figure 7 —	 See figure 7 See figure 7

[a]Weight includes strut.

[b]Weight does not include center-engine inlet duct, center-engine cowls, support beam, and mounts.



(a) Design Limit Pressure Loads

(b) JT8D Refan Fatigue Pressure Loads

Figure 7.—Nacelle Design and Fatigue Pressure Loads

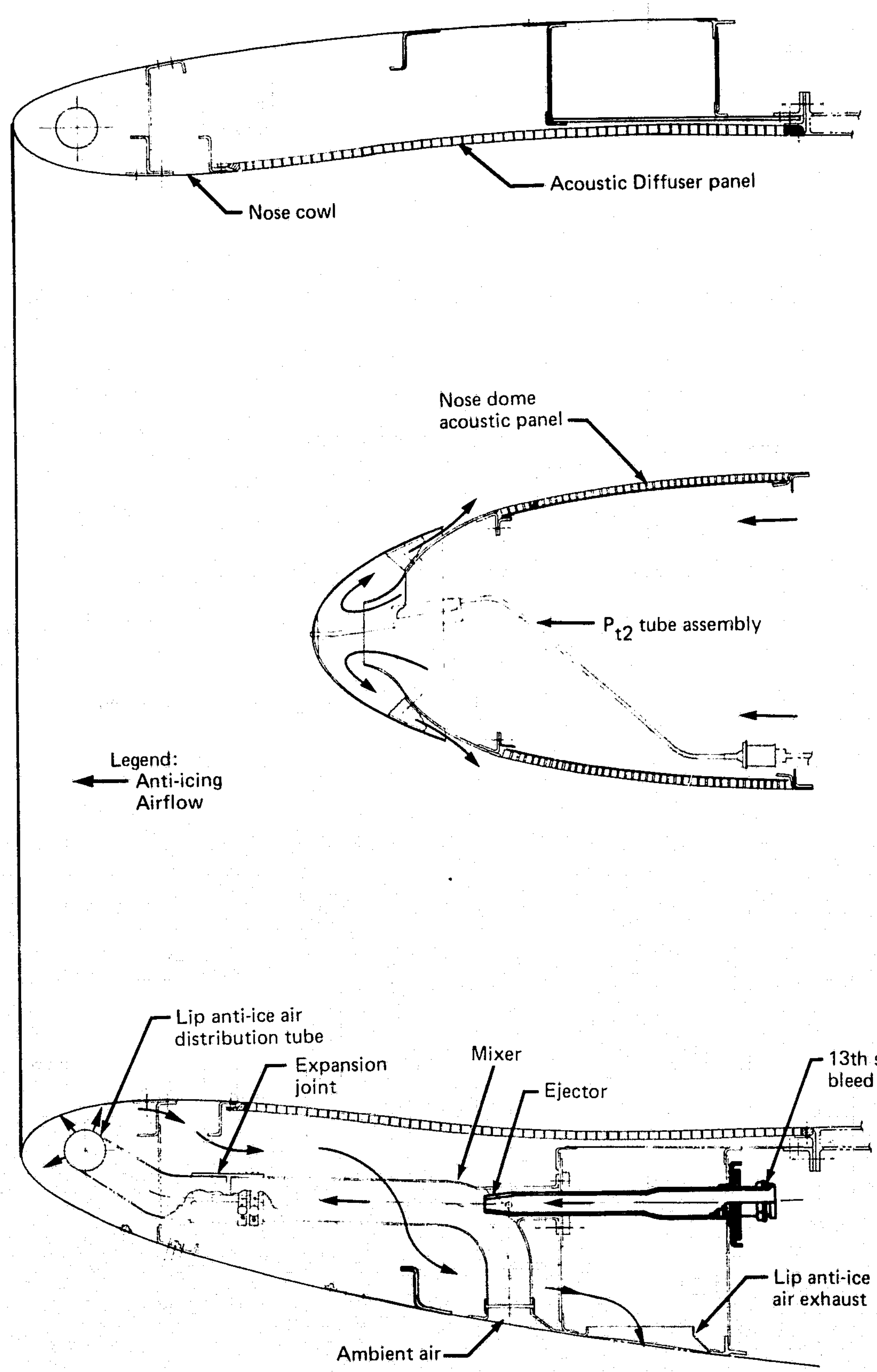


Figure 8.—JT8D Refan Side-Engine Inlet Construction

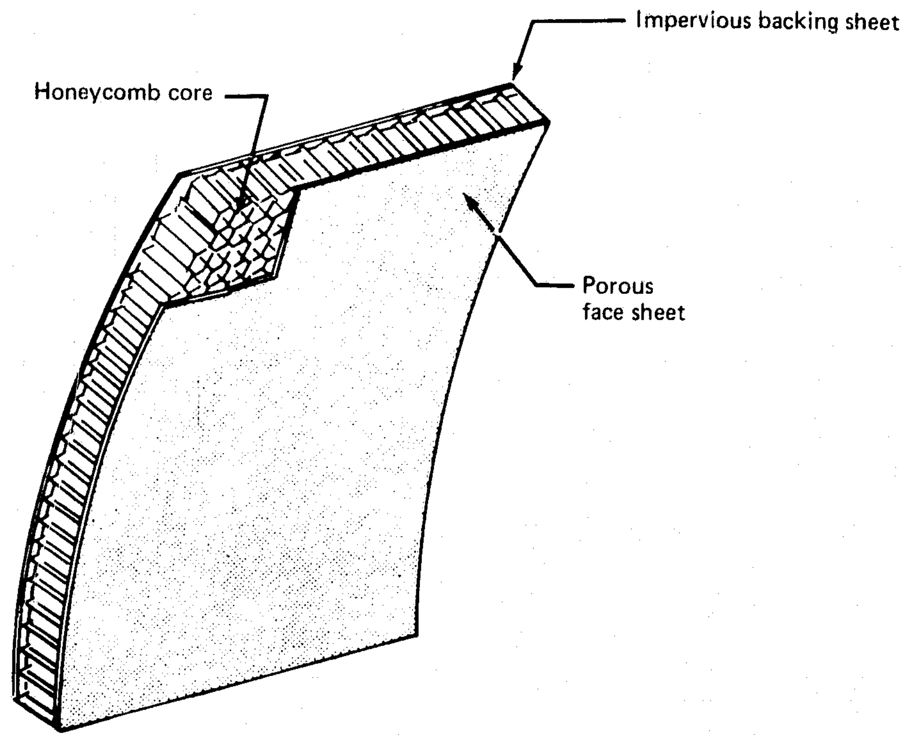


Figure 9.—JT8D Refan Side-Engine Nose-Cowl Acoustic Treatment Construction for Diffuser Panel and Nose Dome (Material is Polyimide Impregnated Fiberglass)

The honeycomb core has 0.375-in. (9.5-mm) cell size and 0.30-in. (7.6-mm) depth, faced with a porous laminated acoustic skin, and backed with a structural nonporous skin. Acoustic skin porosity, core depth, and core cell size details, listed in table 2, were chosen to maximize acoustic attenuation at FAR Part 36 approach condition.

The nose-cowl exterior skin panels are 0.063-in. (1.60-mm) thick aluminum sheet, chemically milled to 0.04 in. (1.02 mm) between frames, and stabilized with circumferential zee-section stiffeners. One bottom access panel is included to allow inspection of the anti-icing system. The primary load path to the engine attachment flange is through a cylinder wall of 0.05-in. (1.27-mm) aluminum from a torque box formed by the cylinder, the two aft bulkheads, and the exterior skins. An aluminum bulkhead aft of the inlet lip supports the anti-icing air distribution as shown in figure 10. Holes in the bulkhead control the flow of anti-icing air aft into the nose cowl. The inlet anti-ice air exhaust is on the bottom of the cowl (fig. 8).

The critical design condition for the side-engine nose-cowl mounting flange results from the aerodynamic loads defined in figure 7. A comparison of the refan configuration and the baseline 727 shows that the ultimate shear and moment loads at the engine face are increased from 5330 lb (23 708 N) and 174 000 in-lb (19 658 m-N), respectively, to 6570 lb (29 223 N) and 214 500 in-lb (24 234 m-N). The number of nose-cowl attachment bolts was reduced from 24 to 12 to facilitate field maintenance. As a result, the bolt design ultimate loads are increased from 665-lb (2958-N) current production to 2400 lb (10 675 N). The maximum fatigue load per bolt is 600 lb (2669 N). Figure 11 shows nose-cowl installation details.

3.1.1.2 Nose Dome

The nose dome is approximately 25 in. (63.5 cm) long and consists of a thermally anti-iced, formed-aluminum nose cap and an acoustically treated shell. The shell is bonded fiberglass-honeycomb structure of 0.30-in. (7.6-mm) deep, 0.375-in. (9.5-mm) cell core, faced with a porous laminated acoustic skin, and backed with a nonporous structural skin, table 2. The P_{t2} probe is located inside the nose dome (figs. 8 and 12).

The critical design load for the nose dome attachment to the engine is a combination of axial blowoff due to anti-icing air pressure and moment caused by an unsymmetrical surge at takeoff power. The nose dome is attached with five captured bolts, as shown in figure 12, to prevent the possibility of ingestion of loose bolts into the engine. The maximum load per bolt is 1755 lb (7806 N); the maximum fatigue load per bolt is 620 lb (2758 N). During anti-icing operation, the nose-dome acoustic panels will have a thermal gradient of 200°F (111 K) with 300°F (422 K) on the back of the panel and 100°F (311 K) on the exterior acoustic skin.

3.1.1.3 Alternate Design

The alternate inlet configuration shown in figure 13 provides an option for additional noise suppression in the forward quadrant by adding an acoustically lined splitter ring to the side-engine inlet as previously described in section 3.1.1.1. The ring, positioned aft of the diffuser throat, is 31.2-in. (79.2-cm) average diameter by 23.2-in. (58.9-cm) long. It is of

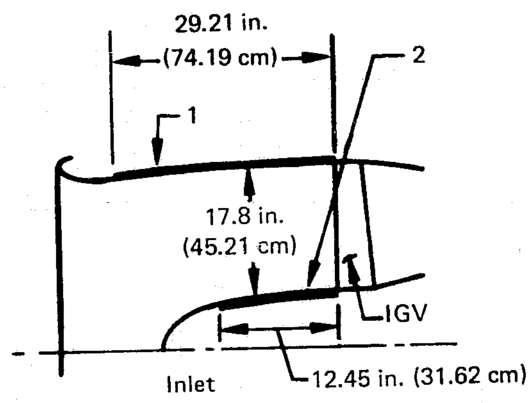
Table 2.—JT8D Refan Acoustic Lining Definition—Side-Engine Inlet

Lining section		Specifications					
				Rayl number			
Location	Function	Area,[a] ft^2 (m^2)	Material	$R/\rho c$[b]	$V_P/\sqrt{\theta}$ cm/sec[c]	Core depth, in. (cm)	Cell size, in. (cm)
1 Inlet diffuser	Fan tone 1/4 wave type	29.9 (2.78)	Polyimide-impregnated fiberglass	2.16 ± 15%	82.3	0.30 (0.76) ±5%	0.375 (0.95)
2 Inlet nose dome	Fan tone 1/4 wave type	4.3 (0.39)	Polyimide-impregnated fiberglass	2.16 ± 15%	82.3	0.30 (0.76) ±5%	0.375 (0.95)

[a]Net active lining area (gross treated surface area less surface area rendered inactive by structural splices, edge closures, etc.)

[b]Unidirectional flow resistance ratio after bonding with core where R = flow resistance of sample in $N{\cdot}sec/m^3$ (MKS Rayls) and ρc = reference flow resistance in $N{\cdot}sec/m^3$ (MKS Rayls).

[c]$V_P/\sqrt{\theta}$ where V_P = particle velocity and θ = static temperature ratio $T_S{}^{\circ}R/519(T_SK/288)$ of air approaching sample in flow resistance test.



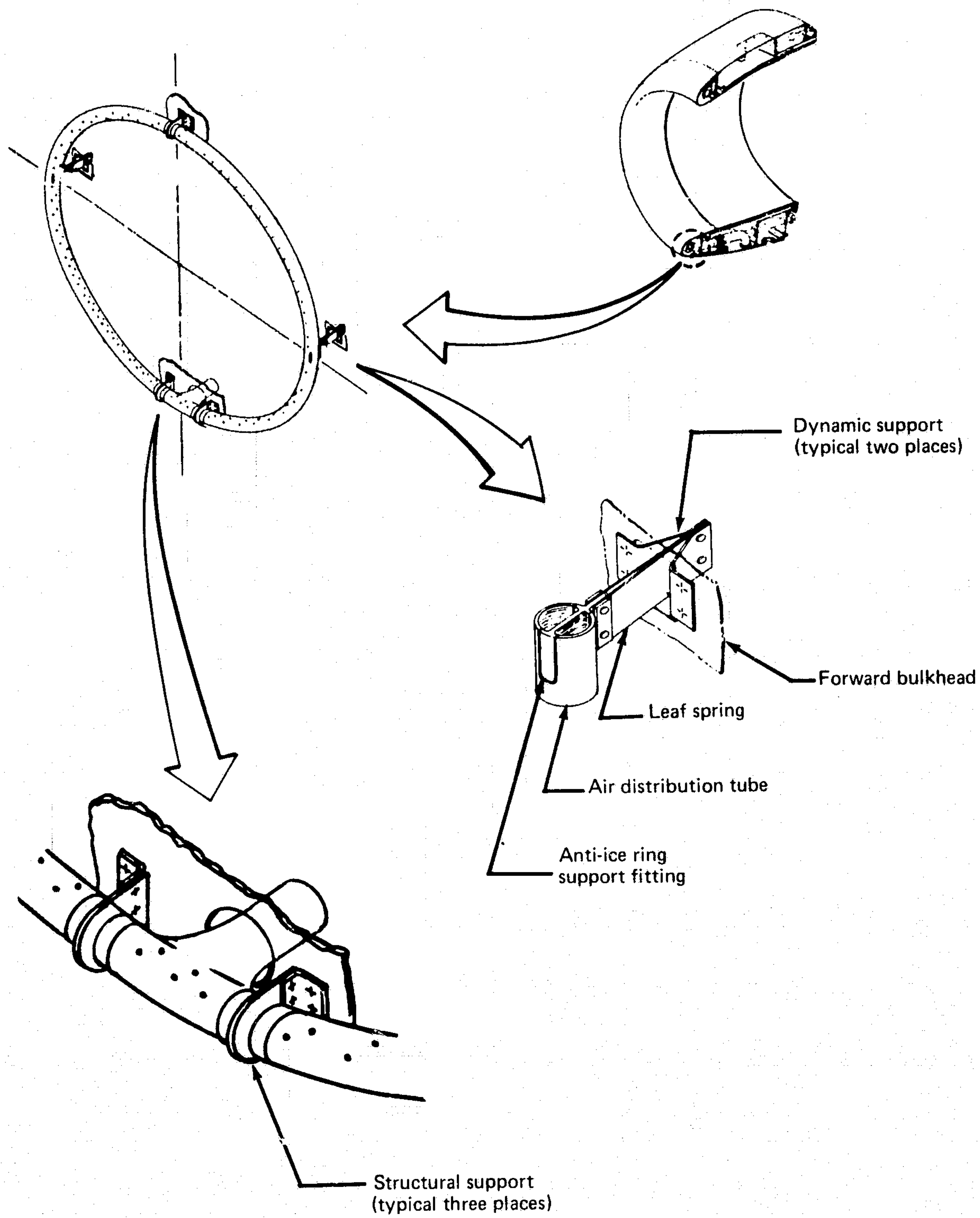


Figure 10.—JT8D Refan Mounting Attachment—Side-Engine Inlet-Lip Anti-Ice Air Distribution Tube

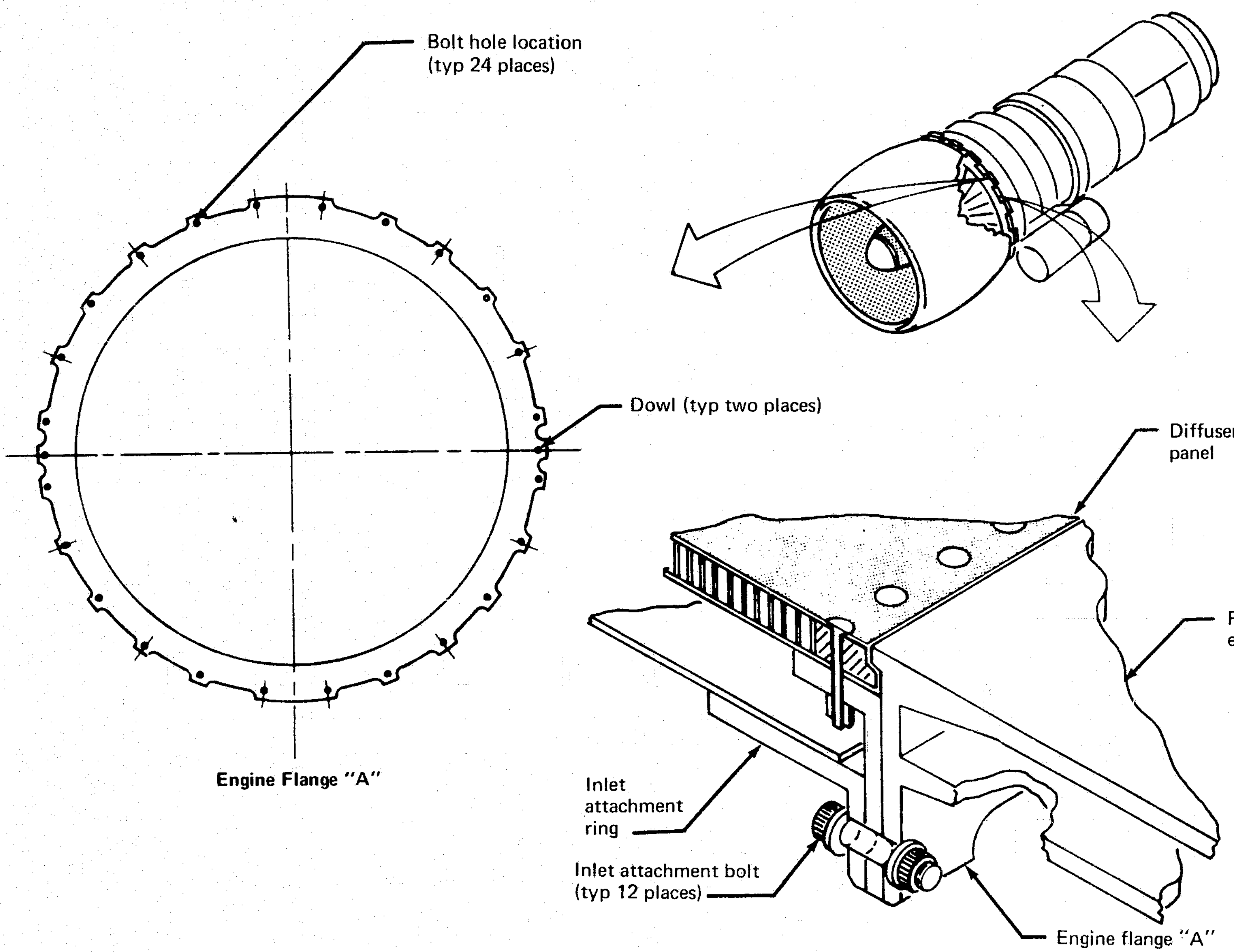


Figure 11.—JT8D Refan Side-Engine Nose-Cowl Installation/Removal

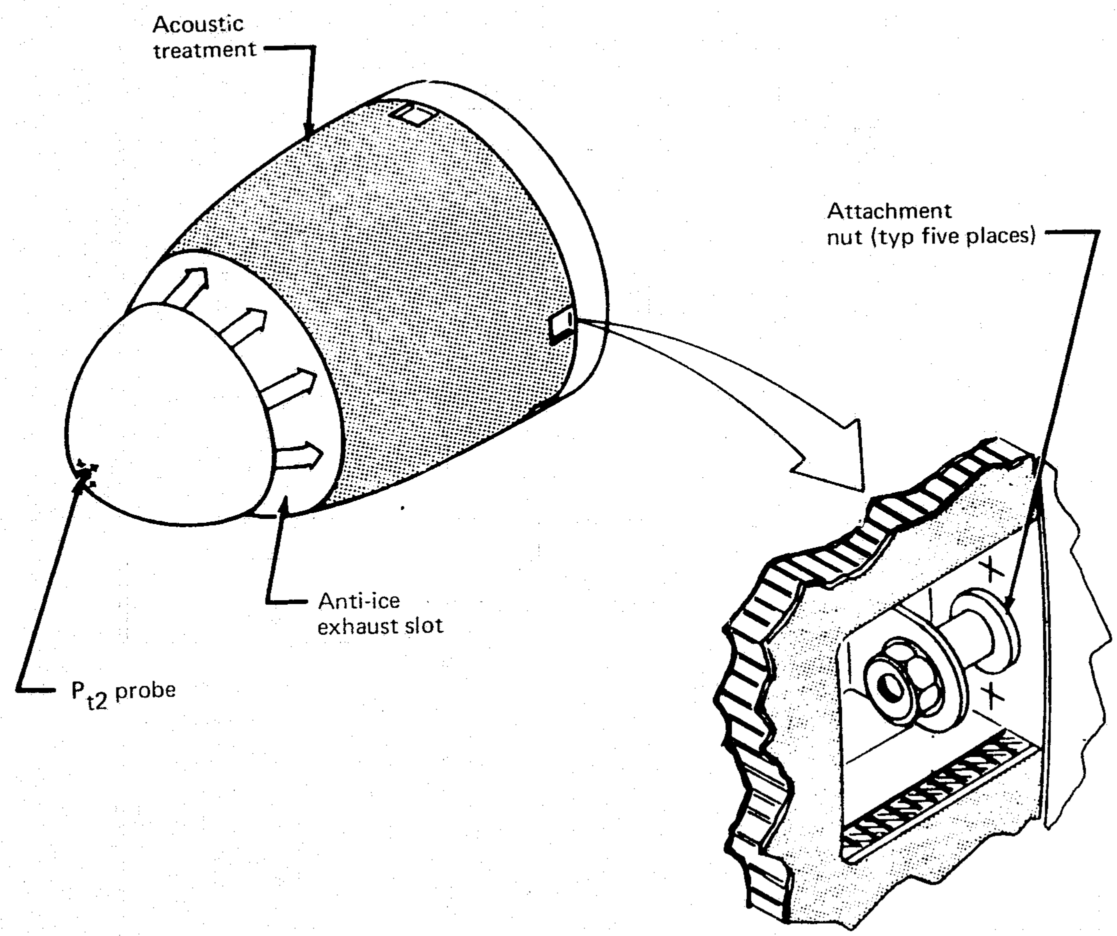


Figure 12.—JT8D Refan Nose Dome

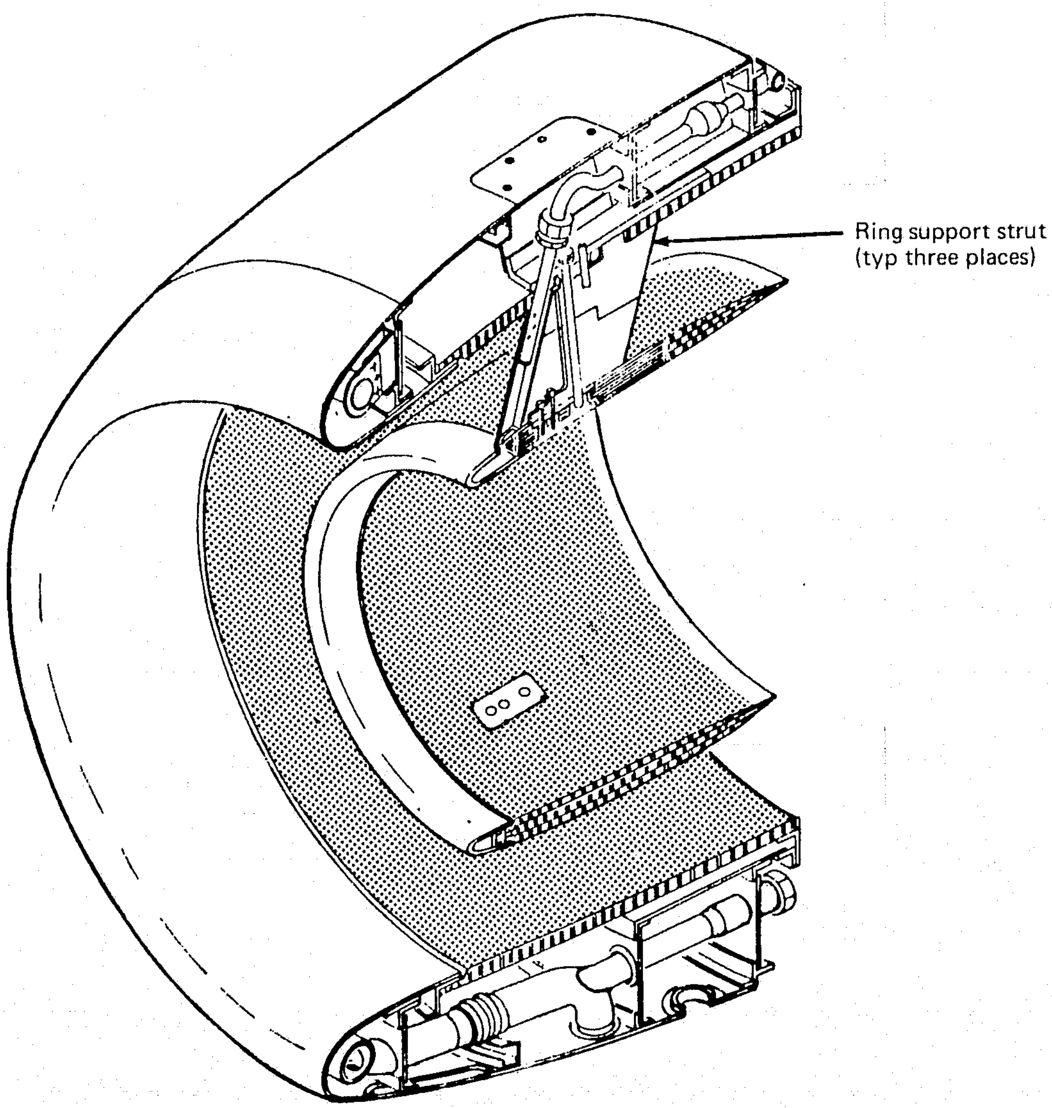


Figure 13.—JT8D Refan Side-Engine Inlet Cross Section With Acoustic Ring Installation Option

polyimide-impregnated fiberglass construction with a structural honeycomb spacer core sandwiched between acoustic panels on either side (fig. 14 and table 3). To match acoustic lining characteristics with the geometry of the inlet flowpath in the alternate design, the core depth in the ring outer panel is 0.18 in. (4.6 mm) and in the inner panel 0.17 in. (4.3 mm). Correspondingly, the core depths in the diffuser wall panel and the nose dome panels were changed to 0.18 in. (4.6 mm) and 0.17 in. (4.3 mm), respectively.

Additional longerons are incorporated in the cowl wall to attach three radial struts on which the ring is supported. The ring/strut assembly is removable, as illustrated in figure 15, providing access to the fan face.

The strut leading edges are hollow sections of Inconel 625, and the ring leading edge is electro-formed nickel arranged as shown in figure 16 to distribute anti-icing air fed through a manifold from engine 13th-stage compressor bleed. The unmixed 13th-stage bleed air is fed through each of the struts into the leading edge of the ring. The ring leading edge is compartmented so that the bleed air is first passed through the forward passage to the mid point between struts. At this point, the air returns through the aft passage toward the point of entrance. The aft passage has exhaust ports in its aft bulkhead, that allow the air to escape out through slots between the leading edge and the main body of the acoustic ring.

3.1.1.4 Side-Engine Inlet Ground Test Design

The side-engine inlet, previously described in sections 3.1.1.1 through 3.1.1.3, was replaced for ground test with a unit that duplicated the propulsion and acoustic functions of the production design, but did not incorporate anti-icing provisions, and was not a flight weight design. The propulsion requirements were met by duplicating the production inlet contours, and the acoustic function was achieved by using the same acoustic wall construction and materials for the face skins and core that were specified on the production configuration.

Details of the method of fabrication are discussed later in section 3.2.1.

3.1.2 COWL PANELS

The cowl panels on the side engines consist of three sections and are installed between the inlet and exhaust systems as shown in figure 17. The inboard fixed section adjacent to the strut is attached to the engine frames and includes access panels for the engine mounts and system disconnects. The remaining sections are hinged to the fixed cowl and to each other with removable hinge pins, which allow for a variety of door open positions, or which allow complete removal from the engine. The upper and lower removable panels are interchangeable between side engines.

Panel thickness is 1 in. (2.54 cm), and its construction consists 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 (fig. 18). This system of construction was adopted to reduce the number of detail parts and the labor involved in fabrication of a typical riveted sheet metal cowling. This construction is estimated to reduce fabrication cost by 40%, based on experience with similar fiberglass-honeycomb parts. Sandwiched in the inner skin laminate is a stainless steel wire mesh fire barrier. The ability of the fire barrier to meet Civil Air Regulations (CAR)

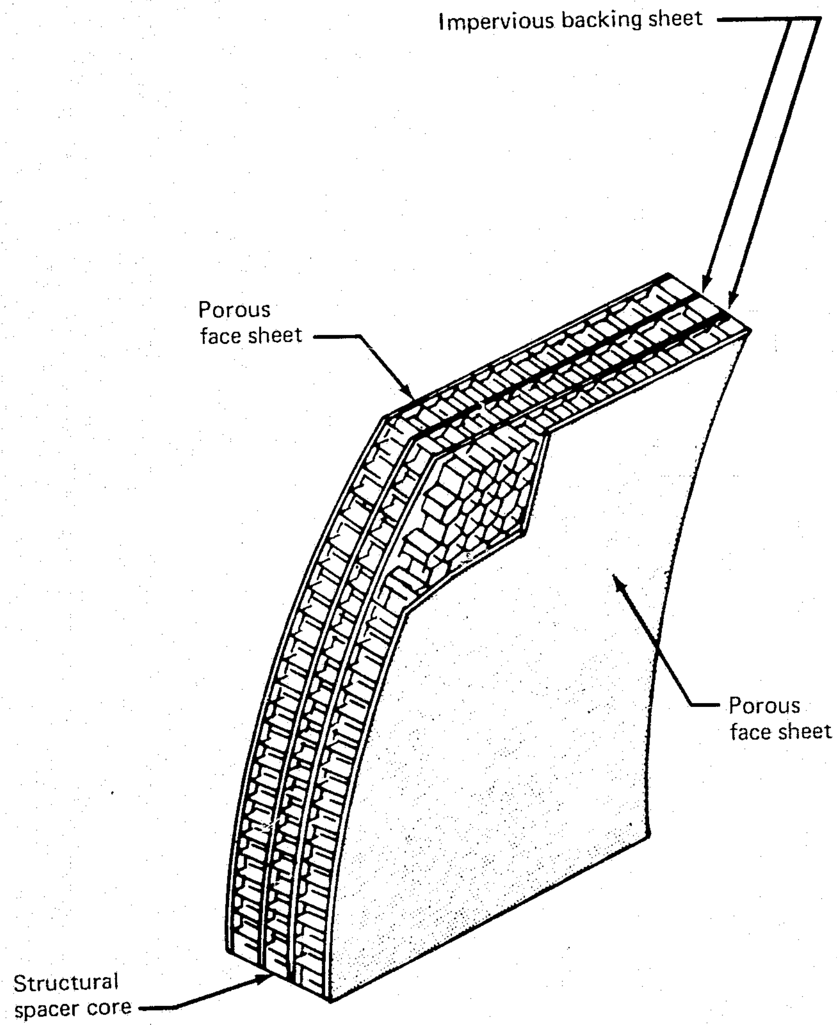


Figure 14.—JT8D Refan Inlet-Ring Acoustic-Wall Construction (Material Is Polyimide Impregnated Fiberglass)

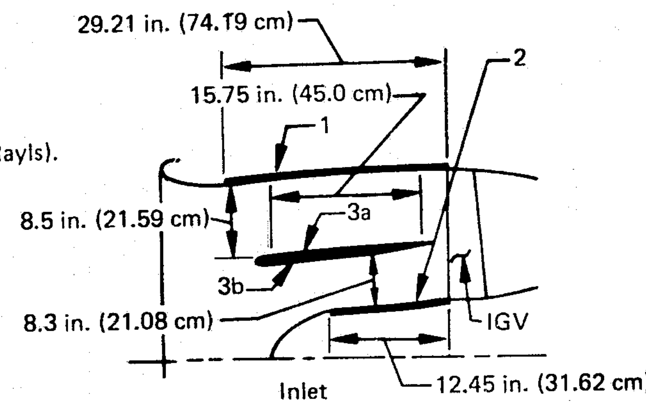
Table 3.—JT8D Refan Alternate Design—Acoustic Lining Definition—Side-Engine Inlet

Lining section		Specifications					
				Rayl number			
Location	Function	Area[a], ft^2 (m^2)	Material	R/ρ_c [b]	$V_p/\sqrt{\theta}$ cm/sec[c]	Core depth, in. (cm)	Cell size, in. (cm)
1 Inlet diffuser	Fan tone 1/4 wave type	29.4 (2.73)	Polyimide-impregnated fiberglass	2.03 ± 15%	77.4	0.18 (0.46) ±5%	0.375 (0.95)
3a Inlet ring	Fan tone 1/4 wave type	13.3 (1.23)	Polyimide-impregnated fiberglass	2.03 ± 15%	77.4	0.18 (0.46) ±5%	0.375 (0.95)
3b Inlet ring	Fan tone 1/4 wave type	12.7 (1.18)	Polyimide-impregnated fiberglass	2.42 ± 15%	64.8	0.17 (0.43) ±5%	0.375 (0.95)
2 Inlet nose	Fan tone 1/4 wave type	4.3 (0.39)	Polyimide-impregnated fiberglass	2.42 ± 15%	64.8	0.17 (0.43) ±5%	0.375 (0.95)

[a]Net active lining area (gross treated surface area less surface area rendered inactive by structural splices, edge closures, etc.).

[b]Unidirectional flow resistance ratio after bonding with core where R = flow resistance of sample in N·sec/m^3 (MKS Rayls) and ρc = reference flow resistance in N·sec/m^3 (MKS Rayls).

[c]$V_p/\sqrt{\theta}$ where V_p = particle velocity and θ = static temperature ratio T_S°R/519 (T_SK/288) of air approaching sample in flow resistance test.



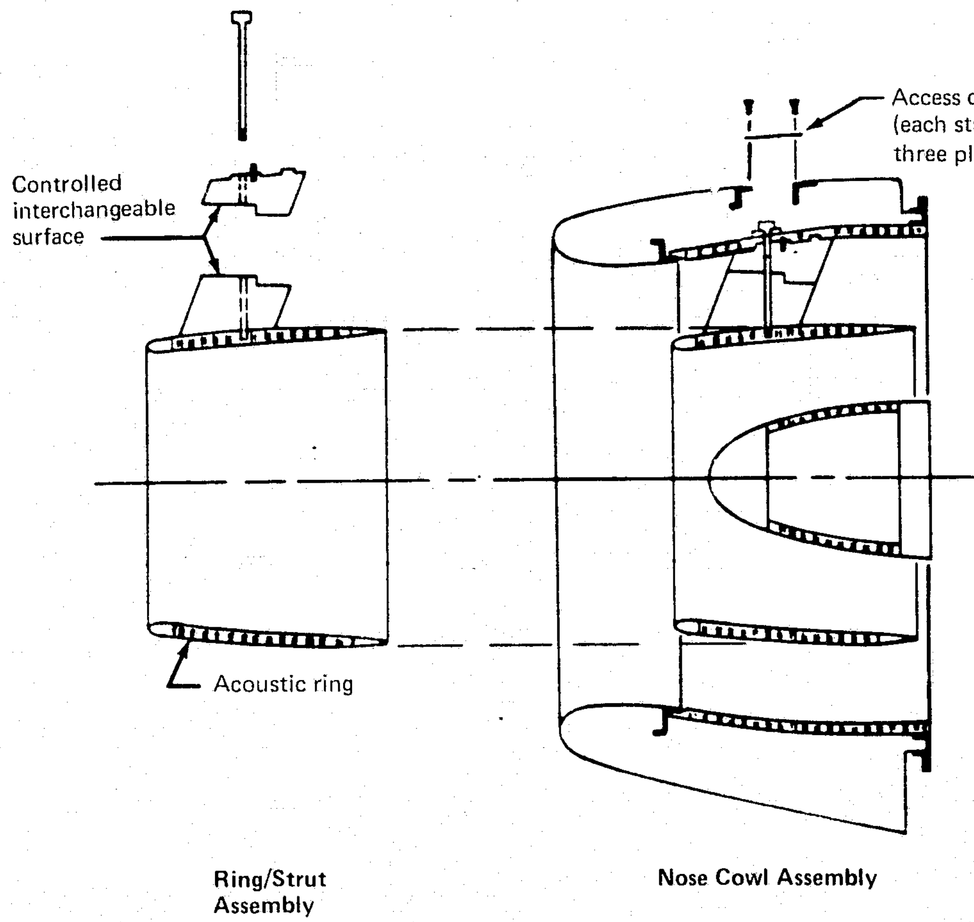


Figure 15.—JT8D Refan Side-Engine Inlet Assembly With Acoustic Ring

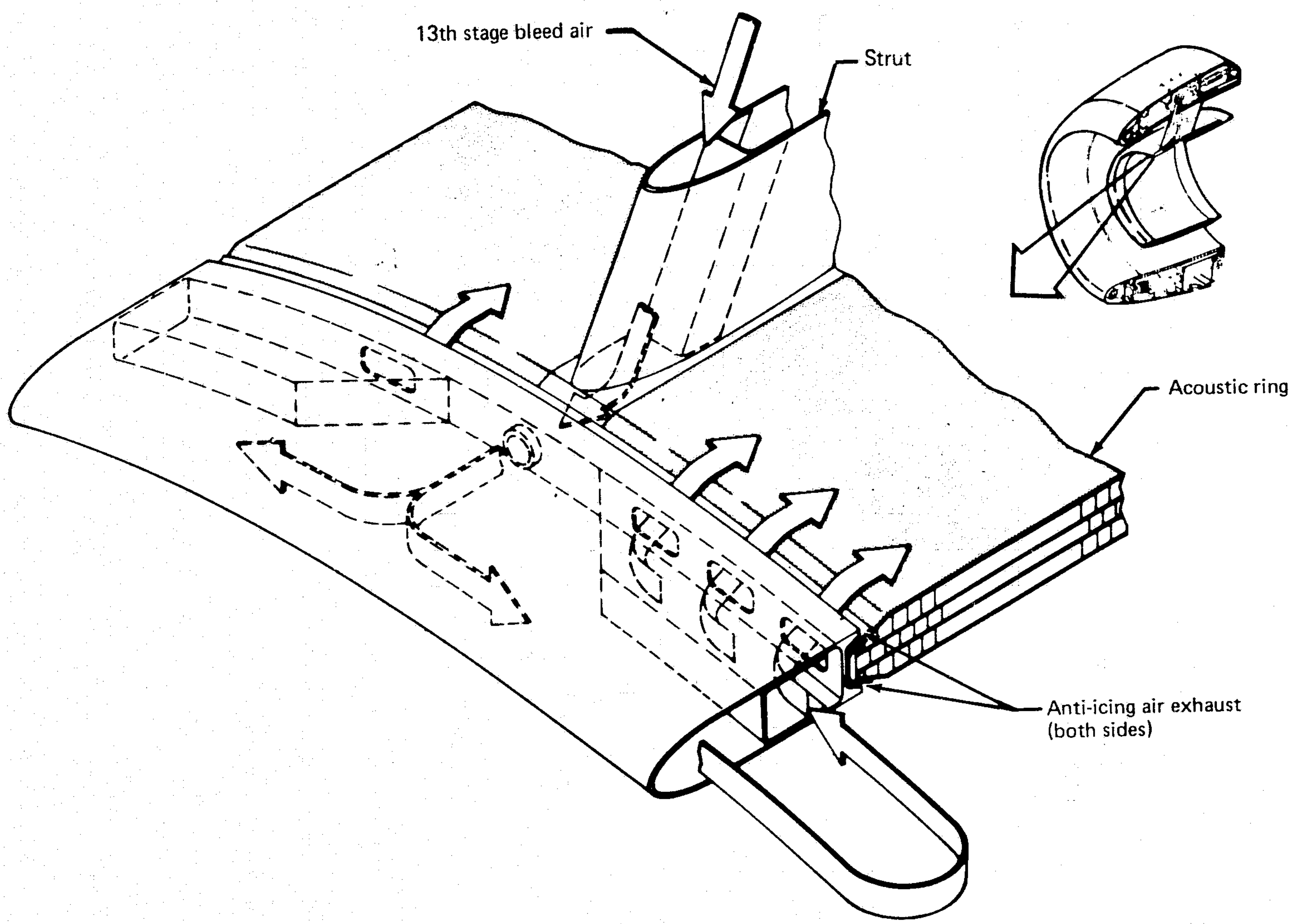


Figure 16.—JT8D Refan Side-Engine Inlet Strut/Ring Anti-Ice System

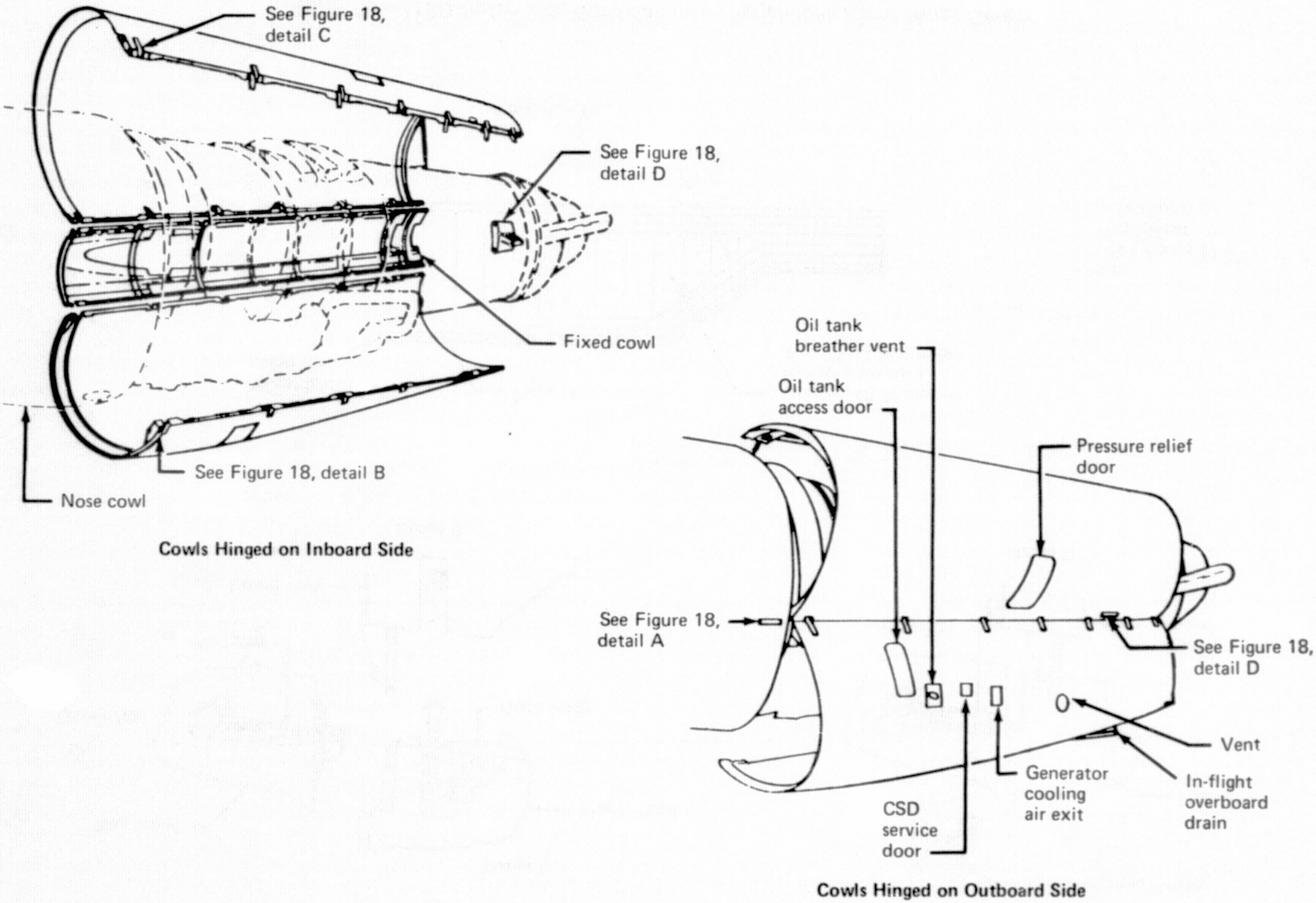
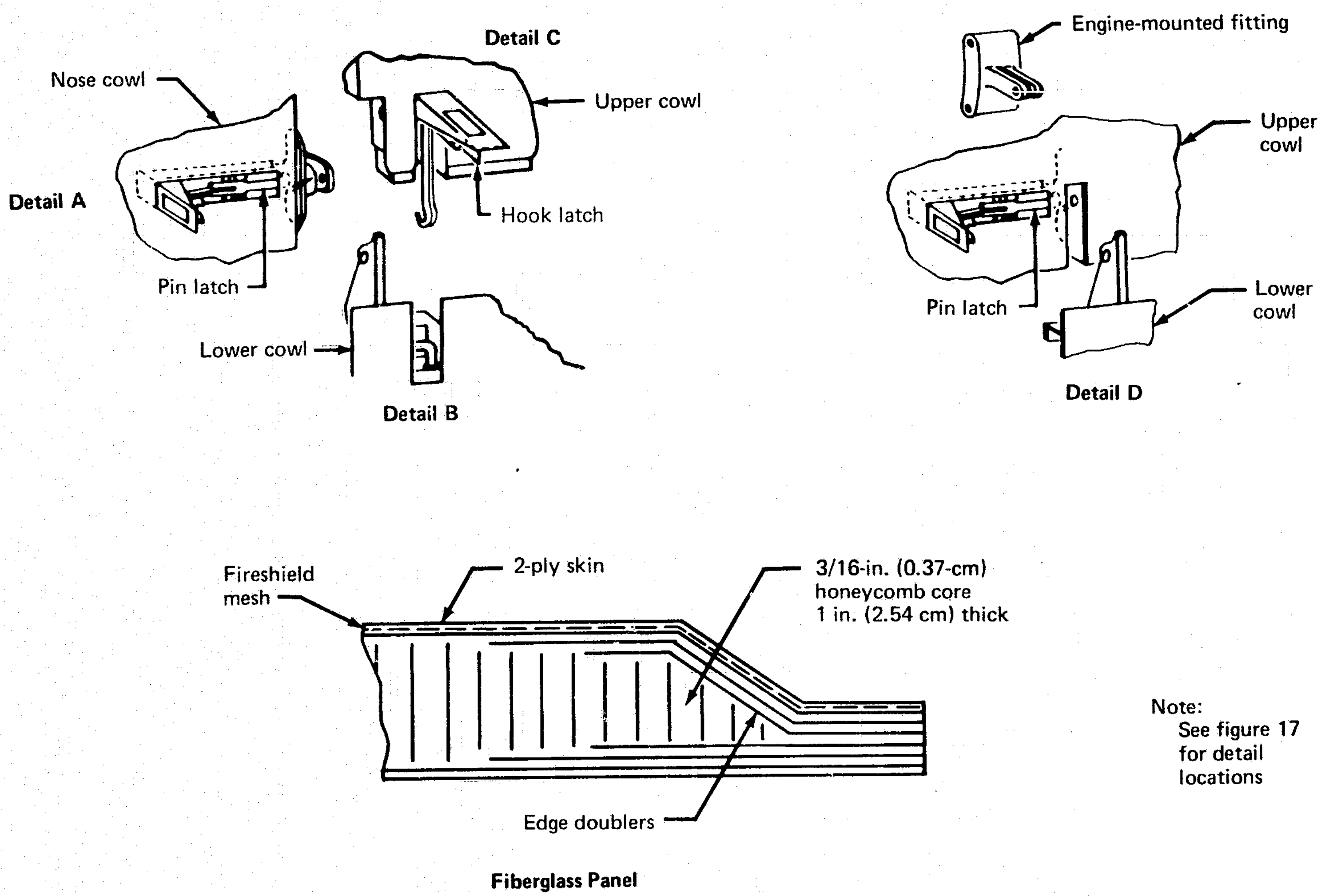


Figure 17.—JT8D Refan Side-Engine Cowl Panels



Note:
See figure 17 for detail locations

Figure 18.—JT8D Refan Side-Cowl Sandwich Panel—Latch and Hinge Details

standards was proven by testing various samples of fiberglass-honeycomb construction. A summary of these test results is presented in reference 4. The wire mesh also serves as an electrical shroud around the engine. The panel longitudinal edges are stiffened with sheet metal intercostals fastened between latch fittings. The fore and aft edges are stiffened with sheet metal frames. All lap joints between the cowl panels and all mating structure contain a wear surface coating.

The U-bolts that engage the cowl latches have been replaced with eye bolts that allow for external adjustment (fig. 19). The refan conversion lengthens the engine and therefore the cowl so that one additional latch, for a total of seven, is required along each longitudinal edge.

The center-engine cowl panels, shown in figure 20, are faired to the existing aft body lines and attach to the existing hinge points. There are two forward and two aft panels that latch together at the bottom centerline. Cowl material and construction are the same as used in the side cowls.

The ultimate design conditions for the cowl panel are: (1) Operating--Aerodynamic pressures resulting from a high angle of attack at 460 KEAS (237 m/sec EAS), 13 500-ft (4115-m) altitude, and 3.75-g load factor with a gross weight of 167 000 lb (75 750 kg), and (2) Failsafe--Engine-bleed duct failure causing ultimate outward gage pressure of 3.36 psi (2.32 N/cm^2) acting on the inside of the cowl. This pressure is limited by a pressure relief door. The fatigue design load is 25% of the ultimate design condition.

3.1.3 EXHAUST SYSTEM

The exhaust system of the 727-200/JT8D refan engine consists of a two-piece exhaust duct (wedge duct and nozzle), a fan/primary flow divider, an engine center-body exit plug, and the wedge duct external aerodynamic fairings (fig. 21). The exhaust duct acts as a mixing chamber for the hot primary and cold secondary flow discharging through a common nozzle. The length of the mixing chamber; the flow areas of fan-, primary-, and final-nozzle streams; and the geometry of the thrust-reverser doors are integrated within the nacelle external aerodynamic contour (fig. 4) to meet the requirements for engine match and reverser performance.

Acoustic treatment was used in the exhaust duct wall and in the fan/primary divider walls, as defined in table 4, to reduce aft-transmitted fan and turbine noise. Acoustic skin porosity, core depth, and core cell size were chosen to maximize acoustic attenuation at FAR Part 36 approach condition.

The installation of the refan engine adds weight to the airplane, which must be compensated by the addition of forward ballast to restore airplane balance. Titanium was used extensively to reduce weight where operating temperatures permitted. Aluminum-brazed titanium honeycomb, adapted from the FAA-sponsored Supersonic Transport Program, was used in the nozzle wall and the flow divider between fan and primary engine gas streams. Two different approaches to the manufacturing of the honeycomb are described.

The thrust reverser was designed with extensive use of titanium for frames and temperature resistant inner skins in a further effort to reduce weight. The structural supports for the thrust reverser are integrated into the titanium nozzle wall (fig. 21).

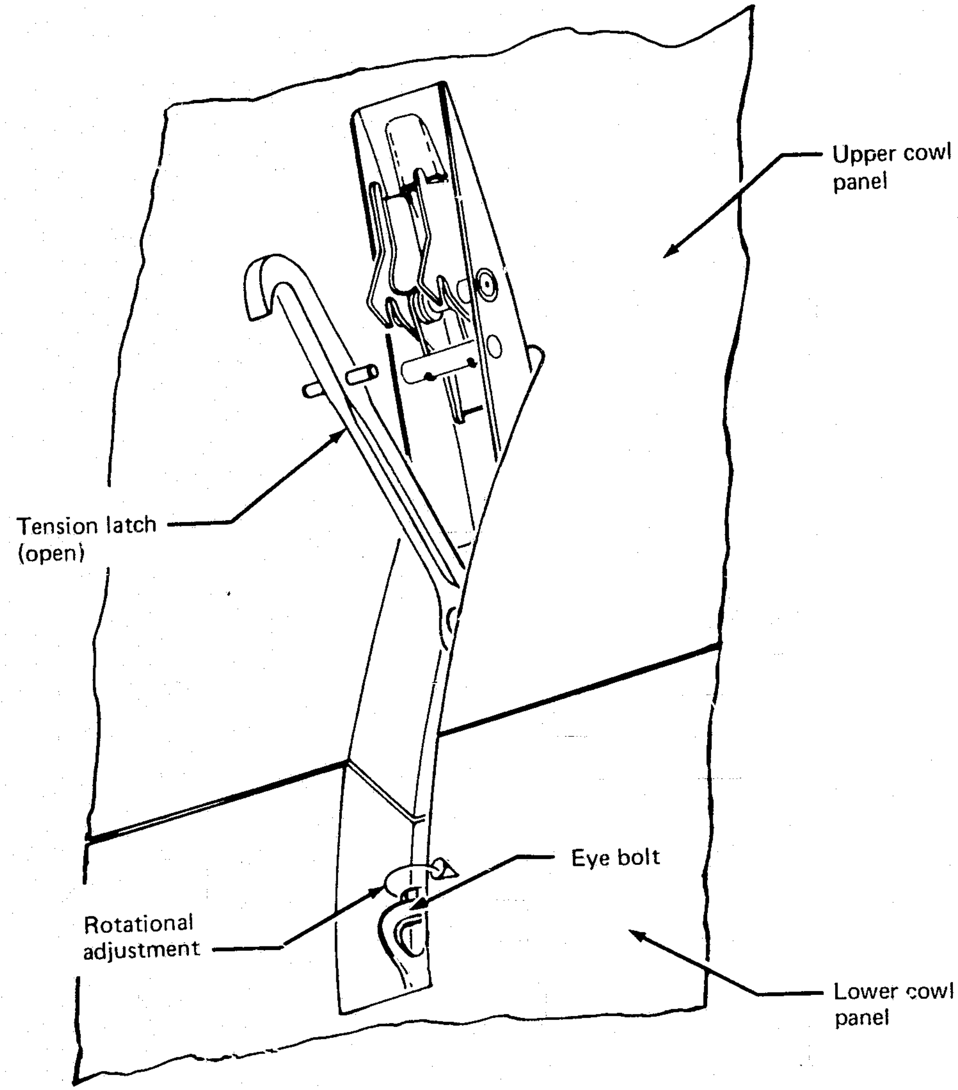


Figure 19.—JT8D Refan Side-Cowl Latch Adjustment—Cowls Closed

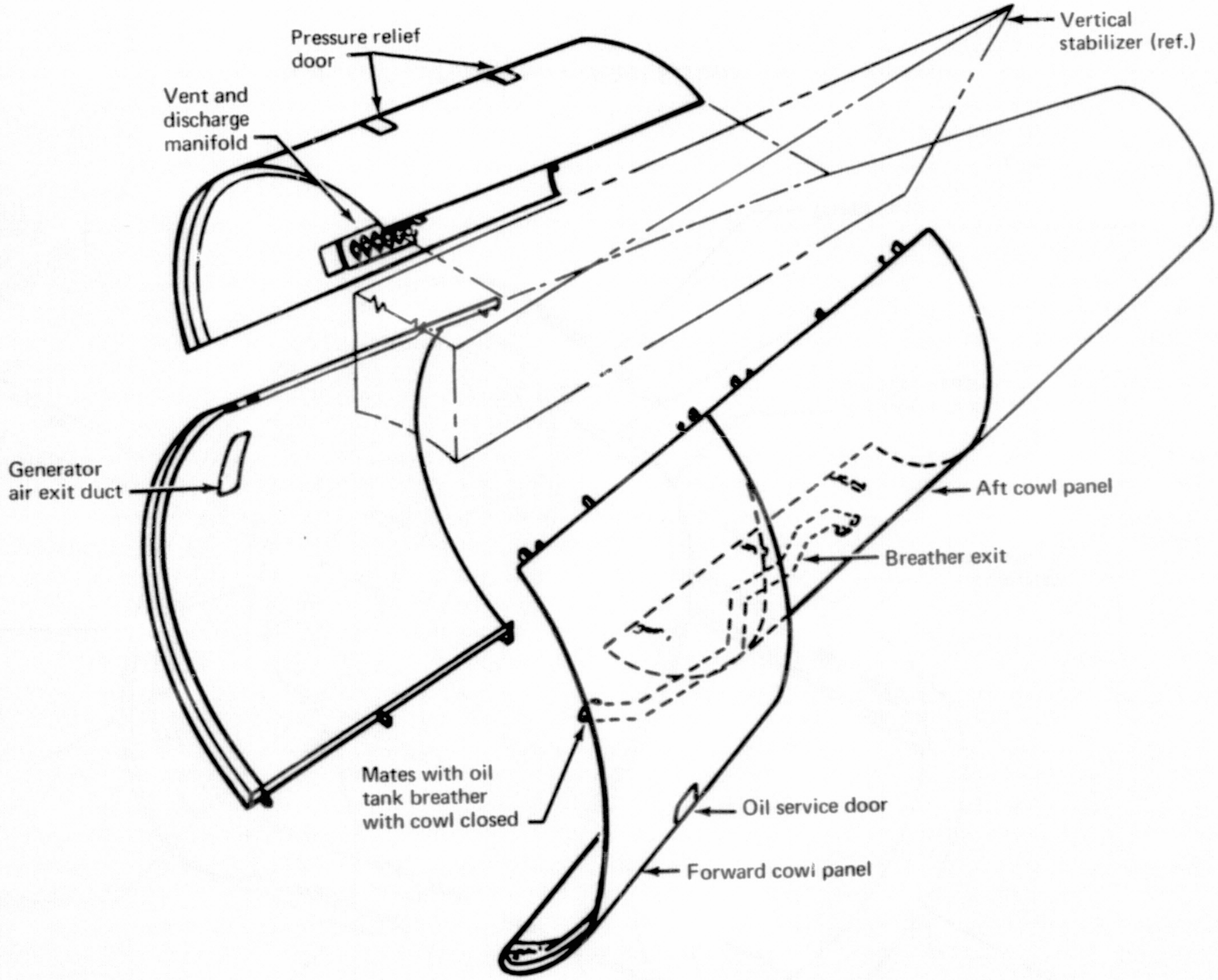


Figure 20.—JT8D Refan Center-Engine Cowl Panels

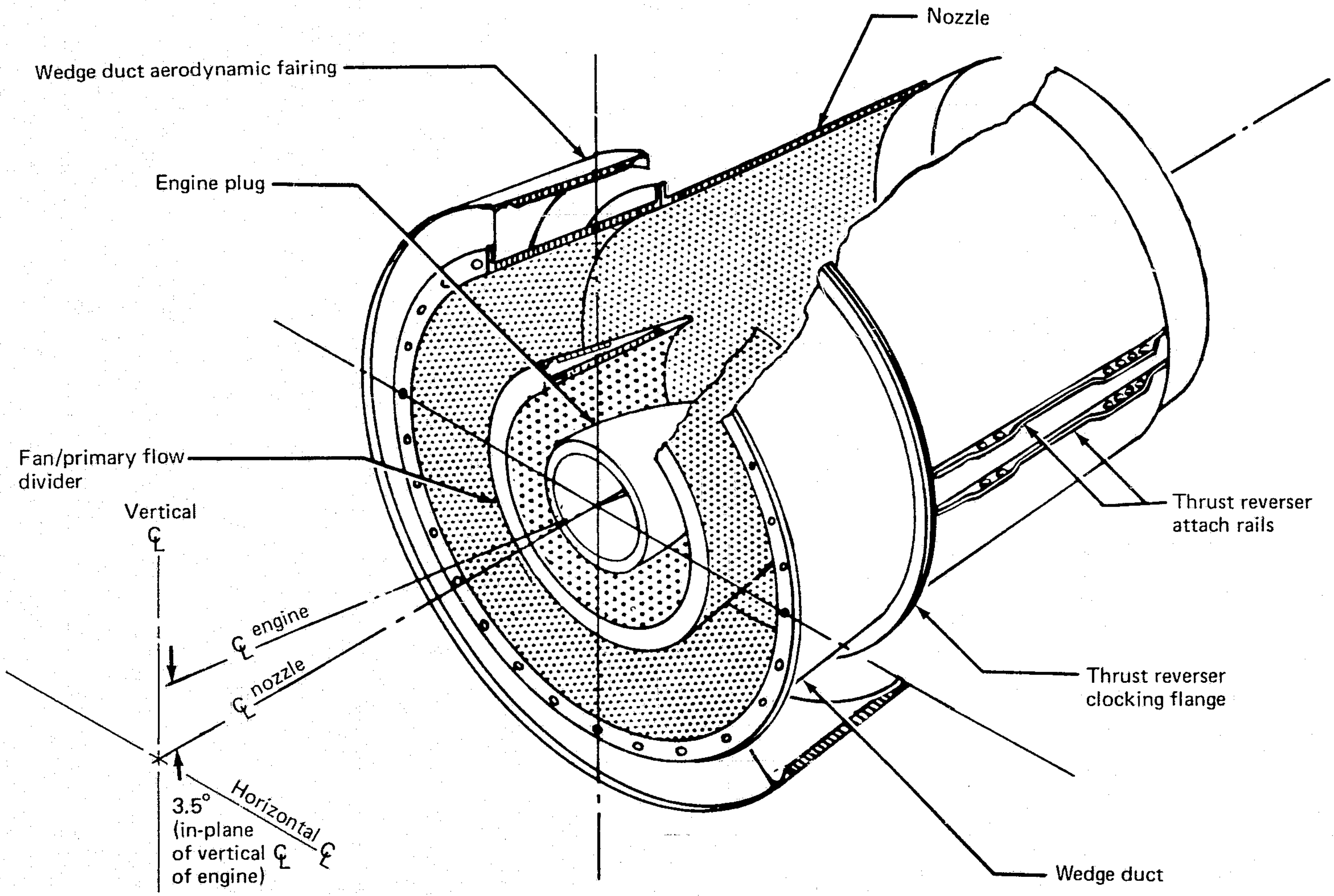


Figure 21.—JT8D Refan Exhaust System

Table 4.—JT8D Refan Acoustic Lining Definition—Exhaust System

Lining section				Specifications						
Location	Function	Area[a], ft^2 (m^2)	Material	Rayl number $R/\rho c$[b]	Rayl number $V_p/\sqrt{\theta}$ cm/sec[c]	Core depth, in. (cm)	Cell size, in. (cm)	Skin perforation open area[d], %	Skin gage, in. (cm)	Nominal hole diameter, in. (cm)
1 Wedge duct	Fan tone, harmonic 1/4 wave type	20.0 (1.86)	Titanium	$1.46^{+0.48}_{-0.36}$	40	[e]0.50 (1.27) ±5%	0.375 (0.95)	2.8	0.014 (0.035)	0.042 (0.107)
2 Nozzle	Primary tones 1/4 wave type	31.0 (2.89)	Titanium	$1.46^{+0.48}_{-0.36}$	40	[e]0.50 (1.27) ±5%	0.375 (0.95)	2.8	0.014 (0.035)	0.042 (0.107)
3 Divider, fan flow side	Fan tone, harmonic 1/4 wave type	5.9 (0.55)	Titanium	$1.46^{+0.48}_{-0.36}$	40	[f]1.0 (2.54) tapered to 0.25 (0.63)	0.375 (0.95)	2.8	0.014 (0.035)	0.042 (0.107)
4 Divider, primary flow side	Primary tones 1/4 wave type	7.2 (0.67)	Inconel	$1.46^{+0.77}_{-0.50}$	40	[e] 0.50 (1.27) ±5%	0.375 (0.95)	3.3	0.015 (0.038)	0.040 (0.102)

[a]Net active lining area (gross treated surface area less surface area rendered inactive by structural splices, edge closures, etc.).

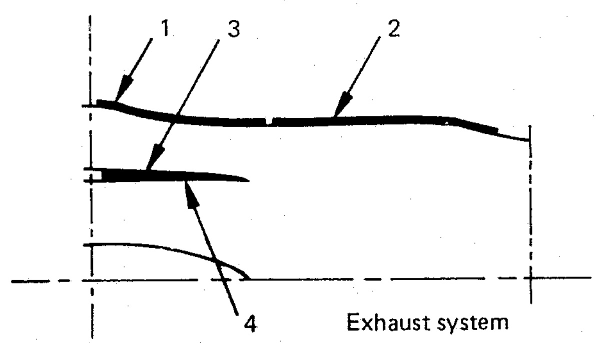
[b]Unidirectional flow resistance ratio after brazing to core where R = flow resistance of sample in N·sec/m^3 (MKS Rayls) and ρc = reference flow resistance in N·sec/m^3 (MKS Rayls).

[c]$V_p/\sqrt{\theta}$ where V_p = particle velocity and θ = static temperature ratio T_S°R/519 (T_SK/288) of air approaching sample in flow resistance test.

[d]Based on open perforations in active treatment area after brazing.

[e]Core depth established by structural constraints.

[f]Alternate construction constant core depth = 0.25 in. (0.63 cm) ±5%



3.1.3.1 Exhaust Duct (Wedge Duct and Nozzle)

The 21-in. (53.3-cm) long forward portion of the exhaust duct (referred to as the wedge duct) provides a 3.5° cant that turns the 44-in. (111.7-cm) long nozzle section with the thrust reverser upward relative to the engine centerline to provide ground clearance for the center-engine exhaust duct during airplane rotation and to direct the exhaust flow from the side engines parallel to the airplane centerline.

The forward section of the nozzle has two pairs of longitudinal rails integrated into the outer skin of the nozzle, as shown in figure 22, to provide support for the thrust reverser. The flanges between the wedge duct and the nozzle permit positioning of the nozzle and thrust reverser in 90° increments about the nozzle axis to accommodate the reverser deflector door positions on the side and center engines of the airplane. In addition, positioning capability of ±10° is included for refinement of the reverser efflux pattern.

The original design for the wedge duct and nozzle is shown in figure 23 and consists of a continuous 360° panel of aluminum-brazed titanium honeycomb with perforated inner skin and machined closure members. The external skin and end closures form a welded assembly. The aft exit cone of the nozzle is a titanium sheet welded to the honeycomb structure.

The ground test exhaust-duct hardware used an alternate design, as illustrated in figure 24. This alternate method was used to minimize fabrication time and to provide maximum probability of achieving an acceptable brazement in the fabrication of the wedge duct and nozzle parts. It utilizes circumferential strips of 1/8-in. (3.2-mm) cell core replacing the machined fore and aft closeout flanges shown in figure 23. The dense core strips and the machined closeouts are structurally equivalent.

The wedge duct and nozzle structure are designed to withstand an ultimate axial load of 20 355 lb (90 539 N) imposed through each of the two thrust reverser attach fittings during inadvertent in-flight deployment of the reverser. Design ultimate loads from inadvertent in-flight reversal (including gas pressure loads) at the engine attach flange are:

Moment	=	158 700 in-lb (17 930 m-N)
Shear load	=	2047 lb (9105 N)
Axial load	=	46 345 lb (206 143 N)

The operating temperature is 280°F (411 K). Fatigue loads are based on the thrust reverser normal operation.

3.1.3.2 Fan/Primary Flow Divider

The fan/primary flow divider extends the separate fan and primary flow passages approximately 17-in. (43.2-cm) downstream of the turbine flange to which it is attached (fig. 21). The divider consists of two structural/acoustic honeycomb panels, an Inconel 625 inner panel and trailing edge with perforated inner wall, and an aluminum-brazed titanium outer panel with perforated outer wall (fig. 25). The outer panel is attached to the inner panel near the trailing edge, and both panels are directed up 3.5° to maintain concentricity with the wedge

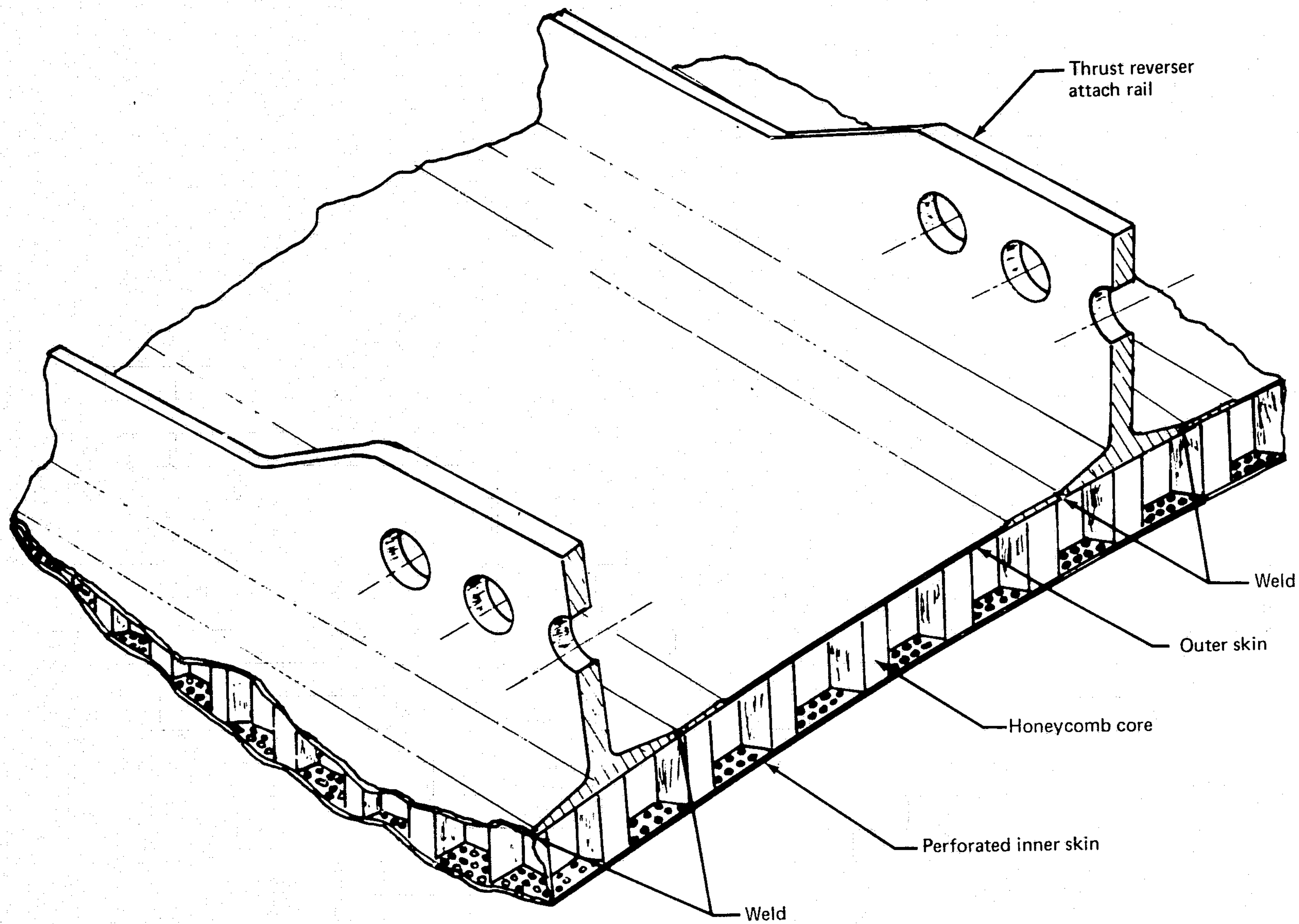


Figure 22.—JT8D Refan Thrust-Reverser Attach Rails in Outer Nozzle Wall

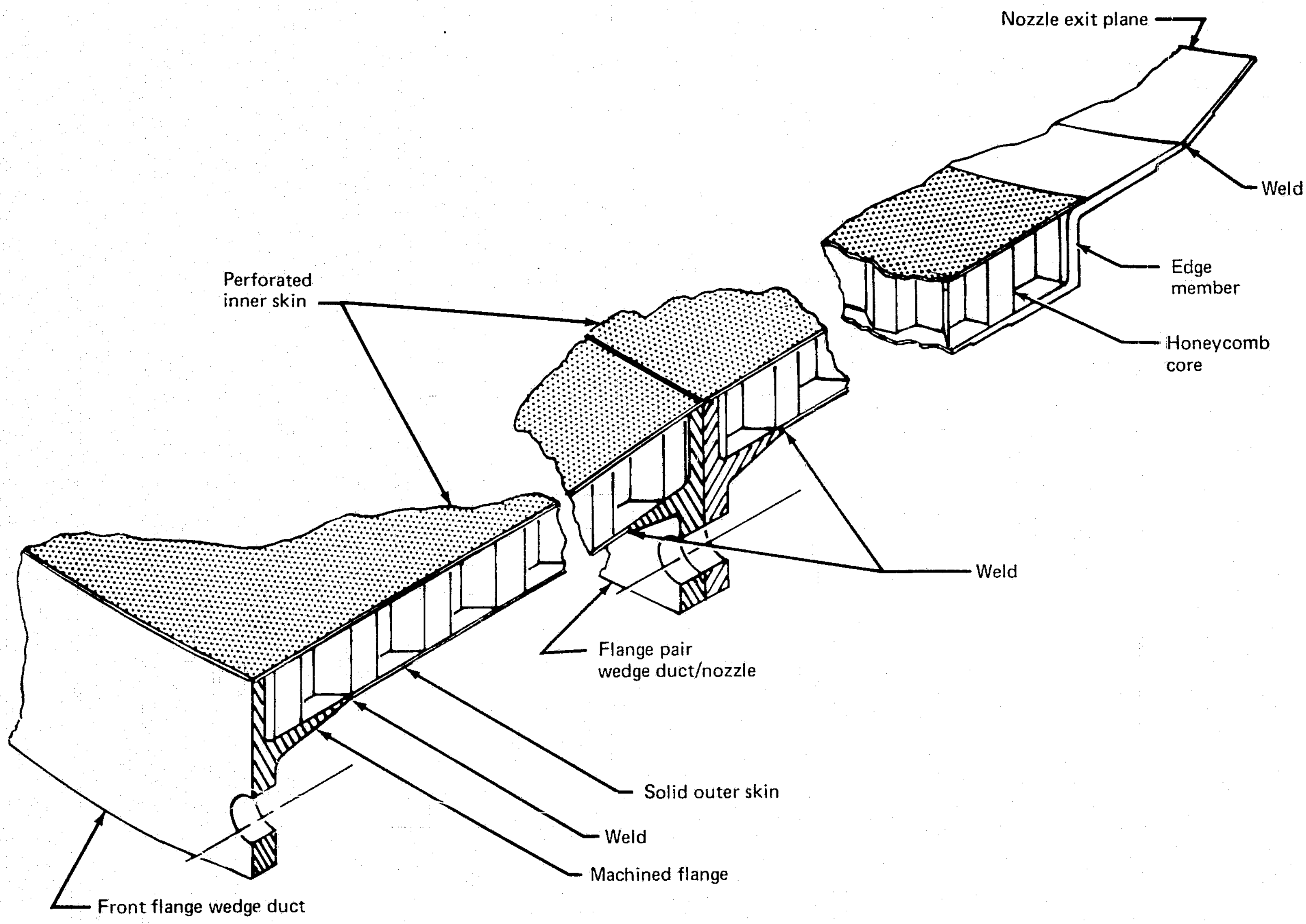


Figure 23.—JT8D Refan Original Design Exhaust Duct—Aluminum-Brazed Titanium Acoustic Honeycomb Panels

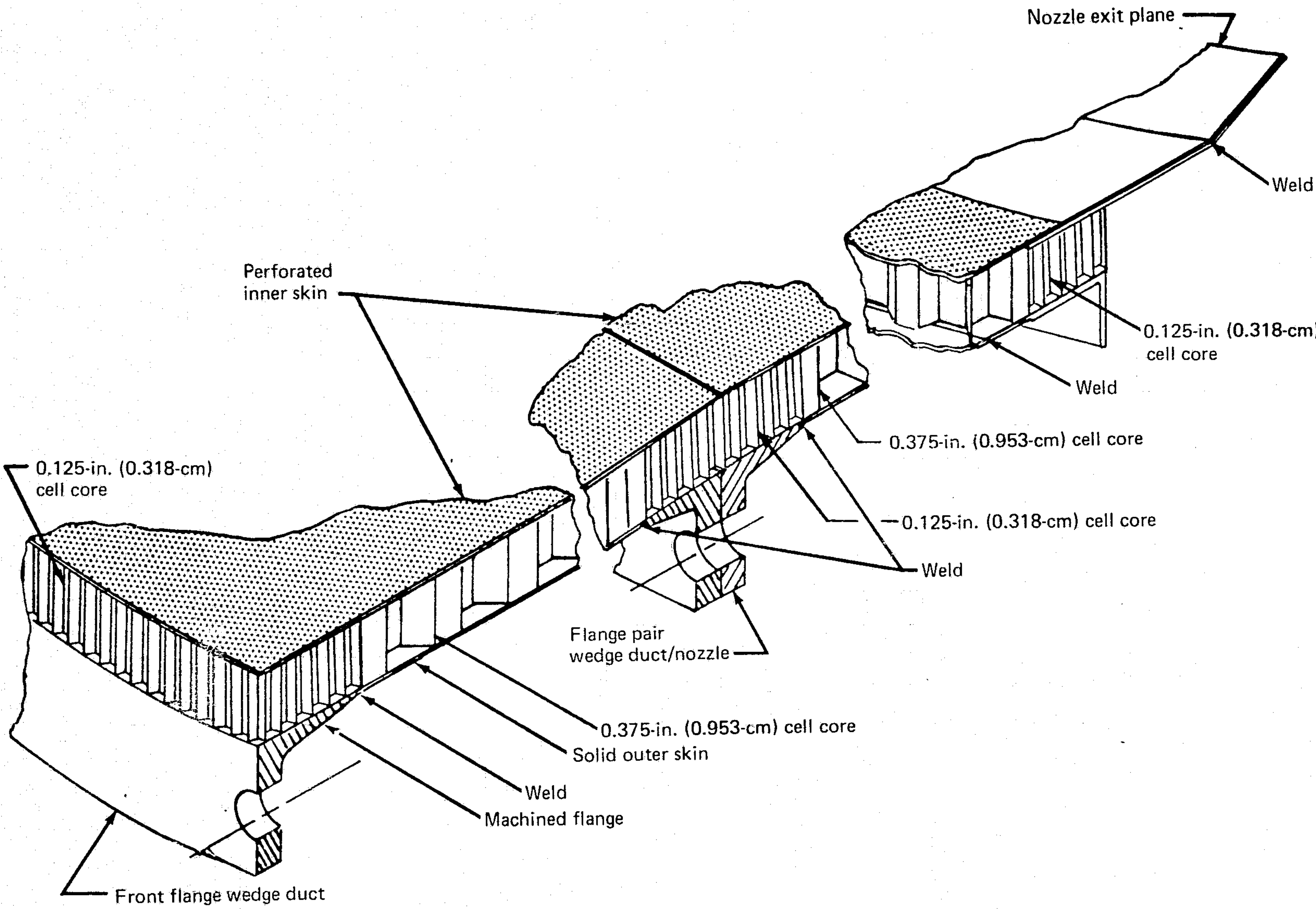


Figure 24.—JT8D Refan Alternate Design Exhaust Duct—Aluminum-Brazed Titanium Honeycomb Construction With Dense Core Closures

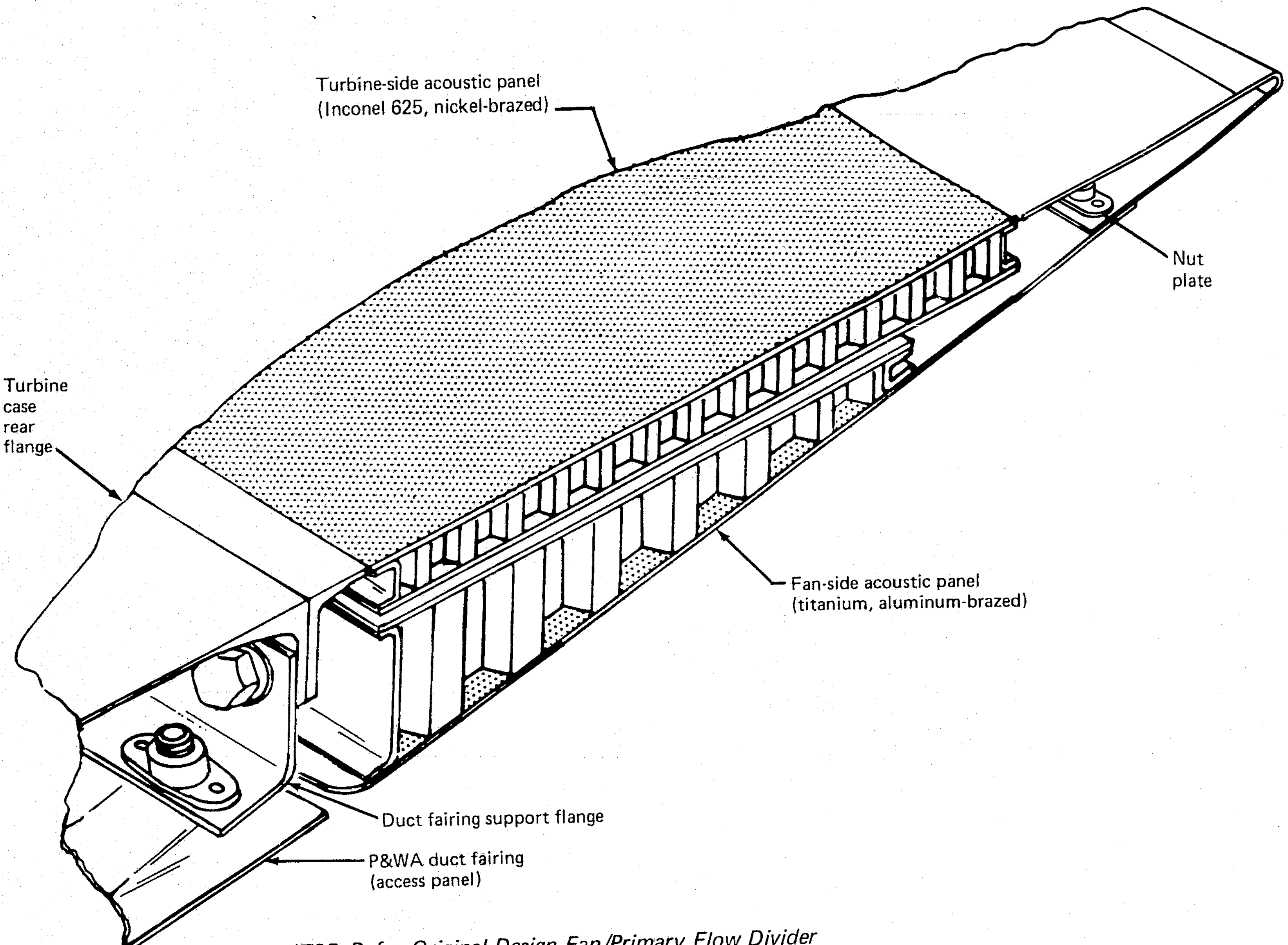


Figure 25.—JT8D Refan Original Design Fan/Primary Flow Divider

duct and nozzle. Figure 25 illustrates the original divider assembly design with a tapered outer panel incorporating fore and aft closure flanges on the honeycomb core. The alternate design shown in figure 26 includes a constant thickness outer panel with circumferential strips of 1/8-in. (3.2-mm) cell core forming the forward and aft closures. As in the exhaust duct, this alternate design was used to minimize tooling requirements and maximize the probability of achieving an acceptable brazement.

The loads used in the design of the fan/primary flow divider were due to a 5-psi (34 474-N/m^2) pressure differential or 40-g vibration loads resulting from rotating system blade loss. Design ultimate loads at the engine attach flange are:

Moment = 24 300 in-lb (2745 m-N)
Shear = 2640 lb (11 743 N)
Axial = 1130 lb (5026 N)

Maximum operating temperatures are 600°F (589 K) on the fan side (outer wall) and 1200°F (922 K) on the primary side.

3.1.3.3 Exhaust Center Plug

The 20-in. (50.8-cm) long parabolic plug (fig. 21) is fabricated from Inconel 625 sheet metal with machined attach flange. The plug is directed up 3.5° relative to the engine centerline. It is loaded by 5-psi (34 474-N/m^2) pressure differential or 40-g vibration due to engine blade loss as defined by P&WA. Design ultimate loads at the engine flange are:

Moment = 6000 in-lb (678 m-N)
Shear = 600 lb (2669 N)
Axial = 770 lb (3425 N)

3.1.3.4 External Aerodynamic Fairing

The external fairing covers the wedge duct as shown in figure 21. The fairing consists of four epoxy fiberglass-honeycomb panels supported forward and aft on aluminum sheet-metal bulkheads and stabilized by two pairs of aluminum sheet-metal intercostals 30° either side of top and bottom center. The forward bulkhead mates with the rear end of the engine cowl doors, the rear bulkhead mates with the forward edge of the stowed thrust reverser doors, and the top and bottom fairing panels are removable for access purposes.

3.1.4 THRUST REVERSER

The thrust reverser used with the 727-200/JT8D refan installation is a hydraulically actuated target-type that is basically a scaled-up version of the reverser currently in use on the 737 (fig. 27). The same reverser unit is used on all three engine positions and is rotated (clocked) relative to the vertical centerline for each installation to obtain the exhaust efflux pattern that will minimize the interference effects and produce the shortest stopping distance.

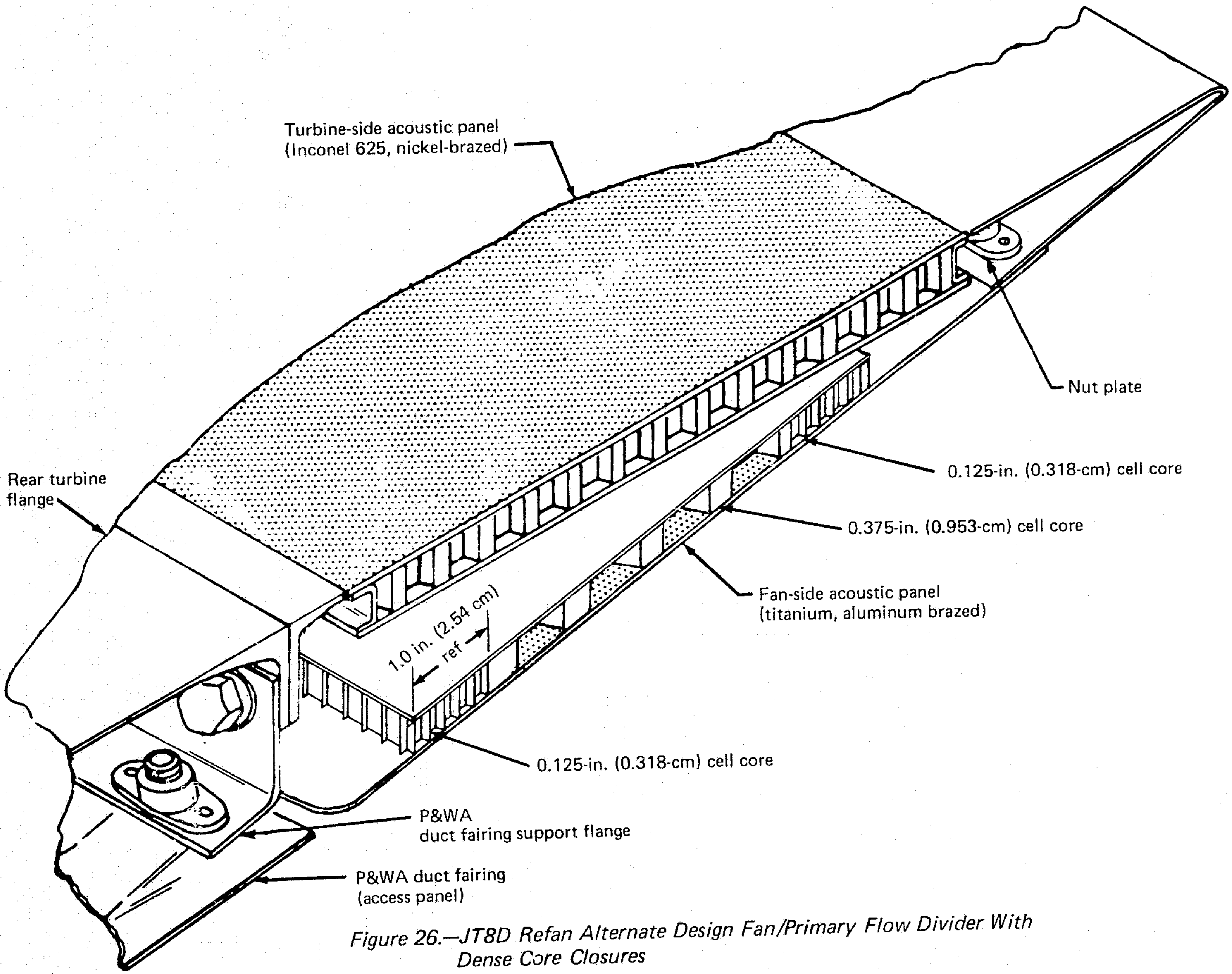


Figure 26.—JT8D Refan Alternate Design Fan/Primary Flow Divider With Dense Core Closures

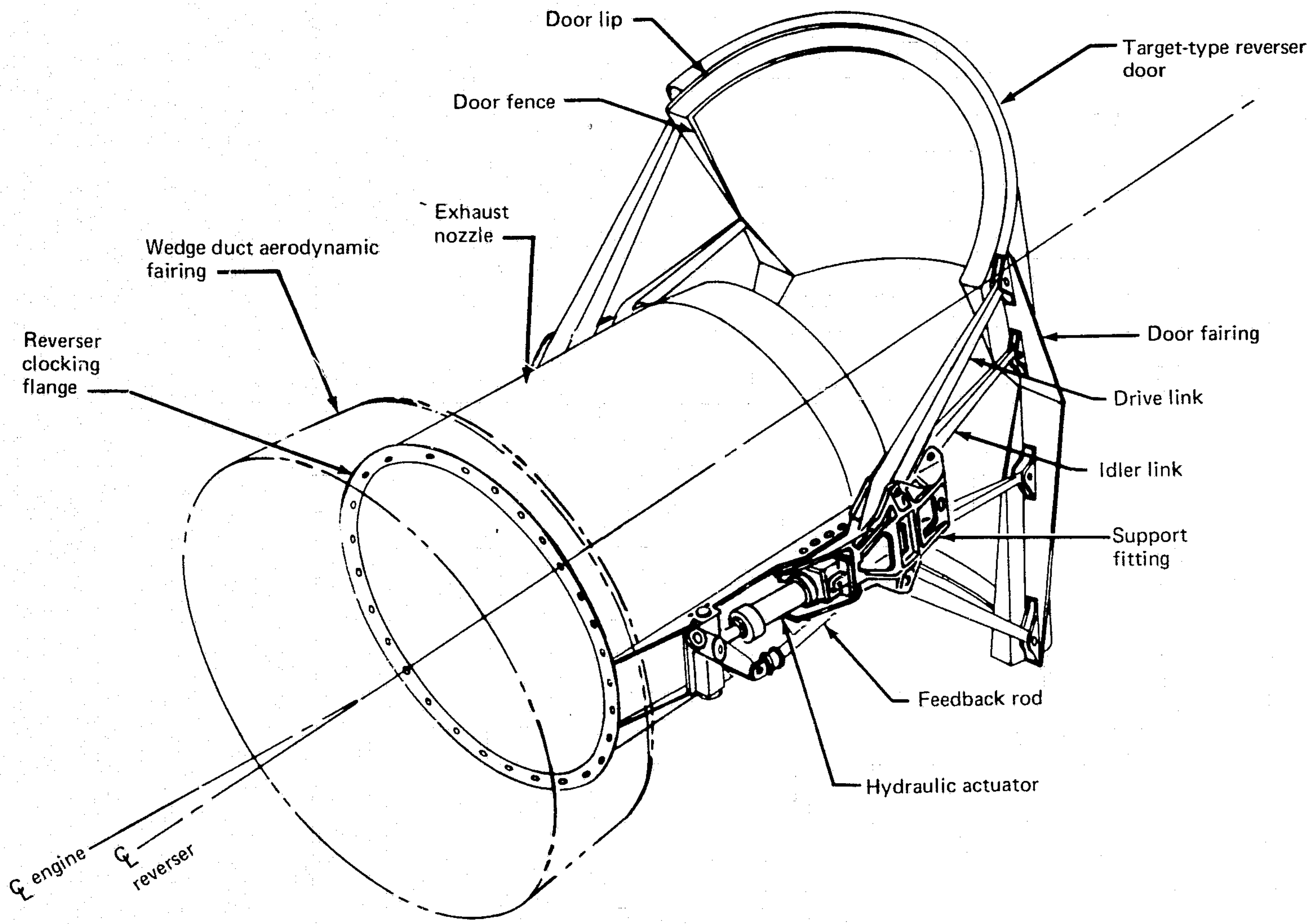


Figure 27.—JT8D Refan Thrust Reverser—Hydraulically Actuated

The criteria influencing the design of the thrust reverser were as follows:

- Static performance equivalent to current design (Model test results are presented in ref. 7)
- No degradation of airplane controllability (Model test results are presented in ref. 8)
- Reingestion improved over the current 727 (Test results are presented in ref. 9)
- Reliability improved over the current 727

3.1.4.1 Reverser Doors

In operation, the target-type reverser doors move from a stowed position on the exhaust duct to a deployed position immediately aft of the nozzle exit (fig. 27), thereby deflecting the exhaust gas and discharging it in a forward direction. The doors are approximately 42 in. (1.07 m) long and of double-wall construction. The inner wall fabricated of 6Al-2Sn-4Zr-2Mo titanium sheet, a temperature resistant alloy, is connected by five 6Al-4V titanium frames to an aluminum outer wall, contoured to conform with the lines of the nacelle and actuator fairing when in the stowed position. Zee-section longerons stiffen either side, and a machined doubler reinforces the trailing edge. Exit edge lip and side fences are used to control distribution of the efflux in the reverse mode.

The total loads on the reverser doors result from a combination of gas pressure, aerodynamic, and thermal gradient loads. The thrust reverser gas and aerodynamic ultimate load are calculated to be 44 550 lb (198 158 N) with an 1800-lb (8006-N) side load. This is combined with a temperature gradient of 550°F (305 K) resulting from 1015°F (819 K) on the gas impingement side and 465°F (514 K) on the back side. The supporting links have been designed with flexibility to minimize the effect of thermal stresses. The door fatigue load (normal landing cycle) is 20 180 lb (89 761 N) with an 800-lb (3558-N) side load. The corresponding temperatures on the gas side and back side are 790°F (694 K) and 290°F (416 K), respectively.

3.1.4.2 Linkage

A four-bar linkage (fig. 27) is used to position the reverser doors, and an over-center link preloads the linkage in the stowed position to minimize vibration effects at the pivots and to hold the door faired against negative aerodynamic loads.

The driver and idler links are machined from titanium bar. The over-center links are machined from 17-4PH bar stock. The linkage support fitting and the actuator slide carriage are titanium castings. Single pin joints have either spherical bearings or are bushed to protect fittings. Rework allowances are provided. The bushing/bearing material combination is Stellite 6 in contact with 17-4PH corrosion-resistant steel (CRES), which has been nitrided and coated with a dry film lubricant. The one exception to this combination is the thrust reverser carriage to guide rod surfaces. This combination consists of hard chrome-plated 17-7PH CRES in contact with 17-4PH CRES which has been nitrided and coated with a dry film lubricant.

The driver link is sized by the 270-KEAS (138.9-m/sec EAS) inadvertent deployment condition, and the idler link is sized by the refused takeoff (RTO) condition. The linkage loads, which occur during a normal landing reverse-thrust cycle, were used for fatigue analysis.

3.1.4.3 Actuation

Actuation by means of hydraulic or pneumatic power was considered. Hydraulic power was selected primarily because of significantly better economics and because of better predicted reliability when compared to pneumatic power.

The actuators, located on either side of the assembly, drive the deflector door linkages. The primary power source is from the airplane "A" hydraulic system, as shown in figure 28. Backup power capable of deploying all three thrust reversers is provided by a hydraulic accumulator.

A local fluid run-around feature is incorporated near the actuators, as shown in figure 29. During deployment, this feature permits fluid from the head end of the actuators to be shunted directly to the rod end, thus effecting a significant reduction of flow rate demand from the airplane "A" system.

The actuator housing (piston rod and run-around valve material) is 4330M; the plumbing is 21-6-9 CRES. The reverser is designed to withstand inadvertent in-flight deployment loads up to landing gear extension placard speed, 270 KEAS (138.9 m/sec EAS). The critical actuation system load occurs at this point with the actuator fused to prevent higher loads from occurring. The normal landing reverse thrust cycle is used for fatigue analysis.

3.1.4.4 Controls

The existing mechanical interlock/followup feature between the thrust reverser and throttle/reverse thrust lever is retained (see fig. 29). The interlock limits engine power to idle until the reverser position agrees with the mode selected. The throttle followup retards engine power to idle in the event of inadvertent extension or retraction of the reverser. Additional safety features include a fire shutoff valve connected to the fire protection system and a manual shutoff valve to preclude operation during ground inspections. The system features a double-switch system that operates reverser-unlocked and reverser-deployed lights on the instrument panel (fig. 28).

The thrust reverser is maintained in the forward thrust mode by mechanical over-center linkages on each hydraulic actuator and by a lock on one side of each door, as shown in figure 30. Hydraulic pressure is isolated from the reverser system by the landing gear air-ground switch to prevent inadvertent deployment.

The feedback rod connecting through a reduction arm and flexible cable to the throttle interlock is fabricated from CRES tubing with self-aligning rod end bearings. The reduction arm is an aluminum casting. The push-pull cable assembly materials are the same as used on the current 727.

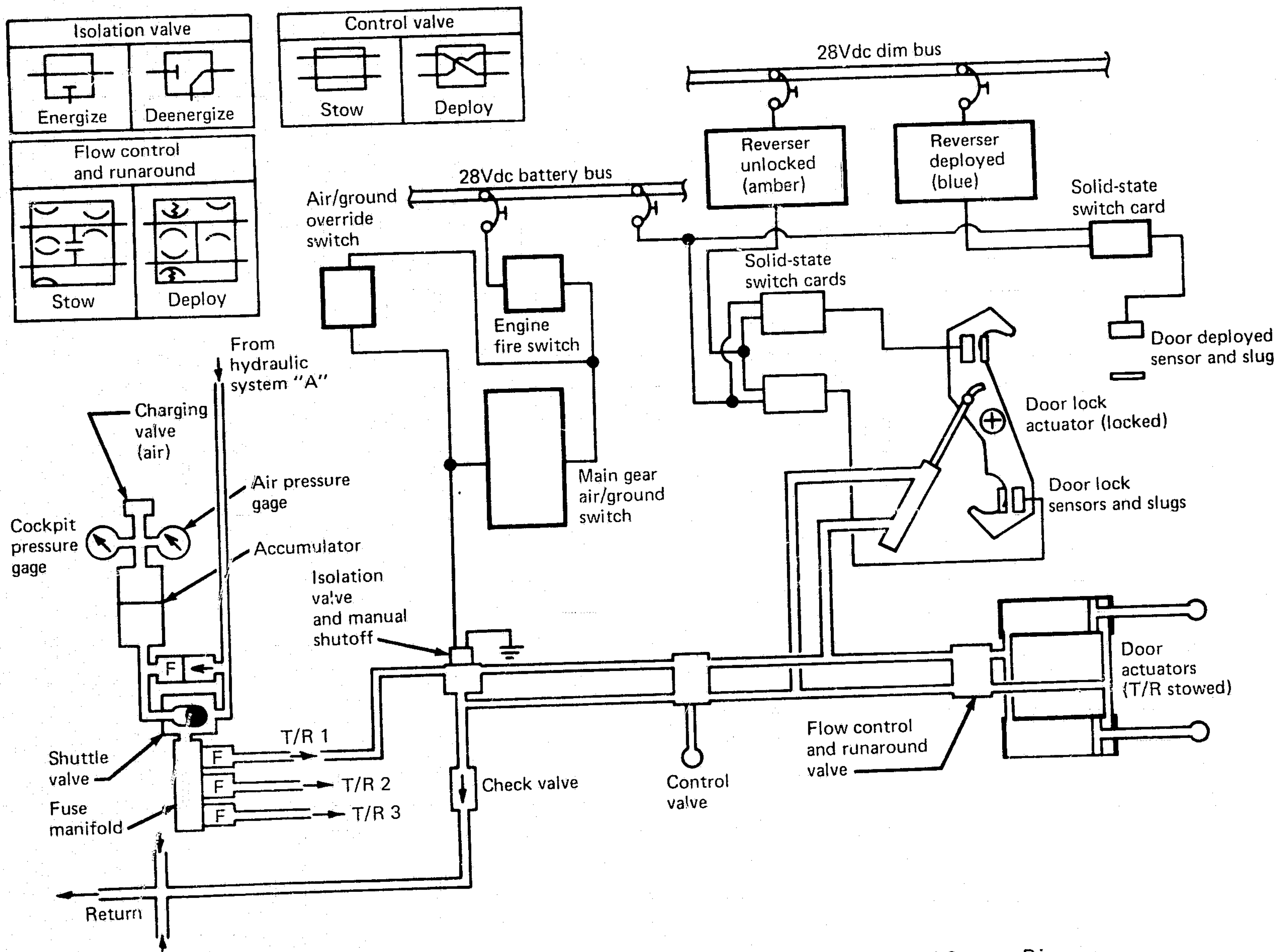


Figure 28.—JT8D Refan Thrust-Reverser Hydraulic/Electrical System Diagram

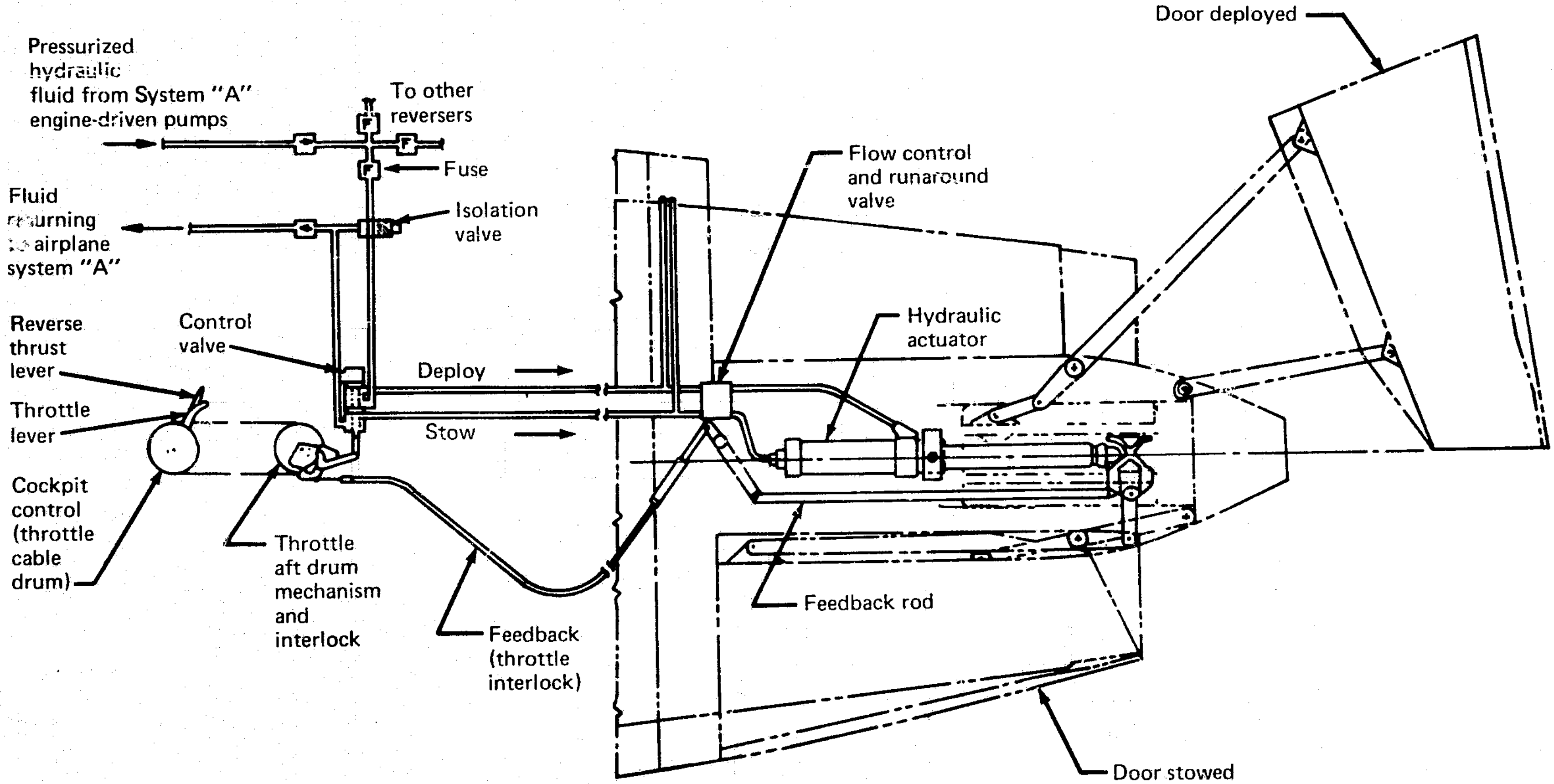


Figure 29.—JT8D Refan Thrust-Reverser Actuation and Control Diagram

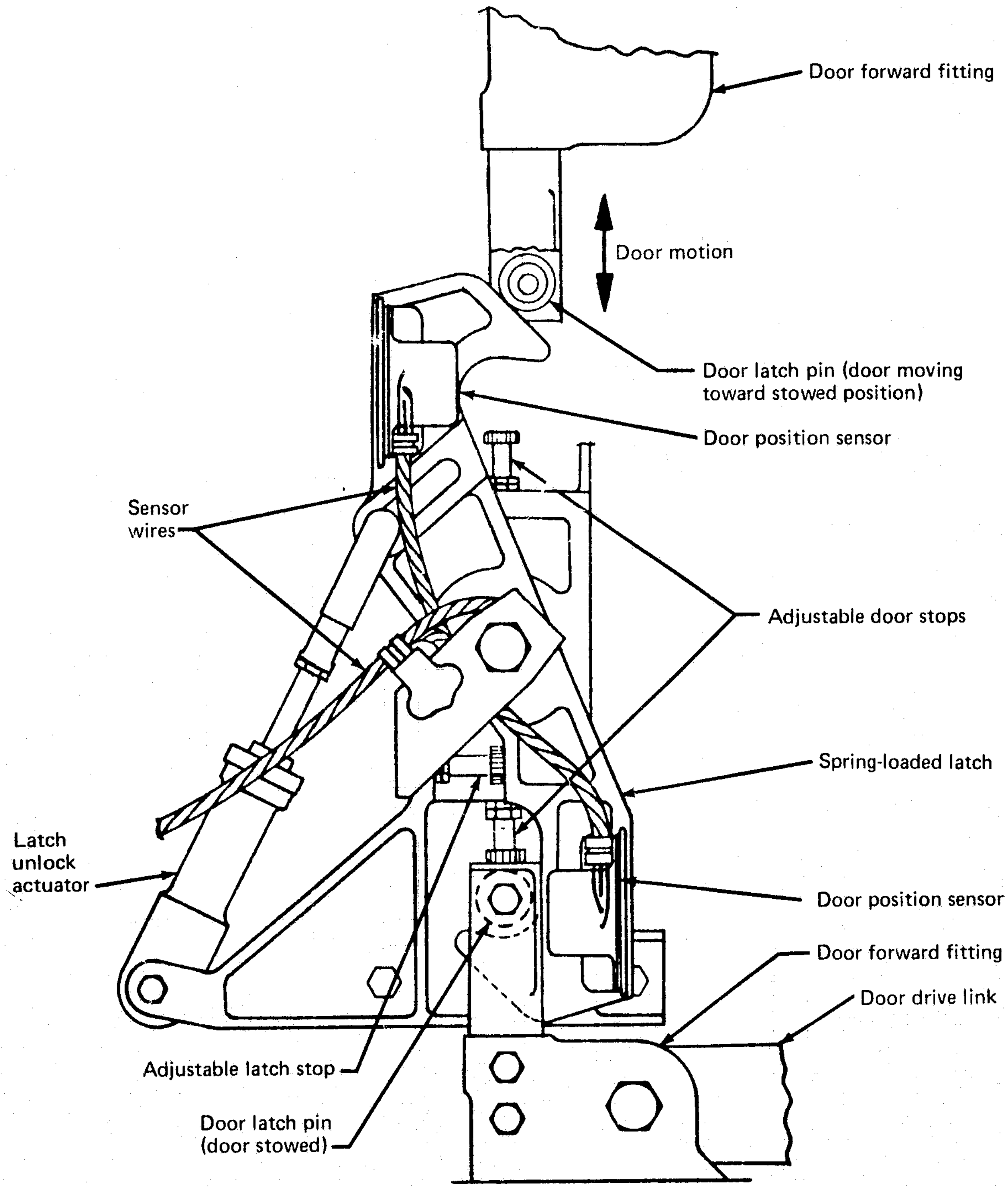


Figure 30.—JT8D Refan Thrust-Reverser Lock Mechanism

The door lock latch is a 17-4PH casting actuated by the same hydraulic actuator as used in the 737 system. The latch spring is made from 17-4PH wire. The latch critical load occurs when the lock actuator fails to rotate the latch during the deploy cycle.

3.1.5 CENTER-ENGINE INLET DUCT

The air inlet duct for the center engine was designed to accommodate the larger mass flow of the refan engine, 480 lb/sec (217.7 kg/sec) compared to 334 lb/sec (151.5 kg/sec) for the existing JT8D-15 engine on the 727-200, without increasing duct loss and flow distortion. The flow geometry was developed as reported in reference 10 to accomplish this within the constraint of the existing opening in the vertical tail front spar forging. Structural/acoustic bonded aluminum/fiberglass honeycomb construction was selected to minimize weight and cost. The length of the duct permits acoustic lining sections to be tailored to a wide range of detail geometry, as defined in table 5, in order to provide attenuation coverage in the noise spectrum to protect the passenger cabin from buzz-saw noise on takeoff and to protect the community at the FAR Part 36 approach condition.

3.1.5.1 Center-Duct Inlet

The center-engine inlet for the JT8D-109 has a throat diameter of 47.8 in. (121.4 cm) and a contraction ratio of 1.30 resulting in an inlet lip highlight diameter of 54.5 in. (138.4 cm). The lower lip highlight is located the same distance above the body and forward of the vertical tail as on the 727-200 airplane. The lip section, approximately 11-in. (28-cm) long, incorporates a distribution ring for thermal anti-icing using compressor bleed air (figs. 31 and 32). The lip skin is die-formed aluminum sheet and serves as part of the structure that reacts the thrust loads generated by the inlet duct. The critical ultimate thrust load is generated by engine surge and is 23.76 lb/peripheral inch (41.61 N/cm).

The lip anti-ice spray tube is constructed of 6061-aluminum alloy and is supported in the same manner in use on the current 727-200 airplane.

3.1.5.2 Center Duct

The center-engine inlet duct assembly is shown in figure 33. Figures 34 through 37 illustrate various duct details. The duct is assembled in two major sections joined at the vertical tail front spar to form a single unit from the inlet lip to the aft structural bulkhead. The duct support scheme is simplified with attachment to the housing structure at the inlet lip and adjustable tie rod links that position the duct in relation to the vertical tail front spar and the aft structural bulkhead.

The upper duct assembly is fabricated in two subsections, each approximately 70-in. (178-cm) long. The forward subsection is circumferentially continuous structural-acoustic bonded honeycomb as shown in figure 33. The inner face is perforated-aluminum sheet, bonded to a high temperature phenolic-impregnated-fiberglass honeycomb core and backed by an intermediate impervious septum, a structural core, and an impervious fiberglass/epoxy outer skin.

The upper duct aft subsection is of similar construction except without the intermediate septum in the honeycomb structure. This subsection includes the rain impingement

Table 5.—JT8D Refan Acoustic Lining Definition—Center-Engine Inlet Duct

Lining section				Specification							
					Rayl number						
Location	Function	Treatment length, in. (cm)	Area[a], ft^2 (m^2)	Material	$R/\rho c$[b]	$Vp/\sqrt{\theta}$ cm/sec[c]	Core depth, in. (cm)	Cell size, in. (cm)	Skin perforation open area[d], %	Skin gage, in. (cm)	Nominal hole diameter, in. (cm)
1 Center duct lower aft	Deep buzz saw	56.7 (146.3)	22.2 (2.06)	Aluminum	(e)		1.25(3.17) +10% - 5%	0.375 (0.95)	26 to 30	0.040 (0.102)	0.050 (0.127)
2 Center duct lower center	Shallow buzz saw (fan tone, takeoff)	66 (167.6)	54.1 (5.02)	Aluminum	0.46 ± 15%	340	0.18 (0.46) ± 5%	0.375 (0.95)	14.8	0.032/0.025[f] (0.081/0.063)	0.040 (0.102)
3 Center duct lower fwd	Fan tone, 1/4 wave type	42.6 (108.2)	40.7 (3.78)	Aluminum	0.75 ± 15%	117	0.18 (0.46) ± 5%	0.375 (0.95)	7.1	0.032/0.025[f] (0.081/0.063)	0.040 (0.102)
4 Center duct upper aft	Fan tone, 3/4 wave type + interior noise	53 (134.6)	29.1 (2.70)	Aluminum	1.37 ± 15%	36.3	2.50 (6.35) ± 5%	0.375 (0.95)	3.5	0.020 (0.051)	0.040 (0.102)
5 Center duct upper fwd	Fan tone, 1/4 wave type	26 (66.0)	58.3 (5.42)	Aluminum	1.65 ± 15%	30.1	0.18 (0.46) ± 5%	0.375 (0.95)	3.5	0.028 (0.071)	0.040 (0.102)

[a]Net active lining area (gross treated surface area less surface area rendered inactive by structural splices, edge closures, etc.).

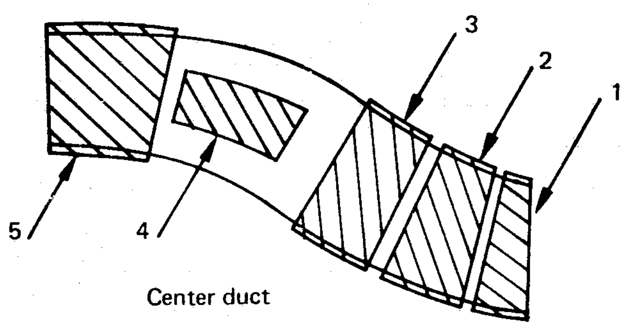
[b]Unidirectional flow resistance ratio after bonding with core where R = flow resistance of sample in N-sec/m^3 (MKS Rayls) and ρc = reference flow resistance in N·sec/m^3 (MKS Rayls).

[c]$Vp/\sqrt{\theta}$ where Vp = particle velocity and θ = static temperature ratio T_S°R/519 (T_SK/288) of air approaching sample in flow resistance test.

[d]Based on open perforations in active treatment area after bonding with core.

[e]Use skin perforation open area.

[f]Face sheet is segmented. Gage of top and bottom sections is 0.032 in. (0.813 mm). Gage of side sections is 0.025 in. (0.635 mm). For attenuation predictions an average value of 0.028 in. (0.711 mm) was used.



Center duct

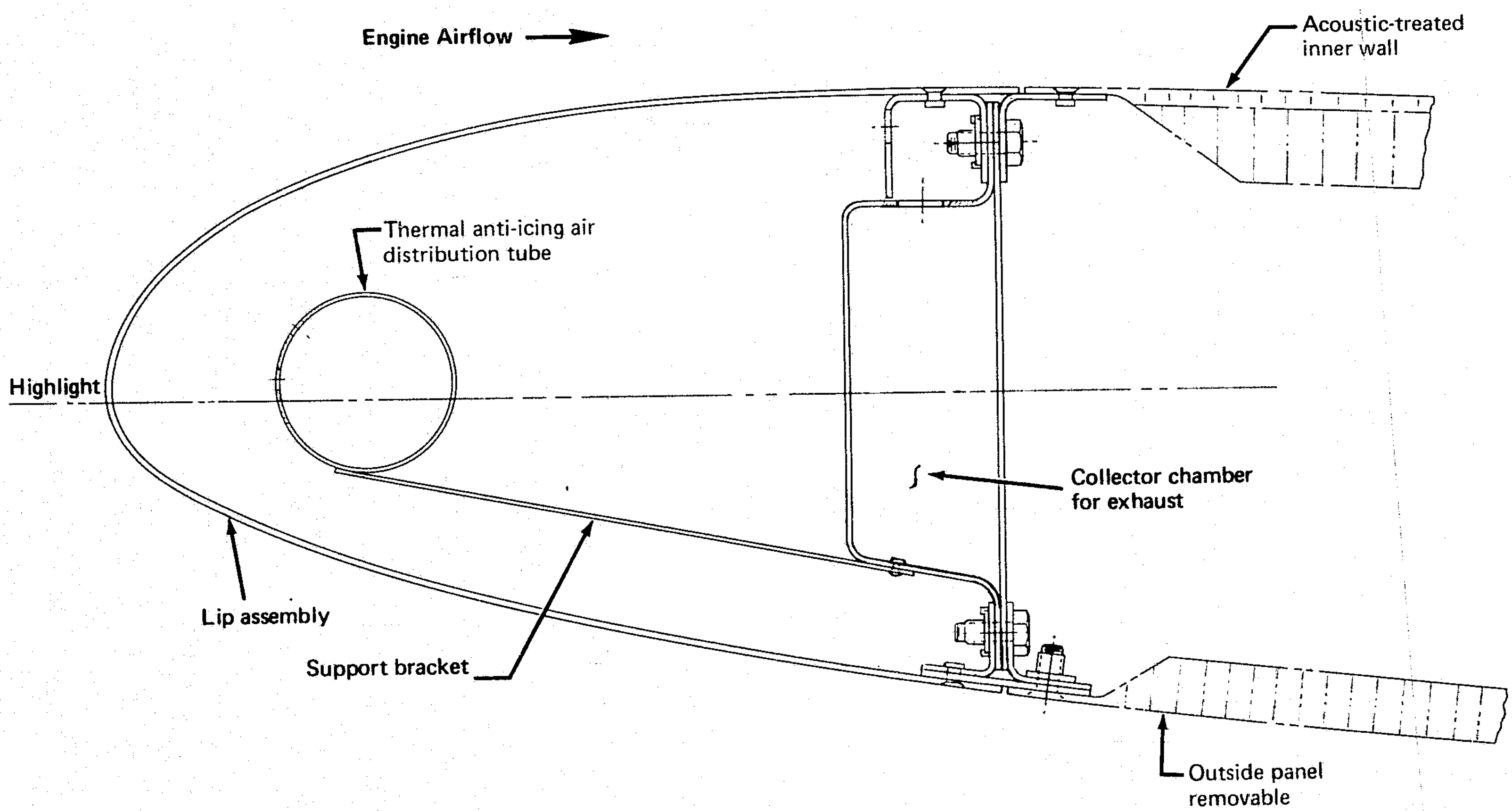


Figure 31.—JT8D Refan Lip Assembly—Center-Engine Inlet Duct

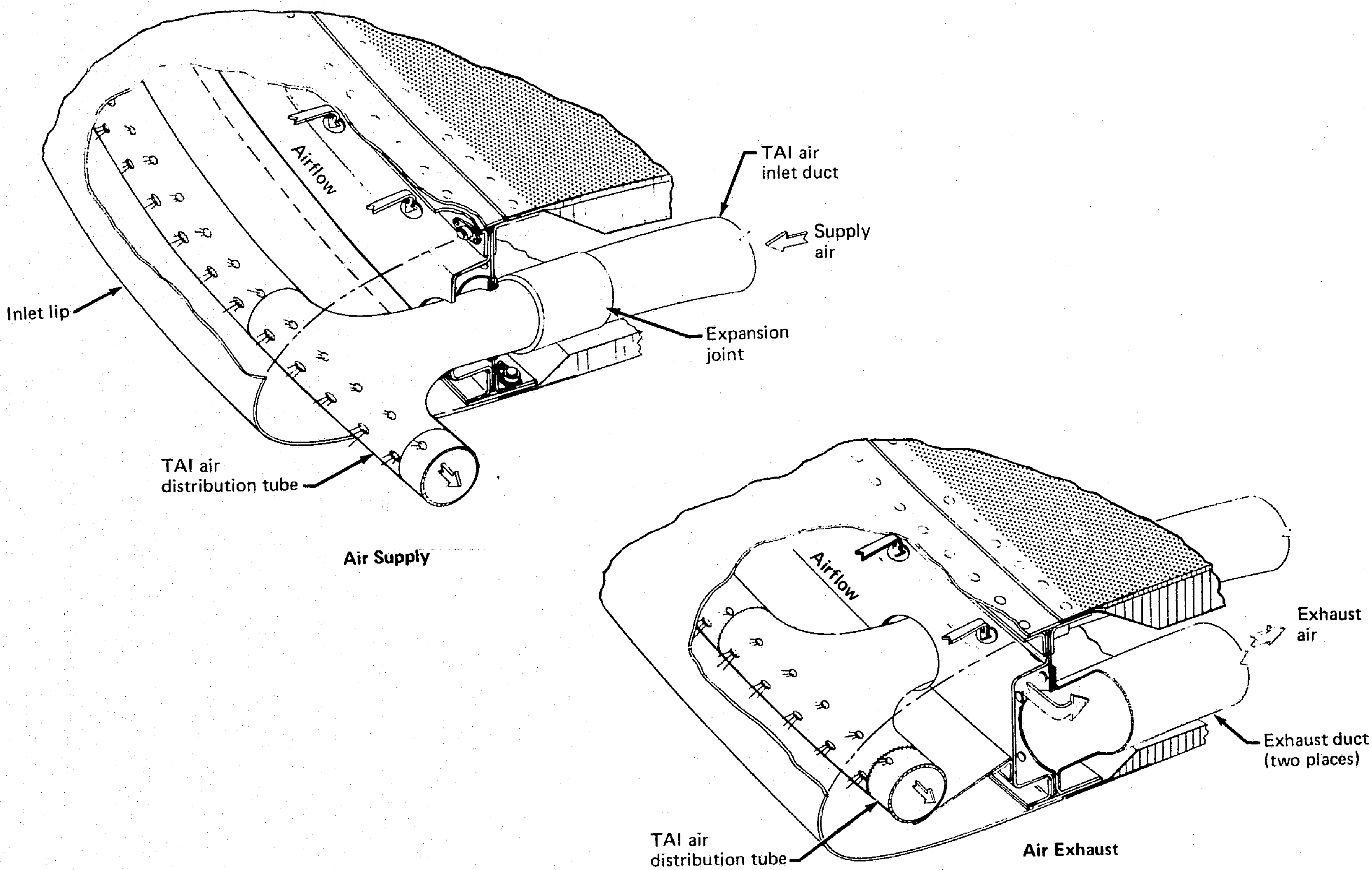
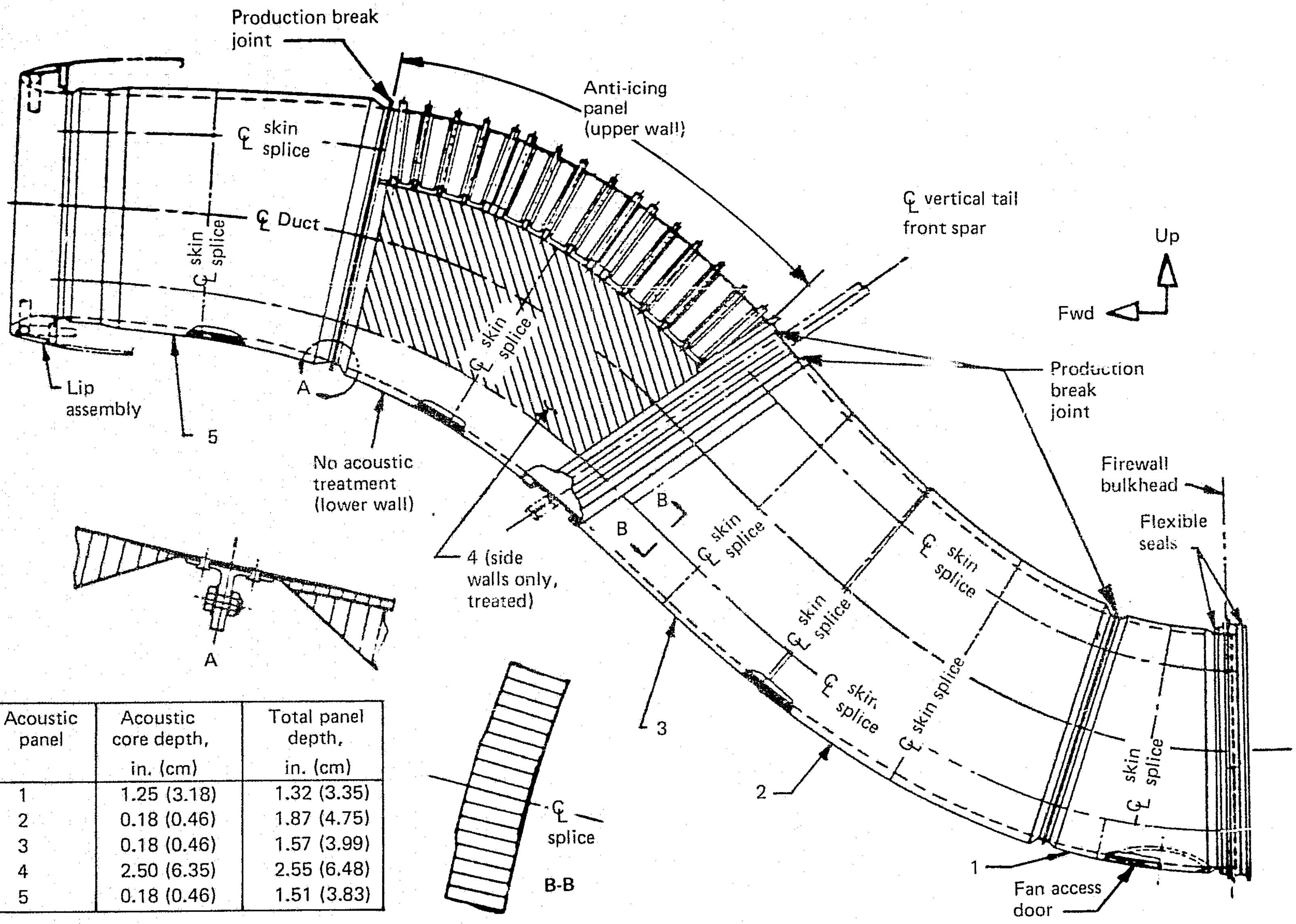


Figure 32.—JT8D Refan Thermal Anti-icing—Center-Engine Inlet Lip



Acoustic panel	Acoustic core depth, in. (cm)	Total panel depth, in. (cm)
1	1.25 (3.18)	1.32 (3.35)
2	0.18 (0.46)	1.87 (4.75)
3	0.18 (0.46)	1.57 (3.99)
4	2.50 (6.35)	2.55 (6.48)
5	0.18 (0.46)	1.51 (3.83)

Figure 33.—JT8D Refan Center-Engine Inlet Duct

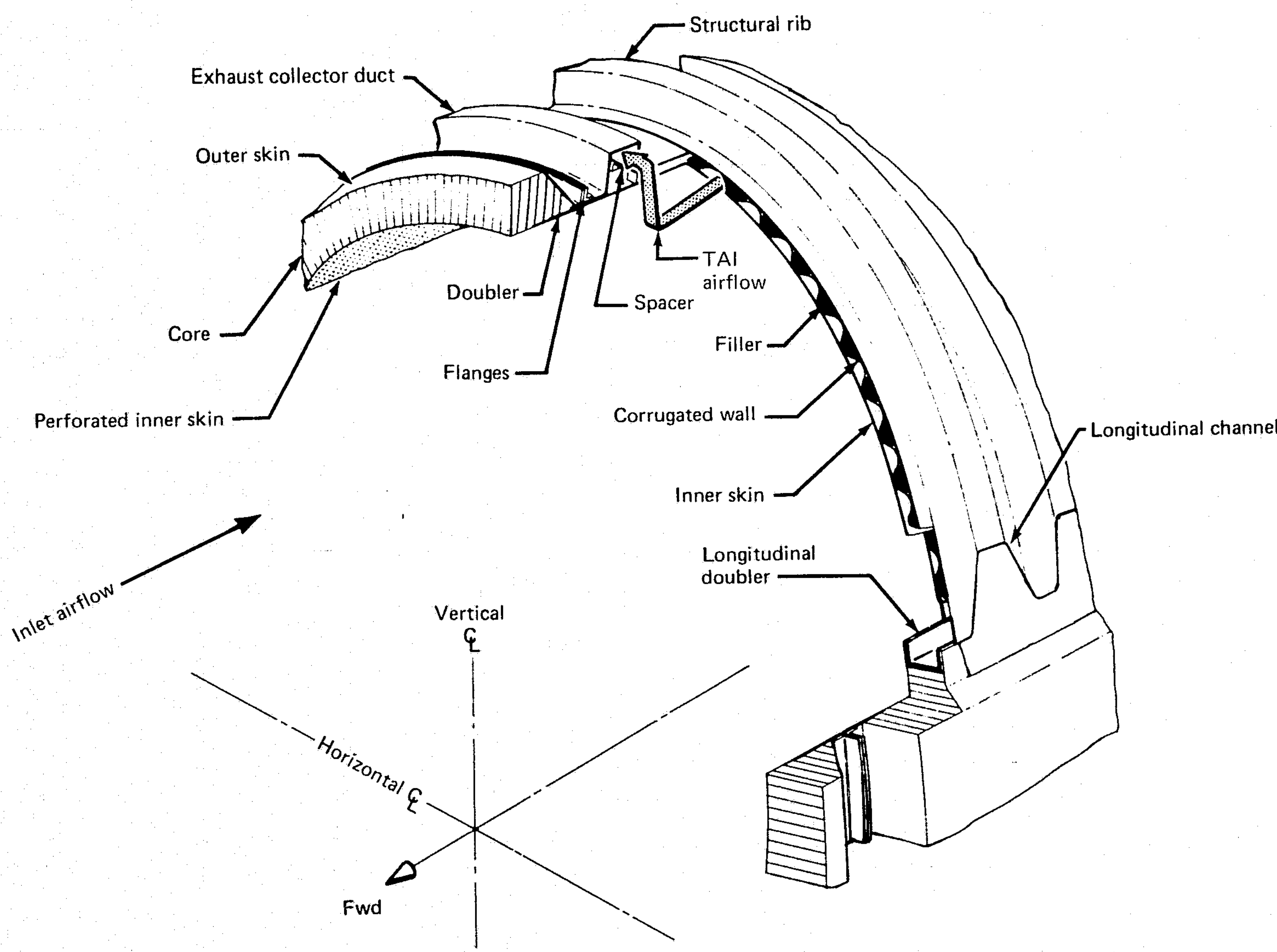


Figure 34.—JT8D Refan Thermal Anti-Icing Panel—Center-Engine Inlet Duct

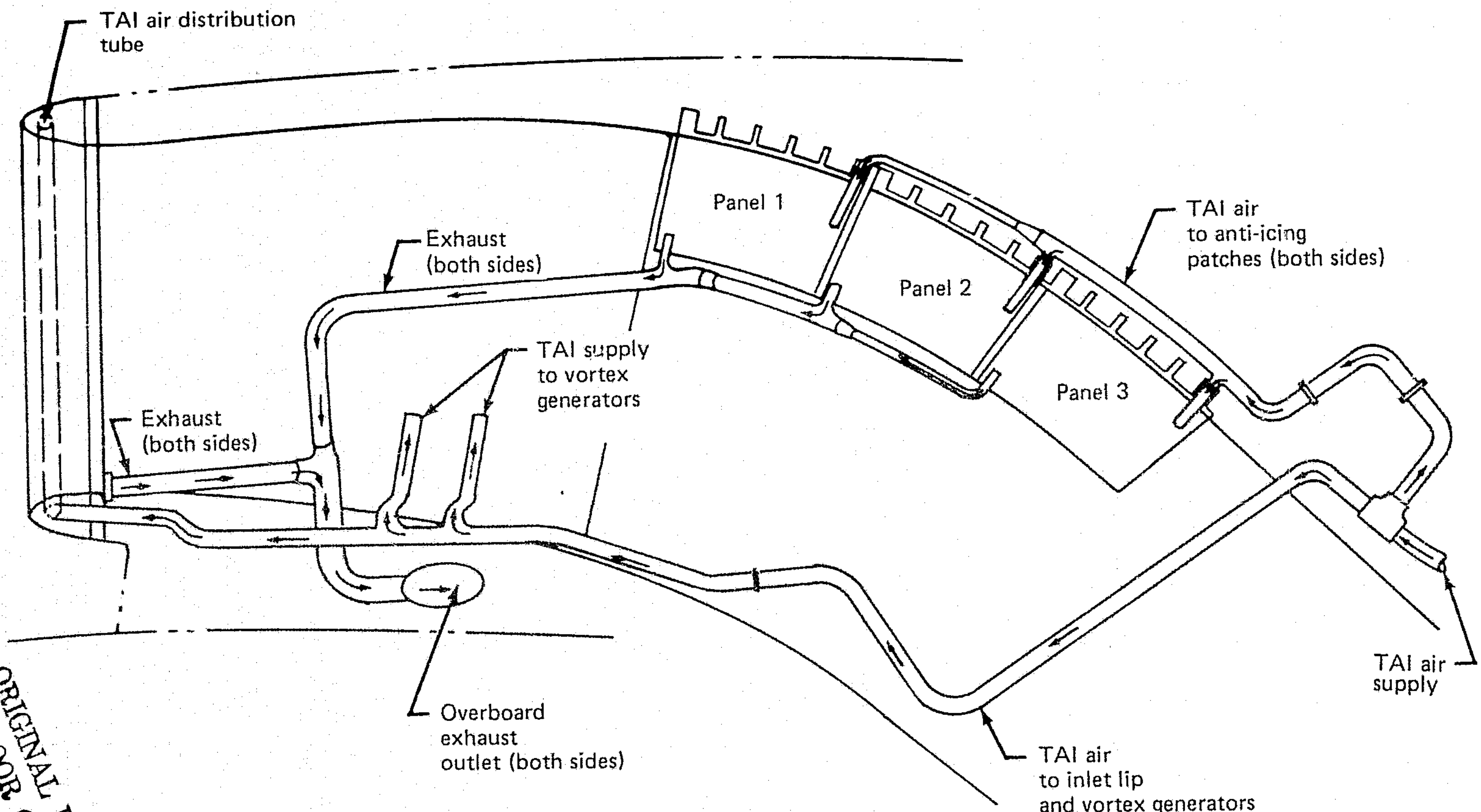


Figure 35.—JT8D Refan Thermal Anti-Icing Air-Supply System—Center-Engine Inlet Duct

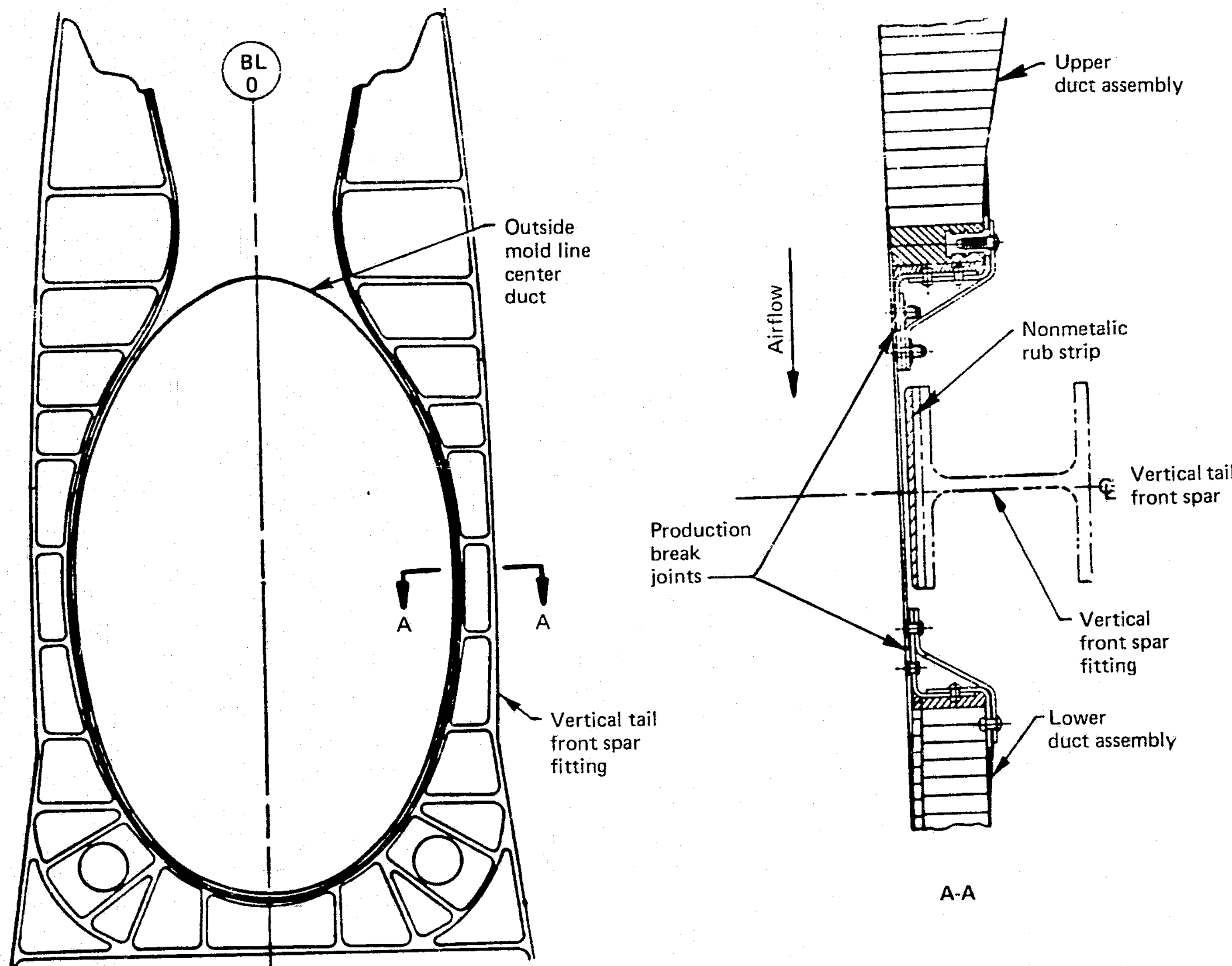


Figure 36.—JT8D Refan Center-Engine Inlet-Duct Interface at 727 Refan Airplane Vertical Tail Front Spar

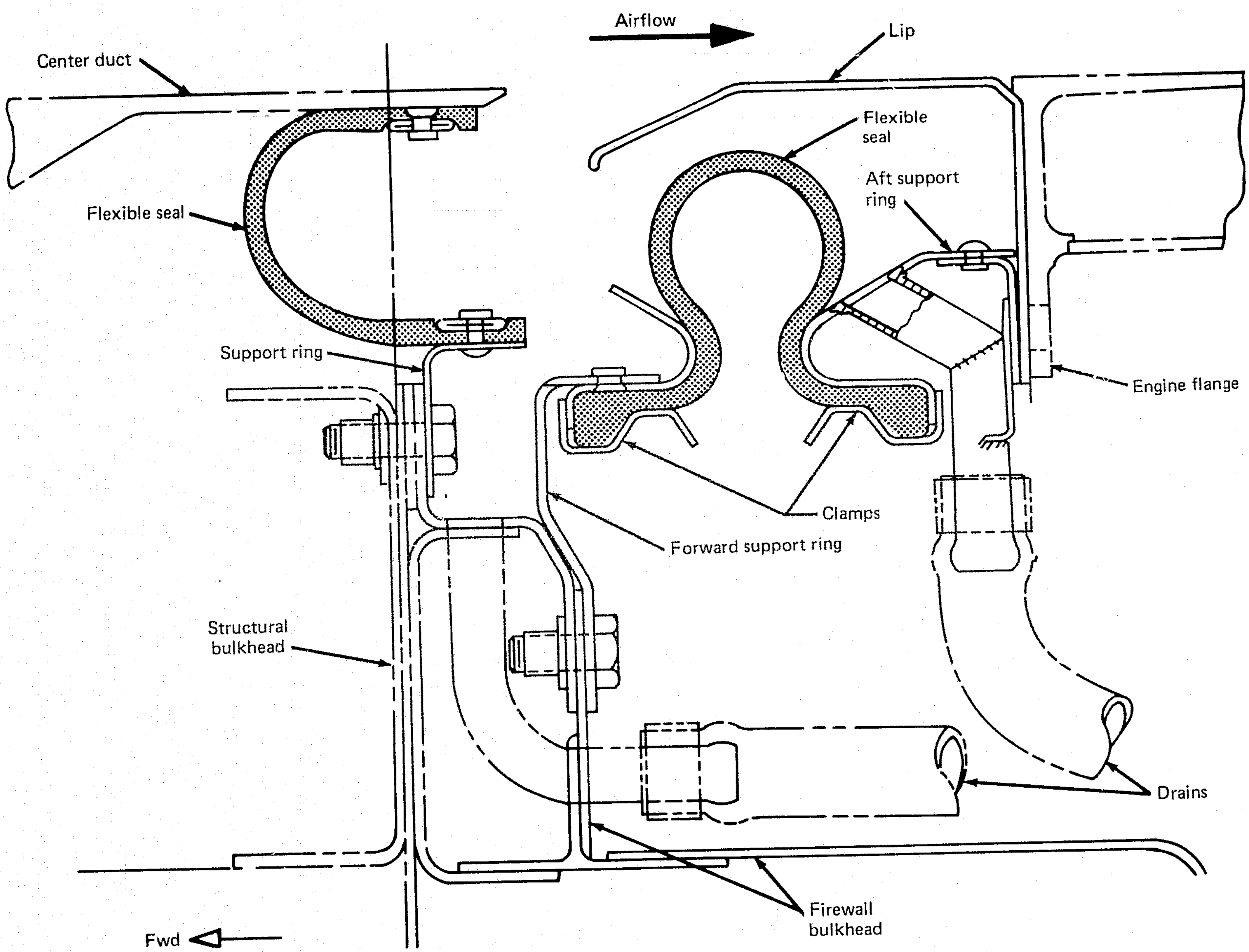


Figure 37.—JT8D Refan Center-Engine Inlet-Duct Flexible Seal Assembly

anti-icing area of the duct in which an aluminum skin backed by aluminum corrugations provides for bleed-air heating as in the existing airplane. (See figs. 34 and 35.) Tentative locations of the vortex generators on the lower wall of this subsection were selected as a result of scale model tests. (Final selection and verification of the vortex generator positions were accomplished by full-scale tests.)

The lower duct assembly (extending from the vertical tail front spar to the aft structural bulkhead) is also fabricated in two subsections and is similar to the upper duct assembly except for differences in face-sheet gage, percent open area of the face-sheet perforations, and core depth (table 5, and figs. 33 and 36). As in the baseline configuration, an access panel is provided for inspection of the engine front face.

3.1.5.3 Alternative Design

An alternative design for the center-engine inlet duct was completed. This design eliminates all of the splice plates and doublers used in the all-bonded test duct. The alternative configuration would use 2219-Al perforated-sheet rolled and welded on a single longitudinal joint to form a cylinder. The cylinder would then be bulge-formed to the required duct shape to form the acoustic lining face. Bonding of the core and fiberglass/epoxy backing skins to the face would be performed in the same manner as previously described for the refan center-engine test inlet duct.

3.1.5.4 Center-Duct Support

The duct support links are located at the vertical tail front spar and aft at body station 1310 in. (33.274 m). Support link ultimate design loads are 7700 lb (34 251 N) per link at the front spar and 13 300 lb (59 161 N) per link at station 1310 in. (33.274 m). This ultimate load case is the critical design condition for the duct and it corresponds to an internal surge gage pressure of 15.75 psi (108 591 N/m^2) in the duct.

No restraint is applied to the duct at the aft end, which is joined to the firewall by a flexible seal (fig. 37). Retention details of the flexible seal between the firewall and engine fan case (also shown in fig. 37) have been revised from the baseline airplane to simplify installation procedures. Deflection of the duct from elliptical to circular section under internal surge pressure is constrained by the vertical tail front spar. The magnitude of the force transmitted to the front spar forging is 820 lb/peripheral inch (1436 N/cm) for the ultimate load case.

The duct will be subjected to a once-per-flight fatigue cycle of -3.0 psi (-20 684 N/m^2) to +2.25-psi (+15 513-N/m^2) internal gage pressure. This is within the capability of the design as sized by the ultimate loads.

3.1.6 ENGINE AND NACELLE SUBSYSTEMS

The engine systems consist of the airframe-furnished equipment required to integrate the engine (and its systems) into the airplane. This includes such items as engine mounts, cooling and ventilation, vents and drains, fire protection, lubrication and fuel systems, CSD/generator, controls and instrumentation, engine starting, engine bleed air, and ice protection, as shown installed on the engine in figures 38 and 39.

All existing systems have been retained to the maximum extent. In general, components are retained, but ducting, plumbing, and bracketry are completely new.

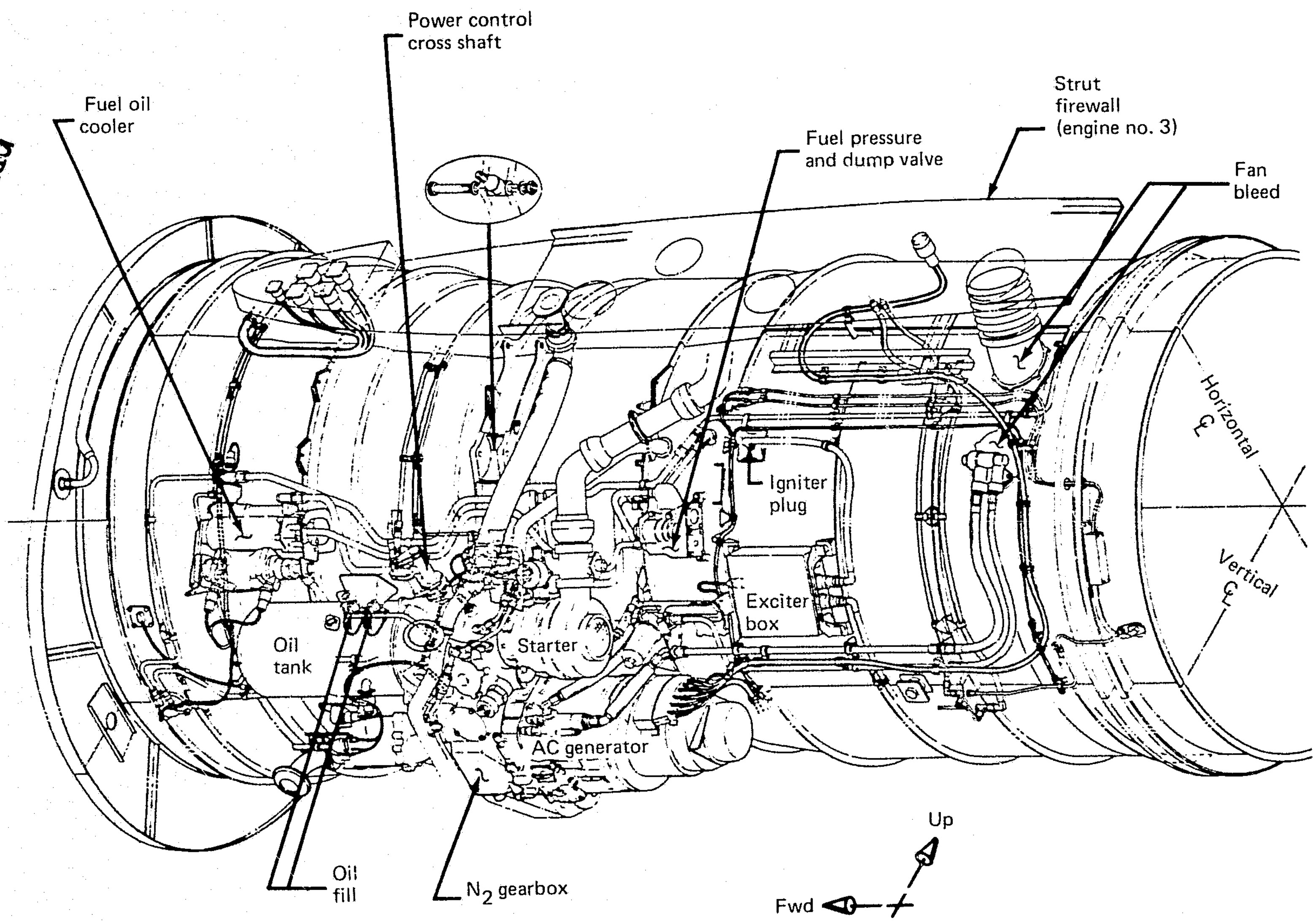


Figure 38.—JT8D Refan Powerpack Assembly—Lower Left-Hand Side

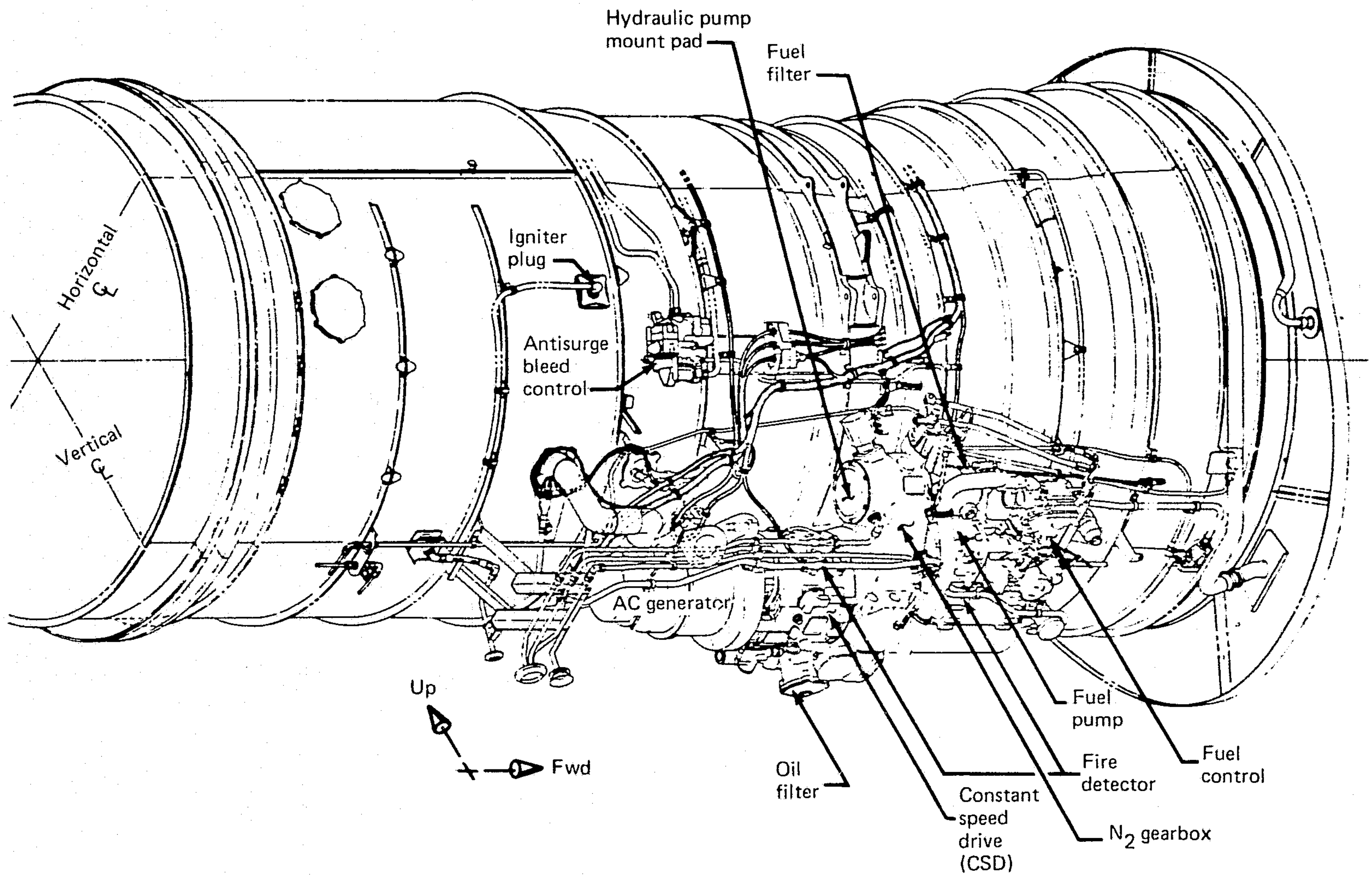


Figure 39.—JT8D Refan Powerpack Assembly—Lower Right-Hand Side

3.1.6.1 Engine Mounts

Side-Engine Mounts.–The side-engine mount scheme is shown in figure 40 and remains essentially unchanged from the baseline airplane.

The basic vibration isolator concept and criteria used on the baseline are satisfactory for application to refan engine installation; however, minor adjustments are required to match the isolators with the refan nacelle weight and inertia. The installation geometry requires changes to match the refan engine flanges and to prevent intermixing of isolators and cone bolts between baseline and refan.

No changes are required in the strut-mounted forward attach fittings; however, new aft tee-fittings are required.

Center-Engine Mounts.– Figure 41 shows the center-engine mount system. The new longer engine requires both mounts to be moved 10.7 in. (27.2 cm) aft. An all-new front engine mount assembly, including forging, vibration isolators, cone bolts, and drag links, is attached to a relocated clevis fitting on the horizontal fire wall, resulting in the engine centerline being lowered 4.5 in. (11.4 cm) from the existing position. The aft mount, consisting of a vibration isolator and cone bolt, is suspended from a new cantilevered support fitting.

3.1.6.2 Cooling and Ventilation

The full-length bypass duct on the JT8D engine shields the externally mounted equipment from the hot core of the engine. This feature results in a relatively cool nacelle environment that permits installation of equipment and accessories without cooling or shielding from the effects of engine case-radiated heat. No blast cooling is used on any equipment. Ventilation is also held to a minimum allowing only normal joint leakage and venting to accommodate changes in altitude. This is done for two reasons:

1. In the event of a nacelle fire, ventilation would support combustion.

2. The fire-extinguishing system would have to be of much greater capacity in order to extinguish a nacelle fire if the nacelle were ventilated.

3.1.6.3 Engine and Nacelle Drains

The engine accessory drain system is arranged to collect fluids from the following three source groups:

1. Fuel pump drive pad, starter drive pad, and oil tank scupper drain.

2. Hydraulic pump drive pad drain on all three engines and hydraulic pump seal drain on engines 1 and 2 only.

3. CSD output pad drain.

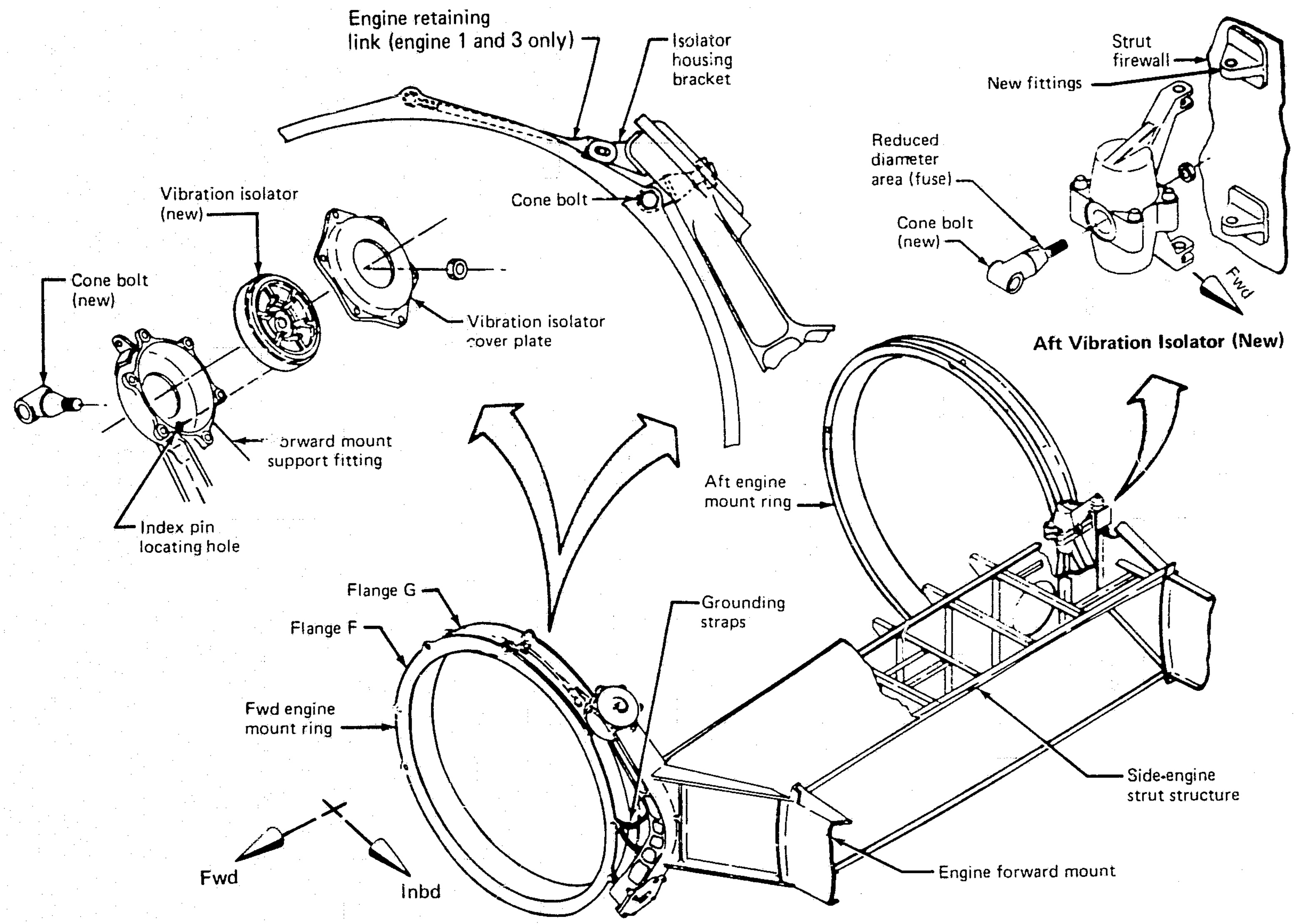


Figure 40.—JT8D Refan Side-Engine Mounts

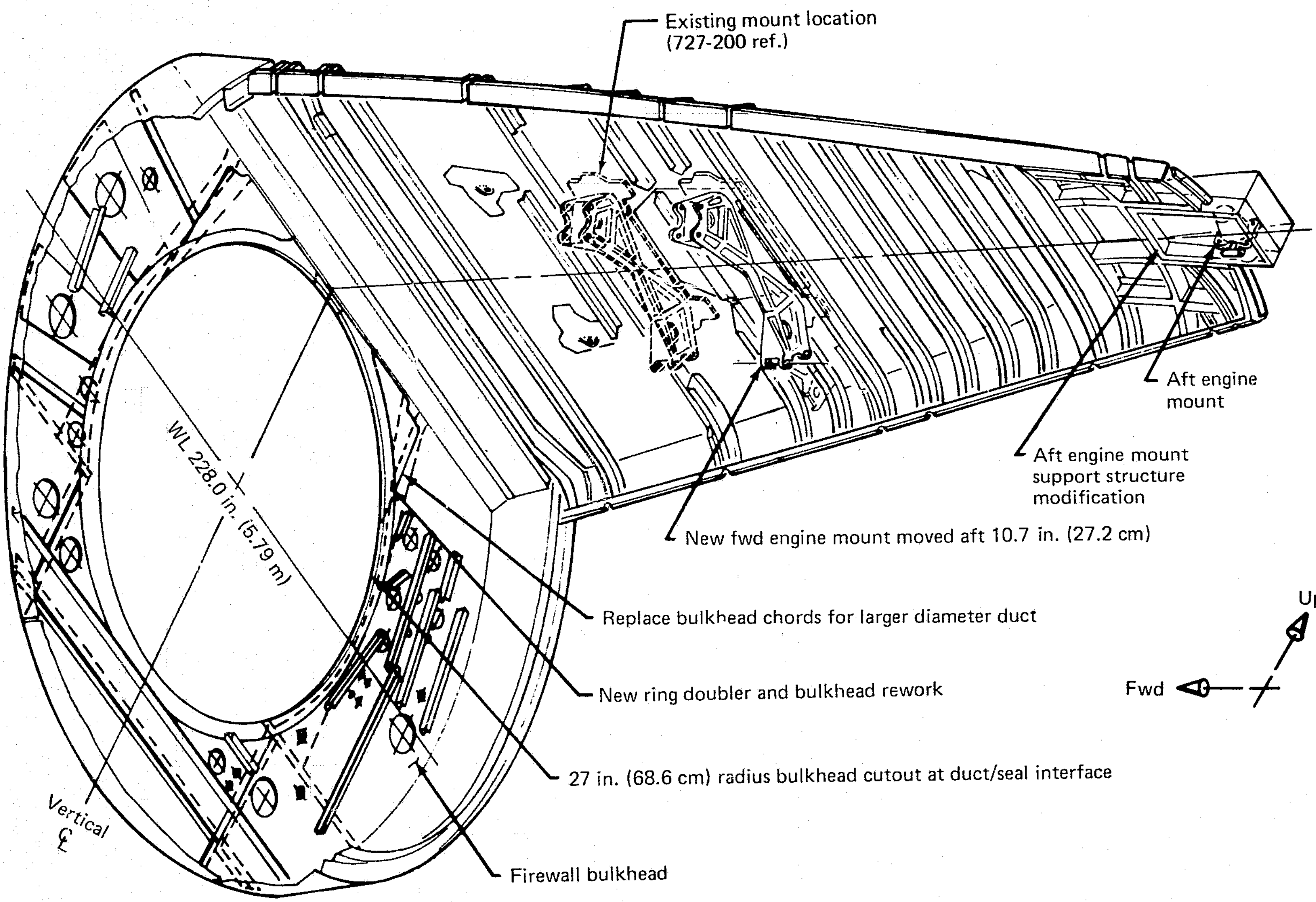


Figure 41.—727 Refan Center-Engine Mount Relocation and Vertical Firewall Rework

In side-engine installations, drainage is routed directly overboard (fig. 42). The nominal drainage is limited to 1 cc/hr/pad. On the center engine because of its location over the aft passenger entry stairway, drainage is collected in a three-compartment tank, illustrated in figure 43, which is normally evacuated by pressure syphoning in flight. Jiffy drains are provided to permit manual draining of the tank compartments when the aircraft is on the ground. Incorporation of the tank on side engines is optional to accommodate customer preferences. On both center and side engines, fluid leakage may be traced to the source group by observation of the drain exits. The burner case drain is piped directly overboard to ensure isolation of the combustion system from the accessory drainage system. There is normally *no* fuel drainage except following an unsuccessful starting attempt.

3.1.6.4 Fire Protection

Fire Zones and Barriers.—The designated fire zones include:

- Compressor and accessory sections external of the engine outer case
- Combustor
- Turbine

The zones are isolated from the rest of the airplane by a fluid- and vapor-tight firewall and fire barriers in the side cowl as shown in figures 44 and 45. The following steps are taken to minimize the fire danger:

1. The number of joints in fluid lines is kept to a minimum to eliminate leak paths.
2. All electrical equipment installed in the zone is explosion proof.
3. Fuel lines are routed as remotely as possible from the hot air ducts.
4. Drains are provided for seal leakage from the accessory drive cavities. Burner case drains are routed overboard so that fuel being drained will not reenter the nacelle.
5. All fluid lines that carry combustible fluids in the fire zone are constructed of fireproof materials.

In addition to positive steps to prevent fire, fire-detection and fire-extinguishing systems are provided.

Fire Detection.—The existing fire detection system is retained (figs. 45 and 46), although some wiring and brackets are new to be compatible with new system locations. Three systems providing warning of fire in the engine compartment are currently in use on the airplane, namely; Kidde, Lindberg, and Graviner. The systems include detectors, a control unit, warning lights, an alarm bell, detector inoperative lights, and two test switches. In addition, a Fenwall continuous-element overheat detector is installed in each side-engine strut to detect overheat conditions that could occur if a bleed air duct should rupture. Overhead caution lights and a test switch for these circuits are located on the third crewman's panel.

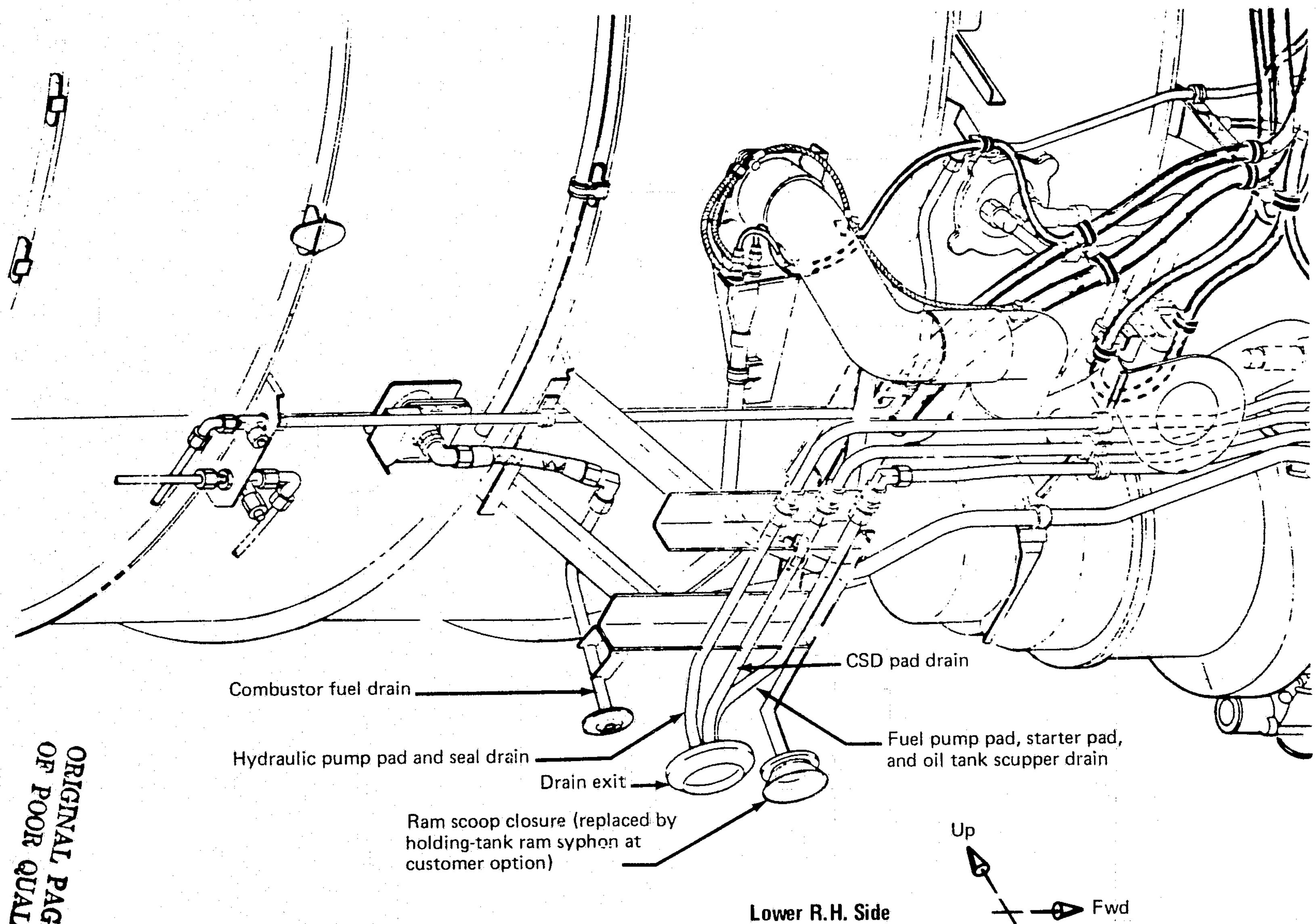


Figure 42.—JT8D Refan Side-Engine Drains

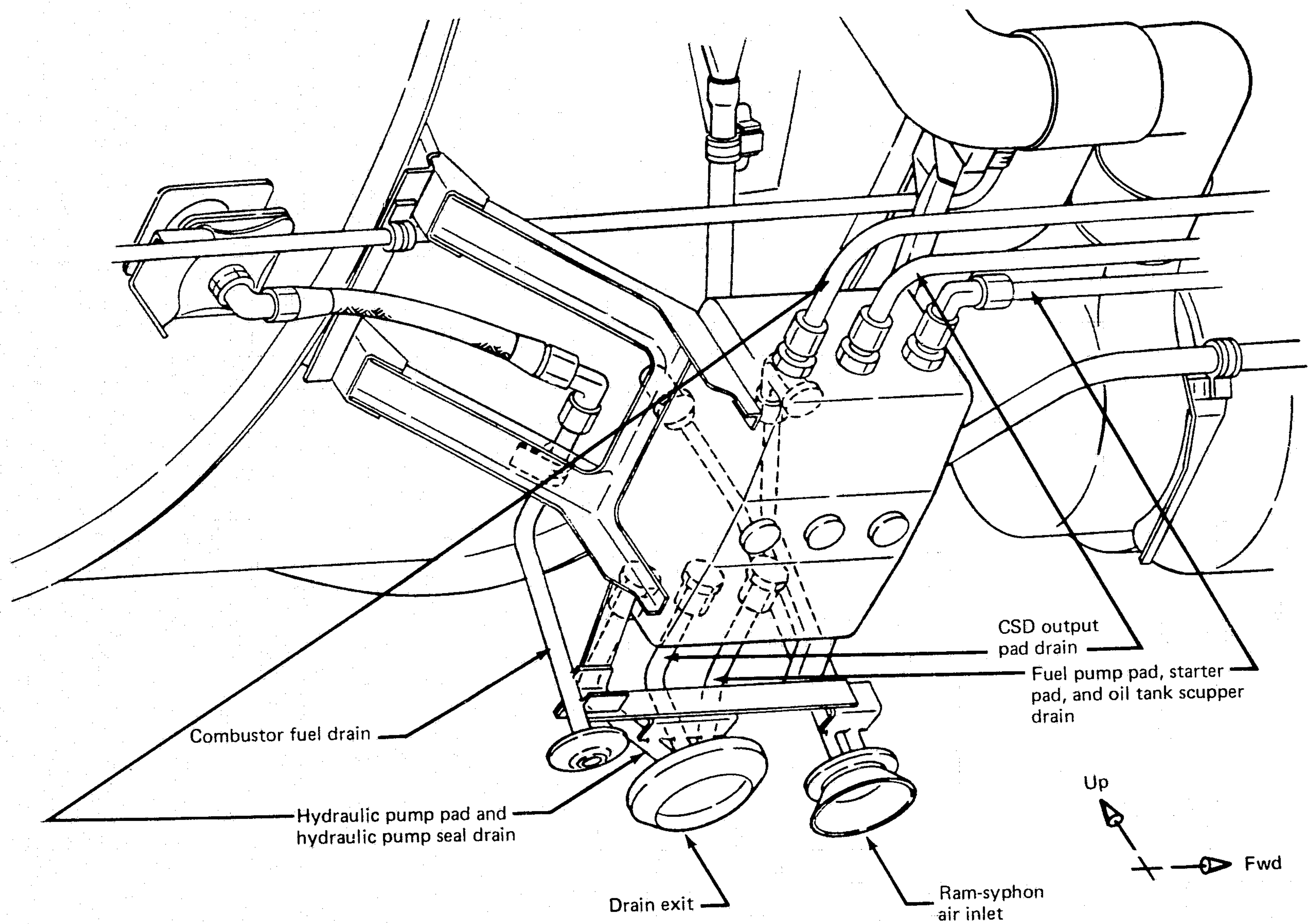


Figure 43.—JT8D Refan Center-Engine Drains

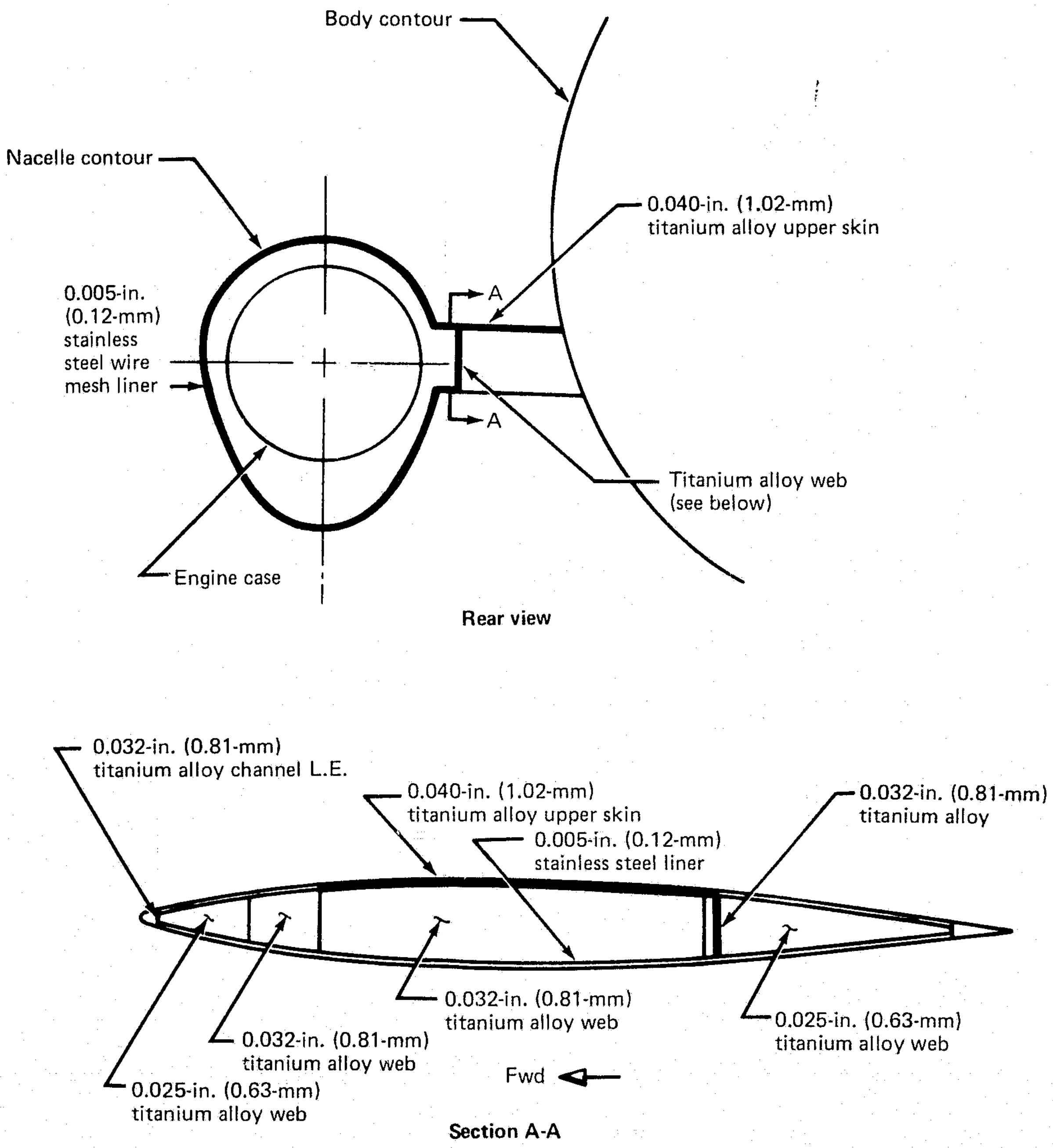


Figure 44.—727 Refan Side-Engine Firewall Location

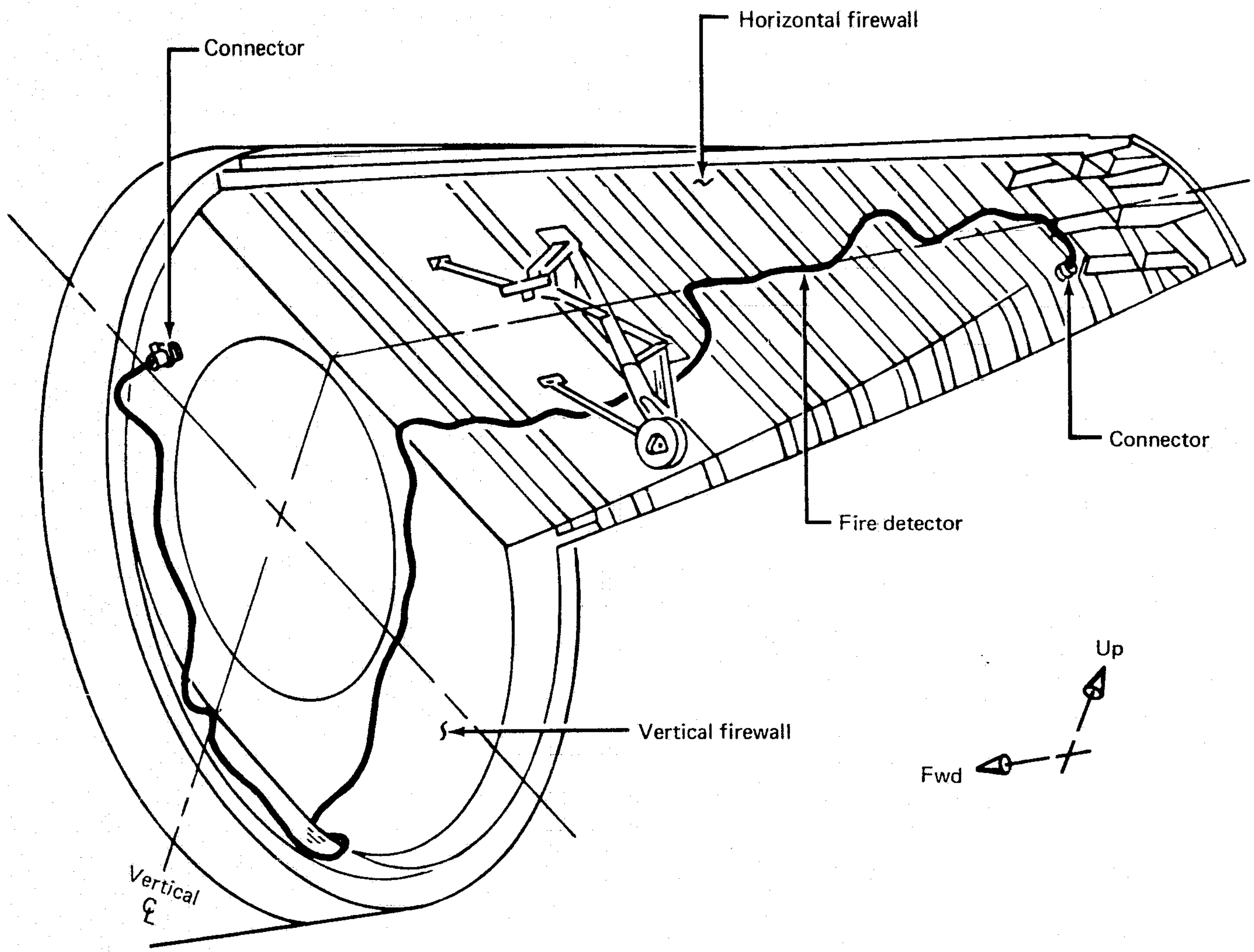


Figure 45.—727 Refan Center-Engine Firewall and Fire Detectors

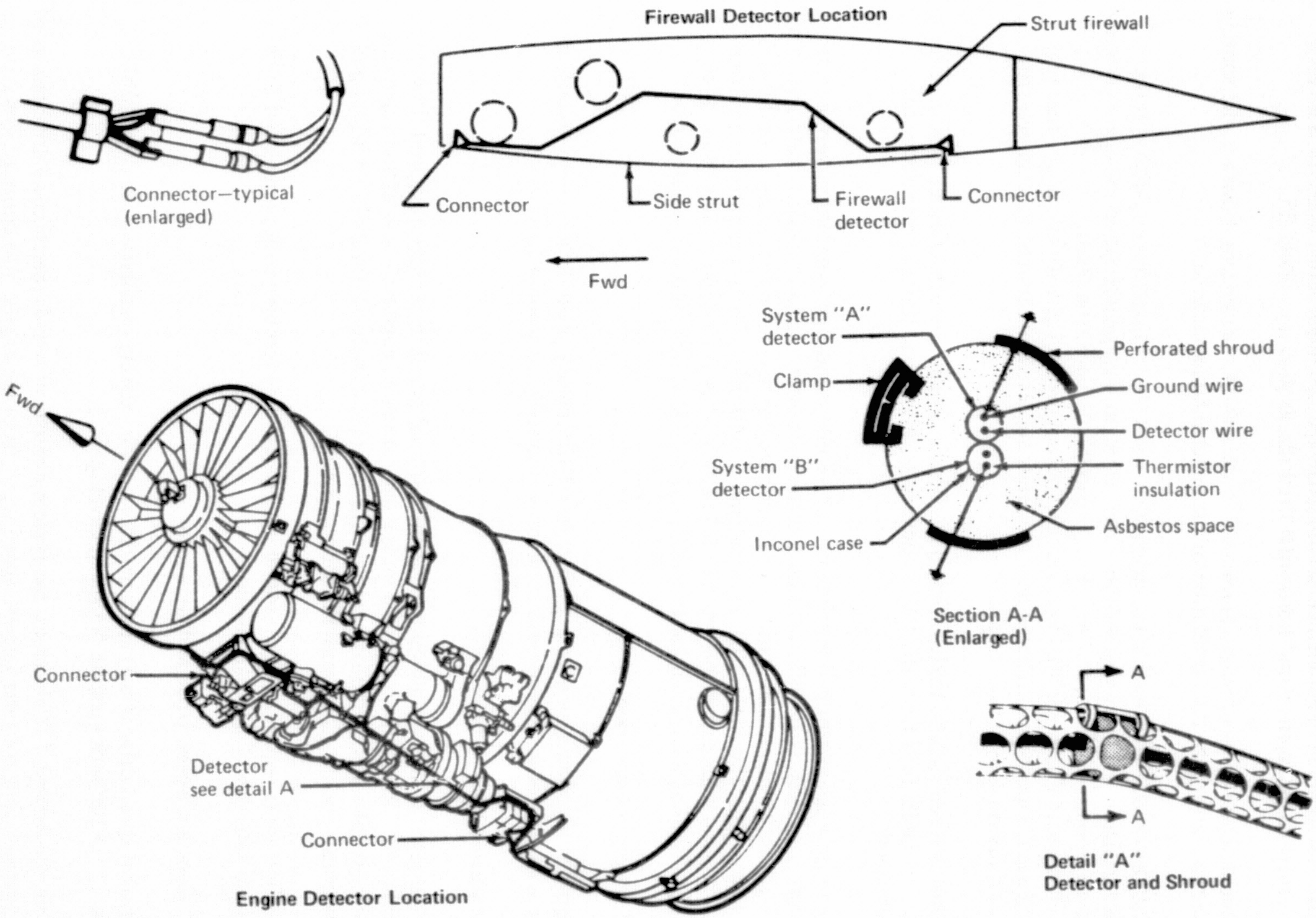


Figure 46.—JT8D Refan Side-Engine Fire-Detector System—Kidde Option

The detectors on the bottom of each engine and on the strut firewalls are supported to prevent both vibration and maintenance handling damage. An unshrouded detector is located on the center-engine vertical and horizontal firewalls, as shown in figure 45.

The same detector element length is retained in the basic Kidde system; however, the routing is revised to conform to the installation of the larger refanned engine.

Fire Extinguishing.—The existing engine compartment fire-extinguishing system is retained, as shown in figure 47. It is a gaseous smothering system, designed to flood the engine cowling space with an inert gas in case of fire. Two fire-extinguisher bottles containing trifluorobromomethane (CF_3Br) per MIL-E-22285 are located on the right aft side of the rear pressure bulkhead. The bottle discharge lines are interconnected and routed through selector valves to spray nozzles in each engine area.

The thrust reverser isolation valve control has been added to the extinguisher arming circuitry to block hydraulic flow from the "A" system or standby system to the reverser of the affected engine.

The quantity of agent required is a function of nacelle volume and amount of ventilation in the nacelle. Analysis has confirmed that the current bottle size and quantity will be satisfactory for the refan engine installation. The center-engine nacelle, which is the largest, has a cavity surrounding the engine that has a volume of 160 ft^3 (4.53 m^3) in the current installation compared with approximately 147 ft^3 (4.16 m^3) in the refan configuration. (This is a result of installing a larger engine in a body cavity that is not proportionately larger.)

3.1.6.5 Engine Lubrication

The engine lubrication system is a completely self-contained engine system with no airframe interfaces xcept for instrumentation, which is discussed in section 3.1.6.8.

3.1.6.6 Engine Fuel System

Fuel is delivered to the fuel pump inlet at the required pressure, temperature, and flow rate. From this point downstream, the system is a self-contained engine system with no airframe interfaces except for an overboard exhaust duct from the engine-furnished fuel heater and instrumentation, which is discussed in section 3.1.6.8.

No modification is required to the system, except for the plumbing routing required to be compatible with the JT8D refan engine.

3.1.6.7 Constant Speed Drive and Generator

The constant speed drive (CSD) and generator on the existing installation are compatible with the JT8D-100 series engine N_2 speed envelope.

On all but the earliest 727 airplanes, the system consists of a hydromechanical drive mounted on the gearbox, that converts variable speed input from the engine into constant speed output to drive the 40-kVA ac generator that is mounted on the constant speed drive.

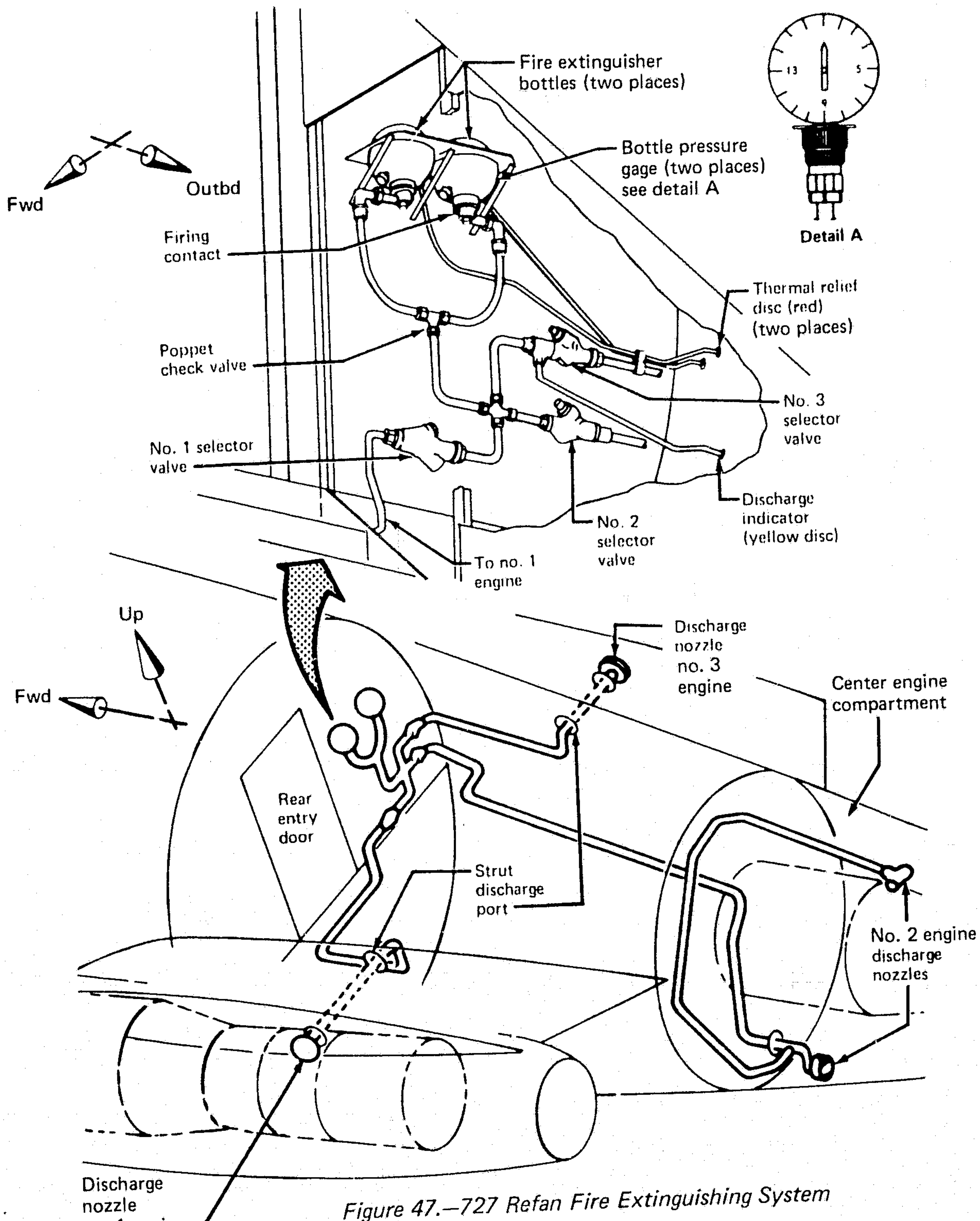


Figure 47.—727 Refan Fire Extinguishing System

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A new CSD oil cooler is installed consisting of a fin-type oil cooler mounted in the fan case. This installation is adapted from the 737 airplane and has been certified for the 727-200. New plumbing is provided as shown in figure 48. The generator (with grease-packed bearings) is air-cooled by fan air, and the cooling air is then discharged overboard as shown in figure 49.

The instrumentation required to monitor performance is retained. It consists of:

- CSD oil temperature and oil temperature rise across CSD
- CSD low oil pressure warning
- CSD disconnect

3.1.6.8 Engine Controls and Instrumentation

Engine Controls.—Two basic engine controls are required by the airframe manufacturer: start control and thrust control. The engine manufacturer installs a cross-shaft that permits the airframe-engine control interface to be made on either side of the engine. Cable systems from start and power levers in the flight deck to the firewalls are retained. The power levers control both engine power and thrust directivity.

The controls from the aft quadrant of the cable system to the input cranks on the side engine are modified to compensate for the change in location of the input cranks on the engine with respect to the airplane (fig. 50).

The center-engine control mechanism of the existing airplane (fig. 51) requires extensive modification to compensate for the shift of the engine 10.7 in. (27.18 cm) to the rear and to eliminate radial interference with the larger diameter fan case illustrated in figure 52. The flexible push-pull cable system shown in figures 53 and 54 is provided, eliminating the existing push rods and compensator rod mechanism.

Instrumentation.—The following parameters are used to control and monitor engine performance:

- Low pressure rotor speed (N_1)
- High pressure rotor speed (N_2)
- Fuel flow rate (W_f)
- Exhaust gas temperature (EGT)
- Engine pressure ratio (EPR)

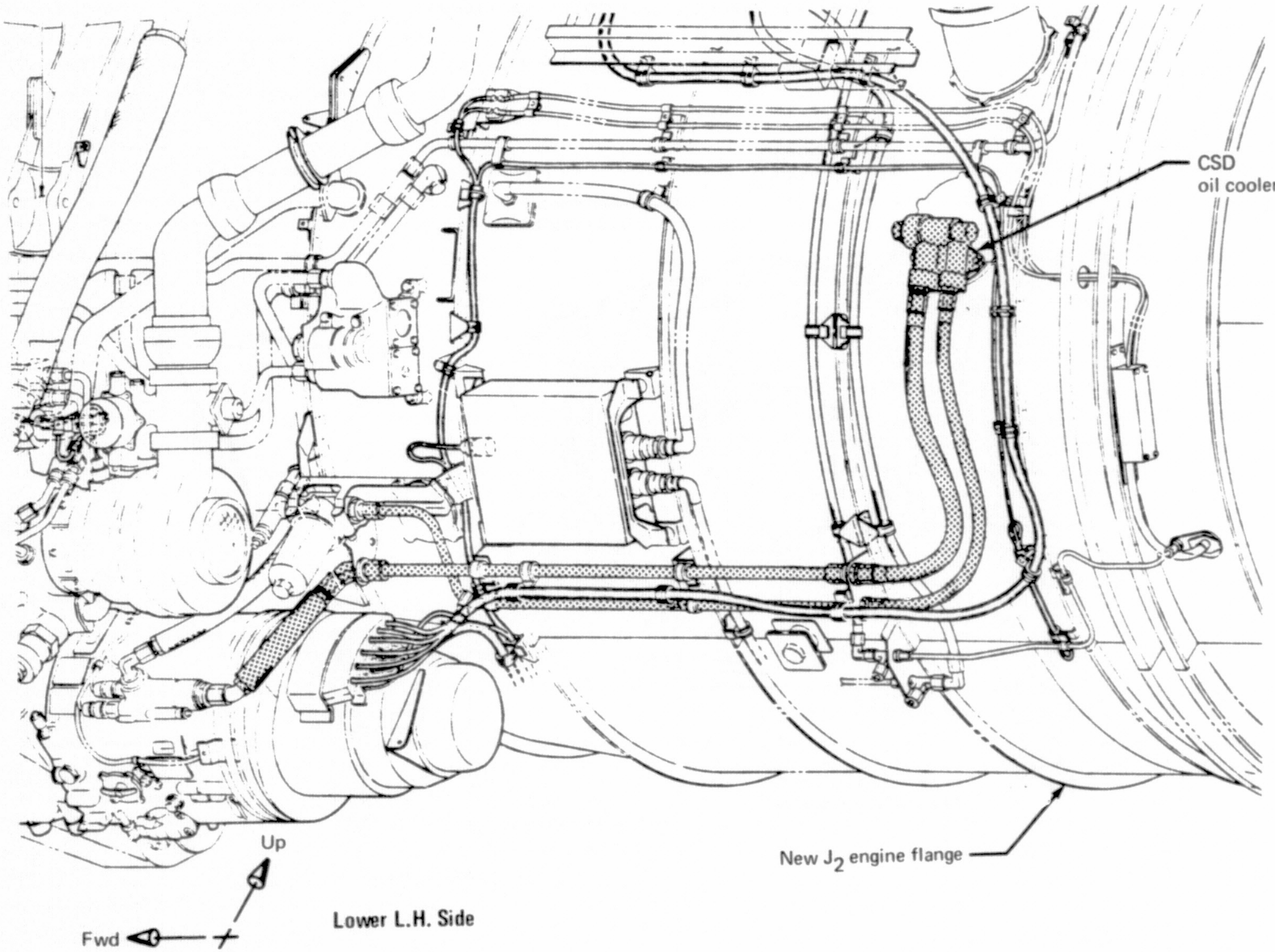

Figure 48.—JT8D Refan Powerpack Assembly—Constant Speed Drive (CSD) Oil Cooler Installation

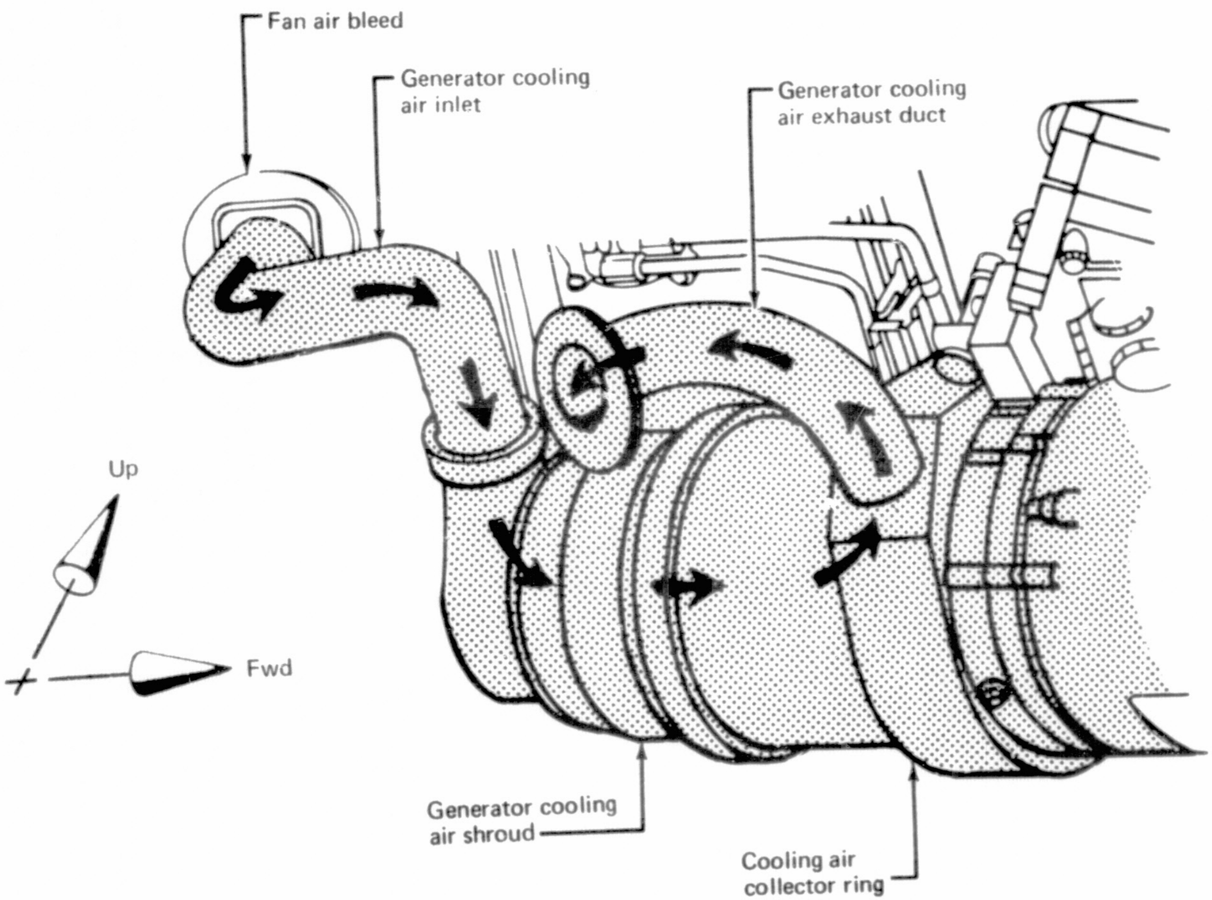

Figure 49.–JT8D Refan Generator Cooling

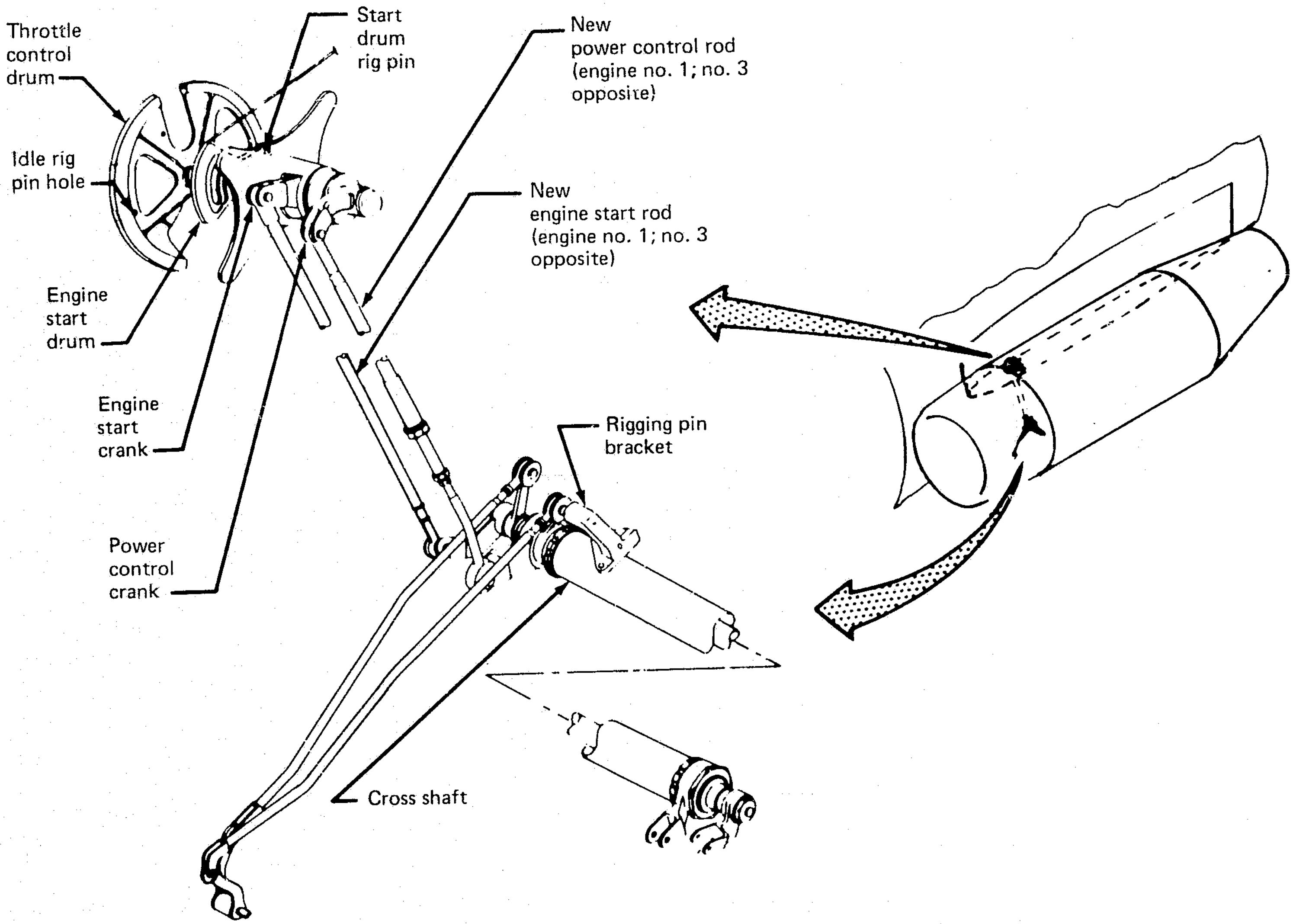

Figure 50.—727 Refan Side-Engine Control Linkage

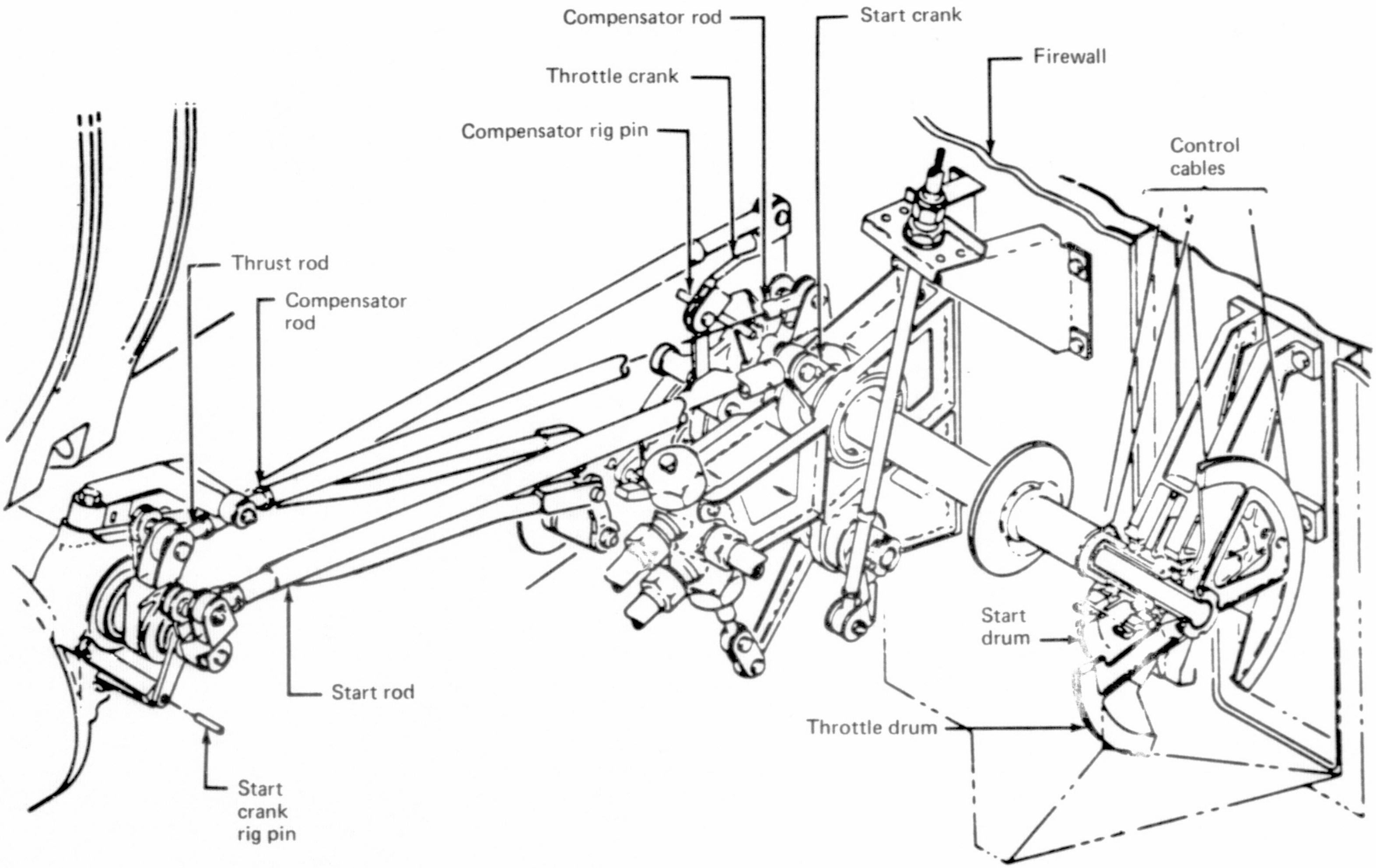

Figure 51.—727-200 Center-Engine Control Linkage

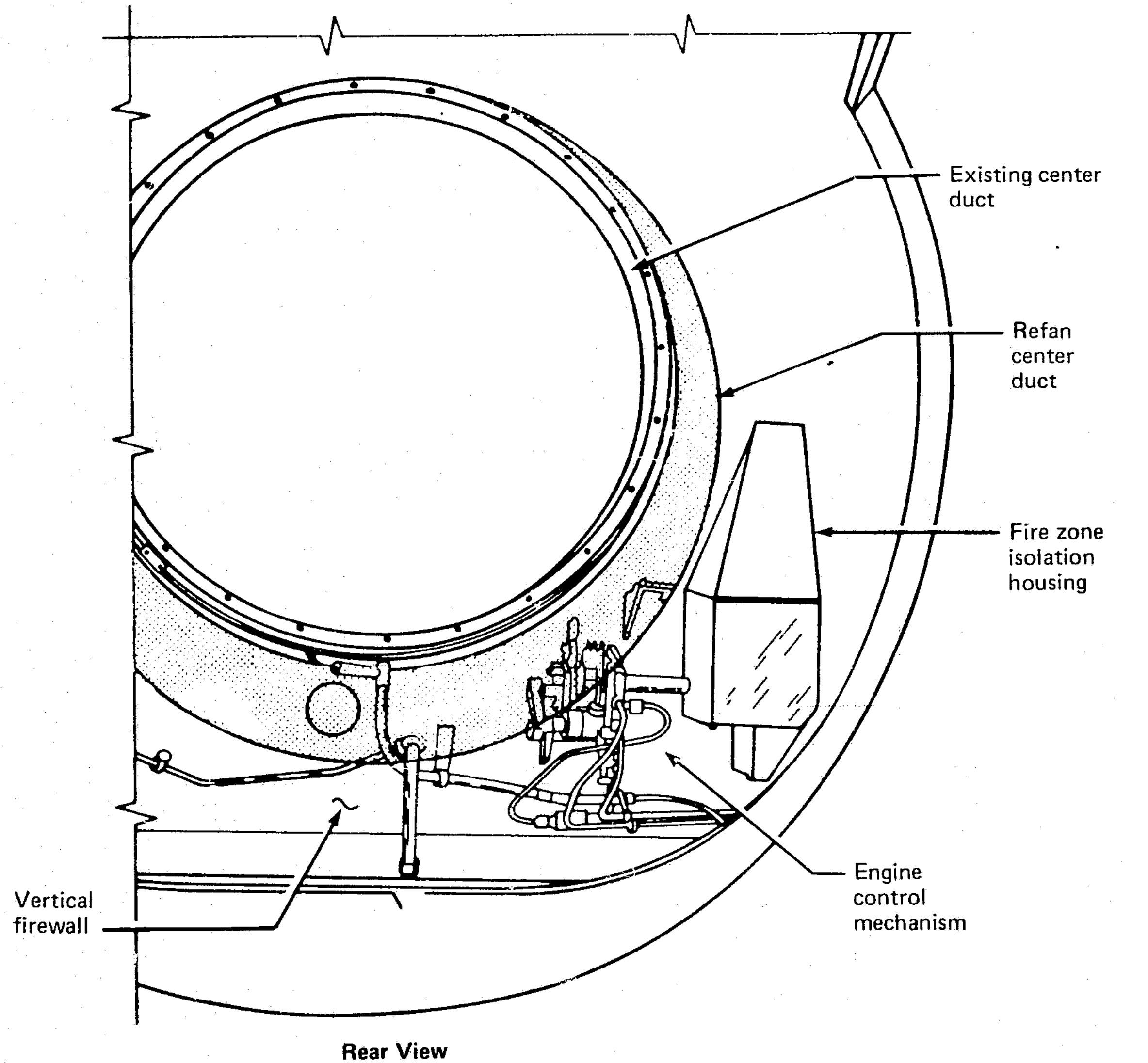

Figure 52.—727 Refan Inlet Envelope, Superimposed on 727-200 Center-Engine Control Mechanism

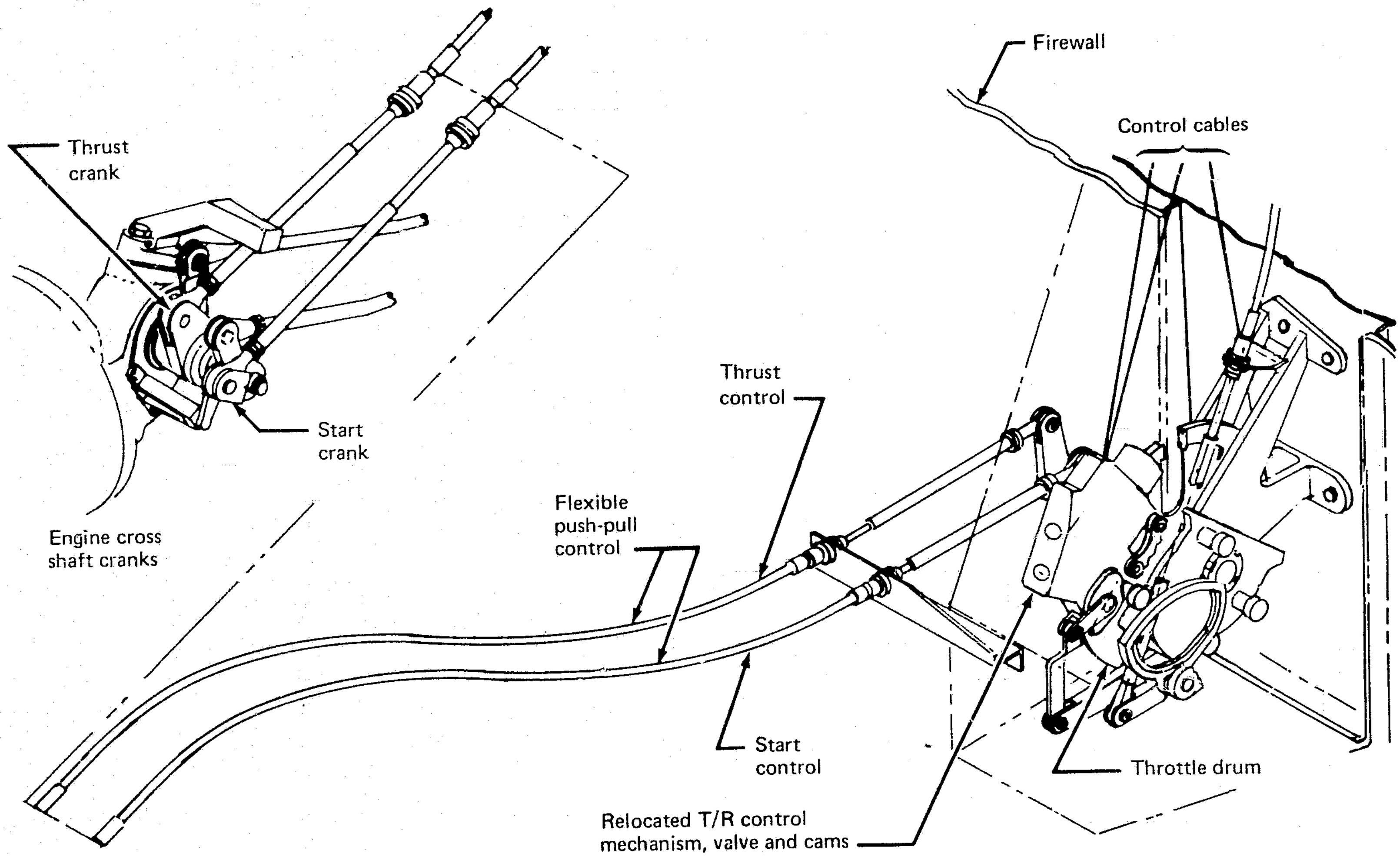

Figure 53.—727 Refan Center-Engine Control Linkage

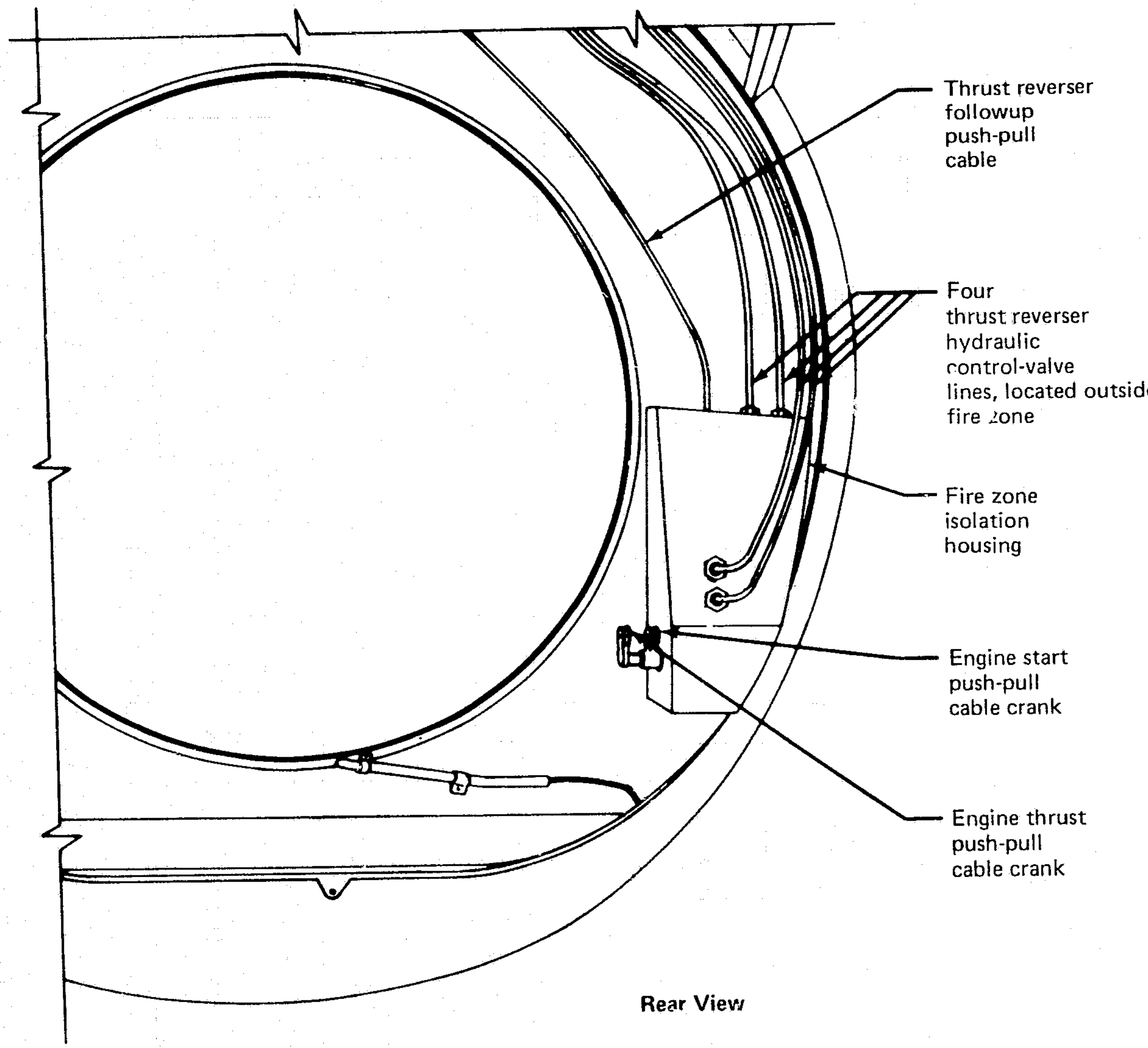

Figure 54.—727 Refan Center-Engine Control Mechanism

In addition to these essential instruments, the following instruments are provided to show satisfactory operation of engine systems and warnings of impending problems:

- Fuel filter Δ pressure (warning of fuel icing, corrected by crew selection of fuel heat)
- Oil quantity
- Oil pressure
- Low oil pressure
- High differential pressure across main oil filter (bypass)
- Oil temperature
- Engine vibration (optional)
- Thrust reverser indicator lights

The existing sensors are retained, but the existing indicators located on the cockpit instrument panels may require rework to adjust limits.

There are no requirements for new instrumentation other than thrust reverser position indication. This will be a two-light system, indicating both stowed and deployed positions of the reverser.

Instrumentation plumbing, wiring, and brackets are revised, as required, to be compatible with the larger engine (figs. 55, 56, 57, and 58).

3.1.6.9 Engine Starting

A low-pressure air turbine starter and control valve are mounted on the aft side of the accessory gearbox (fig. 59). This starter is used for all ground starts. Low-pressure air to power the starter is provided by an onboard auxiliary power unit (APU), by an external ground source, or by cross-bleed from an operating engine (fig. 60). The starter is splined to the N_2 rotor gearbox and cranks the rotor through a tower shaft.

3.1.6.10 Engine Bleed Air

The bleed air system remains schematically very similar to the existing system, as shown in figures 60 and 61. However, the powerplant ducts and installation are completely new to fit the larger diameter engine.

All high temperature air ducting in the nacelle (fig. 62) is made from Inconel 625. This material is easily workable in manufacturing and has better tensile and yield strengths than Hastalloy X, which is presently used. The existing ball joints are replaced by sealed flexible duct joints of the same type used on the 747 airplane (fig. 63). In general, existing components (valves, etc.) are retained, and most line sizes are unchanged.

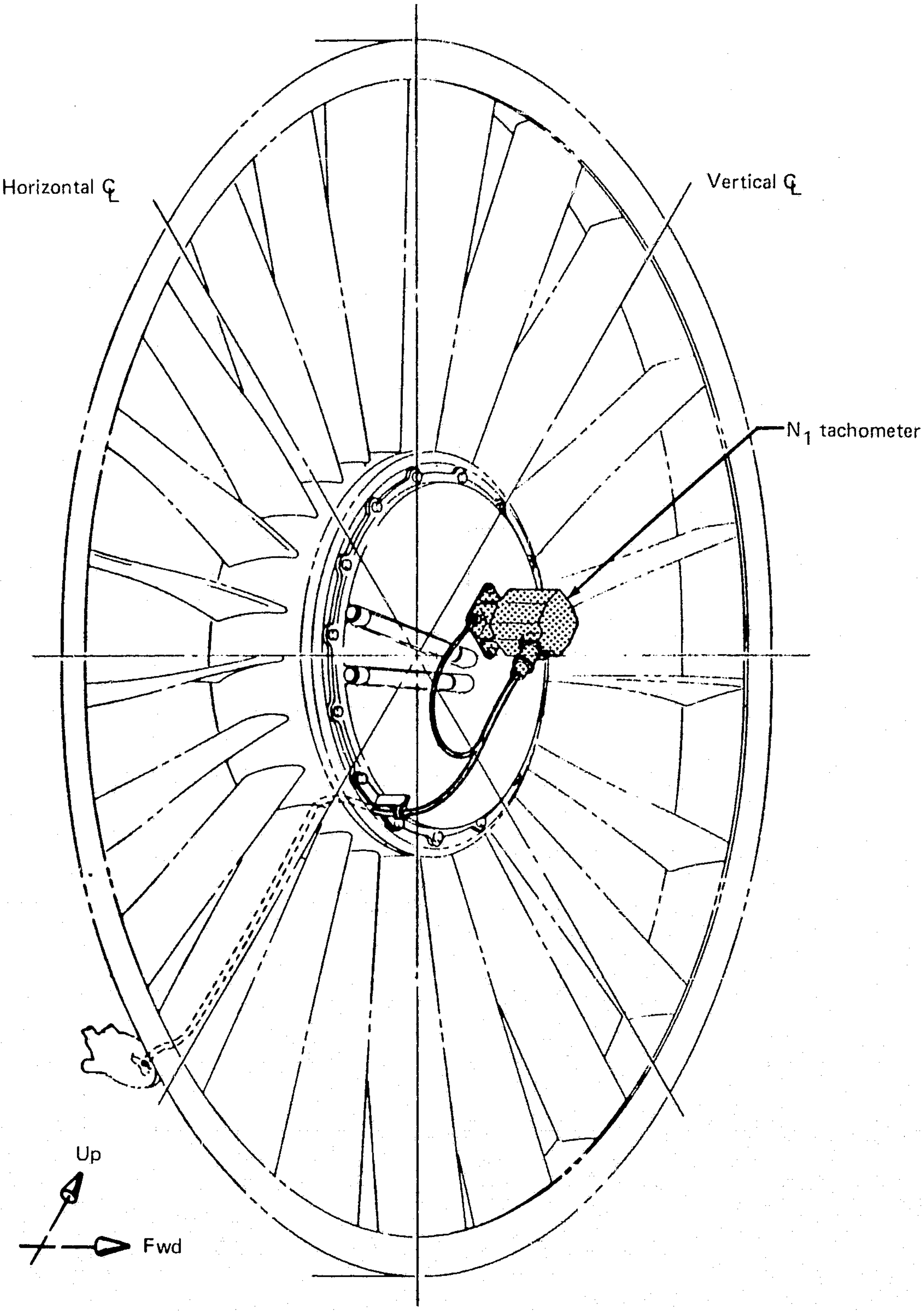

Figure 55.—JT8D Refan Engine N_1 Tachometer Transducer Installation

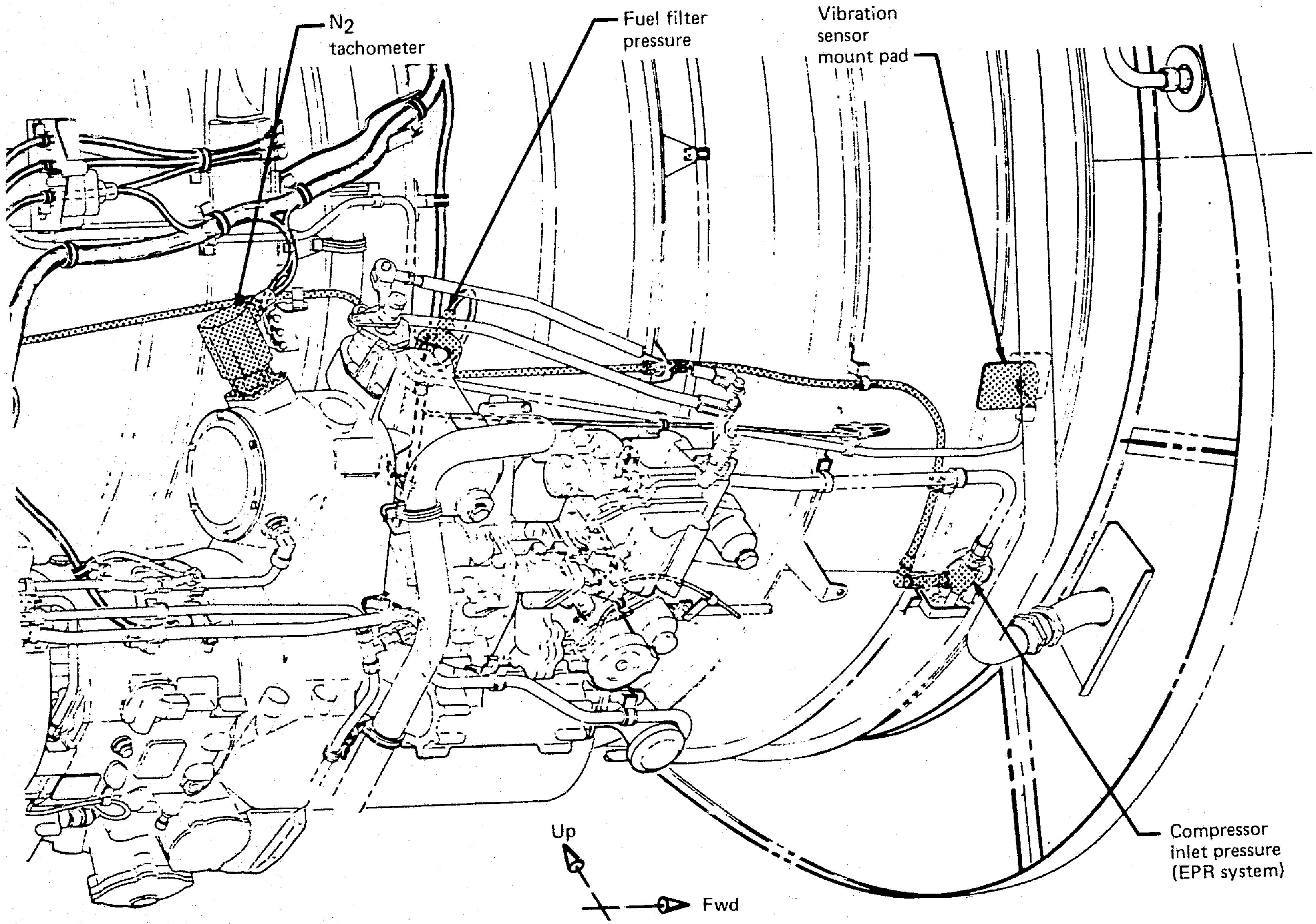

Figure 56.—JT8D Refan Engine Instrumentation Installations—Lower Right-Hand Side

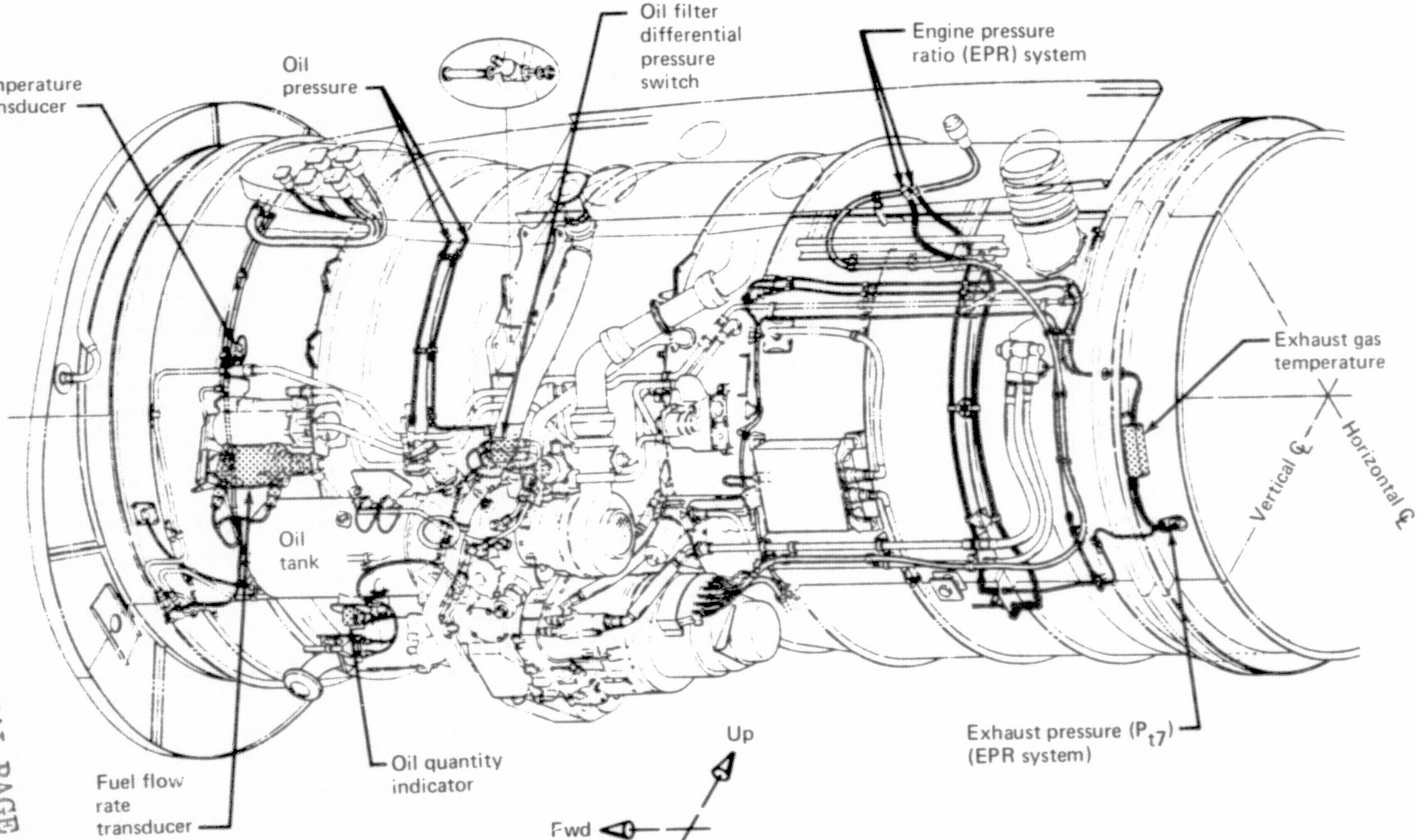

Figure 57.—JT8D Refan Engine Instrumentation Installations—Lower Left-Hand Side

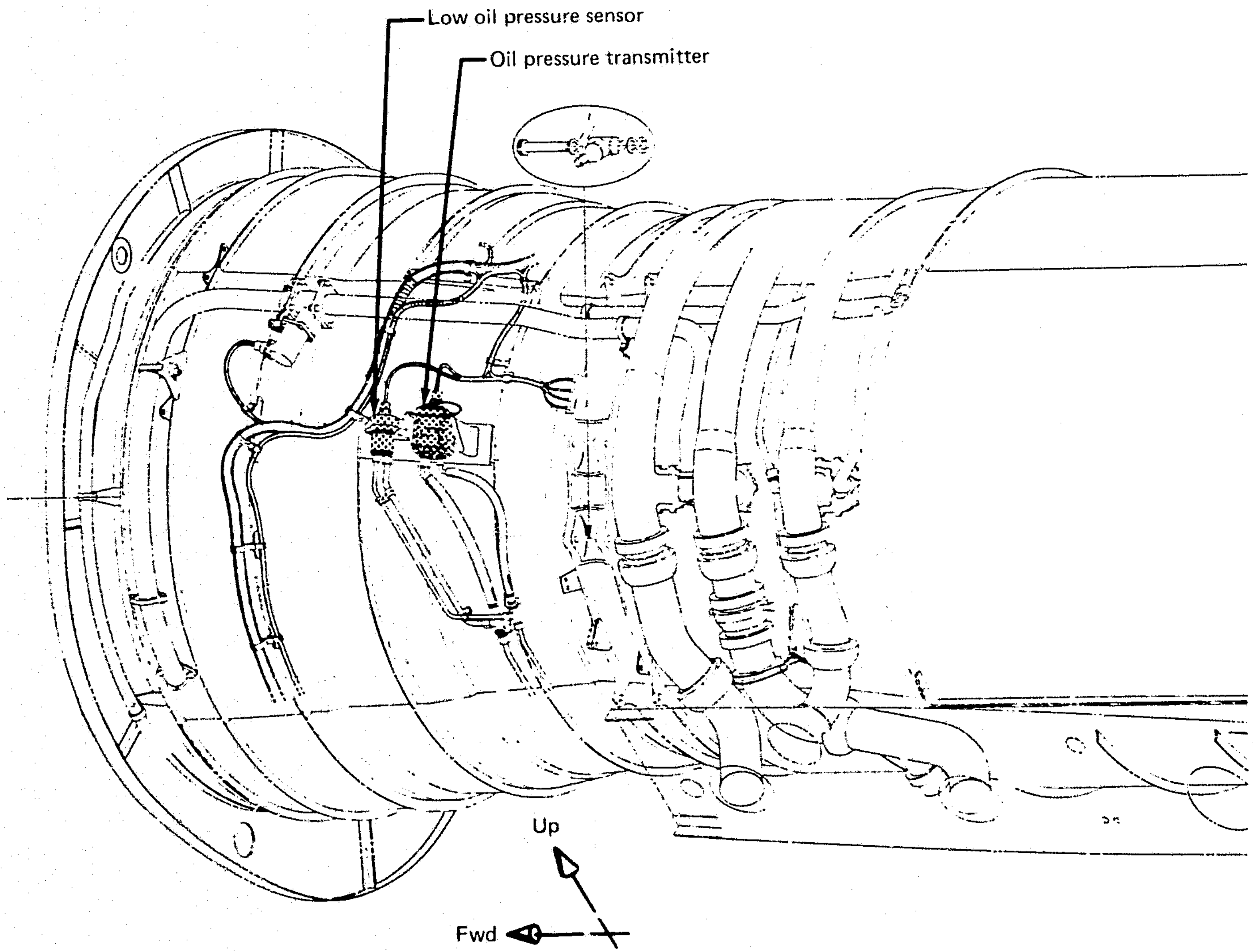

Figure 58.—JT8D Refan Engine Instrumentation Installations—Upper Left-Hand Side

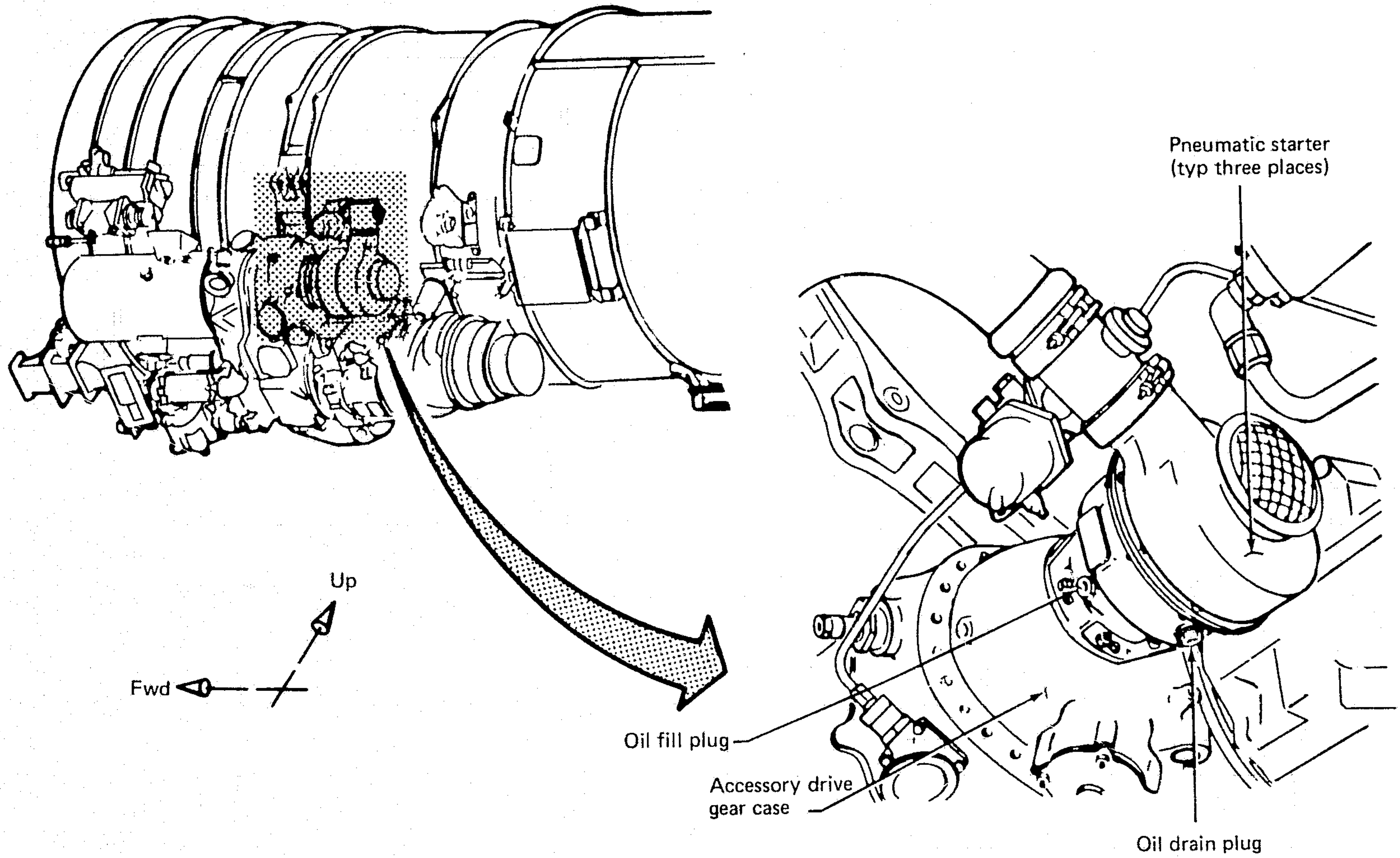

Figure 59.—JT8D Refan Engine Starter

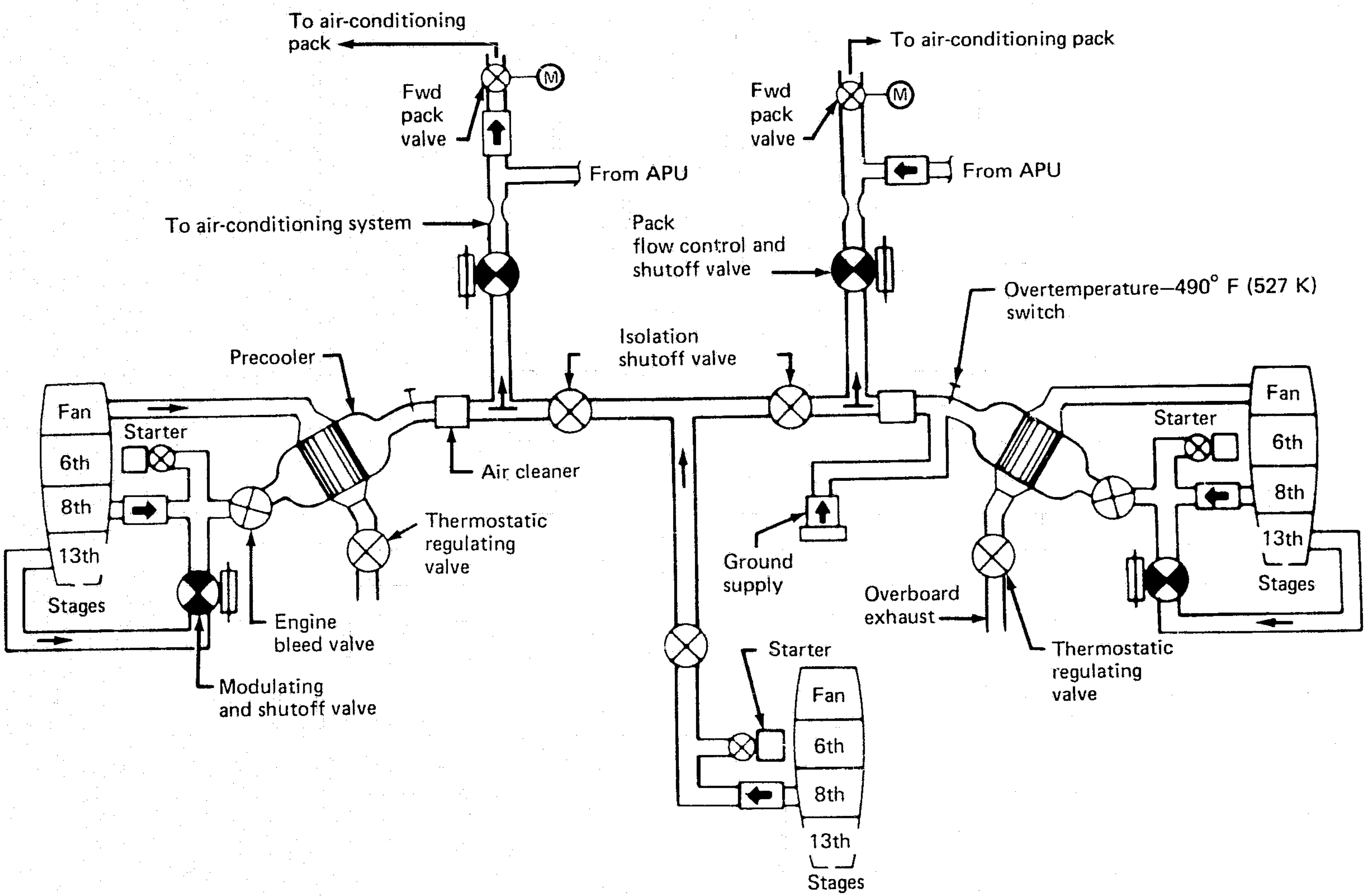

Figure 60.—727 Refan Airplane Pneumatic System Schematic

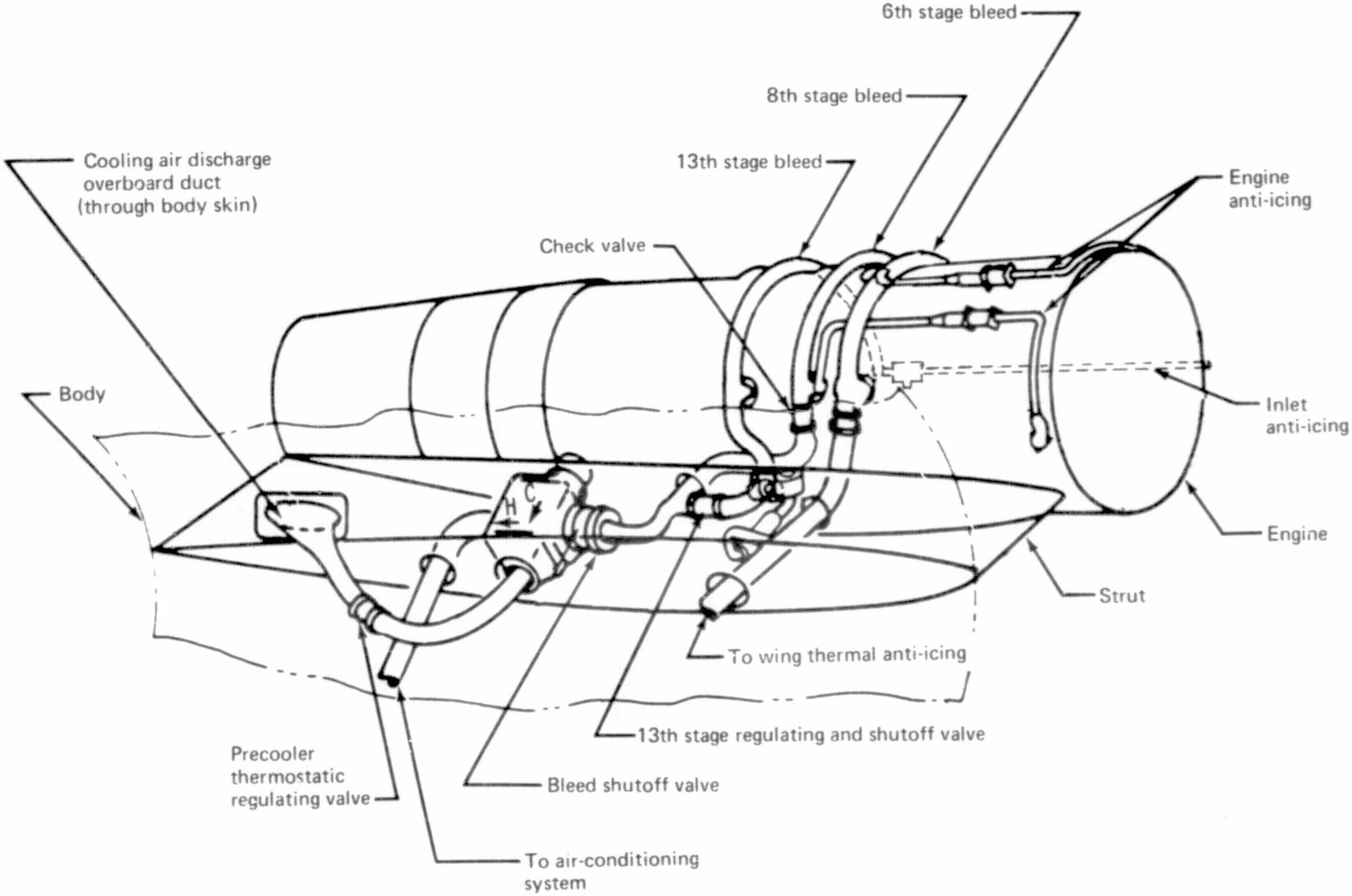

Figure 61.—JT8D Refan Engine-Bleed Air System, Air-conditioning, and Thermal Anti-Icing

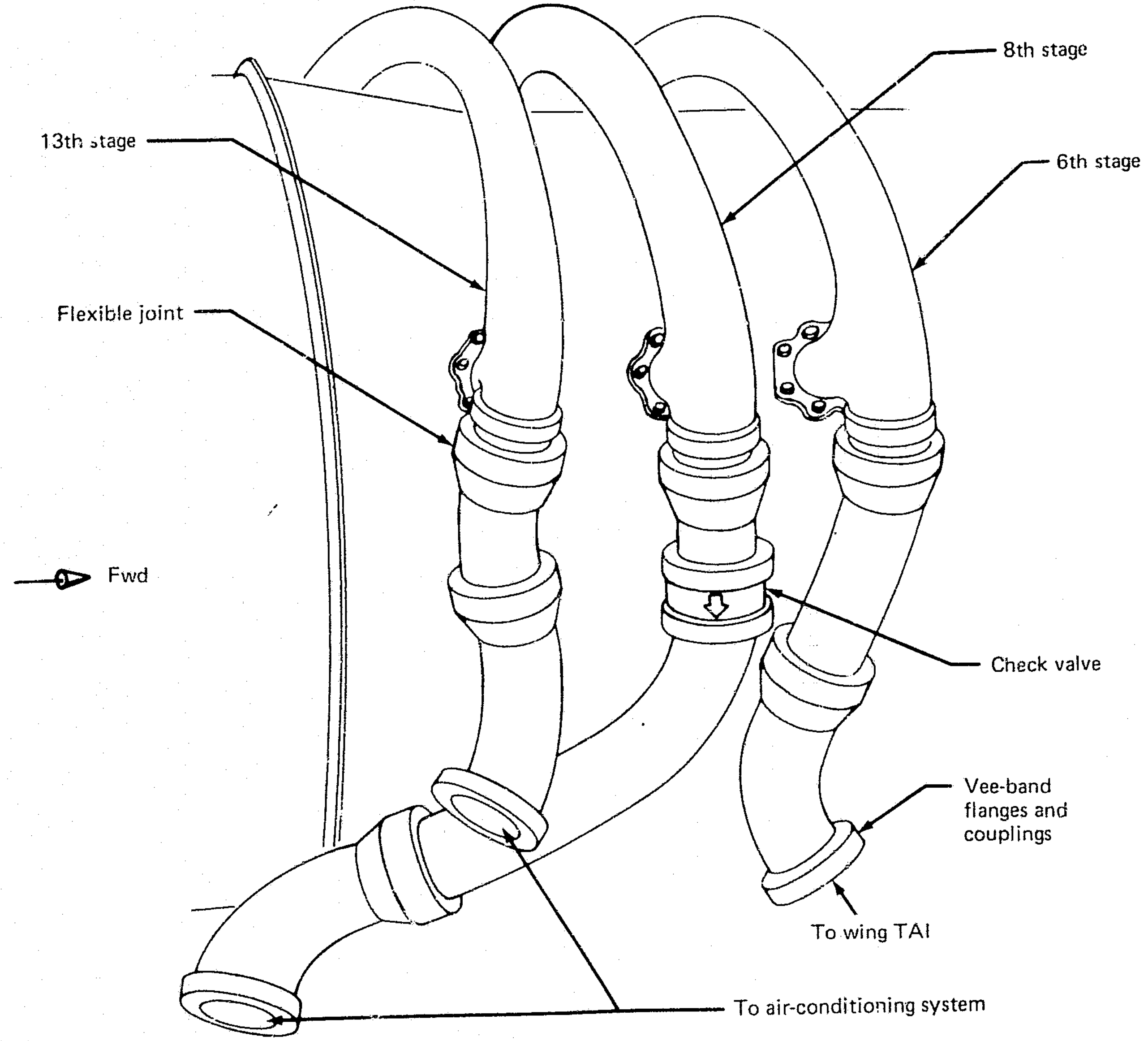

Figure 62.—JT8D Refan Thermal Anti-Icing and Air-Conditioning Duct Installation

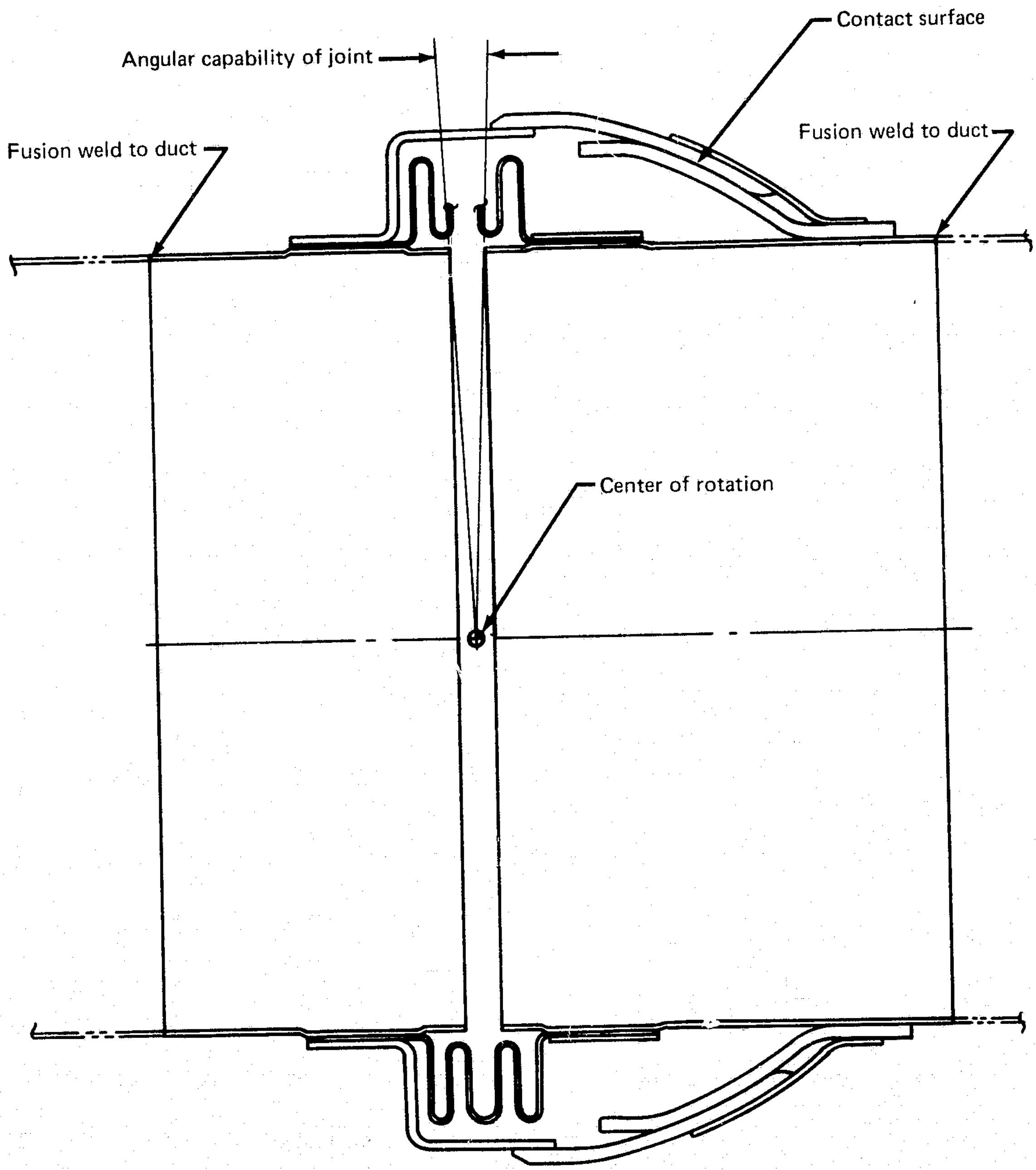

Figure 63.—JT8D Refan Flexible Duct Joint

C. 2

Side-engine compressor bleed is the air source for cabin pressurization, air-conditioning, and wing and inlet anti-icing. Air-conditioning packs are located inside a fairing under the fuselage just forward of the wing carry-through structure. Bleed air from the 8th-stage of the compressor is used during takeoff and most climb and cruise conditions. During some low thrust conditions of descent, holding, climb, cruise, and taxi, the 8th-stage bleed air is supplemented or replaced by 13th-stage bleed air. A bleed air control system automatically selects and controls the bleed air from the engine 8th- and 13th-stage bleed ports.

The 8th-stage air is bled from two ports, connected by a manifold. From this manifold bleed air is ducted to a bleed shutoff valve, a precooler in the strut, and then into the fuselage as shown in figure 61. A manifold also connects two 13th-stage bleed ports. This air is ducted to a regulating and shutoff valve and then into the 8th-stage bleed duct upstream of the precooler. A check valve in the 8th-stage duct, shown in figure 62, prevents reverse flow into the engine.

The high temperature 8th- and 13th-stage bleed air is passed through the precooler in order to limit duct temperatures in the fuselage to 450°F (505 K). Cooling air is bled from a port in the fan case through the precooler, then through a modulating thermostatic control valve, and overboard through an opening in the body above the strut.

The center engine provides 8th-stage bleed capability, which is not normally used; and in the event of a side-engine failure or bleed system failure, it may be bled with suitable temperature monitoring by the flightcrew.

3.1.6.11 Thermal Anti-Icing (TAI)

Airplane thermal anti-icing using engine bleed air is provided for the wing leading edge, side-engine nose cowl, VHF antenna, and the center-engine inlet duct, as indicated in figure 64.

Wing Anti-Icing.—Hot air for wing TAI is supplied by the side engines using 6th-stage bleed, which is aspirated by 13th-stage bleed air in an ejector.

A manifold connects the two 6th-stage bleed ports (fig. 62). The air then passes through a check valve that precludes reverse flow into the engine. The duct is routed into the strut where the ejector and ejector shutoff valve are located. Existing ducting from the ejector and ejector shutoff valve downstream is retained. The ducting in the nacelle to the ejector is new.

Engine Nose Cowl Anti-Icing.

Side Engines: Each side-engine nose cowl is anti-iced by 13th-stage bleed air, controlled by a thermostatic flow regulator, and tempered for the inlet lip with ambient air in an ejector (fig. 8). The mixed air from the ejector is ducted to a circumferential distribution tube at the cowl leading edge. This system is similar to that presently used.

Center Engine: The center-engine nose cowl is anti-iced by 13th-stage bleed air, controlled by a thermostatic flow regulator, and mixed with 6th-stage bleed air in an ejector (fig. 64). This air is then directed to the cowl inlet lip where it flows through a circumferential distribution tube similar to the side-engine nose cowl systems.

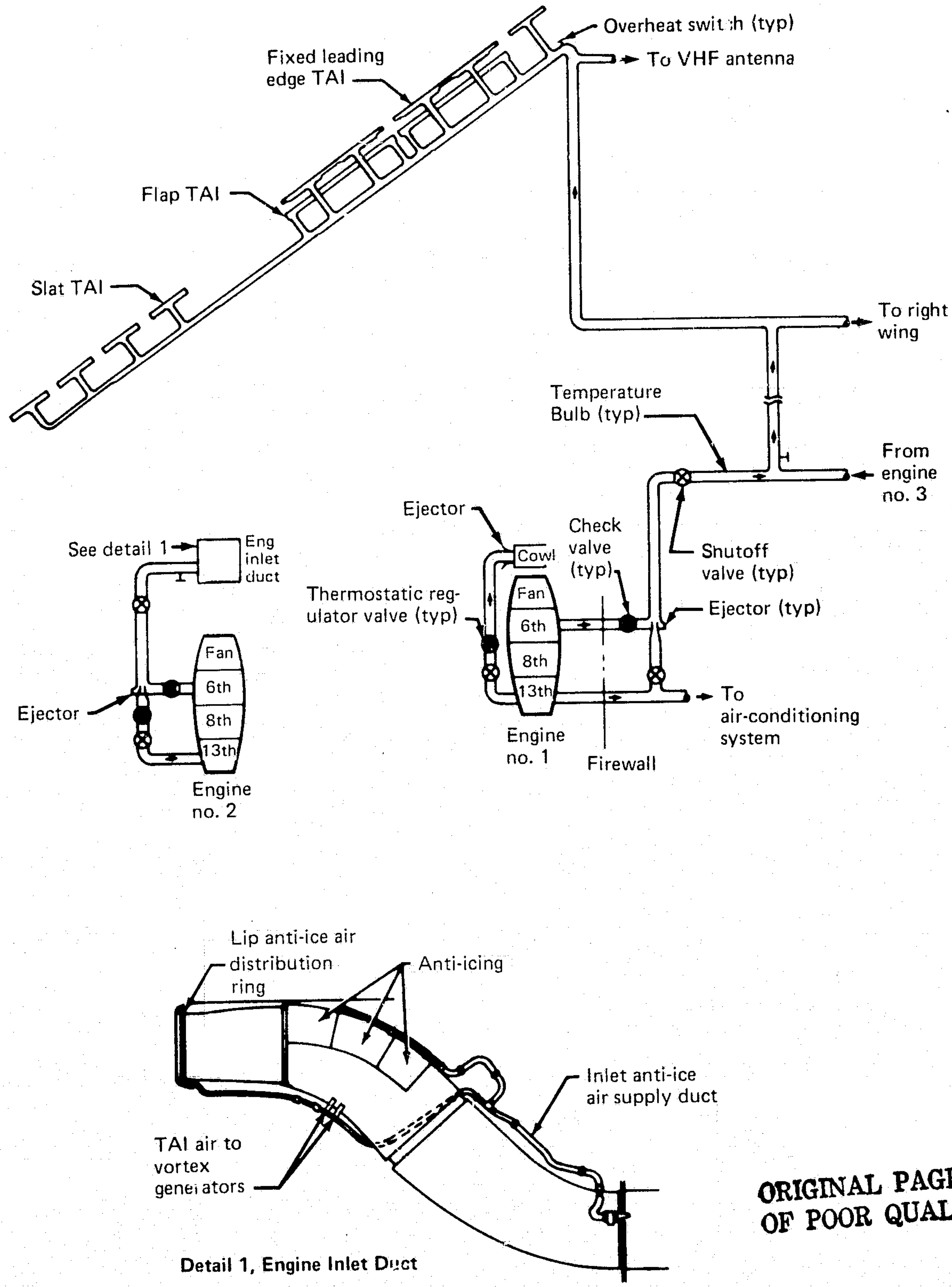

Figure 64.—727 Refan Thermal Anti-Icing System

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The upper half of the first bend of the center duct is protected by three anti-icing "patches" also shown in figure 64. Hot air is supplied to each patch from the duct that supplies the anti-icing air for the cowl inlet lip; i.e., it is a mixture of 6th- and 13th-stage bleed. The system is similar to that presently used.

A system of vortex generators installed in the lower half of the first bend of the center duct is anti-iced by hot air supplied from the same source used for the inlet lip and anti-ice patches. The anti-icing air from the vortex generators is exhausted into the inlet and into the engine.

Inlet Nose Dome Anti-Icing.—Anti-icing air for the nose dome and P_{t2} probe enters the nose dome from holes in the engine front case, flows around the P_{t2} probe to the nose dome cap, and exits from the cap into the engine inlet (fig. 8).

3.1.6.12 Miscellaneous Bleed

Small quantities of bleed air are required for the following:

- Fan bleed for ac generator cooling (fig. 65)
- 13th-stage pressure for hydraulic reservoir pressurization
- 13th-stage bleed for fuel heater (fig. 65)

3.1.6.13 Commonality

Every effort was made to maximize commonality between the baseline 727 installation and the refan installation, as well as mutual commonality between engines 1, 2, and 3. The bleed manifolds are symmetrical with end connections to permit the use of the same manifold at all locations.

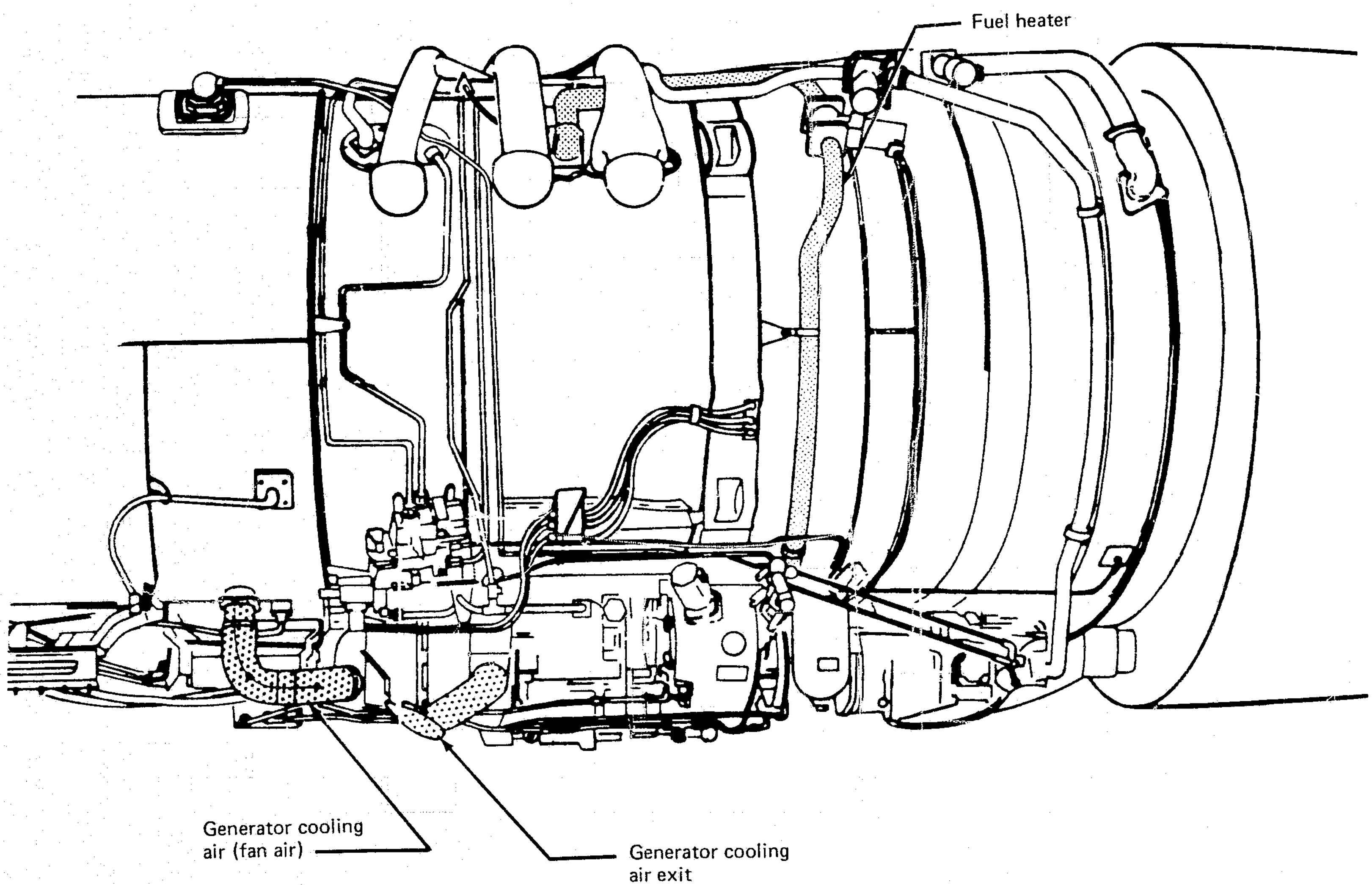
Table 6 illustrates the "parental" commonality; i.e., the equipment that is retained from the baseline engine installation. Table 7 illustrates commonality of bleed ducting among engines on the 727-200 refan.

3.1.7 AIRFRAME MODIFICATION DESCRIPTION

3.1.7.1 Airframe Structure

The major portion of the required structural changes affects the aft body section in the area of attachment of the new engines. There are no anticipated major changes to the forward body or to the wing structure.

Minor reinforcement of body structure may be required to support ballast. The ballast is used to balance the airplane by compensating for the additional weight of the refan engine installation.



No. 3 Engine—Right Side

Figure 65.—JT8D Refan Powerpack Assembly—Generator and Fuel Heater Bleed

Table 6.—Commonality, Major Installation Hardware Components, 727-100/200 Versus 727 Refan

Engine position	No. 1	No. 2	No. 3
Starter (existing)	X	X	X
Hydraulic pump (existing)	X	X	
Constant speed drive (existing)	X	X	X
Generator (existing)	X	X	X
Tach generators			
N_1 (existing)	X	X	X
N_2 (existing)	X	X	X
Precooler (existing)	X		X

Table 7.—Engine Bleed Duct Commonality, 727 Refan

	Estimated percent commonality by engine position	
Engine position bleed duct commonality	No. 1, 3	No. 2
Side engine positions	75	
Center engine to side engine	15	15

Fuselage.—The body bulkhead at station 1342.4 in. (34.095 m) (fin rear spar attachment) is reworked to permit passage of the larger inlet duct for the center engine. This rework involves considerable alteration to the bulkhead and firewall. The diameter of the hole in the bulkhead is increased to 54 in. (137.2 cm), and the centerline of the hole is lowered 4.5 in. (11.4 cm). New framing is required around the enlarged hole. The inboard portion of the control bracket is moved outboard to become completely enclosed within the reworked firewall cover box. The holes for the passage of the electrical wiring bundles, hydraulic lines, fire extinguisher, electrical power, and P_{t2} and P_{t7} lines are relocated as shown by comparing figures 66 and 67.

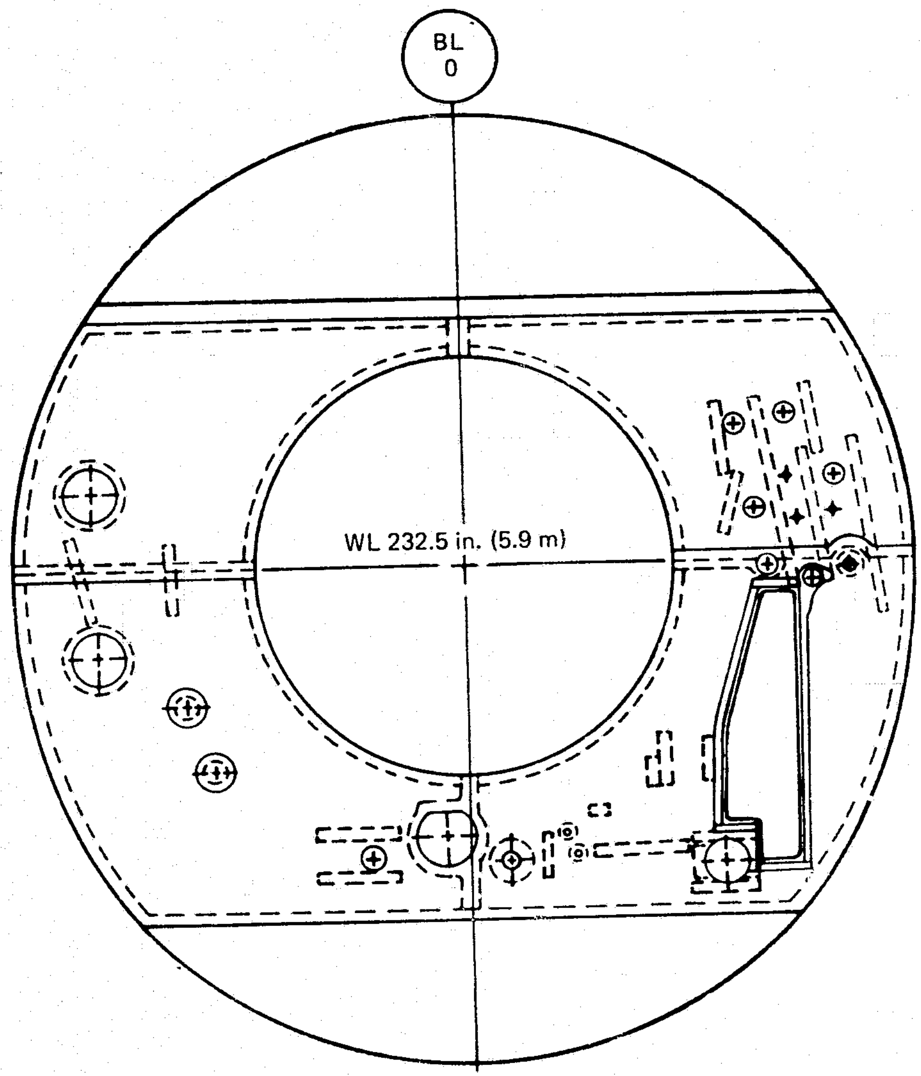
A recess is required at the intersection of the body crown with the pressure bulkhead, body station 1183 in. (30.048 m), to clear the larger center duct. The bulkhead was lowered 8 in. (20.3 cm) at the top centerline, and a contoured skin panel, approximately 14 in. (35.5 cm) by 30 in. (76.2 cm), is added to close off the opening in the upper body skin (fig. 68). Reinforcing is added to the pressure bulkhead to restore the original strength.

The body frame at station 1303 in. (33.096 m) is also reworked to accommodate the enlarged center duct. The upper part of the duct penetrates the existing frame structure by 2 in. (5.08 cm). The web and extruded angle are cut back to provide the necessary clearance. A new structural angle is added to the edge of the cutout to achieve the required frame strength.

Vertical Tail and Aft Body.—The center engine is moved 4.5-in. (11.4-cm) down. The horizontal firewall is retained, the engine supports are moved 10.7-in. (27.2-cm) aft to accommodate the new engine mount locations as shown in figures 68 and 69 and described in the following listing:

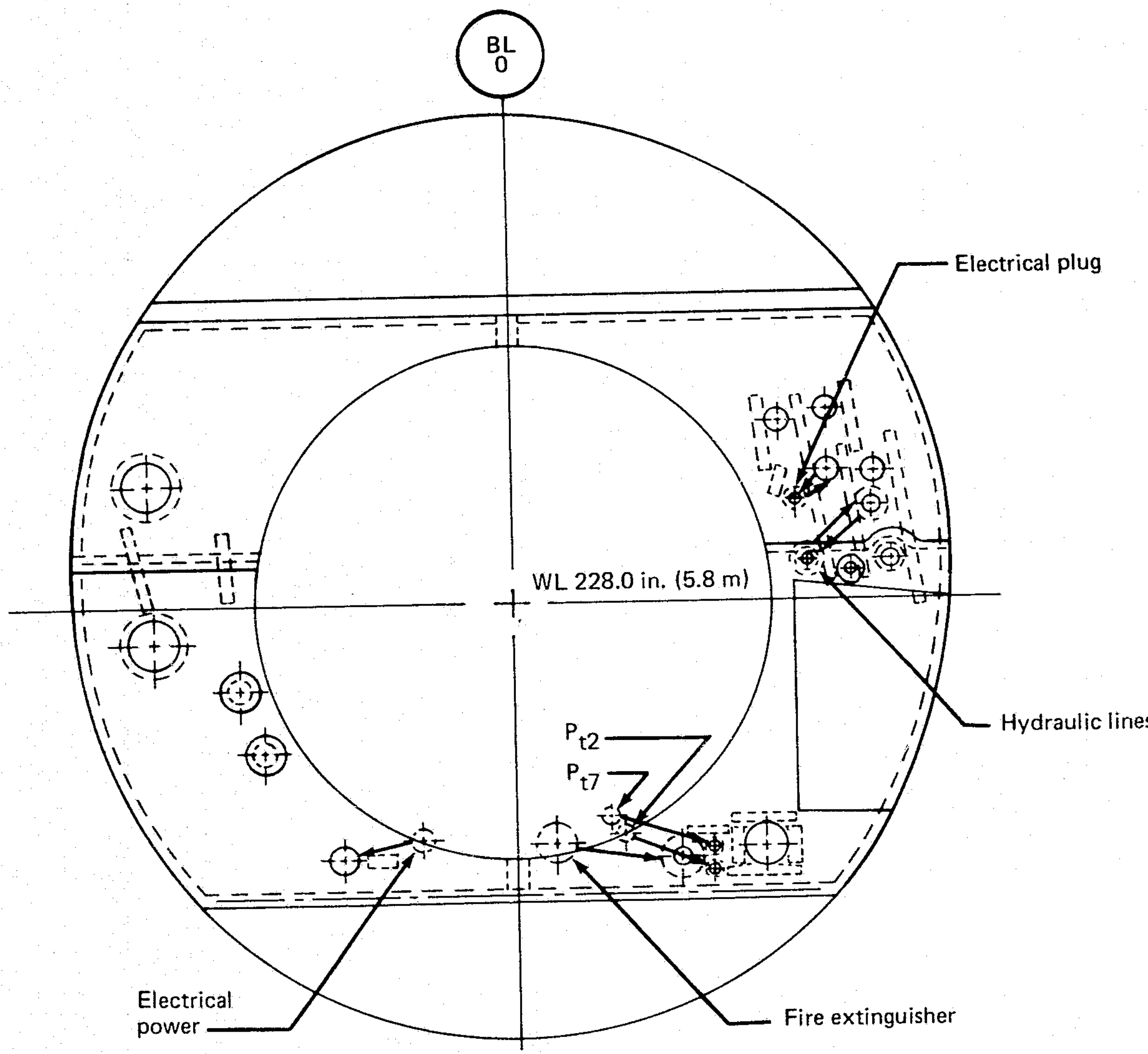
- The two forward engine mount fittings are removed, along with the associated support structure in the vertical tail.
- The forward thrust link attachment fittings on the firewall are replaced at station 1376.66 in. (34.967 m).
- A new steel front engine-mount fitting is installed for attachment of the front engine mount in its new location at station 1392.20 in. (35.362 m). New internal structure is added to distribute the load from the new engine mount fittings into the primary structure of the vertical tail.
- The existing aft engine-mount support fitting is replaced by a cantilevered fitting that moves the engine mount 10.7-in. (27.2-cm) aft.

The aft body structure will be exposed to the same loads as the existing airplane with a slight increase to account for increased nacelle weights and new center-of-gravity location. The baseline body loads account for a one-factor composite nacelle weight of 14 442 lb (6551 kg) acting at body station 1268 in. (32.207 m). The body loads of the refan installation account for a composite engine weight of 16 542 lb (7504 kg) acting at body station 1264 in. (32.18 m).



Rear View

Figure 66.—727-200 Center-Engine Firewall Bulkhead



Rear View

Figure 67.—727 Refan Center-Engine Firewall Bulkhead

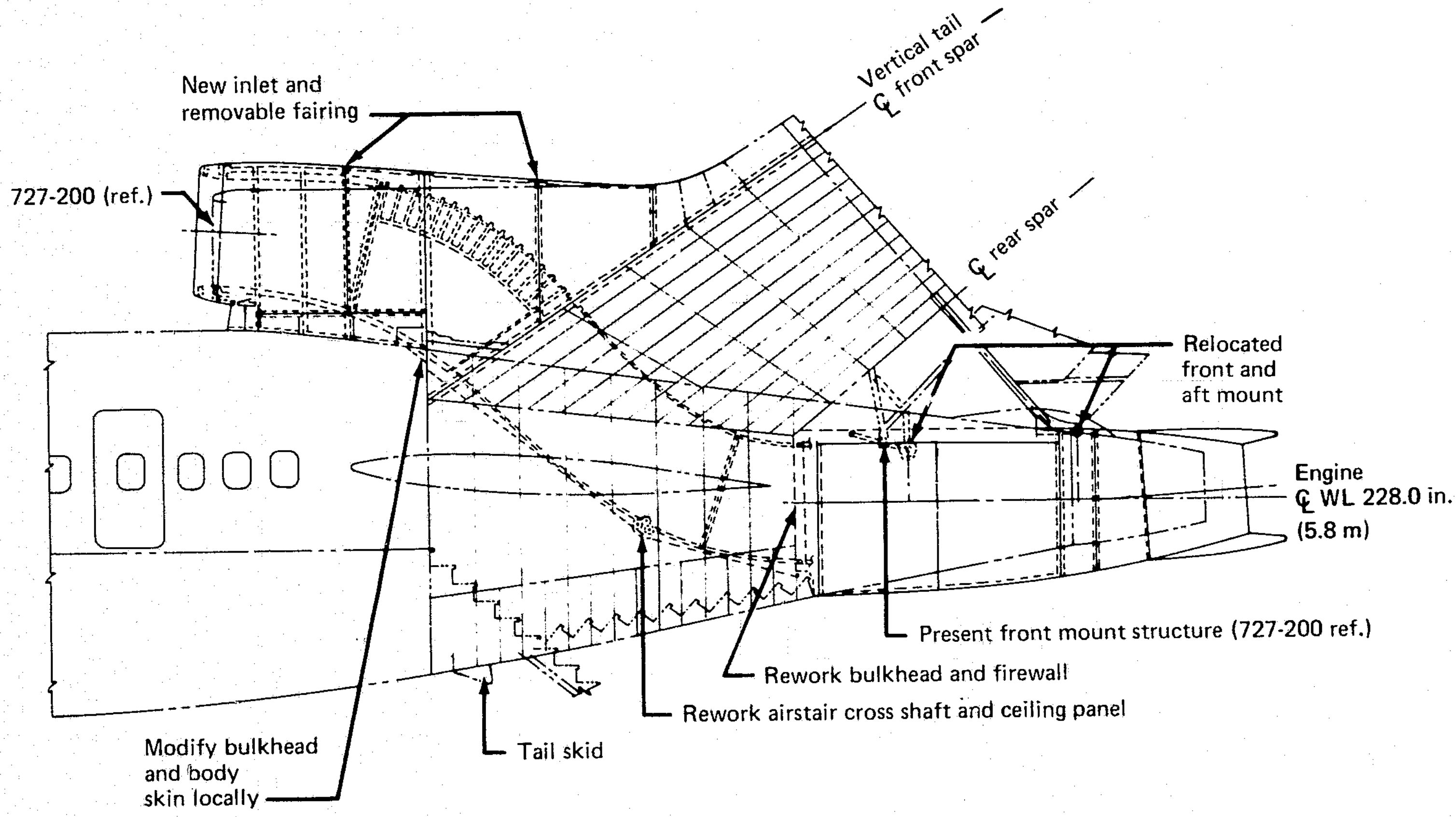


Figure 68.—727 Refan Aft Body Modification

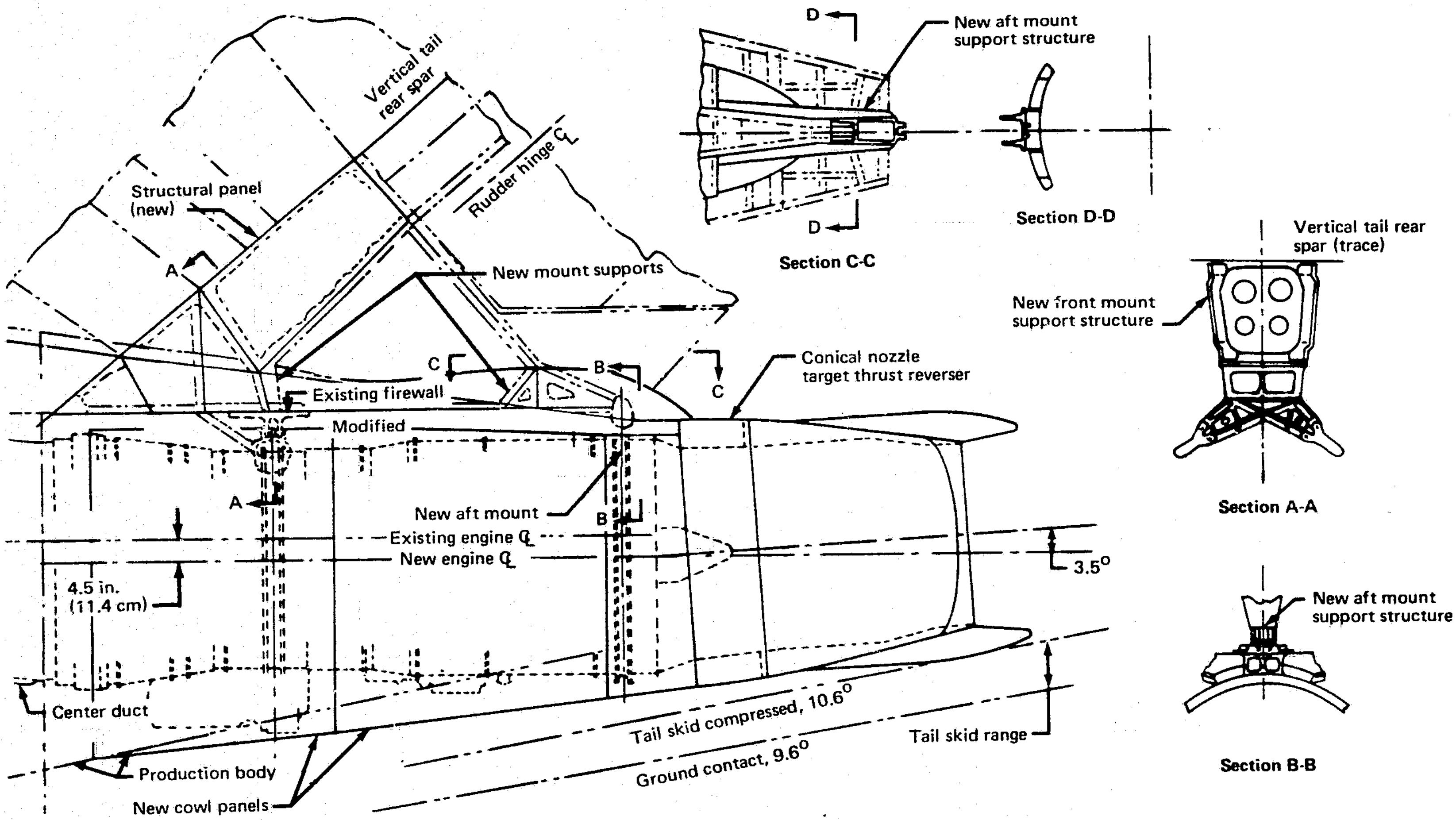


Figure 69.—727 Refan Center-Engine Installation

Rudder.—No change to the rudder is required. Wind tunnel data (ref. 11) indicate that rudder effectiveness is not affected by the nacelle installation.

Center-Inlet Fairing.—All of the vertical tail leading-edge structure forward of body station 1283 in. (32.588 m) is revised to accommodate the larger inlet. The outer surface of the new fairing structure consists of 0.50-in. (1.27-cm) thick, contoured, fiberglass-epoxy honeycomb paneling. The panels are supported by aluminum circumferential frames, installed at stations 1110 in. (28.194 m), 1130 in. (28.702 m), 1148 in. (29.159 m), 1181 in. (29.997 m), 1183 in. (30.048 m), 1233 in. (31.318 m) and an existing frame at station 1283 in. (32.588 m). Longitudinal aluminum members are installed at the top centerline and the junction to the pedestal, so that the honeycomb paneling may be divided into workable-sized sections, as shown in figure 68.

Tail Skid.—Modification of the tail skid was required to prevent contact of the thrust reverser with the runway during airplane rotation. This resulted from the relocation of the center engine 4.5-in. (11.4-cm) lower and 10.7-in. (27.2-cm) aft plus the increased length and diameter. The tail skid is modified to make ground contact with a 9.6° aircraft ground rotation attitude by lowering the mechanism pivot points and retaining the current door and tail skid tip assembly.

The design incorporates a ring spring and crushable cartridge combination as shown in figure 70. The ring spring allows the loads on the spring and cartridge to remain as currently designed, but the deflection of the cartridge is reduced as indicated by the load versus deflection characteristics given in figure 71.

A comparison of operating attitudes relative to tail skid geometry and center-engine clearance is presented in table 8. The table shows the ground rotation operating bands as well as center-engine ground clearance.

Reducing ground rotation angle from 10.0° on 727-200 airplanes to 9.6° on the 727-200 refan airplane increases potential tail skid strike frequency, but incorporation of the ring spring permits low initial contact forces and linear load increase. The softer blow to the system favors a low incidence of tip damage and cartridge replacement as well as reduced mechanical and structural fatigue.

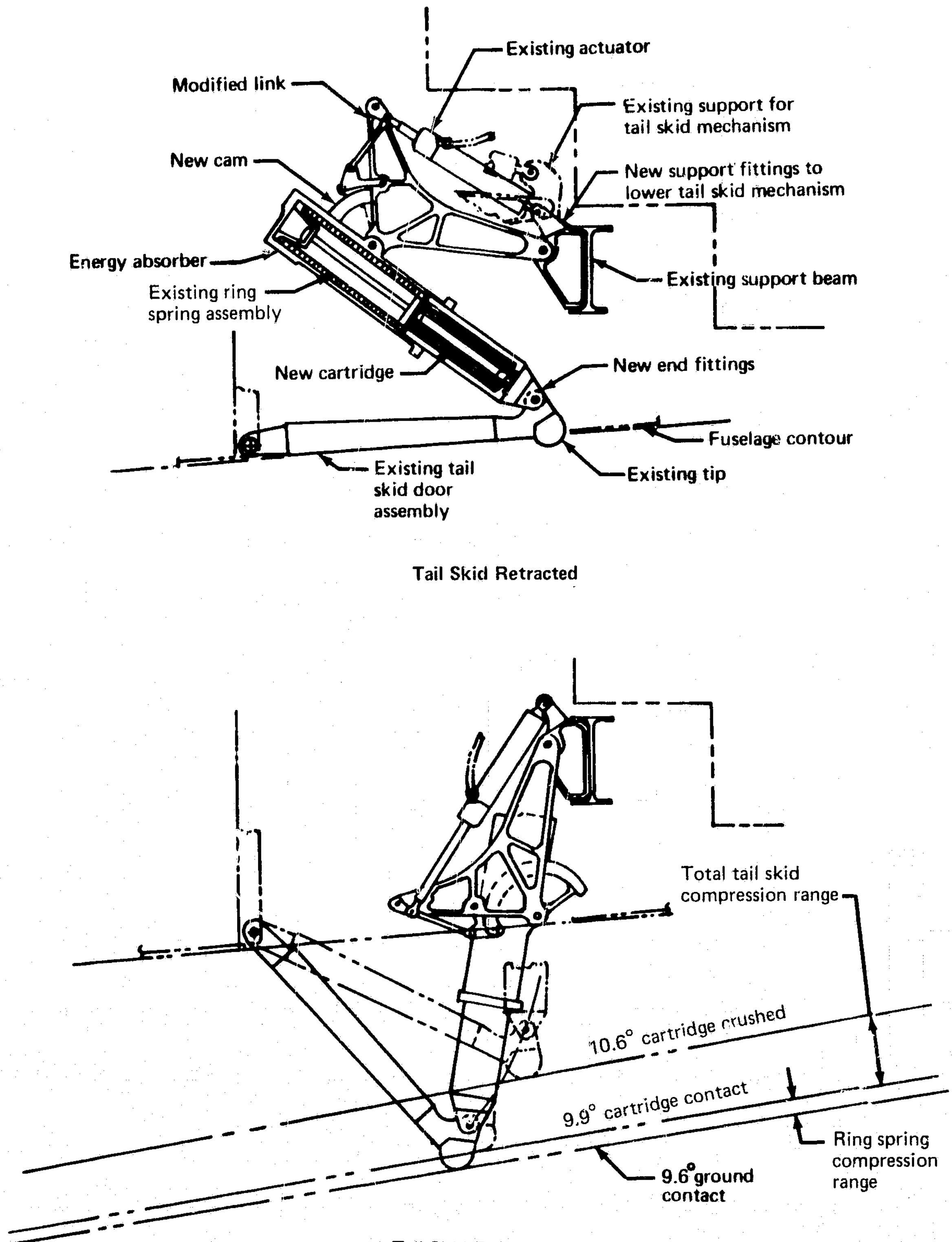
Airstairs.—The lowering of the center engine by 4.5 in. (11.4 cm) results in the following changes to the aft airstairs structure and mechanism, (fig. 72).

- The powered torque tube at station 1278.2 in. (32.466 m) is "doglegged" to 6.2-in. (15.7-cm) below pivot point.

- The uplock torque tube at station 1338.55 in. (33.999 m) is displaced approximately 1-in. (2.5-cm) down at BL 0.

- The uplock bungee is relocated below the torque tube.

- The airstairs ceiling panels are lowered aft of station 1268 in. (32.207 m) to clear the modified airstair torque tube and air-conditioning ducts.



Tail Skid Retracted

Tail Skid Extended

Figure 70.—727 Refan Tail Skid

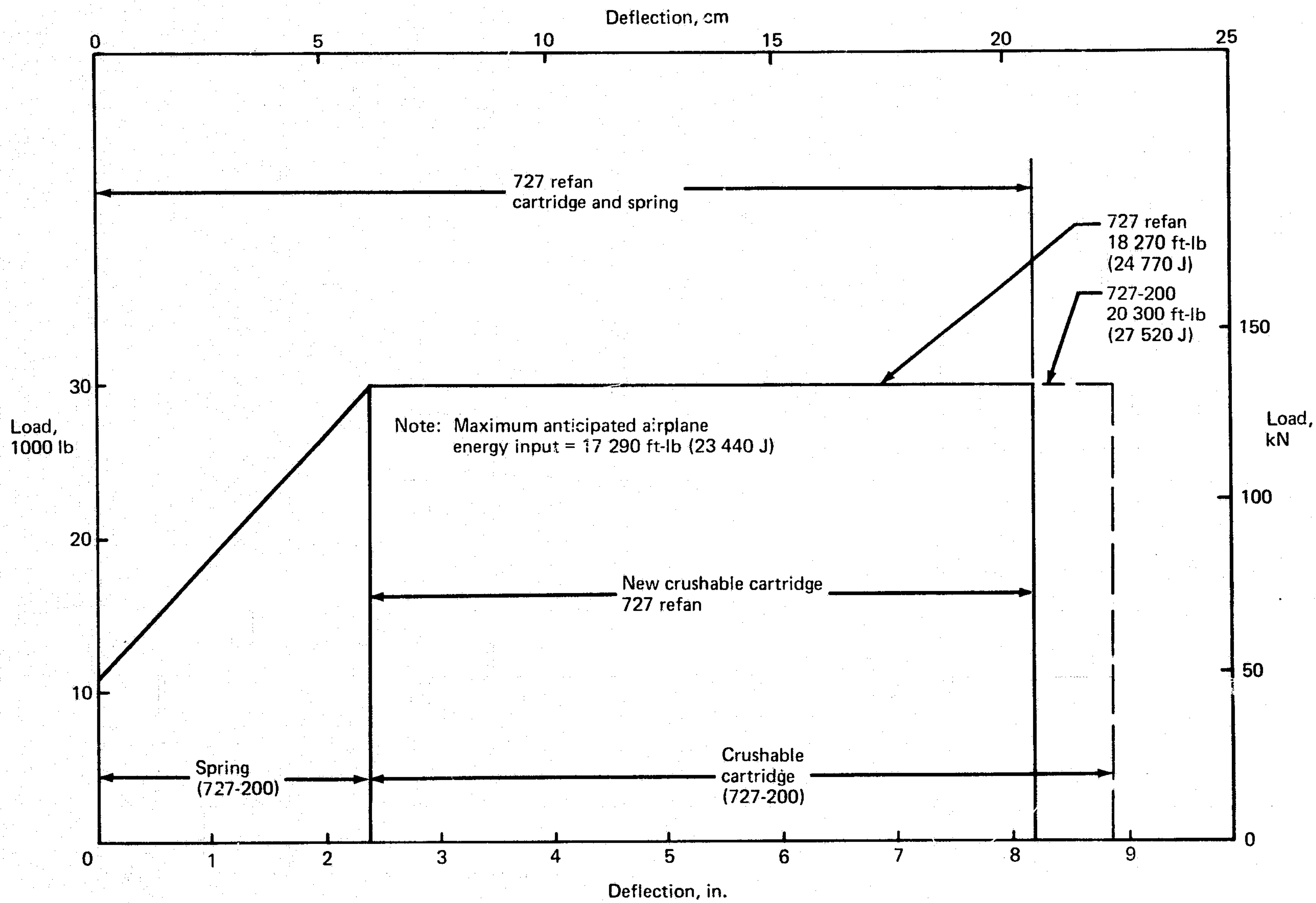


Figure 71.—727-200/727 Refan Energy Absorber Characteristics—Tail Skid

Table 8.—727 Refan Body Attitude Summary

Model	Flap setting, deg	Ground rotation angle, deg				Clearance to tail skid contact, deg	Clearance to cartridge contact, deg	Center engine ground clearance, in. (cm)		
		Normal liftoff	Skid contact	Cartridge contact	Skid max comp			At takeoff	At tail skid contact	At tail skid max comp
727-200 cartridge and spring	5	9.8	10.0	10.3	11.22	0.2	0.5	20.0 (50.8)	16.5 (41.9)	2 (5.1)
	15	9.1	10.0	10.3	11.22	0.9	1.2	29.0 (73.7)	16.5 (41.9)	2 (5.1)
	25	8.1	10.0	10.3	11.22	1.9	2.2	39.5 (100.3)	16.5 (41.9)	2 (5.1)
727-200 refan, cartridge and spring	5	9.45	9.6	9.9	10.6	0.15	0.45	12.4 (31.5)	13 (33.0)	0.62 (1.57)
	15	9.1	9.6	9.9	10.6	0.5	0.8	19.2 (48.8)	13 (33.0)	0.62 (1.57)
	25	8.1	9.6	9.9	10.6	1.5	1.8	31.6 (80.3)	13 (33.0)	0.62 (1.57)

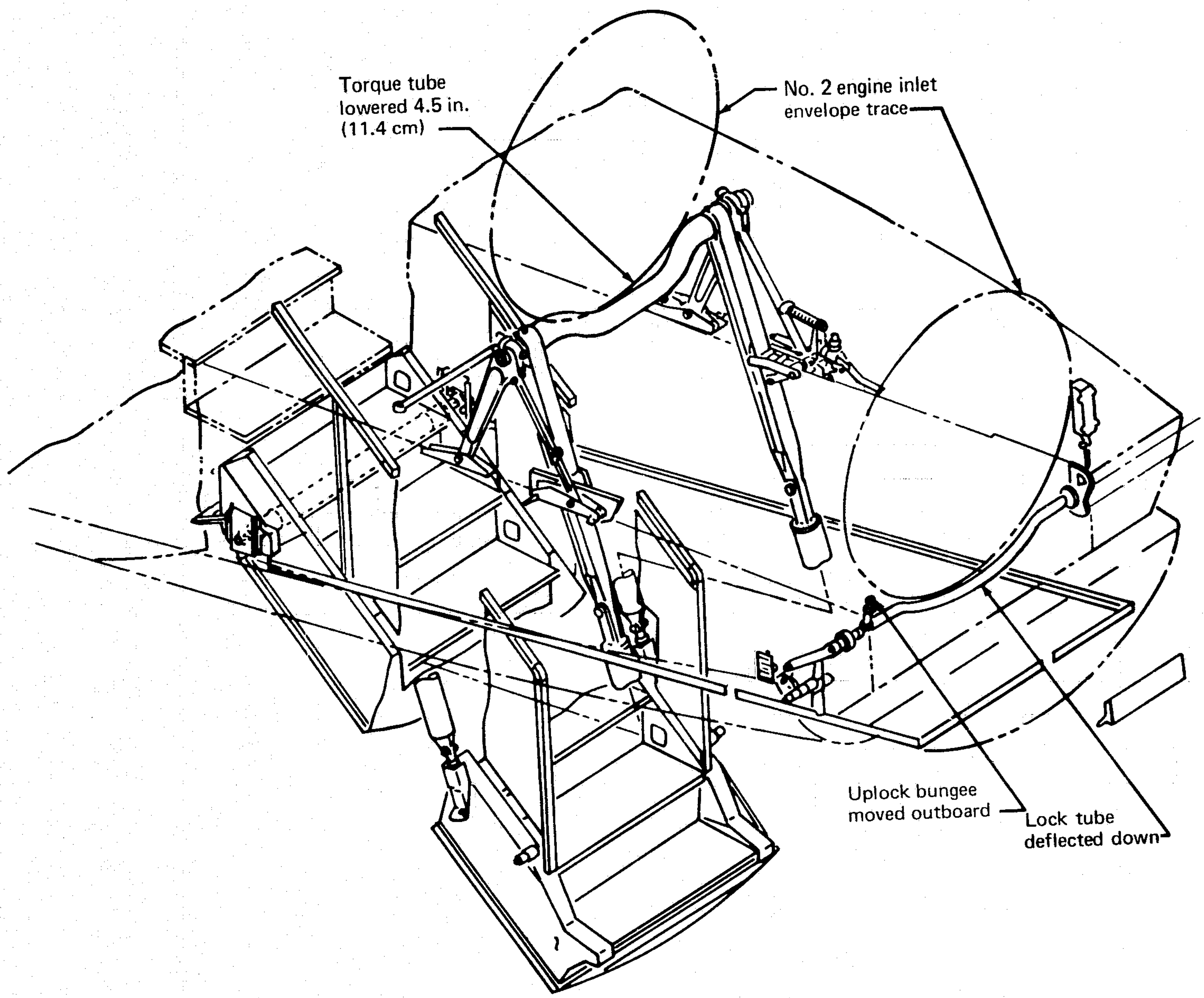


Figure 72.—727 Refan Aft Airstairs Actuation Mechanism

Aft Galley Door Evacuation Slide Installation.—Studies and tests conducted prior to this program showed the suitability of the existing evacuation slide installation including the feasibility of safe emergency egress with the engines running as part of certification procedure. Despite the close proximity to the inlet face and the higher mass flow of the JT8D refan engines, no difficulty is expected in completing a standard emergency evacuation procedure, and no change is necessary in the existing slide installation.

3.1.7.2 Airframe Systems

Revisions to airframe systems are confined to those changes that are necessary to ensure compatibility with the new engine installation.

Air-Conditioning.—The basic air-conditioning system remains unchanged. In addition to the engine ducting, the ducts forward of the center-engine bulkhead are relocated in the area of the center duct to clear the larger duct diameter.

- The 4.5-in. (11.4-cm) diameter cabin air-supply duct at body station 1266.42 in. (32.167 m) is rerouted below the center duct at station 1283 in. (32.588 m).

- The isolation shutoff valve in the air duct is moved outboard and forward approximately 30 in. (76.2 cm).

- The anti-ice air supply duct for the center-engine inlet duct is relocated from above the inlet duct to the position previously occupied by the CSD cooling air duct, which in turn is deleted by incorporating the revised CSD cooler previously described in section 3.1.6.7.

Cockpit Instruments.—The following is a list of the engine instruments provided.

- Engine Instrument Panel (See fig. 73).
    - Reverser indicator lights
    - Engine pressure ratio (EPR)
    - Low pressure rotor speed (N_1)
    - Exhaust gas temperature (EGT)
    - High pressure rotor speed (N_2)
    - Fuel flow rate (W_f)
    - Low oil pressure warning

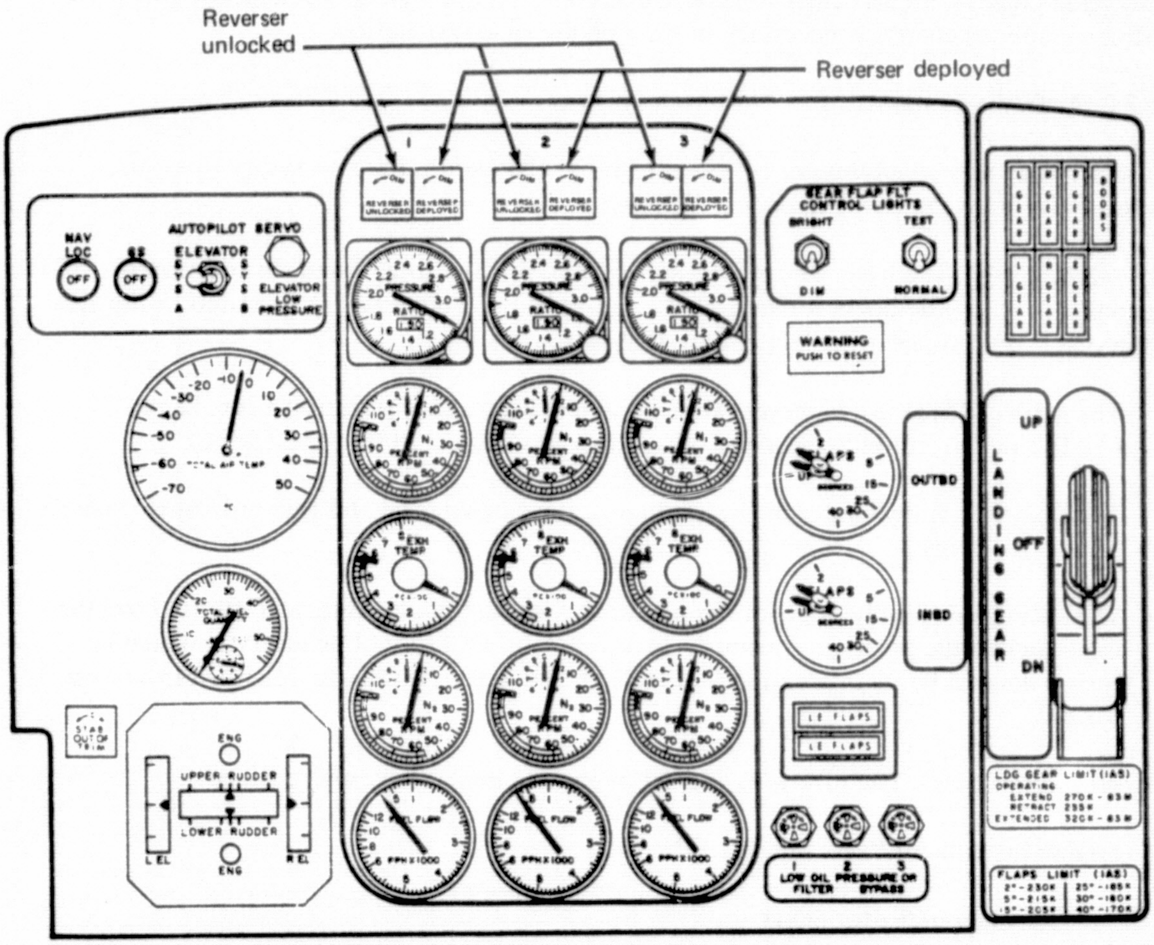


Figure 73.—727 Refan Cockpit Instruments

- Third Crewman's Lower Panel
  - Oil quantity
  - Oil temperature
  - Oil pressure
  - Engine vibration indicator (optional)
  - Fuel heater control

All of the existing cockpit instruments are retained; however, indicator limits may require adjustment. An additional indicator light is used providing display of in-transit and reverse thrust positions for each reverser (fig. 74).

The thrust reverser indication system is revised to employ a thrust reverser unlocked light and a thrust reverser deploy light. The system indicates thrust reverser locked when all lights are out, in-transit when the unlocked light is lighted, and deployed when the deployed light is lighted. This system differs from the existing system, which has a single light, indicating thrust reverser unlocked. (See figures 73 and 74.) The sensor signals may be utilized to provide indicating light sequence options to suit the preference of the operator.

The engine instrumentation system was previously discussed in more detail in section 3.1.6.8.

Autothrottle.—The autothrottle system is an electromechanical servosystem that controls the airspeed of the airplane by automatically positioning the throttles to maintain a selected airspeed. Changes in the autothrottle system, other than possible revisions to limit switch actuation points, are not expected.

Fuel.—No change to fuel systems in distribution or capacity is planned.

Hydraulics.—Hydraulic fluid at 3000-psi (20 684-kN/m^2) gage pressure is supplied to the hydraulically operated airplane components by three separate and independent power systems; hydraulic system A, B, and the standby hydraulic system. System A is powered by engine-driven pumps located on engines 1 and 2, while system B and the standby system receive their pressure from aft body-mounted ac motor-driven pumps.

The new target thrust reverser is hydraulically actuated by system A, which is the basic airplane hydraulic system. An accumulator is provided to supply backup reverser power in the event of pressure loss in the "A" system. System A is protected from fluid loss by a hydraulic fuse in the supply line to each reverser.

Engine Controls.—The system consists of two separate mechanical control systems for each engine: the engine power and the start control. Reverse thrust is obtained through operation of a *piggy-back* handle mounted on the throttle lever. Initial movement of this lever from the stowed position initiates thrust reverser door deployment. Further movement of the piggy-back handle controls engine power while the reverser is in the deployed position. This system is unchanged from the existing airplane except for possible revisions of detent positions.

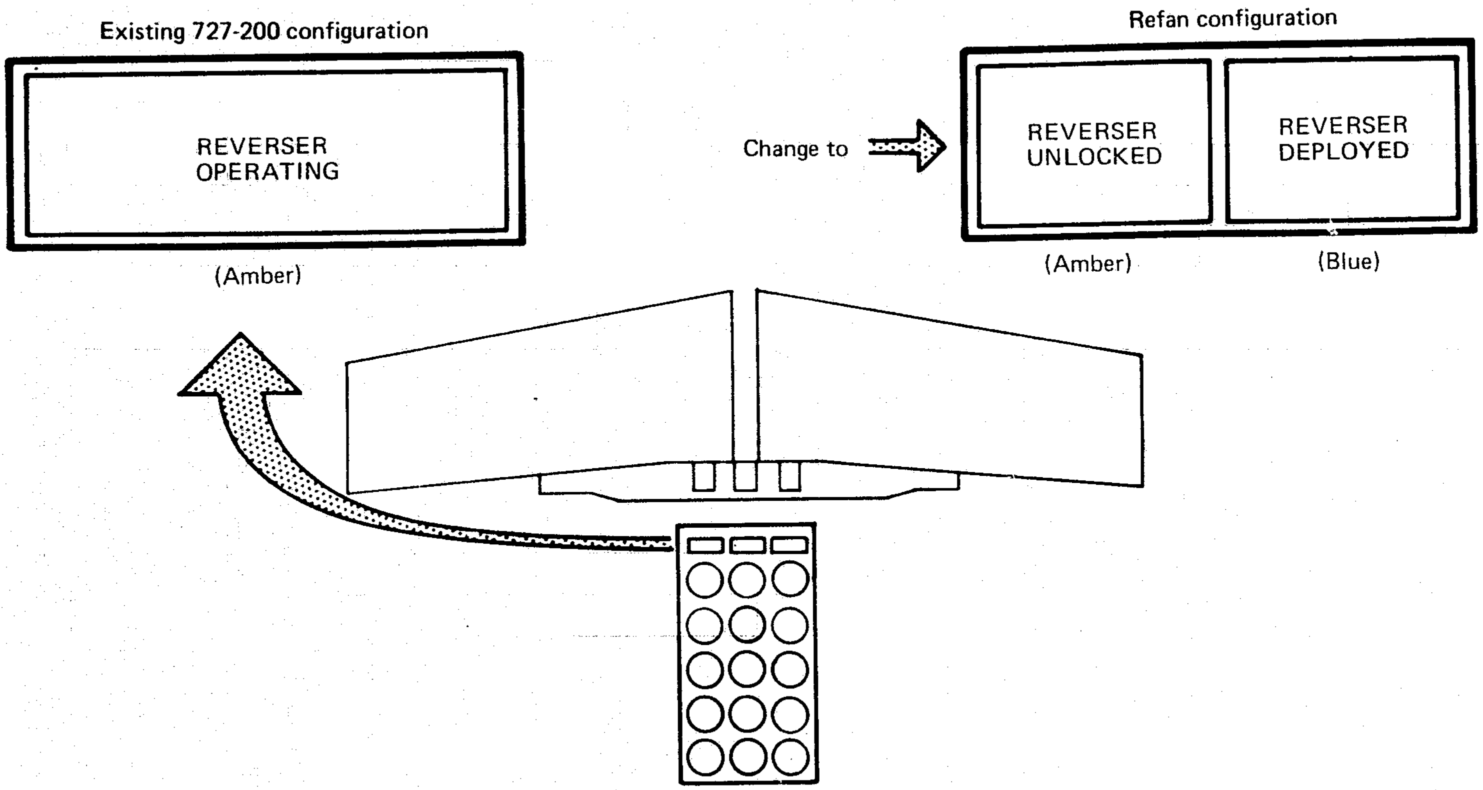


Figure 74.—Comparison of 727-200 Thrust Reverser Cockpit Indication With 727 Refan

An interlock is incorporated in the engine control drum-and-shaft mechanism that prevents the increase of engine power beyond idle unless the reverser is in the position selected. The mechanism also embodies a feature that reduces engine power to idle if a malfunction causes the reverser to deploy or stow contrary to the selected position of the reverse thrust lever.

For the side engines, the drum-and-shaft mechanism is unchanged except for modification of the interlock/followup (feedback) cam and substitution of a hydraulic valve for the pneumatic thrust reverser control valve.

The center-engine control drum-and-shaft mechanism incorporates these same changes but is also redesigned to provide clearance for the enlarged engine-inlet duct, previously discussed in section 3.1.6.8.

Electrical System.—Electrical energy is provided by three three-phase, 115- to 200-volt (V), 400-cycle, ac systems. Single-phase transformers are used to reduce a portion of this power to 28-V ac. Transformer rectifiers, fed from three-phase systems, are used to furnish 28-V dc. A battery is installed to furnish emergency power for critical needs when the basic power is deenergized.

The generating system consists of three engine-driven generators that may be operated separately or in parallel to supply power while in flight. An identical generator driven by the auxiliary power unit is mounted in the main landing gear wheelwell and is used for power supply when on the ground. An external power receptacle that allows connection to conventional ground power carts is installed.

3.2 MANUFACTURING

The objective of the manufacturing effort in support of the NASA Refan Program was to fabricate flightworthy, certifiable hardware to engineering requirements using normal production practices and facilities while minimizing cost where feasible by the use of soft or expendable tools.

The major components fabricated for this program were an exhaust-nozzle 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.

3.2.1 SIDE-ENGINE INLET

The side-engine inlet (fig. 75) manufactured in support of the ground test of the refan engine, was not flightworthy. The unit was built without anti-icing provisions but duplicated propulsion and acoustic critical requirements.

A plaster model (PM) (fig. 76) was built to define internal and external contours of the inlet. The PM was made in a complete 360° configuration by placing aluminum headers (cross-section cuts through the internal and external contour lines on radial planes) on a substantial

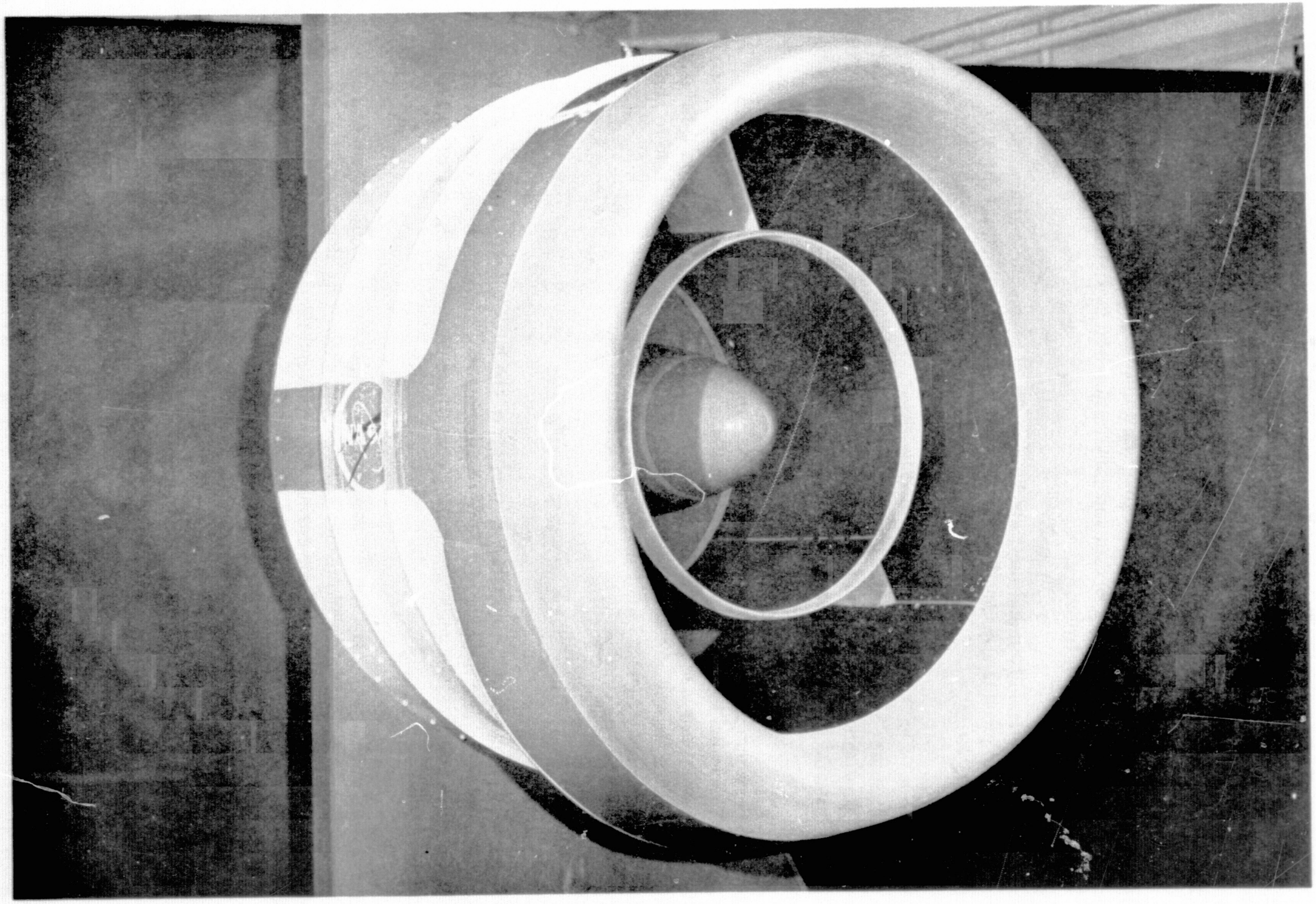


Figure 75.—JT8D Refan Side-Engine Ground Test Inlet

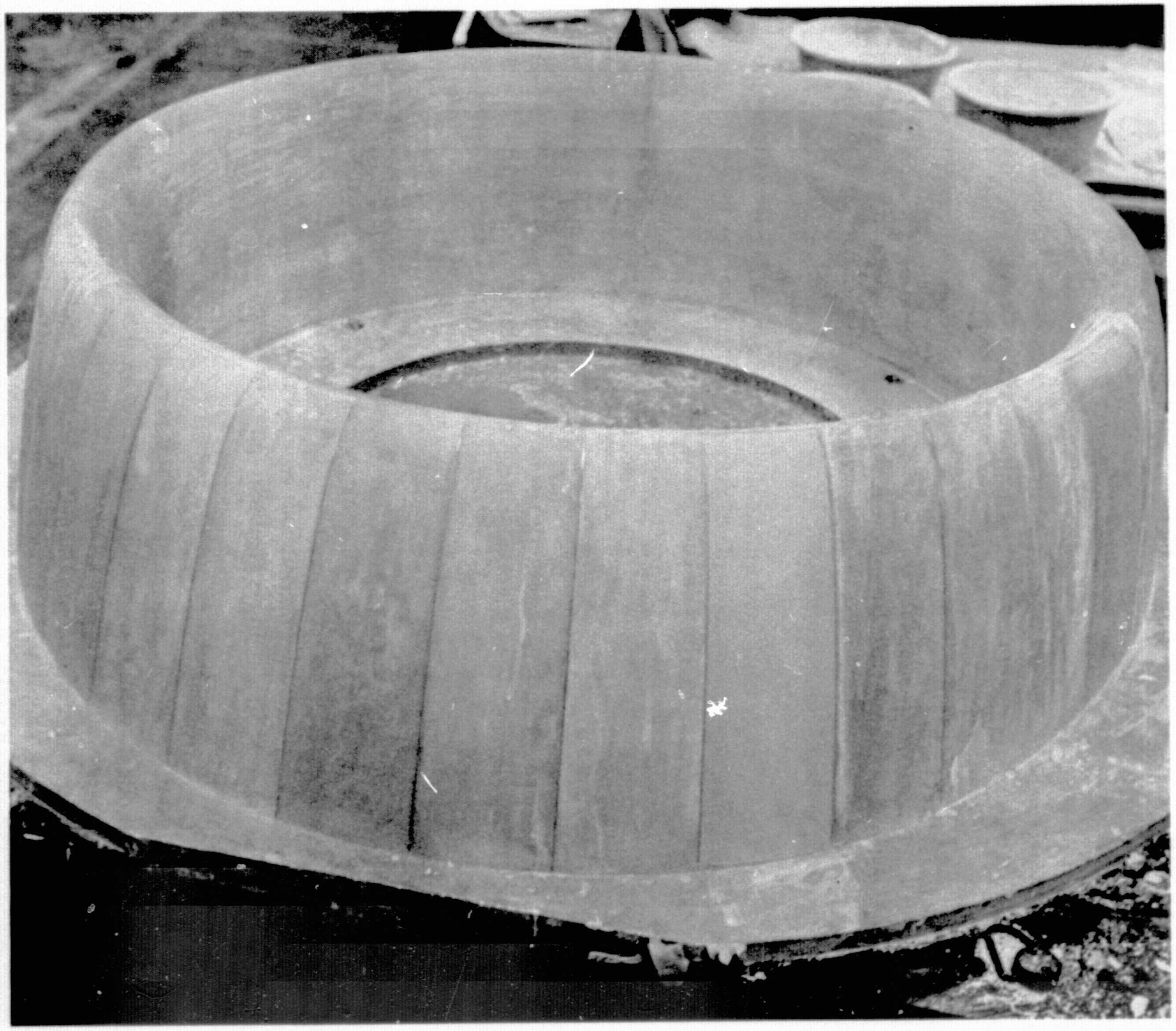


Figure 76.—JT8D Refan Side-Engine Inlet Plaster Model

base and fairing one to another with plaster. Lines were scribed on the plaster and identified to locate ends of the lip and diffuser panel sections.

All subsequent tools for the side-engine inlet were coordinated back to the PM. Every effort was made to use the minimum tools, where possible, consistent with the limited requirements of the ground test program. The acoustic panels with polyimide skins were bonded on high-temperature fiberglass-reinforced epoxy tools, which had been planned for use in the fabrication of the flightworthy inlet (fig. 77).

The inlet lip was made of bonded laminated fiberglass cloth to the contours defined by the PM. The lip and the diffuser panels were mounted on superstructure, consisting of rings and axial struts, and a cylindrical outer shell made from sheet aluminum, as shown in figures 78 and 79.

The inlet ring shown in figure 80 duplicated the acoustic and propulsion requirements of the flight weight inlet, but substituted a solid aluminum plate for the honeycomb core between the acoustic panels. This aluminum plate also served as the support and attaching structure for the ring. The leading edge of the ring was made as a turned-aluminum part, and the support struts were machined from aluminum plate.

The inlet center body (fig. 81) was fabricated using a sheet-metal cone and rings to form the substructure of the part. The acoustic panel made of polyimide fiberglass was then supported from the substructure and trapped by rings on each end.

3.2.2 SIDE COWLS

The side cowls for the refan installation were to be fabricated as a fiberglass-honeycomb bonded assembly with local edge stiffening rather than the skin and frame construction presently used on the 727-200 airplane. The major advantage to using honeycomb is that the numerous detail parts and tools required for skin and stiffener construction can be largely eliminated.

The side-engine side cowls were not fabricated, but various samples of fiberglass-honeycomb construction were built and subjected to fire tests to determine the ability to meet CAR fire barrier standards. The construction selected as a result of these tests consisted of a heat-resistant phenolic-impregnated fiberglass-honeycomb core bonded with inner and outer skins of 2-ply structural glass fabric with a stainless steel wire mesh fire barrier sandwiched in the inner-skin laminate.

A plaster model is required to control contour. The PM was made in two halves with aluminum headers (cross-section cuts from the external contour lines) mounted in proper relative positions on substantial bases and faired, one to another, with plaster as shown in figures 82 and 83. Lines were scribed on the plaster and identified to locate ends of the cowl panels and other pertinent details. All subsequent tools for the side-cowl details and assemblies were coordinated to the plaster model.

Careful consideration was exercised to utilize as much soft tooling as possible for the limited production requirement of the refan ground test program. The cowl panels were among the items that were not completed. When work was stopped, the tools were 80% complete.

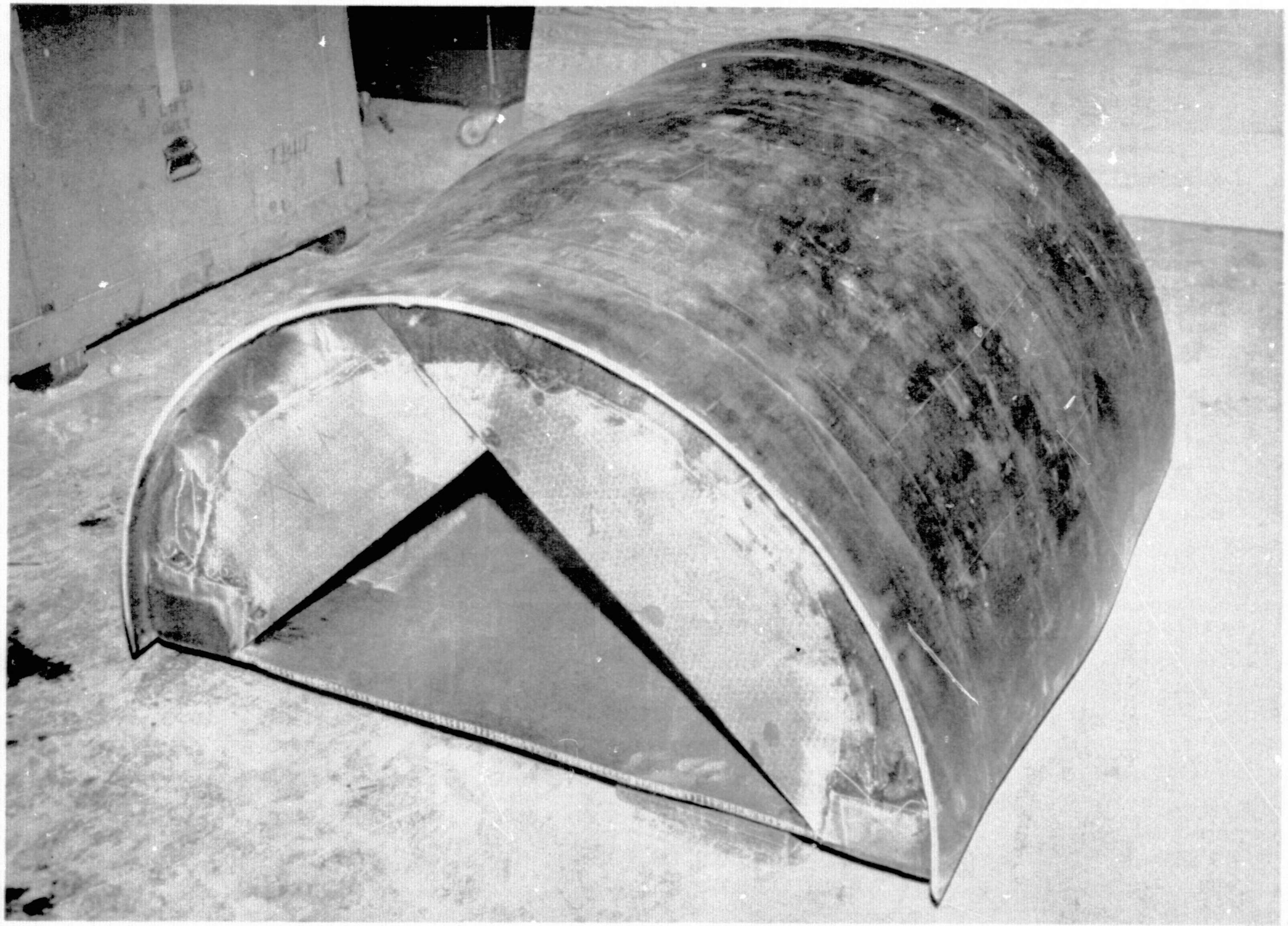


Figure 77.—JT8D Refan Side-Engine Inlet Bond Assembly Jig

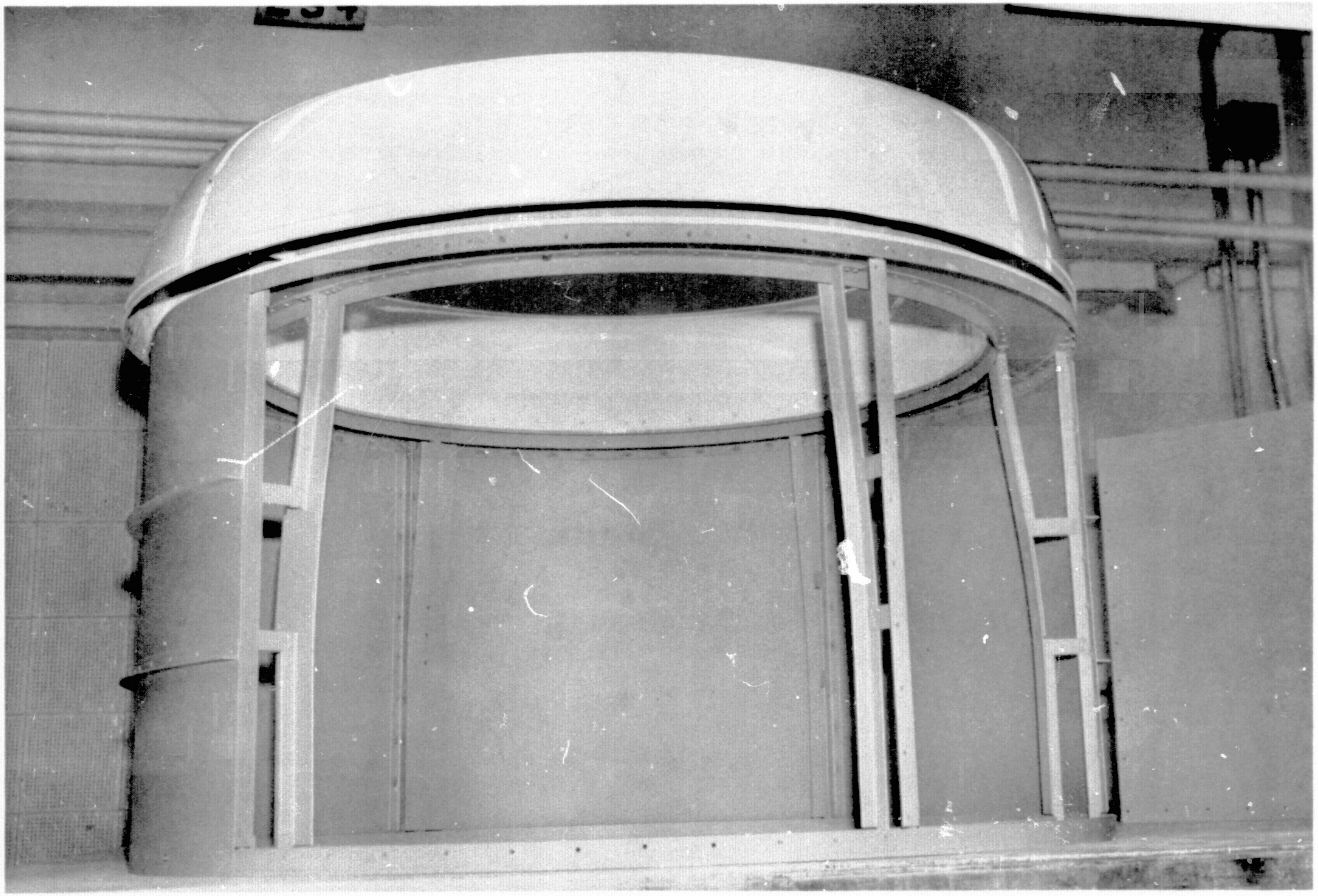


Figure 78.—JT8D Refan Side-Engine Inlet Lip and Support Structure

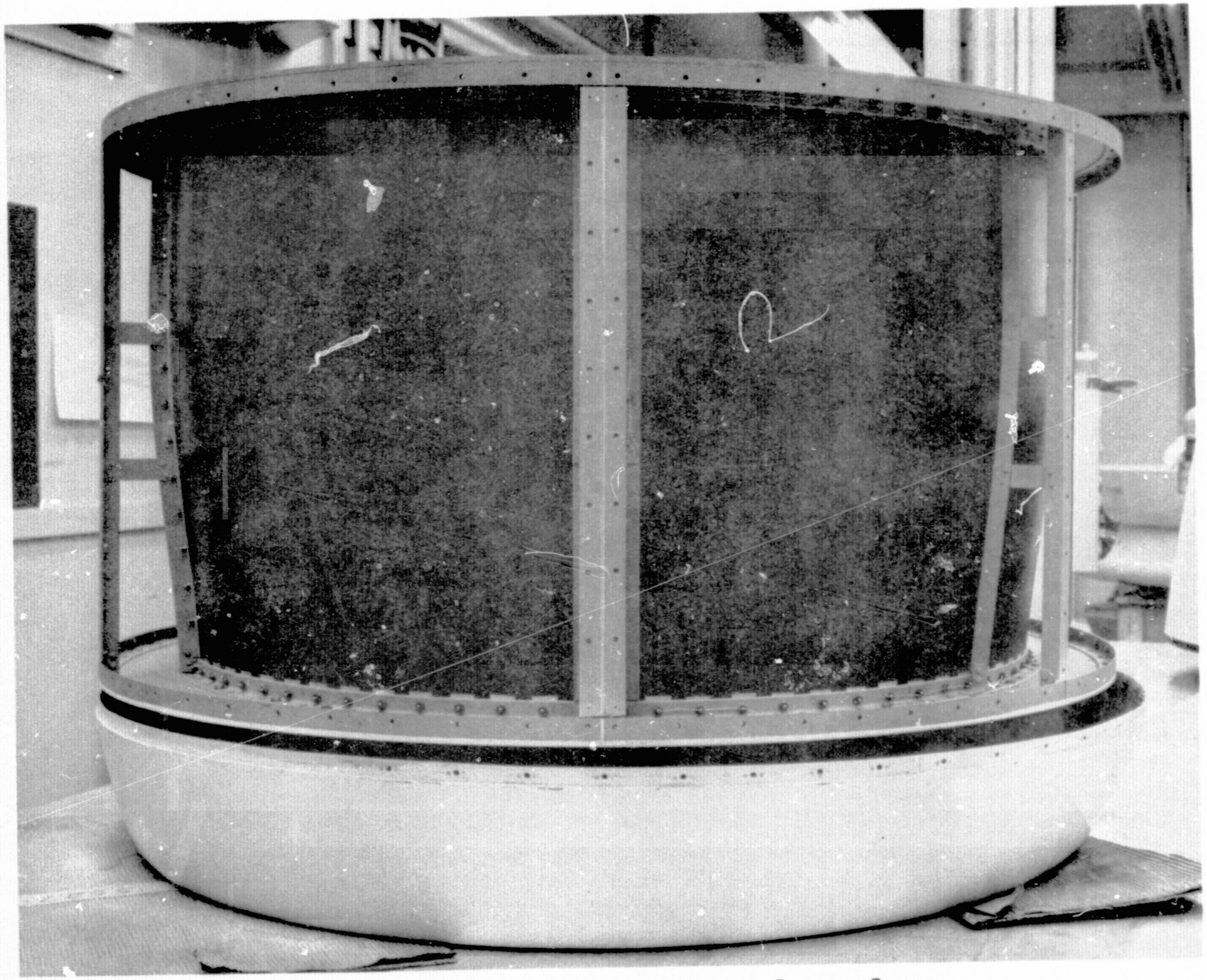


Figure 79.—JT8D Refan Side-Engine Inlet Lip, Support Structure, and Acoustic Diffuser Panel

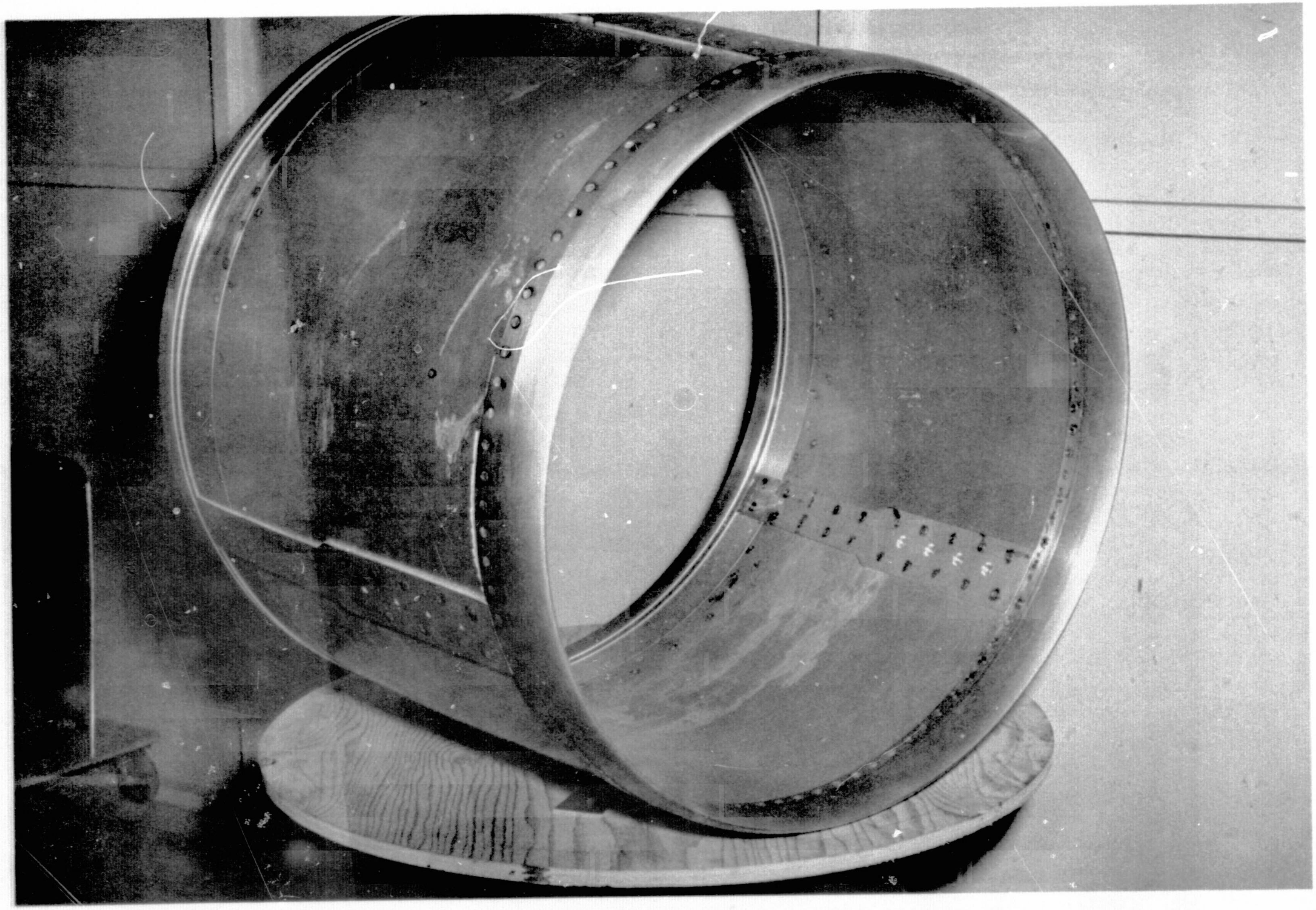


Figure 80.—JT8D Refan Inlet-Ring Support Structure

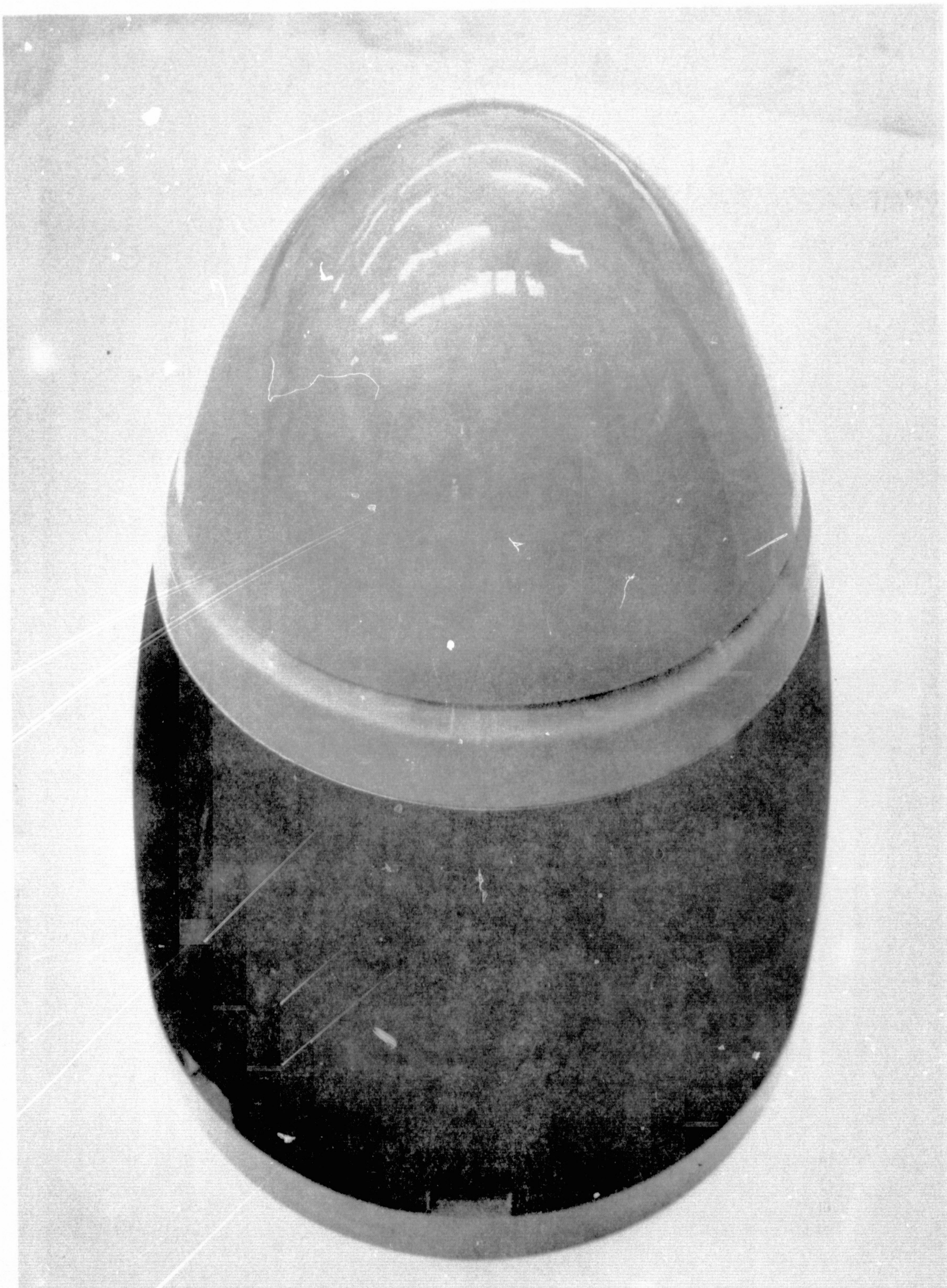


Figure 81.—JT8D Refan Inlet Plug Assembly With Acoustic Treatment

Figure 82.—JT8D Refan Side-Engine Side-Cowl Plaster Model Preparation

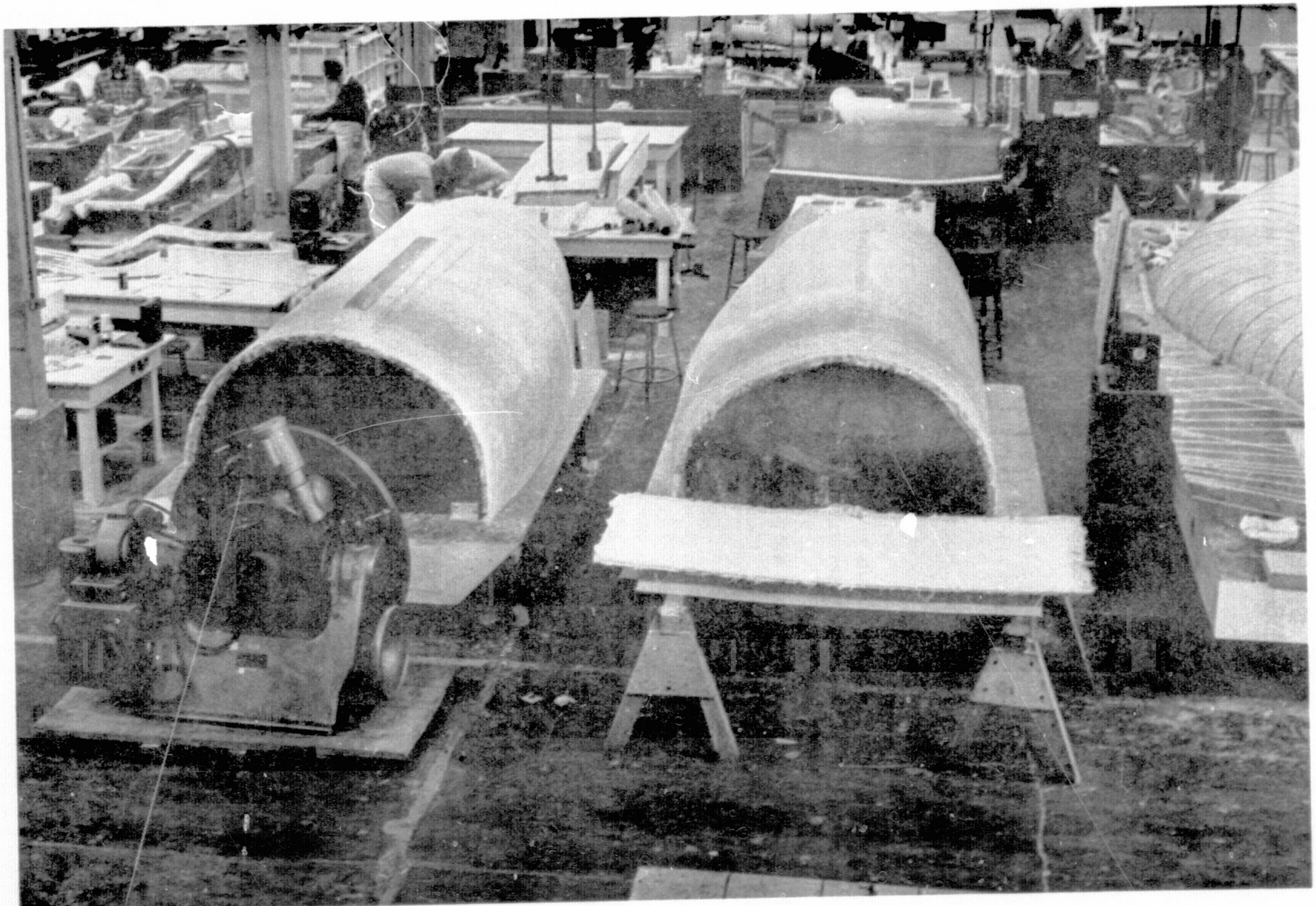


Figure 83.–JT8D Refan Side-Engine Side-Cowl Plaster Models

The assembly sequence of a typical side-cowl panel would be as follows:

1. A single piece fiberglass-reinforced bond assembly jig (BAJ) would be required for each section of cowl.

2. The outer skin, consisting of 2-plies of preimpregnated fiberglass cloth, would be placed on the BAJ and bonded to form a rigid outer skin.

3. The honeycomb core would be fitted to the skin and bonded using the BAJ for support.

4. The inner skin, which consists of a layer of stainless steel wire mesh sandwiched between 2-plies of preimpregnated fiberglass cloth, would be fitted to the core and bonded.

5. The longerons, which stiffen the edges of the cowl, would be installed using the BAJ as a locating tool.

6. Hinges, latches, and all other details would then be fitted into fixturing locations in a single locating tool that coordinates critical cowl interfaces.

7. Final skin trims would be made in the same tool so that when two mating cowls are joined, proper fit-up is achieved.

3.2.3 EXHAUST SYSTEM

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

The assembly sequence for the Refan Program ABTi components was as follows:

1. The end attachment rings were machined to an undersized condition from ring-rolled forgings.

2. The rings outer skin and reverser support rails (nozzle only) were welded into an assembly that forms the brazement outer shell, as shown in figure 84.

3. The outer skin assembly was placed on a conical CRES sizing mandrel (fig. 85), and hot sized in a furnace to remove all weld distortion and to provide an optimum surface for brazing.

4. The inner skin was cut to size and prepared for perforating by coating with a light sensitive film.

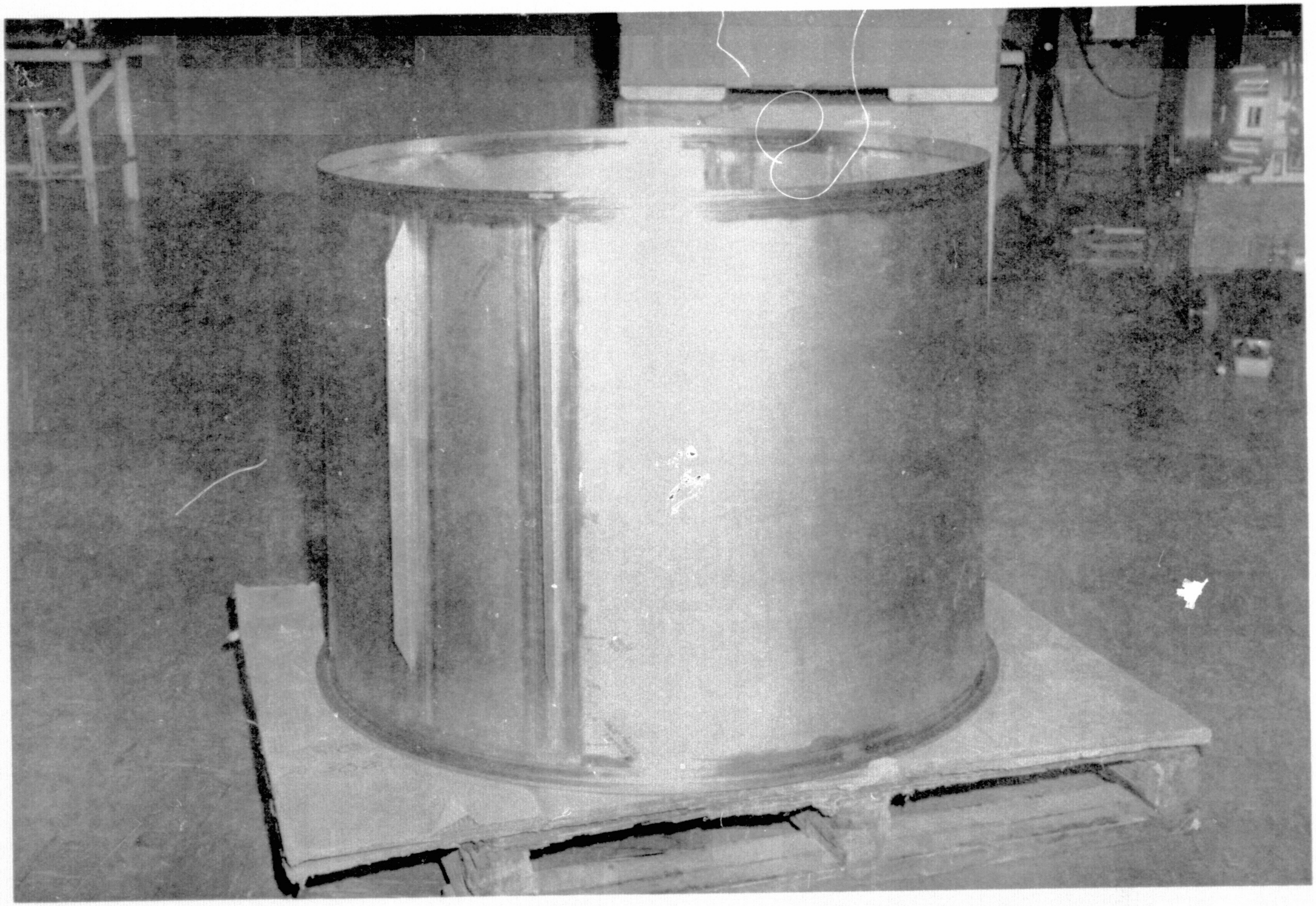


Figure 84.—JT8D Refan Brazement Outer Shell

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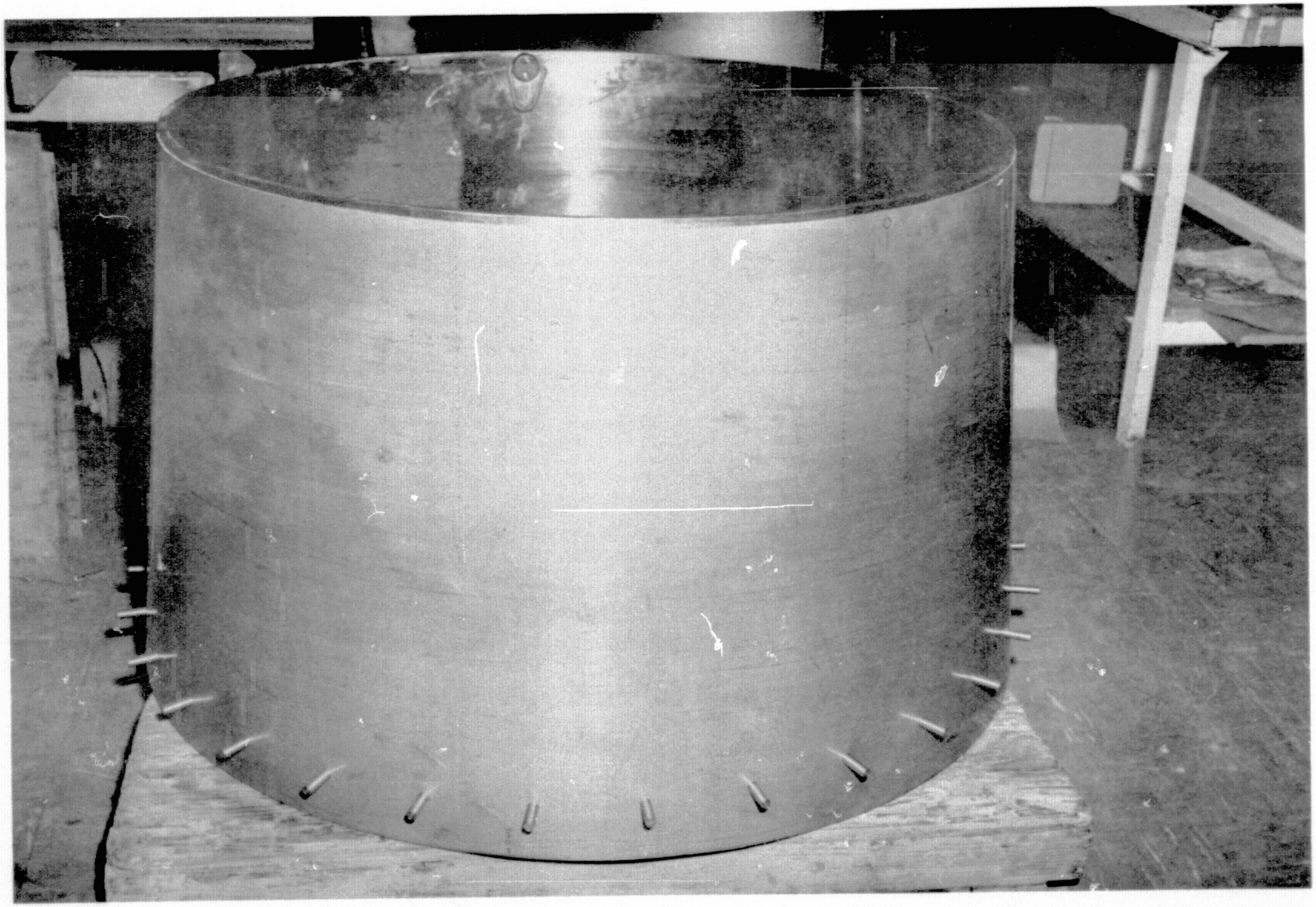

Figure 85.—JT8D Refan Brazement Shell Sizing Mandrel

5. The inner skin was exposed through a photo mask, which contains the acoustic hole pattern, and was then passed through a developer to transfer the hole pattern to the face of the material.

6. The inner skin was chemically milled to produce the perforations required for acoustic purposes.

7. The inner skin was wrapped into a circle and welded (fig. 86).

8. The core blanket was cut, trimmed, and spliced into a properly sized cone as shown in figure 87.

9. The outer skin, core, and inner skin were assembled with the specified amount of braze foil and installed on the braze mandrel cone as shown in figure 88.

10. The braze mandrel and brazement layup were enclosed in a weld-sealed retort as shown in figure 89.

11. The mandrel was placed on a rotating braze fixture and plumbed and wired for atmospheric and temperature control in the furnace.

12. The part was subjected to a controlled braze cycle and removed from the furnace.

13. The retort was opened, and the brazement was removed from the mandrel as shown in figure 90.

14. The braze assembly was subjected to nondestructive testing by eddy current, developed during prior Contractor research in support of the FAA-sponsored Supersonic Transport Program, to ensure braze quality; all welds were x-rayed to establish weld quality.

15. The end flanges were machined flat and drilled to provide matching holes and interface planes.

16. The component closures and fairings, as applicable, were welded to extensions of the component skins.

Experience gained during the manufacturing of these aluminum-brazed titanium components led to the conclusion that several areas require improvement for production implementation. These areas of improvement include:

- Use of a vacuum furnace to speed up the process
- Development of a production rate method of chem-milling holes in the perforated acoustic face
- Development of a better method of braze alloy application
- Development of a more compatible "stop off" material to prevent "mark off" of panel skin
- Better methods of nondestructive testing

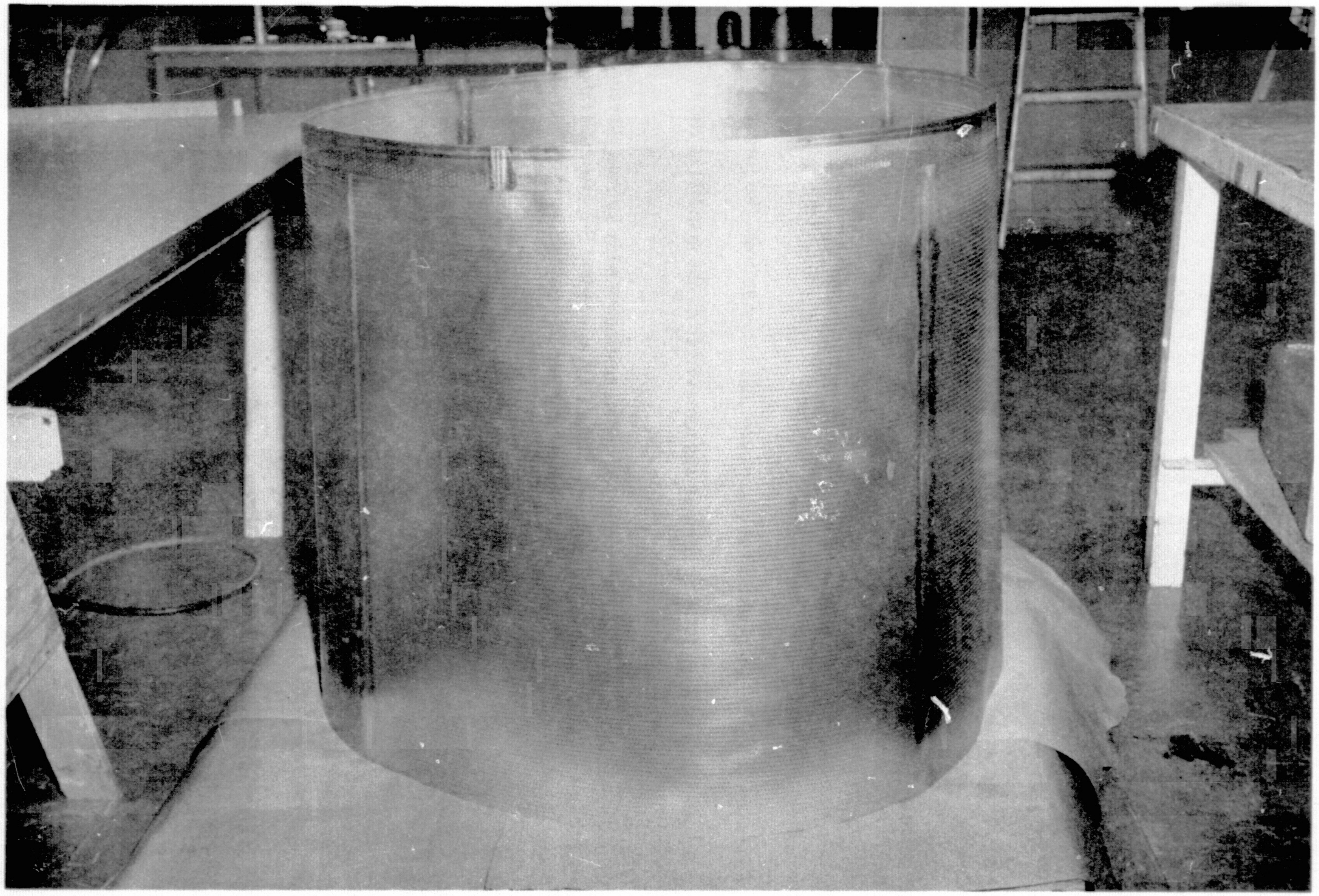

Figure 86.—JT8D Refan Brazement Acoustic Face Skin

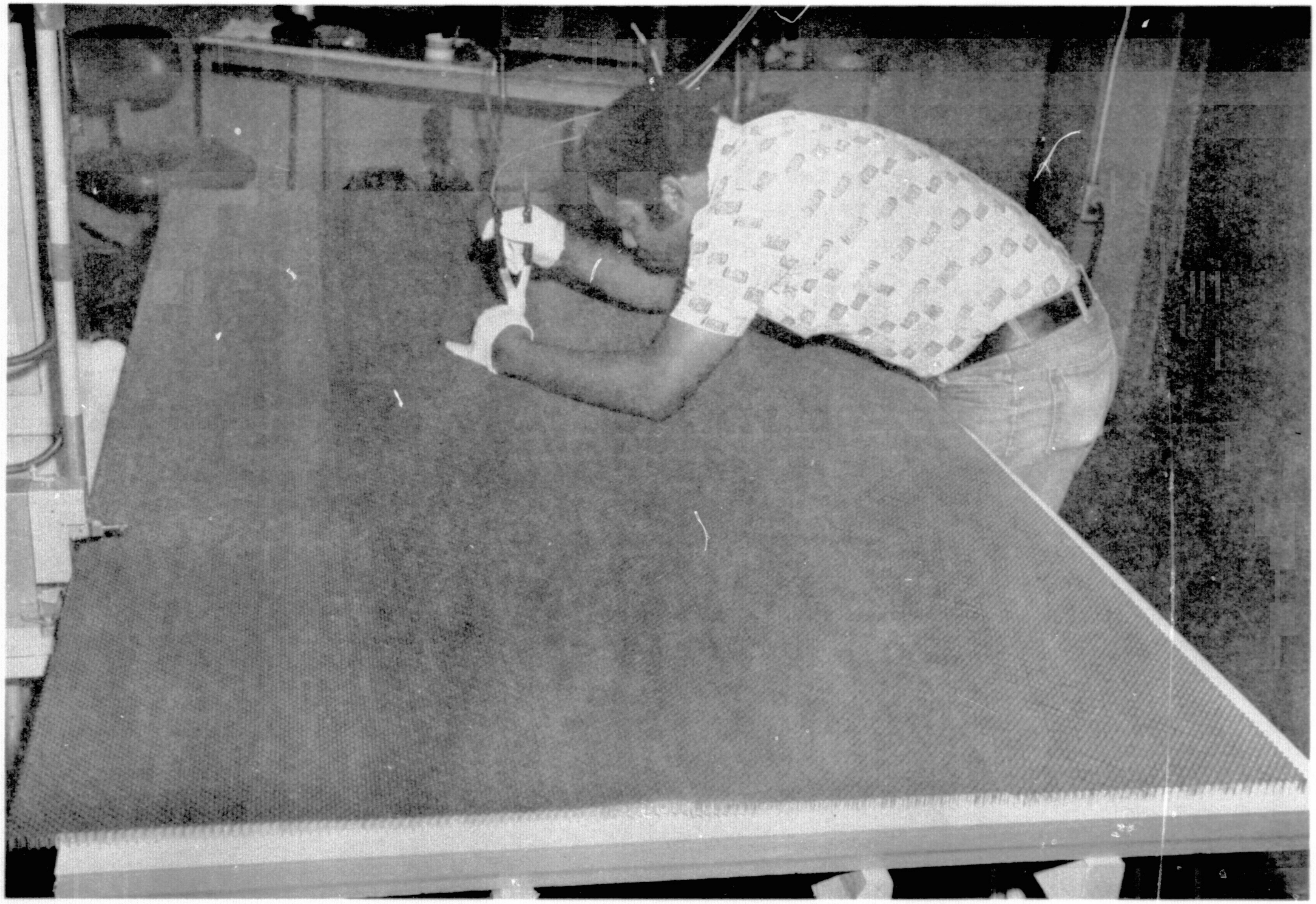

Figure 87.—Core Blanket Splicing

Figure 88.—Placing JT8D Refan Brazement on Mandrel

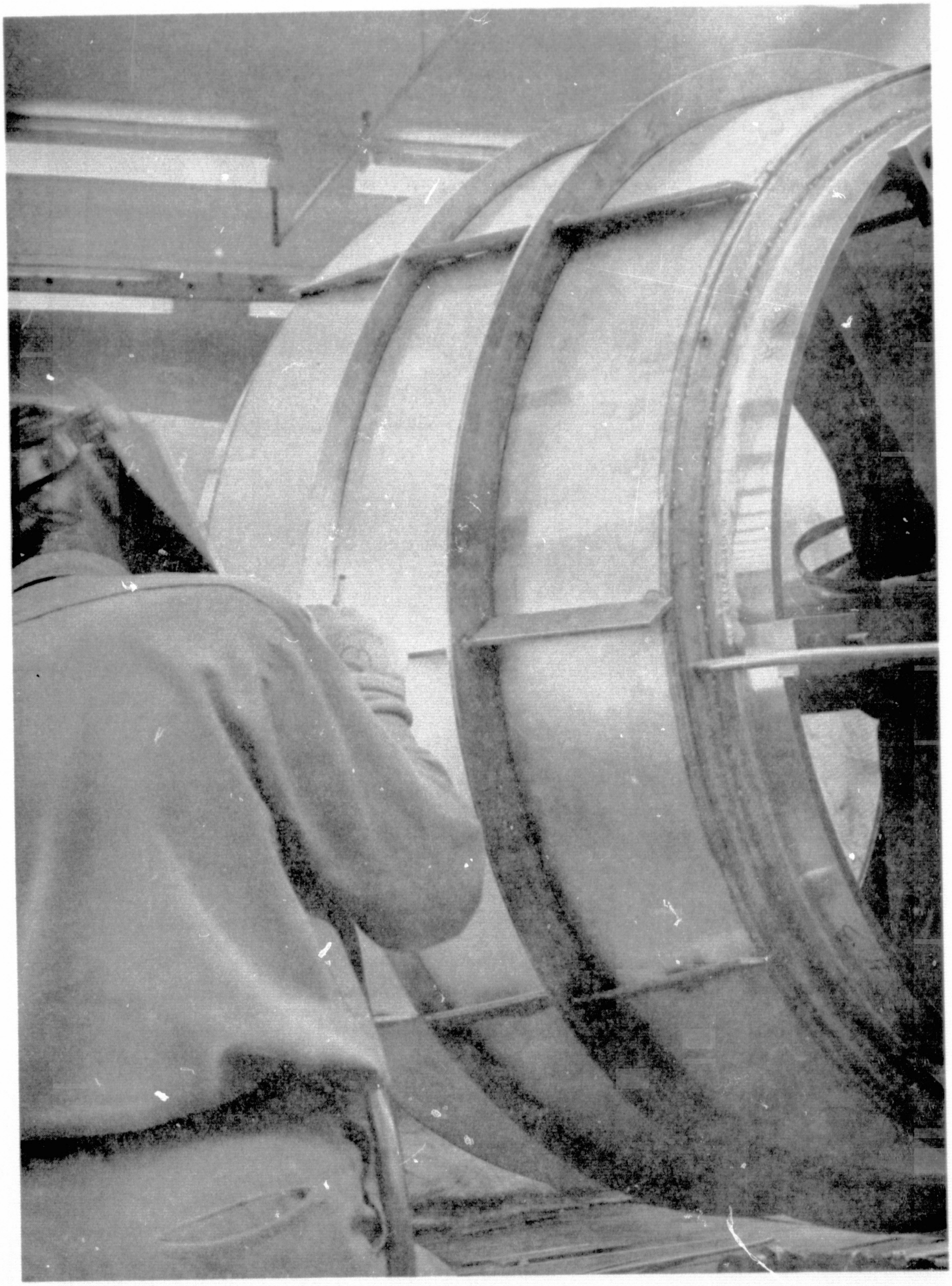

Figure 89.—Weld Sealing JT8D Refan Brazement in Retort

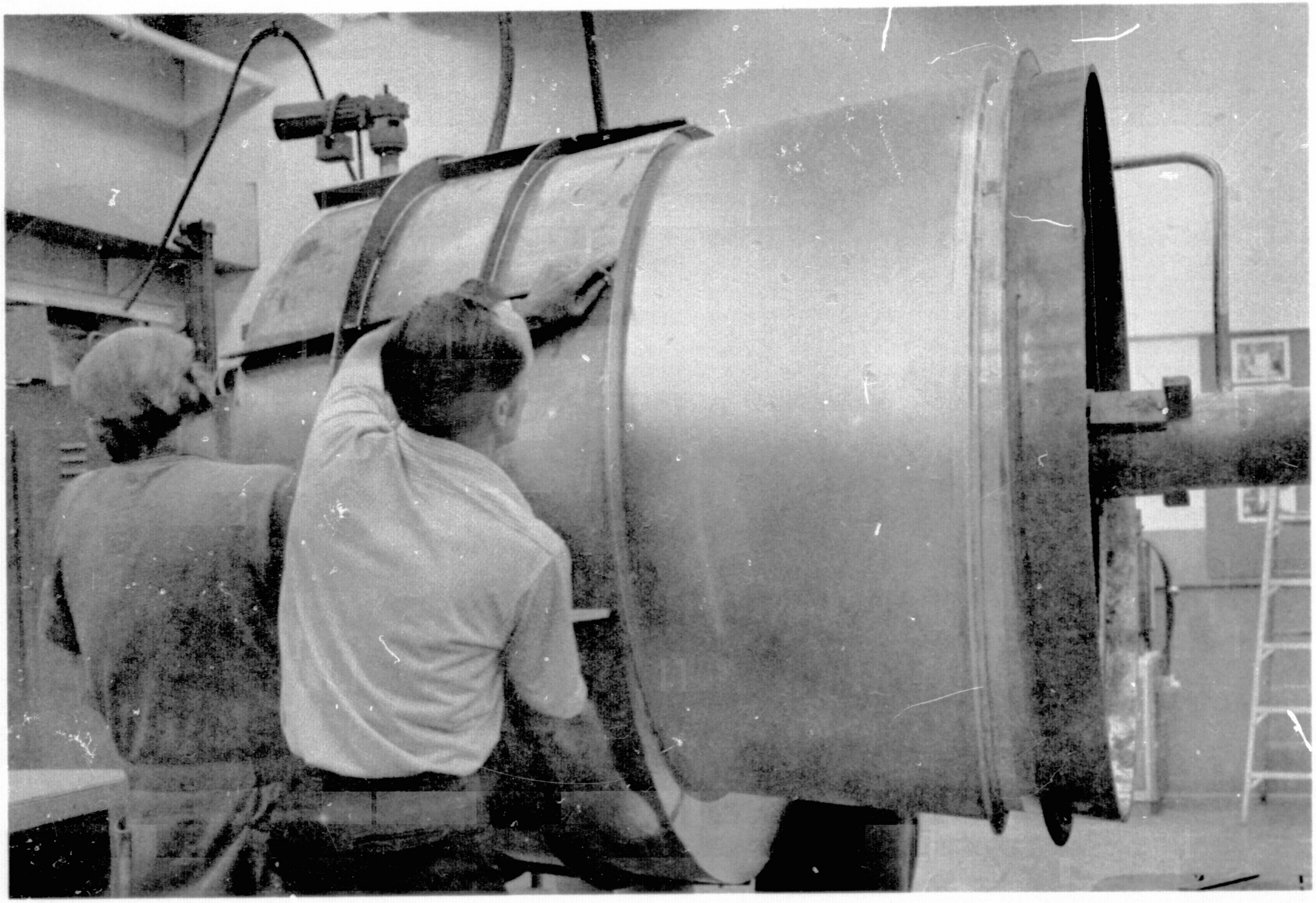

Figure 90.—Removing Retort From JT8D Refan Brazement

A typical JT8D refan exhaust-system brazement is shown in figure 91.

The Inconel 625 brazed component of the primary flow side of the fan/primary divider followed the same general method of assembly, except for the choice of materials, method of perforating, the braze alloy, and the furnace temperature cycle.

The center-body plug was bulge-formed (as a parabolic body of revolution) of light-gage sheet metal, which was welded to a mechanical attachment ring and a formed end cap.

3.2.4 THRUST REVERSER

The thrust reverser for the refan project is similar to the current target-type thrust reverser in use on the 737-100 airplane. The refan reverser is much larger due to the larger diameter engine nozzle. The manufacturing task would be somewhat complicated because of the extensive use of titanium and the larger size of the reverser. The JT8D refan thrust reverser mockup is shown in figure 92.

The refan reverser target door is made of formed titanium frames, a titanium interior skin, and an aluminum outer skin. The character of titanium heat-treatable alloys requires that they be hot-formed at temperatures approaching 1500°F (1088.7 K). Since this requires tooling that is not cost effective for limited production, machining of the frames from ring-rolled forgings was allowed as an option. The reverser was among the items not completed due to funding limitations. When work was stopped, the tools were approximately 80% complete; detail part fabrication was approximately 10% complete.

The typical assembly sequence for a reverser door would be as follows:

1. Upon receipt, the inner skin and door frames would be placed in the assembly jig where they would be fitted, drilled, and riveted to form the basic door structure.

2. The link attachment fittings would also be located in this jig and fastened to the inner skin and frames.

3. The outer skin would be placed over the frames, fitted, and drilled. The outer skin would then be removed, and the assembly cleaned of all debris.

4. The outer skin would be riveted to the frames with blind fasteners.

5. The door lips and fences would be bolted to the completed door.

The reverser door is supported by four machined titanium links. Since the links require machining on all surfaces, the parts were machined from bar stock. If forgings of sufficient accuracy could be procured, considerable cost could be saved in machining.

The reverser links and actuation system are supported by one large-cast fitting (fig. 93). The option to machine the part from bar was allowed. However, the casting was successfully procured which saved approximately 500 hours of machine time. The reverser links, support fitting, and doors are supported from the exhaust system, previously described in section 3.2.3.

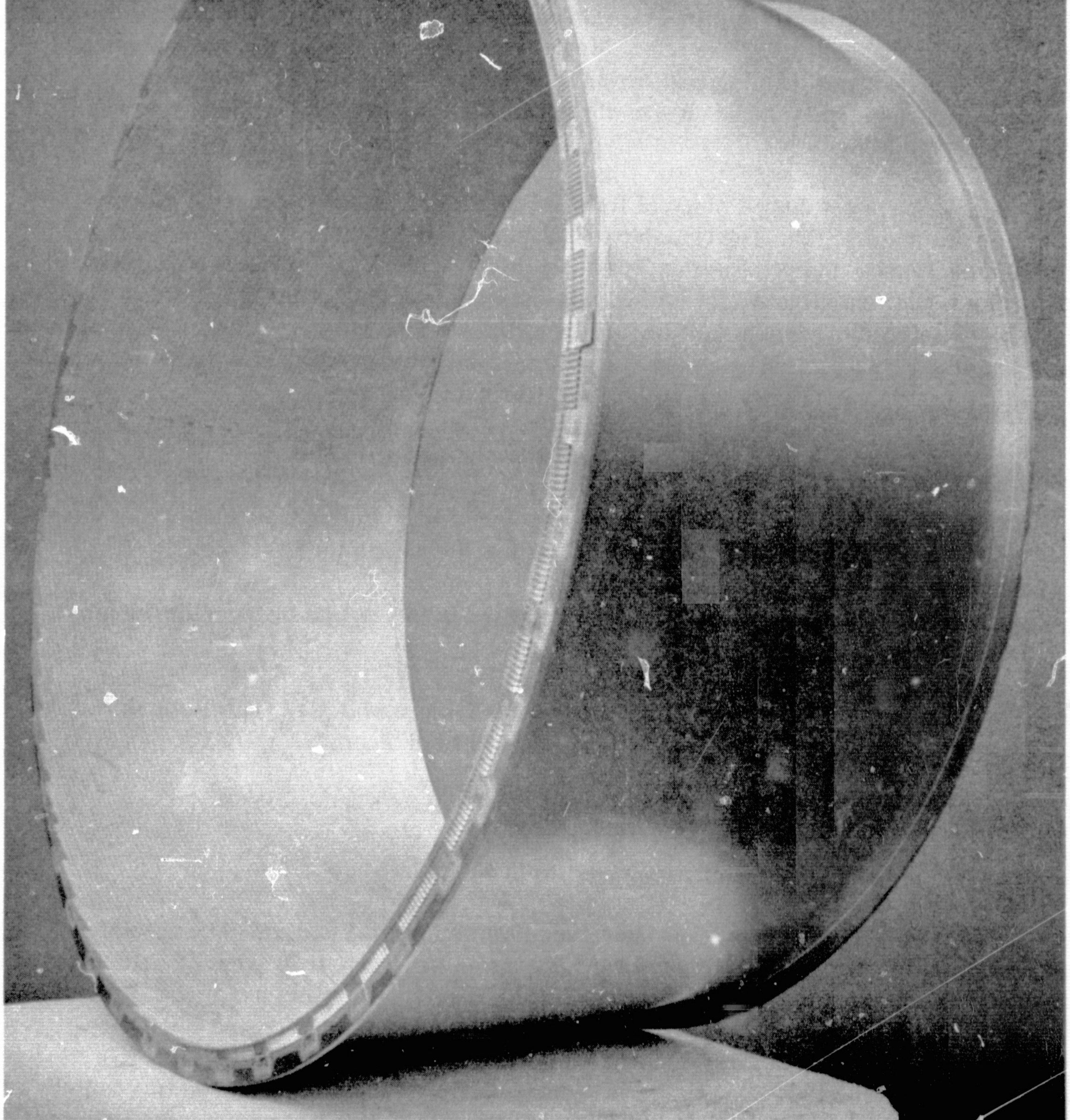

Figure 91.—JT8D Refan Brazement

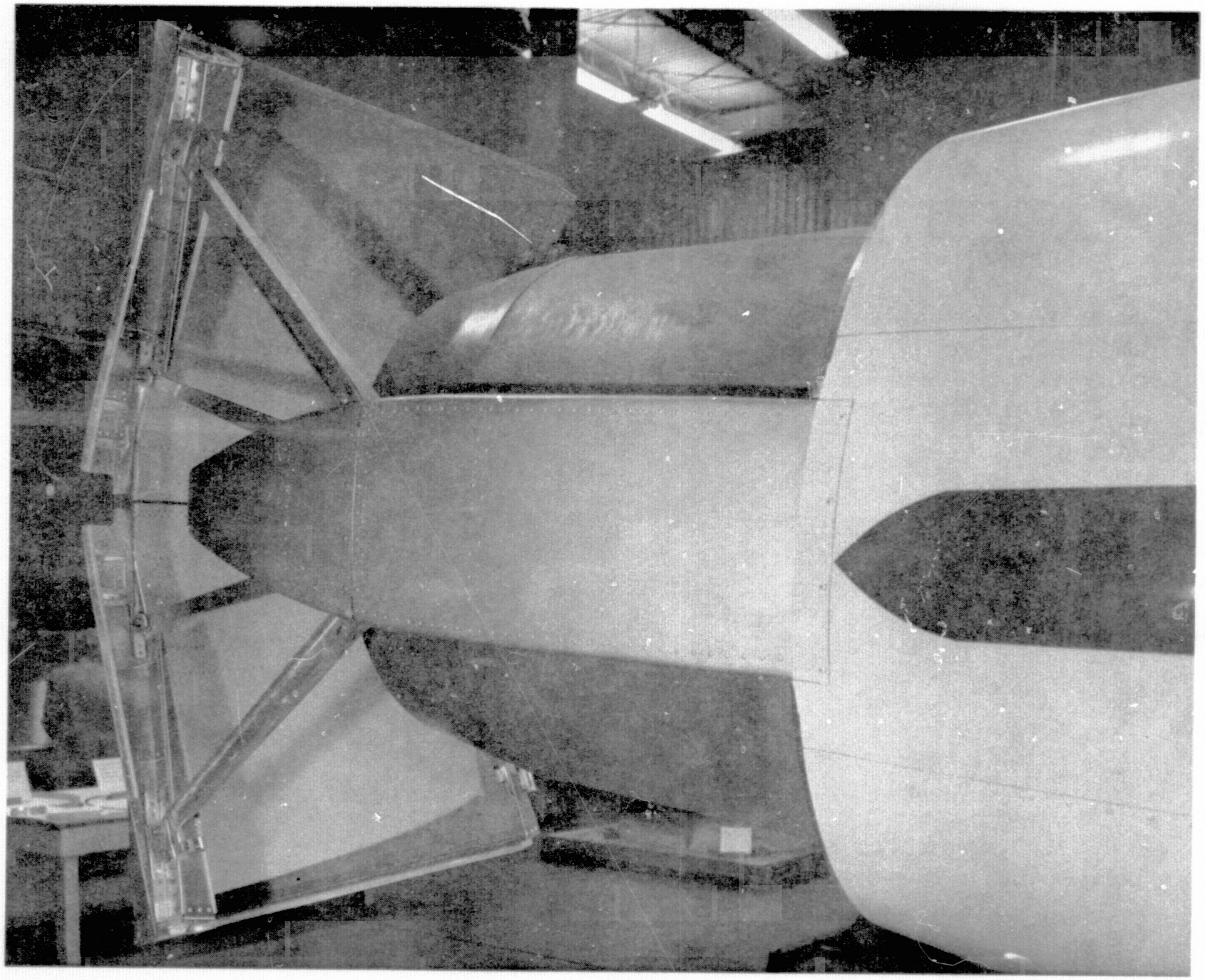

Figure 92.—JT8D Refan Thrust-Reverser Mockup

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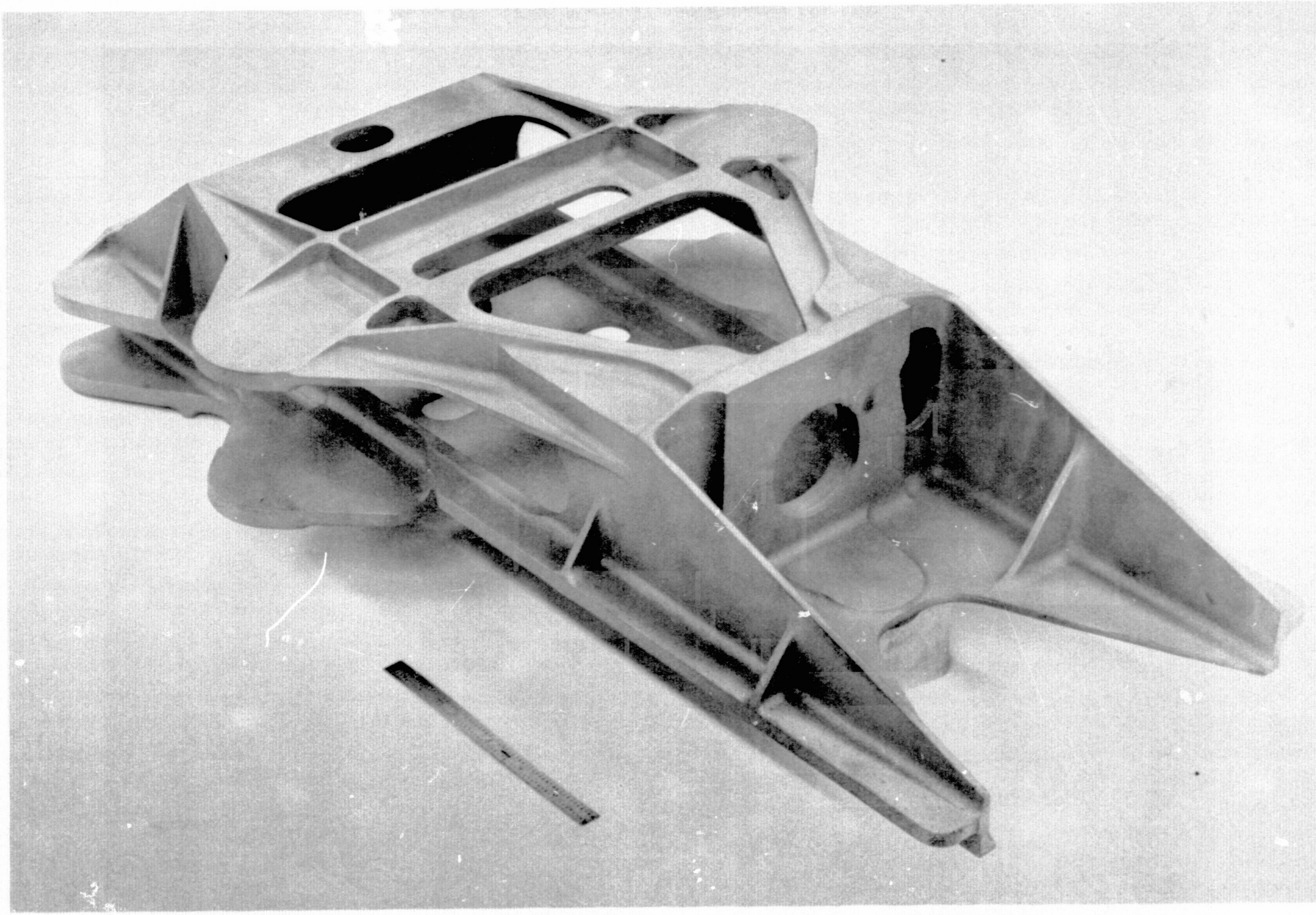


Figure 93.—JT8D Refan Thrust-Reverser Support Fitting Casting

3.2.5 CENTER-ENGINE INLET-DUCT ASSEMBLY

The flightworthy center-engine inlet-duct assembly (fig. 94) has a complex internal shape that is a continuous transition from circular section at the forward end to an ellipse at the vertical tail front spar to a circle at the engine inlet. The center-engine inlet-duct assembly was manufactured in four major sections. Three of the sections are of circumferentially continuous bonded construction with perforated-aluminum inner skin backed by structural/acoustic 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.

This configuration required a full-scale plaster model (fig. 95) that was made in two halves with aluminum headers (cross-section cuts from the internal contour lines) mounted in proper relative positions on substantial bases (fig. 96) and faired, one to another, with plaster as shown in figure 95. Lines were scribed on the plaster and identified to locate ends of the duct sections, skin and doubler trim lines, and cutouts.

All subsequent tools for center-duct details and assemblies were coordinated to the plaster model. Careful consideration was exercised to utilize as much soft tooling as possible for the limited requirement of the refan ground test program. Of the 124 tools fabricated, 62 were stretch-form blocks for inner skin panels, and 25 were Kirksite hammer dies used to form details of the inlet lip, the thermal anti-icing panel, and the flange joints. Examples of the fabrication tools (such as the center-engine inlet-duct stretch-form dies, inlet-lip hammer die, and anti-icing panel hammer die) are shown in figures 97, 98, and 99, respectively. In addition, there were shop aids and intermediate partial molds (splashes) of plaster made from the PM to fabricate both tools and detail parts.

The assembly sequence of a refan center-duct section was as follows:

1. A single-piece fiberglass-reinforced bond-assembly jig (BAJ) was prepared (fig. 100) using a plaster transfer tool (fig. 101) that duplicated the shape of the applicable section from the master model (fig. 95).

2. The perforated aluminum stretch-formed inner-skin panels and sheet aluminum splice doublers were placed on the BAJ and bonded together. The completed skin assembly is shown in figure 102.

3. The honeycomb core was fitted and bonded in place.

4. The intermediate septum was applied and bonded.

5. The outer honeycomb core was fitted and bonded.

6. The outer skin and core closeout edge-pieces were applied and bonded to complete the assembly as shown in figure 103.

7. The BAJ was physically cut apart (destroyed) and removed from the bonded assembly.

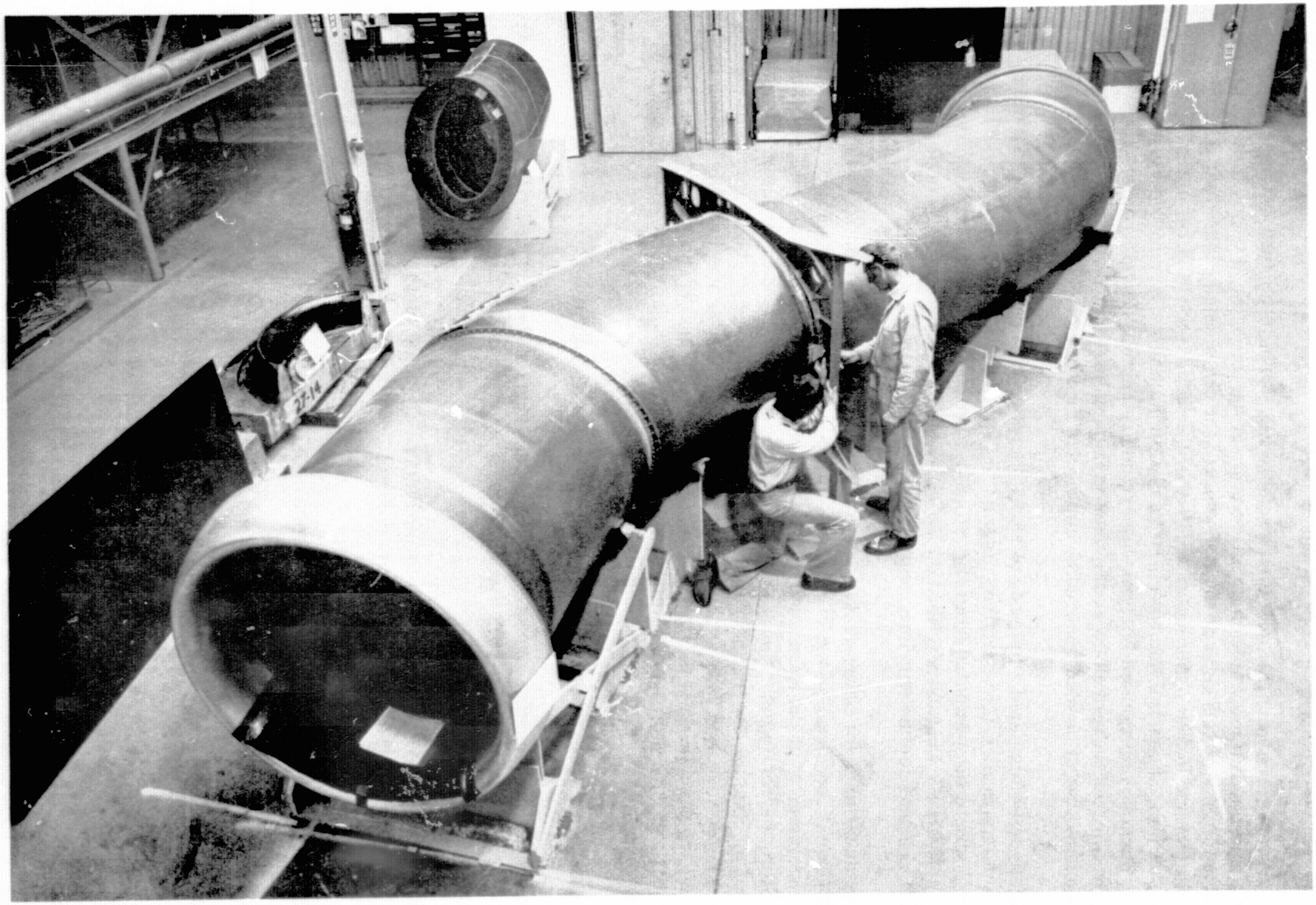


Figure 94.—JT8D Refan Center-Engine Inlet-Duct Assembly

Figure 95.—JT8D Refan Center-Engine Inlet-Duct Plaster Models

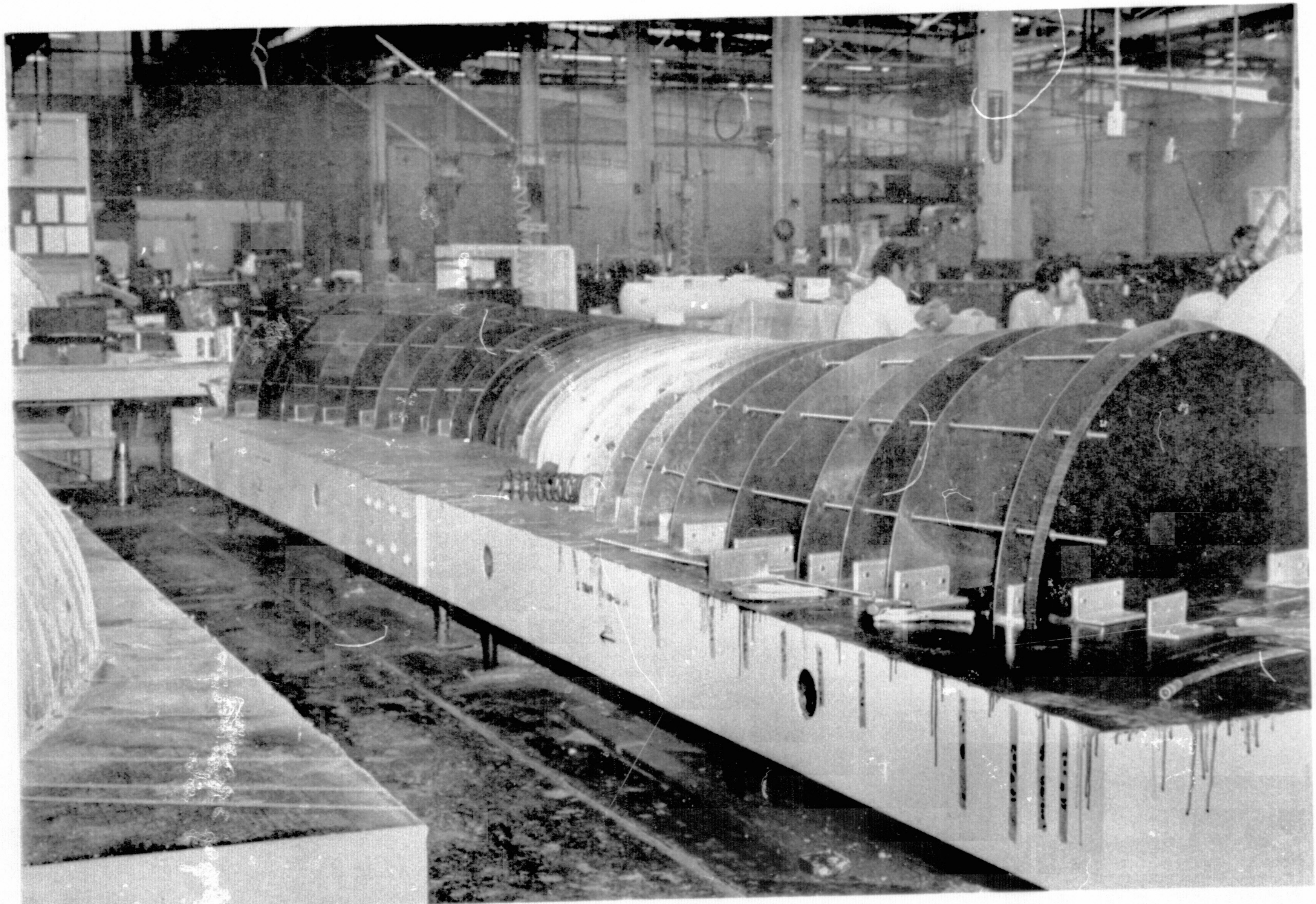


Figure 96.—JT8D Refan Center-Engine Inlet-Duct Plaster Model Preparation

Figure 97.—JT8D Refan Center-Engine Inlet-Duct Stretch-Form Dies

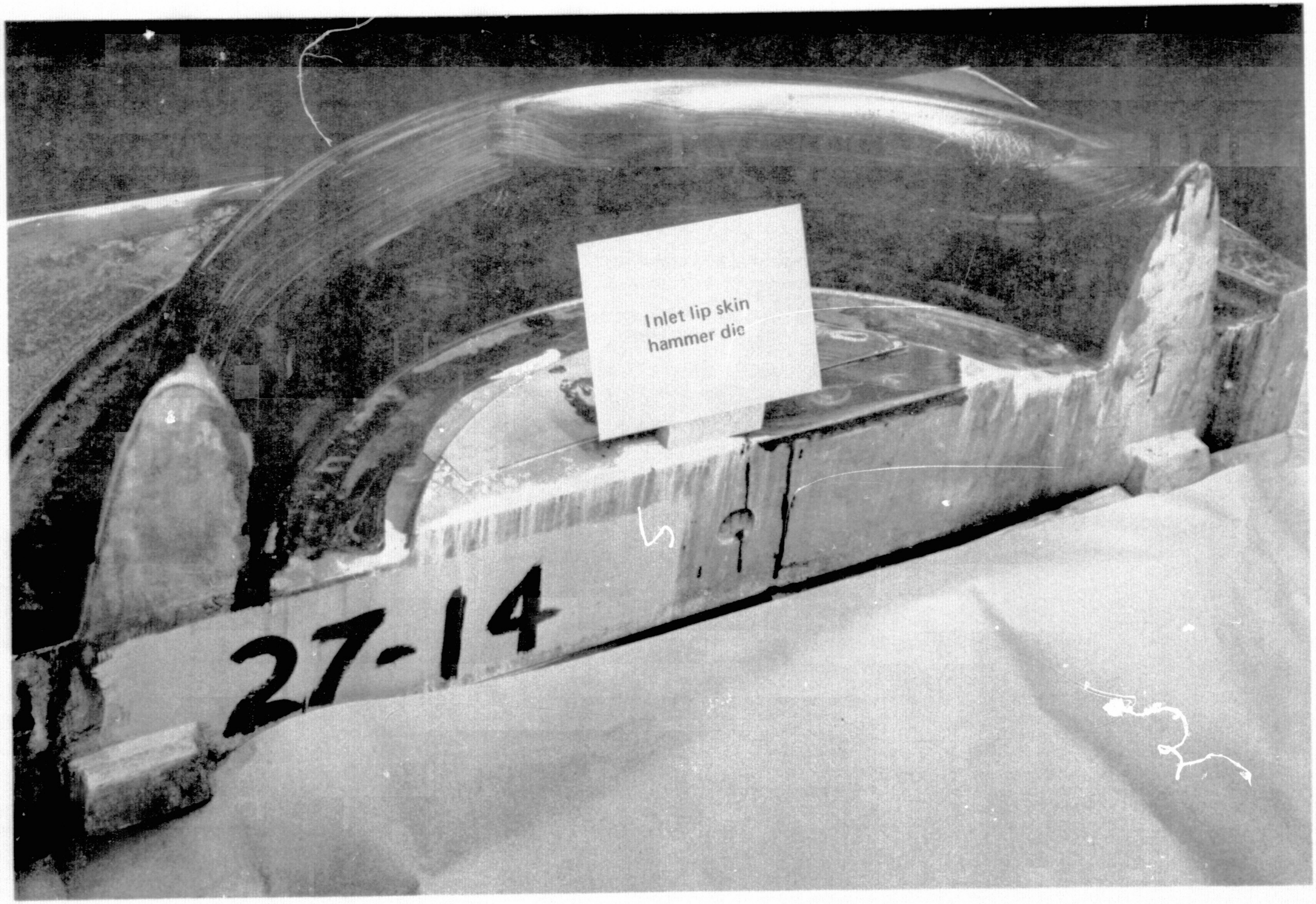


Figure 98.—JT8D Refan Center-Engine Inlet-Lip Hammer Die

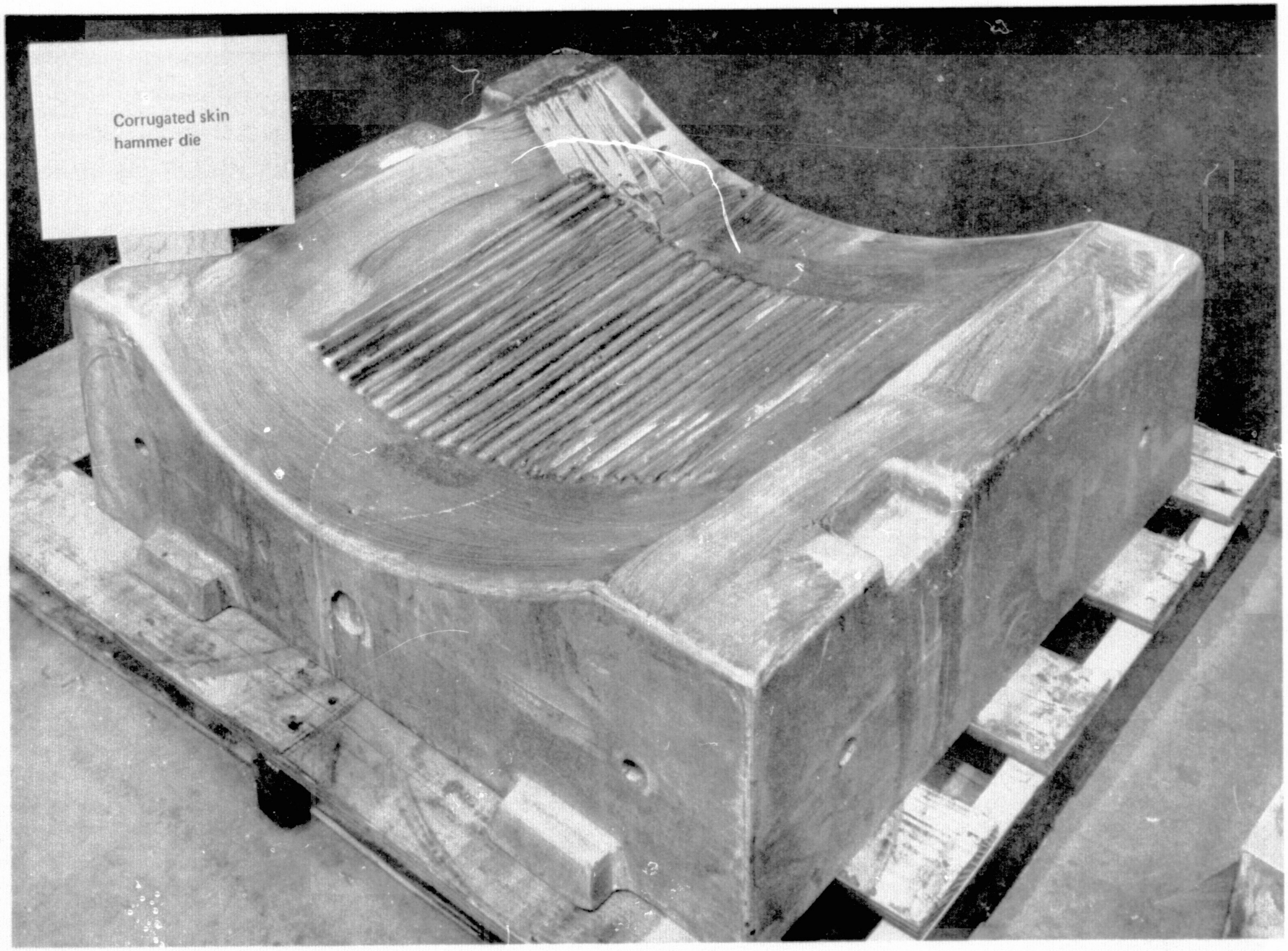


Figure 99.—JT8D Refan Center-Duct Anti-Ice Panel Hammer Die

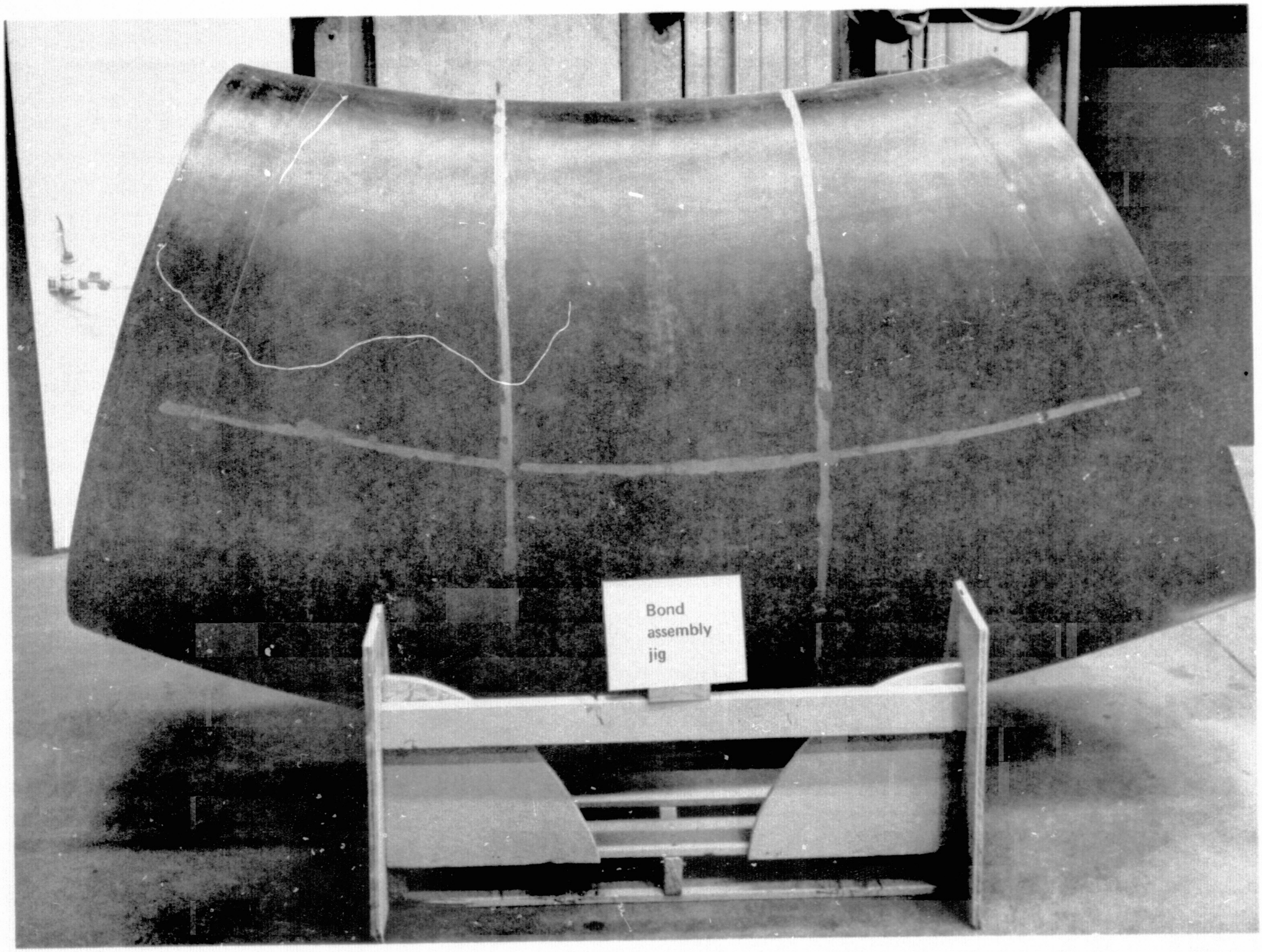


Figure 100.—JT8D Refan Center-Engine Inlet-Duct Bond-Assembly Jig

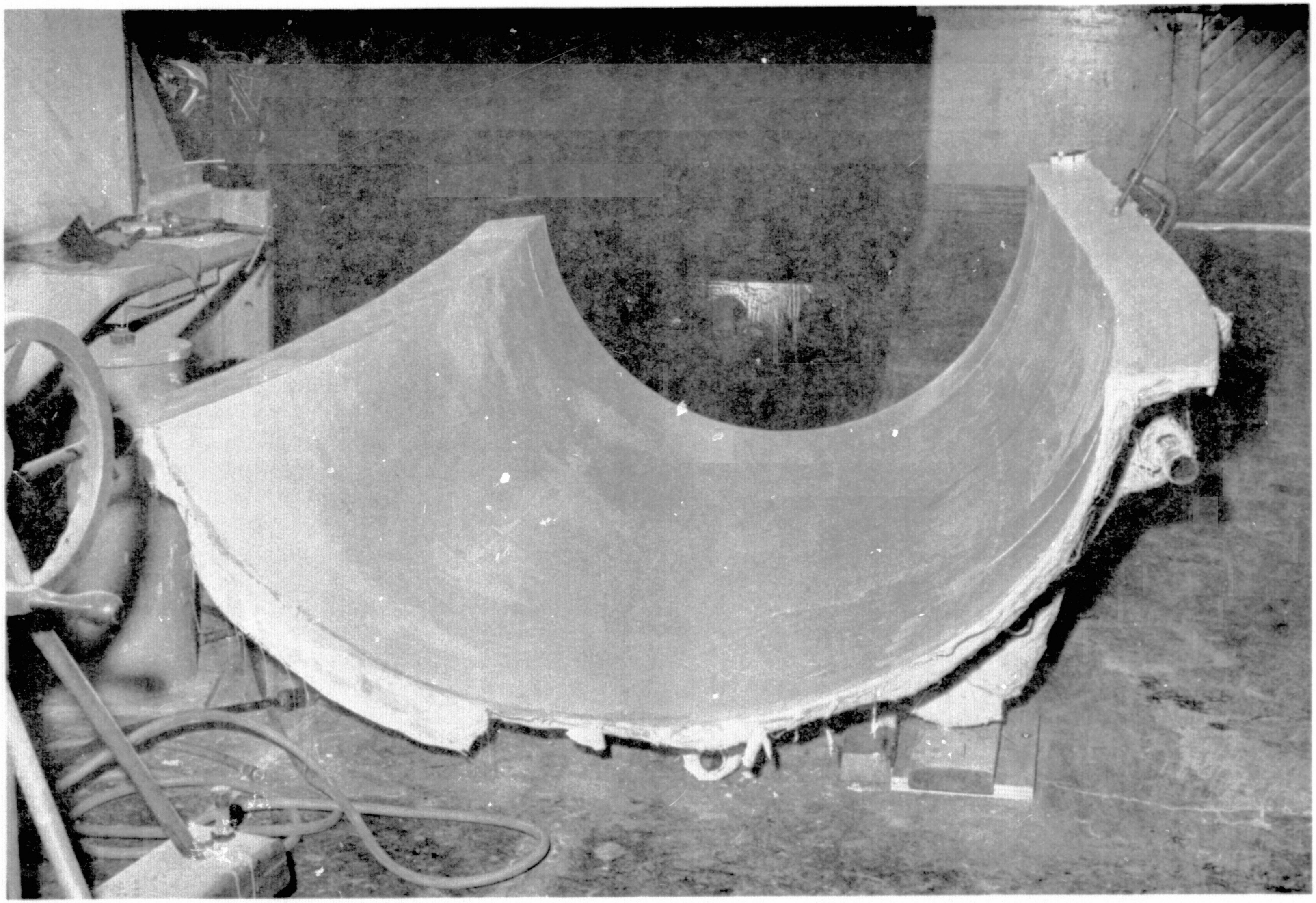


Figure 101.–JT8D Refan Center-Engine Inlet-Duct Contour Transfer Tool

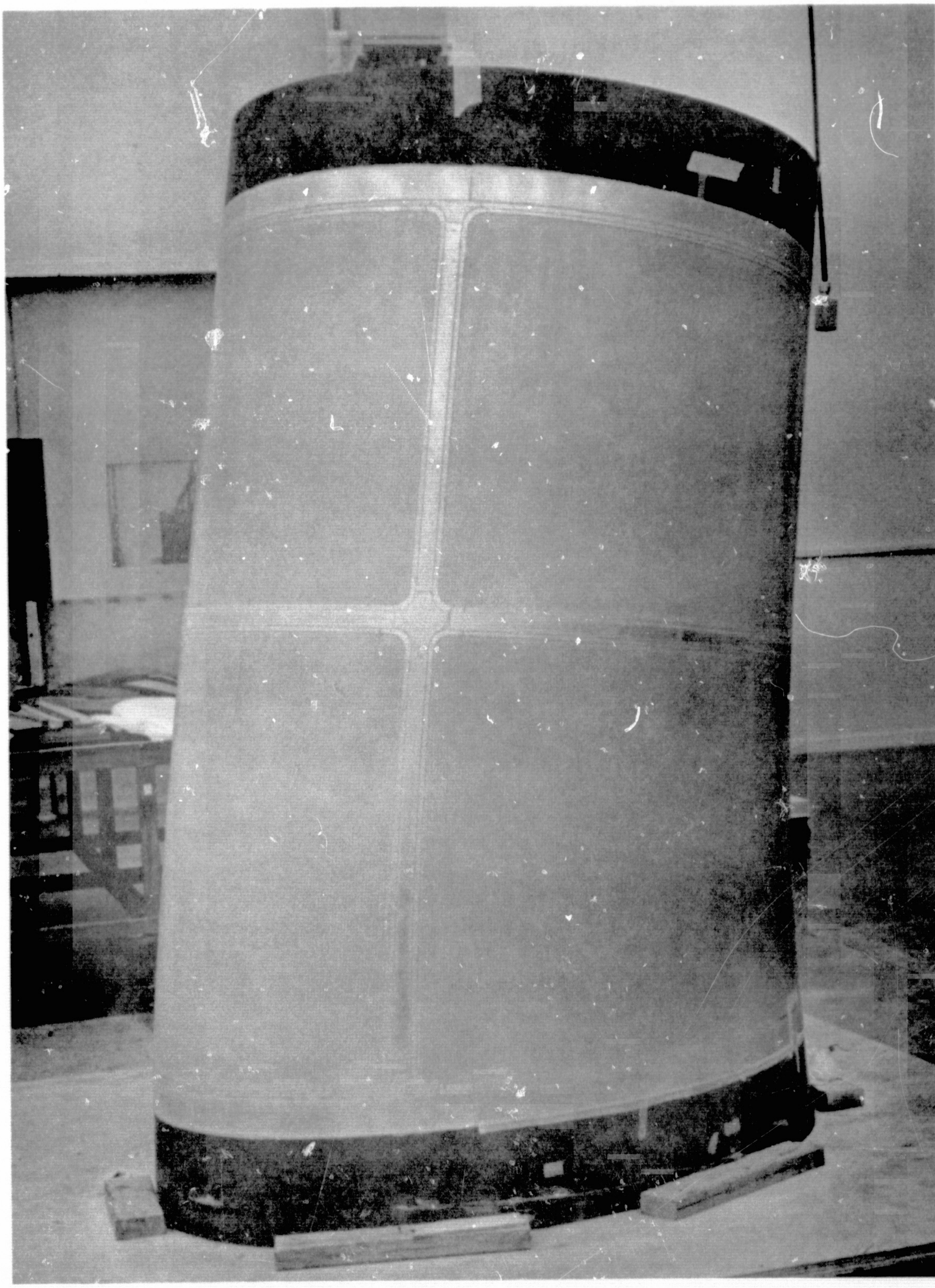


Figure 102.—JT8D Refan Center-Engine Inlet-Duct Section —Skin Bond Assembly

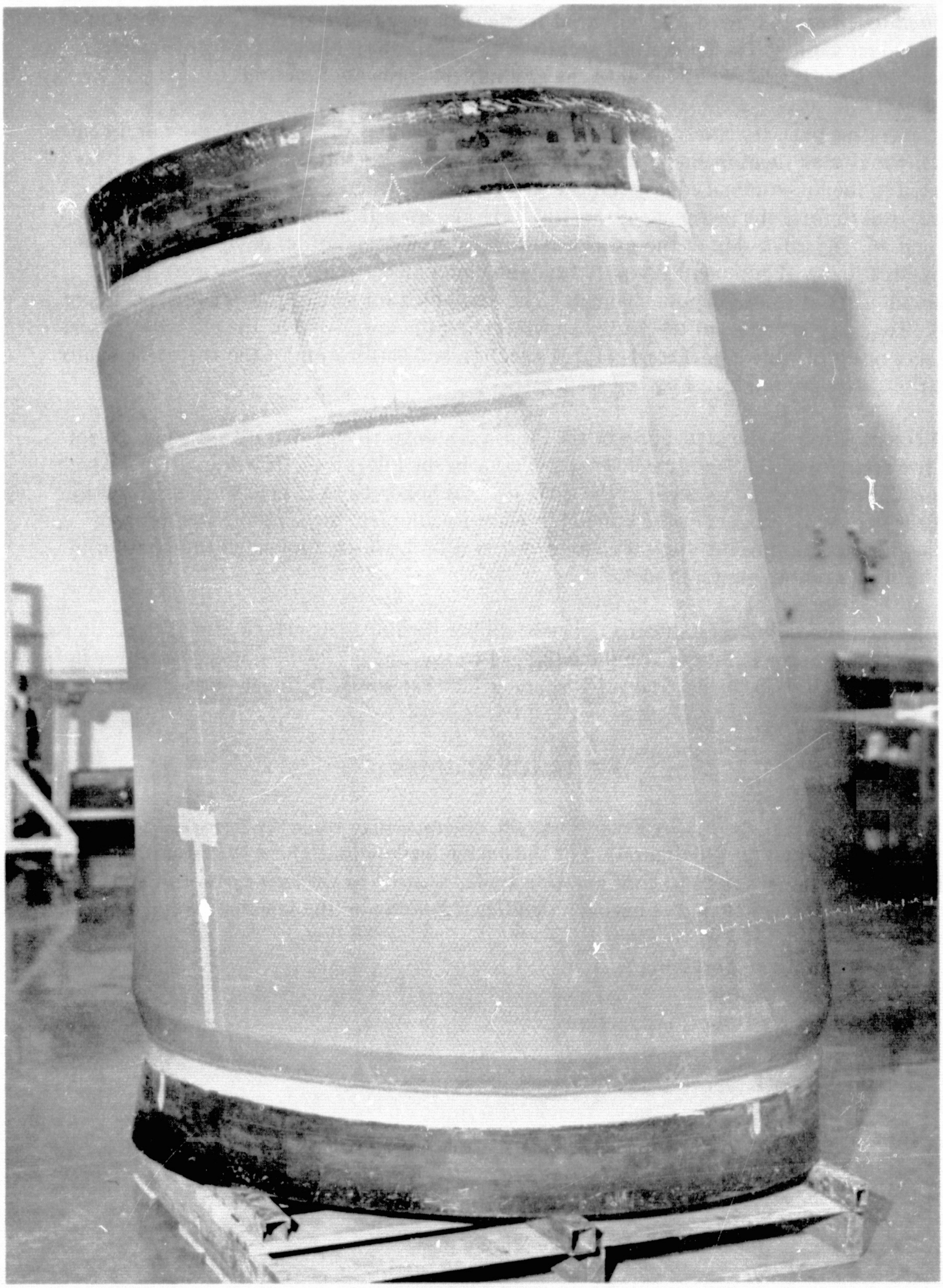


Figure 103.—JT8D Refan Center-Engine Inlet-Duct Section—Bond Assembly

The inlet lip of the center duct was constructed of skins hammer-formed in three sections, welded together, and fitted to a bulkhead frame with bolt flange attachment to the downstream duct section. The lip thermal anti-icing air distribution tube was deleted from the assembly, since it was not essential to the ground test hardware function.

The anti-icing panel assembly, which forms the upper wall of the forward elbow in the inlet duct, was riveted sheet-metal construction, similar to the existing production part. It was riveted to the longitudinal edge members of the bonded structural/acoustic honeycomb lower wall to form the complete elbow with fore and aft attachments as shown in figures 33 and 36. The inner skin of the panel was stretch-formed, and other details were hammer-formed. The use of commercially pure titanium eliminated the need for hot-forming the titanium parts of the air supply channels. The assembled forward elbow is shown in figure 104. Tentative locations of the vortex generators on the lower wall of the elbow were selected as a result of scale model tests. (Final selection and verification of the vortex generator positions were accomplished by full-scale tests.)

The construction of the aft section of the duct was similar to the forward sections, except for the presence of the fan inspection access door in the lower wall. The door frame, which forms the core closeout member in the opening, was bonded and riveted to the inner skin, and the core and outer skin were bonded in place to complete the section. The door, of similar construction to the duct, was bonded over a BAJ, which duplicated the contour of the local area on the plaster model.

The Nomex and fiberglass-reinforced silicone rubber flexible seals, which attach the center duct to the rear-spar bulkhead and the bulkhead to the engine (fig. 37), were formed as in present production methods. Seal support and attach rings were hammer-formed, welded, and riveted.

3.3 TRADE STUDIES

In the early stages of the NASA Refan Program, several design trade studies were completed as an aid in establishing the configuration of the engine installation. These studies ranged from items affecting detail design to configuration trades relating to airplane operation and community noise. Trade studies having a significant bearing on the selected design are:

- Side-Engine Inlet Anti-Icing System
- Thrust-Reverser Door Construction
- Tail Skid Design
- Inlet Access
- Center-Engine Inlet-Duct Construction
- Center-Engine Bleed to Increase Surge Margin

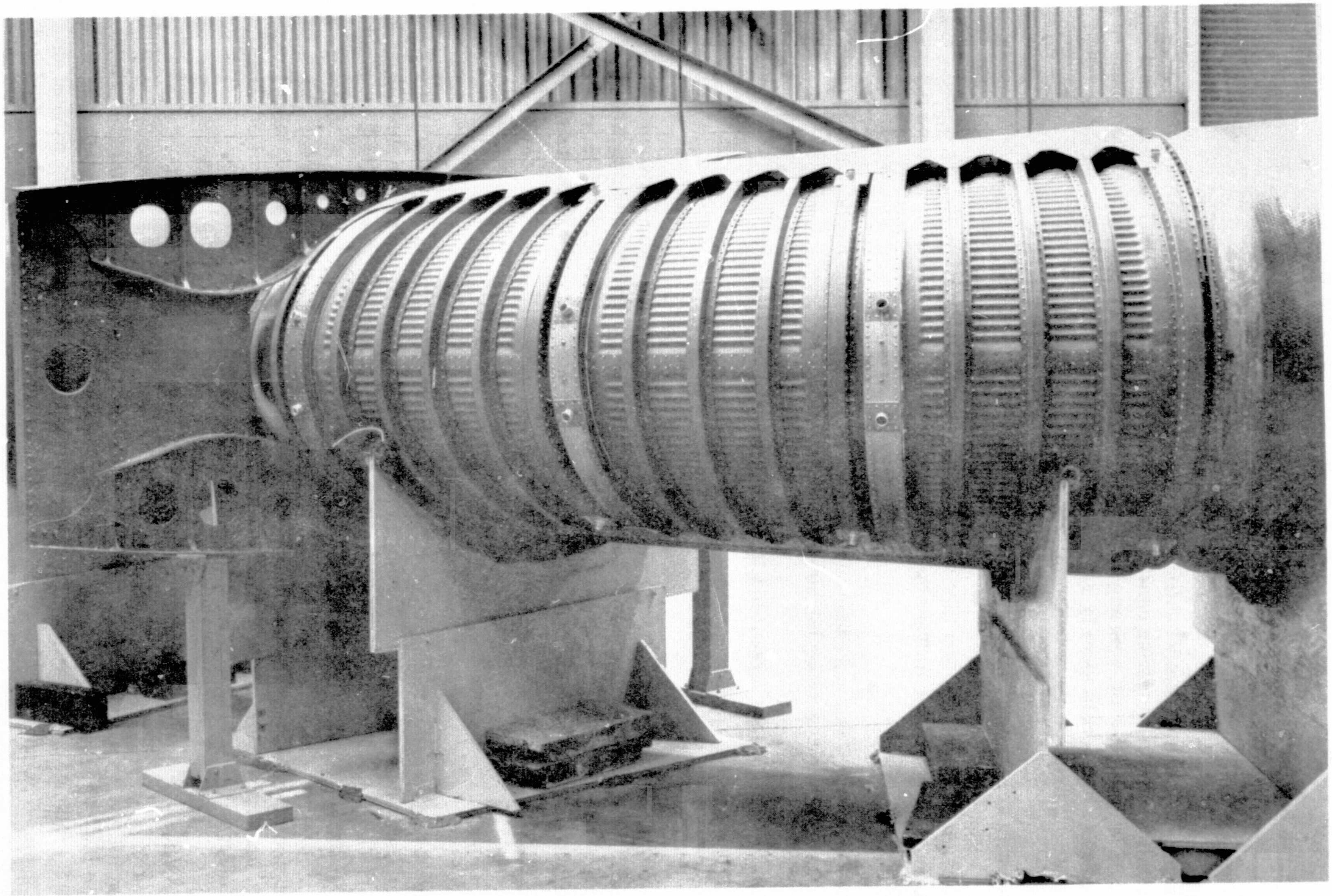


Figure 104.—JT8D Refan Center-Engine Inlet-Duct Forward Elbow With Anti-Ice Patch

- Side-Engine Inlet Acoustic Treatment
- Exhaust-System Acoustic Treatment

3.3.1 SIDE-ENGINE INLET ANTI-ICING SYSTEM TRADE STUDY

The existing 727 side-engine inlet anti-icing system (fig. 105) consists of a circumferential air distribution tube of aluminum construction mounted in the nose-cowl leading edge and supplied, through an ejector, with engine bleed air mixed with ambient air. Four concepts were studied in an effort to identify a distribution tube and support configuration that would improve the durability of the installation.

Problems with the existing system fall into three main categories:

1. Rotation of the distribution tube within its mounting clamps allows fretting of the feeder tube against the forward bulkhead, resulting in failure of the feeder tube and bulkhead.
2. The O-ring in the thermal expansion slip joint on the feeder tube has been blown out by surge pressure, allowing hot air to escape into the inlet cavity.
3. The distribution tube support brackets fail because of vibration.

3.3.1.1 Concept 1 – Improved Distribution Tube Installation

The concept shown in figure 106 supports the air distribution tube rigidly in two places spaced 180° apart. A metal bellows-type thermal expansion joint is incorporated, and the support brackets are redesigned to resist the effects of vibration. An alternative support for the distribution tube, shown in figure 107, uses one rigid mount adjacent to the feeder tube inlet and three floating links.

3.3.1.2 Concept 2 – D-Duct

This concept follows the design used on the installation for the JT9D on the 747 airplane. The duct, shown in figure 108, is basically a 0.067-in. (1.7-mm) thick aluminum sheet, formed in a semicircular section, and riveted to an insulated 0.10-in. (2.5-mm) thick aluminum forward bulkhead.

The system on the 747 uses engine bleed air reduced to 350°F (450 K) by a precooler. This relatively low temperature allows the use of aluminum as duct material, but requires a large volume of air to be circulated through the anti-ice system.

3.3.1.3 Concept 3 – High Temperature Distribution Tube

This concept, shown in figure 106, follows the design used on the installation for the CF6-50 engine on the 747 airplane. Bleed air at 724°F (657 K) is ducted directly into an Inconel 625 distribution tube mounted forward of the nose cowl leading-edge bulkhead. The exhaust air is collected in an annular chamber between the first and second bulkheads and is then ducted overboard.

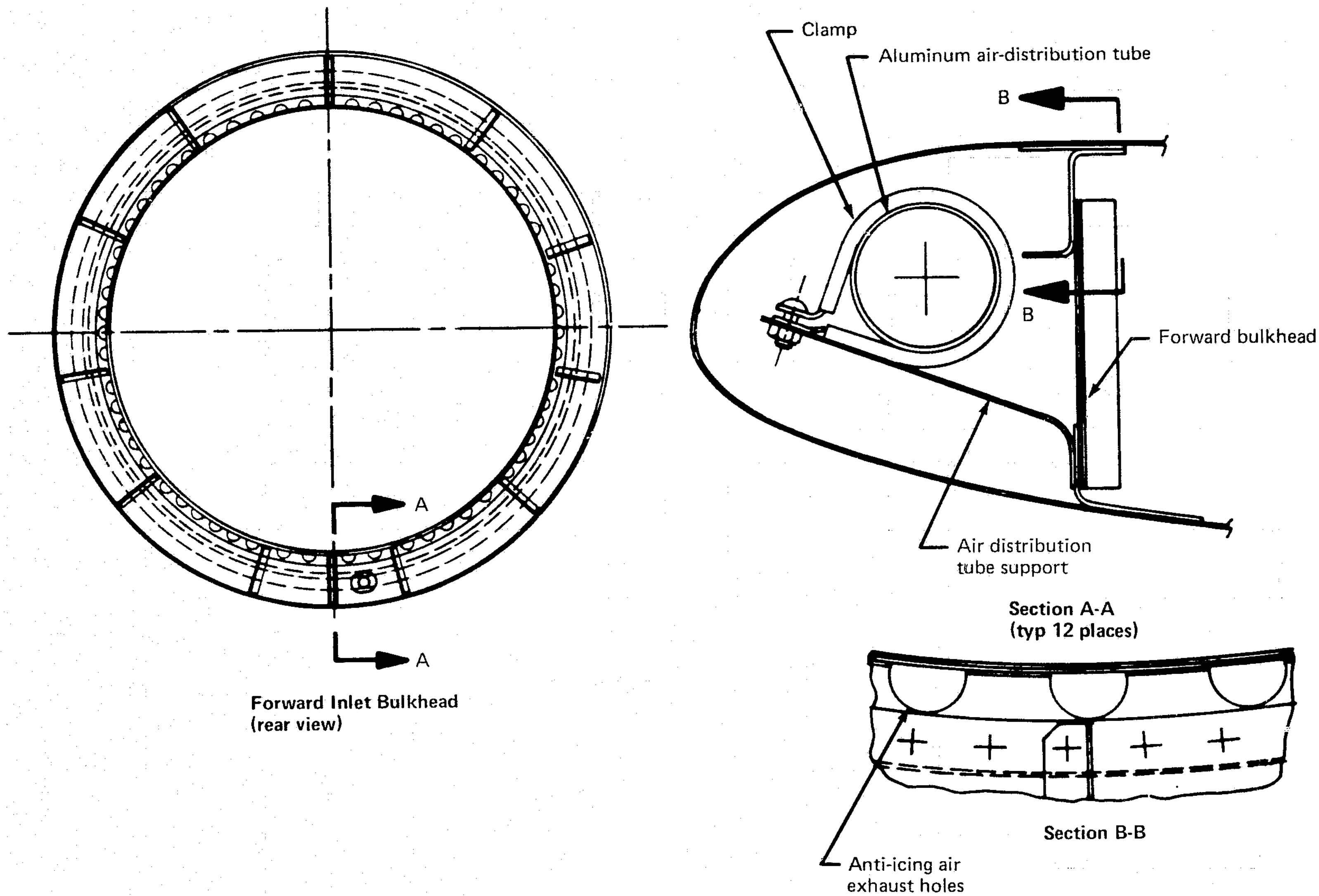


Figure 105.—Existing 727-200 Inlet Anti-Icing System Configuration

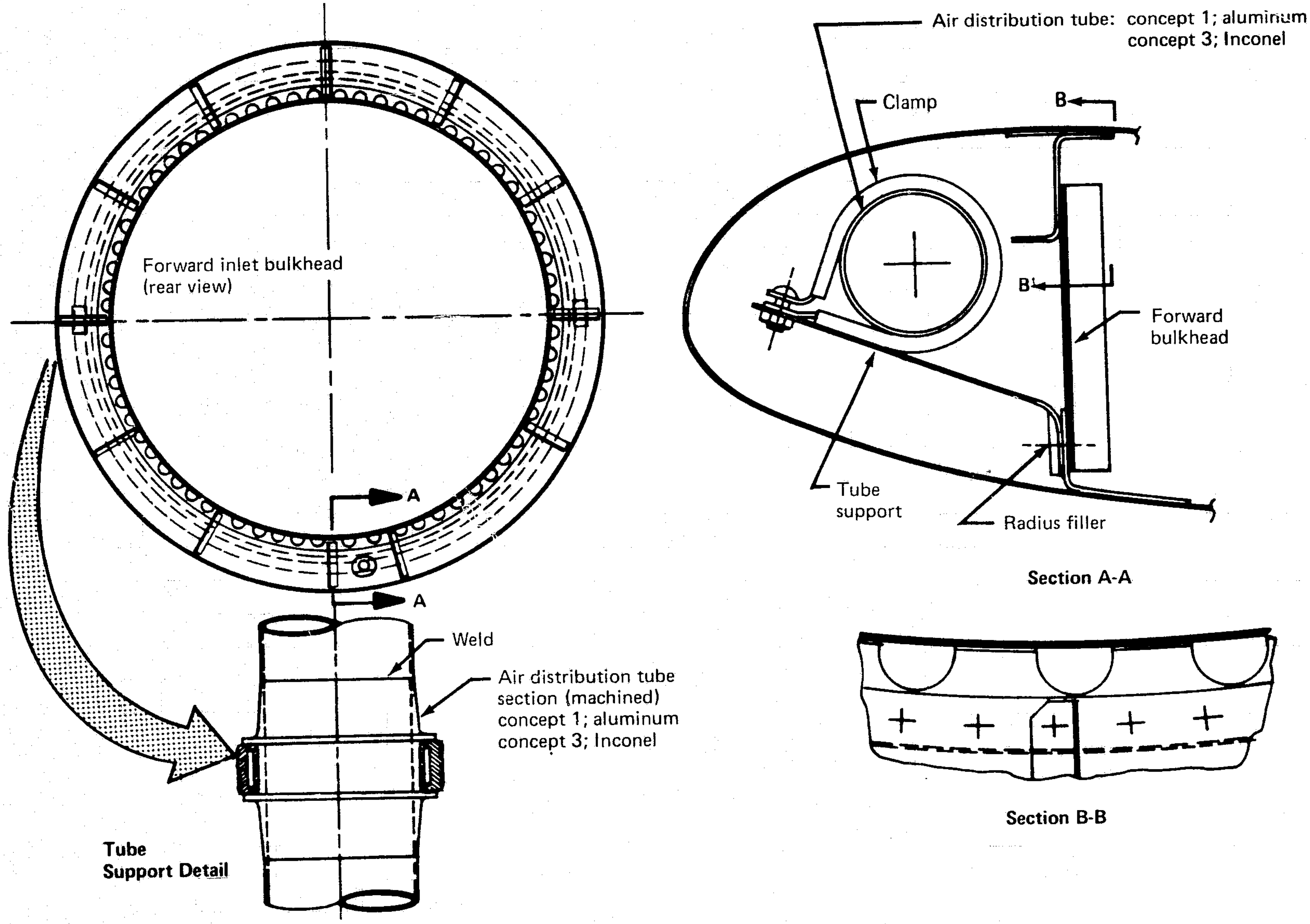


Figure 106.—Inlet Anti-Icing System Trade Study (Concepts 1 and 3)

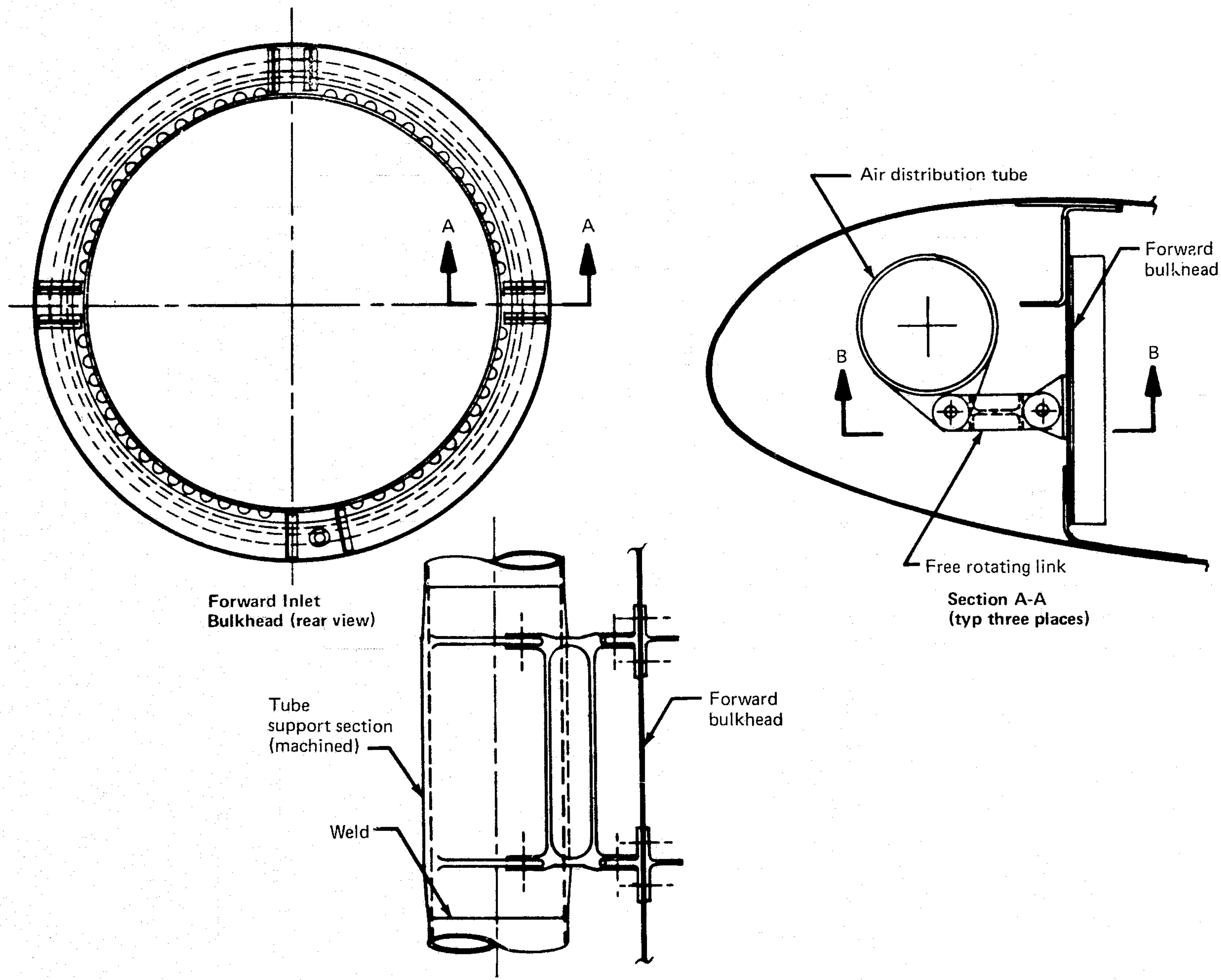


Figure 107.—Inlet Anti-Icing System Trade Study (Concept 1 Alternate Mounting)

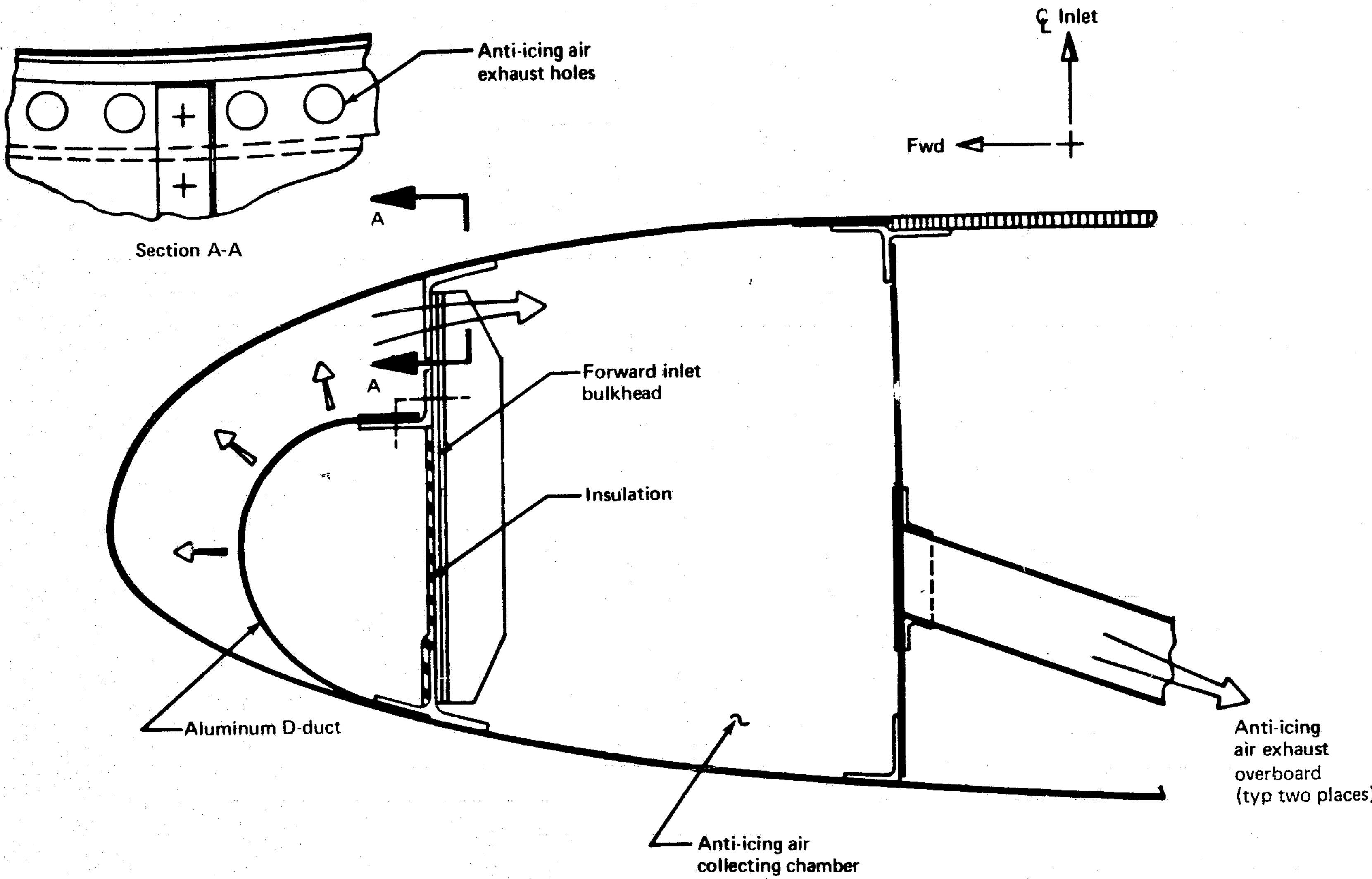


Figure 108.—Inlet Anti-Icing System Trade Study (Concept 2)

3.3.1.4 Concept 4 – Double-Skin Leading Edge

This design, shown in figure 109, uses an enlarged D-duct that forms a double skin with the nose cowl leading edge with approximately a 0.10-in. (2.5-mm) gap between the two skins. A formed leading-edge bulkhead completes the duct. Bleed air at 724°F (657 K) is used. The duct and bulkhead are both hot-formed Ti-6Al-4V.

3.3.1.5 Comparison of Concepts

Concept	Δ weight per airplane, lb (kg)	Anti-ice air temperature, °F (K)	Duct material
1	baseline	450 (505)	aluminum
2	+27 (12.2)	350 (450)	aluminum
3	+21 (9.5)	724 (657)	Inconel 625
4	+30 (13.6)	724 (657)	Ti-6Al-4V

Concept 2 requires increased airflow and with the added anti-icing requirement of an inlet acoustic splitter ring, bleed air extraction would be close to the limit. The D-duct temperature is not compatible with 727/JT8D requirements of 250°F (394 K) at hold and 450°F (505 K) at climb; i.e., if the maximum temperature at climb were reduced to 350°F (450 K), the temperature at hold would drop below an adequate level.

Concept 3 is a heavier variant of concept 1 and does not offer any improvement.

Concept 4 requires costly tooling for hot-formed parts and is even heavier than concept 1.

The changes proposed in concept 1 should alleviate the service difficulties experienced in the past. This concept is the lightest and least costly and is a system of known performance that would not require recertification.

3.3.2 THRUST-REVERSER DOOR CONSTRUCTION TRADE STUDY

A target-type thrust reverser scaled from the existing 737 reverser was selected for the 727/JT8D refan engine installation in order to utilize a proven concept and to provide maximum latitude for installation of acoustic treatment in the exhaust duct. The aft-mounted engine configuration on the 727 airplane makes it very desirable to reduce weight of all nacelle components. This trade study addresses the weight, space, and performance aspects of various target thrust-reverser door construction methods.

The doors are sized in proportion to the engine nozzle exit diameter, which is 38.48 in. (97.74 cm) for the refan engine, compared with 29 in. (73.6 cm) for the JT8D-9. The area of the reverser door is increased by 70%, and the engine thrust load, which it must sustain, is increased about 20%. Although most of the dimensions are increased 30%, the radial depth available for the target door structure is reduced 20% by the requirements for internal nozzle contours and nacelle lines. For these reasons, the most efficient door design was sought in order to hold the weight and cost to a minimum.

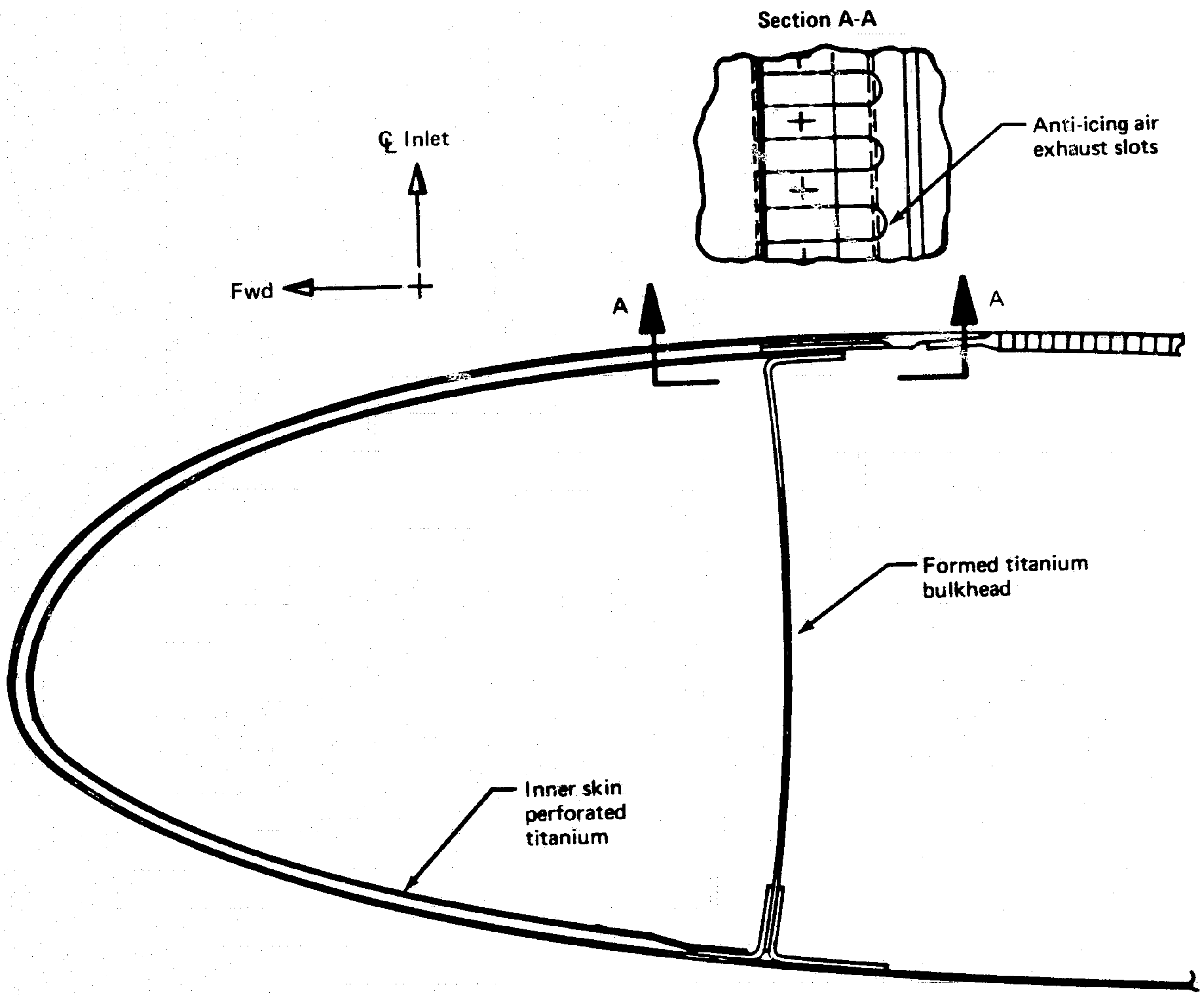


Figure 109.—Inlet Anti-Icing System Trade Study (Concept 4)

The study included review of the service history of current 737 and 727 reversers, revealing that the 737 target reverser experienced 700 000 flight-hours with only three flight delays charged to the reverser. The service data on the 727 reverser, although of a different type, indicate that 737-type target reversers can be expected to improve both the service record and the performance on the 727 refan installation.

Temperature measurements on existing 727 and 737 reversers were also reviewed and related to the exhaust temperatures from the JT8D/JT8D refan series engines in order to estimate the temperatures expected on the refan reverser.

Single- and double-skin reverser door design concepts (figs. 110 and 111) were compared. Both concepts incorporate frames terminating at the connections to the idler and drive links. The drive link frame on the single-skin door incorporates the deflector lip. Both doors are stiffened by edge members connecting the idler and drive link attachment fittings. Single-skin designs of Inconel 718 and Ti-6Al-4V, using three intermediate longitudinal beams and a 2-in. square chem-milled waffle pattern in the inner skin surface, were compared with double-skin designs of Inconel 718 and Ti-6Al-4V, using two intermediate frames and aluminum 2219 outer skins. These design concepts were analyzed for shear buckling strength, bending from gas and air loads, hoop tension stress, thermal stress, acoustic fatigue, inertia loads, and mechanical and thermal fatigue.

Table 9 summarizes the results of the study. There are only small weight savings in the single-skin door. While the thermal stress caused by exhaust gas contact is substantially less in the single-skin construction, this gain is offset by the stress in the unsupported flanges of the stiffening members. Substantial weight savings were indicated with the use of titanium over Inconel 718.

Based on this study, the double-skin door using titanium inner skin and aluminum outer skin had the least weight and most proven design and, therefore, was selected to be used for the refan design.

3.3.3 TAIL SKID DESIGN TRADE STUDY

The tail skid configuration initially proposed for the 727-200 refan airplane utilized an extended tip, a hard spacer to replace the production ring-spring assembly, and a 33 000-lb (146 784-N) crushable cartridge designed to limit the energy absorber stroke to 6.3 in. (16.0 cm).

An alternate concept, shown in figure 70, incorporates a ring spring in combination with a crushable cartridge. The energy absorber stroke is increased to 8.2 in. (20.8 cm), and the airplane rotation angle at tail-skid ground contact is reduced from 9.8° to 9.6°. Cartridge contact at 9.9° and crushed condition at 10.6° rotation remain the same for both configurations. Addition of the ring spring and increased travel in the energy absorber allow the loads on the spring and cartridge to remain as currently designed (fig. 112) with a stroke slightly less than the current 727-200 configuration.

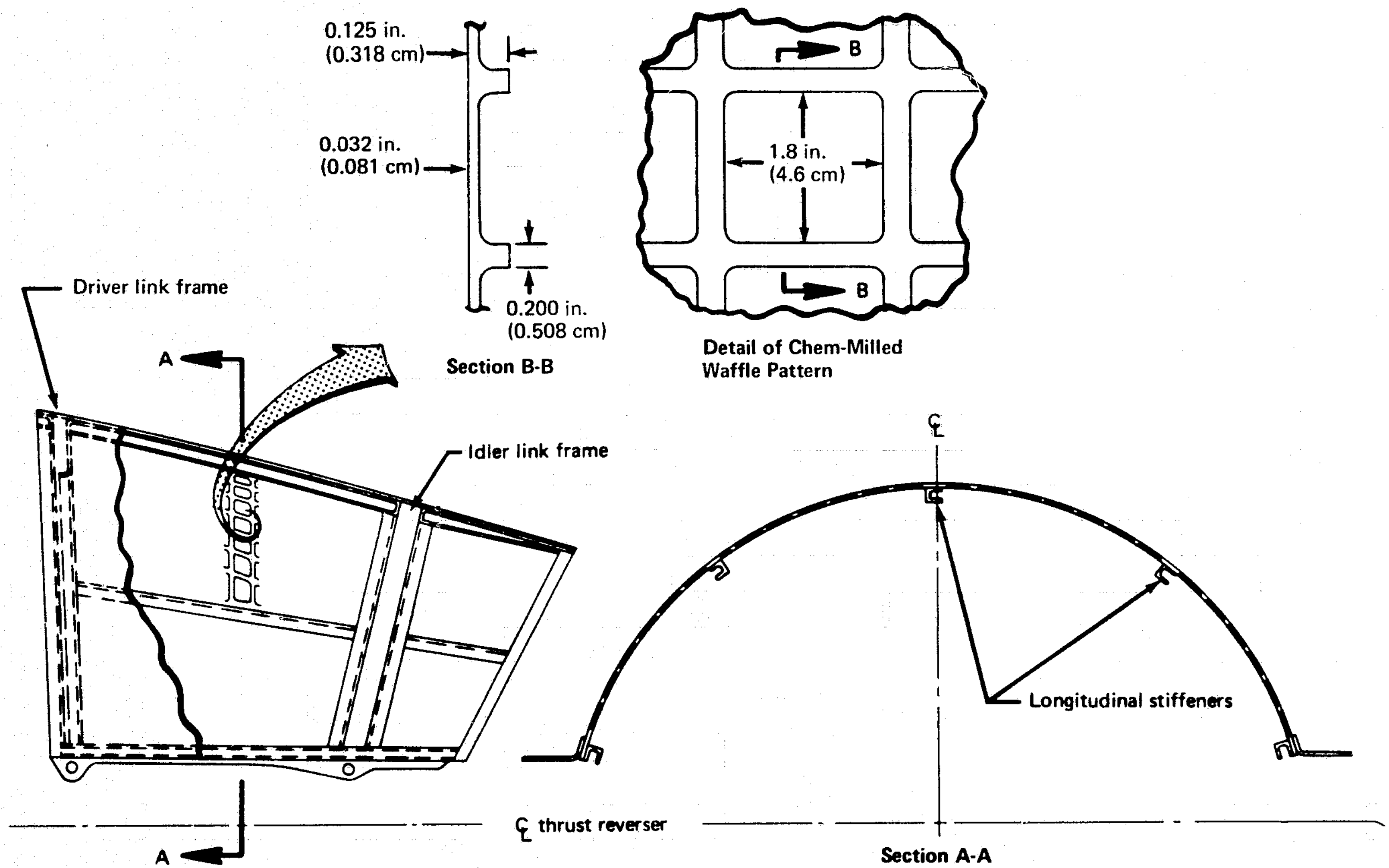


Figure 110.—Thrust-Reverser Door Construction Trade Study—Single Skin Door

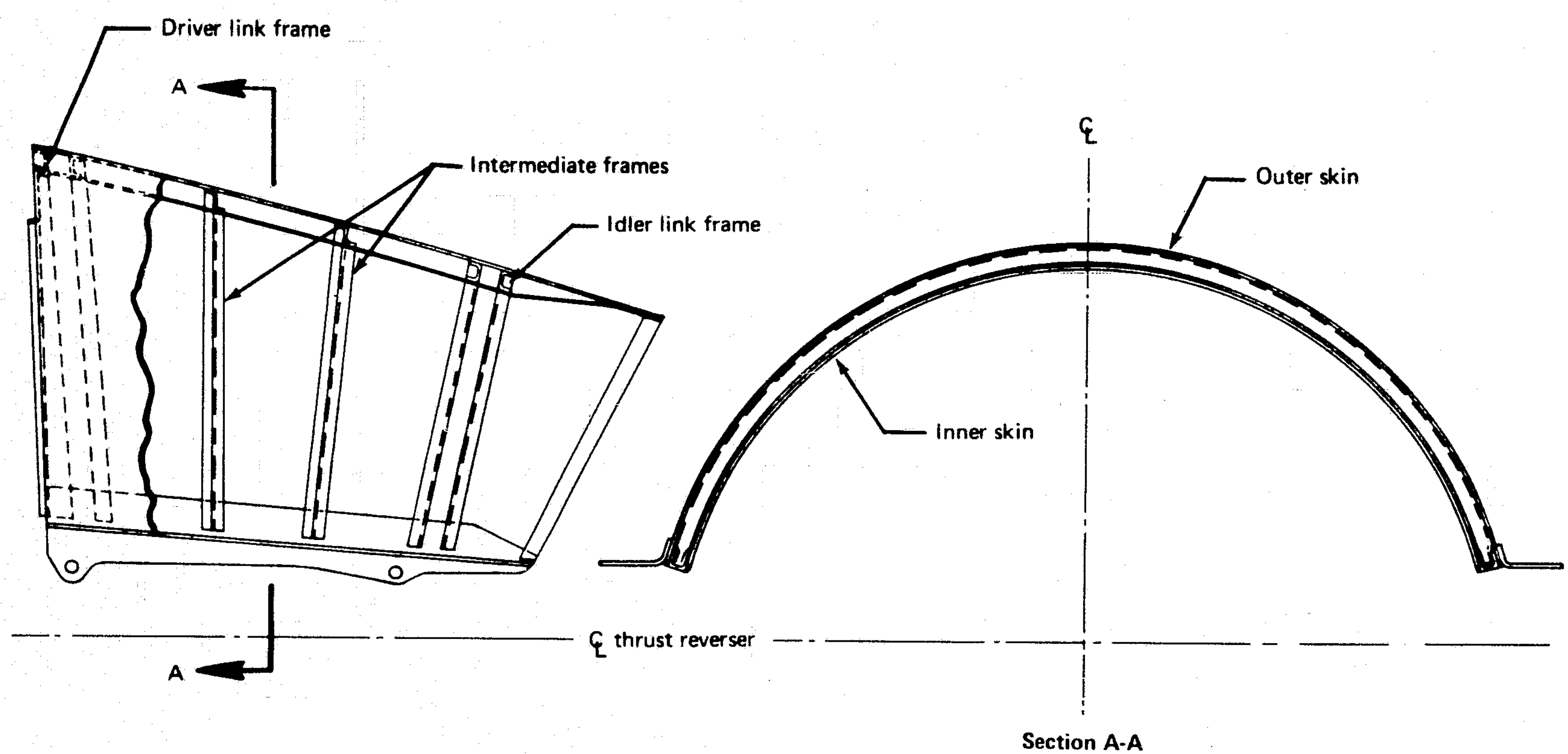


Figure 111.—Thrust-Reverser Door Construction Trade Study—Double Skin Door

Table 9.—727 JT8D Refan Double-Skin Versus Single-Skin Target Thrust-Reverser Door

Door configuration	Estimated weight, lb (kg)	No. of parts	No. of fasteners	Weld-ability	Access-ibility	Fabrication operations	Remarks
Double-skin Inconel 718 and aluminum 2219	100 (45.3) per door	36	1360	Very good	Poor	Forging Hot forming Blind rivets Countersunk rivets	737 type proven performance and reliability; high thermal stress in frames
Double-skin Ti-6Al-4V aluminum 2219	80 (36) per door	36	1360	Good	Poor	Forging Hot forming Blind rivets Countersunk rivets	737 type proven performance and reliability; high thermal stress in frames
Single-skin Inconel 718 waffle pattern in skin	Flat: 105 (47.6) per door waffle: 100 (45.3) per door	30	900	Very good	Excellent	Forging Hot forming Chem milling Countersunk rivets	More efficient structure; low thermal stress; easy inspection and repair
Single-skin Ti-6Al-4V waffle pattern in skin	Flat: 78 (35) per door waffle: 75 (34) per door	30	900	Good	Excellent	Forging Hot forming Chem milling Countersunk rivets	More efficient structure; low thermal stress; easy inspection and repair

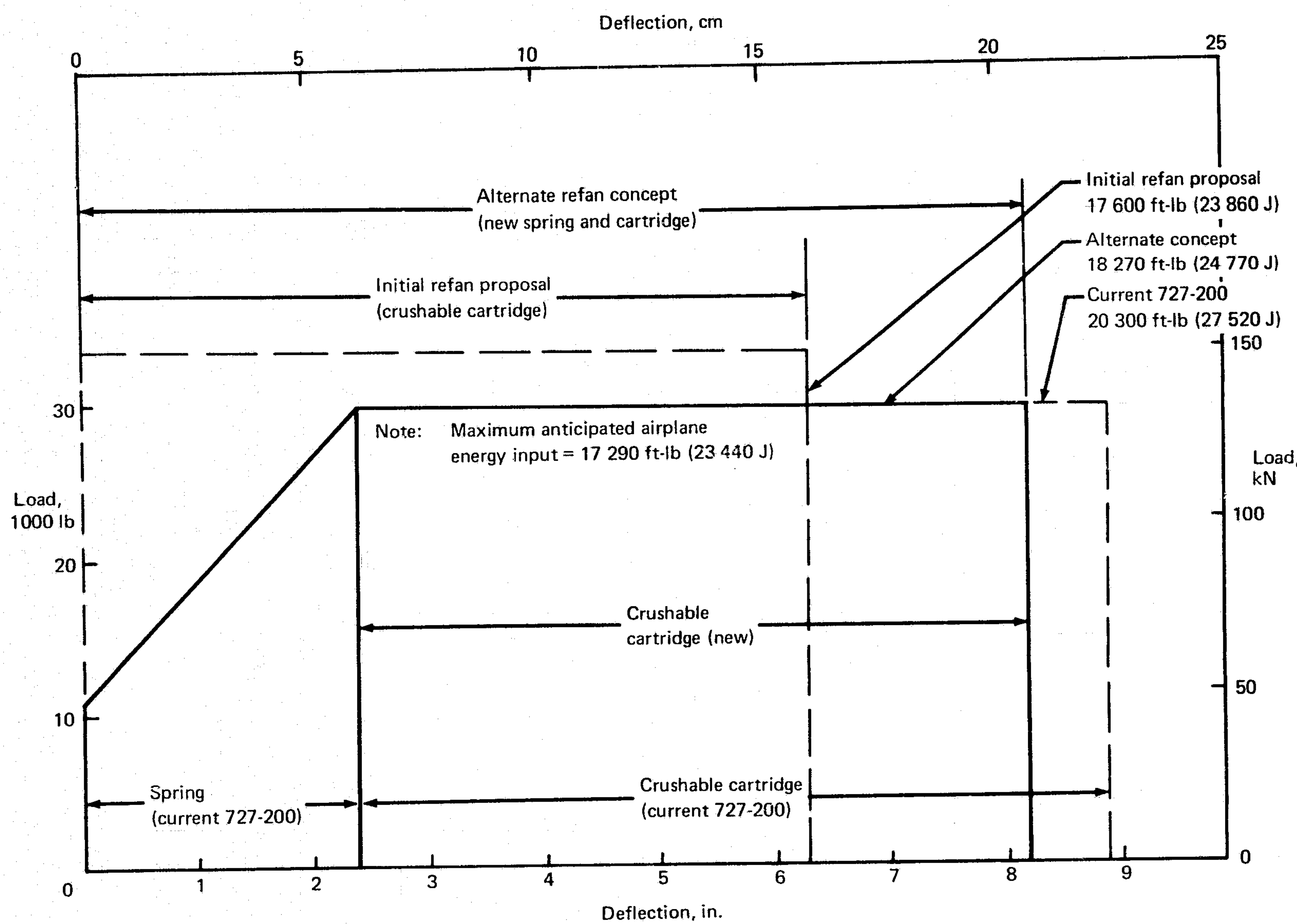


Figure 112.—Energy Absorber Characteristics—Tail Skid Trade Study

A comparison of operating attitudes relative to tail-skid geometry and center-engine clearance is presented in table 10. The table shows the ground rotation operating bands as well as center-engine clearance with the ground. With the alternate configuration, clearance between the ground and skid tip is maintained in the critical takeoff mode, but the 2.5-in. (6.3-cm) increase in absorber stroke results in less rotation available with a normal 5° flap takeoff. Takeoff with 5° flap represents a minor portion of the operating envelope. This suggests that the limited skid strike potential, combined with the softer initial contact afforded by the ring spring, would favor a potential reduction in mechanical and structural fatigue, tip damage, and cartridge replacement. This configuration was selected for incorporation into the design to produce a skid contact at 9.6° as previously described in section 3.1.7.1 under Tail Skid. The aerodynamic performance was changed to provide a positive rotation clearance of 0.15°, which resulted in a small increase in takeoff field length for the 5° flap condition.

3.3.4 SIDE-ENGINE ACCESS TRADE STUDY

The addition of an acoustic ring in the 727/JT8D refan side-engine inlet greatly reduces the access for inspection and maintenance of the fan. Two hinge concepts were studied as alternates to the 24-bolt fan-case flange attachment to reduce nose cowl removal time. A third configuration, not a part of this trade study, involved removal of the inlet ring and was chosen for incorporation in the refan engine design (described in sec. 3.1.1).

Concept 1, shown in figure 113, incorporates simple hinges mounted on the engine front flange and retains the 24 bolts to attach the nose cowl.

Concept 2, shown in figure 114, replaces the hinges by tracks and slide blocks, allowing the cowl to move forward on the engine centerline for a short distance before rotation. This allows the use of a combination of bolts and shear pins to attach the nose cowl.

The number of parts and the weight for each concept are compared as follows:

Concept	No. of parts per airplane	Weight per airplane, lb (kg)
1	12	18.0 (8.16)
2	34	41.0 (18.6)

Both approaches reduce the access time for checking the front engine face.

Concept 1 is lighter and less costly (as gaged by number of parts) and reduces inspection time by not requiring total removal and replacement of the nose cowl. Concept 2 is heavier and has more parts, but, because of a reduced number of fasteners, would require considerably less time for opening the nose cowl.

Concept 1 appears to be the better compromise, considering weight, cost, and time saved per inspection. However, subsequent study resulted in choosing the concept previously discussed in section 3.1.1.

The concept chosen required only the removal of the inlet ring to permit timely access to the fan disc for inspection without the attendant weight penalty for hinges in concepts 1 and 2.

Table 10.—727-200/727 Refan Ground Rotation Body Attitude and Tail Skid Summary

Model	Flap setting, deg	Ground rotation angle, deg				Clearance to tail skid contact, deg	Clearance to cartridge contact, deg	Center engine ground clearance, in. (cm)		
		Normal liftoff	Skid contact	Cartridge contact	Skid max comp			At takeoff	At tail skid contact	At tail skid max comp
Existing production, cartridge and spring	5	9.8	10.0	10.3	11.22	0.2	0.5	20.0 (50.8)	16.5 (41.9)	2.0 (5.1)
	15	9.1	10.0	10.3	11.22	0.9	1.2	29.0 (73.7)	16.5 (41.9)	2.0 (5.1)
	25	8.1	10.0	10.3	11.22	1.9	2.2	39.5 (100.3)	16.5 (41.9)	2.0 (5.1)
Refan initial proposal, cartridge only	5	9.65	9.8	9.9	10.6	0.15	0.25	12.4 (31.5)	10.5 (26.7)	0.62 (1.57)
	15	9.1	9.8	9.9	10.6	0.7	0.80	21.7 (55.0)	10.5 (26.7)	0.62 (1.57)
	25	8.1	9.8	9.9	10.6	1.7	1.80	34 (86.6)	10.5 (26.7)	0.62 (1.57)
Refan alternate, cartridge and spring	5	9.45	9.6	9.9	10.6	0.15	0.45	12.4 (31.5)	13.0 (33.0)	0.62 (1.57)
	15	9.1	9.6	9.9	10.6	0.5	0.80	19.2 (48.8)	13.0 (33.0)	0.62 (1.57)
	25	8.1	9.6	9.9	10.6	1.5	1.80	31.6 (80.3)	13.0 (33.0)	0.62 (1.57)

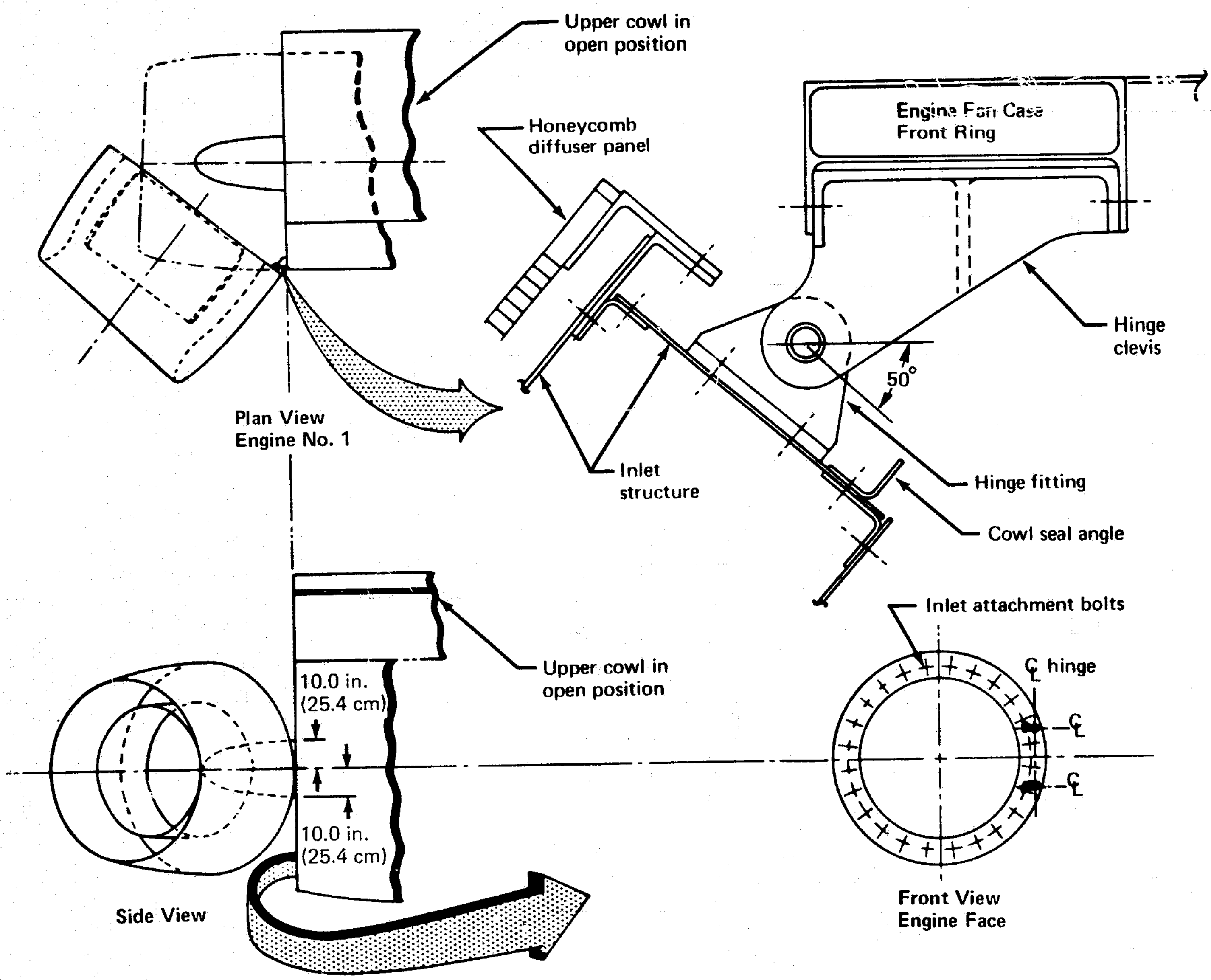


Figure 113.—Inlet Access Trade Study (Concept 1)

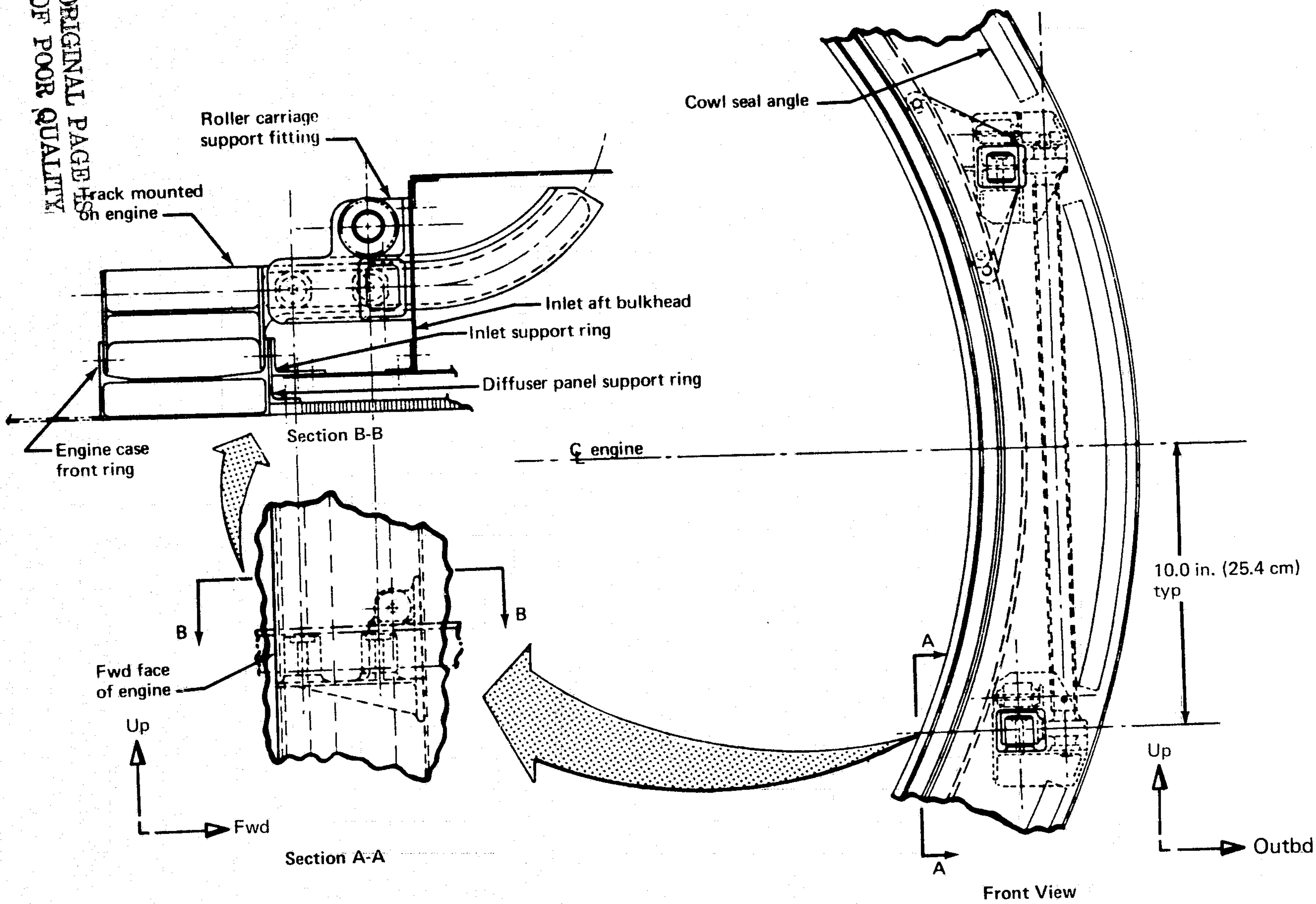


Figure 114.—Inlet Access Trade Study (Concept 2)

The selected concept also had the added feature of permitting aircraft dispatch without the ring installed in the event of ring damage.

3.3.5 CENTER-ENGINE INLET-DUCT CONSTRUCTION TRADE STUDY

Structural stiffness and weight of three types of construction were evaluated in an effort to guide the design of the refan center-engine inlet duct toward minimum cost and weight. These included an aluminum-honeycomb duct, an epoxy/fiberglass duct, and a skin and frame duct construction similar to that used on the 727 production center-engine inlet duct.

Radial deflections and stresses were computed for each of the three configurations in the elliptical cross-section region of the duct. The ducts were sized in two ways to provide: (1) the same strength and (2) the same stiffness as the aluminum-honeycomb duct. Relocating duct joints to positions of minimum stress was investigated to determine the effect on deflections.

Table 11 shows the radial deflections of the three duct configurations at the major and minor axes of the ellipse at the tail-fin front spar location for two conditions: (1) engine surge pressures and (2) for normal operating pressures. Resulting deflections for each duct are presented for two longitudinal joint positions: (1) at the major axis and (2) at the point of minimum stress, approximately 50° from the minor axis.

The relative weights of the three duct configurations are shown in table 12 when they are designed, first, for the same strength and then designed for the same stiffness. The aluminum-honeycomb duct was chosen as the baseline configuration.

Various methods of anti-icing the ducts were considered. An electrical system was studied for the epoxy fiberglass-honeycomb duct. To compensate for the low thermal conductivity of fiberglass, a conductive coating applied to the inner surface of the inside duct skin or, alternatively, an electrical grid embedded in the skin was considered. For the aluminum-honeycomb and skin/frame ducts, the hot-air anti-icing system, similar to the type used on the 727 production center duct, was studied. The effect of orienting the corrugated skins circumferentially instead of longitudinally was assessed.

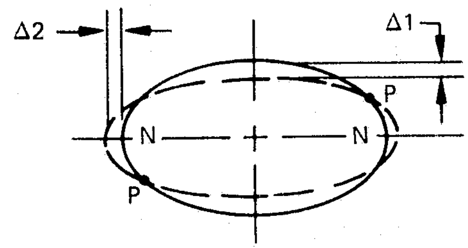
Of the anti-icing systems considered, the hot-air system with corrugated skins oriented to distribute the air longitudinally was the most efficient. The electrical system for the epoxy duct was unsatisfactory because an additional generator was required to satisfy power requirements, and the reliability of the system was questionable.

The results of the duct study are summarized as follows:

1. An aluminum-honeycomb duct would probably be both lighter and stiffer than ducts made of either epoxy/fiberglass or of skin/frame construction.

2. Longitudinal splices should be positioned in areas of minimum stress. This will reduce radial deflections by approximately 30% as shown in table 11.

Table 11.—Estimated Deflections in Elliptical Cross Section of Center-Engine Inlet Duct at Tail-Fin Front Spar Location



Load condition		Δ1 = minor axis Δ2 = major axis	Duct deflection, in. (cm)					
			Aluminum honeycomb		Epoxy fiberglass honeycomb		Skin/frame	
			Joint at NN	Joint at PP	Joint at NN	Joint at PP	Joint at NN	Joint at PP
Engine surge condition	Max pos press.	Δ1	0.87 (2.21)	0.61 (1.55)	1.60 (4.06)	1.11 (2.82)	1.0 (2.54)	0.69 (1.79)
		Δ2	-0.68 (-1.73)	-0.38 (-0.96)	-1.33 (-3.38)	-0.74 (-1.88)	-0.81 (-2.06)	-0.44 (-1.12)
	Max neg press.	Δ1	-0.48 (-1.22)	-0.36 (-0.91)	-0.88 (-2.23)	-0.66 (-1.68)	-0.56 (-1.42)	-0.42 (-1.07)
		Δ2	0.34 (0.86)	0.21 (0.53)	0.66 (1.68)	0.41 (1.04)	0.64 (1.62)	0.36 (0.91)
Normal operation	Max pos press.	Δ1	0.36 (0.91)	0.25 (0.63)	0.60 (1.52)	0.42 (1.07)	0.42 (1.07)	0.29 (0.74)
		Δ2	-0.26 (-0.66)	-0.15 (-0.38)	-0.51 (-1.29)	-0.29 (-0.74)	-0.30 (-0.76)	-0.17 (-0.43)
	Max neg press.	Δ1	-0.25 (-0.63)	-0.19 (-0.48)	-0.46 (-1.17)	-0.35 (-0.89)	-0.29 (-0.74)	-0.22 (-0.56)
		Δ2	0.17 (0.43)	0.11 (0.28)	0.33 (0.84)	0.21 (0.53)	0.20 (0.51)	0.12 (0.30)

Table 12.—Center-Engine Inlet Duct—Relative Weight of Alternate Construction Concepts

Structural configuration	Relative weight	
	Strength design	Stiffness design
Aluminum honeycomb (baseline configuration)	1.00	1.00
Epoxy fiberglass honeycomb	1.25	1.74
Aluminum skin/frame	1.34	1.34

3. The vertical tail front spar-frame locally constrains the elliptical section of the duct by restricting it from deflecting radially. Further study was required to establish a design concept that provides the proper relationship between clearance at the front spar, duct stiffness, and duct internal flow performance.

4. The center-duct hot-air anti-icing system of the present 727 airplane, consisting of framing, hot-air ducts, and corrugated skin distribution panels, is the most efficient system for use on the refan duct.

Selection of the flightworthy duct construction for the refan installation necessarily involves failsafe considerations for the inner skin and fit-up problems inherent in the formed skins of an all-metal construction as well as weight.

The requirement for full-length acoustic treatment of the duct and problems associated with manufacturing dictated the selection of a compromise configuration using a perforated aluminum-acoustic face, bonded to a high temperature phenolic core with fiberglass/epoxy septums and outer skins, as previously described in section 3.1.5.

3.3.6 CENTER-ENGINE BLEED TO INCREASE SURGE MARGIN TRADE STUDY

Two concepts were compared with the existing 727 system that utilizes bleed air from the two side engines to independently supply the two air-conditioning packs. The objective was to investigate use of center-engine bleed for normal air-conditioning supply in order to achieve a primary benefit of increased surge margin on the center engine. In considering alternate concepts, it is essential that the amount of air bleed from each engine be known to ensure that the engine will operate within allowable limits. This criterion was applied in the concepts studied.

Concept 1—center-engine bleed plus one side-engine bleed, shown schematically in figure 115, required no bleed flow analysis as it merely substituted the center-engine bleed for one side engine in the system.

Concept 2—three-engine bleed system (fig. 116) employs manifolding with flow-biased regulators to provide flow sharing among the three engines. This provides a solution; however, the flow split between the three engines is no longer well defined as in the existing airplane between two engines.

While concept 1 offers the simpler system with no weight increase, it would require different thrust settings for each of the three engines, which would present an unacceptable increase in pilot workload.

Concept 2, which adds manifold ducts, new air control valves, and a precooler on the center-engine bleed, would result in an estimated 145-lb (65.8-kg) weight increase, including ballast, to maintain airplane balance.

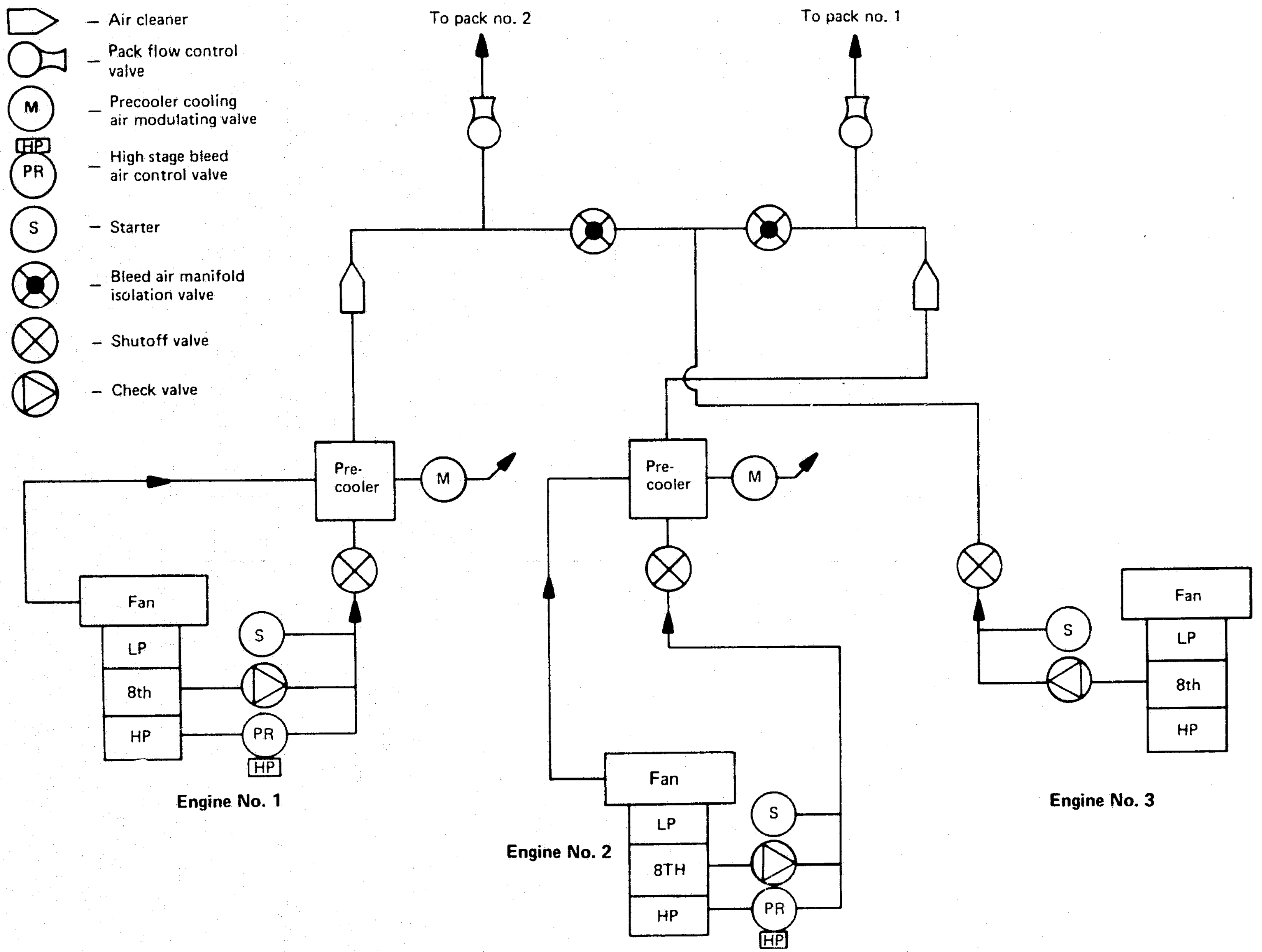


Figure 115.—Center-Engine and One Side-Engine Bleed (Concept 1)

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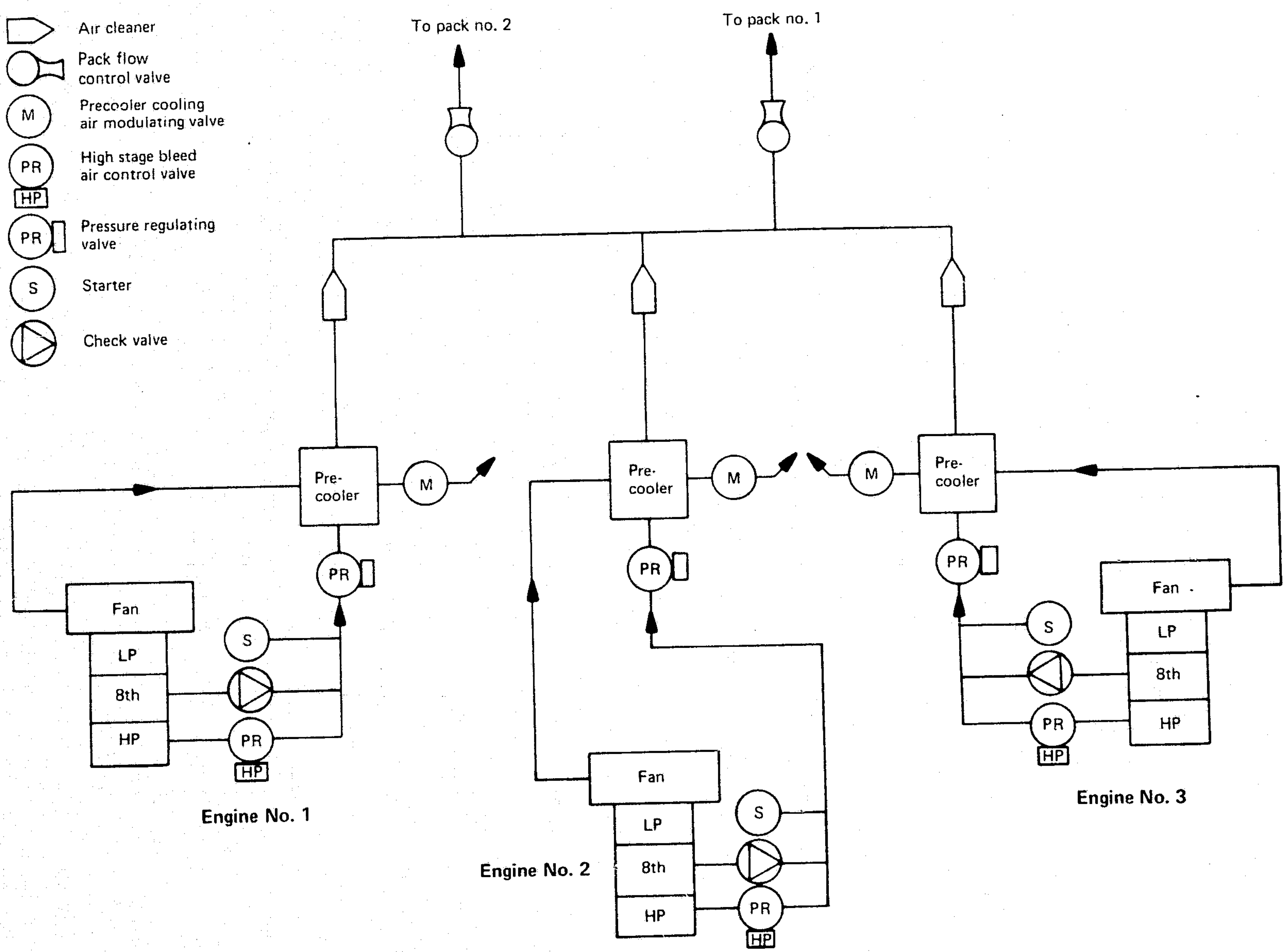

Figure 116.—Three-Engine Bleed System (Concept 2)

It was concluded as a result of this trade study that use of center-engine bleed as a routine practice was not desirable because of the weight penalties and the small surge margin increase. Results from the engine ground tests have shown that adequate surge margin exists for the center-engine installation and, thereby, eliminated the need for consideration of center-engine bleed.

3.3.7 SIDE-ENGINE INLET ACOUSTIC TREATMENT TRADE STUDY

Studies were performed to evaluate effects on inlet noise and airplane performance of alternate inlet acoustic treatment configurations as follows:

- Concept 1—Substitution of perforated aluminum or "Brunscoustic" replacing polyimide treatment in the diffuser and nose-dome walls (no splitter ring).
- Concept 2—Replacement of the treated nose dome with a short untreated nose dome (with and without splitter ring).
- Concept 3—Substitution of double-layer lining on the diffuser wall and nose dome (no splitter ring) replacing single-layer lining with splitter ring.

General ground rules pertaining to all the studies were:

1. The baseline configuration consisted of fiberglass-reinforced polyimide treatment (described in sec. 3.1.1) with components specified in tables 13, 14, and 15 for each concept.
2. All acoustic lining was optimized for FAR Part 36 approach condition, and noise comparisons were made for that condition only.
3. Engine performance variations due to acoustic configuration were not iterated to the point of recalculating the noise-source levels.
4. Structure was sized for minimum manufacturing gages, except where acoustic or structural integrity requirements dictated heavier gages.
5. Weight comparisons were based on the total airplane, including ballast if required.
6. An increase of 25% in attenuation level was assumed for double-layer linings compared with single-layer linings.

Specific ground rules for the individual studies were:

1. For the material substitution, concept 1, equal single-layer lining areas were assumed for all three materials.
2. For concept 2, the lining material was polyimide/fiberglass. The splitter ring location was not changed when the nose dome was revised.

Table 13.—727 JT8D Refan Inlet Acoustic Material Trade Study

Trade study	Treatment location	Material	Noise ΔEPNL,[a] EPNdB	Engine performance: Takeoff thrust,[b] lb (N)	Engine performance: Cruise SFC,[c] %	Airplane weight ΔGW,[d] lb (kg)	Aero performance: T.O. Δfield length,[e] ft (m)	Aero performance: Δrange,[f] nmi (km)
Concept 1: materials selection trade study using single layer treatment	Diffuser wall and centerbody	Polyimide (baseline)						
	Diffuser wall and centerbody	Perforated aluminum	More of a design risk	Negligible	Negligible	−12 (−5.4)	Negligible	Negligible
	Diffuser wall and centerbody	Bruns-coustic	Less acoustic design risk	Negligible	Negligible	+76 (+34)	Negligible	−5 (−9)

[a] FAR 36 approach flight condition.

[b] Sea level; 84° F (302 K); pounds per engine; 100 KTAS (51.4 m/sec).

[c] 30 000 ft (9144 m) altitude; Mach at 0.84; std day.

[d] Total airplane weight including ballast if required.

[e] Sea level; 84° F (302 K); GW = 172 500 lb (78 246 kg).

[f] For maximum brake release gross weight.

Table 14.—727 JT8D Refan Inlet Centerbody Acoustic Material Trade Study

Trade study	Treatment location	Material	Noise ΔEPNL,[a] EPNdB	Engine performance		Airplane weight ΔGW,[d] lb (kg)	Aero performance	
				Takeoff thrust,[b] lb (N)	Cruise SFC,[c] %		T.O. Δ field length,[e] ft (m)	Δ range,[f] nmi (km)
Concept 2: treated long versus untreated short centerbody without ring	Diffuser wall and centerbody	Polyimide						
	Diffuser wall	Polyimide	+0.3	Negligible	Negligible	-28 (-13)	Negligible	Negligible
Concept 2: treated long versus untreated short centerbody with treated ring	Diffuser wall, ring, and centerbody	Polyimide						
	Diffuser wall and ring	Polyimide	+0.3	Negligible	Negligible	-28 (-13)	Negligible	Negligible

[a]FAR 36 approach flight condition.

[b]Sea level; 84° F (302 K); pounds per engine; 100 KTAS (51.4 m/sec).

[c]30 000 ft (9144 m) altitude; Mach at 0.84; std day.

[d]Total airplane weight including ballast if required.

[e]Sea level; 84° F (302 K); GW = 172 500 lb (78 246 kg).

[f]For maximum brake release gross weight.

Table 15.—727 JT8D Refan Inlet Acoustic Material Trade Study—Double Layer Versus Single Layer

				Engine performance			Aero performance	
Trade study	Treatment location	Material	Noise ΔEPNL,[a] EPNdB	Takeoff thrust,[b] lb (N)	Cruise SFC,[c] %	Airplane weight ΔGW,[d] lb (kg)	T.O. Δ field length,[e] ft (m)	Δ range,[f] nmi (km)
Concept 3: one ring single layer versus peripheral double layer	Diffuser wall, ring, and centerbody	Single layer polyimide						
	Diffuser wall and centerbody	Double layer polyimide	+0.5	+150 (+667)	-0.7	-201 (-91)	-110 (-33.5)	+25 (+46)

[a]FAR 36 approach flight condition.

[b]Sea level; 84° F (302 K); pounds per engine; 100 KTAS (51.4 m/sec).

[c]30 000 ft (9144 m) altitude; Mach at 0.84; std day.

[d]Total airplane weight including ballast if required.

[e]Sea level; 84° F (302 K); GW = 172 500 lb (78 246 kg).

[f]For maximum brake release gross weight.

3. For concept 3, the area of the double-layer lining is the same as the concept-1 area. The material is polyimide/fiberglass.

The results of the inlet studies may be seen in tables 13, 14, and 15. The concept-1 comparison of Brunscoustic, perforated aluminum, and polyimide-impregnated fiberglass face skins indicates negligible differences in acoustic performance at the engine operating condition for which the acoustic skins are designed. The acoustic characteristics of Brunscoustic cause it to be less critical to off-design conditions; therefore, somewhat less risk is involved in its use for an untested engine than with perforated aluminum or polyimide/fiberglass. There is a negligible difference among the three materials relative to engine performance and inlet flow distortion. From a structural point of view, Brunscoustic face sheet lining has a disadvantage because it is slightly heavier and has a poorer thermal fatigue life. This results in an airplane range loss of approximately 5 nmi (9.3 km) relative to the polyimide/fiberglass baseline.

The substitution of a short untreated nose dome for the long treated nose dome has the same effect on acoustic attenuation with and without the inlet ring installed; therefore, the following discussion may be applied to both. An acoustic performance comparison shows a slight degradation for the untreated nose dome, and approach flyover EPNL is higher by 0.3 EPNdB. The airplane is lighter by 28 lb (12.7 kg) with an unlined short nose dome. Other performance items are essentially unchanged, resulting in a negligible range change.

In concept 3, the single-layer linings of the splitter-ring configuration provide 0.5 EPNdB more suppression at the FAR Part 36 approach condition than the double-layer linings without the ring. It should be noted that there is more risk involved with the design and prediction of double-layer lining than for single-layer lining. The change in inlet pressure recovery, P_{t2}/P_{t0}, associated with removal of the splitter-ring is estimated to be +0.006. Structural complexity of the double-layer no-ring inlet is appreciably less than for the single-layer one-ring inlet; therefore, confidence in structural integrity would be more easily assured. Airplane weight is decreased by 201 lb (91.2 kg), takeoff thrust is increased by 150 lb (667 N) per engine, and SFC is decreased by 0.67%, resulting in a takeoff field length reduction of 110 ft (33.5 m) and a range increase of 25 nmi (46.3 km) if the no-ring inlet with double-layer lining is adopted.

The alternative inlet acoustic treatment configuration did not have any significant advantage over the selected configuration described in section 3.1.1. Therefore, the side-engine inlet configuration was chosen to reduce manufacturing risk and to leave the design flexible so that the inlet ring could be removed if test results prove its benefit to be negligible.

3.3.8 EXHAUST-SYSTEM ACOUSTIC-TREATMENT TRADE STUDY

Studies were performed to evaluate the 727-200/JT8D refan flyover noise and flight performance of several acoustic treatment design variations in the engine exhaust system. The variations studied were relative to the two basic exhaust system concepts considered for the refan installation, as depicted in figures 117 and 118. These concepts are described as follows:

- Concept 1—Baseline—Inconel 625 acoustic-honeycomb peripheral treatment in the exhaust duct with no extension of the fan/primary divider

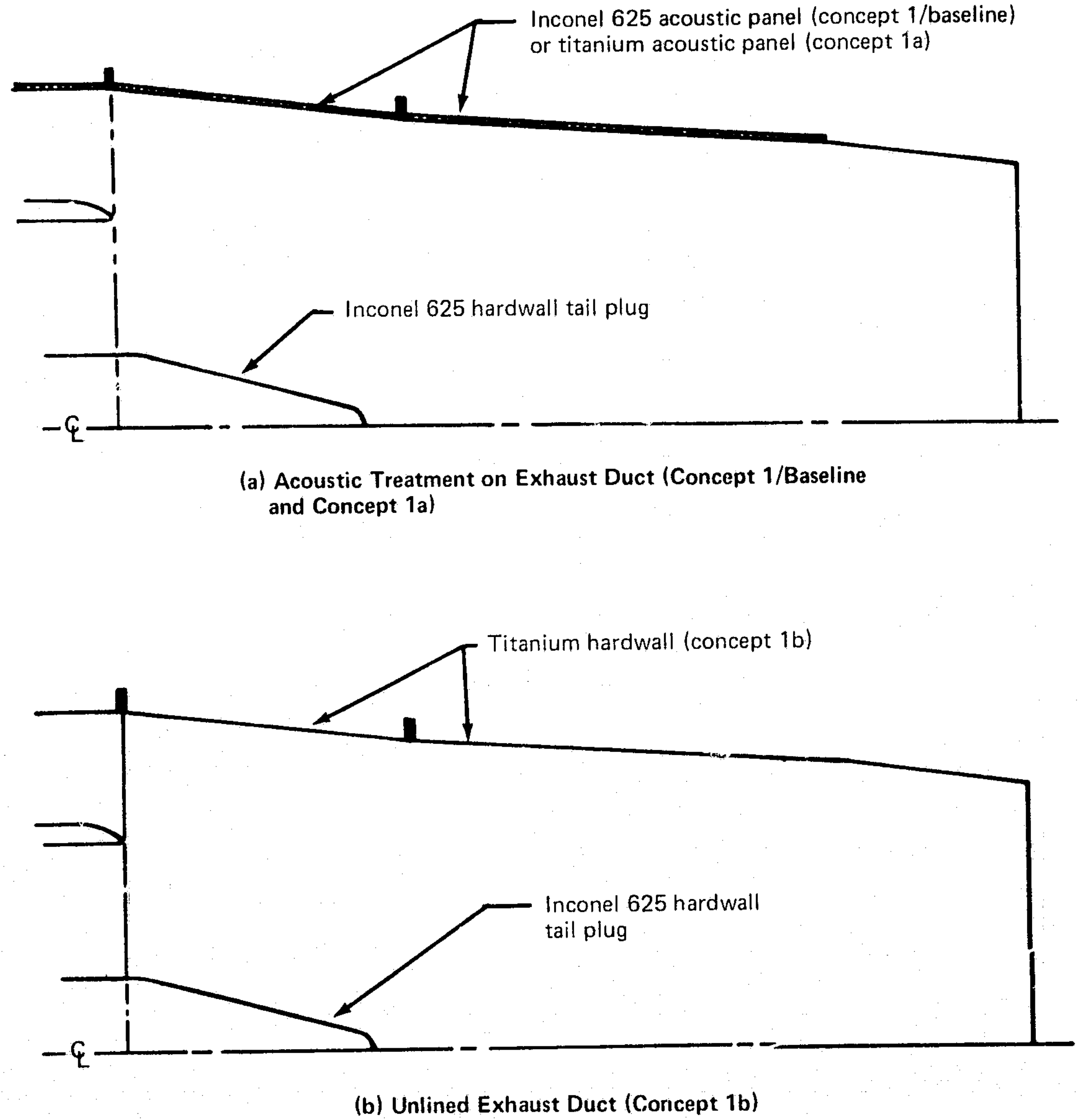

Figure 117.—Exhaust System Acoustic Treatment Configurations for Concept 1 Trade Studies

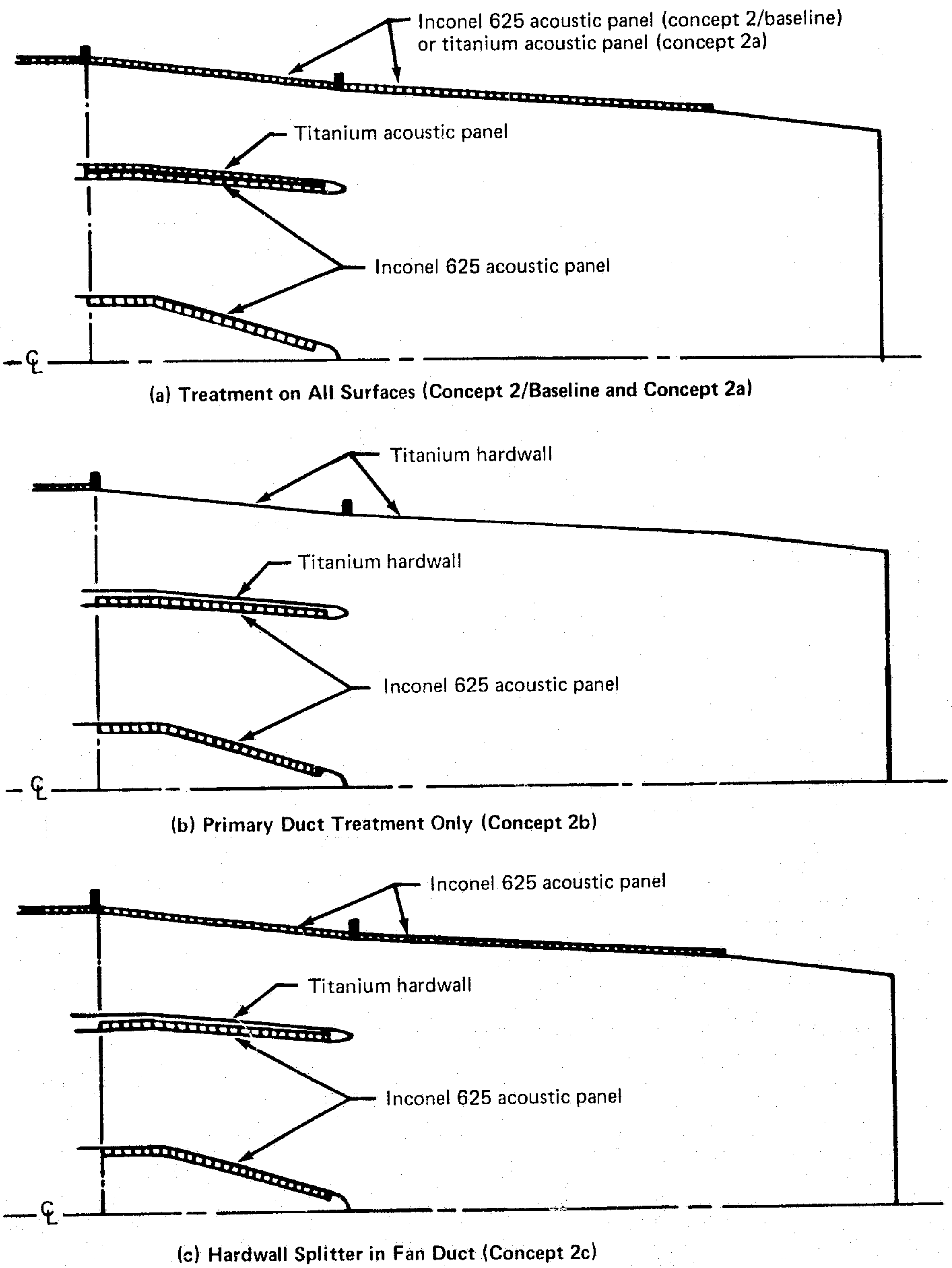

Figure 118.—Exhaust System Acoustic Treatment Configurations for Concept 2 Trade Studies

- Concept 1a—Substitution of titanium acoustic honeycomb for the Inconel 625 peripheral treatment

- Concept 1b—Titanium hardwall exhaust duct

- Concept 2—Baseline—Extended center plug with Inconel 625 acoustic-honeycomb panel; extended fan/primary divider with Inconel 625 acoustic-honeycomb inner panel and titanium acoustic-honeycomb outer panel; exhaust-duct peripheral treatment of Inconel acoustic honeycomb

- Concept 2a—Baseline with substitution of titanium honeycomb peripheral treatment in exhaust duct

- Concept 2b—Baseline with titanium hardwall on divider outer panel and on exhaust-duct periphery

- Concept 2c—Baseline with titanium hardwall on divider outer panel

General ground rules pertaining to all the studies were:

1. All acoustic lining was optimized for the FAR Part 36 approach condition, and noise comparisons were made for this condition only.

2. Engine performance variations due to trades were not iterated to the point of recalculating the noise-source levels.

3. Structure was sized for minimum manufacturing gages, except where acoustic or structural integrity requirements dictated heavier gages.

4. Weight comparisons were for the total airplane, including ballast if required.

5. For the material substitution trade study, lining areas for Inconel 625 and titanium are equal.

The results of the studies are summarized in table 16. The material changes in the peripheral treatment (concepts 1a and 2a) to titanium provide a significant weight saving of 330 lb (149.6 kg) per airplane over the Inconel 625 construction with negligible change in performance and a 15-nmi (27.8-km) increase in airplane range relative to the respective baselines.

A slight increase in the takeoff thrust, a decrease in cruise SFC, and a further weight reduction of 15 lb (6.8 kg) per airplane would result from substitution of titanium hardwall as in concepts 1b and 2b. In concept 1b, the substitution would cause an EPNL increase of 0.4 EPNdB for the FAR Part 36 approach condition. This could be appreciably larger if turbine noise levels were significant. The deletion of peripheral and fan-side splitter lining in concept 2b would cause a much larger (1.9 EPNdB) increase in approach noise with a takeoff field length reduction of 10 ft (3 m) and a range increase of 25 nmi (46.3 km). Turbine noise attenuation would be less of a problem for this concept, compared to concept 1b, as a result of the treatment on the plug and the splitter inner wall.

Table 16.—727 JT8D Refan Exhaust System Acoustic Treatment Trade Study Summary

Trade study	Concept	Treatment location	Material	Noise ΔEPNL,[a] EPNdB	Engine performance		Airplane weight ΔGW,[d] lb (kg)	Aero performance		Comments
					Takeoff thrust,[b] lb (N)	Cruise SFC,[c] %		T.O. Δfield length,[e] ft (m)	Δrange,[f] nmi (km)	
Baseline	1	Peripheral	Inconel 625							
Material change	1a	Peripheral	Titanium	Negligible	Negligible	Negligible	-330 (-150)	Negligible	+15 (+28)	
Material change and treatment deletion	1b	None	Titanium (hardwall)	+0.4	+20 (+89)	-0.2	-345 (-156)	Negligible	+20 (+37)	Probable noise increase from turbine
Baseline with splitter	2	Peripheral and fan side of splitter	Inconel 625 and titanium							
Material change	2a	Peripheral and fan side of splitter	Titanium and titanium	Negligible	Negligible	Negligible	-330 (-150)	Negligible	+15 (+28)	
Material change and treatment deletion	2b	None	Titanium (hardwall)	+1.9	+40 (+178)	-0.4	-345 (-156)	-10 (-3)	+25 (+46)	
Treatment deletion	2c	Peripheral	Inconel 625	+0.2	+20 (+89)	-0.2	Negligible	Negligible	+5 (+9)	

[a] FAR 36 approach flight condition.

[b] Sea level; 84° F (302 K); pounds per engine; 100 KTAS (51.4 m/sec).

[c] 30 000 ft (9144 m) altitude; Mach at 0.84; std day.

[d] Total airplane weight including ballast if required.

[e] Sea level; 84° F (302 K); GW = 172 500 lb (78 246 kg).

[f] For maximum brake release gross weight.

Elimination of the splitter fan-side treatment, concept 2c, would afford a slight engine performance advantage relative to the concept-2 baseline, but would increase approach EPNL by 0.2 EPNdB. Other effects are too small to consider.

It is concluded that the loss in noise attenuation by elimination of acoustic treatment is too great to justify the slight weight and performance advantage. On the other hand, the weight advantage in the use of titanium construction, where temperature permits, warrants consideration.

4.0 SUMMARY OF RESULTS AND CONCLUSIONS

In Phase II of the Refan Program, the Contractor completed the design necessary to evaluate the retrofit of the JT8D-100 series engines on the 727-200 airplane. During the design effort, a series of reviews was conducted to ensure that the design was producible, certifiable, and appropriate for commercial use. The basic design and fabrication approach provided the basis for application of previously unused material and process specifications following determination of appropriateness by structural analysis. The manufactured components include the center-engine inlet duct, the exhaust system components, and a nonflightworthy side-engine inlet. Fabrication was started on the side-engine side cowls and thrust reverser, but was not completed because of funding limitations. In conclusion, the design concept is technically feasible and would meet the requirements for flightworthy certifiable retrofit hardware.

4.1 SIDE-ENGINE INLET

The side-engine inlet design for retrofit was based on the use of state-of-the-art materials such as riveted aluminum structure and polyimide-impregnated fiberglass for acoustic treatment. The use of these materials plus unique features, such as the removable ring in the inlet for engine blade access, makes the concept feasible, producible, certifiable, and maintainable.

A nonflightworthy side-engine inlet was successfully fabricated using the same materials and tools that would have been required to fabricate the acoustic lining designed for production, thus proving the feasibility of the basic concept. In conclusion, the inlet design satisfies the design objectives of feasibility and practicality.

4.2 SIDE-ENGINE SIDE COWLS

The side-engine side cowl design employed the use of fiberglass-honeycomb sandwich to reduce the cost of fabrication without a penalty in airplane weight or safety. The side-engine side cowls were not fabricated, but samples of fiberglass-honeycomb construction were made and subjected to fire tests, which led to the conclusion that this concept would meet the airplane safety requirements for fire protection. Analysis also showed that the honeycomb cowls would be less expensive to fabricate. Based on experience with similar fiberglass components, the fire testing, and the cost analysis, it may be concluded that this design concept meets the requirements of feasibility and practicality with the potential of a significant cost saving.

4.3 EXHAUST SYSTEM

The design of the exhaust system depended heavily on the use of titanium to reduce weight while retaining strength. The system integrated the functions of pressure-vessel structure acoustic lining, and thrust-reverser support. This was accomplished by the extensive use of aluminum-brazed titanium honeycomb sandwich. This process was adapted from technology generated during the FAA-sponsored Supersonic Transport Program. Its use required new concepts in design, tooling, manufacturing, perforating, and inspection.

The tooling concept required that each component be brazed on a rotating thermally expanding mandrel in an inert atmosphere. Perforation of the titanium face skins was accomplished by chemical milling, using photographic means to control the hole size and spacing. Nondestructive testing by eddy current, developed during prior Contractor research in support of the FAA-sponsored Supersonic Transport Program, was adapted to permit inspection of circular components like the nozzle.

A titanium exhaust system was successfully manufactured resulting in an integrated structure that performs both an acoustic and structural role. An airplane weight saving of 450 lb (204 kg) was realized when compared to the same parts made from Inconel 625, a high nickel-base alloy. Technological feasibility and practical application in a nozzle system were demonstrated for aluminum-brazed titanium structure.

4.4 THRUST REVERSER

The thrust-reverser design was completed and determined to be producible and certifiable and showed the potential of effecting a significant weight saving. This was possible as a result of the extensive use of titanium. Special temperature-resistant and high-strength titanium alloys were used in the design to make titanium usable in the reverser environment.

Fabrication of the reverser was started but not completed because of funding limitations: however, several important conclusions can be drawn from the work that was accomplished. A highly successful titanium casting was made to support the thrust reverser linkage, thus paving the way for future use of titanium castings in other applications. The reverser door and linkage, which also made wide use of titanium, resulted in a projected weight saving of 540 lb (245 kg) per airplane when compared to the same parts made from corrosion-resistant steel. In conclusion, the reverser designed for the JT8D refan engine meets the objectives of feasibility and practicality while providing a significant weight saving.

4.5 CENTER-ENGINE INLET DUCT

The design of the center-engine inlet duct combined the acoustic treatment with a structural shell made from a perforated aluminum inner skin bonded to fiberglass-honeycomb core and outer skin. This technique takes advantage of the cellular honeycomb structure for acoustic purposes and the inherent strength and stiffness of honeycomb sandwich to carry the pressure loads. This design concept is considered to be feasible and producible while providing all of the required functions of acoustic attenuation, structural integrity, and optimum aerodynamic shape control in a minimum weight configuration.

The fabrication required the development of tools to make the duct sections without hoop discontinuities. The fabrication techniques were successful and technologically feasible. Additional development is required to define production tooling concepts to reduce cost. Therefore, it is concluded that the center-engine inlet duct met the objectives of feasibility, producibility and practicality.

4.6 INSTALLATION HARDWARE

During the design and mockup phases, no unforeseen problems were uncovered. In general, most components on current JT8D engine installations can be used directly on the refan installation. Because of the engine size, plumbing and wiring are all new, and some modification is required to control systems.

4.7 AIRPLANE MODIFICATIONS

The airplane modification design effort was completed to the extent required to define those areas of modification required for retrofit and the feasibility of accomplishing the modifications. The primary modification design areas are the center-engine inlet duct support, changes to provide clearance for the duct, center-engine mount relocation, center-engine cowls, and tail skid redesign. Sufficient design was accomplished to demonstrate that there are no physical barriers to installation of the JT8D-100 series engines on the 727-200 airplane.

APPENDIX

SYMBOLS AND ABBREVIATIONS

ac	Alternating current
Al	Aluminum
APU	Auxiliary power unit
BAJ	Bond assembly jig
BL	Buttock line
CAR	Civil Air Regulations
cc	Cubic centimeters
℄	Centerline
cm	Centimeter
comp	Compression
CRES	Corrosion-resistant steel
CSD	Constant speed drive
daN	Dekanewton
dB	Decibel re 0.0002 μbar
dc	Direct current
deg, $^{\circ}$	Degrees (units of plane angular increment)
$^{\circ}$F	Degrees Fahrenheit
$^{\circ}$R	Degrees Rankine
Δ	Delta (increment of change)
EAS	Equivalent air speed
EGT	Exhaust gas temperature
EGV	Exit guide vane
EPNdB	Effective perceived noise level in decibels
EPNL	Effective perceived noise level
EPR	Engine pressure ratio
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
F_N	Net thrust
ft	Feet
ft-lb	Foot-pound
fwd	Forward
g	Gravity
GW	Gross weight
IGV	Inlet guide vane
in.	Inch
inbd	Inboard
J	Joule
K	Kelvin
KEAS	Knots equivalent air speed
kg	Kilogram
km	Kilometer
kN	Kilonewton
KTAS	Knots true air speed

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APPENDIX (Continued)

kVA	Kilovolt-ampere
lb	Pound
L/D	Length/diameter
L.E.	Leading edge
L.H.	Left hand
m	Meter
Mach	Mach number
max	Maximum
MKS	Meter kilogram second measurement system
mm	Millimeter
Mo	Molybdenum
N	Newton
N_1	Low pressure rotor speed
N_2	High pressure rotor speed
neg	Negative
nmi	Nautical mile
No.	Number
outbd	Outboard
%	Percent
PM	Plaster model
pos	Positive
press.	Pressure
psi	Pounds per square inch
P_{to}	Freestream total pressure
P_{t2}	Engine compressor-face total pressure
P_{t7}	Turbine exit pressure
P&WA	Pratt & Whitney Aircraft
ref.	Reference
R.H.	Right hand
RTO	Refused takeoff
sec	Second
SFC	Specific fuel consumption
Sn	Tin
std	Standard
TAI	Thermal anti-icing
T.E.	Trailing edge
temp	Temperature
Ti	Titanium
T.O.	Takeoff
T/R	Thrust reverser
T_S	Static temperature
typ	Typical
V	Volt

APPENDIX (Continued)

Vac	Alternating current voltage
Vdc	Direct current voltage
VHF	Very high frequency
W_f	Fuel flow rate
WL	Waterline
Zr	Zirconium

DEFINITIONS

Nacelle:	As used in this document, the engine nacelle includes all components of an externally mounted propulsion package, including the engine plus all engine-mounted parts and accessories; the inlet, cowling, and thrust reverser (i.e., all components suspended from the engine mounts)
Strut:	A structure that separates and supports the nacelle external from the airframe, including primary and secondary structure and provisions for installation of airplane and engine systems components
Accessories:	Components required for engine operation and airplane systems components, which are mounted on the engine and strut
Engine:	The dry engine provided by P&WA
Inlet assembly/side-engine nose cowl:	The portion of the nacelle forward of the fan case, including internal and external fairings and all components attached and normally removed with the inlet assembly/nose cowl
Thrust reverser:	The structure and mechanisms required to reverse engine thrust
Interchangeability:	The quality that will allow a part to substitute or be substituted for another part meeting all physical, functional, and structural requirements and to be installed by the application of the attaching means only (bolts, nuts, screws, washers, pins, etc.). This specifically precludes the use of trimming, cutting, filing, reaming, drilling, and forming during installation. No tools other than those normally available to service mechanics are required for the installation of the item. No operation or alterations except design adjustments are required on supporting and surrounding structure in order to install the item
Replaceability:	The quality that will allow a part to substitute or be substituted for another part meeting all physical, functional, and structural requirements, but which may require operations in addition to the attaching means. Such operations may include shimming, drilling, reaming, cutting, sawing, filing, and forming. These operations are performed by the use of handtools normally available to service mechanics

APPENDIX (Concluded)

Commonality:	The multiple application of identical parts with the objective of system total ownership cost savings
727-200:	The current production model 727 airplane
727 refan:	The 727-200 airplane equipped with JT8D refan engines
JT8D:	The current P&WA engine used on the 727-200 airplane
JT8D refan:	The P&WA JT8D-100 series engine developed from the JT8D engine during the NASA Refan Program

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