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PRELIMINARY DESIGN OF LOW-COST TITANIUM STRUCTURE

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LOS ANGELES DIVISION
INTERNATIONAL AIRPORT
LOS ANGELES, CALIFORNIA 90009

SEPTEMBER 1977

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WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

NOTICE

This technical report has been reviewed and is approved for publication.

Rodman D. Goblove
Project Engineer/Scientist

FRANCIS J. JANIK
Chief, Advanced Structures
Development Branch

FOR THE COMMANDER

Howard L. Farmer
HOWARD L. FARMER, Col, USAF
Chief, Structural Mechanics Division

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Results of a study program to evaluate the application of advanced titanium fabrication techniques to the Air Force B-1 bomber engine nacelle structure for improvements in cost and weight are presented. There are five items for the study. Two of them are primary structure, one of which is a removable access panel. The remaining three items are secondary structure. Superplastic forming with concurrent diffusion bonding, including expanded

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sandwich, were investigated. Weight savings range up to 49 percent. Potential weight savings are 362 pounds per aircraft. Cost savings range up to 69 percent, resulting in a potential savings of up to $48,622,800 for 240 aircraft.

FOREWORD

The design study presented in this report was performed by the Los Angeles Division (LAD) of Rockwell International Corporation (Rockwell) for the Advanced Structures Development Branch, Structural Mechanics Division, Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio under Contract F33615-76-C-3066. This research was conducted under Project 1368, "Advanced Structures for Military Aerospace Vehicles", Task 136802, "Advanced Airframes for Military Flight Vehicles". Mr. R. D. Joblove (AFFDL/FBS) was the technical monitor.

The performance period for this project was 1 April 1976 through 29 April 1977.

This report presents the results of design and analysis efforts to apply Rockwell patented advanced titanium manufacturing processes to the B-1 engine nacelle structure.

Mr. J. Pulley was the program manager for Rockwell. Contributing technical personnel were J. Swanger, Structural Design; L. Israeli, Structural Analysis; C. Yen, Fatigue and Fracture Mechanics Analysis; R. Allen, Mass Properties; D. Schultz, Materials and Producibility Analysis; Z. Conkle, Manufacturing Methodology; and P. Blaser, Operations Analysis.

This report was submitted by the author in April 1977 for publication as an AFFDL Technical Report.

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Section I

INTRODUCTION

INTRODUCTION

The science of aircraft technology is continually being pressured to develop new and innovative concepts to produce aircraft with higher performance and lower cost. This is particularly true in the field of aircraft structures, since this technology represents a large fraction of the cost and weight of aircraft. A new technology is emerging in the field of titanium fabrication which promises a quantum step in the state-of-the-art toward meeting the challenge of reducing airframe costs. This new and innovative process combines superplastic forming and diffusion bonding (SPF/DB) into a single process that promises to revolutionize titanium fabrication and structural design.

New design concepts heretofore considered impractical because of high costs and fabrication difficulties are now possible using the SPF/DB process. These concepts include sandwich structures in which face sheets, core, and edge members can be formed and bonded into a practical structure, all in one operation. Other structures such as beaded panels, corrugated or sine wave spars and frames, panels with integral frames, etc, are now possible, at low cost, with this process.

These complex configurations have been produced in titanium by the SPF/DB process in a single cycle which could otherwise not be fabricated by conventional methods. Manufacturing feasibility and cost savings potential have been established through recently completed programs.

OBJECTIVES

The objectives of the program described in this report are to apply SPF/DB technology to selected B-1 bomber structural components, to determine cost and weight effectiveness when compared to the currently proposed methods of construction and to demonstrate the advantages of these new low-cost titanium construction techniques. These objectives were achieved through program activities that were interrelated as shown in Figure 1.

SUMMARY

During task I, baseline data were obtained from the airframe engineering group. These data were used to define five evaluation points (Figure 2) that were to be studied during the subsequent tasks. These data also provided the

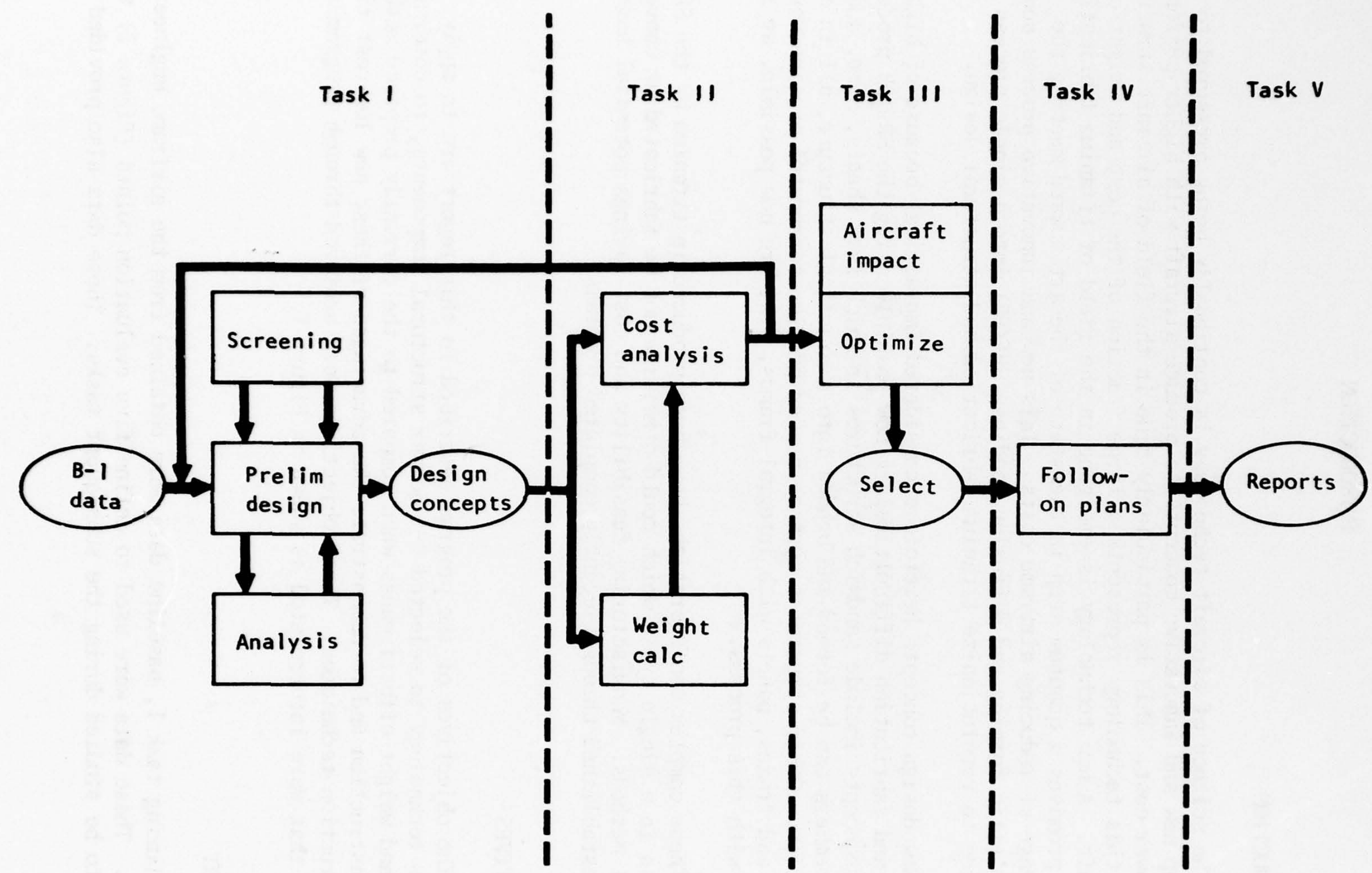


Figure 1. Program task flow diagram.

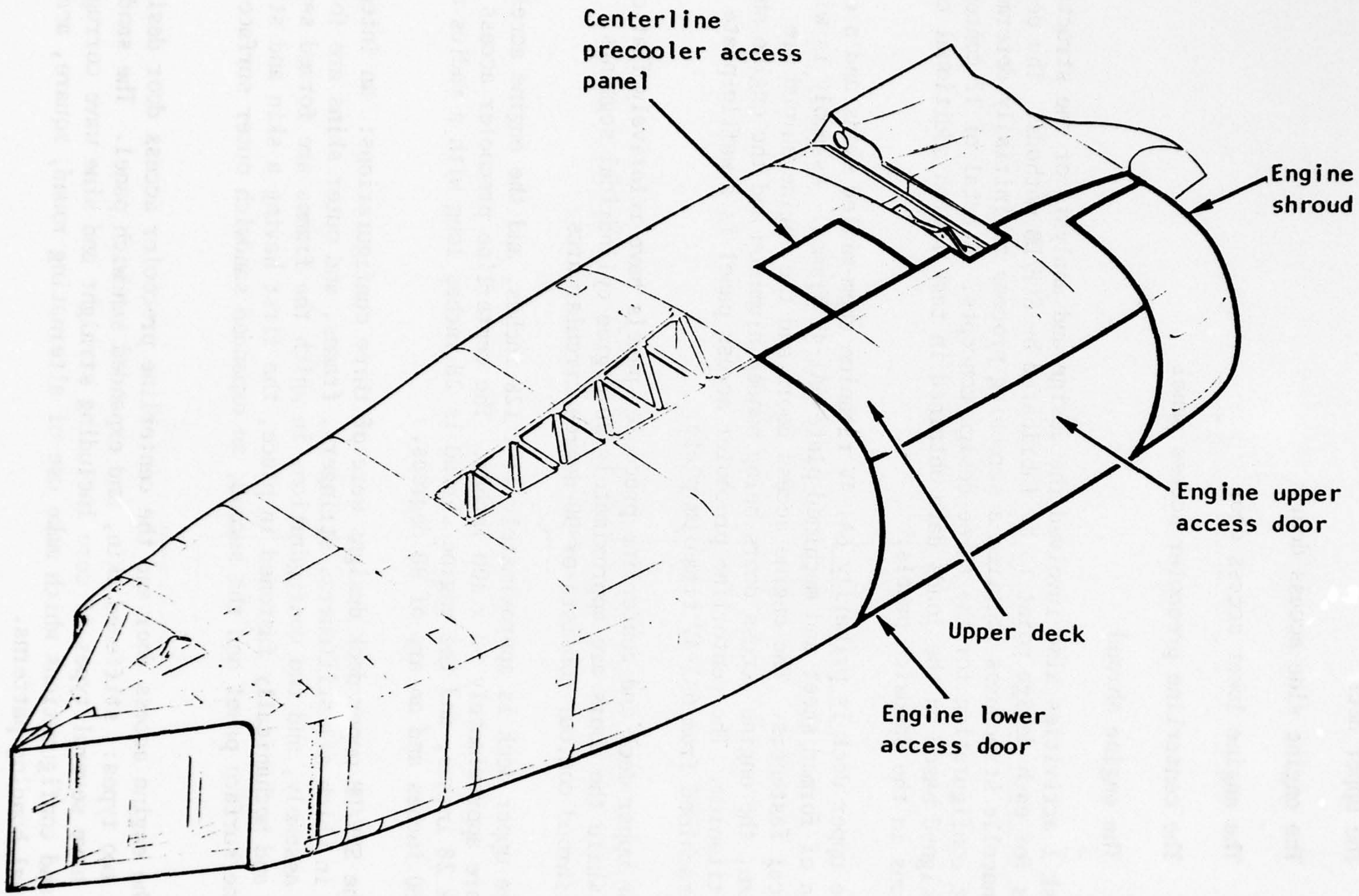


Figure 2. B-1 nacelle - selected structure for SPF/DB impact.

baseline construction methods in which evaluations would be measured against SPF/DB effectiveness. The five evaluation points were as follows:

1. The upper deck
2. The engine side access door
3. The engine lower access door
4. The centerline precooler access panel
5. The engine shroud

Task I activities also involved the design and analysis of the structural concepts for each design point to be fabricated by SPF/DB methods. The design of the nacelle structures required a screening process to initially determine the best configuration for the three design concepts. A total of 12 concepts were designed based on the loads data obtained in task I with additional core variations in the sandwich panels.

The upper deck is primarily 6Al-4V titanium chem-milled skins and a combination of formed sheet and machined plate 6Al-4V frames. Assembly is with mechanical fasteners. The engine access doors and the engine shroud are honeycomb, the engine access doors being bonded aluminum and the engine shroud brazed titanium. The centerline precooler access panel is a waffle-plate design machined from 6Al-4V titanium plate.

The upper deck and centerline precooler panels have relatively flat contours, while the doors are approximately 90-degree cylindrical segments. The engine shroud contour consists of 90-degree circular arcs.

The upper deck is approximately 44 x 128 inches, and the engine access doors are approximately 50 x 100 inches. The centerline precooler access door is 28 x 28 inches, and the engine shroud is 28 inches long with a radius of 29 to 30 inches and an arc of 90 degrees.

The SPF/DB upper deck designs were of three configurations: an integral design in which all stiffeners, stringers, frames, and outer skins are formed in one assembly, and two configurations in which the frames are formed separately and mechanically fastened in place, the first having a skin and stringer moldline surface panel and the second, an expanded sandwich outer surface panel.

The engine access door and the centerline precooler access door designs are of two types: stiffened skin, and expanded sandwich panel. The sandwich panels have several types of core including straight and sine wave corrugations and configurations which make use of alternating round, square, and hexagonal bonding patterns.

Each concept was then analyzed in detail for cost and weight during task II. Changes due to marginal producibility, high cost, or excess weight were recycled through the design and analysis functions.

Task III activities have been assumed by the aircraft project design group. Change proposals have been written to initiate the required studies and testing to implement the adoption of SPF/DB technology on the five parts studied in this program plus an additional four parts.

Included in the task IV activities is the recommendation of follow-on plans for the further development of the application of SPF/DB technology to the B-1.

Task V activities are the monthly progress and the final reports.

Results obtained during this program show both cost and weight savings are possible for each design point considered and for the total aircraft when SPF/DB structure is utilized. Weight savings (Table 1) range from -4 to 49 percent. Cost savings, also shown in Table 1, vary from 17 to 69 percent for the design points. Total aircraft structural weight savings is 362 pounds. Cost savings on a complete aircraft unit is $202,595 based on a production quantity of 240 aircraft. Total 240 aircraft program cost savings would be $48,622,800.

The significance of these savings indicates the desirability for further development of manufacturing confidence, design technique, and structural characterization of the SPF/DB technology so that these savings may be realized at the earliest date possible.

TABLE 1. SUMMARY OF WEIGHT AND COST SAVINGS

Item	Weight Savings (Percent)	Cost Savings (Percent)
Upper deck		
Dimple core sandwich	42	58
Integral frames	49	69
Stiffened skins	16	63
Engine side access door		
Hat section panel	14	17
Cone core sandwich	24	-5
Truss core sandwich	20	-2
Engine lower access door		
Sine wave core sandwich	18	34
Cone core sandwich	18	29
Truss core sandwich	18	31
Hat section panel	29	44
Centerline precooler		
Access panel		
Beaded panel	41	65
Single pyramid core sandwich	46	61
Double pyramid core sandwich	46	55
Engine shroud		
Truss core sandwich	24	55
Beaded panel	-4	67

Section II

PROCESS DESCRIPTIONS

Superplasticity in titanium is a phenomenon in which very large tensile elongations may be realized because local thinning (necking) does not occur under the proper conditions of temperature and strain rate (Figure 3). Diffusion bonding is the joining of titanium under pressure at elevated temperature without melting or use of bonding agents. Fortunately, through a natural occurrence, SPF/DB of titanium can be accomplished under identical parametric conditions. This is the basis for the combined SPF/DB processes.

SUPERPLASTIC FORMING PROCESS

Rockwell has pioneered the SPF of titanium alloy sheet components. Much additional work was done, under Air Force contract, with the Air Force Materials laboratory (Reference 1). It has been shown that SPF monolithic components can replace designs requiring numerous details and large numbers of fasteners while realizing significant cost and weight savings (Figure 4). Under the Air Force contract, a superplastic frame was redesigned to replace a conventional frame composed of eight separate hot-sized and machined parts and 96 fasteners. As shown in the figure, cost estimates indicating savings of 55 percent are possible, accompanied by weight savings of 33 percent. SPF is an approved process for the B-1, with aircraft No. 1 through 3 having several SPF components. Aircraft No. 4 will incorporate much more additional SPF structure. Space shuttle components, also being made by SPF, include windshield seal frames which replace an aluminum design using formed sheet and machined details. Six SPF/DB frames replace 25 machines fittings, 72 sheet metal details, 30 splice plates, and 396 each of screws, washers, and nuts (Figure 5).

In the Rockwell patented SPF process, a metal diaphragm possessing superplastic properties is placed across a die (Figure 6) with the desired part configuration and is sealed by the top plates in a hydraulic press. Argon gas is introduced, and heat is applied through cermaic platens to heat the diaphragm to temperatures at which the material becoms superplastic. For titanium, this temperature is 925° C (1,700° F). Argon gas pressures up to a maximum of 2 by 10^3 kpa (300 psi) are varied to produce stretching at the material proper strain rate. This is an arbitrary pressure limit and is a function of tooling limitations, rather than forming limitations. The actual forming time at temperature is a function of the part configuration and strain rate limitations, and can be as low as 20 minutes. The resulting part will exactly match the die configuration, because springback associated with normal forming methods is not present with this process. The material is fully annealed and stress-free upon process completion.

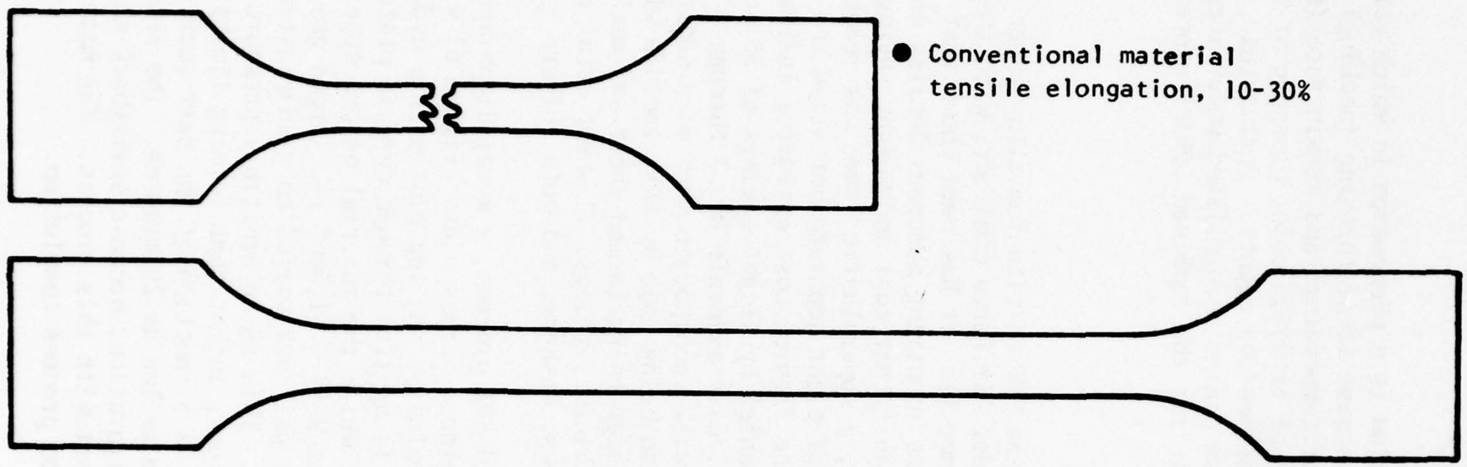


Figure 3. The superplastic phenomenon.

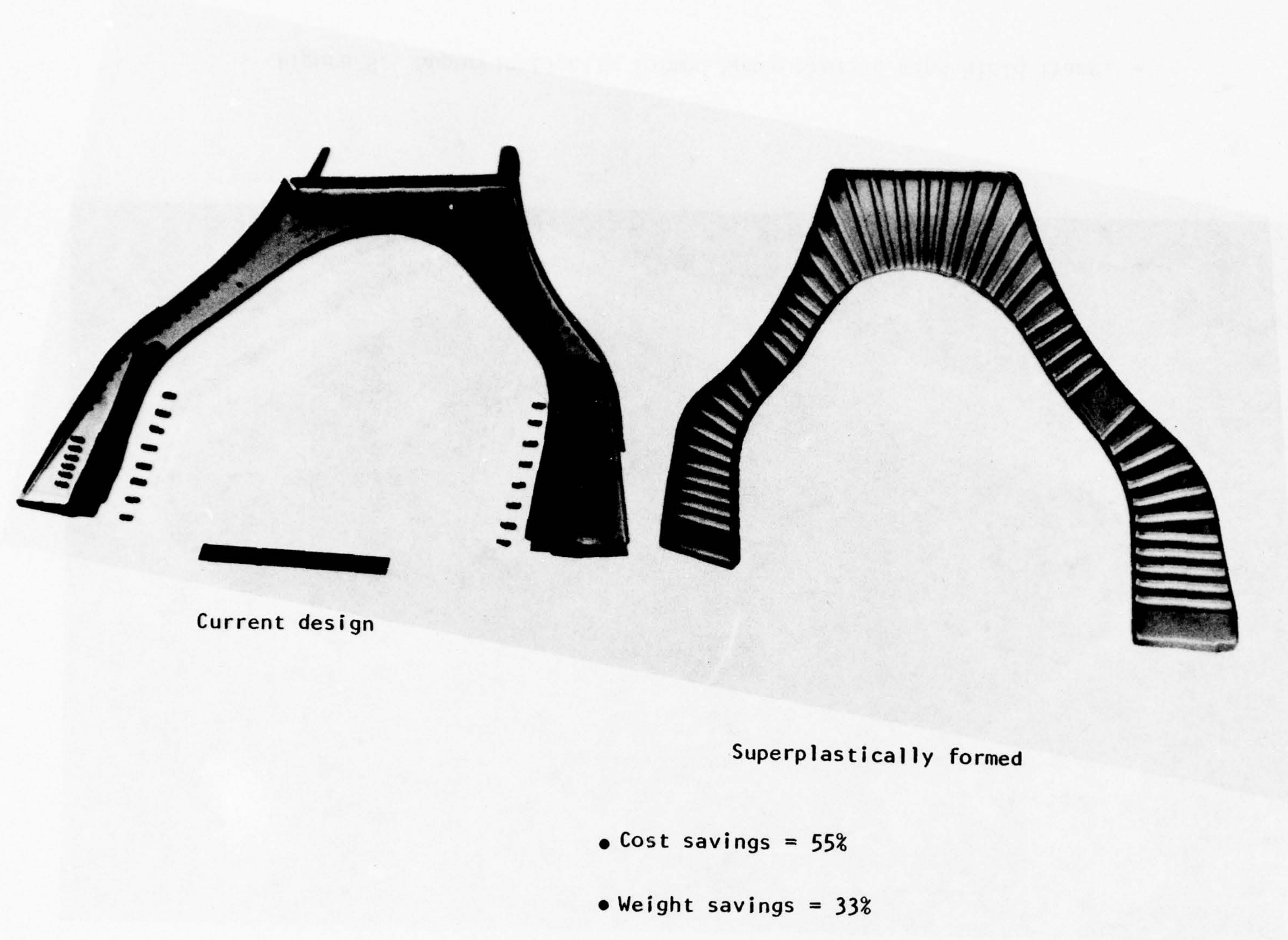


Figure 4. Nacelle frame redesign comparison.

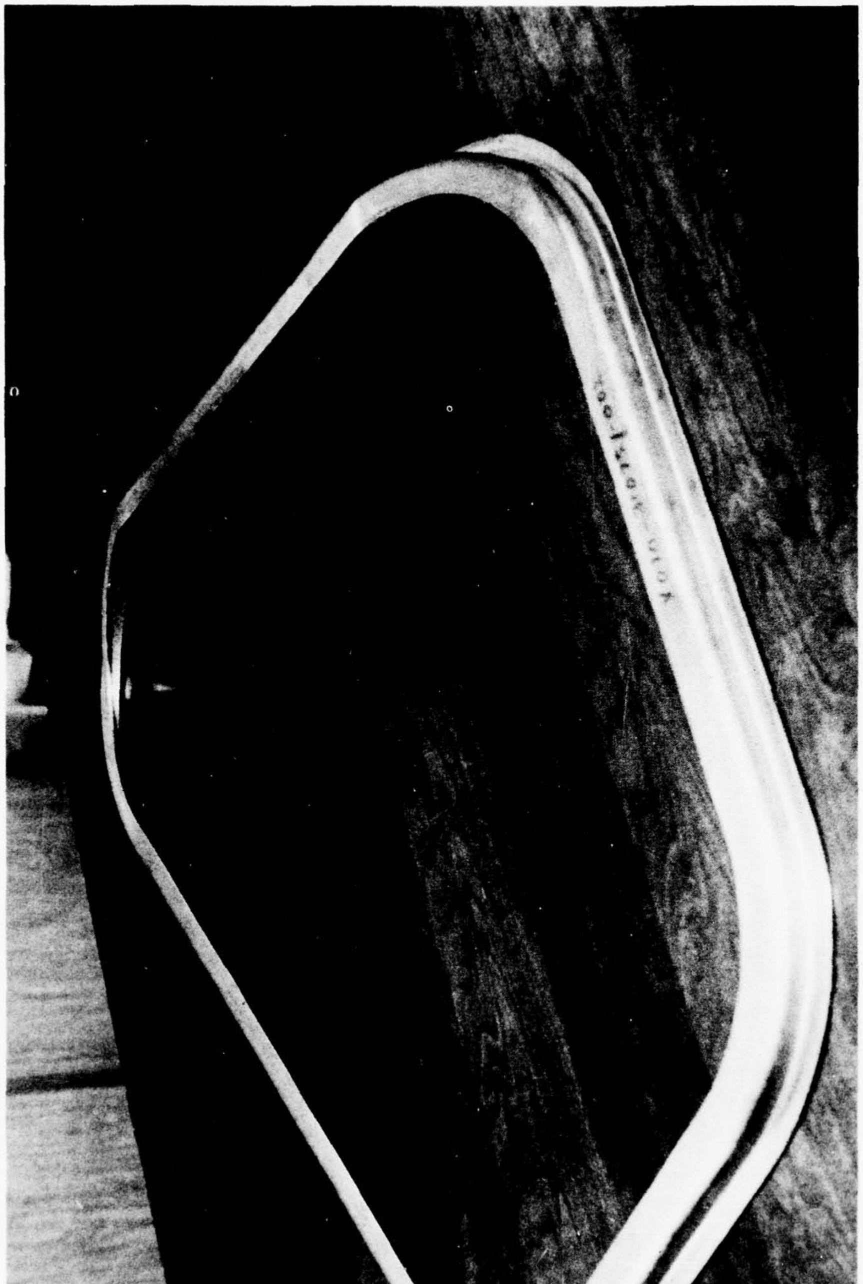


Figure 5. Superplastically formed Space Shuttle windshield frame.

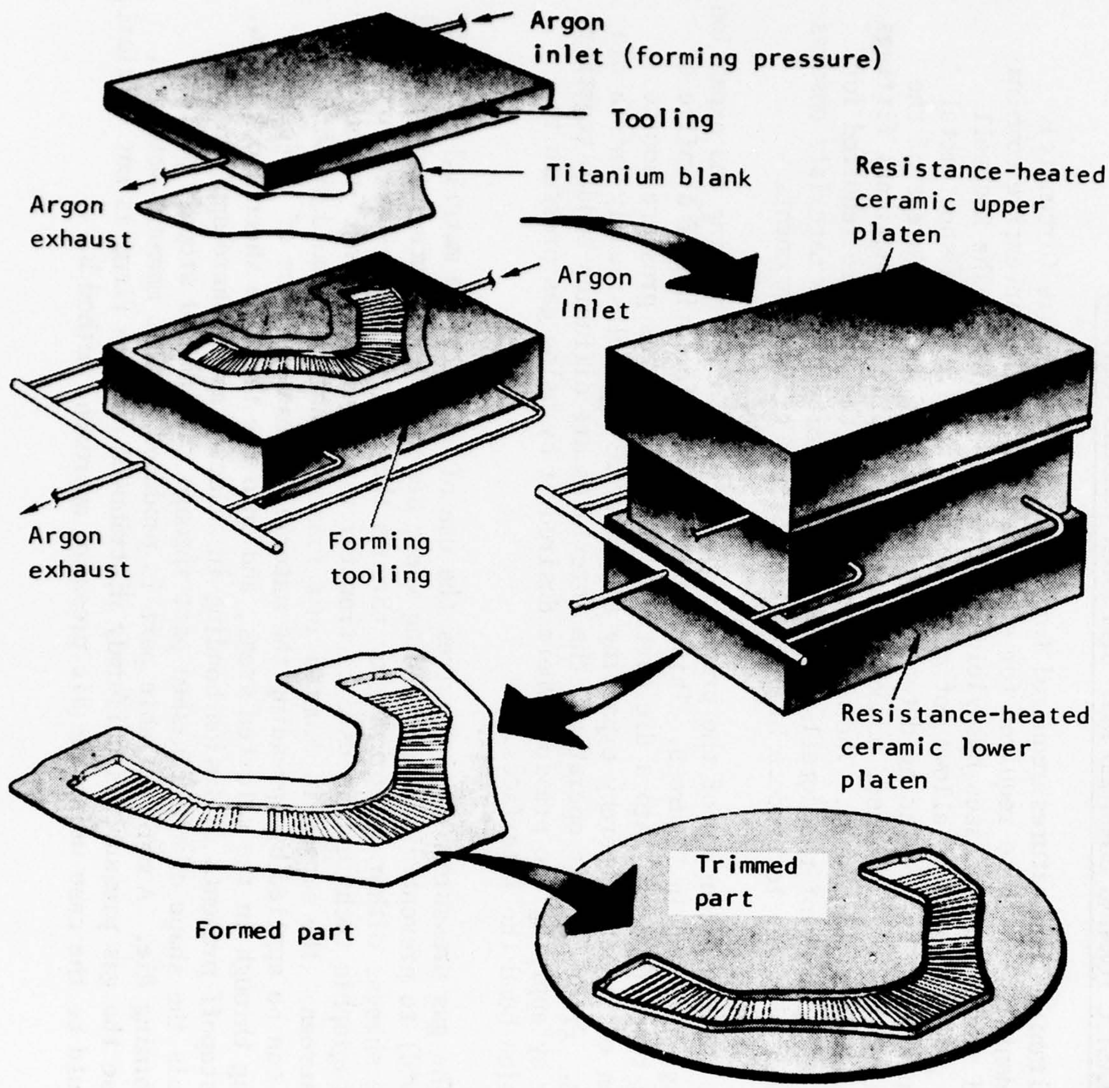


Figure 6. Superplastic forming of titanium.

Structural configurations which were previously considered impossible with conventional forming methods are easily fabricated with this process. Figure 7 shows a sine wave beam made using SPF, which is an efficient structural shear member, particularly in lifting surface structure. The frame shown in Figure 4 also produces an efficient shear-resistant structure, with beads of corrugations forming an integral part of the structure.

SUPERPLASTIC FORMING COMBINED WITH DIFFUSION BONDING (SPF/DB)

Titanium temperatures required for diffusion bonding are fortunately coincidental with those required for superplasticity. The inventive combination of these two processes has yielded impressive results. The Rockwell SPF/DB patented process allows not only the forming of complex sheet metal structure, but, by preplacing details in the tooling, selected areas of the structure can be reinforced, padded, or otherwise joined to functional fittings or attachments (Figure 8). The argon gas provides the pressure required for diffusion bonding of the details, while the plasticity of the materials ensures a perfect part fit to produce highly reliable, repetitive components.

A further extension of the process utilizes diffusion bonding and expansion forming, as shown in Figure 9. This illustrates the formation of a waffle or beaded-type structure into a die cavity by inserting a gas pressure source between two sheets, thereby expanding the material superplastically into a die cavity. Prior to this operation, the interfaces are diffusion-bonded together, either by applying die pressure where desired or by using gas pressure to diffusion bond the interfaces.

The gas pressure method requires the use of an interface material (stopoff compound) to prevent diffusion bonding where desired. This material is applied to the sheets, either by spraying or through the use of a silk screen process. A photographic technique is used to transfer the required stopoff layout to the silk screen. The screen is mounted in a frame so that the liquid stopoff compound can be applied by spreading the material across the face of the screen, passing through in the selected areas, and onto the titanium sheet stock below. This stopoff prevents diffusion bonding in selected areas where applied and controls the shape of the finished part through the applied stopoff pattern and forming die. A more reliable part is produced in this manner, method A, because the gas pressure is uniformly distributed and die fitup is not critical, as would be the case using the die pressure approach, method B.

EXPANDED SANDWICH

A particularly important development in SPF/DB is the method of expanded sandwich structure. In this Rockwell patented process, at least three titanium alloy sheets are diffusion bonded in selected areas and then expanded apart by

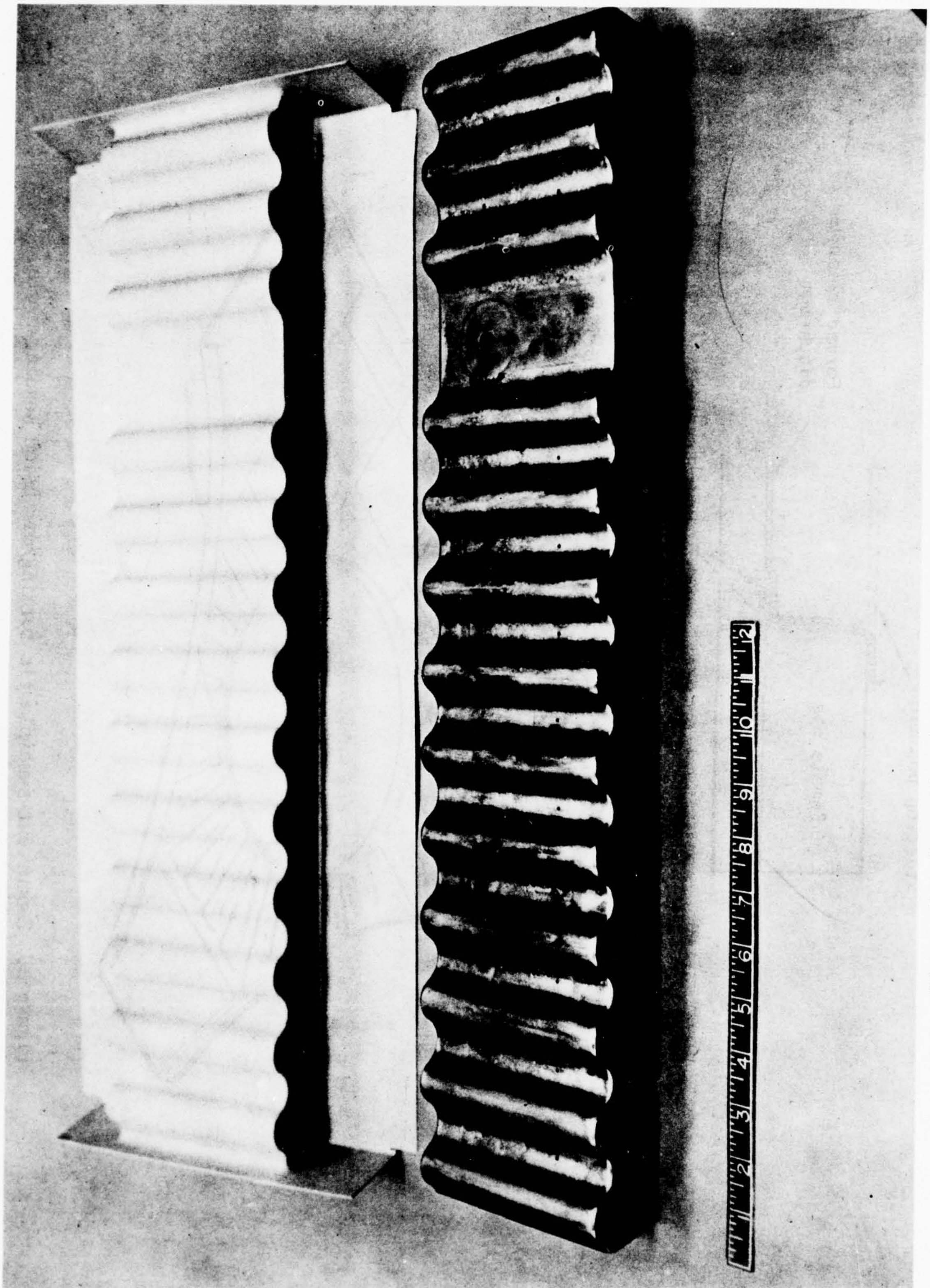


Figure 7. Superplastically formed sine wave beam.

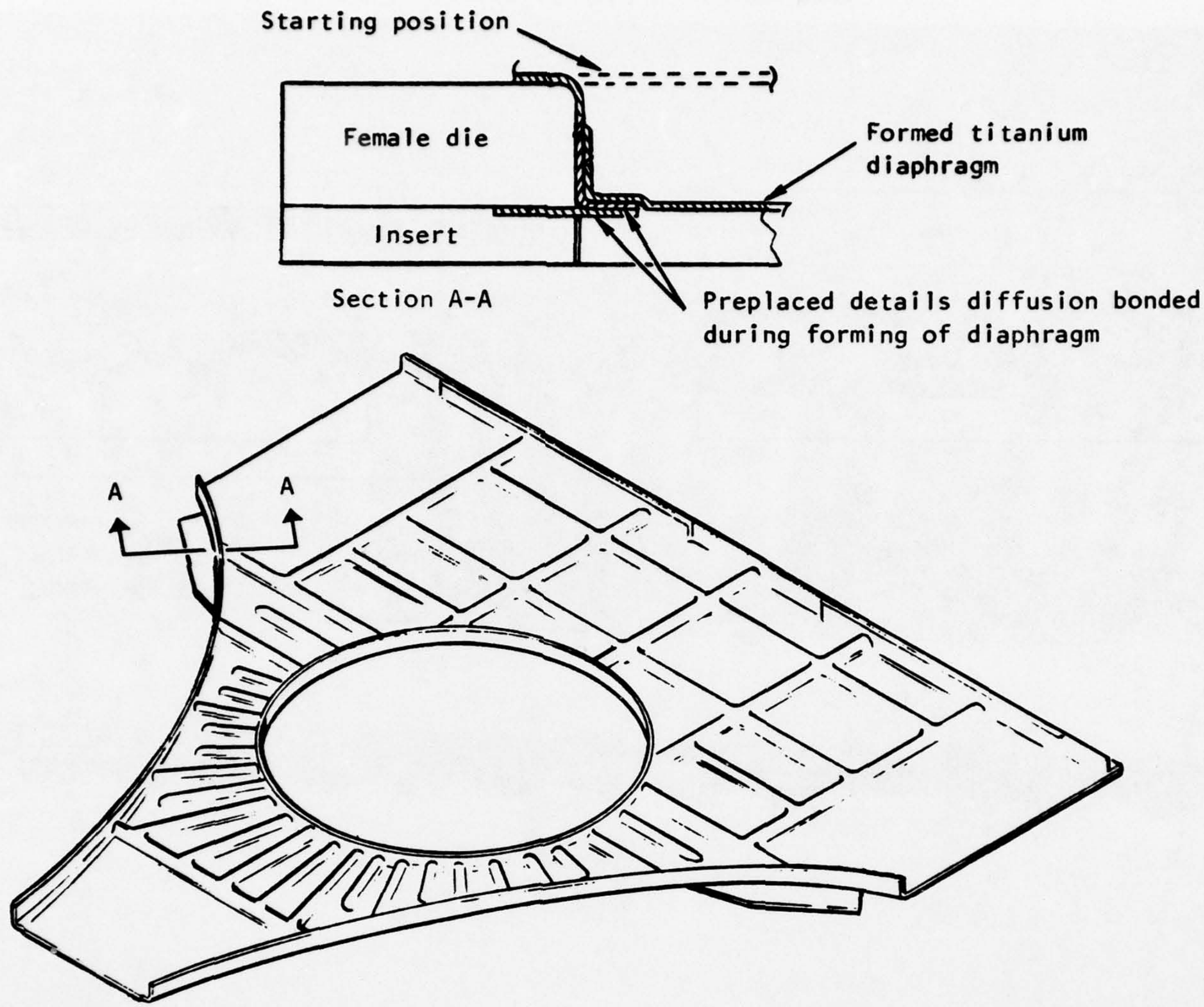


Figure 8. Concurrent superplastic forming/diffusion bonding cycle.

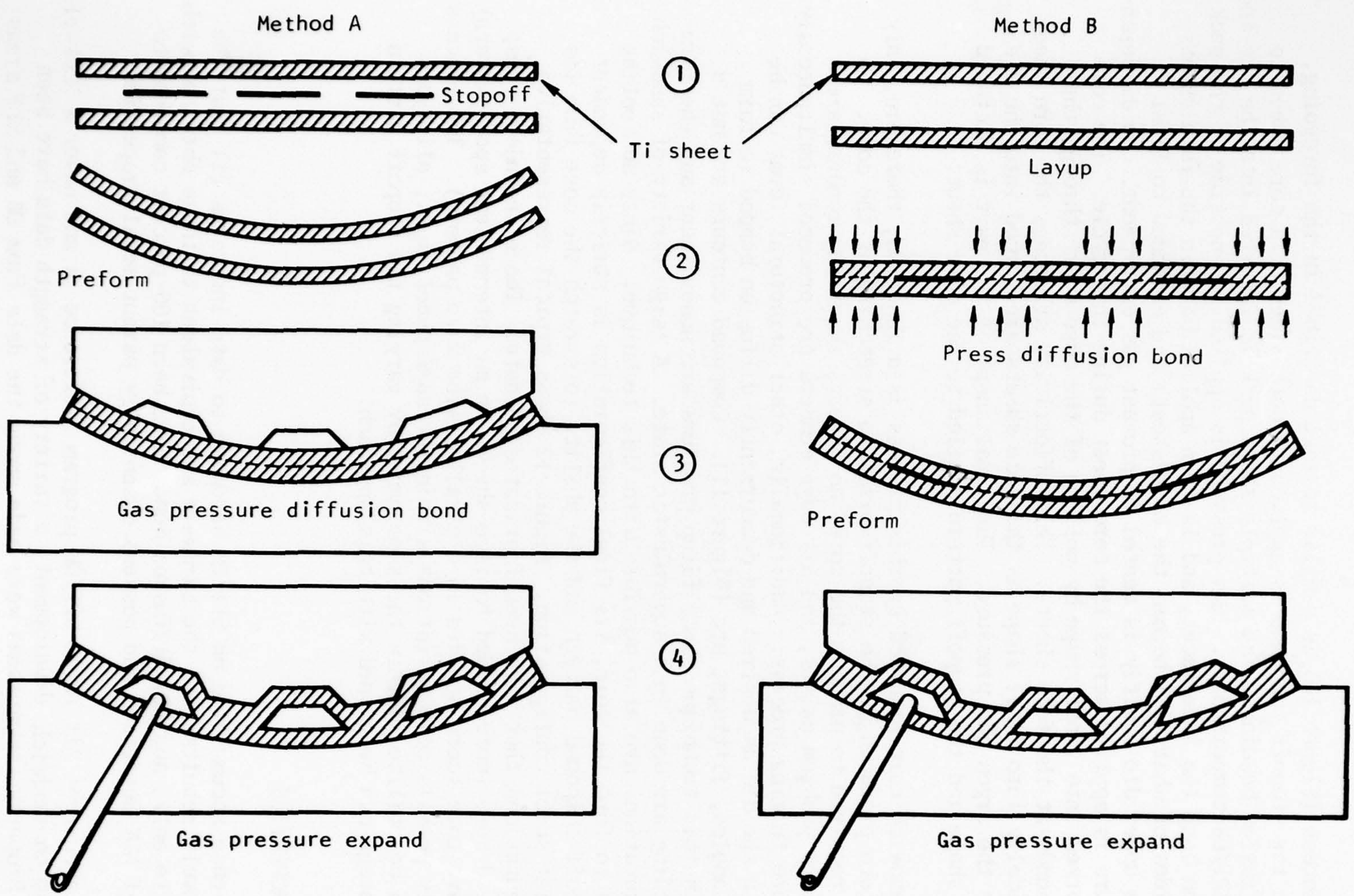


Figure 9. Superplstic forming/diffusion bonding expansion process.

internal pressure in the containment tooling. Thus, an integrally stiffened sheet metal structure may be produced in one operation.

The process (Figure 10) is similar to that described in the foregoing, except that the stopoff compound is applied to both sides of a core sheet to prevent diffusion bonding. The multiple sheet pack is inserted into the die and heated to SPF/DB temperatures. Gas pressure is applied to one side of the pack to diffusion bond the interfaces, and is then applied between the face sheets (on both sides of what will become the core sheet) and expanded to final shape. The upper die cavitiy is vented to prevent gas entrapment. No differential pressure is applied across the core sheet during this cycle. The core sheet is formed into final shape by pulling of the core apart through the diffusion bonds at the face sheets. This effectivity stretches the core sheet superplastically into final shape as the face sheets are forced into the die cavities by the argon gas pressure. The final shape of the part is dictated by the die shape and the stopoff pattern applied to the core sheet.

The sandwich core produced by this process is a function, therefore, only of the pattern produced by the stopoff prior to stretching of the core. No tooling is required to produce the core, no inserts requiring removal are used, no fitup problem exists, and all edge members are produced simultaneously with the core forming process. Additionally, other structural forms can be preplaced in the die as desired and concurrently diffusion bonded to form attachment angles, fittings, etc (Figure 11). Compound contours are not a problem with this technique since fitup problems are nonexistent and the forming and bonding are done in a superplastic state. A large variety of sandwich core configurations are also possible with this technique. Since no tooling is required to form the core, its final configuration is strictly dependent on the stopoff compound pattern and the ability to stretch the core from its original flat sheet configuration. Figure 12 shows typical representative core configurations that have been fabricated to date. These include a truss core, dimpled core (core bonded to face sheets in an intermittent spot pattern), and sine wave core (core bounded in a parallel sine wave pattern). The process also readily permits core variations within the same panel; i.e., all types of core can be utilized within the same panel by varying the stopoff pattern if an advantage can be gained with this approach.

MATERIAL PROPERTIES

Experience accumulated on SPF/DB hardware to date indicates (1) that the strength levels resultant in the hardware are equivalent to those obtained with the SPF cycle only, and (2) diffusion bonds have been 100-percent complete to the limit of NDT detection and possess. essentially parent metal properties.

Under a current Air Force SPF/DB program (Reference 2) and under a Rockwell IR&D program on sandwich development, a variety of strength data have been obtained. Property comparisons were made among the data from DB and SPF areas

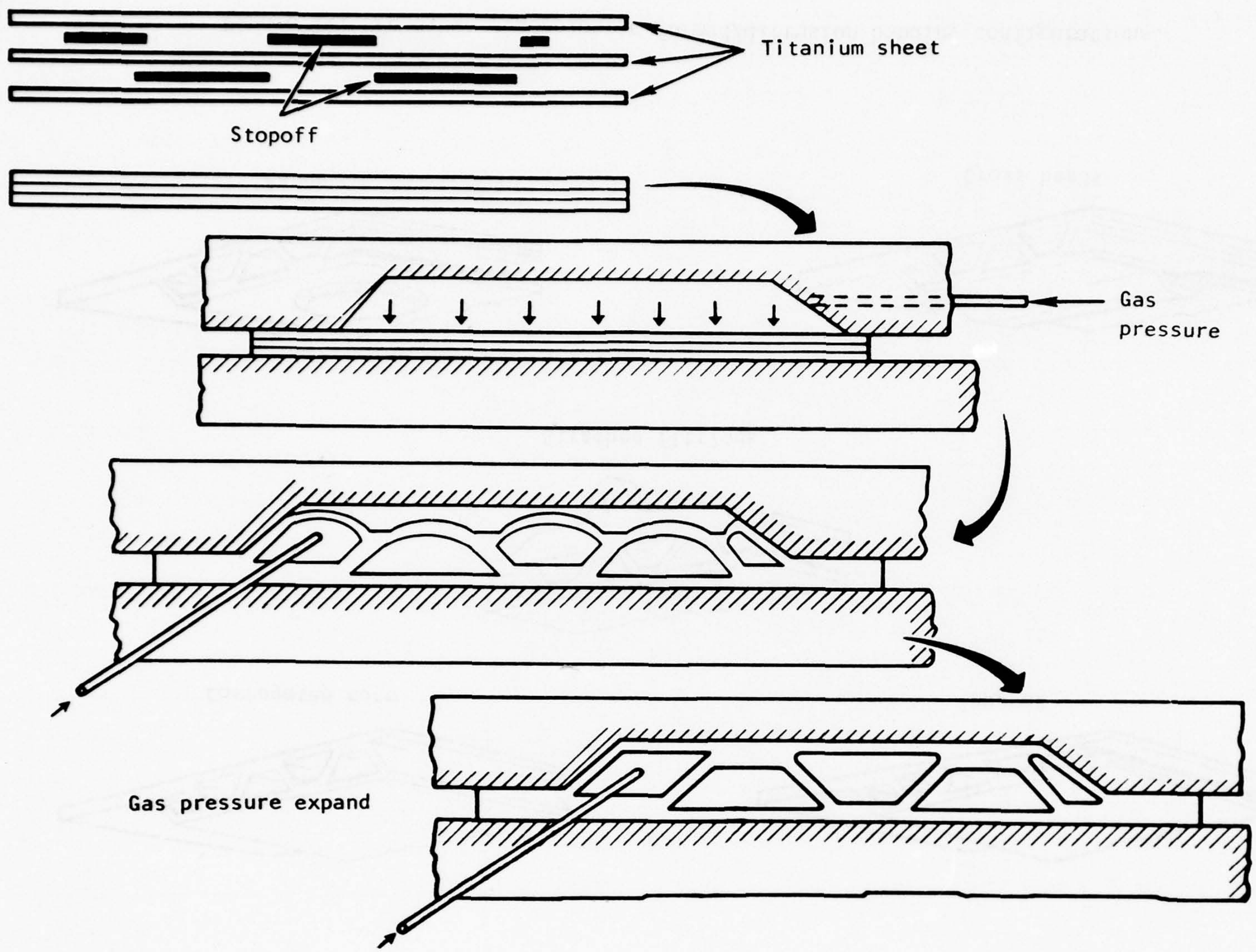


Figure 10. Expanded sandwich process.

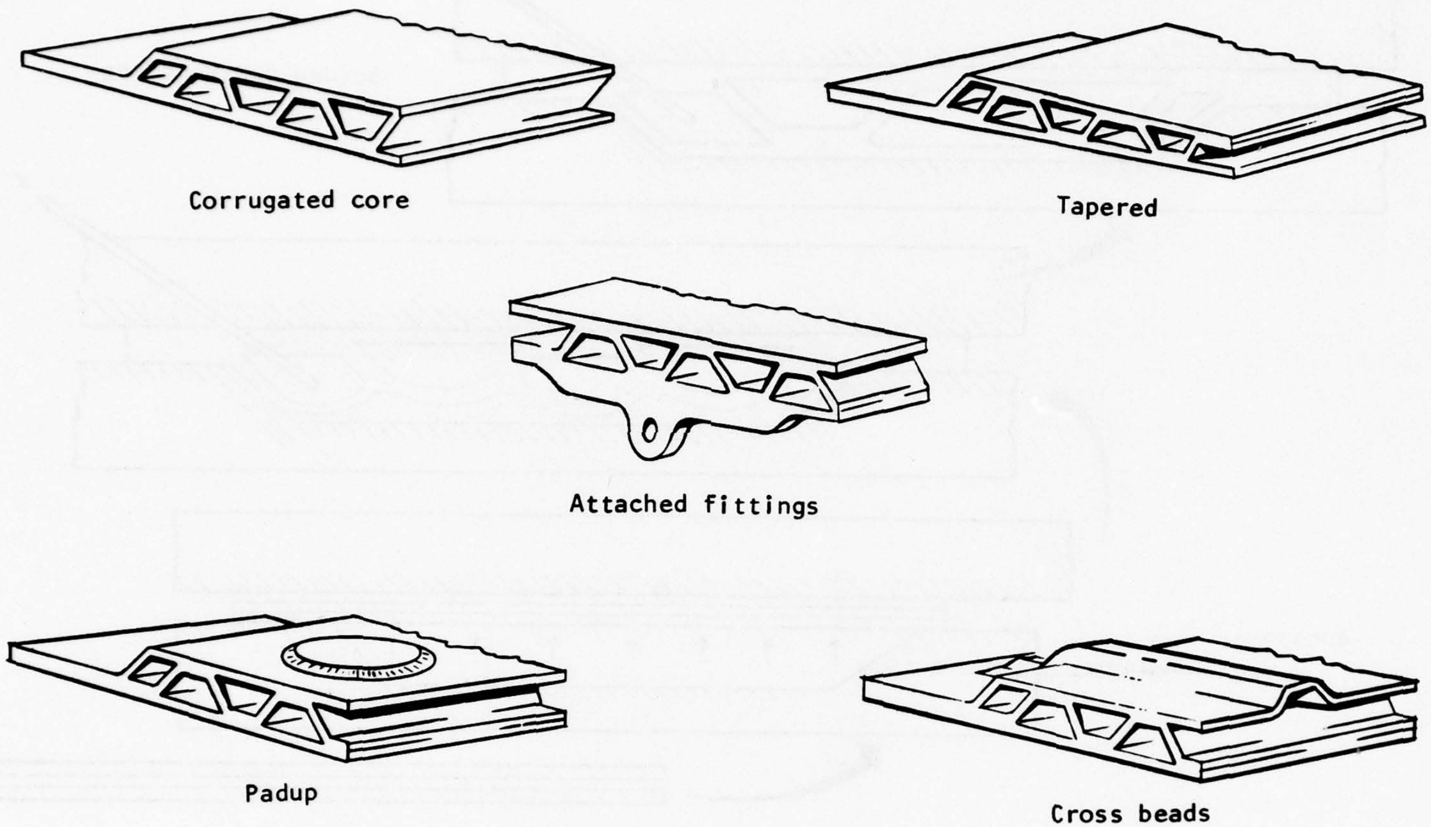


Figure 11. Possible superplastic-formed/diffusion bonding configurations.

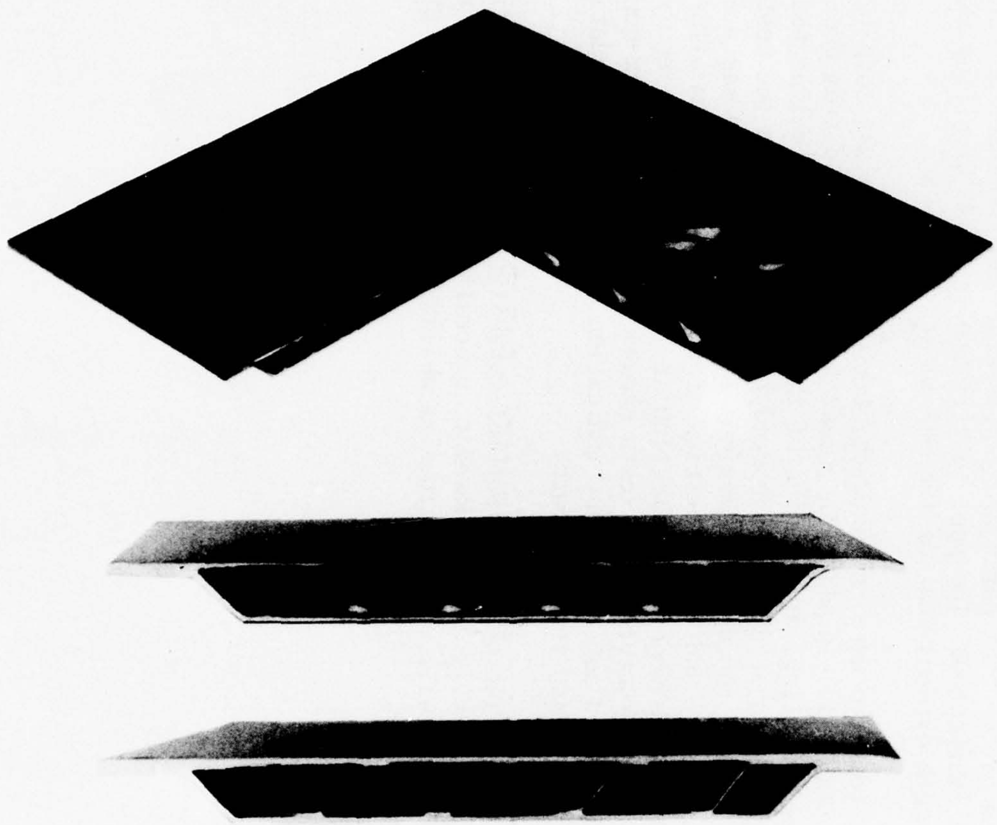


Figure 12. Examples of actual expanded sandwich hardware.

of a SPF/DB-processed part, data from superplastic-formed parts, and data from diffusion-bonded parts. The comparison indicates that the mechanical properties of the Ti-6Al-4V parts subjected to SPF, DB, or SPF/DB processes are similar.

The results of single lap-shear tests showed 5.44 by 10^5 kPa to 6.1 by 10^5 kPa (79.0 to 89.5 ksi) ultimate shear strength at the DB interface (Table 2). The shear values agree well with those obtained on double-lap-shear tests of 5.522 by 10^5 kPa to 5.93 kPa (80.1 to 86.1 ksi) for the fully bonded interface, indicative of parent metal strengths. The slightly larger scatter in test results for the single-lap-shear tests is believed to be caused by the off-centered or asymmetric loading of the specimen.

Static peel tests resulted in parent metal fracturing without evidence of peeling at the bond plane (Table 3). The sheet gage used and the part geometry simulated in the test parts are representative of the SPF/DB full-scale parts to be fabricated. The peel test fracturing mode signifies that the DB joint strength exceeds that of the SPF metal.

The strength tests to date on sandwich, limited to the truss core type, are summarized in Table 4. In all tests, load falloff resulted from predictable buckling, wrinkling, or crushing of the structure, as delineated in the table. No separation of diffusion-bonded joints occurred in the tests. No cracks were developed in the metal at maximum load. Maximum load was a function of the structure geometry and the properties of the 6Al-4V titanium alloy. Loading deflections far beyond the deflection at maximum load were required to develop cracks in the structure. The tests showed that the diffusion-bonded joints were sound and did not reveal any indication of material degradation by the process used to produce the structure.

At present, prediction of the structural capability of discrete designs will require specific verification. However, generalizations emerging from current and future work will allow increasing ability to predict structural behavior with confidence.

TABLE 2. RESULTS OF SINGLE LAP SHEAR TESTS

Test area	Grain direction	Specimen (ID)	Test thickness		F_{su}	
			mm	(in.)	MPa	ksi
DB	L	4-19	5.8	0.230	555	80.6
		4-20	5.8	.230	588	85.3
	LT	15-15	3.9	.155	595	86.3
		15-16	3.9	.155	552	80.1
		15-17	2.56	.101	617	89.5
		15-18	2.56	.101	569	82.6
	L	8-23	2.1	.084	561	81.4
		8-24	2.1	.084	600	87.1
		16-35	2.6	.103	576	83.5
		16-36	2.6	.103	581	84.3
	LT	8-21	2.1	.084	545	79.0
		8-22	2.1	.084	588	85.3

TABLE 3. PEEL TEST RESULTS, SPF/DB CORNER INTERSECTION

Test area	Specimen (ID)	Gage		Peel strength*	
		mm	(in.)	N/mm	lb/in.
DB/SPF juncture	15-1	1.8	0.071	258	1475
	15-2	℄	℄	251	1435
	15-3	1.8	.071	229	1310
	15-4			262	1495
	13-1	1.8	0.071	224	1278
	13-2	℄	℄	230	1312
	13-3	3.2	.125	236	1350
	13-4			232	1325

*Parent metal (SPF member) failed.

TABLE 4. MECHANICAL PROPERTIES OF EXPANDED SANDWICH STRUCTURES

Type test	Specimen size, mm (in.)	Thickness: Face sheets, mm (in.)	Thickness: Core, mm (in.)	Test direction	Maximum stress, Mpa (psi)	*Failure description
Flatwise tension	12.7 x 44.5 x 44.5 (1/2 x 1-3/4 x 1-3/4)	1.8/1.5 (0.070/0.060)	0.3 (0.012)	-	>3.287 (>476.8)	Adhesive bond between specimen and test fixture failed
Flatwise compression	12.7 x 50.8 x 50.8 (1/2 x 2 x 2)	1.65 (.065)	.3 (.012)	-	1.15 (167.4)	Core buckling
	10 x 76 x 76 (.4 x 3 x 3)	.81 (.032)	.3 (.012)	-	2.2 (319.3)	Core buckling
Edgewise compression	12.7 x 76 x 76 (1/2 x 3 x 3)	.46/.4 (.018/.016)	.3 (.012)	Transverse	79 (11 458)	Face sheet buckling
	12.7 x 76 x 76 (1/2 x 3 x 3)	.48/.46 (.019/.018)	.3 (.012)	Transverse	79 (11 525)	Face sheet buckling
	12.7 x 76 x 76 (1/2 x 3 x 3)	.46/.43 (.018/.017)	.3 (.012)	Longitudinal	653 (94 728)	Core and face sheet buckling
	12.7 x 76 x 76 (1/2 x 3 x 3)	.48/.46 (.019/.018)	.3 (.012)	Longitudinal	702 (101 927)	Core and face sheet buckling
Core shear	12.7 x 38 x 127 (1/2 x 1-1/2 x 5)	1.65 (0.065)	.3 (0.012)	Transverse	1.047 (151.9)	Core buckling
	12.7 x 50 x 101 (1/2 x 2 x 4)	1.65 (0.065)	.3 (0.012)	Longitudinal	6.16 (894.7)	Core wrinkling
Beam bending	11.9 x 66.6 x 232 (.47 x 2-5/8 x 9-1/8)	.43/.5 (.017/.020)	.43 (.017)	Transverse	110 (16 000)	Face sheet buckling
	11.9 x 50 x 229 (.47 x 2 x 9)	.46/.5 (.018/.020)	.3 (.012)	Transverse	110 (16 200)	Face sheet buckling
	10.9 x 76 x 178 (.43 x 3 x 7)	.48/.5 (.019/.020)	.3 (.012)	Longitudinal	>643 (>93 300)	Core crushing at a loading point

Section III

BASELINE

The B-1 aft engine nacelle was chosen for this study because it presents an area of conventional structure on a high-technology supersonic aircraft in a relatively severe environment where costs of the airframe have been traditionally high. The area of study extends from the front face of the engines aft to include the engine-mounted shrouds which cover the engine exhaust nozzle actuators.

Aircraft No. 4 of the B-1 production series was chosen as the baseline aircraft for the purposes of this study except for the engine access doors, which are aircraft No. 5 baseline. The baseline parts are conventional aluminum and titanium aircraft structures. Five areas were chosen for study, i.e., the upper deck, the side and lower engine access doors, the centerline precooler access panel, and the engine shrouds. The upper deck and the centerline precooler access panel are primary nacelle structure, while the side and lower engine access doors and the engine shrouds are secondary structure.

UPPER DECK

The upper deck structure is approximately 44 inches wide and 128 inches long, and consists of three areas of approximately equal length (Figure 13). The contour is a relatively flat compound contour.

The forward area has inner and outer skins which are chem-milled after forming for weight reduction. Together with the outboard longeron and the nacelle center beam, they form a torque box which transfers the engine access door and the upper deck loads to the bulkhead at the front of the engines. Four frames support the skins, some of which are sheet metal and some are machined from plate. All parts in this area are annealed 6Al-4V titanium except the outer skin, which is 2024-T81 aluminum.

The center section is made of three parts; i.e., an outer skin and an inner skin which are superplastically formed, incorporating fore and aft stiffening beads. The two skins are then riveted together. The inboard side has a machined skin 7.75 inches wide which has integral stiffeners and is machined from plate. There are no frames in this area because of the close proximity to the engine. The material in this section is annealed 6Al-4V titanium.

The aft section has an outer chem-milled skin and five frames. All material is, again, 6Al-4V titanium. The outboard longeron extends the length of the assembly and supports the four machined engine access door hinges. The longeron assembly and installation also contains many small sheet metal clips and brackets.

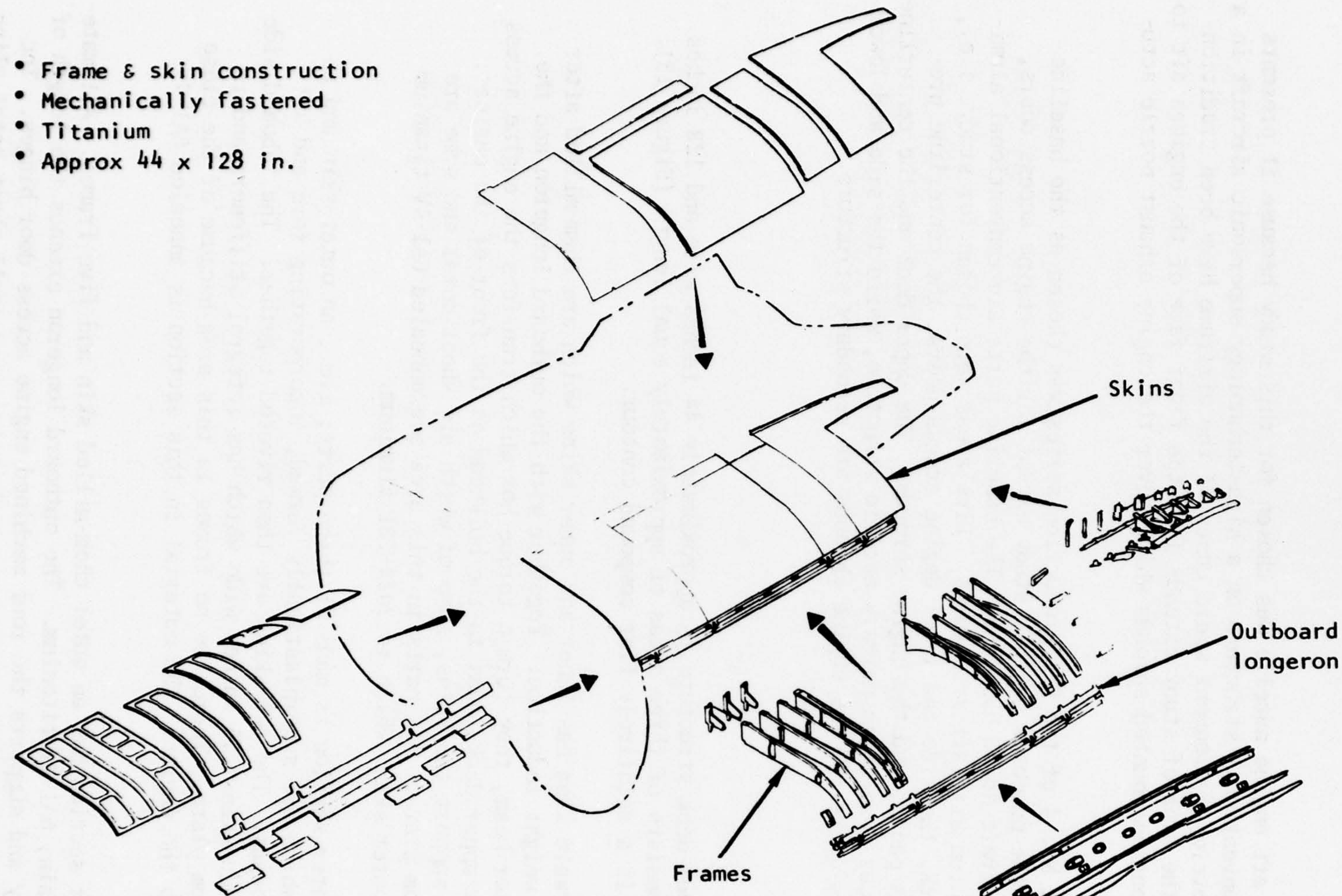


Figure 13. Upper deck baseline.

The upper deck assembly has approximately 120 parts and 1,500 mechanical fasteners. Assembly and installation is with clips and brackets with mechanical fasteners.

ENGINE ACCESS DOORS

The side door is hinged at the top, the lower door is hinged at the inboard edge, and they are attached to each other by five quick-release latches. The doors have compound contours that are approximately circular arcs. The lower door has a reversal in contour which results in high internal bending loads. Each door is approximately 50 by 100 inches (Figure 14).

The doors are adhesive-bonded honeycomb structure 1-1/2 inches thick. The face sheets and the honeycomb core are aluminum. The basic honeycomb density is 2 pounds per cubic foot, with 8 pounds per cubic foot in highly loaded areas. Doublers are bonded to the face sheets in high load areas such as the latches and hinge fittings. The hinge fittings are bonded in place, while the latches are attached with bolts through the vertical legs of hat section brackets, which are bonded in place. The bolts penetrate both upstanding legs of the bracket and the latches. Edge closures are prepreg fiberglass fabric. Each door bonded assembly contains approximately 100 parts, not including the multiple-part honeycomb core, approximately 70 rivets, and several layers of fiberglass edge closures.

CENTERLINE PRECOOLER ACCESS PANEL

The centerline precooler access panel is a "waffle plate" design which is machined from annealed 6A1-4V titanium plate and then hot formed to contour. The contour is relatively flat with a small bend at the center. The panel is approximately 0.6 by 28 by 29 inches and is installed with screws (Figure 15).

ENGINE SHROUDS

Each engine shroud consists of four 90-degree segments which cover the exhaust nozzle actuators. Each segment is approximately 28 x 48 inches. The shrouds, which have titanium skins and 1-1/4 inches deep honeycomb core, are installed with screws. Assembly is by brazing. Doubler pads are created by chem-milling of the face sheets, and additional doublers are brazed in place. Each shroud braze assembly contains approximately seven parts (Figure 16).

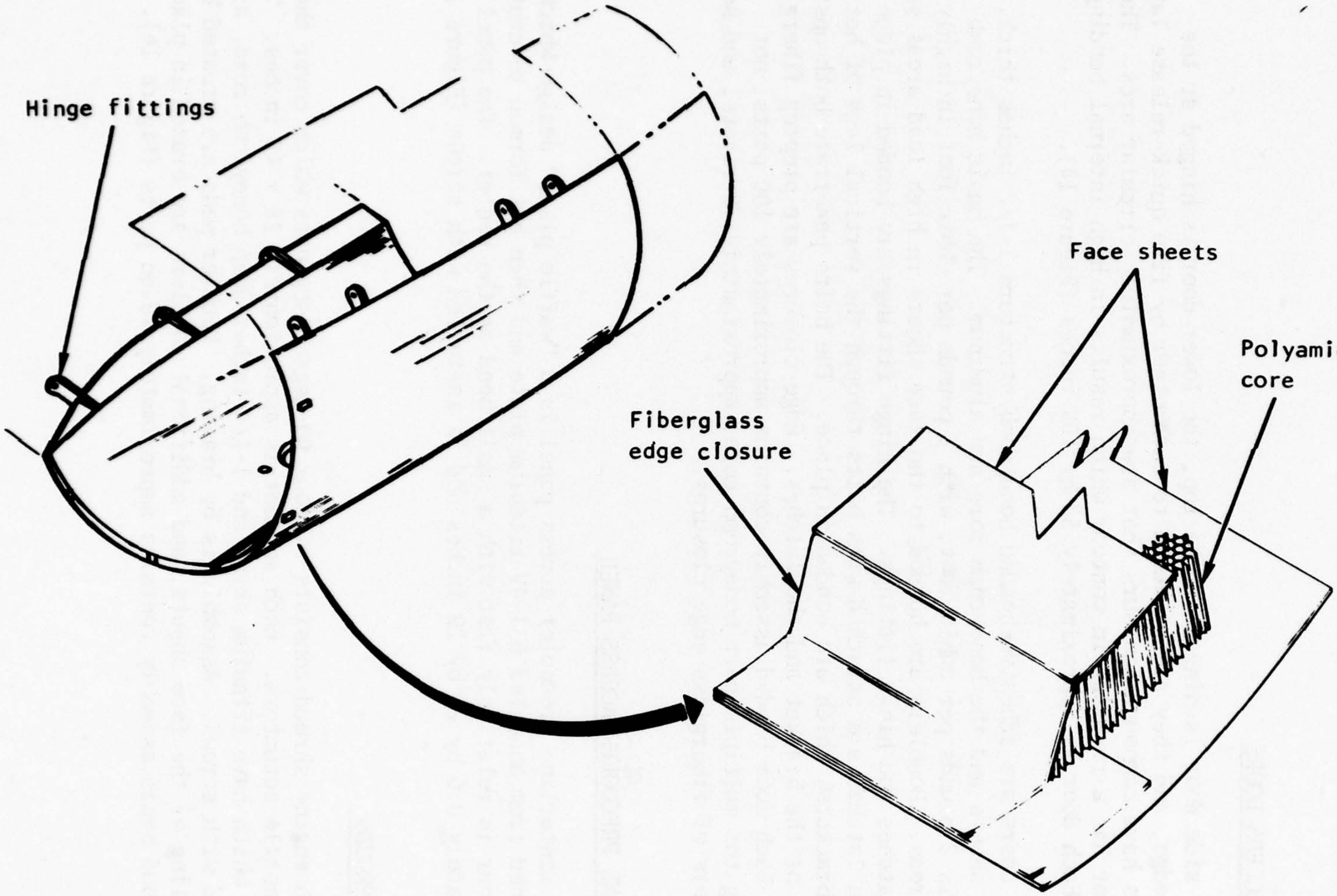


Figure 14. Engine access doors baseline.

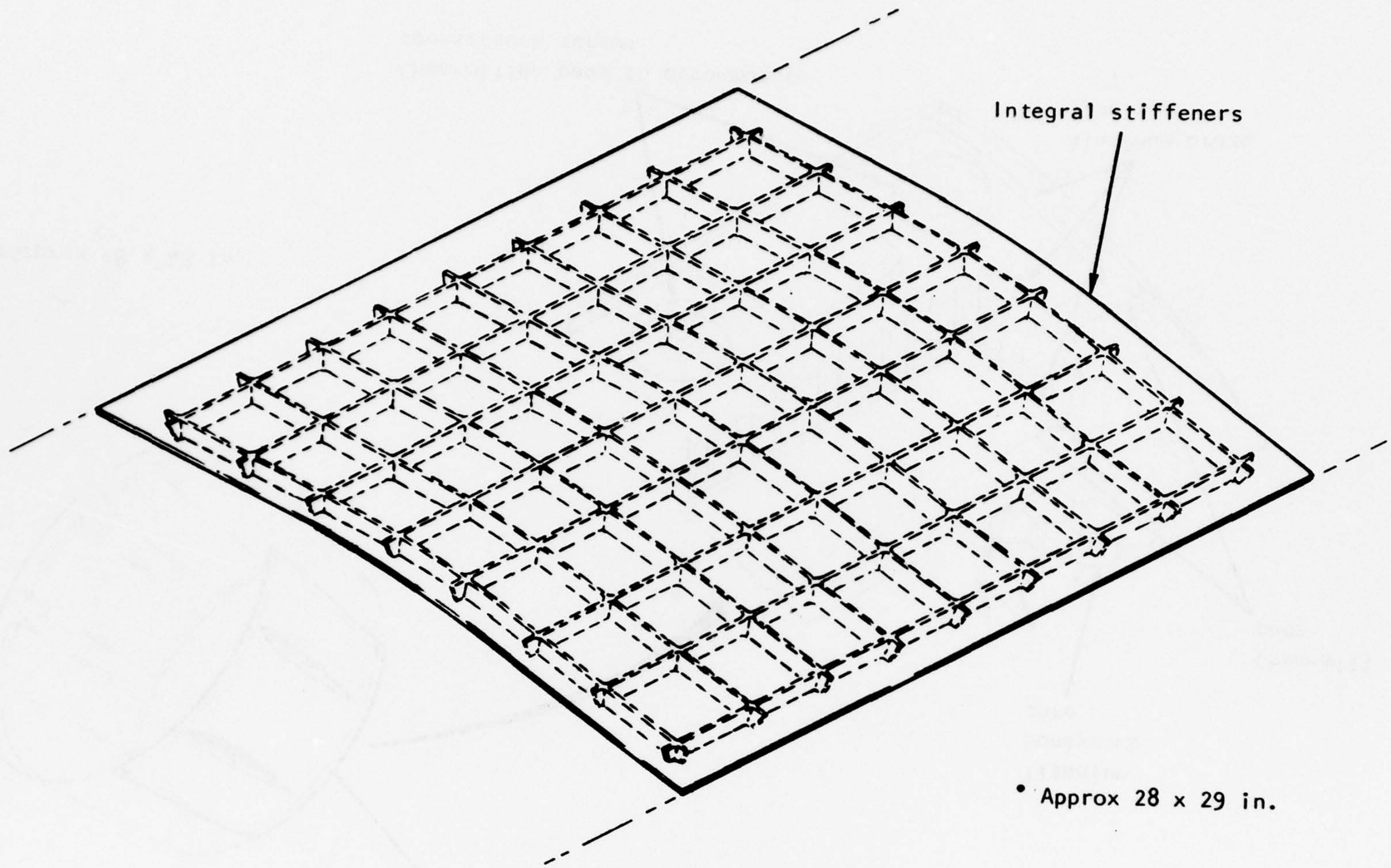


Figure 15. Centerline precooler access panel baseline.

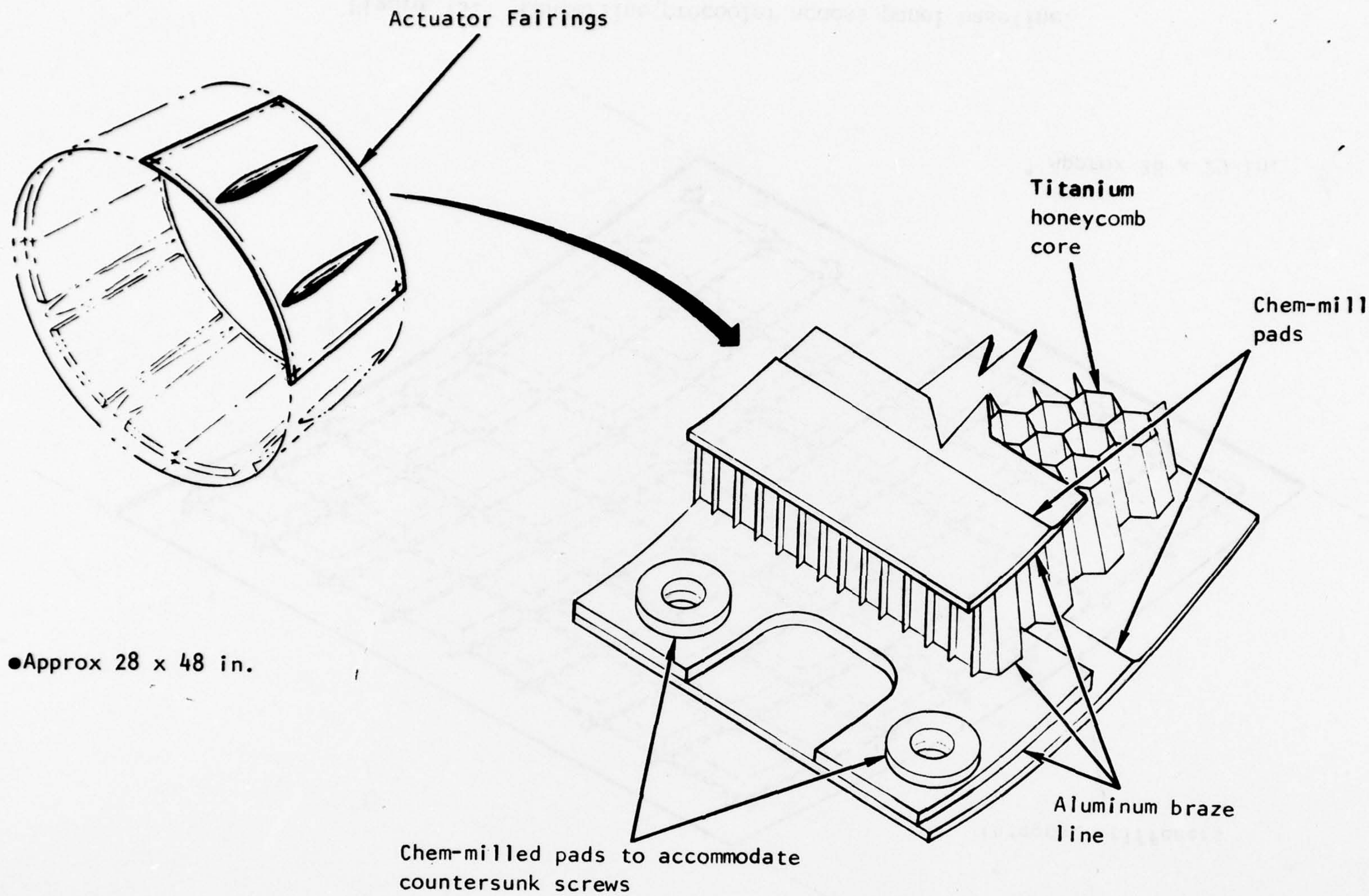


Figure 16. Engine shroud baseline.

SUITABILITY FOR COMPARISON

These structures are representative of a wide range of conventional structural fabrication and two of the most common materials, aluminum and titanium. Machined titanium fittings and skin panels, stretch-formed titanium and aluminum skins with machined and formed frames, and stringers attached with mechanical fasteners are represented by the upper deck and precooler access panel. The engine access doors are bonded honeycomb with aluminum skins and nonmetallic core. The engine shrouds are on all-titanium brazed honeycomb structure. The manufacturing methods are conventional machining, shearing, routing, and hot and cold forming. The assembly methods include riveting, bolting, brazing, and bonding. Both primary and secondary structures are represented.

These structures, therefore, offer a wide range of structures for comparison to SPF/DB structures.

Section IV

SPF/DB DESIGN

DESIGN APPROACH

The specific goal of this design program was to show trends in the cost and weight effectiveness of aircraft structures designed to be fabricated by unique SPF/DB methods. These trends were established by designing structures capable of replacing the conventional state-of-the-art construction methods used on a baseline aircraft. These new designs were developed by producing a range of design concepts that provide a basis for selecting the best possible SPF/DB structure from a cost, weight, and producibility standpoint.

These designs, presented in Appendix A, are not necessarily the final form that would be used in production, but are only intended to be used as a starting point from which definitive aircraft structure can be developed.

Many assumptions have been used in the design, including panel configuration allowables and damage-tolerance effects. Follow-on programs are required to substantiate the directions taken in this program.

UPPER DECK

Three upper deck designs were created (Figure 17); i.e., an integrated assembly with the skins and frames produced in one bonding, forming cycle, and two designs with separate frames. The first of these has a skin-stringer outer surface, and the second has a sandwich panel design.

INTEGRAL FRAMES

The forward and aft sections of the skin have longitudinal stringers formed into the inner skin, while the center section, where there is insufficient clearance for frames, has a reinforced "waffle" skin design, with longitudinal stringers and transverse stiffeners.

The frame spacing has been increased in the aft section to reduce the number of frames by two. The frames are created by expanding the inner sheet into a deep die cavity, forming a hat section frame. Beads in the die form sine wave webs on the hat section side walls for stiffening. Cap strips preplaced in the bottom of the die cavities are diffusion bonded to the frame as it expands to the bottom of the cavity. The frame upper caps are formed by strips placed between the inner and outer sheets and diffusion bonded in place prior to the expansion cycle.

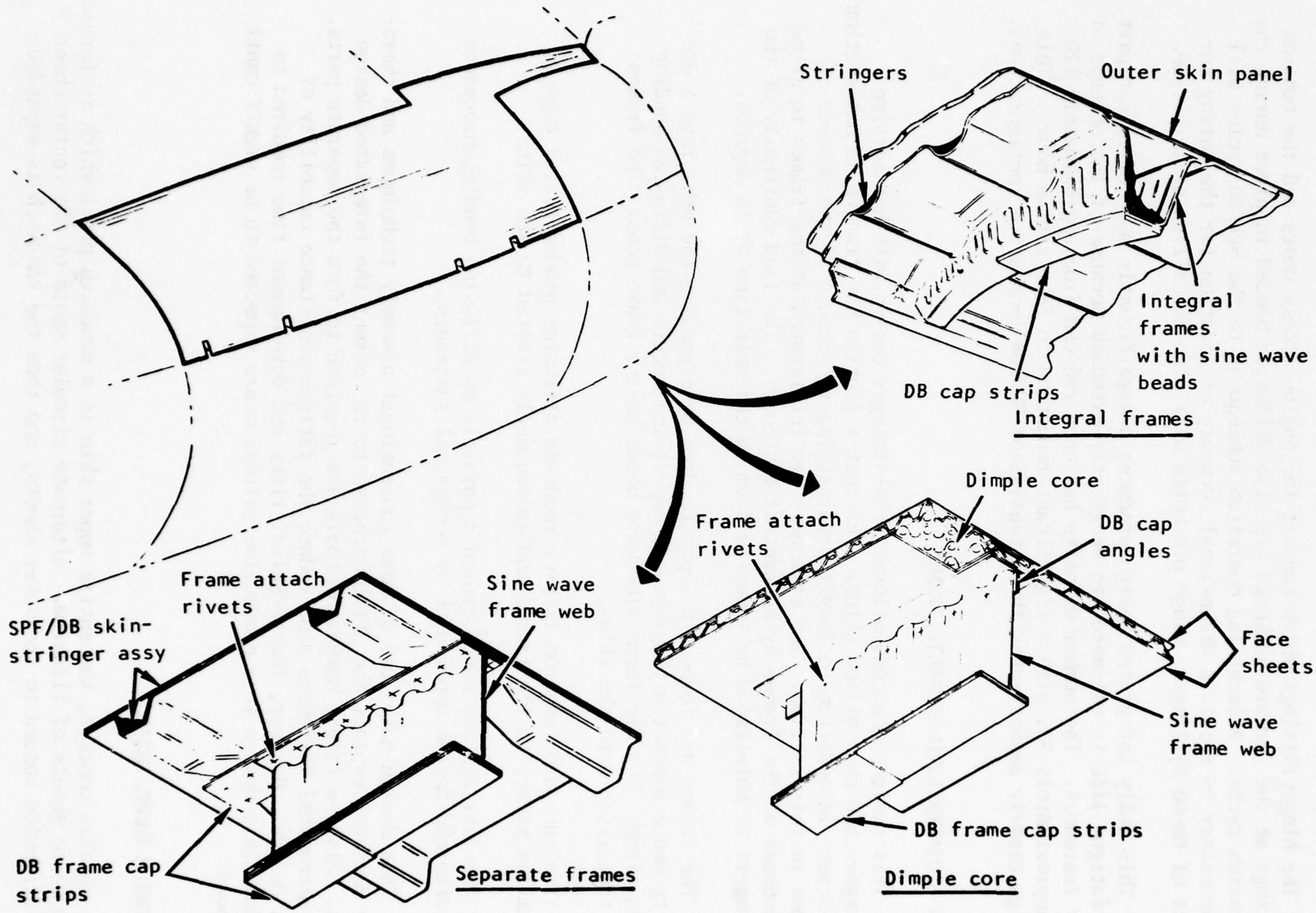


Figure 17. Upper deck SPF/DB designs.

The hinge fittings which support the engine access doors and the tension fittings at the forward bulkhead are also diffusion bonded in place during the expansion cycle. A machining operation subsequent to the SPF/DB cycles will be necessary to maintain dimensional accuracy of location for the mating surfaces of these fittings. Hinge pin holes will also be drilled at this time.

This fully integrated design produces a significantly more efficient part. The fatigue life is estimated to be greatly extended because of the absence of many fasteners. The number of parts has been reduced from approximately 120 to approximately 50, with a significant reduction in fabrication hours. This design clearly demonstrates the potential of SPF/DB innovative configurations.

SKIN-STRINGER WITH SEPARATE FRAMES

This design is a conventional skin-stringer design with hat-section stringers and chem-milled skins. The center section has transverse hat-section stiffeners in addition to longitudinal stringers because of the absence of frames in this section. The stringers are interrupted at the frames to allow attachment of the frames by mechanical fasteners. The load continuity of the stringers is maintained by tapering them to the mold line at 15 degrees.

The frames are formed in separate dies by expanding the webs into a die cavity where contact with preplaced cap strips occurs and diffusion bonding takes place. The die forms sine wave beads in the frame webs. The frames are then riveted to the skins.

The outboard longeron is preformed and diffusion bonded to its caps in a similar manner to the frames and subsequently riveted to the skins.

The fittings are manufactured separately by diffusion bonding processes and attached to the upper deck by mechanical fasteners.

This design makes use of more conventional assembly techniques and therefore does not exploit the SPF/DB process to the extent the integrated design does. Also, a larger number of tools are required to form the separate parts. The mechanical fasteners also reduce the fatigue-resistance capability of this design. However, the technical risks and development time required to produce this design in a production situation are expected to be significantly reduced.

SANDWICH PANEL SKINS

In this concept, the entire upper skin is a sandwich panel which is formed from three sheets of titanium. Alternate circular spots of the center sheet are diffusion bonded to the outer sheets, and then the sandwich is expanded in a die cavity to form a sandwich panel with a core which has a dimple configuration. Strips of titanium are bonded to the inside of the upper sheet to form the frame caps. Doubler sheets reinforce the core sheet at the frame stations to carry the frame shear through the sandwich to the cap strips. Back-to-back angles diffusion bonded to the inner face sheet during the sandwich expansion cycle are used to attach the frames.

The frames, longerons, and fittings are manufactured and installed in a similar manner as for the skin and stringer design.

This design also produces significant advantages over the baseline and the skin stringer SPF/DB design. It is the logical alternate to the integral frame design for near-term structure.

ENGINE ACCESS DOORS

The engine access door designs are of two basic types. The first is with circumferential beads or hat sections, and the second type is sandwich panels with several different core sheet configurations. In all cases, the hinge fittings are diffusion bonded to the door panels during the expansion cycle of the SPF/DB process (Figures 18 and 19).

It was advantageous to revise the method of attaching the door latches to more fully exploit the SPF/DB process. The baseline design utilizes hat sections which are bonded in place. Bolts extend through the upstanding legs of the hats and through the body of the latches in a direction approximately parallel to the nacelle moldline. The hat section configuration appeared impractical for the SPF/DB cycle; therefore, a new latch design was adopted which attaches by bolts through the door mold line skin. This was used for all SPF/DB door concepts.

HAT SECTION DOORS

This design has radial hat-section stiffeners 1-1/2 inches high which are formed from the inner skin. They are formed by expanding the inner skin into cavities in the die. Cap strips, preplaced in these cavities, are then diffusion-bonded to the crown of the hats as the inner skin is forced against them by the gas pressure. Because very thin walls are required in the upstanding legs of the hats for structural efficiency, these surfaces have sine wave stiffening beads. Since they are formed in the die, they all must be perpendicular to the tool parting plane rather than radial (perpendicular to the mold line) to facilitate removal of the door from the die. These beads then add to the complexity of the dies required for this design. The stopoff

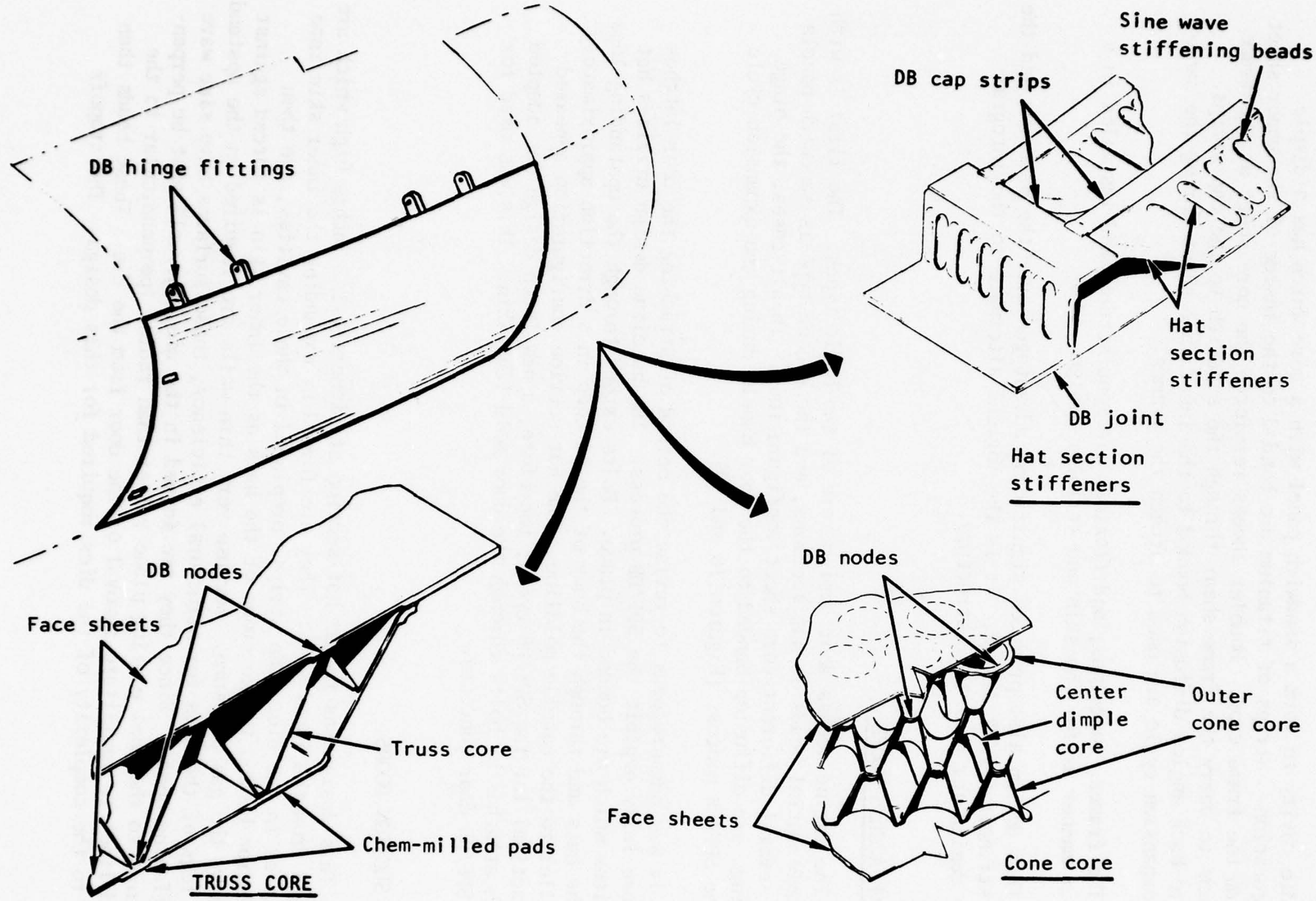


Figure 18. Engine side access door SPF/DB concepts.

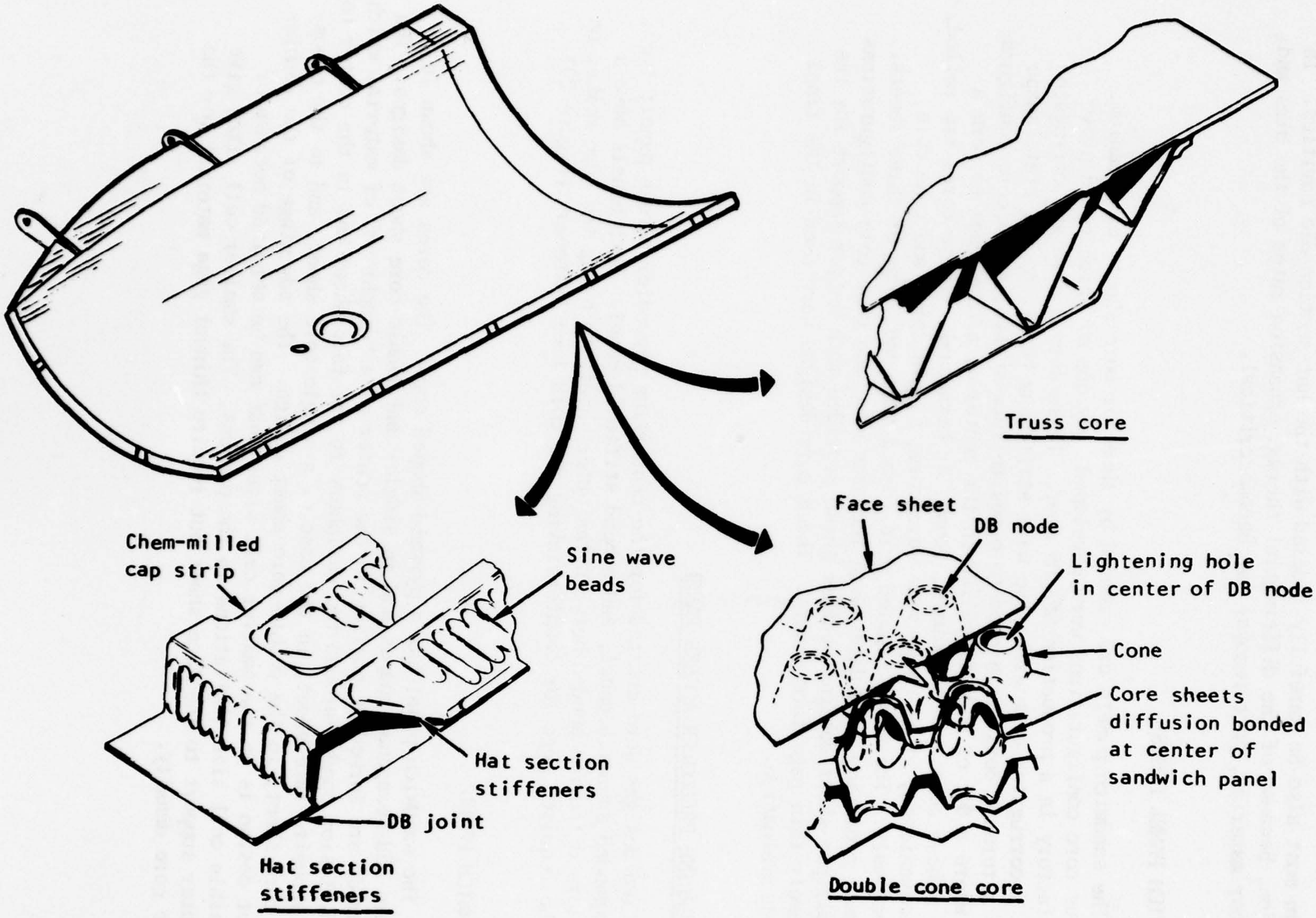


Figure 19. Engine lower access door SPF/DB concepts.

pattern must also be carefully indexed with the hat-section die cavities. In addition, because of the differential thermal expansion rates of the dies and the door material, part removal may become critical.

SANDWICH PANEL DOORS

The sandwich panels are created by three or more sheets of titanium. Various core configurations were developed, any one of which could prove satisfactory in a production SPF/DB door. These were a straight corrugated core, a corrugated core with sine wave stiffening beads, an egg crate shape where alternate dots are bonded to opposite face sheets, and a core configuration where a dot or node is pulled in the center of a diaphragm to form a cone. These cones can be square, round, or hexagonal. These cores are called, for convenience, truss core, sine wave core, dimple core, and cone core, respectively. The cores studied were formed from one, two, or three sheets. The most promising candidates were the sine wave and cone core configurations in multiple-sheet designs because these provided much better support for the extremely thin gage face sheets. These core designs were used in the final design evaluation.

CENTERLINE PRECOOLER ACCESS PANEL

Two designs were created for the centerline precooler access panel; i.e., an expanded sandwich panel, and a bead stiffened panel. Both panels have a doublers diffusion bonded between the outer sheets to bring the edge member up to the required gage for countersinking the mold line fasteners (Figure 20).

SANDWICH PANEL

The sandwich panel has a pyramid-shaped core. The cores are shown in square and hexagonal shapes and in single- and double-core sheet designs. The pyramids are formed by pulling in the center of a "diaphragm" of material which is diffusion bonded around the periphery to one face sheet and in the center to the opposite face sheet, in the case of a single-core sheet, and to the opposing core sheet, in the double-core sheet design. The advantage of the double-sheet design is in the smaller cell sizes that can be obtained because of possible cell size limitations in the process. The smaller cell sizes give greater support to the face sheet but require thinner gage material for the same core density.

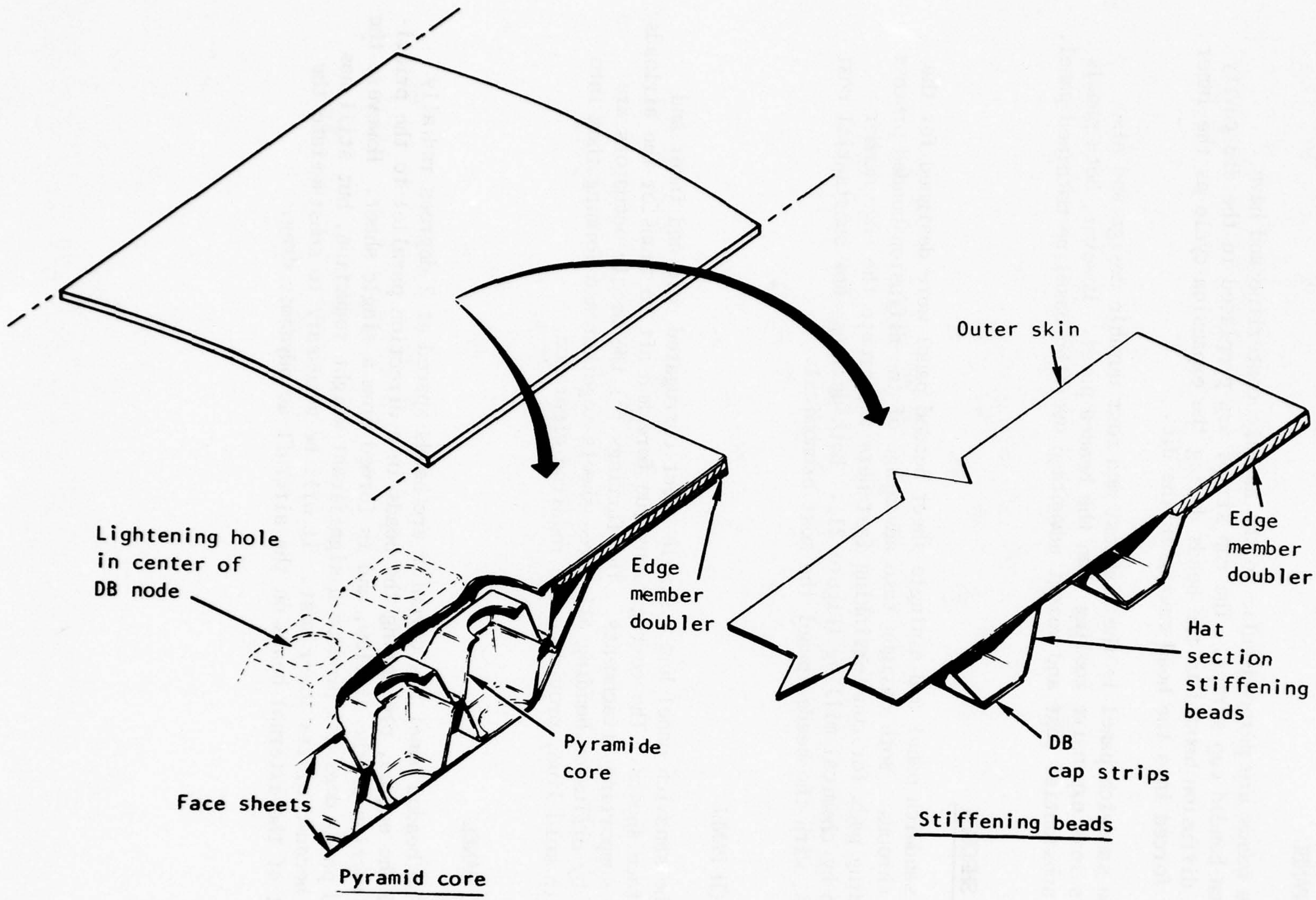


Figure 20. Centerline precooler access panel SPF/DB concepts.

BEADED PANEL

The beads are perpendicular to the nacelle centerline and have diffusion-bonded cap strips. The cap strips are preplaced in the die cavity and are diffusion bonded to the beads during the expansion cycle as the inner skin is forced into the bead cavity in the die.

The sandwich panel is the lightest and most durable design and also requires less expensive tooling than the beaded panel. However, both panels show a substantial cost and weight advantage over the baseline machined panel.

ENGINE SHROUDS

A sandwich panel and a single-sheet beaded panel were designed for the engine shrouds. Both designs take advantage of the diffusion-bonded process for adding pads for countersinking fasteners and create the edge member beef-up by chemical milling (Figure 21). Both designs show substantial cost savings, with the beaded panel the most economical.

SANDWICH PANEL

The sandwich panel has a single-sheet corrugated core and inner and outer face sheets. The corrugations run fore and aft to transfer the airloads to the supporting attachments. The fairings for the nozzle actuators are formed by diffusion bonding all three sheets together and forming them into a smooth mold line, providing the required clearance.

BEADED PANEL

The beaded panel has circular arc beads spaced at 2 degrees radially around the engine, presenting the beads in a direction parallel to the principal direction of the airflow, and is formed from a single sheet. However, the beaded panel does not produce a significant weight reduction, but still has merit because of its lower cost. It will be necessary to substantiate the effect of the external beads on the aircraft aerodynamic drag.

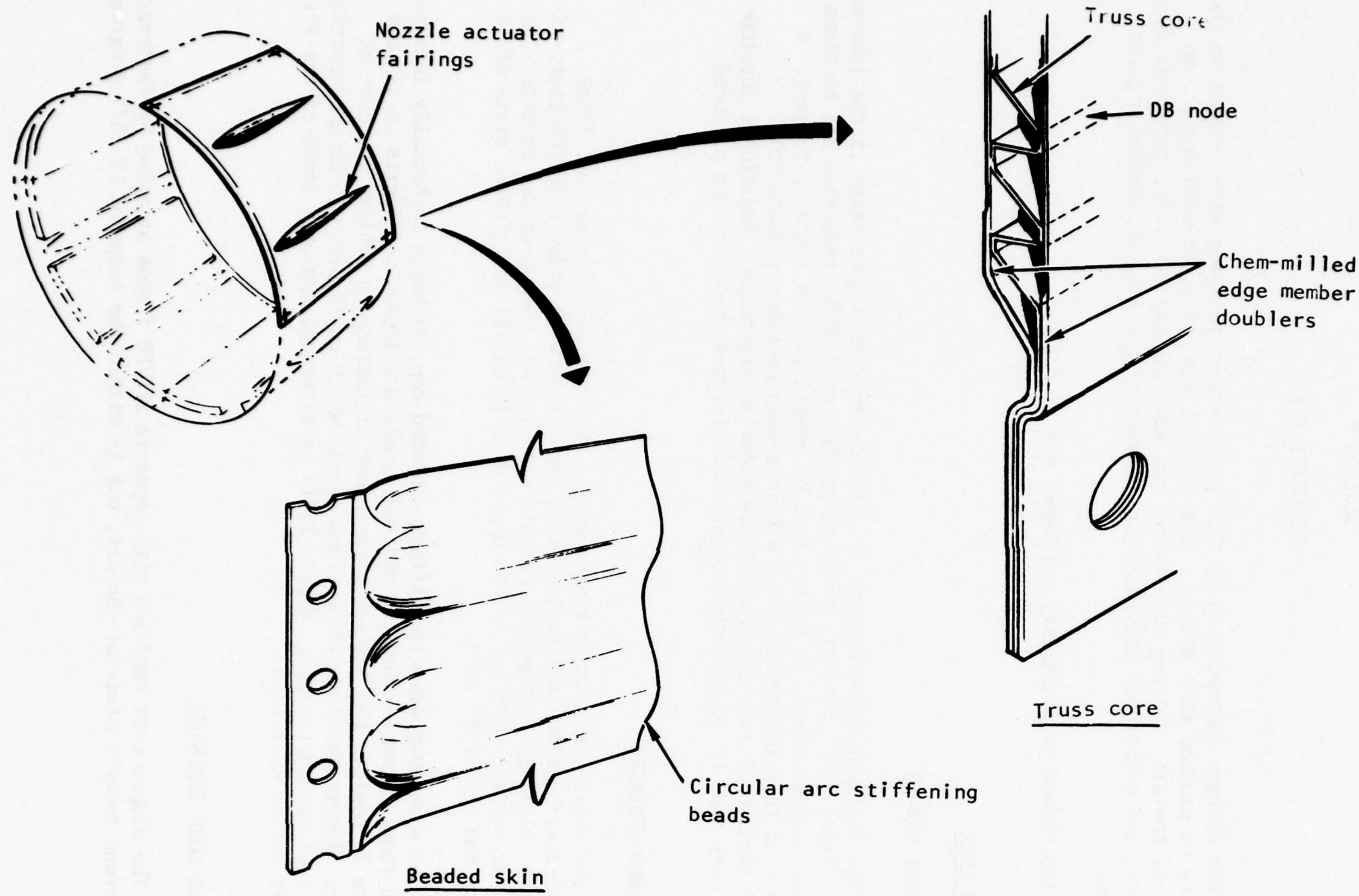


Figure 21. Engine shroud SPF/DB concepts.

Section V

PRODUCIBILITY

The designs incorporated in this program were reviewed with respect to the ability to produce each design. Each concept was critiqued with respect to state-of-the-art, tooling complexity, raw material availability, technical difficulty, and additional developmental activities required to achieve a given design.

Individual producibility critiques are as follows.

UPPER DECK

INTEGRAL FRAMES

The integral frame concept is feasible and was demonstrated in the laboratory (Figure 22). However, the size of the upper deck, requiring hat sections as deep as 9.6 inches, is believed to be beyond today's state-of-the-art. A calculated thinning profile of a 9.6-inch-deep section produced from 0.063-inch-thick starting material is shown in Figure 23. Additional development work must be accomplished before such large-sections can be produced.

SKIN AND STRINGER

The SPF/DB skin and stringer with a separate SPF/DB sine wave frame attached with mechanical fasteners is producible with today's SPF/DB state-of-the-art, although a component of this size has not been produced to date. The skin and stringer portion of the upper deck is within anticipated state-of-the-art by the end of FY 1977.

The sine wave web with diffusion-bonded cap, although technically feasible, would require complex tooling and additional developmental efforts to achieve. Figure 24 depicts the general arrangement of tooling to achieve the part as drawn. Insert No. 2 would be premachined, which could prove to be unattractive from cost considerations. Figure 25 is an alternate approach state-of-the-art, but is not an H-section.

DIMPLE CORE SANDWICH

The dimple core sandwich with separate SPF/DB frames attached by fasteners is beyond today's state-of-the-art, but is within the scope of FY 1977 programs.

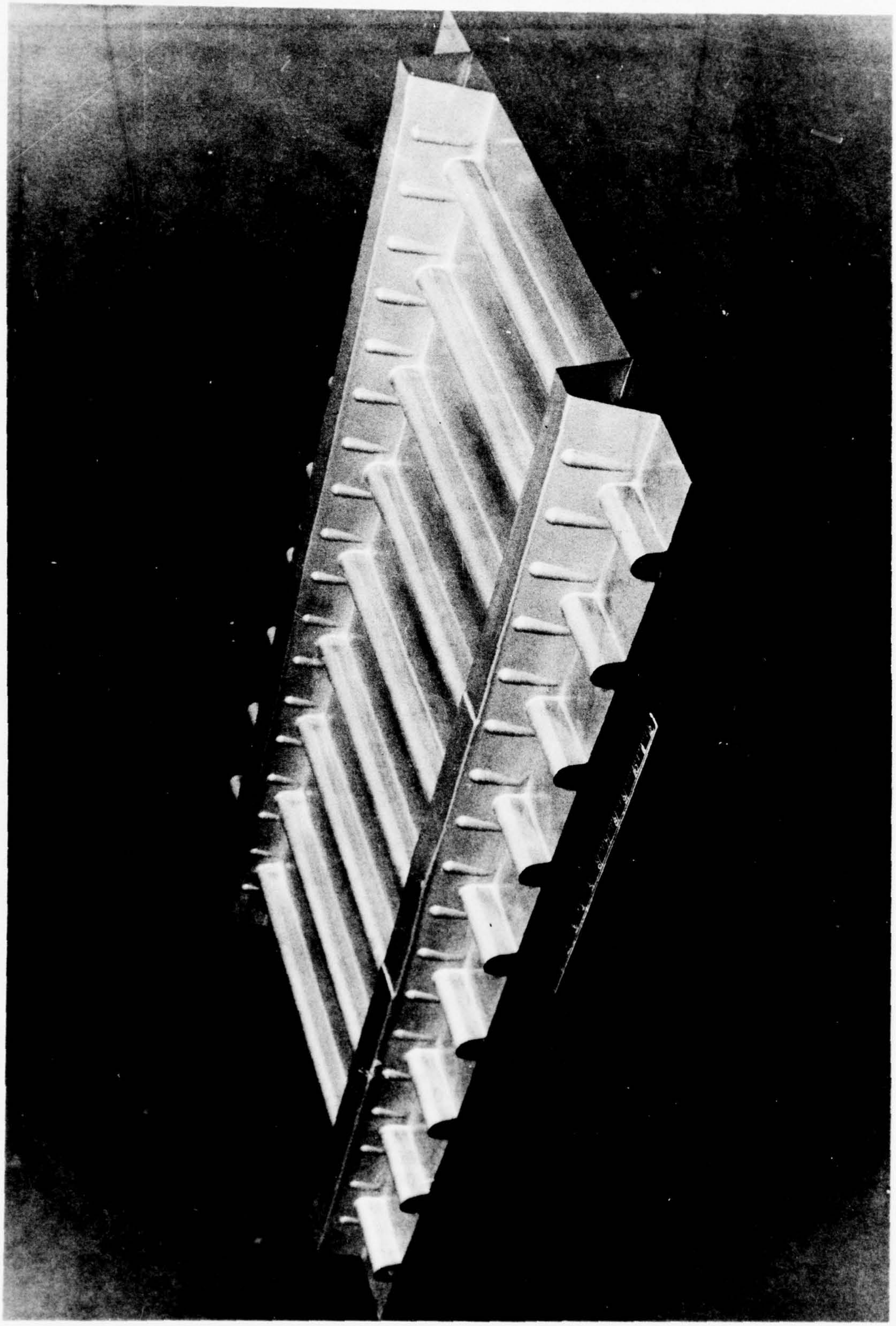


Figure 22. NASA panel LCF No. 11.

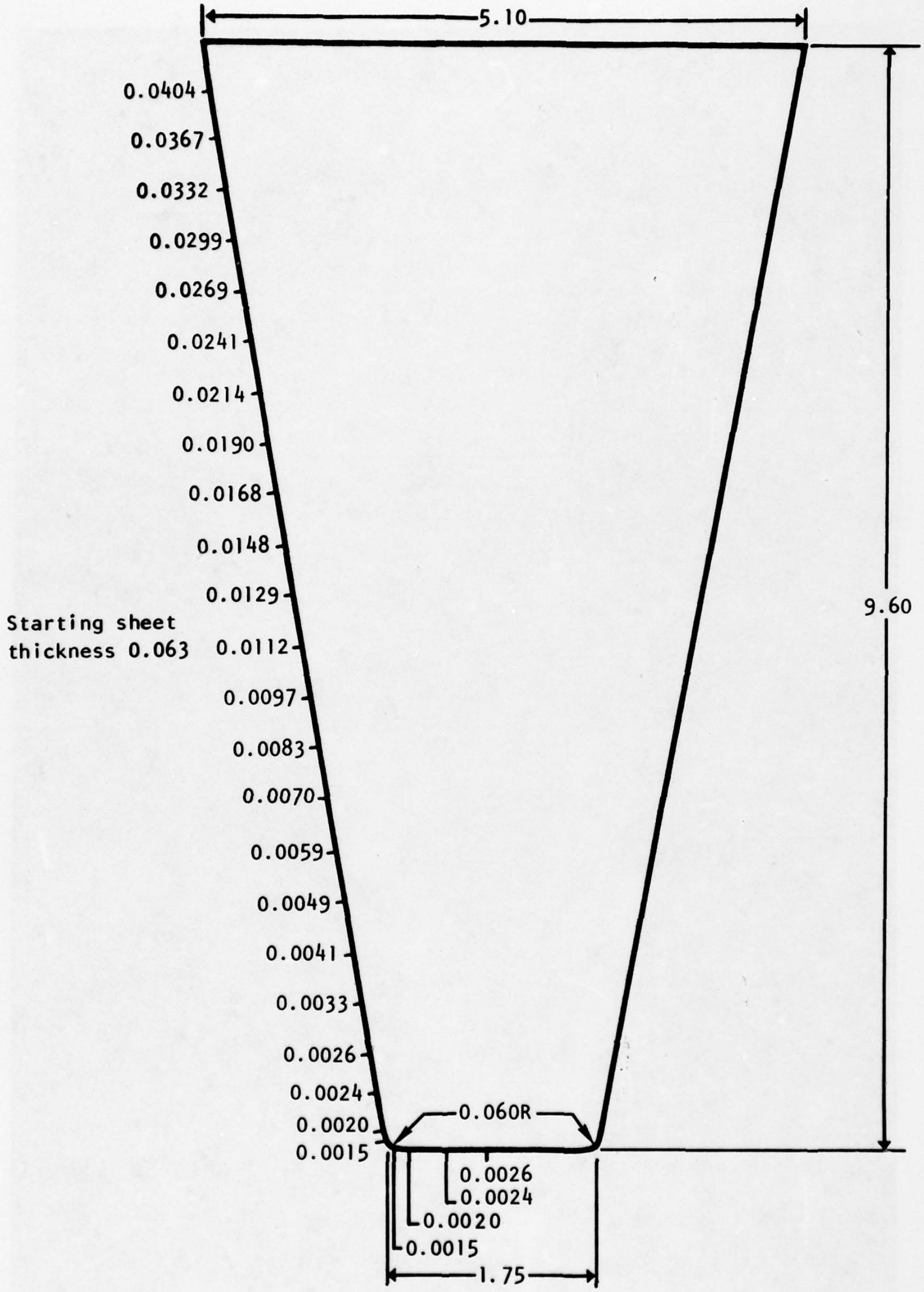
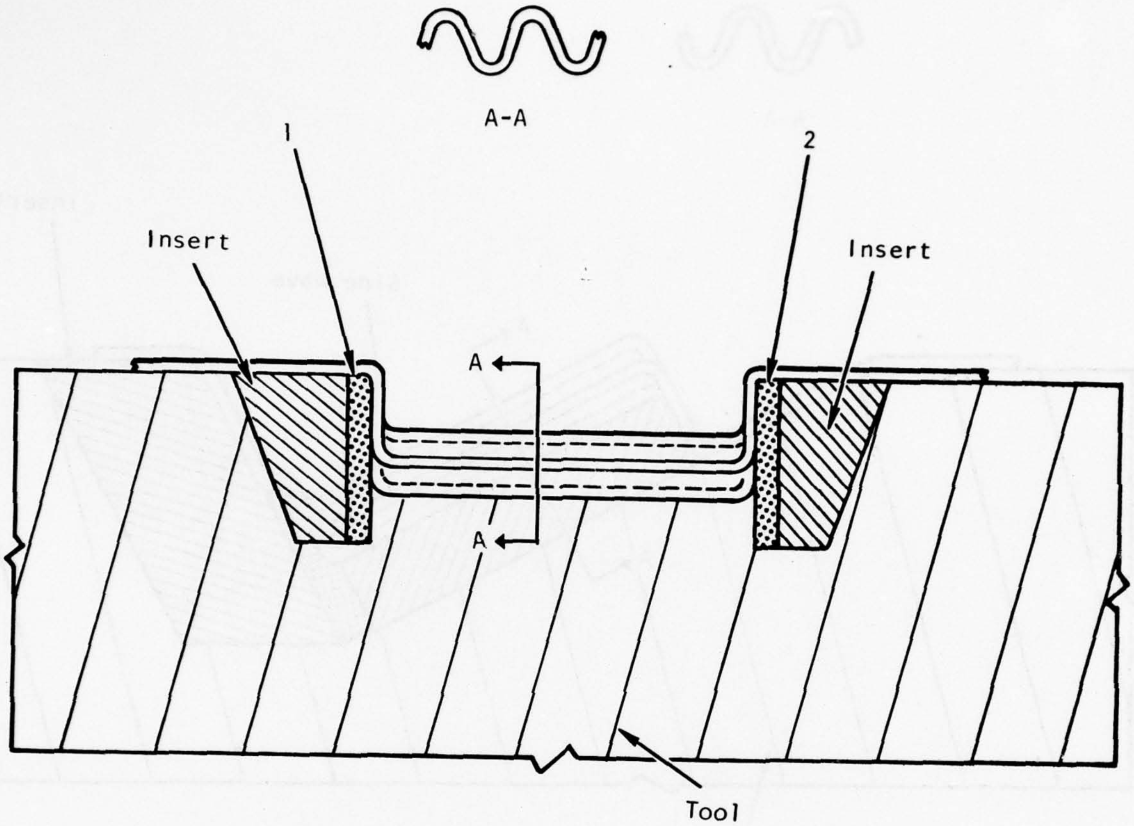
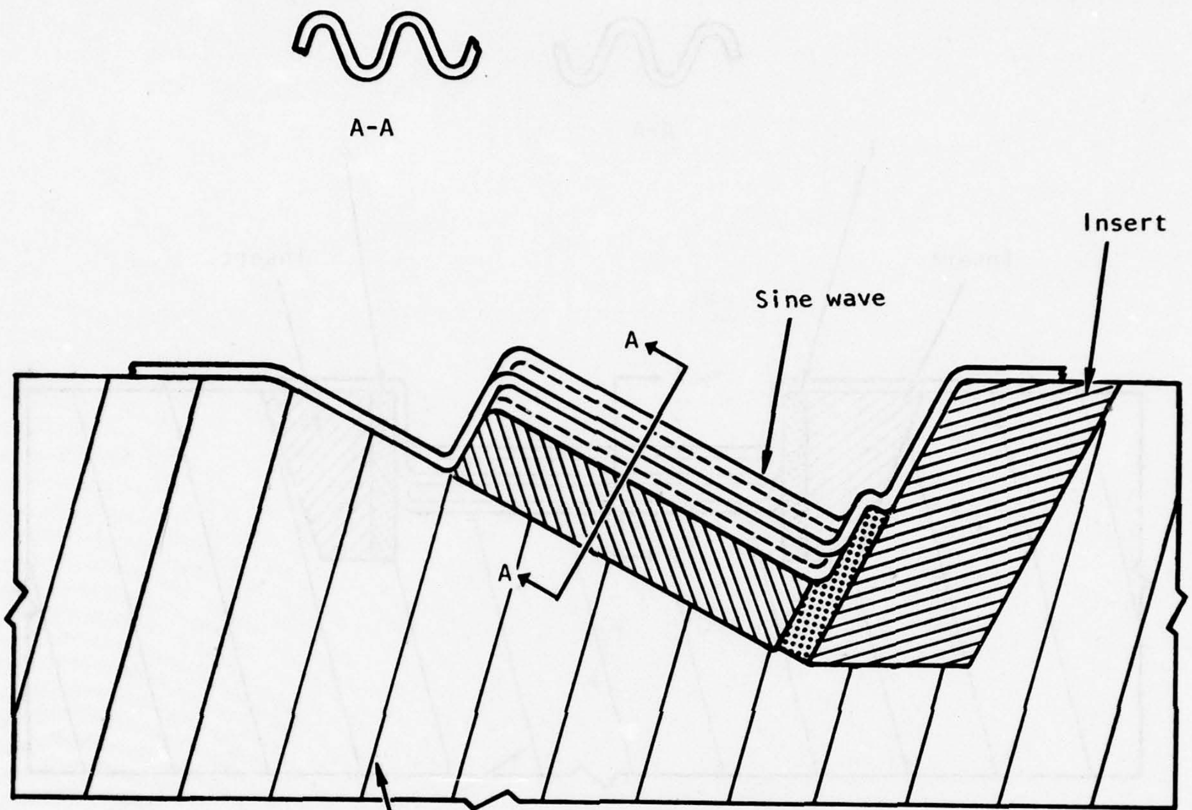


Figure 23. SPF thinning profile.



1. Tool concept for H-section.
2. Cap strip 1 is straight piece.
3. Section 2 sould have to be precountoured to mate with sine wave.

Figure 24. General arrangement of tooling.



1. Cap strip loaded in tool prior to cycle.
2. Cap strip would have to be prechem-milled to match sine wave pattern.
3. I shape less expensive to produce than I section.

Figure 25. Alternate arrangement of tooling.

The core sheet is not available in sheet sizes large enough to produce the part. Also, the elongations required to achieve a 75-degree core (386 percent), while technically feasible, have not been achieved on a predictable basis.

Producers of titanium sheet have been approached on the availability of larger sizes of near-foil gages, and developmental efforts are being made to be able to utilize narrow widths to produce a wide finished component. This concept could be produced within FY 1977.

ENGINE ACCESS DOORS

A developmental program, funded by the Air Force Materials Laboratory (Reference 2), is presently under way to produce a lower engine access door by the SPF/DB process. These doors, produced from Ti-6Al-4V sheet sandwich structure, will be fabricated as part of this contract. The first door is scheduled to be produced by the end of 1977. Therefore, the majority of the non-state-of-the-art comments in this critique will become state-of-the-art when the first door is produced.

HAT SECTION PANEL SIDE AND LOWER DOOR

The side access door featuring hat sections bonded to stiffener caps concept, as mentioned previously, was demonstrated in the laboratory, but on a smaller scale. The sine wave sides of the hat sections are feasible; however, the tooling is, by nature, more expensive than straight sides or sandwich tooling. Drawing titanium sheet by SPF to an angle of 75-degrees does produce considerable thinning, but can be accomplished. The concept is not state-of-the-art, simply because such a large part has not yet been produced by SPF/DB. This part could be produced during CY 1977.

CONE CORE SANDWICH PANEL SIDE DOOR

The cone core-dimple core combination is an extremely lightweight concept utilizing five-sheet sandwich technology with chem milling required on the non-moving face sheet prior to assembling the pack; the core sheets are 0.010-inch thick and deform to 75 degrees. Chem milling the sandwich interior surface prior to assembling the pack has been demonstrated in the laboratory. No five-sheet sandwich has been attempted; however, four-sheet technology is being used on a windshield jet blast nozzle, an SPF/DB part currently being built for the B-1 aircraft No. 4. Figure 26 shows an example of four-sheet

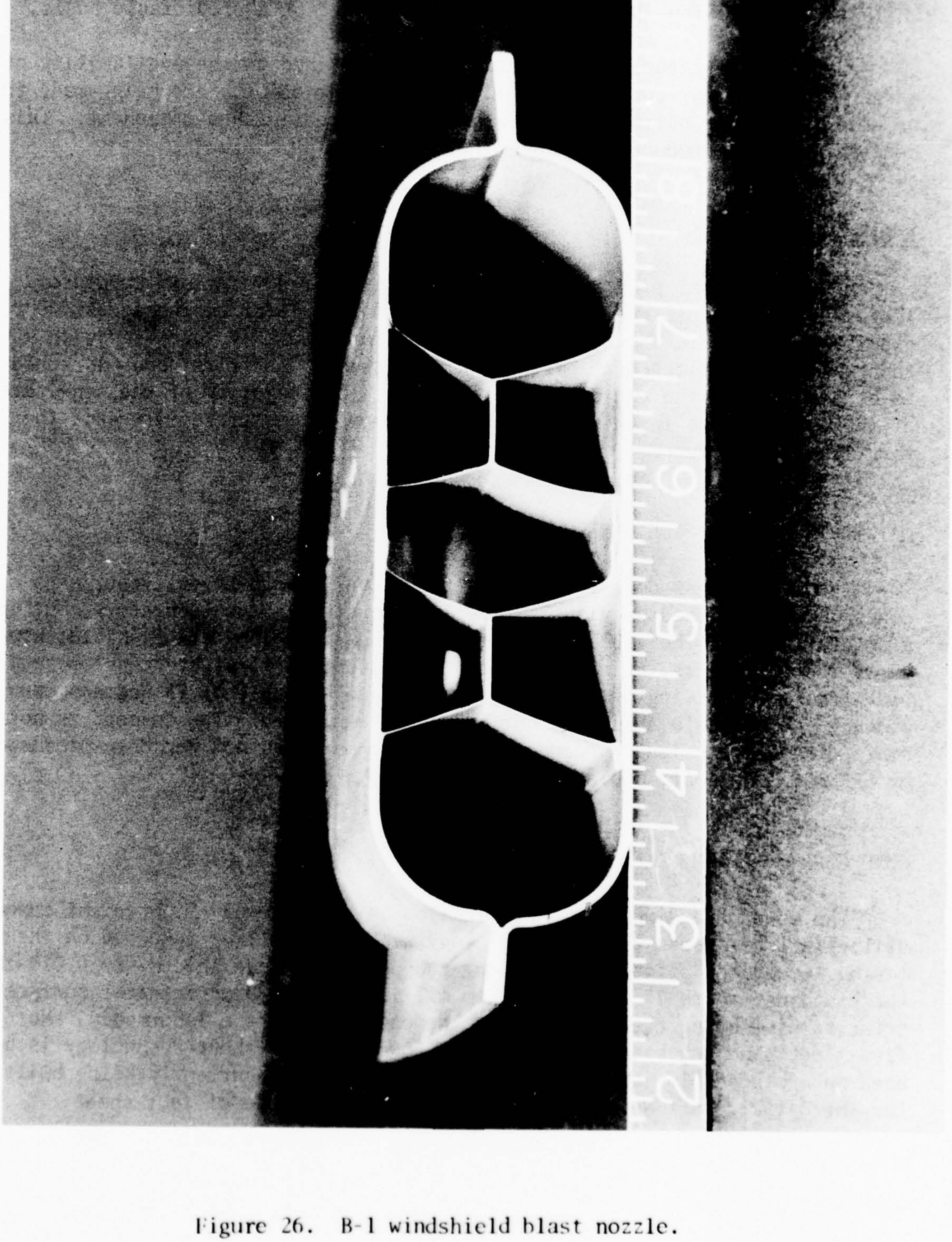


Figure 26. B-1 windshield blast nozzle.

technology. While the five-sheet construction is technically feasible, it requires pack assembly technique beyond presently practiced current state-of-the-art. Also, 0.010-inch-thick sheet in the sizes required is not available at the present time. To produce the door as depicted will require additional development. This part is considered to be FY 1978 technology.

TRUSS CORE SANDWICH SIDE DOOR

The truss core door is four-sheet technology, with interior chem milling prior to pack assembly. Each of the concepts shown in the drawing have been demonstrated; however, not on the same piece of hardware. The core angles of 68 degrees (267-percent elongation) are on the fringe of today's technology, but are possible. This part does fall with FY 1977 technology, although it would require development.

HAT STIFFENER LOWER DOOR

The lower access door featuring hat stiffeners with sine wave bends has essentially the same producibility characteristics as the hat stiffener side access door.

SANDWICH PANEL LOWER DOOR

The truss core sandwich lower door is made from 0.030-inch-thick core sheet drawn to an angle of 75-degrees (386-percent elongation). The current access door work has resulted in demonstration panels 1-1/2-inches deep with truss core drawn to 60-degrees (200-percent elongation). However, 75 degrees made from 0.030-inch starting stock is beyond FY 1977 technology. The concept as depicted is considered to be technically feasible and could probably be reduced to practice by FY 1978.

CENTERLINE PRECOOLER ACCESS PANEL

BEADED PANEL

The bead-stiffened structure with bonded caps concept has been demonstrated, and the panel is considered as state-of-the-art.

PYRAMID CORE SANDWICH PANEL

The pyramid core design is a lighter weight version of the panel featuring sandwich construction. A similar core design has been demonstrated in the laboratory (Figure 27), with the exception of the precut holes in the core sheet. The concept is technically feasible and requires only a demonstration of the holes to qualify as state-of-the-art. This design could be produced during FY 1977.

ENGINE SHROUD

BEADED PANEL

No part this large with compound curves has been produced to date. However, no problems are foreseen, and the design is considered state-of-the-art. This part could be produced within FY 1977.

TRUSS CORE SANDWICH PANEL

Although curved sandwich panels have been produced with core sheets as thin as 0.010 inch (Figure 28), no curved sandwich this large has been produced. Core sheet 0.014-inch thick is not readily available today in sizes required for this shroud. Work is in progress to produce a curve panel sandwich under development program which will produce 120-degree segments 40 inches in diameter by 12-3/4 inches wide. Therefore, this shroud concept is considered producible in CY 1977.

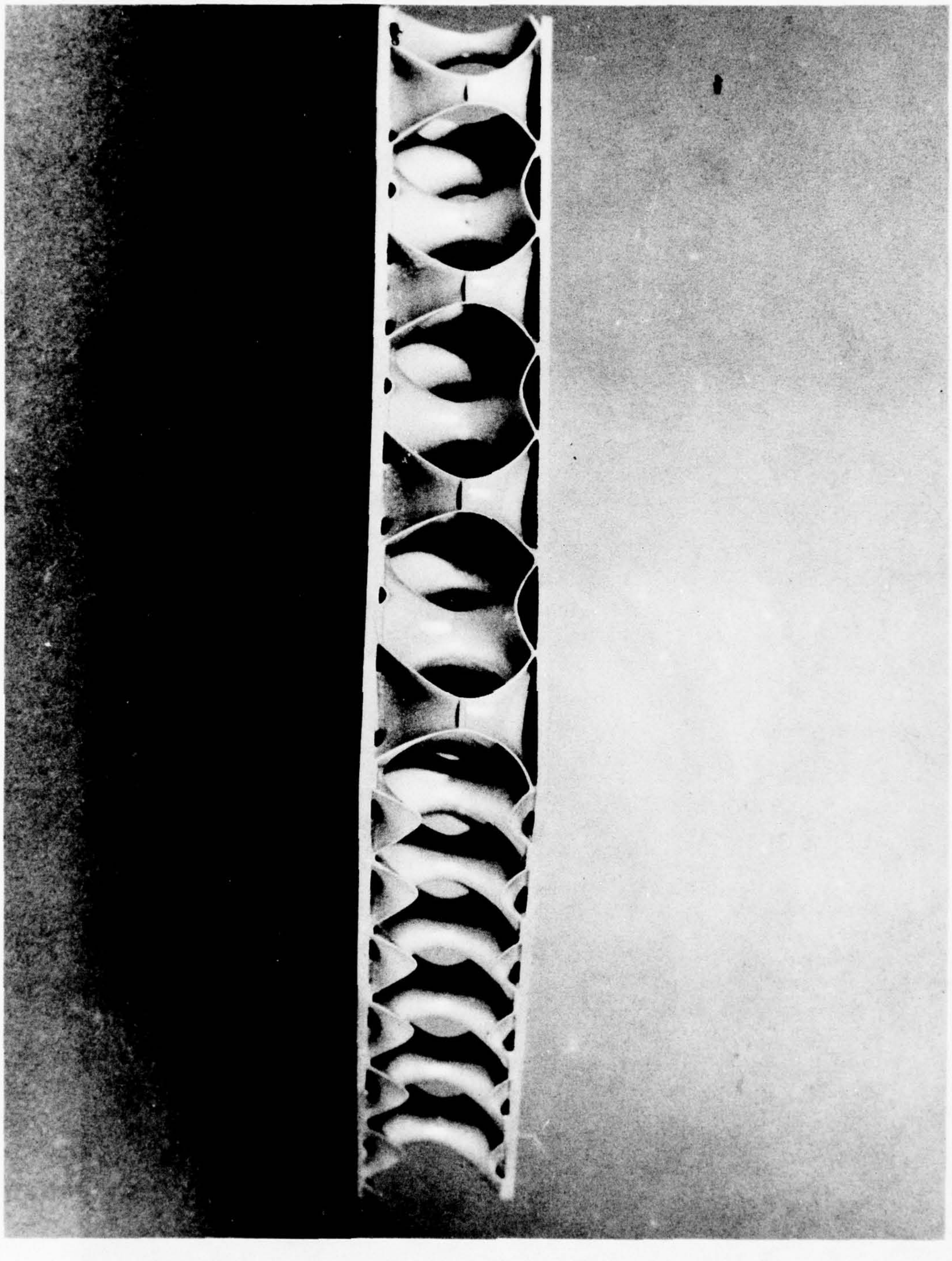


Figure 27. Cone cove panel.

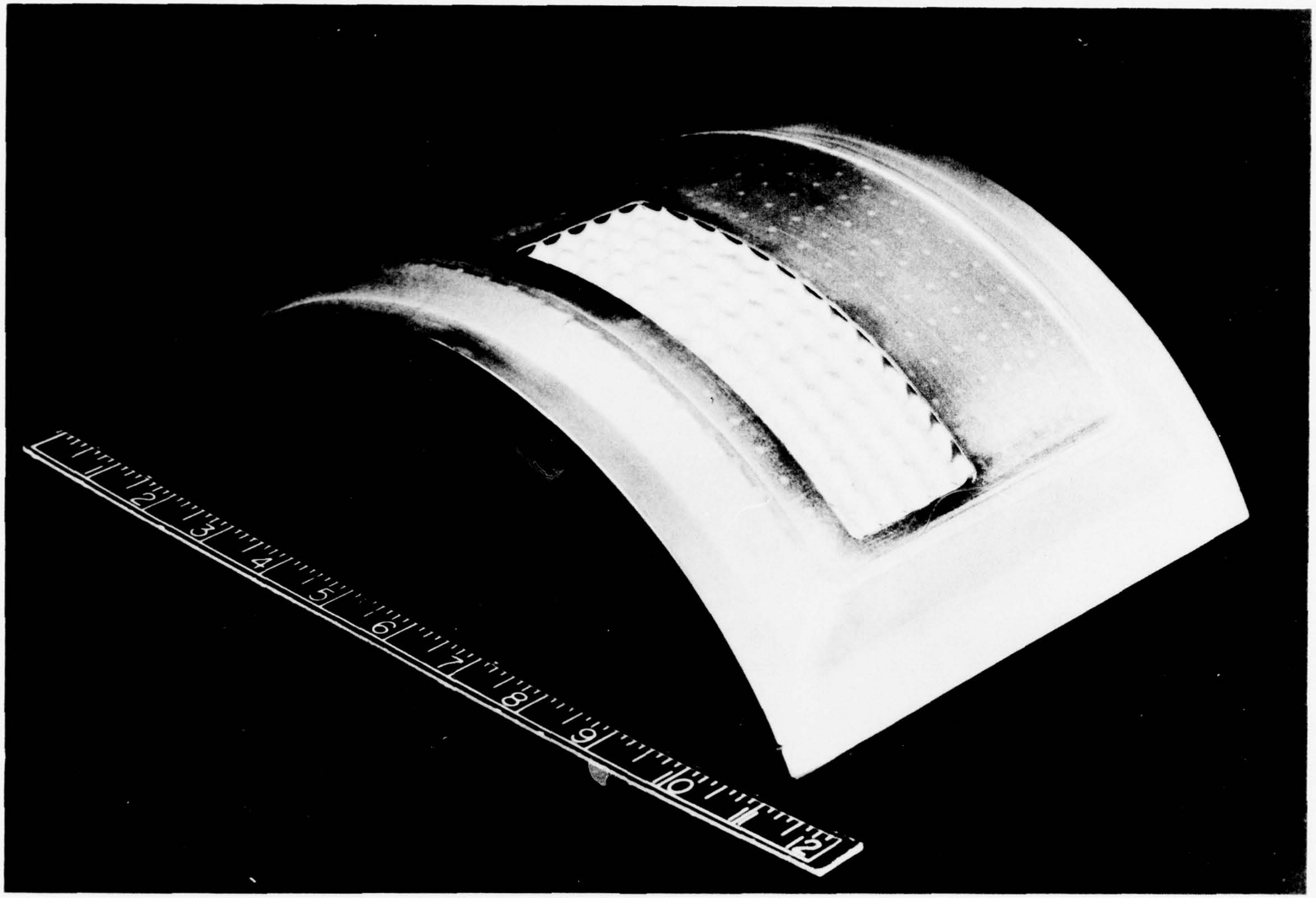


Figure 28. Curved dimple core sandwich.

Section VI

MANUFACTURING APPROACH

TOOL DESIGN

The tool design for the titanium nacelle structural members under study is predicated on past experience with both the superplastic forming process (SPF) and the concurrent forming/bonding (SPF/DB) operation. The tooling setup involves the use of top and bottom dies into which the desired configuration has been machined. Tooling material is 22-4-9 nickle-chrome-molybdenum steel alloy, which has been used extensively in diffusion bonding and more recently in the SPF/DB process. All tooling will be oxidized prior to use by heating at 1,400° F for 2 hours.

These tools will feature a male lower die into which the particular hat section, sine wave, beads, or sandwich construction will be machined (Figure 29). The upper female die will be machined to the mold line contour of the nacelle. Both dies will be recessed to accept machined fittings and doublers which, during diffusion bonding, become integral with the structure.

NUMERICAL CONTROL (NC) MACHINING

NC machining will be utilized due to the complexity of the tool configuration. Sloped ends of the tool cavity facilitate removal of the bonded assembly. Provisions will be made to vent the argon gas through the tool bottom to prevent gas entrapment during forming. The plate beneath the form die will be grooved to facilitate venting of the gas during forming. The bottom grooved plate will be sealed with titanium wire around the periphery and held by press pressure against the dies. The top half of the die will require machining on the lower surface to provide a projection for the upper seal. The projection (0.060 to 0.090 inch) will bite into the titanium sheets of the diffusion-bonded pack during application of press pressure, thus sealing the die cavity. The different coefficient of expansion between steel and titanium will be taken into consideration during the machining of the die cavity.

SIMILARITY OF TOOLING

Tooling for the engine shrouds and precooler access door (Figures 30 and 33) will be self-contained and can be processed in smaller hydraulic presses. of 150 to 300 tons than the larger parts, which require presses of 4,500 to 7,000 tons to react the 300 psi pressure.

Tooling for either beaded or sine wave webs, which are subsequently assembled to individual frames, will also utilize the 22-4-9 steel alloy and will consist of a container, machined inserts, and top plate (Figure 31).

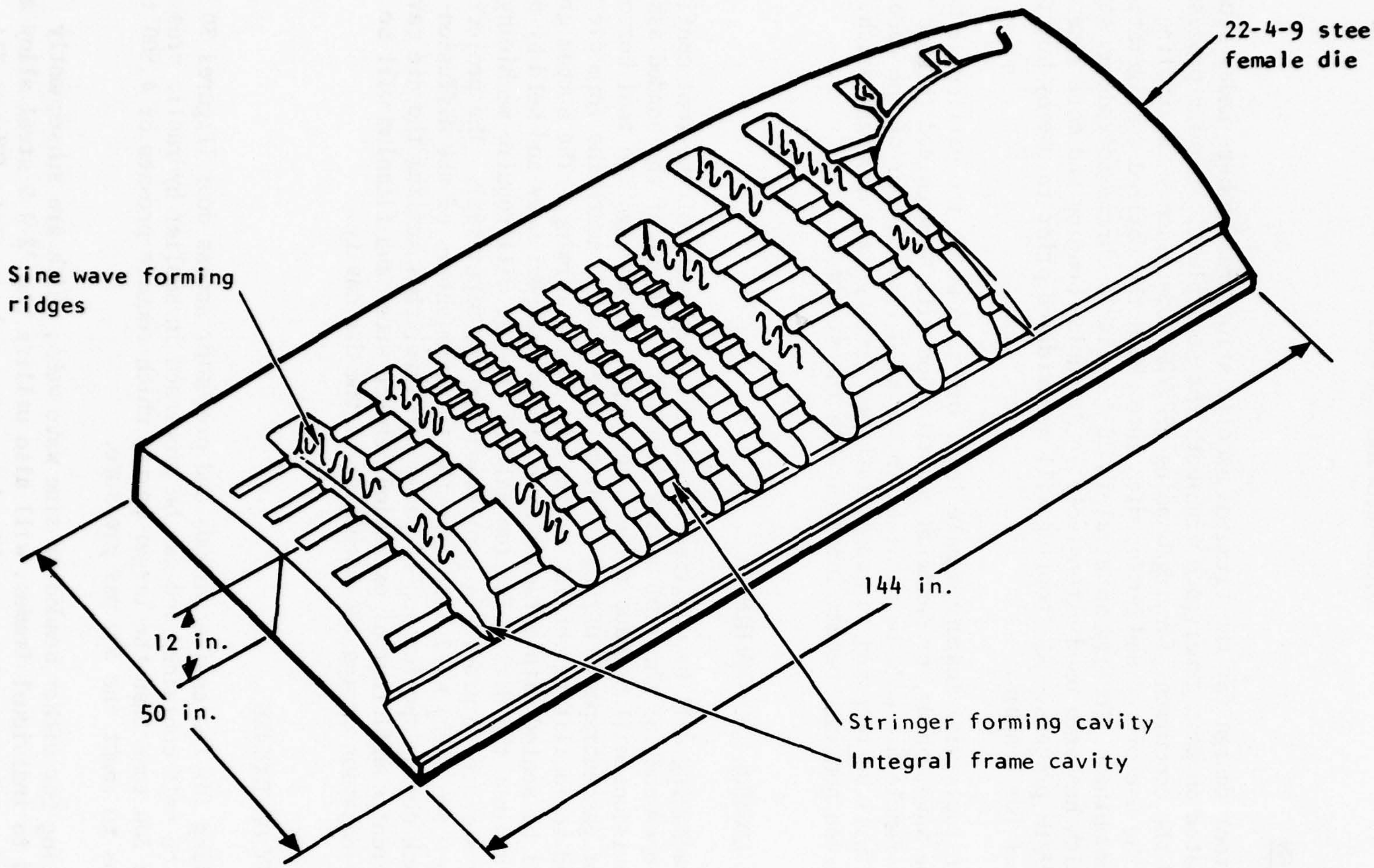


Figure 29. Nacelle SPF/DB integral upper deck bonding-forming platen.

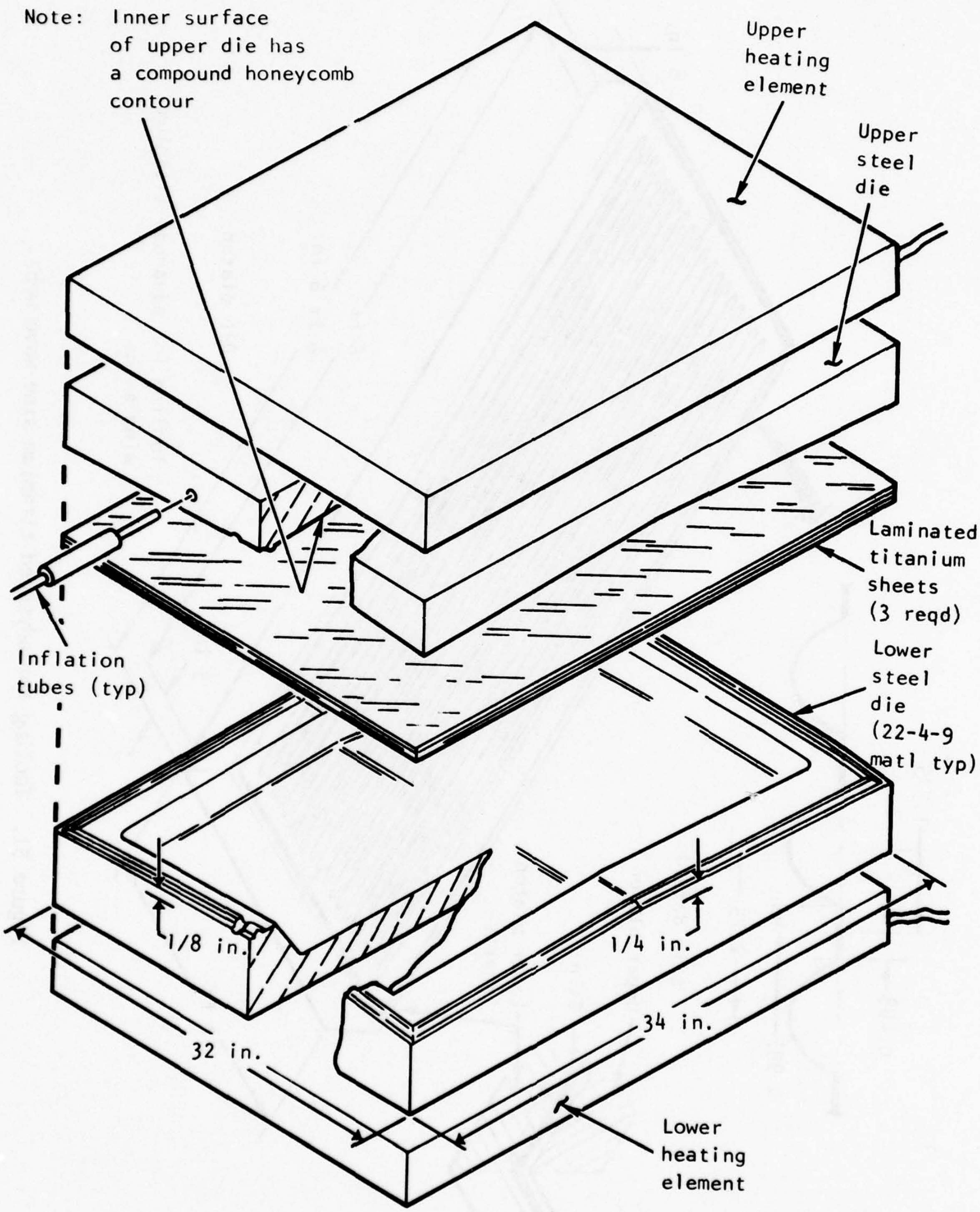


Figure 30. Tooling concept - centerline precooler access panel.

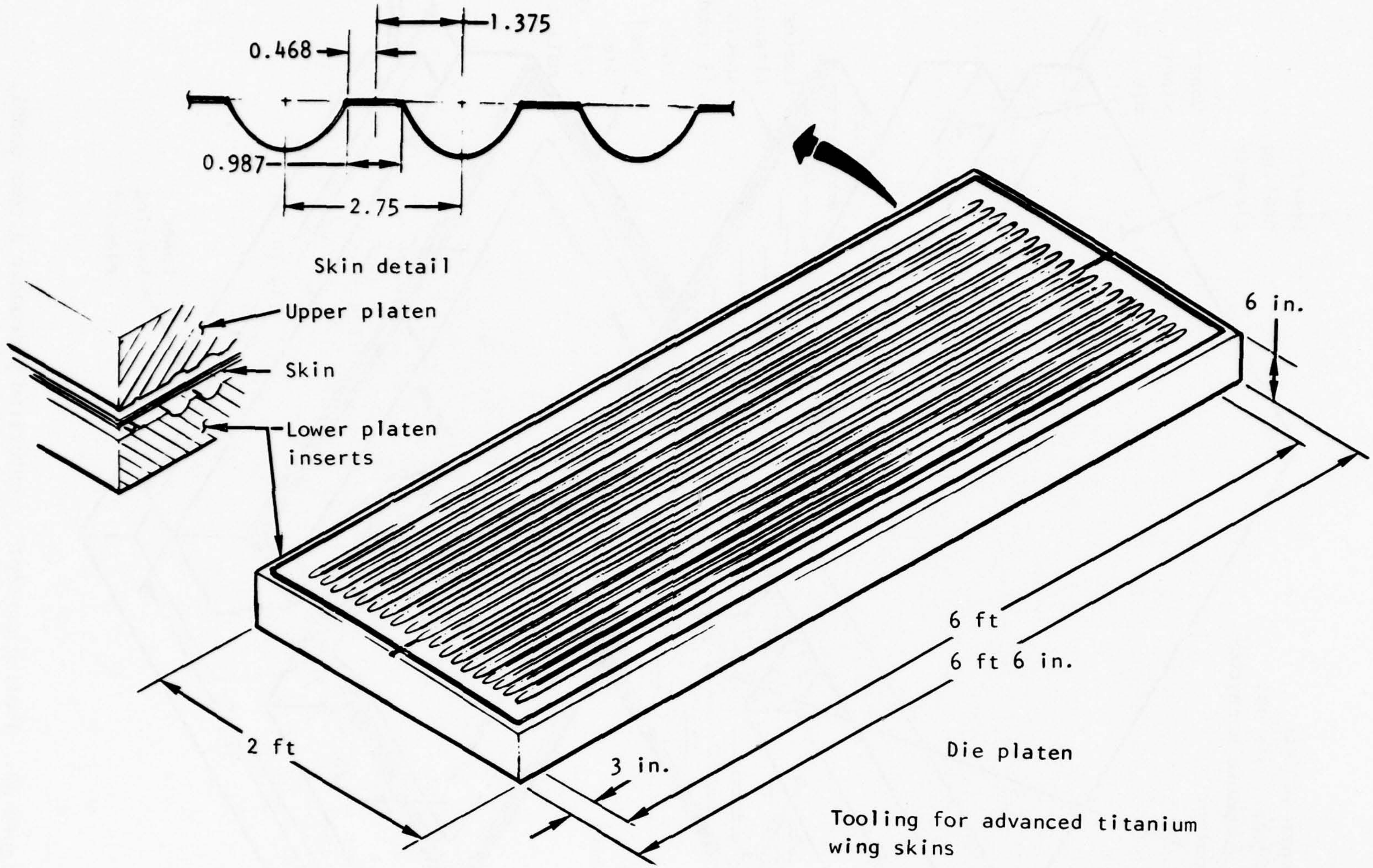


Figure 31. Tooling for advanced titanium sine wave webs.

The insert and container concept was chosen for these configurations in order to provide a universal holder where the inserts can be changed to provide for different web configurations.

FABRICATION

The general approach to the fabrication of any nacelle SPF or SPF/DB part will utilize the following steps:

1. Sizing and cleaning the titanium sheets and details.

2. Stopoff application to the core sheet and lubricant application to the tooling.

3. Mating of titanium components into SPF/DB pack, installation of index pins (as required), installation of argon gas tubes in the pack, and tack welding to maintain registry among the details.

4. Assembling the titanium pack in the form die in the press.

5. Press closure, argon purge, heatup of dies to 1,700° F, application of argon pressure, and diffusion bonding.

6. After diffusion bonding time and temperature are achieved, argon pressure between the sheets is started to superplastically expand the pack to fill the die cavity.

7. Remove and inspect by X-ray, die-penetrant, ultrasonic, and dimensional procedures, as required.

8. Trim to size, and inspect.

9. Assemble

Indexing pins will be used in the titanium diaphragm to align the stop-off pattern with the tool cavity (Figure 32). The location of the indexing pins will be specified on a stopoff pattern on Mylar which is generated from the numerical control machining tape with proper modification to correct for steel and titanium expansion during heatup. These indexing points will be placed on the titanium sheet, on the tool inserts, and on locating templates for the stop-off pattern.

The introduction of the argon gas between the titanium sheets for superplastic expansion after diffusion bonding will be accomplished by small - diameter tubes placed in specially prepared grooves in both face sheets. The groove will be deeper in the thicker sheet, as compared to the groove in the

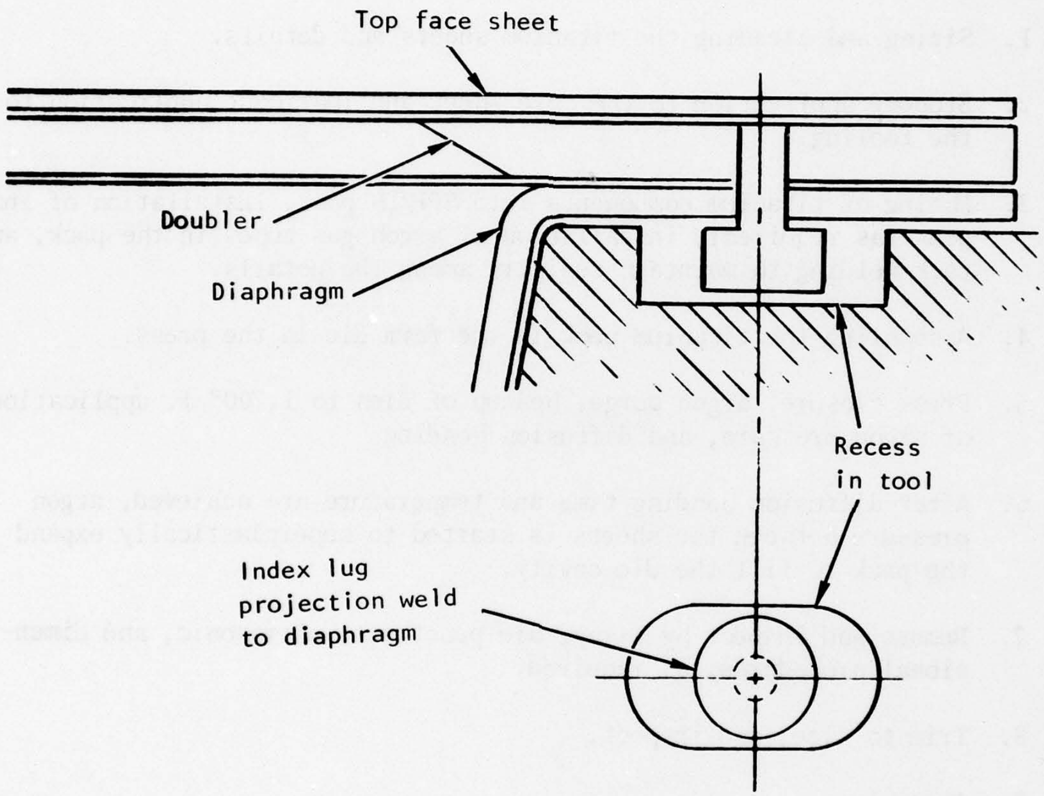


Figure 32. Indexing pins for alignment of stopoff pattern to tool cavity.

thinner of the two sheets. The argon gas inlet and outlet tubes will project through the titanium pack to the tangent point of the stop-off area. A continuous path of stop-off material must exist from the gas inlet to outlet.

STOP-OFF APPLICATION

Stop-off application will be accomplished by silk screening whereby dimensional accuracy is maintained and overall pattern location is directly related to the indexing points on the titanium sheet and steel tool. The stop-off material is mixed with a suitable binder to the consistency required for the silk screen operation. The stop-off will be applied to one or both sides of the titanium diaphragm, as required.

A lubricant material will also be sprayed onto the tooling surfaces, both top and bottom plates.

SPF/DB CYCLE

Subsequent to stop-off application, the titanium sheets, indexed to each other and tack welded together, will be placed on the bottom tooling using the slots provided in the insert. The entire tool pack is placed between heating platens in a hydraulic press. During heatup to 1,700° (±50°)F, a continuous flow of argon gas will be introduced to the pack assembly on the top side of the upper sheet, the bottom side of the lower sheet, and in between the two sheets, with the higher pressure maintained in the lower tool cavity. After heatup to 1,700° F, diffusion bonding of the selected areas will be accomplished by application of argon gas pressure. Argon gas pressure and the time at pressure will be predetermined; typically, the cycle is 300 psi for 1-1/2 hours for complete bonding. Subsequent to bonding, the gas pressure is reduced in the lower tool and increased between the titanium sheets to accomplish the diaphragm expansion. This portion of the cycle will be predetermined also. The time and pressure are based on the material strain-rate and flaw stress properties in conjunction with the specific configuration desired.

At the end of the forming cycle, the heating elements are turned off, but argon gas will continue to flow until the part temperature reaches 1,200° F, at which time the part will be removed (Figure 33). All parts will be inspected, trimmed, and prepared for the next assembly.

ASSEMBLY

Assembly of the nacelle parts will vary due to configuration. The engine access doors and upper deck will have attaching details bonded into the assemblies and will require machining of hinge lugs and latches prior to assembly.

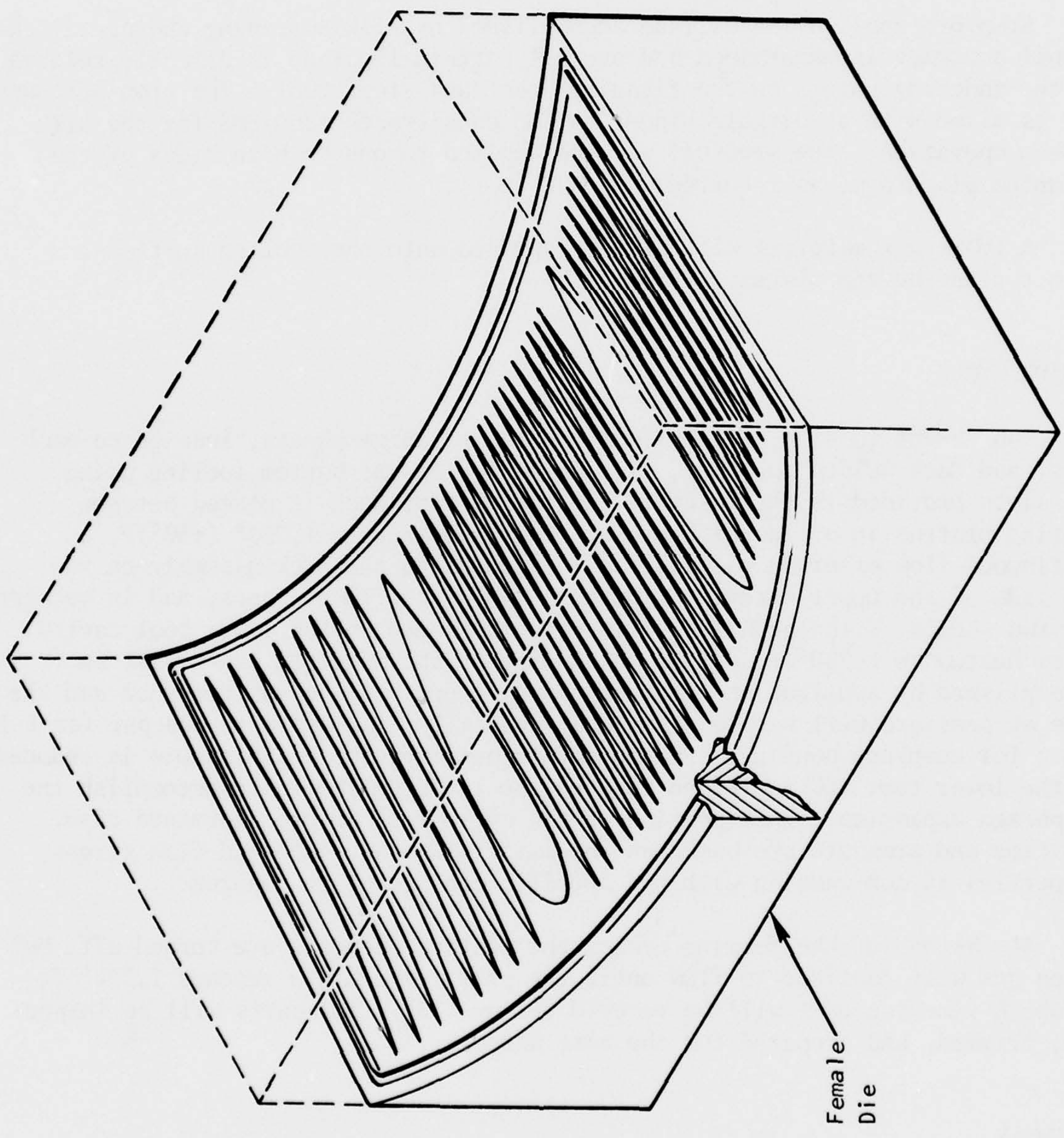


Figure 33. Beaded engine shroud tooling.

These operations will be performed in existing B-1 assembly tools after minor alterations. SPF/DB panels for shrouds and precooler access doors will require only trimming in the detail and will be drilled on assembly in existing assembly jigs (AJ).

SPF/DB sine wave frames will be trimmed to size prior to assembly to individual frames. These assemblies will be mechanically fastened together in small assembly jigs wherein parts are loaded and positioned, drilled, and cleaned, and fasteners are installed. Mold line configuration will be controlled by locators on the tool.

Section VII

STRUCTURAL ANALYSIS

STRENGTH ANALYSIS

UPPER DECK

Design Criteria

The upper deck is a primary load-carrying structure with critical design loads of 5 psi ultimate external pressure and a shear flow of 500 pounds per inch at a temperature of 350° F.

Method of Analysis

The frame webs were checked for shear, and the caps were sized for the bending moment resulting from the external pressure. The skin panels were assumed to be stiffened in two directions and were allowed to buckle. The stiffeners were then checked for crippling and also as beams under an equally distributed load. The stiffener webs were checked for shear buckling; the caps, for compression buckling.

The skin was then analyzed for local buckling and also for general stability using the orthotropic panel theory. The dimple core sandwich panel was checked for local and general stability, assuming that no buckling was allowed.

ENGINE ACCESS DOORS

Design Criteria

The engine access door critical loads are 10 psi uniform pressure and a combination of inertia and nacelle loads which are transmitted through the hinges and the radial and split line latches.

Method of Analysis

A computer run idealized the door structures by dividing them into bars and quadrilaterals. These loads were recombined and applied to the SPF/DB structures. The stress concentration areas and edge members were sized for equivalent strength to the baseline doors in lieu of a complete analysis because of limited time available for the analysis.

CENTERLINE PRECOOLER ACCESS DOOR

Design Criteria

The critical load conditions are a pressure of 3 psi and a shear flow of 600 pounds per inch ultimate at a temperature of 400° F.

Method of Analysis

The bolted parameter of the panel was assumed to be simply supported and was identical in design and thickness to the baseline; therefore, no analysis was done for this area.

The panel was checked for local stability under a combination of shear and pressure loads and for general stability under shear loads only. The stabilizing effect of lateral pressure was neglected.

The sandwich panel was assumed to behave as a honeycomb sandwich and was analyzed using methods commonly used for honeycomb sandwich. The panel was checked for general and intracell buckling, wrinkling, shear crippling, core flatwise compression, and core shear.

The beaded panel is an orthotropic structure with very low flexural stiffness in the direction perpendicular to the beads. The panel was, therefore, analyzed as a series of simply supported beams one-bead wide. The beams were checked for flexural stresses and/or shear stresses, as applicable.

ENGINE SHROUDS

Design Criteria

The critical load conditions are an external pressure of 3.5 psi ultimate at a temperature of 300° F.

Method of Analysis

The expanded sandwich shroud was assumed to be an idealized curveal beam between the actuator blisters. The beam was checked for local and general stability. The beam was assumed to be fixed at one end and simply supported at the other.

The beaded panel could not be analyzed in the same manner because it does not have lateral rigidity. Therefore, each bead was analyzed as an independent beam. The beams were checked for local buckling. The beams were assumed to be fixed at one end and pinned at the other.

DURABILITY AND DAMAGE TOLERANCE ANALYSIS

Because of insufficient fatigue and damage tolerance data relating to SPF/DB specifically, it is impossible at this time to analyze the structural concepts presented here on a meaningful basis. The following section presents the analysis approach preliminary data that is available.

METHODS OF ANALYSIS

Loads Spectrum

For fatigue evaluation, the flight-by-flight-type load spectrum will be more accurate than the block spectrum. Training flights and mission profile flights in various routes may be combined into a composite mission spectrum. After composing the loads in a realistic mission segment sequence, the variation of mean loads makes it necessary to apply more or less formal methods of range pairing in order to account for the full fatigue-damage-producing potential of the loads.

Damage Accumulation

For damage assessment, the traditional linear cumulative damage Miner's rule is used. However, because of many inaccuracies associated with Miner's rule, the local stress-strain approach involving Neuber's rule or the like should be employed, if possible. The damage evaluation method using this approach has been well developed. Cycle-by-cycle analysis of local stress at a stress concentration area is performed for each load reversal, including the tracing of the elastoplastic stress and strain values along the hysteresis loops. In this manner, the load sequence effect and the residual stress effect due to local yielding are inherently accounted. In the application of this method, the cyclic stress-strain curve and the strain-controlled fatigue test data of the materials are needed.

Crack Growth Analysis

In order to meet the fail-safe requirement, the emphasis of the damage-tolerance analysis is the calculation of subcritical flaw growth. The method used to calculate the flaw growth is based on the principles of fracture mechanics. An existing Rockwell computer program utilizes a specialized integration routine where the initial crack size is given, and the crack growth rate da/dN is integrated to yield the relationship between the crack size, "a," and the number of fatigue cycles, "N," for a structure containing cracks subjected to a given stress spectrum.

Residual Strength

Existing computer programs based on theory of fracture in ductile metals and static internal loads have been in use at Rockwell to determine the static residual strength for a damaged structure. The theory of fracture in ductile metals is derived by extending the basic Griffith theory of brittle fracture to obtain new expression for the fracture strength of a simple structure containing a partial through or through crack (Reference 6). Two material parameters are needed, and both can be derived from the material stress-strain curve.

For complex structures with or without broken principal elements, analysis can be performed in detail by finite-element numerical solutions. Relatively fine grid models can be made of components of the full-scale structure to study the transfer of load, for crack growth purposes, from one principal element to an adjacent principal element.

Temperature Effect

Solution of temperature problems in the flight of the B-1 may consist of the following:

1. To determine real- and short-time temperature correlation so that short-time material properties data and short-time tests may be used.

2. To determine thermal stress due to differential temperature between surface structure and deep structure, and then to add the thermal stress to the mechanical stress as the final operating stress value.

3. To determine the effect of long-time temperature exposure or thermal cycling effect on the material properties. For primary structures made of SPF/DB titanium, this should pose no problem.

TEST DATA NEEDED FOR ANALYSIS

Because the application of the SPF/DB process is quite new, necessary data sets for fatigue and fail-safe strength evaluation of SPF/DB structure are not available. Material properties are needed as basic premise. Structural test data are needed to check the analytical model, to reinforce the analysis methodology, and to improve the design. Without these data, any analysis would be academic without practical engineering significance.

For material properties, specimens should be made from both SPF and DB areas of SPF/DB processed part. Monotonic stress-strain curves as well as cyclic stress-strain curves are necessary for a variety of uses. Fatigue Goodman diagrams with families of constant-life curves for notched and smooth specimens are needed for fatigue strength evaluation by linear cumulative damage rule. The tests which generate the conventional Goodman diagram are stress- or load-controlled constant-amplitude tests. For local stress approach for damage evaluation, strain-controlled tests of only smooth specimens are necessary.

For damage-tolerance studies, fracture toughness design allowables for DB 6Al-4V titanium (without SPF process) are available as shown in the following paragraphs, but the combined effect of SPF and DB process should be determined. The crack growth rate da/dN versus stress intensity factor range K-curves for SPF and DB areas of SPF/DB processed metal specimens should be given for crack propagation study of structures.

TEST DATA AVAILABLE

Effort was made to collect available mechanical properties data for SPF/DB 6Al-4V titanium sheet. The static tension, shear, and bearing properties of SPF sheet are listed in Table 5. A comparison of the tension properties of SPF/DB 6Al-4V titanium in three different conditions is shown in Figure 34. Detailed data of static properties may be found in Reference 7.

The S-N data for smooth specimens, DB and SPF processed as compared with parent metal, are shown in Figure 35. A few more data points representing DB and SPF areas of SPF/DB processed parts are plotted in the scatterband of Figure 35, as shown in Figure 36.

S-N data for notched specimens DB and SPF processed separately are compared with the parent metal as received, as shown in Figure 37. The fracture toughness design allowables for DB titanium are shown in Table 6.

ADVANTAGES OF SPF/DB FOR FATIGUE AND FAILURE MODES

Because of the complexity of stress flow and other factors in structural joints, many fatigue cracks have started from weld or bolt joints. However,

TABLE 5. STATIC STRENGTH OF SPF SHEET, 6Al-4V-Ti

Strength	Grain Direction	Sample Size	Minimum (ksi)	Average (ksi)
F_{ty}	L	56	128	133
	T	64	131	139
	L+T	120	128	136
F_{ty}	L	56	111	120
	T	64	109	124
	L+T	120	109	122
F_{cy}	L	12	117	124
	T	12	132	138
	L+T	24	117	131
F_{su}	L	6	78	81
	T	6	82	88
	L+T	12	78	85
F_{bru}	L	6	198	202
	T	6	203	208
e/D=1.5	L+T	12	198	205
F_{bru}	L	6	249	264
	T	6	278	282
e/D=2.0	L+T	12	249	273
F_{bry}	L	6	160	160
	T	6	157	161
e/D=1.5	L+T	12	157	161
F_{bry}	L	6	184	191
	T	6	198	202
e/D=2.0	L+T	12	184	197

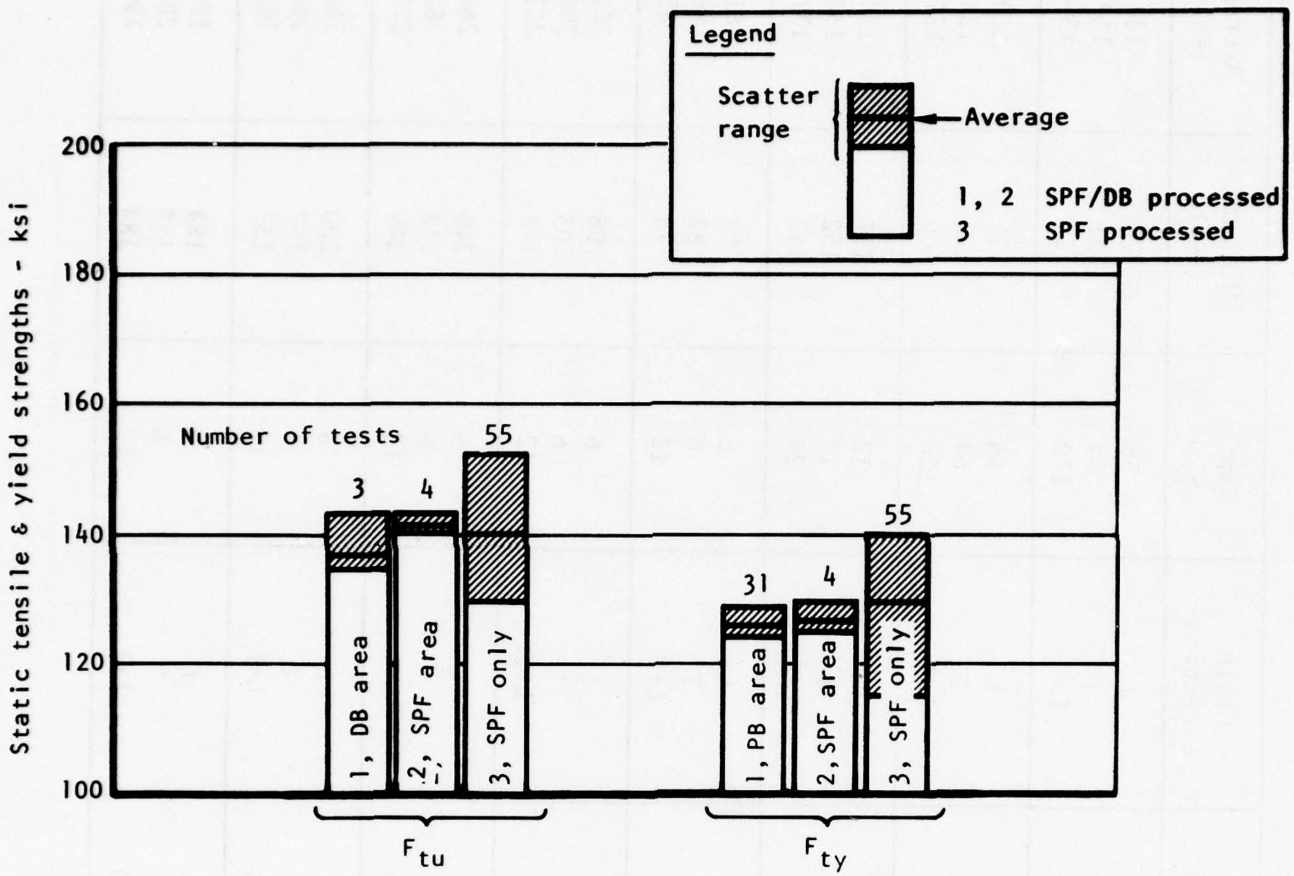


Figure 34. Comparison of tensile properties for material in three different conditions.

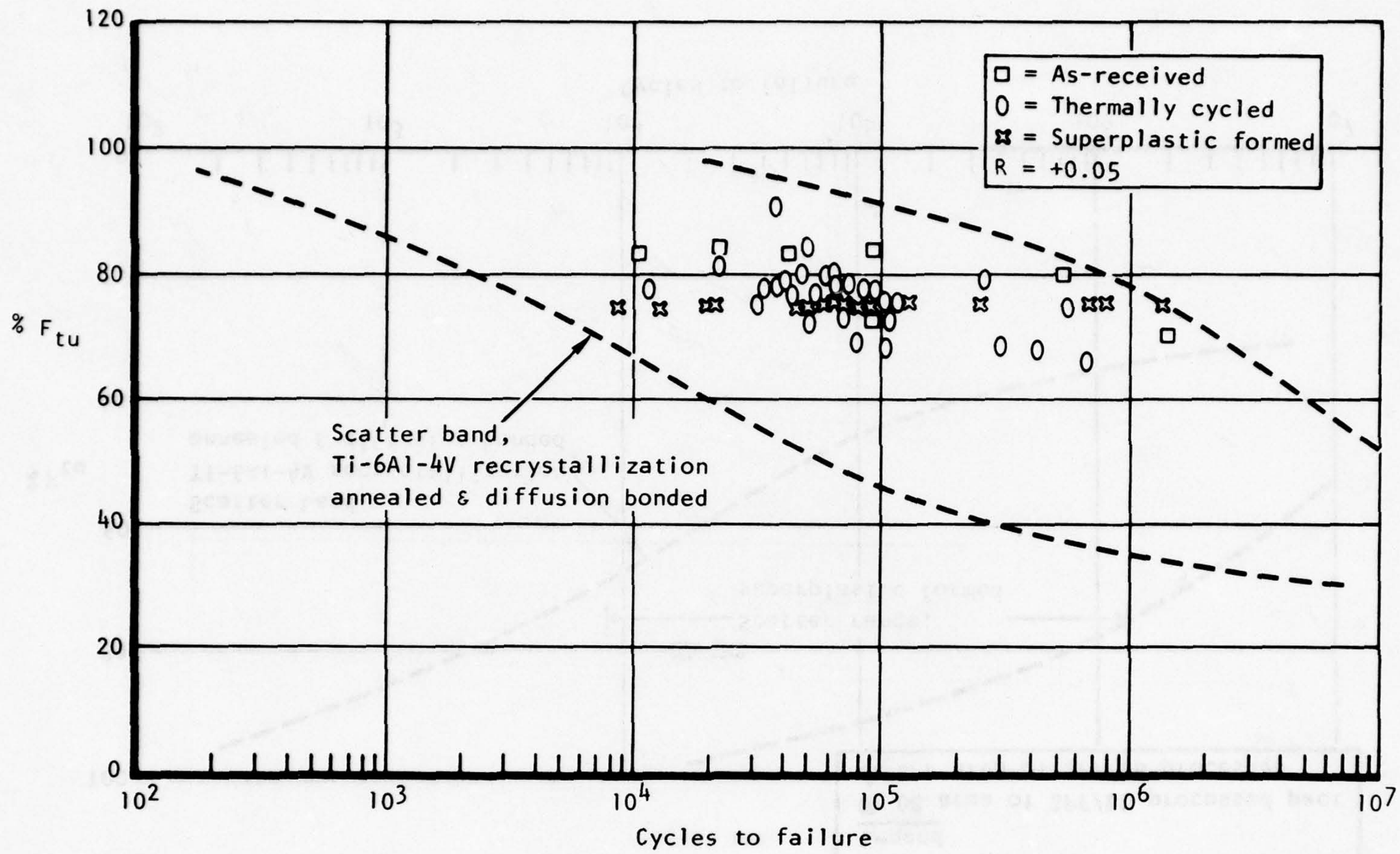


Figure 35. Smooth fatigue properties of as-received, thermally cycled, and superplastic formed Ti-6Al-4V sheet material.

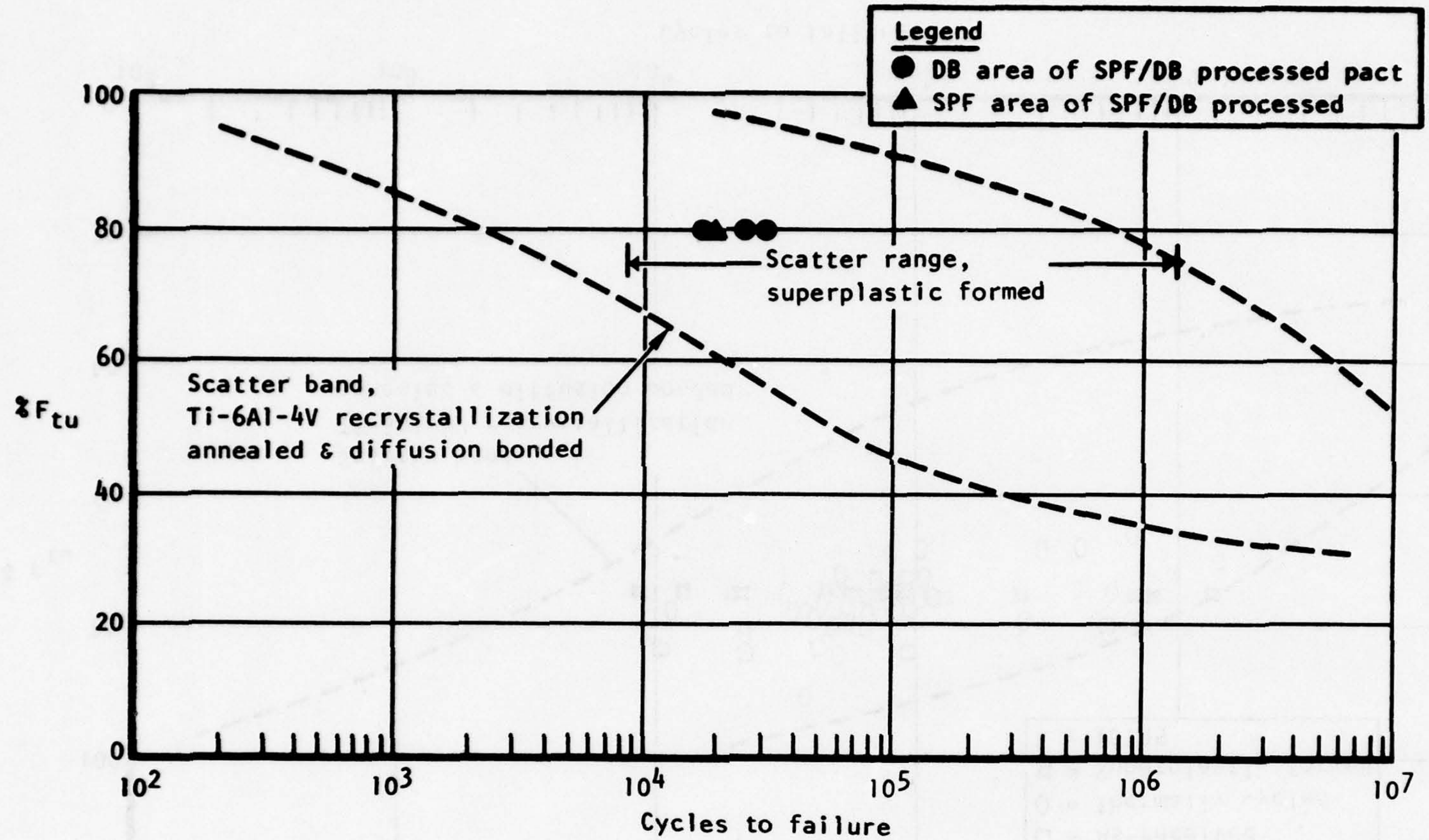


Figure 36. Comparison of smooth fatigue test results for SPF, DB, and SPF/DB processed parts.

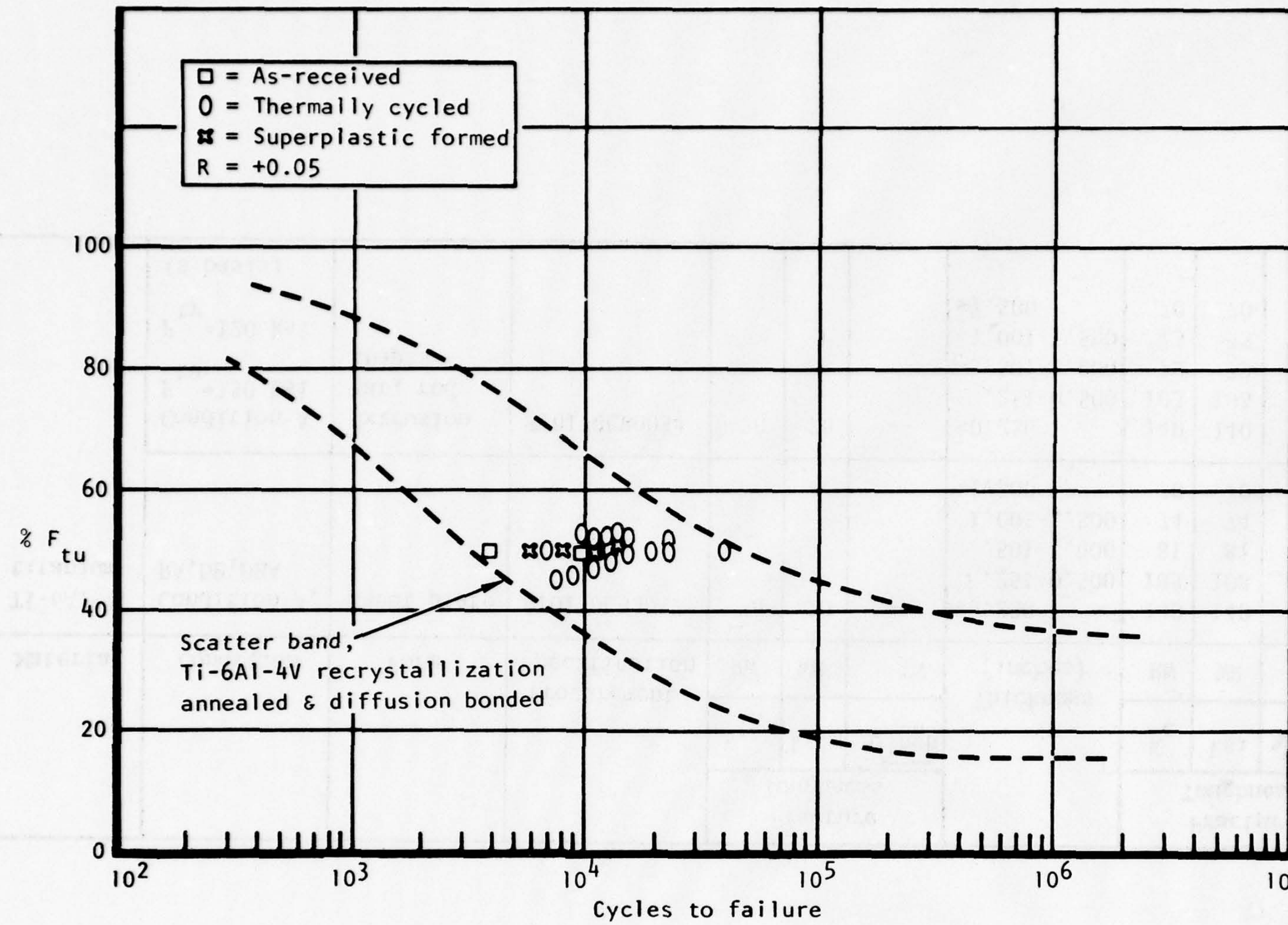


Figure 37. Notched fatigue (K_t = 3) properties of as-received, thermally cycled, and superplastic formed Ti-6Al-4V sheet material.

TABLE 6. FRACTURE TOUGHNESS DESIGN ALLOWABLES

Material	Condition	Form	Procurement Specification	Fracture Toughness K_{I_c} ksi $\sqrt{inch}$ RW	WR	TW	Thickness (inches)	Fracture Toughness K_c ksi $\sqrt{inch}$ RW	WR	TW
Ti-6Al-4V titanium	Condition A, RA,DB,DBA	Sheet plate	ST0170LB0032	70	70	--	≤0.250	140	140	--
							.251-0.500	108	108	--
							.501-1.000	81	81	--
							1.001-1.500	74	74	--
							>1.500	70	70	--
	Condition A F_{tu}=130 ksi F_{ty}=120 ksi (s-basis)	Extrusion bar, rod shapes	ST0170LB0034	70	70	--	≤0.250	140	140	--
							.251-0.500	103	103	--
							.501-1.000	79	79	--
							1.001-1.500	73	73	--
							>1.500	.70	70	--

a DB joint is far superior to other joints, in that during the joining process, the entire connecting parts are immersed and pressed at a high temperature in inert atmosphere. There is no contamination from air. After the SPF/DB process, the joint is cooled down slowly to room temperature so that there is no residual stress. The metallography of SPF/DB metal is essentially the same as the parent metal, indicating that SPF/DB metal develops the same properties as the parent metal.

Because of the design and the SPF/DB process, which is done at high temperature at slow speed with superplasticity, the geometry of the joint tends to be smooth flowing with relatively little abruptions. The stress concentration, if present, tends to be minimized.

The stress concentration areas where fatigue damage may be accumulated and cracks may initiate will be therefore at plasma arc, or laser beam weld, or at the mechanical fasteners. Therefore, for fatigue and fail-safe analysis in SPF/DB structures, special attention should be given to the details of the conventional weld and mechanical joints.

Section VIII

MASS PROPERTIES

Weight analyses were performed on various B-1 nacelle components for the purpose of making a weight comparison of various aircraft No. 4 nacelle components and selected SPF/DB concepts. The nacelle components used for this study consists of the (1) outboard upper deck, (2) side and lower engine access doors, (3) centerline precooler access door, and (4) engine shroud.

BASELINE WEIGHTS

The baseline component weight data are based on the available aircraft No. 4 nacelle data as of 13 December 1976. It should be noted that as of 13 December 1976, limited amount of weight data were available for the upper deck and side and lower access doors due to (1) all upper deck detail drawings were not released as of that date, (2) side and lower access door detail weights are not furnished by the vendor fabricating the doors, and (3) lack of weight changes due to rework of side and lower access doors. A summary of the baseline weights is shown in Table 7.

SPF/DB WEIGHTS

Weight data for the selected SPF/DB component concepts were based on layout drawings. Due to the lack of detailed information available on these layouts, it was necessary to make rough estimates for certain parts such as the access door latches, seals, hinges, and hardware. A summary of the SPF/DB component weights is shown in Table 8. Weight comparisons of the baseline components and the SPF/DB concepts are shown in Table 9.

TABLE 7. BASELINE NACELLE COMPONENT WEIGHTS

Component Descriptions	Reference Drawing No.	Weight (lb)
Outboard upper deck	L3207101	117.1
Precooler access panel	L3207088	13.0
Engine shroud	L4100065	8.4
Side access door	L3203400	87.8
Lower access door	L3203500	101.6

TABLE 8. SPF/DB NACELLE COMPONENT WEIGHTS

Component Descriptions	Reference Drawing No.	Weight (lb)
Outboard upper deck		
Expanded sandwich	D607-1-701	68.1
Hat stiffener	D607-1-702	60.1
Skin stringer	D607-1-713	98.1
Precooler panel		
Bead construction	D607-1-709	7.7
Expanded sandwich	D607-1-710	7.0
Engine shroud		
Expanded sandwich	D607-1-711	6.4
Bead construction	D607-1-712	8.7
Side access door		
Bead construction	D607-1-703	75.4
Dimple core construction	D607-1-704	66.6
Truss core construction	D607-1-705	70.3
Lower access door		
Sandwich construction	D607-1-706	83.2
Bead construction	D608-1-708	71.8

TABLE 9. WEIGHT COMPARISON OF BASELINE AND SPF/DB COMPONENTS

SPF/DB Components		Baseline Weight	Components per ship set	Wt Savings per ship set	Savings (%)
Descriptions	Weight				
Outboard upper deck			(2)		
Expanded sandwich	68.1	117.1		98.0	42
Integral frames	60.1	117.1		114.0	49
Skin stringer	98.1	117.1		38.0	16
Precooler panel			(2)		
Bead construction	7.7	13.0		10.6	41
Expanded sandwich	7.0	13.0		12.0	46
Engine shroud			(16)		
Expanded sandwich	6.4	8.4		32.0	24
Bead construction	8.7	8.4		(4.8)*	(4)
Side engine access door			(4)		
Bead construction	75.4	87.8		49.6	14
Dimple core construction	66.6	87.8		84.8	24
Truss core construction	70.3	87.8		70.0	20
Lower engine access door			(4)		
Sandwich construction	83.2	101.6		73.6	18
Bead construction	71.8	101.6		119.2	29

*Increase in weight of 4.8 pounds and 4 percent.

Section IX

COST ANALYSIS AND METHODOLOGY

The results of the analyses performed for the B-1 nacelle superplastic forming/diffusion bonding program are presented in Table 10.

METHODOLOGY

Cost analysis and estimating methods were selected to assure equitable comparative cost data for the designs being evaluated. Estimates were made to the level of detail shown on the applicable drawings (Appendix A); therefore, the estimates show reliable cost relationships of the designs being compared. They are not intended to show completed aircraft section costs; however, the elements omitted, such as systems installations or attach fittings, are common to all the designs and would not affect the cost relationships.

MATERIAL

Each design material requirement is calculated by weight or size. Because comparison between designs was the objective, 1977 costs were used for all materials, including the fasteners, which were priced by quantity.

Tooling material was priced on a dollar rate per tooling hour for the baseline tools. The approach for SP/DB is discussed under "Tooling." 1977 procurement rates were included in the material rates, as well as general and administrative costs, to achieve a material cost dollar.

FABRICATION AND ASSEMBLY

A parametric estimate was developed for each SP/DB design. All sheet metal effort prior to forming and bonding was projected on an 85-percent Crawford slope, the SP/DB was projected on an 80-percent curve, and any machined parts projected on a 90-percent slope. This approach represents a conservative estimate. For the baseline effort, either a B-1 detail estimate or vendor quotes were projected for production quantities.

TABLE 10. PRODUCTION COSTS FOR 240 SHIPSETS
(1977 Dollars)

Part	Number Required S/S	Concept	Weight (Lb)	Recurring Costs (Dollars)	Nonrecurring Costs (Dollars)	Total Costs ($)	Part	Concept	Weight (Lb)	Recurring Costs (Dollars)	Nonrecurring Costs (Dollars)	Total Costs ($)	Savings %
Upper deck L3207101	4	Rivet Ti assembly	116.8	114,618	1,925,275	122,640	-701	Dimple core	68.1	46,345	1,114,940	50,991	58
							-702	Integral	60.1	33,889	1,068,156	38,340	69
							-713	Stiffened skin	98.1	40,993	1,114,940	45,639	63
Side access door L3203400	2LH 2RH	Bonded Al HC	87.8	44,895	338,130	46,304	-703	Hat section	75.4	35,914	562,667	38,258	17
							-704	Cone core	66.6	46,845	431,224	48,642	-5
							-705	Truss	70.3	45,654	431,224	47,451	-2
Lower access door L3203500	2LH 2RH	Bonded Al HC	101.6	69,956	528,870	72,160	-706A	Sinewave	71.8	45,309	470,430	47,269	34
							-706B	Cone core	71.8	49,250	470,430	51,210	29
							-706C	Truss	71.8	48,049	470,430	50,009	31
							-708	Beaded	83.2	37,905	580,393	40,323	44
Precooler door L3207088	2	Machined Ti plate	13.0	12,353	10,100	12,395	-709	Beaded	7.7	4,111	61,570	4,368	65
							-710A	Single pyramid	7.0	4,616	39,317	4,780	61
							-710B	Double pyramid	7.0	5,391	39,317	5,555	55
Shroud L4100065	16	Brazed Ti HC	8.4	105,064	89,000	105,435	-711	Truss core	6.4	46,812	102,185	47,238	55
							-712	Beaded	8.7	34,347	144,627	35,050	67

COSTS SHOWN PROVIDE A RELATIVE COMPARISON OF CONCEPTS FOR DESIGN EVALUATION. THESE COSTS DO NOT INCLUDE ALL ELEMENTS REQUIRED FOR PRICING. ESTIMATES FOR FACILITIES, EQUIPMENT, RESEARCH, DEVELOPMENT, TEST, AND ENGINEERING ARE NOT INCLUDED.

TOOLING

Estimates for SP/DB tools were a mixture of parametric estimates and known baseline tools which would be used with SP/DB or conventional parts.

For the recurring tooling cost, a standard tooling maintenance slope of 108 percent was used; this was applied to both the baseline and the SP/DB component tooling.

Because of the size of the tools used in SPF/DB, the standard approach of applying a dollars per hour to tooling hours for material costs was not effective; therefore, for the basic tooling material, the tool was sized, the weight was calculated, and a material cost per pound was applied. For recurring costs, the dollars per tooling hour was applied.

SPF/DB WEIGHTS

Examination of Table 10 shows that SP/DB effects a considerable weight savings. In substitution of titanium for titanium, this amounts to a considerable cost savings. In addition, the elimination of parts and fasteners also adds to the total achievable cost delta. An examination of the various designs shown on the applicable drawings (Figures 17 through 21) which are superplastic diffusion bonded is as follows:

- Aft Nacelle Upper Deck

    1. Dimple core sandwich
    2. Integral frame
    3. Skin-stringer

    The difference between these three parts is in the fabrication costs. The dimple core sandwich was a parametric estimate. The integral frame and skin-stringer were analyzed for differences which appear in final assembly. A ratio was then established between items 1 through 3. The material difference is only about 10 percent. The lowest cost part (3) could only be achieved with considerable development work.

- Side Access Door

    4. Hat section
    5. Cone core
    6. Truss core

The difference in these three parts is in the assembly effort. The sheet metal and machine effort are the same for all three configurations. The material costs are higher on the second two, because of chem milling of the core sheets to get down to the gages required and the number of sheets required for items 5 and 6, and 4 which increases the labor.

• <u>Lower Access Door</u>

7. Sine wave core
8. Cone Core
9. Truss core
10. Hat section

These doors are similar to the side access doors, but more complex in the hinge area. Item 10 is cheaper only because of the material cost, which is less because of lighter gages used in the design. The labor is about equal to 7. Items 8 and 9 are higher in labor costs than 7 and 10 because of additional sheet metal effort.

• <u>Precooler Door</u>

11. Beaded panel
12. Single pyramid core sandwich
13. Double pyramid core sandwich

In these three concepts, the cost differences are based on the number of sheets. Concept 11 is two beaded sheets, 12 is three sheets, and 13 is four sheets.

• <u>Engine Shroud</u>

14. Truss core panel
15. Beaded

Item 14 is made with three sheets of material, while 15 is made from a single sheet. The material cost is primarily the greatest part of the cost delta.

These are design cost trade studies. Certain assumptions were made in their analysis. In gages required on some of the designs, the minimum gage available was assumed to be chem milled. In other designs such as the aft nacelle upper deck in the integral design, the concept requires forming frames, angles, longerons, etc, separately and then diffusion bonding them in position with the skin. This is a large part and, with a development program, might be feasible. The costs shown in these studies reflect production costs. The total production cost savings potential is $48,622,800 for 240 shipsets.

Section X

B 1 IMPLEMENTATION PLANS

Application of superplastic-formed and concurrent diffusion bonding (SPF/DB) manufacturing technology on the B-1 program depends on the following:

1. Successful completion (October 1977) of two test/development programs that will provide the data needed to verify structural integrity of components manufactured by the process.

2. Verification of the cost savings projected for SPF/DB components over the current fabrication methods used on these components.

One of the test programs is under contract, and the second program is in the B-1 program approval cycle. Both programs will be completed in October 1977. Cost and weight savings and the cost of implementation data needed during the implementation decision process are being generated for eight components that will be the first SPF/DB candidates on the B-1 program.

PRODUCIBILITY CHANGE REQUIREMENTS

Application of SPF/DB to the B-1 program requires that this new manufacturing technology be reduced to industry practice. Process development, testing, demonstration of feasibility, capability, repeatability, material processing specifications and procedures, and quality controls have been, or are about to be established to support a production program. In addition, the ability to verify the structural integrity of components manufactured by this process must be established before this manufacturing technique can be approved for B-1 structural application. Successful completion of the development programs previously described will provide the necessary assurance required before component candidates for SPF/DB can be considered.

Candidate SPF/DB components will replace existing designs on the B-1 aircraft, following the procedures established for implementing all design changes to the aircraft configuration. The change category for SPF/DB components will be producibility improvement and will be classed as an internal change except for special circumstances that require component redesign or design changes for other reasons.

GROUND RULES FOR ADOPTING SPF/DB

Producibility change candidates are evaluated on an individual part-by-part bases in the change system, and must satisfy cost-effectiveness and program impact criteria before approval for implementation can be granted. The 10 ground rules for this criteria are:

1. A producibility improvement change must reduce the total recurring cost for product fabrication or inspection, or the total recurring procurement costs for purchased parts, hardware, or services.

2. A producibility improvement change must realize a program return on investment (ROI) of at least 5 to 1. ROI calculations must include all nonrecurring implementation costs and invested or (sunk) tooling costs, but will not include life cycle cost considerations. Life cycle cost will be considered only if adversely impacted by the change.

3. A producibility improvement change which reduces operations nonrecurring costs only such as tooling, planning, etc, must equal three times the total engineering nonrecurring implementation costs.

4. A producibility improvement change which increases aircraft weight must, in addition to the aforementioned, realize a per unit recurring cost reduction of $2,000 per pound of weight added.

5. A producibility improvement change must be within the state of the current manufacturing art (reduction to practice established) and be approved for B-1 application.

6. A producibility improvement change will not invalidate test data unless cost of retest is included in trade analysis.

7. A producibility improvement change will not impact aircraft performance specifications (PID's).

8. A producibility improvement change will not adversely impact:

   a. Interchangeability/replaceability

   b. Maintainability/serviceability

   c. Survivability/vulnerability

9. All cost data will be validated by approved B-1 cost organization.

10. A producibility improvement change will not be restricted to the lot buy philosophy, but may be implemented within a lot if economically justifiable. Operation Scheduling will determine effectivity points

applicable to producibility improvement changes, normally at first of each fabrication release. The establishment of effectivity points will include an analysis of program schedules, spare parts orders, long-lead procurements, field service manuals, etc.

EARLY IMPLEMENTATION - RISK ASSESSMENT

At the time of this writing, no SPF/DB component candidates have entered the formal B-1 change procedure. However, eight components have been identified as possible SPF/DB candidates as a result of this preliminary design study and related activities. These candidates, discussed in subsequent paragraphs, either represent components that can easily be adapted to the concurrent SPF/DB process with relatively low implementation cost, or there is a program requiring extensive nonproducibility design changes where SPF/DB technology can be considered as the redesign fabrication method. Engine shrouds are an example of this later situation and are discussed in a subsequent paragraph.

The eight components identified as SPF/DB candidates are listed herein, along with the current configuration part number. These components will acquire new part number in the SPF/DB configuration.

1. Upper engine access door - L3203400
2. Lower engine access door - L3203500
3. Precooler compartment panel - L3207088
4. Eyebrow panel - L3207151
5. Engine shrouds - L4100065
6. APU door - L3206643
7. ECS door - L3011641
8. Nacelle frame, YAN 91.00 - L3207210
9. Windshield hot-air blast nozzles

The first step of implementation, engineering redesign, will occur in November 1977, following successful completion of the previously described development testing and change processing. However, preliminary evaluations have indicated that early go-ahead, prior to test completion, may have cost benefits to the B-1 program.

An early, conditional go-ahead will be considered for the foregoing eight components, provided present production plans and schedules for these components in the non-SPF/DB configuration are not interrupted. This requires that two parallel programs be maintained to assure minimum technical and schedule risk to the B-1 program. Rough order of magnitude (ROM) cost information is being generated so that the cost impact of early go-ahead may be evaluated. This data package will be ready for evaluation by 1 May 1977.

COMPONENT IMPLEMENTATION PLANS

Use of SPF/DB for the engine-mounted shrouds provides a potential for considerable cost and some weight savings if used to replace the present brazed honeycomb fabrication method. The Air Force is presently planning to make a change to the engine government-furnished equipment (GFE) exhaust nozzle effective on A/C-8 and subsequent. This simplified nozzle will require a redesign of the engine-mounted shrouds. This, therefore, is a logical change point since new tooling will be required. The firm decision on implementation of the simplified nozzle will not be made until December 1977 at the CDR (GE/AF). A decision in December will provide approximately 24 months to do the shroud detail design, provide tooling, and produce shrouds to meet the A/C-8 manufacturing need date. Funds have been provided in CCP 408 (Rockwell support of the Simplified Nozzle Program), Option I, to do the shroud redesign required. This effort will be directed toward use of the SPF/DB fabrication technique.

Also included in the negotiated CCP 408 funding is money to provide two engine sets of shrouds for flight test of the simplified nozzle on A/C-2 starting in July 1978. Studies are currently being conducted to determine if these shrouds can be constructed using SPF/DB within the schedule and funding constraints. This study will be complete by 1 July 1977, at which time the results will be presented to PCB for approval to proceed with SPF/DB fabrication of these flight test shrouds. The results of static and acoustic tests planned on sample panels, as well as fabrication experience from the AFML/P&W engine duct program, will be available for use in the flight test shroud program.

DEVELOPMENT PROGRAMS

AFML Contract F33615-75-C-5058 (Reference 1) is currently in progress to establish manufacturing methods to concurrently SPF/DB and demonstrate the fabrication of three, full-scale, sheet titanium parts:

1. APU door - L3206643
2. Nacelle frame - L3207215
3. Engine access door - L3203400

APU DOOR DOOR

The APU door is two-sheet technology which demonstrates impressive weight savings (22 pounds per aircraft) as compared to the machined plate part used on A/C-1, -2, and -3. The contractual work is complete and implementation on the B-1 is pending acoustic fatigue test results anticipated to be successfully completed in October 1977.

NACELLE FRAME

The nacelle frame is one sheet with bonded-on elements. The contract work will be completed by June 1977, and will demonstrate 40-percent weight and large cost savings.

ENGINE ACCESS DOOR

The engine access door is three-sheet technology and represents a major advance in SPF/DB process technology, being the largest part to date. Within the scope of the contract two tests will be conducted. They are (1) element tests from laboratory-produced sandwich (compression, bending beam, shear, adn fatigue), and (2) a subscale panel will be produced for fatigue testing; three doors will be produced for demonstration and one of these will be subjected to full-scale static testing. The results of the door tests are expected to be available by the fourth quarter of 1977. Implementation of a full set of engine access doors on the B-1 will represent a weight reduction of 189 pounds.

ACOUSTIC TESTS

MCR 40636 is a key B-1 internal test program to complete the testing needed for structural integrity verification of SPF/DB-produced articles on the B-1. This program will provide acoustic properties of two-sheet and three-sheet (sandwich) technology. An acoustic test article based on L3207151 upper nacelle eyebrow panel will be subjected to acoustic testing. Concurrent with this test will be a second test article produced to thinner gages and a sandwich panel. The second test provided by MCR 40636 is a full-scale static test of a SPF/DB-produced upper nacelle eyebrow panel. Test results are anticipated to be completed by October 1977.

Section XI

CONCLUSIONS

The study indicates that the structures that are now possible because of the SPF/DB process are structurally suitable for the intended purposes and have definite weight and cost advantages, as well as giving the designer new degrees of freedom of design.

WEIGHT ADVANTAGES

Weight advantages were gained because of the increased joint efficiency of the diffusion bonds and because of the new configurations that are possible. The diffusion-bonded joints do not require a wide overlap as do mechanically fastened or adhesively bonded joints. Also these joints do not require beef-up because of the limitation of operating temperatures as do the adhesively bonded or brazed joints that they replace. Fatigue problems associated with the holes for mechanical fasteners are also eliminated. Many joints were also eliminated because of the capability to produce very large parts from two or more large titanium sheets.

PRODUCIBILITY ADVANTAGES

The easy formability of titanium at SPF temperatures allows the forming of integral stiffeners, brackets and edge members, and very complex core sheet patterns, greatly increasing the efficiency of the structures and at the same time allowing whole new degrees of freedom to the designer.

COST ADVANTAGES

Cost advantages come primarily from four areas; i.e., (1) greatly reduced part count reduces detail fabrication time; (2) elimination of mechanical, adhesive-bonded, and brazed joints reduces assembly time; (3) reduced material costs because of weight savings and reduction of scrap; and (4) the reduction of tooling costs in some cases.

FUTURE DEVELOPMENT

Much work remains to be accomplished. Although small hardware parts have been demonstrated to actual aircraft requirements, application to large-scale hardware remains to be accomplished. A giant step in this direction will be the successful fabrication of a large B-1 engine access door and successful completion of planned sonic fatigue tests in mid-1977.

AD-A053 327 ROCKWELL INTERNATIONAL LOS ANGELES CA LOS ANGELES DIV F/G 1/3
PRELIMINARY DESIGN OF LOW-COST TITANIUM STRUCTURE.(U)
SEP 77 J K PULLEY F33615-76-C-3066
UNCLASSIFIED NA-77-389 AFFDL-TR-77-81 NL

2 OF 2
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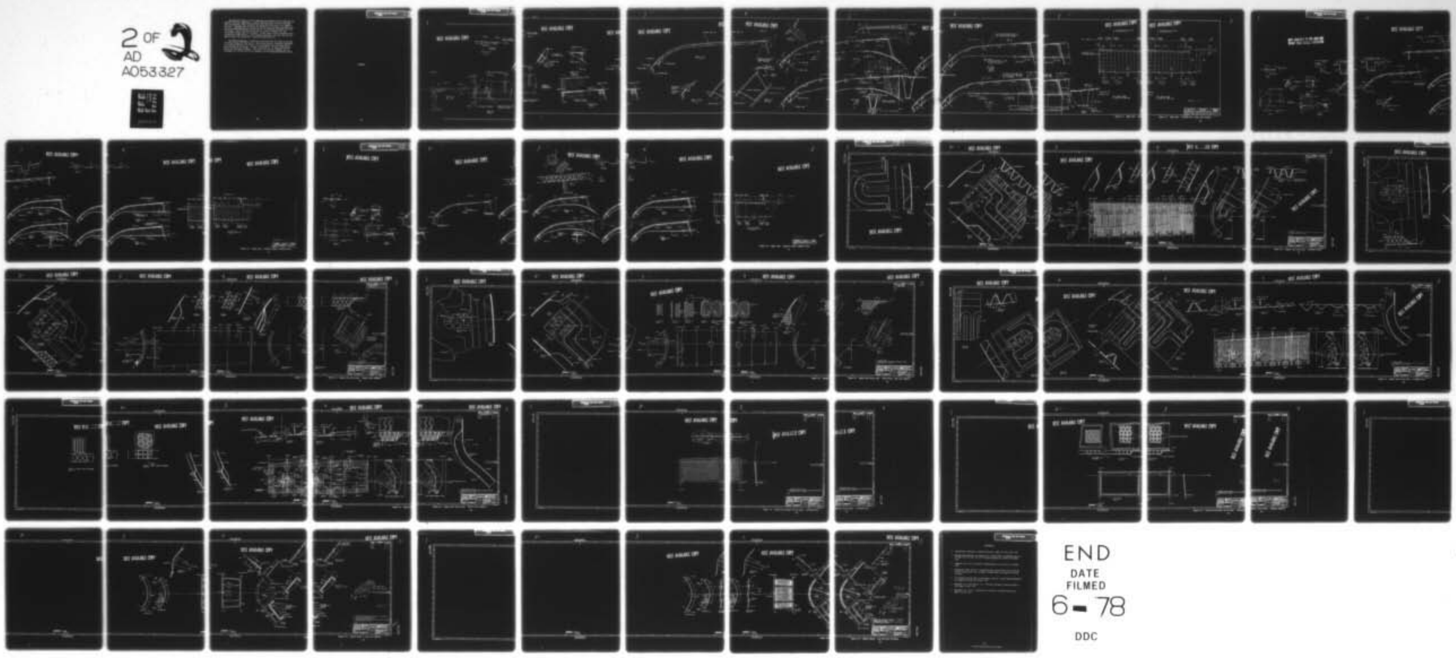
A053327



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The potential impact of this technology on advanced military aircraft can obviously be very significant. However, the data base for this technology does not presently exist to permit the design and fabrication of a complete aircraft. Although some structural design data are available, much more work must be accomplished before an airplane can be completely designed with this technology. Such structural design data as static allowables for new structural concepts must be developed. Fatigue data, fracture mechanics data, new materials applications, crack-stopping techniques, and long-term environmental effects are among those requiring characterization.

The SPF/DB technology is expected to revolutionize the field of aircraft structural design and fabrication. New design concepts heretofore impossible or extremely difficult with state-of-the-art methods are relatively easily made with SPF/DB technology. To date, the potential of these patented processes has only been scratched. The future will see new concepts, as yet unthought of, limited only by the ingenuity of the design/producibility team.

APPENDIX

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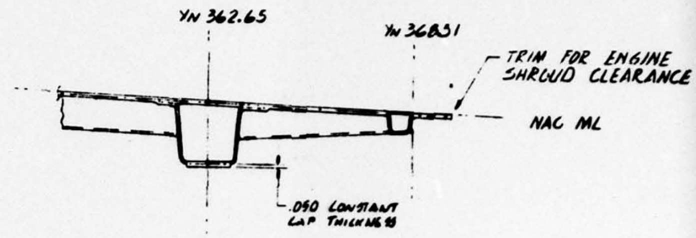

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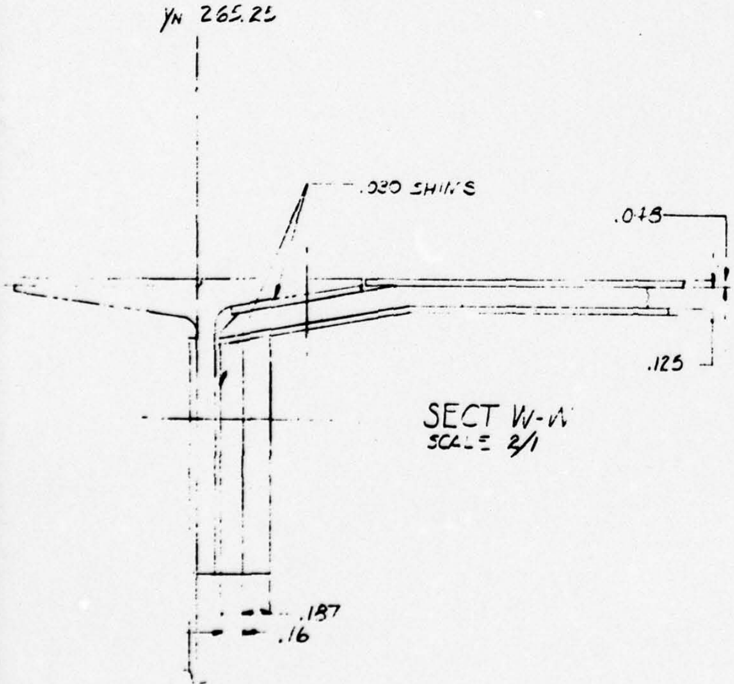

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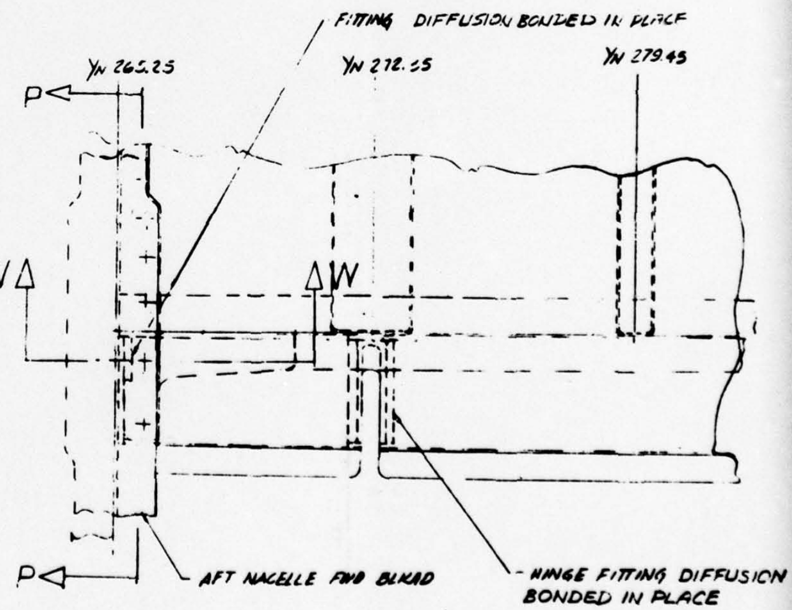

VIEW N

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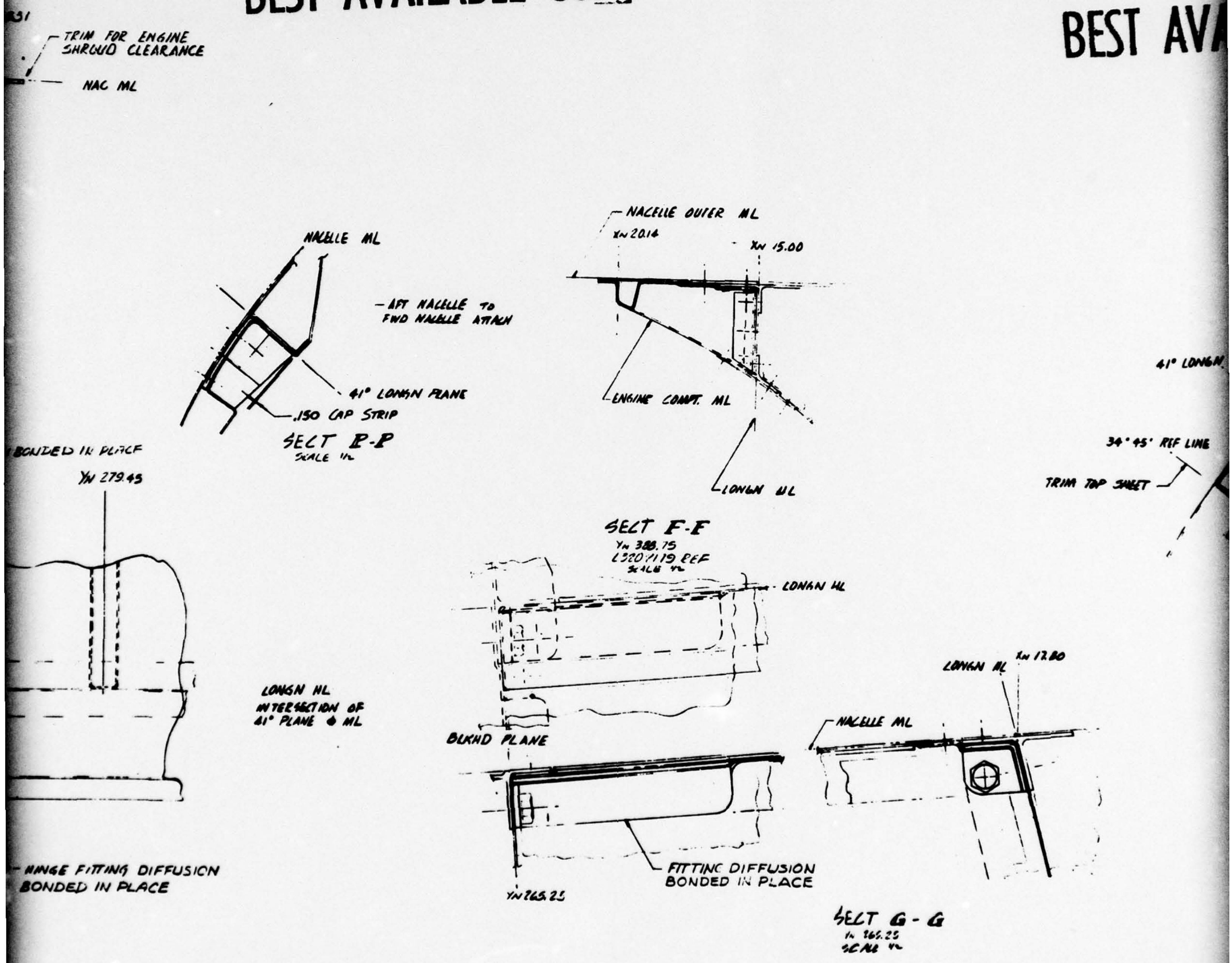
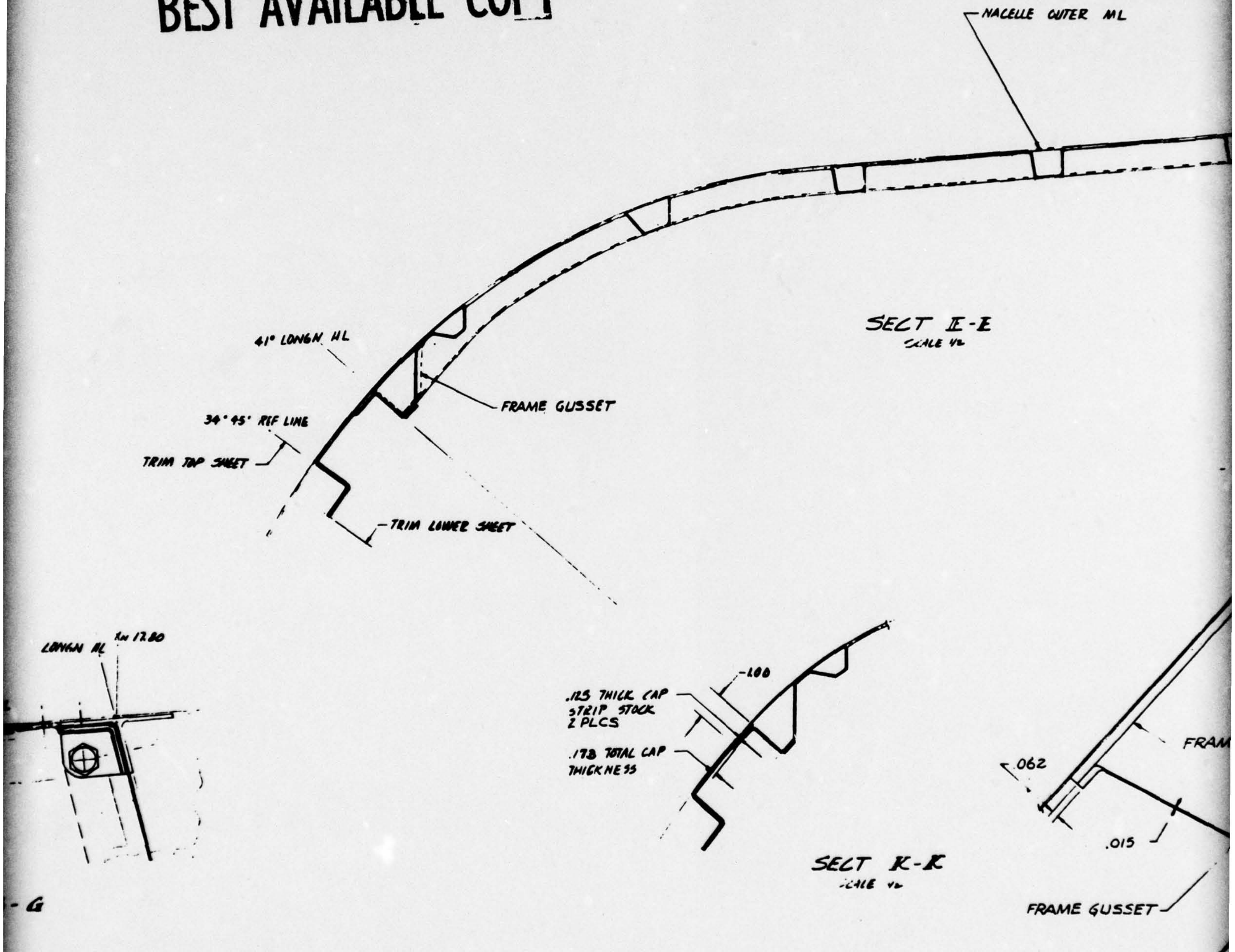

TRIM FOR ENGINE SHROUD CLEARANCE
NAC ML
NACELLE ML
AFT NACELLE TO FWD NACELLE ATTACH
41° LONGN PLANE
.150 CAP STRIP
SECT P-P
SCALE 1/2
NACELLE OUTER ML
XN 20.14
XN 15.00
ENGINE COMPT. ML
LONGN ML
41° LONGN
34° 45' REF LINE
TRIM TOP SHEET
BONDED IN PLACE
YN 279.45
SECT F-F
YN 388.75
LONGN ML
LONGN ML
INTERSECTION OF 41° PLANE & ML
XN 12.80
NACELLE ML
BLKHD PLANE
HINGE FITTING DIFFUSION BONDED IN PLACE
FITTING DIFFUSION BONDED IN PLACE
YN 265.25
SECT G-G
SCALE 1/2

1

3


NACELLE OUTER ML
SECT II-II
SCALE 1/2
41° LONGN HL
FRAME GUSSET
34°45' REF LINE
TRIM TOP SHEET
TRIM LOWER SHEET
LONGN HL
.125 THICK CAP
STRIP STOCK
2 PLCS
.178 TOTAL CAP
THICKNESS
1.00
SECT K-K
SCALE 1/2
.062
.015
FRAME GUSSET

4

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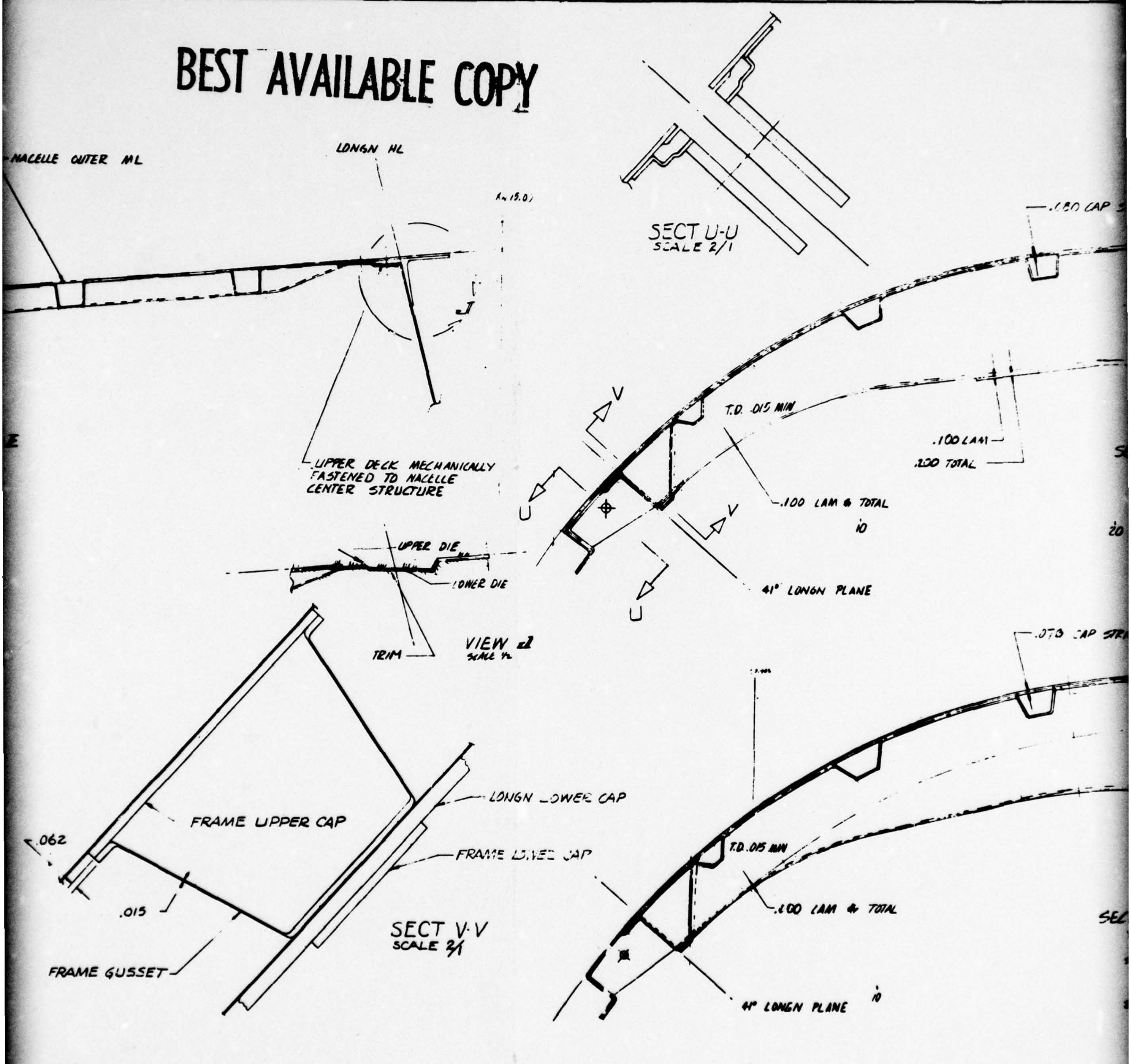

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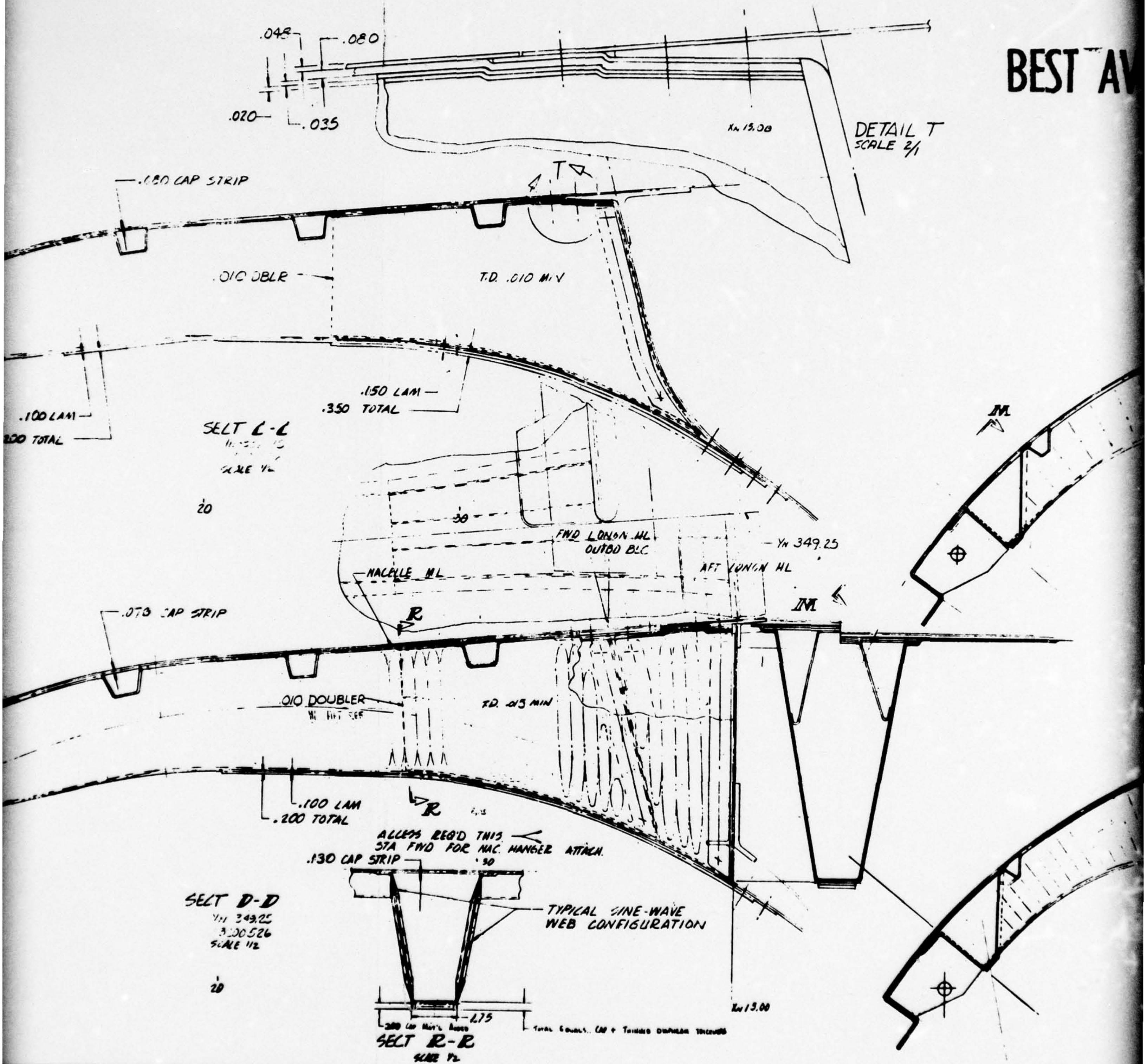
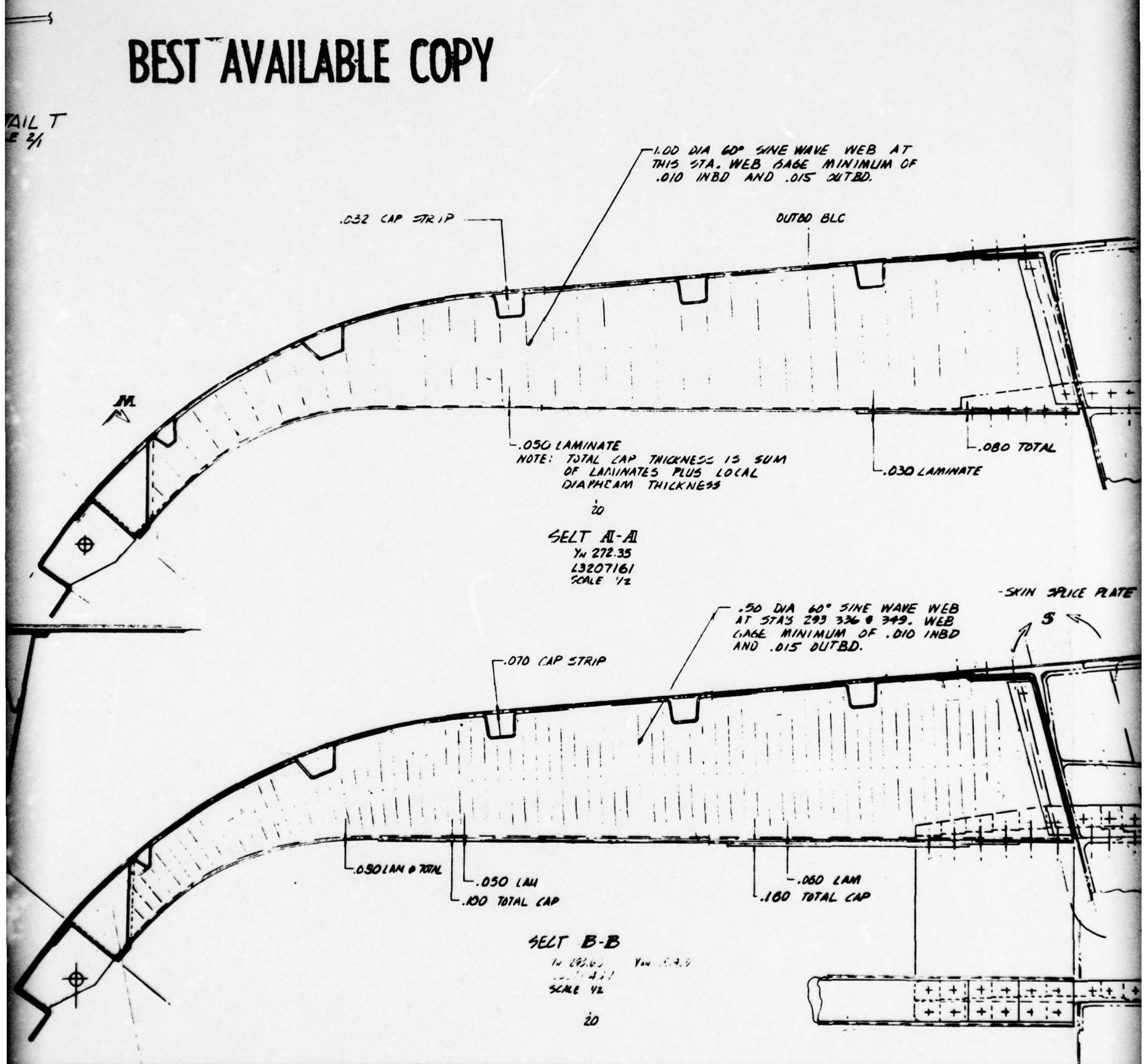

.048
.080
.020
.035
DETAIL T
SCALE 2/1
.080 CAP STRIP
.010 DBLR
T.D. .010 MIN
.150 LAM
.350 TOTAL
.100 LAM
.200 TOTAL
SECT L-L
SCALE 1/2
FWD LONGN ML
OUTBD BLC
Yn 349.25
NACELLE ML
AFT LONGN ML
M
.078 CAP STRIP
R
.010 DOUBLER
T.D. .013 MIN
.100 LAM
.200 TOTAL
ACCESS REQ'D THIS STA FWD FOR NAC. HANGER ATTACH.
.130 CAP STRIP
TYPICAL SINE-WAVE WEB CONFIGURATION
SECT D-D
SCALE 1/2
SECT R-R
SCALE 1/2
Xn 13.00

6


AIL T
E 2/1
1.00 DIA 60° SINE WAVE WEB AT THIS STA. WEB GAGE MINIMUM OF .010 INBD AND .015 OUTBD.
.032 CAP STRIP
OUTBD BLC
M
.050 LAMINATE
NOTE: TOTAL CAP THICKNESS IS SUM OF LAMINATES PLUS LOCAL DIAPHRAM THICKNESS
.030 LAMINATE
.080 TOTAL
20
SECT A-A
Yw 272.35
L3207161
SCALE 1/2
-SKIN SPLICE PLATE
S
.50 DIA 60° SINE WAVE WEB AT STA'S 293 336 & 349. WEB GAGE MINIMUM OF .010 INBD AND .015 OUTBD.
.070 CAP STRIP
.030 LAM & TOTAL
.050 LAM
.100 TOTAL CAP
.080 LAM
.160 TOTAL CAP
SECT B-B
SCALE 1/2
20

7

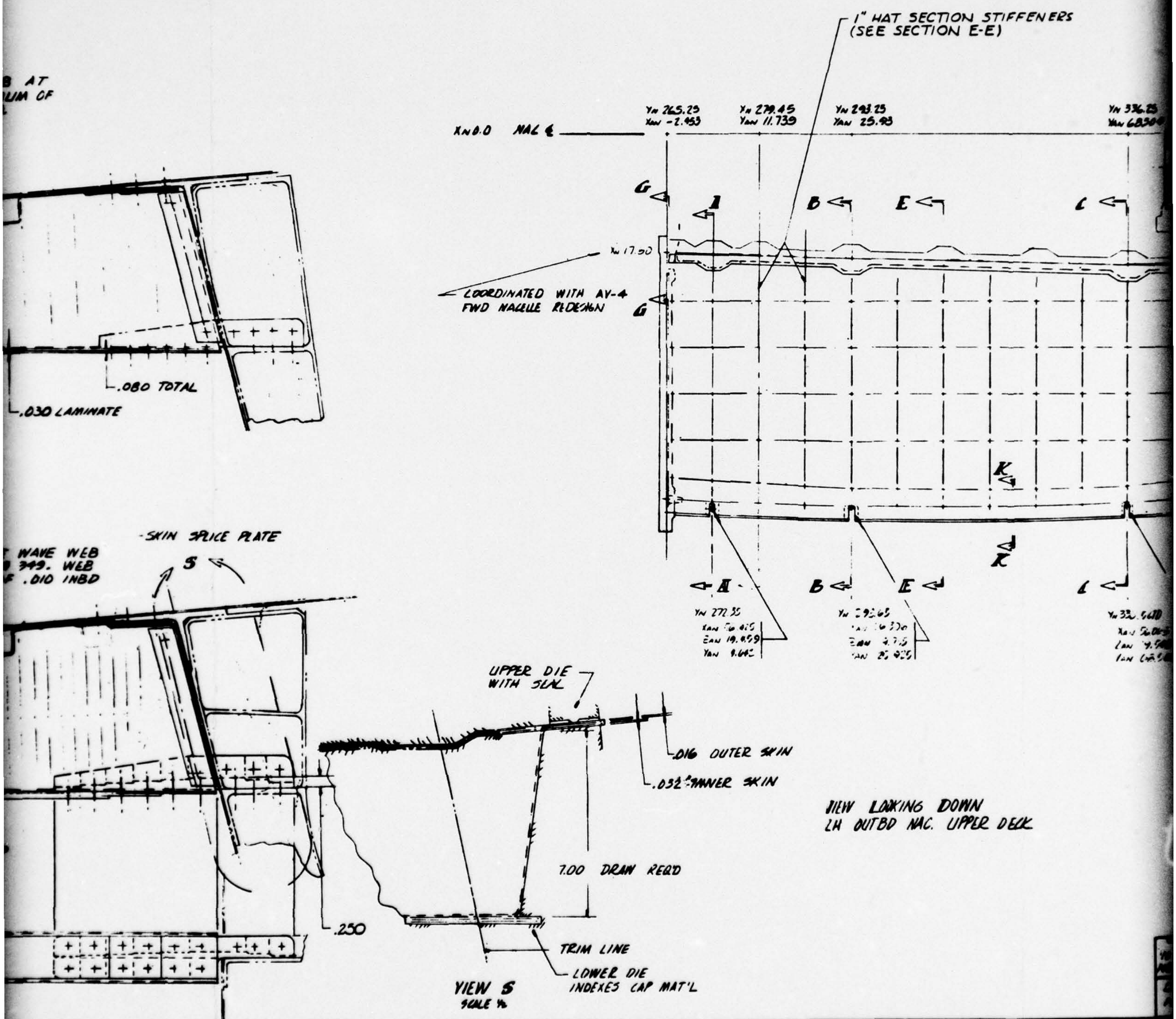


Figure A-1. Upper deck - inte

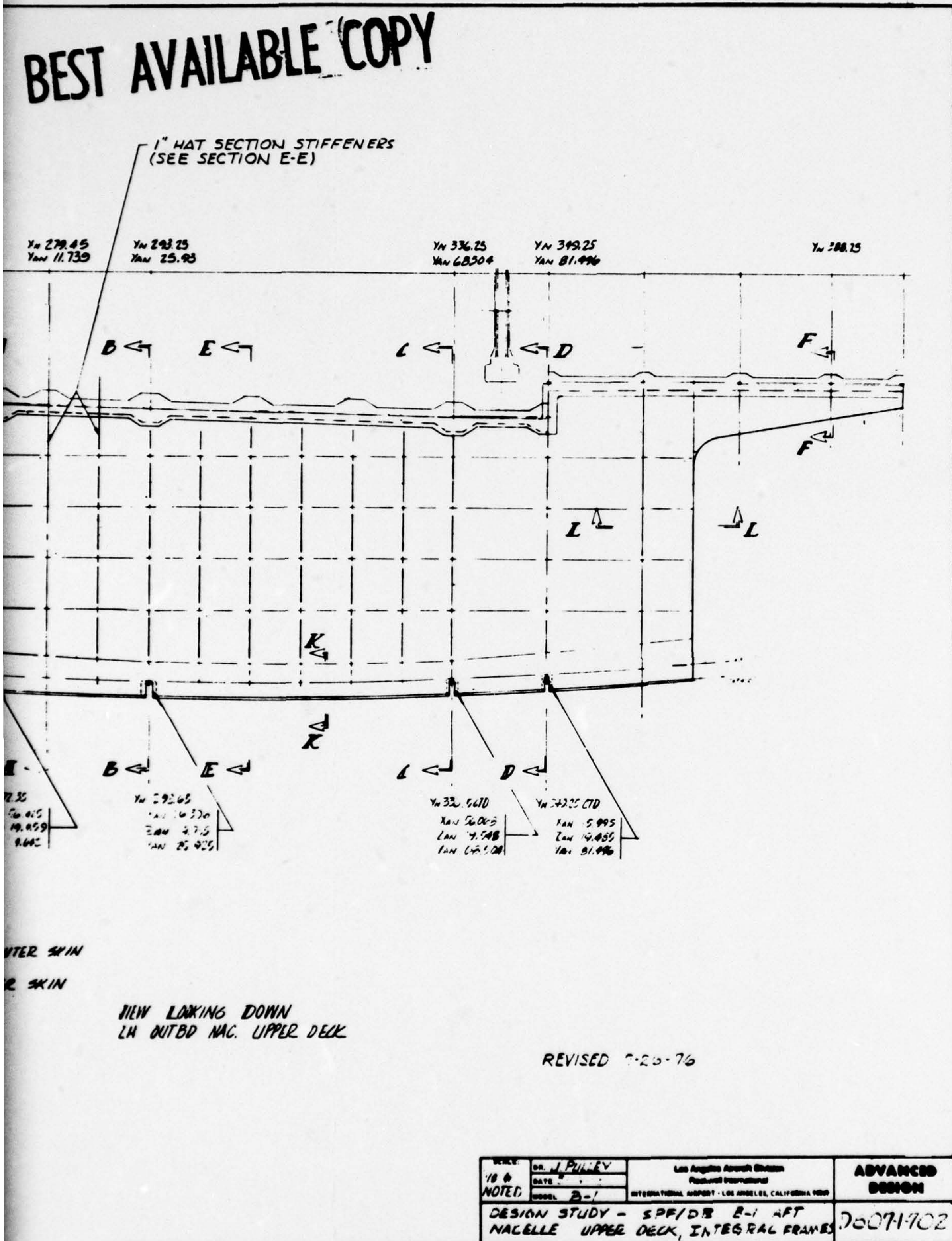
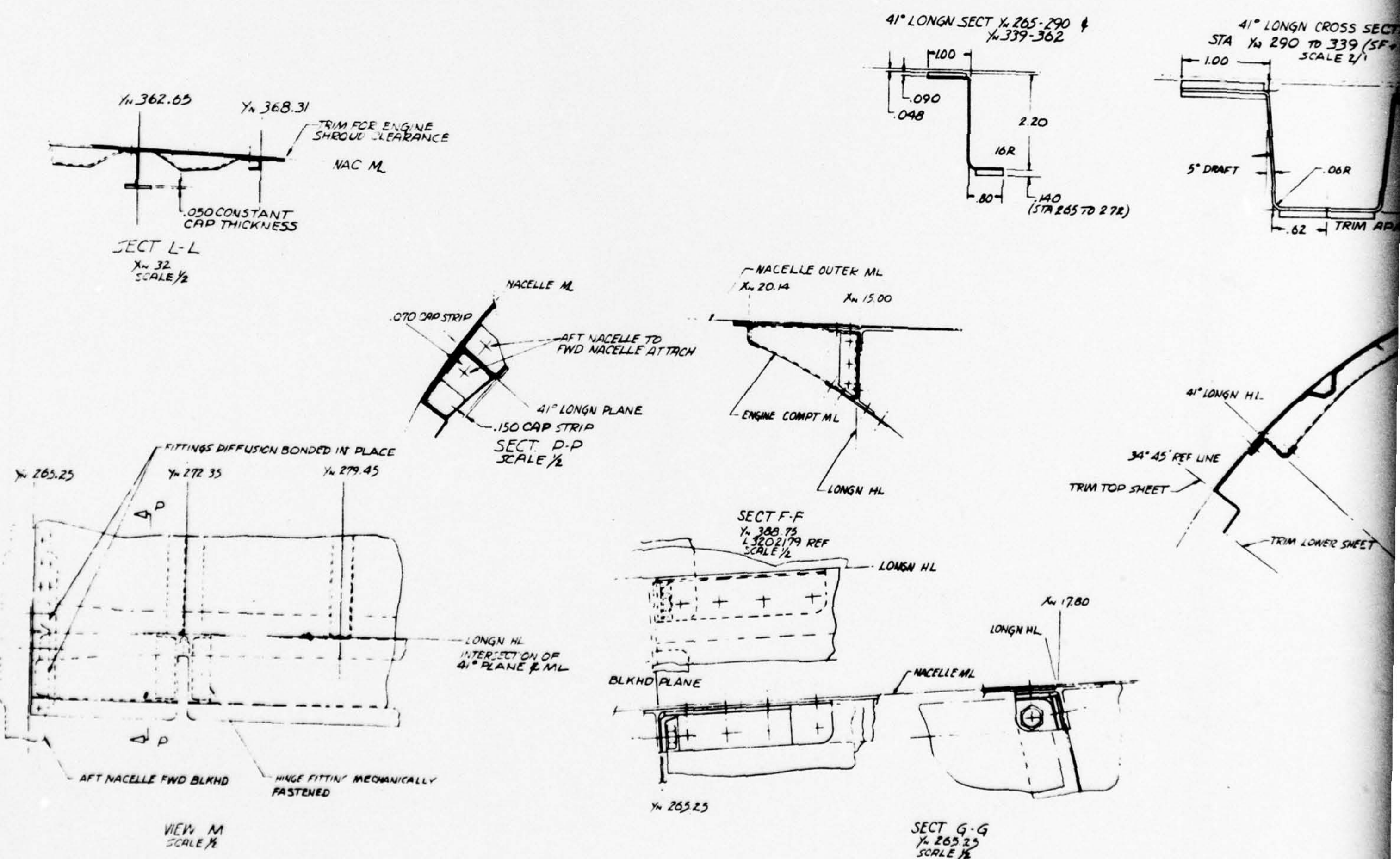
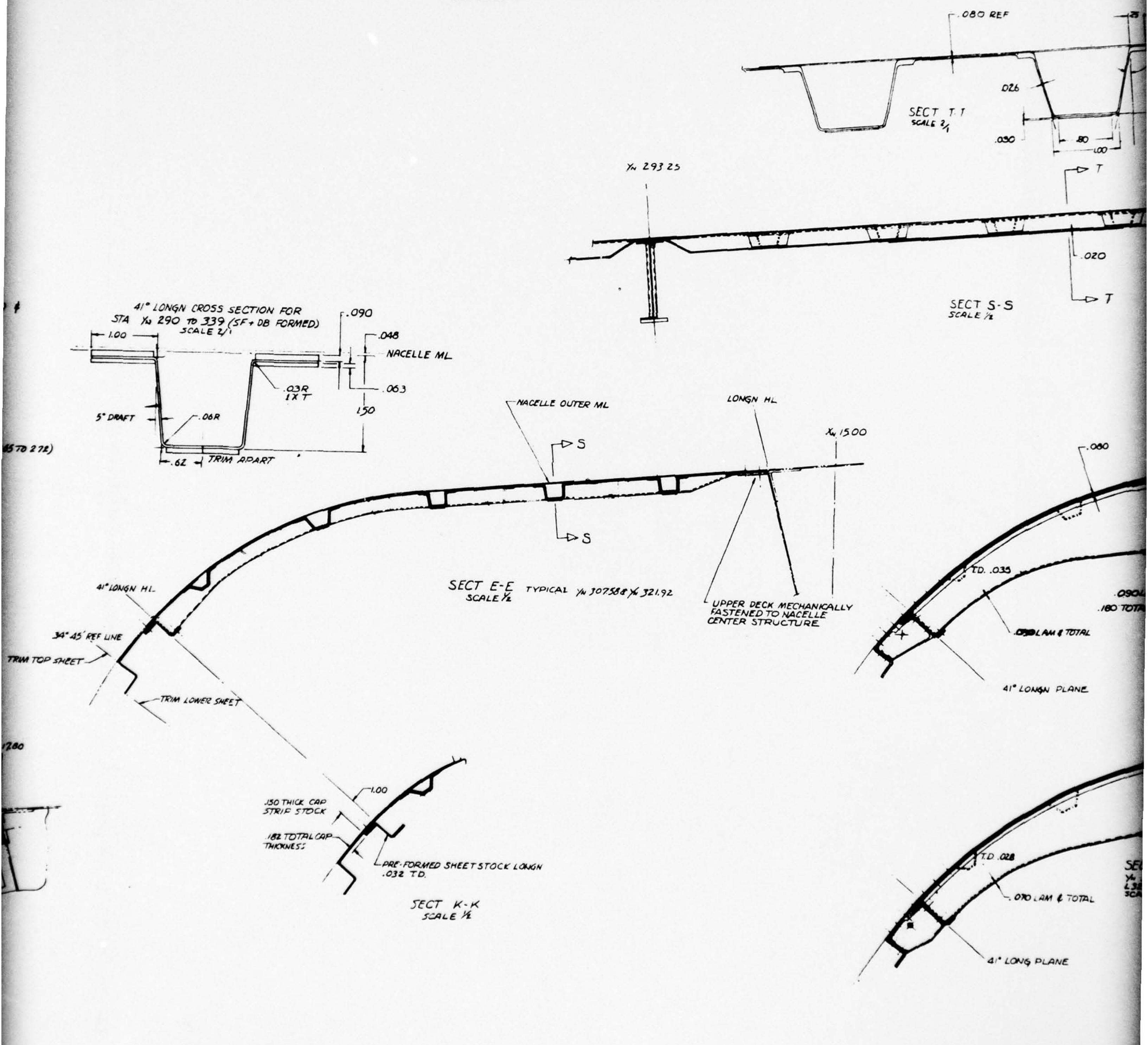


Figure A-1. Upper deck - integral skin, frame, and stringer.


41° LONGN SECT Y. 265-290 & Y. 339-362
1.00
.090
.048
2.20
.16R
.80
.140 (STA 265 TO 272)
41° LONGN CROSS SECT
STA Y. 290 TO 339
SCALE 2/1
1.00
5° DRAFT
.06R
.62
TRIM
Y. 362.65
Y. 368.31
TRIM FOR ENGINE SHROUD CLEARANCE
NAC ML
.050 CONSTANT CAP THICKNESS
SECT L-L
X. 32
SCALE ½
NACELLE ML
.070 CAP STRIP
AFT NACELLE TO FWD NACELLE ATTACH
41° LONGN PLANE
.150 CAP STRIP
SECT P-P
SCALE ½
NACELLE OUTER ML
X. 20.14
X. 15.00
ENGINE COMPT ML
LONGN HL
41° LONGN HL
34° 45' REF LINE
TRIM TOP SHEET
TRIM LOWER SHEET
FITTINGS DIFFUSION BONDED IN PLACE
Y. 265.25
Y. 272.35
Y. 279.45
LONGN HL
INTERSECTION OF 41° PLANE & ML
AFT NACELLE FWD BLKHD
HINGE FITTING MECHANICALLY FASTENED
VIEW M
SCALE ½
SECT F-F
LONGN HL
BLKHD PLANE
Y. 265.25
X. 17.80
LONGN HL
NACELLE ML
SECT G-G
Y. 265.25
SCALE ½

2


.080 REF
.026
SECT T-T
SCALE 2/1
.030
.80
1.00
Yn 293.25
T
.020
T
SECT S-S
SCALE 1/2
41° LONGN CROSS SECTION FOR
STA Yn 290 TO 339 (SF + DB FORMED)
SCALE 2/1
1.00
.090
.048
NACELLE ML
.03R
1 X T
.063
5° DRAFT
.06R
1.50
.62
TRIM APART
NACELLE OUTER ML
LONGN HL
Xn 15.00
S
S
.080
SECT E-E
SCALE 1/2
TYPICAL Yn 307.58 & Yn 321.92
41° LONGN HL
34° 45' REF LINE
TRIM TOP SHEET
TRIM LOWER SHEET
UPPER DECK MECHANICALLY
FASTENED TO NACELLE
CENTER STRUCTURE
T.D. .035
.090
.180 TOTAL
LAM & TOTAL
41° LONGN PLANE
1.00
.150 THICK CAP
STRIP STOCK
.182 TOTAL CAP
THICKNESS
PRE-FORMED SHEET STOCK LONGN
.032 T.D.
SECT K-K
SCALE 1/2
T.D. .028
.070 LAM & TOTAL
41° LONG PLANE

3

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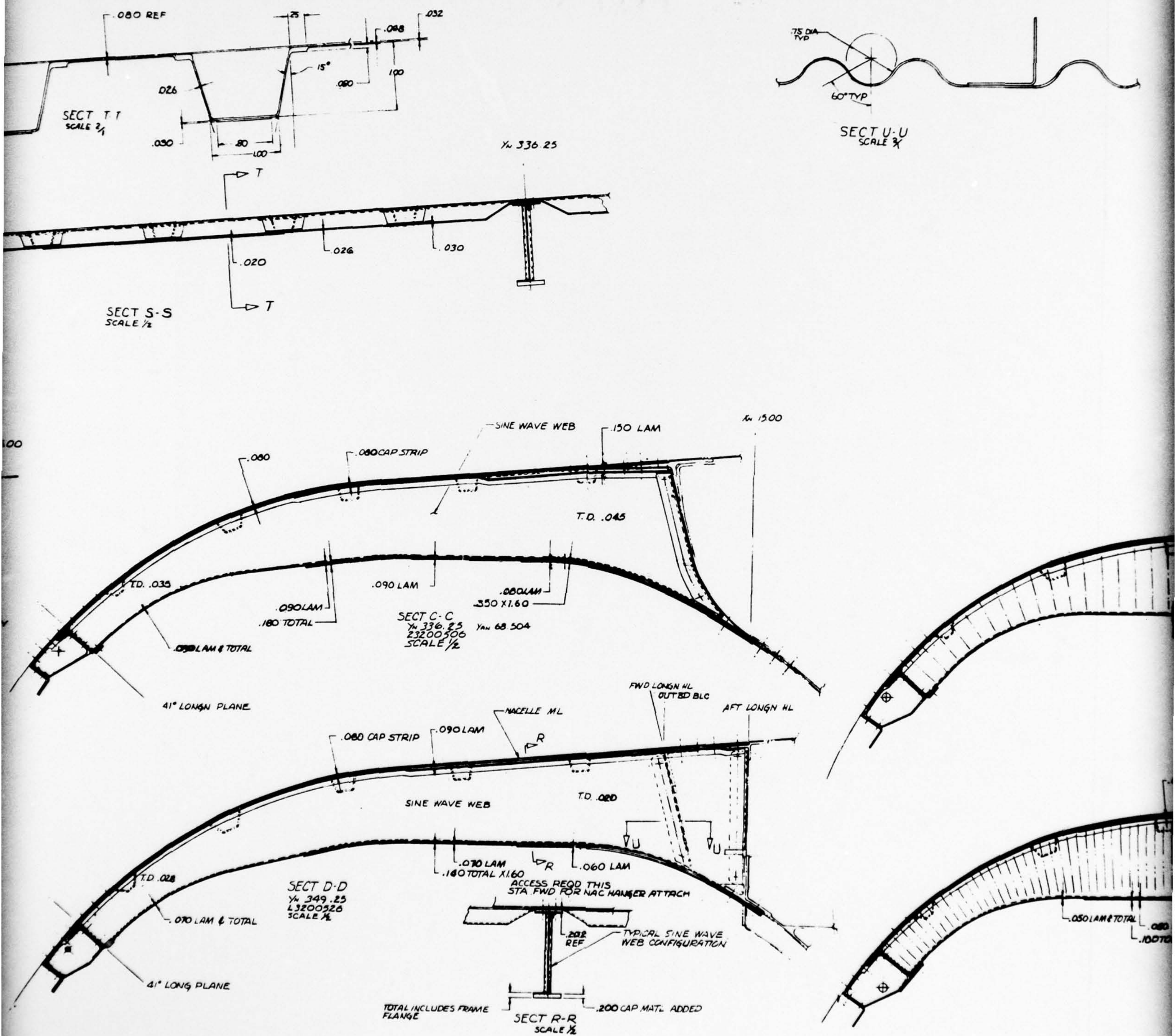

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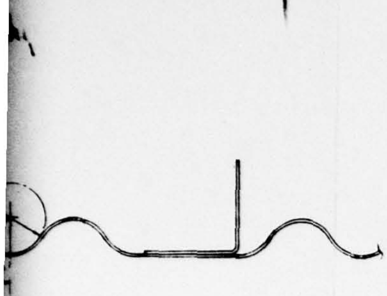
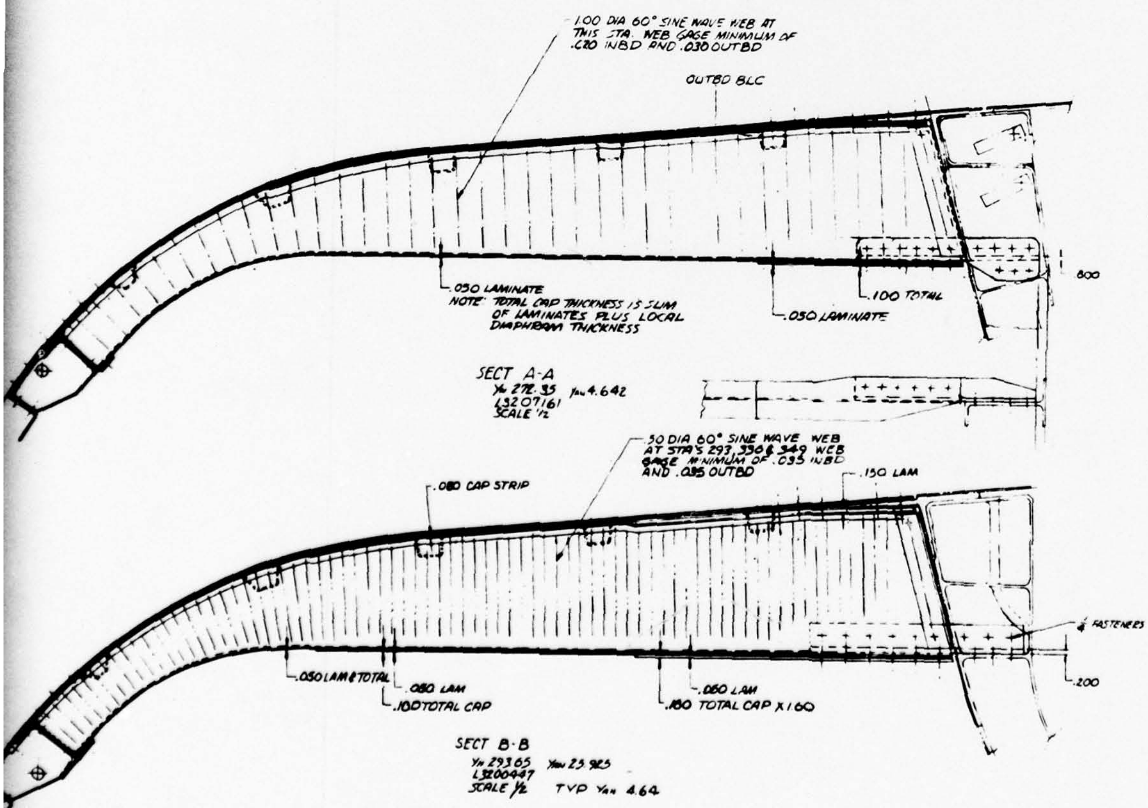
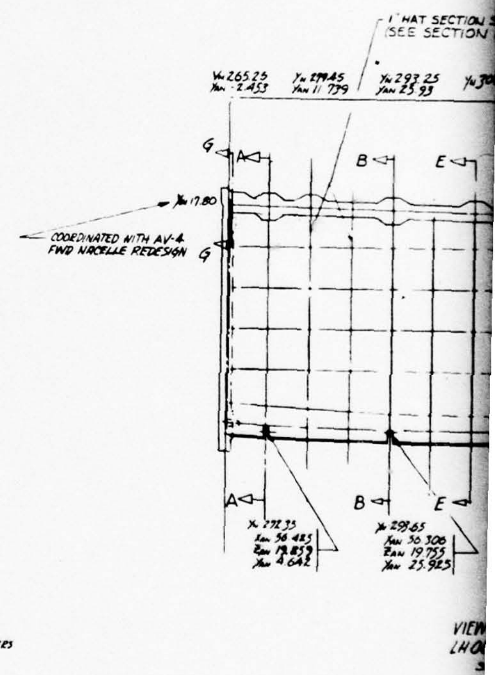

T U-U
CALE 3X


1.00 DIA 60° SINE WAVE WEB AT THIS STA. WEB GAGE MINIMUM OF .020 INBD AND .030 OUTBD
OUTBD BLC
.050 LAMINATE
NOTE: TOTAL CAP THICKNESS IS SUM OF LAMINATES PLUS LOCAL DIAPHRAGM THICKNESS
.100 TOTAL
.050 LAMINATE
.800
SECT A-A
Y_N 272.35 Y_{AN} 4.642
L3207161
SCALE 1/2
.50 DIA 60° SINE WAVE WEB AT STA'S 293, 330 & 349 WEB GAGE MINIMUM OF .035 INBD AND .035 OUTBD
.080 CAP STRIP
.150 LAM
FASTENERS
.050 LAM & TOTAL
.080 LAM
.100 TOTAL CAP
.060 LAM
.180 TOTAL CAP X 160
.200
SECT B-B
Y_N 293.65 Y_{AN} 23.925
L3200447
SCALE 1/2 TYP Y_{AN} 4.64


1" HAT SECTION
(SEE SECTION
Y_N 265.25 Y_{AN} -2.453
Y_N 279.45 Y_{AN} 11.739
Y_N 293.25 Y_{AN} 25.93
G
A
B
E
Y_N 17.80
COORDINATED WITH AV-4 FWD NACELLE REDESIGN
G
A
B
E
X_N 272.35
X_{AN} 56.485
Z_{AN} 19.859
Y_{AN} 4.642
X_N 293.65
X_{AN} 56.306
Z_{AN} 19.755
Y_{AN} 25.925
VIEW
LHO

5

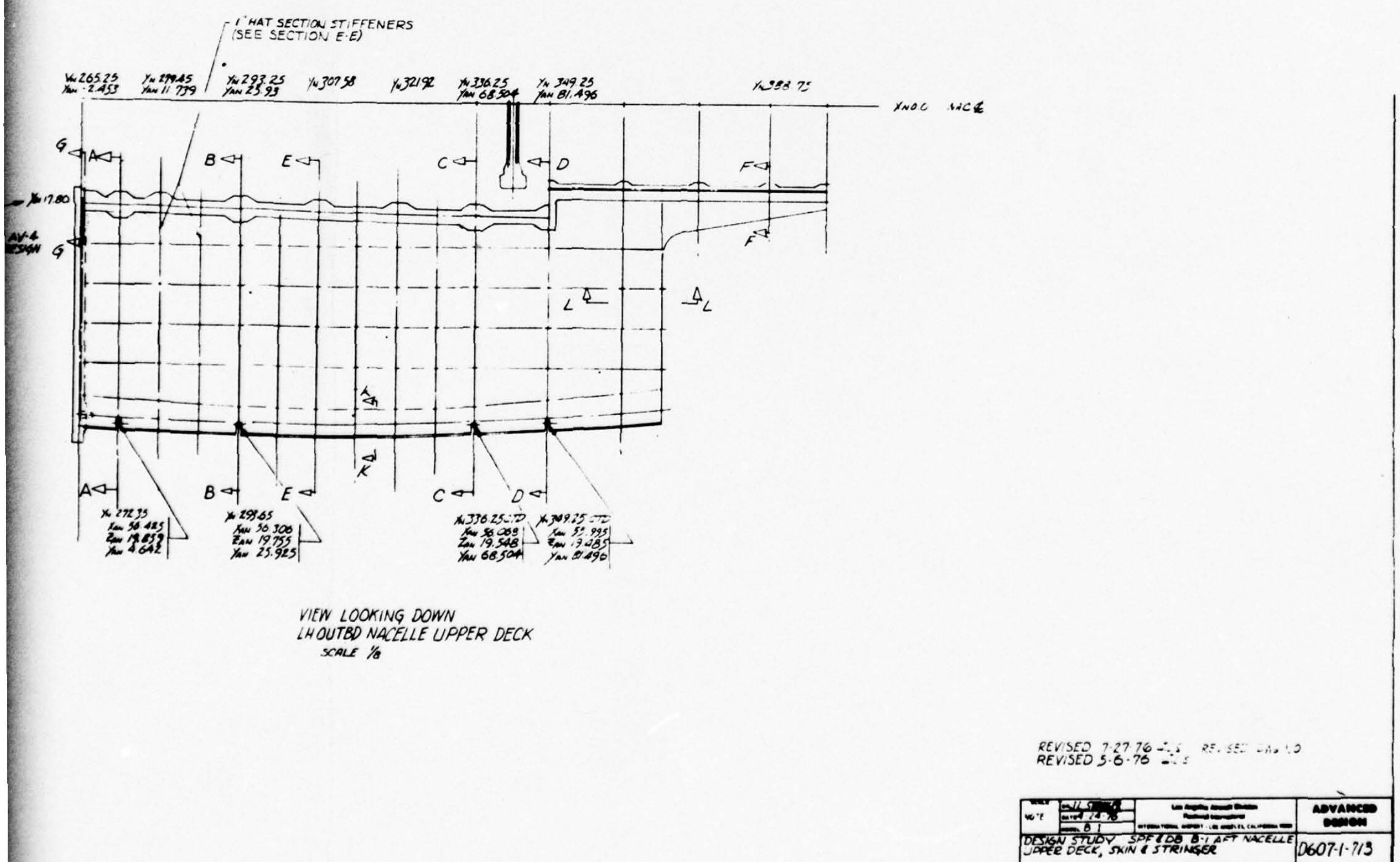
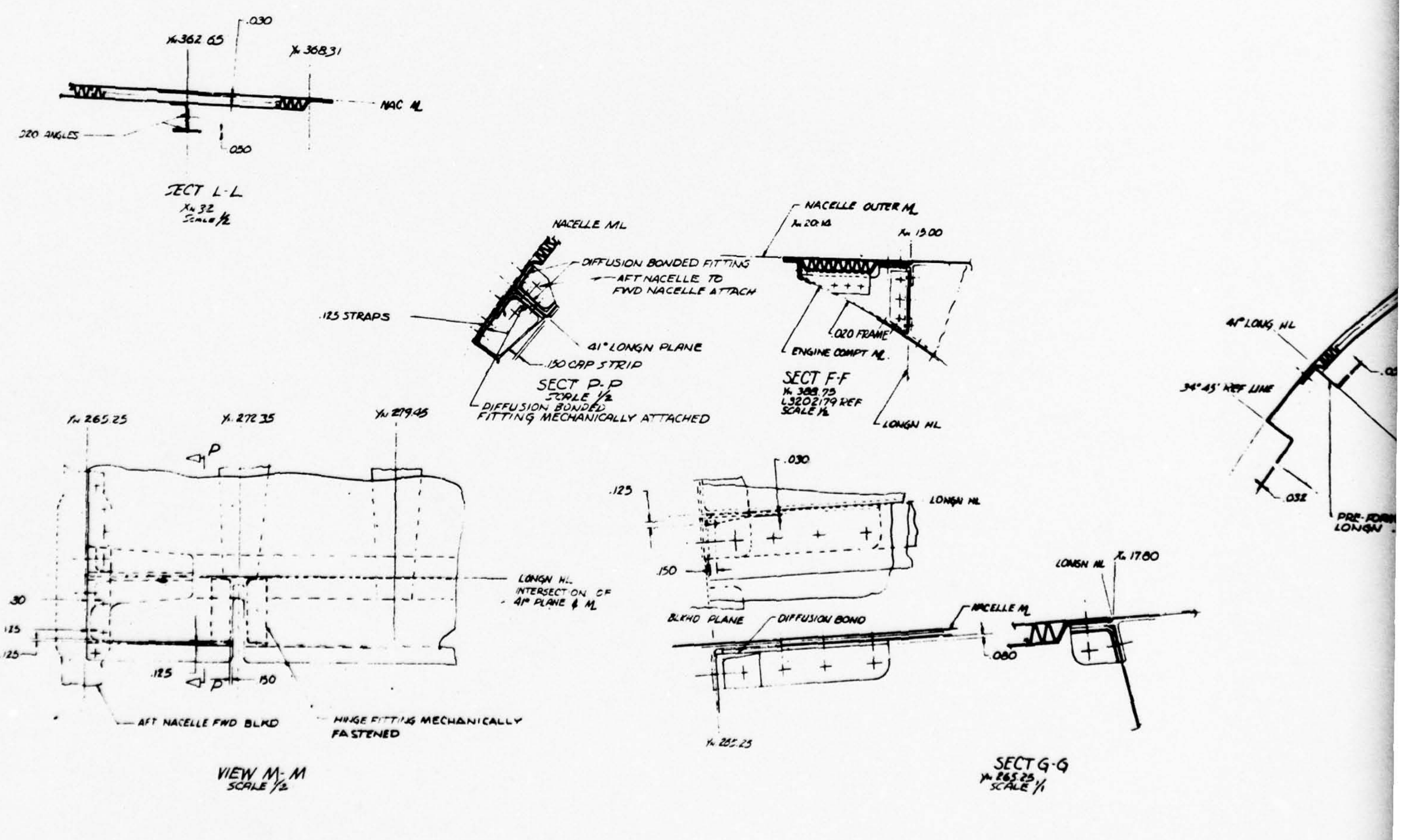
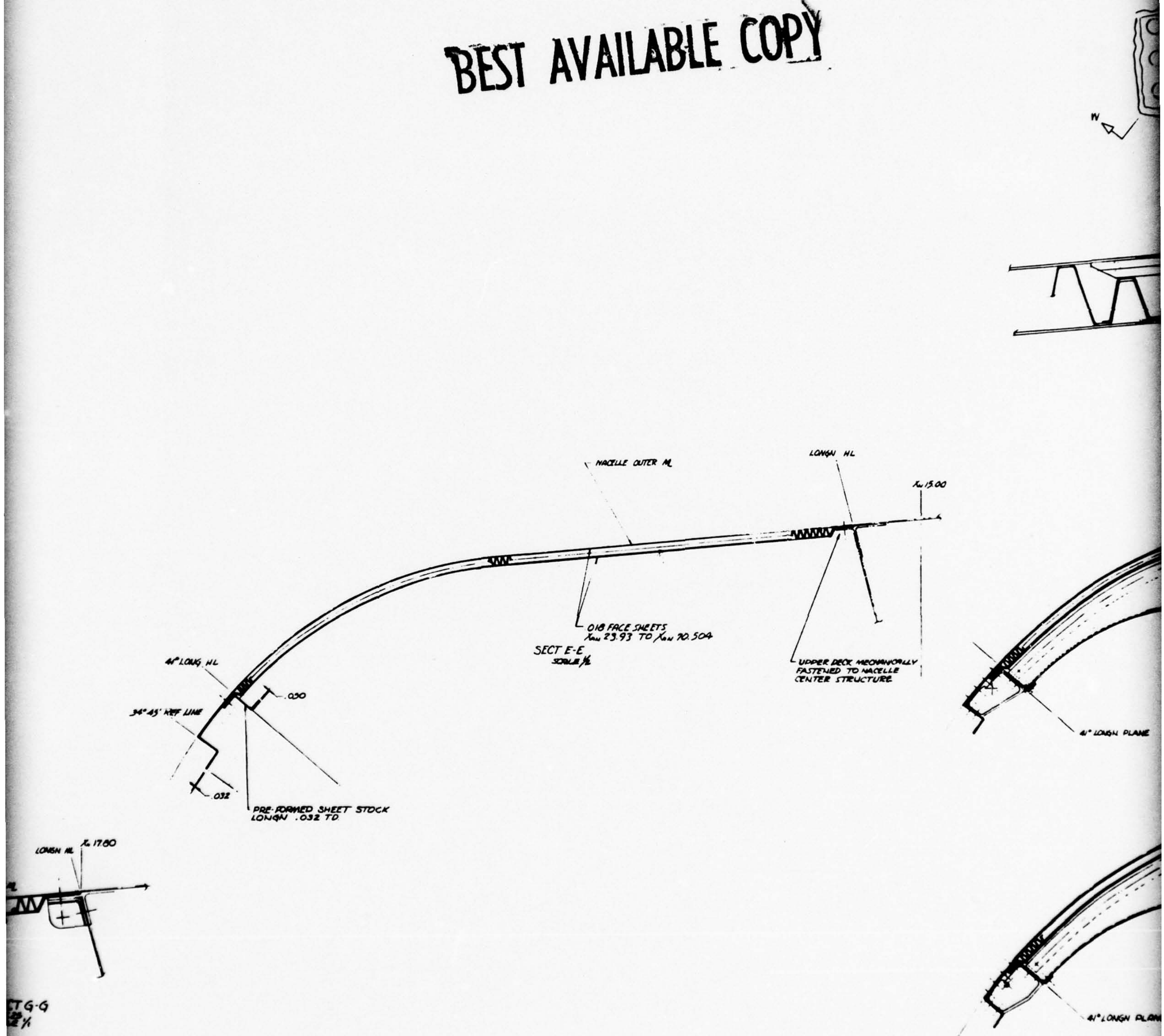


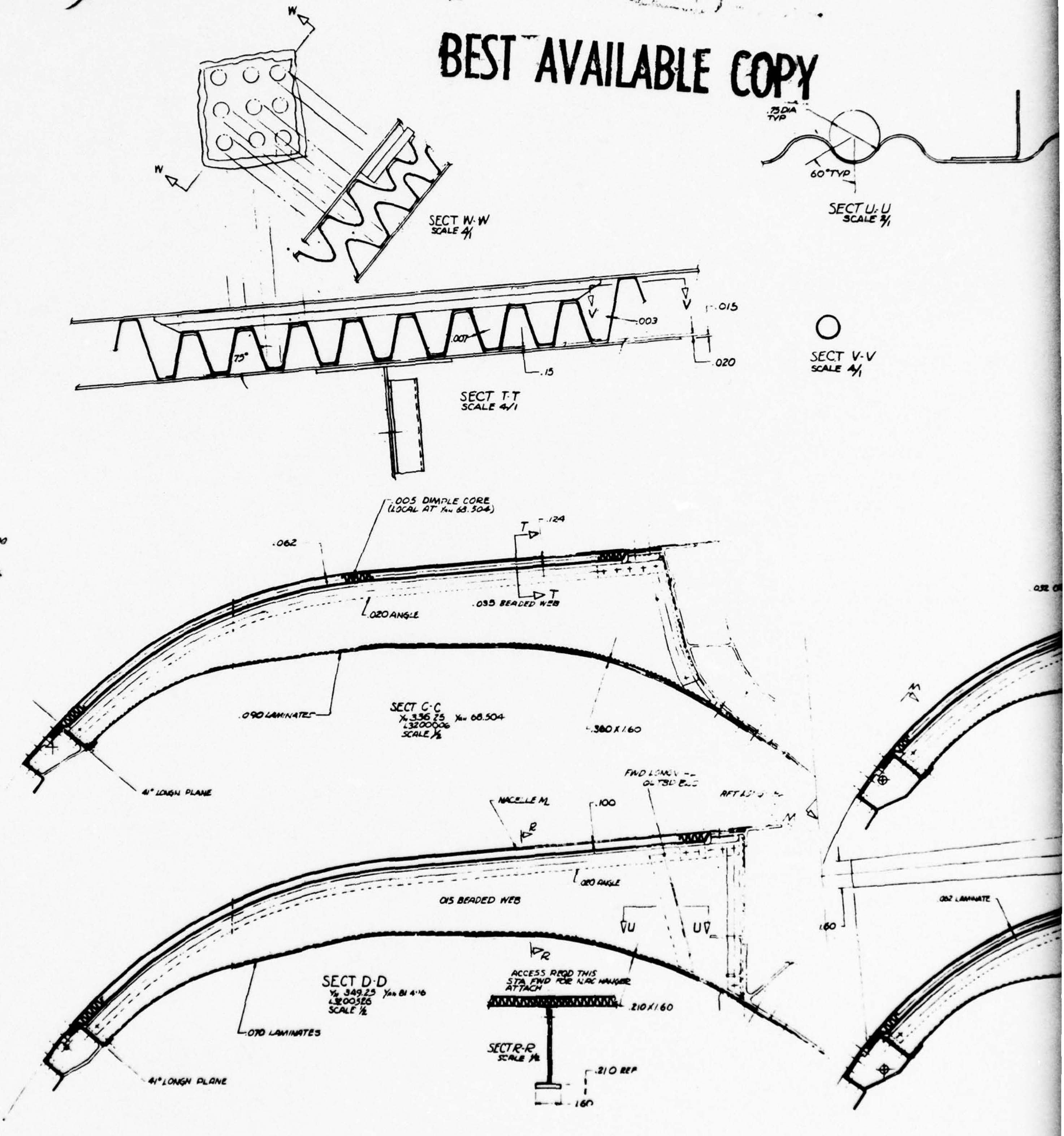
Figure A-2. Upper deck - separate frame, stiffened skin.


.030
X 362.65
X 368.31
NAC ML
.020 ANGLES
.030
SECT L-L
SCALE 1/2
NACELLE ML
DIFFUSION BONDED FITTING
AFT NACELLE TO FWD NACELLE ATTACH
.125 STRAPS
41° LONGN PLANE
.150 CAP STRIP
SECT P-P
SCALE 1/2
DIFFUSION BONDED FITTING MECHANICALLY ATTACHED
NACELLE OUTER ML
.020 FRAME
ENGINE COMPT ML
SECT F-F
SCALE 1/2
LONGN ML
41° LONG. ML
34° 45' REF LINE
.032
X 265.25
X 272.35
X 279.45
LONGN ML
INTERSECTION OF 41° PLANE & ML
.30
.125
.125
.150
AFT NACELLE FWD BLKD
HINGE FITTING MECHANICALLY FASTENED
VIEW M-M
SCALE 1/2
.030
.125
LONGN ML
.150
LONGN ML
BLKHD PLANE
DIFFUSION BOND
NACELLE ML
.080
X 265.25
SECT G-G
X 265.25
SCALE 1/1

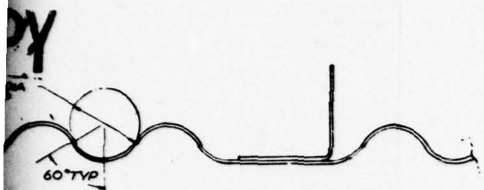
2 1 1


NACELLE OUTER ML
LONGN HL
Xw 15.00
.018 FACE SHEETS
Xw 23.93 TO Xw 70.504
SECT E-E
SCALE ½
UPPER DECK MECHANICALLY
FASTENED TO NACELLE
CENTER STRUCTURE
41° LONG HL
34°45' REF LINE
.050
.032
PRE-FORMED SHEET STOCK
LONGN .032 TD.
41° LONGN PLANE
LONGN ML
Xw 17.60
41° LONGN PLANE

3

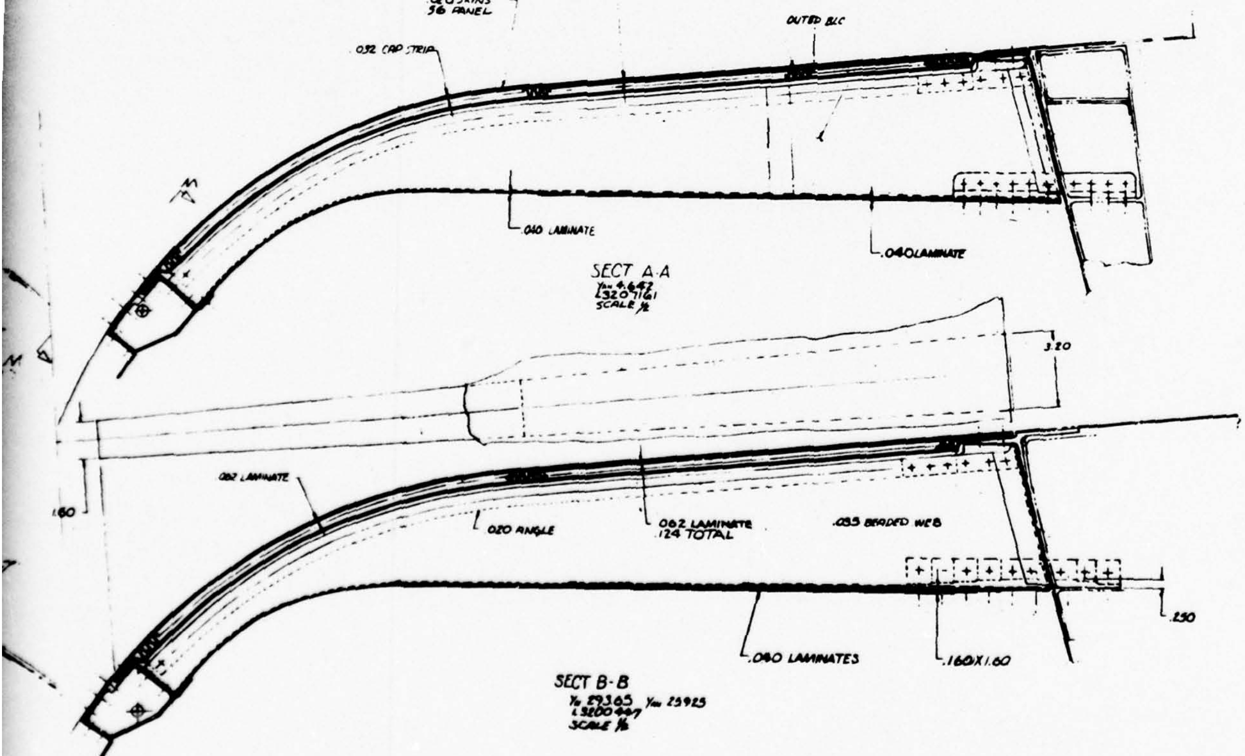

SECT W-W
SCALE 4/1
.75 DIA
TYP
60° TYP
SECT U-U
SCALE 3/1
.015
.003
.007
75°
.15
.020
SECT T-T
SCALE 4/1
SECT V-V
SCALE 4/1
.005 DIMPLE CORE
.124
.062
.020 ANGLE
.035 BEADED WEB
.090 LAMINATES
SECT C-C
Yw 68.504
SCALE 1/2
.380 X 1.60
41° LONGN PLANE
STRUCTURE
NACELLE ML
.100
.020 ANGLE
.015 BEADED WEB
.062 LAMINATE
1.60
SECT D-D
SCALE 1/2
ACCESS REQD THIS
ATTACH
.210 X 1.60
SECT R-R
.070 LAMINATES
41° LONGN PLANE
.210 REF
.160

4



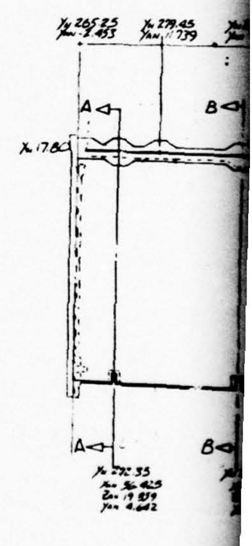
SECT U-U
SCALE 2/1

SECT V-V
SCALE 4/1



SECT A-A
Y= 4.642
L320 7161
SCALE 1/2

SECT B-B
Y= 29365 Y= 25925
L3200487
SCALE 1/2



5

BEST AVAILABLE COPY

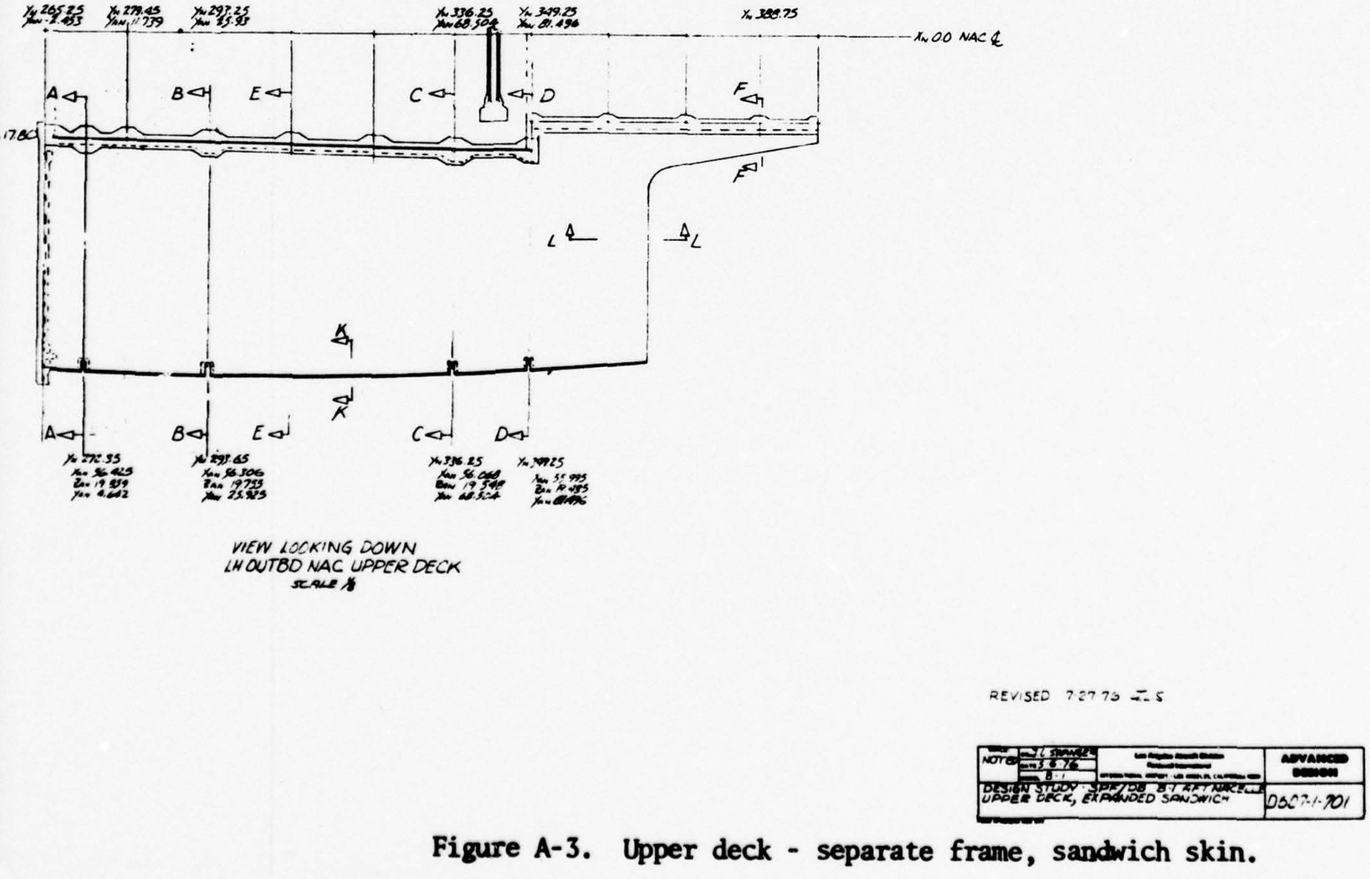
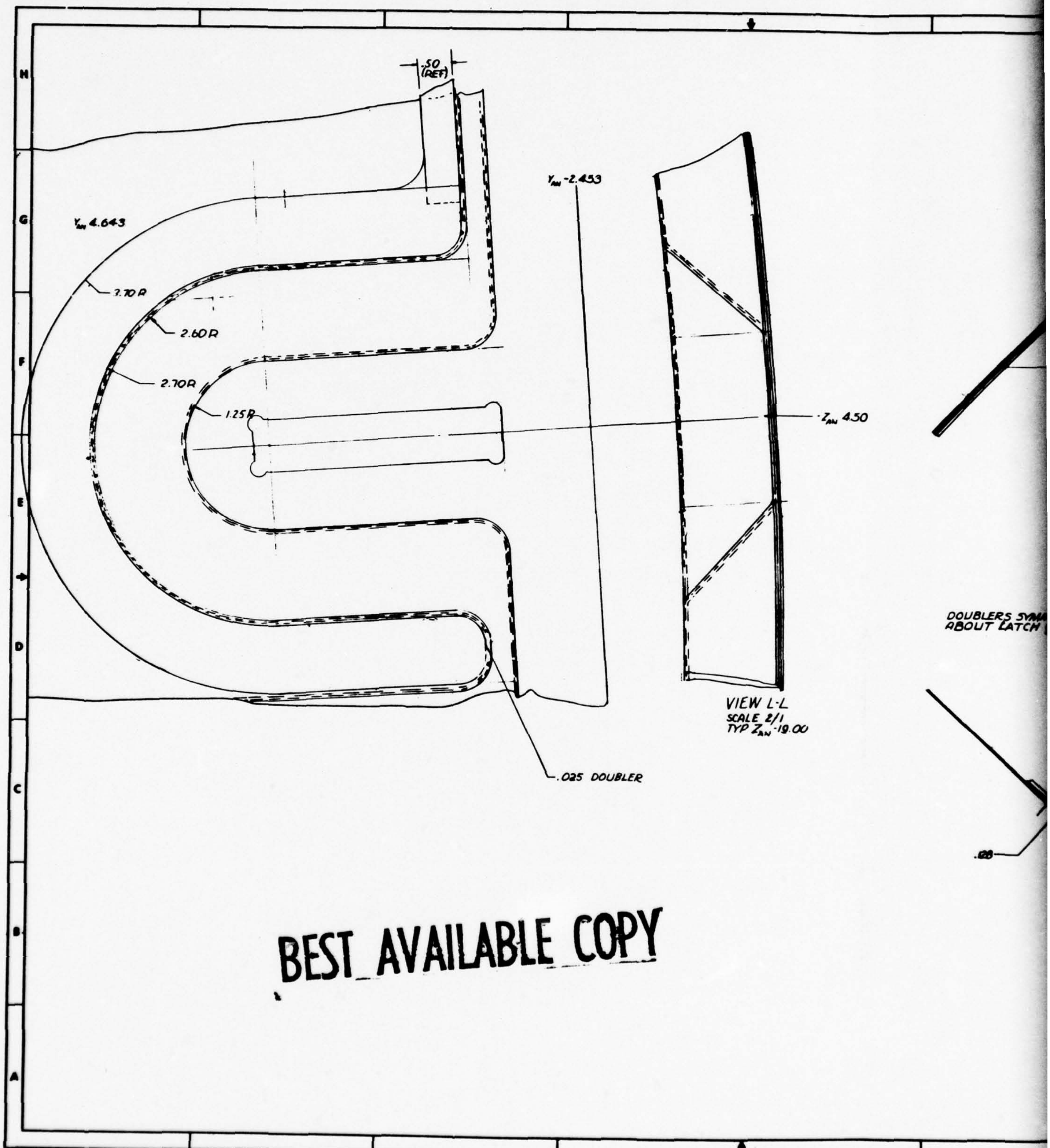


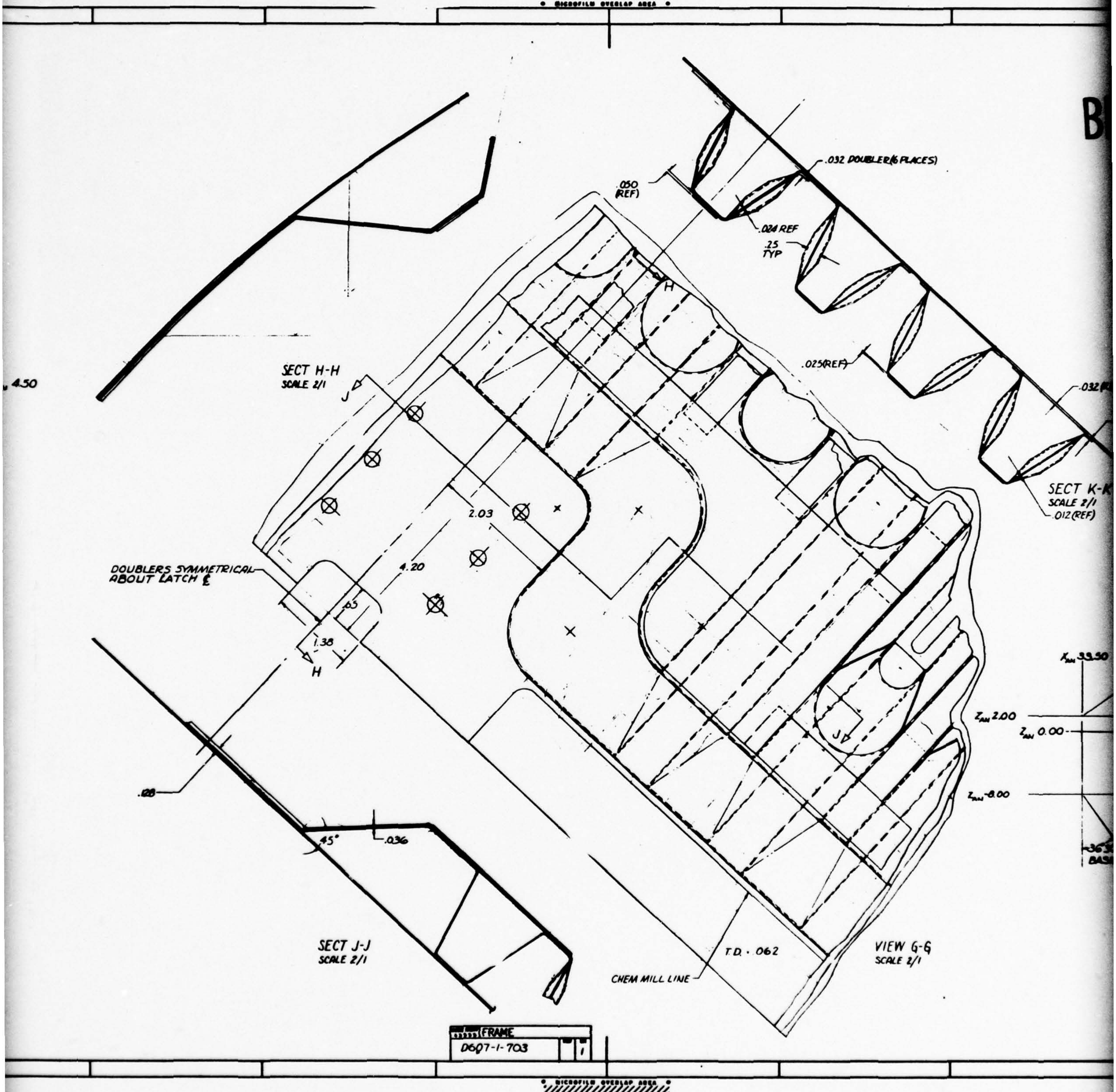
Figure A-3. Upper deck - separate frame, sandwich skin.



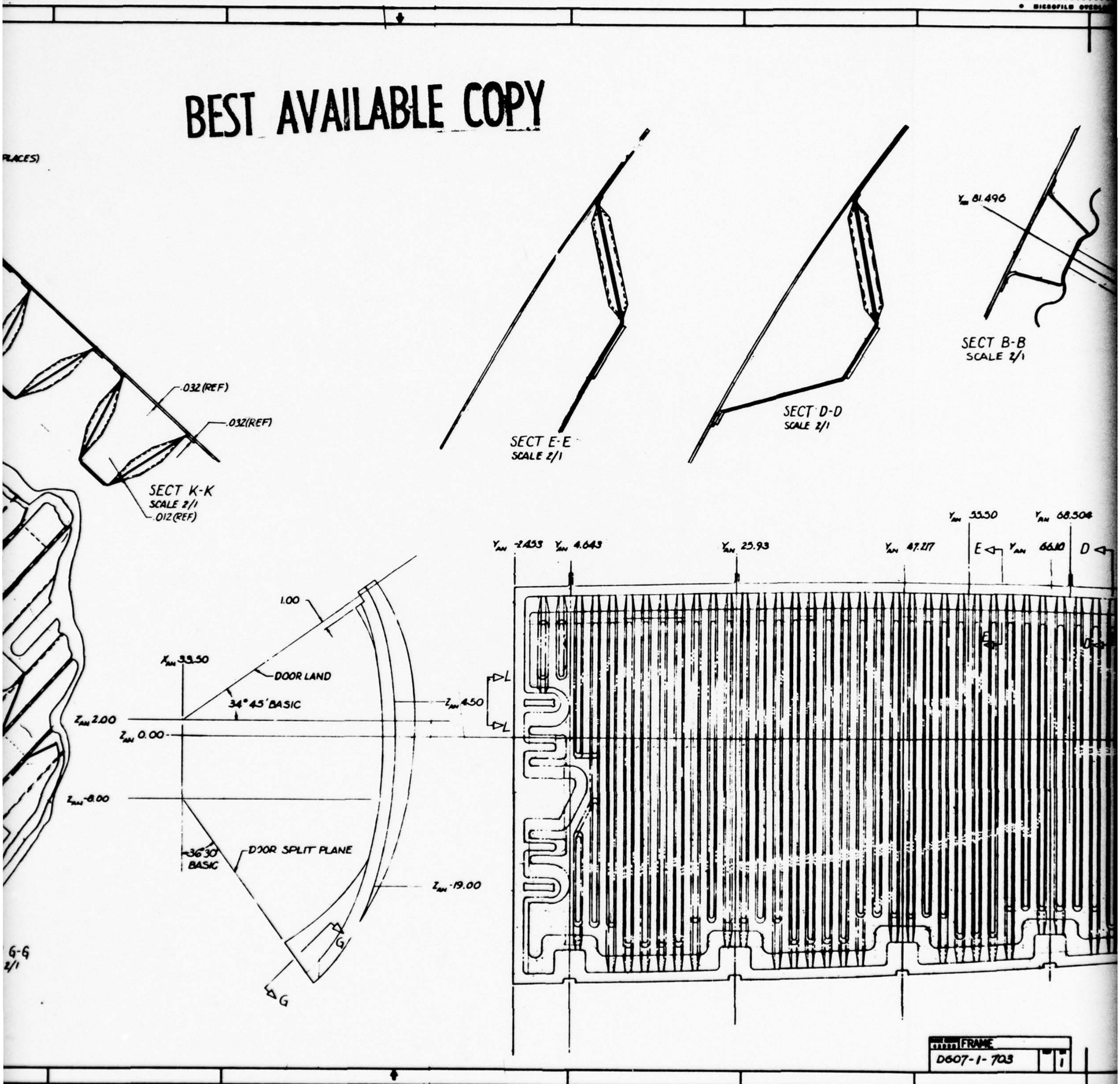
H
G
F
E
D
C
B
A
.50 (REF)
Y AN -2.453
Y AN 4.643
2.70R
2.60R
2.70R
1.25R
Z AN 4.50
VIEW L-L
SCALE 2/1
TYP Z AN -19.00
.025 DOUBLER
DOUBLERS SYM
ABOUT LATCH

2 1

BEST AVAILABLE COPY

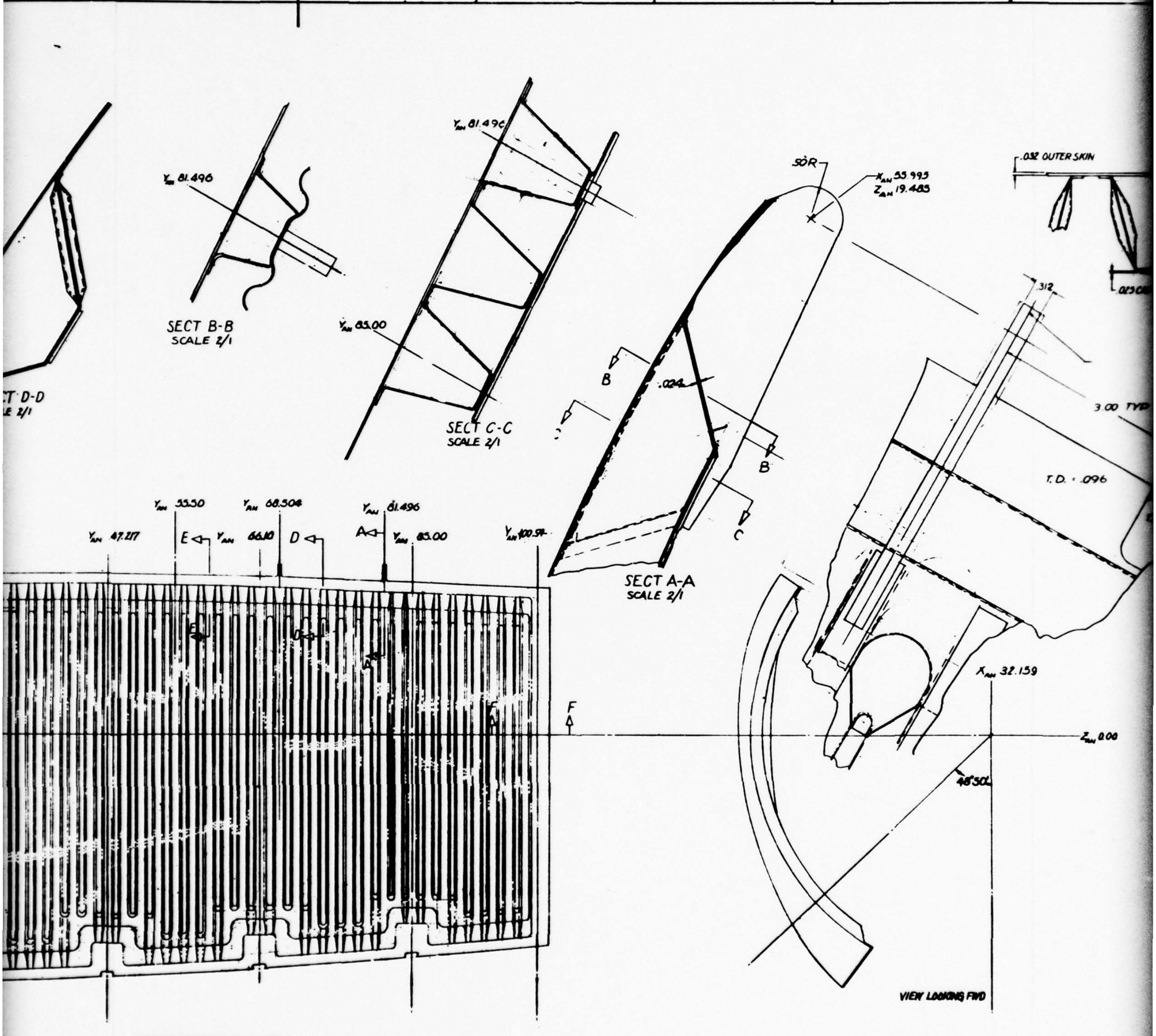


3


PLACES)
.032 (REF)
.032 (REF)
SECT K-K
SCALE 2/1
.012 (REF)
SECT E-E
SCALE 2/1
SECT D-D
SCALE 2/1
Y AN 81.496
SECT B-B
SCALE 2/1
Y AN -2.453
Y AN 4.643
Y AN 25.93
Y AN 47.217
Y AN 55.50
Y AN 68.504
Y AN 66.10
E
D
1.00
X AN 33.50
DOOR LAND
34°45' BASIC
Z AN 4.50
Z AN 2.00
Z AN 0.00
Z AN -8.00
36°30' BASIC
DOOR SPLIT PLANE
Z AN -19.00
G
G
L
L
G-G
2/1
FRAME
D607-1-703
1

4

BEST AV...ABLE COPY



FRAME

D607-1-703

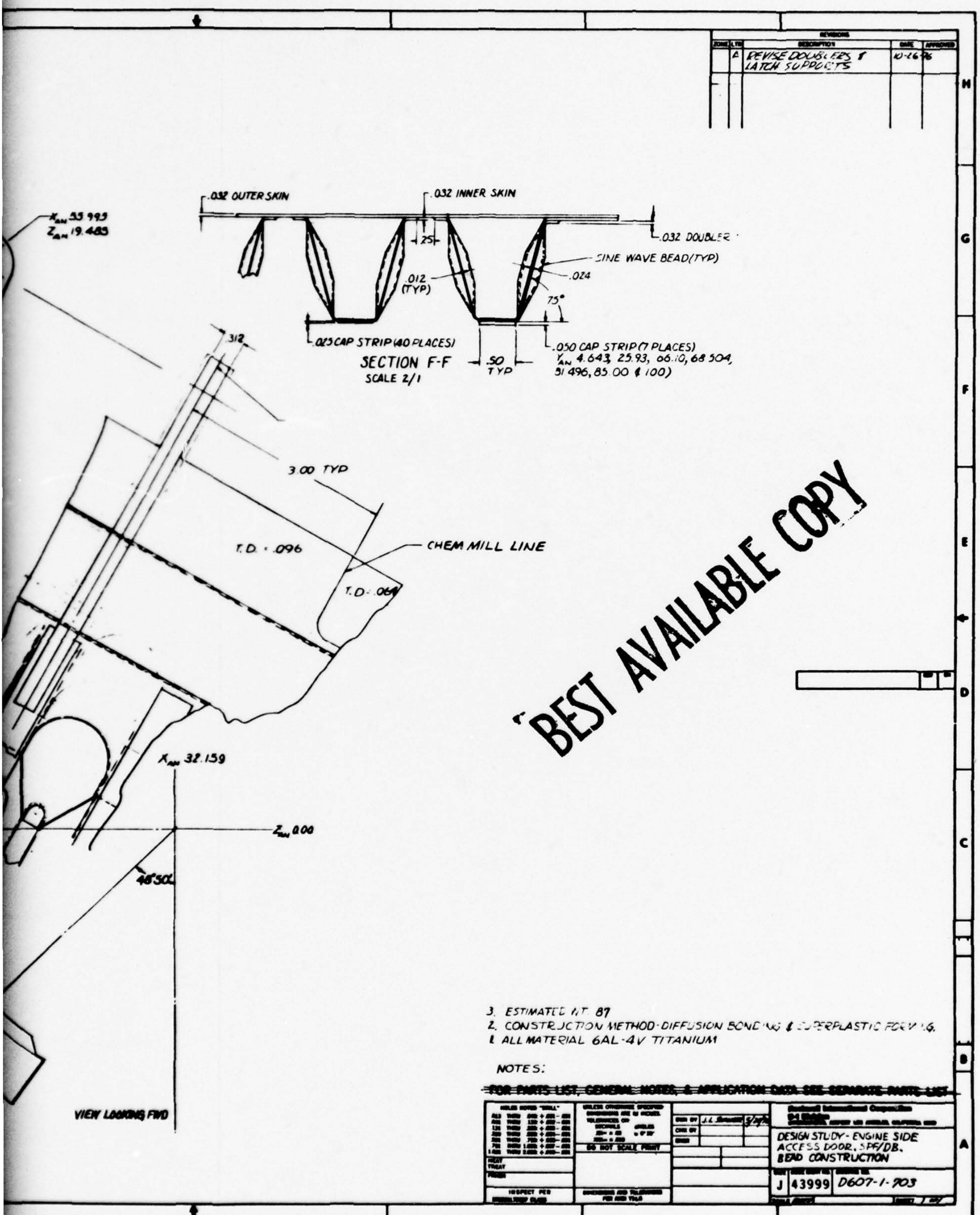
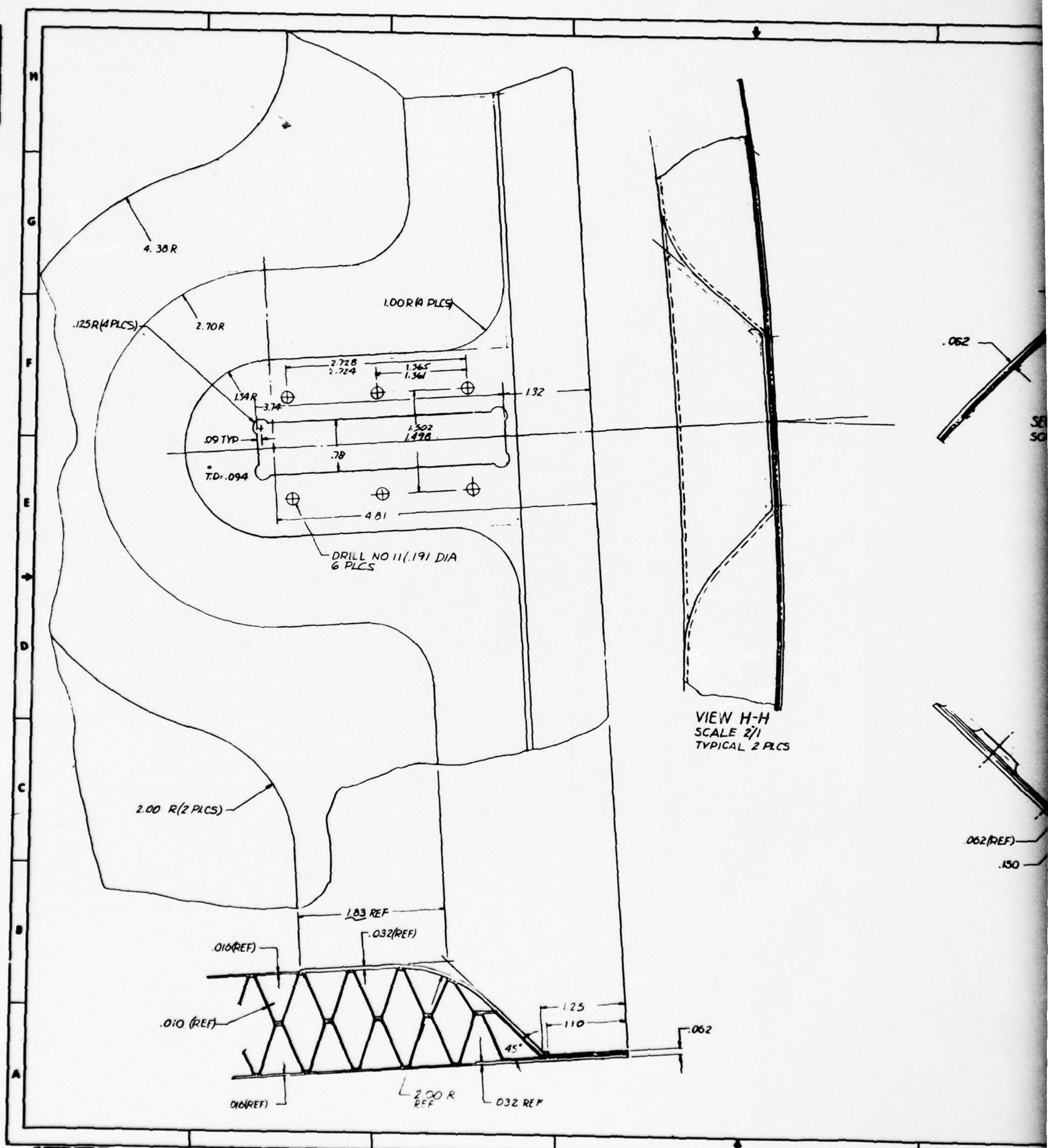
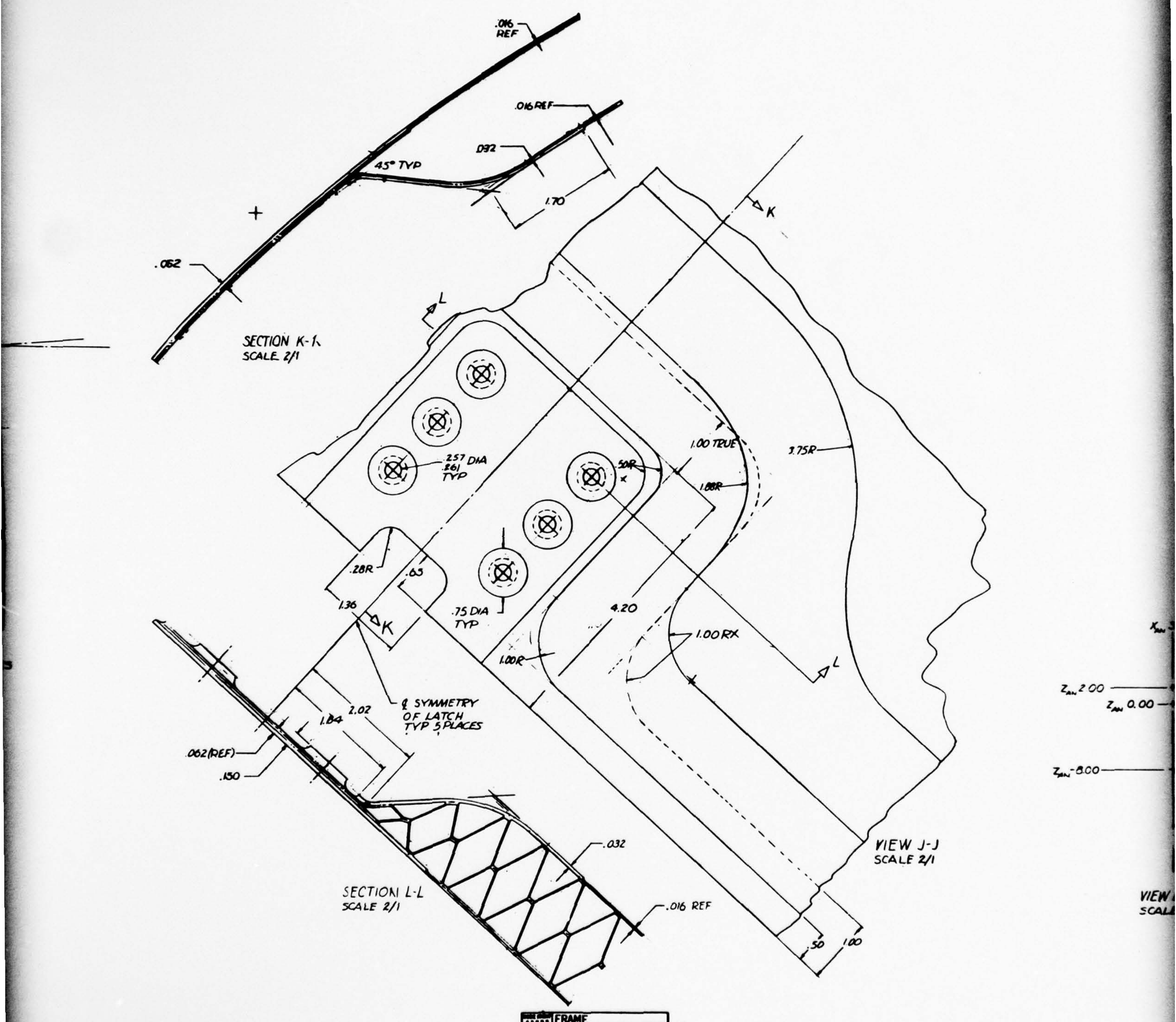


Figure A-4. Engine side access door - stiffened skins.



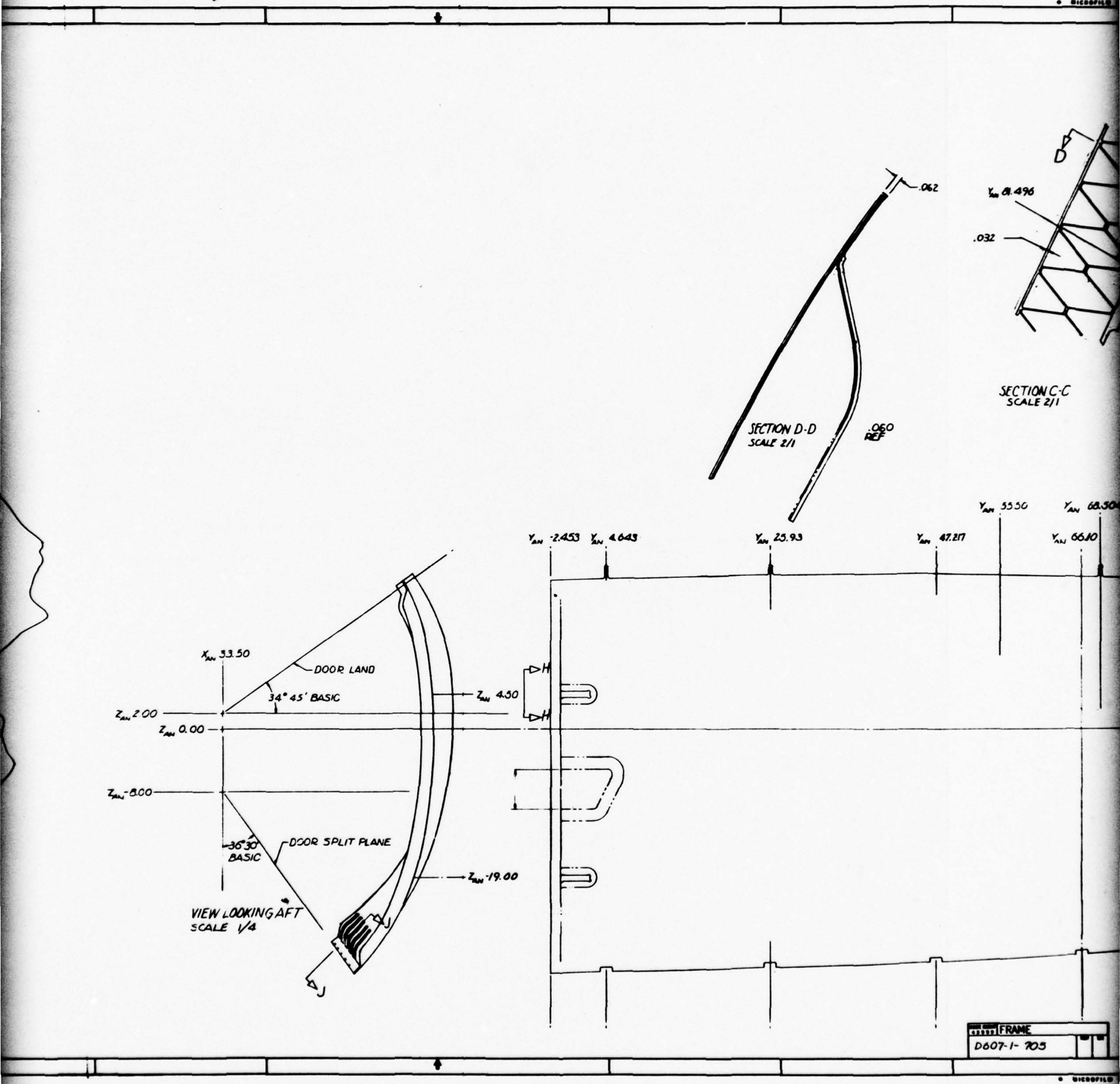
4.38R
2.70R
.125R(4 PLCS)
1.00R(4 PLCS)
2.728
2.724
1.365
1.361
.132
1.54R
3.74
1.502
1.498
.09 TYP
.78
T.D.=.094
4.81
DRILL NO 11(.191 DIA
6 PLCS
2.00 R(2 PLCS)
VIEW H-H
SCALE 2/1
TYPICAL 2 PLCS
.062
.062(REF)
.150
1.83 REF
.016(REF)
.032(REF)
.010 (REF)
1.25
.110
.062
45°
2.00 R
REF
.016(REF)
.032 REF


.016 REF
.016 REF
.032
45° TYP
1.70
.062
SECTION K-K
SCALE 2/1
K
L
.257 DIA
.261
TYP
.50R
1.00 TRUE
3.75R
1.88R
.28R
.63
1.36
K
.75 DIA
TYP
4.20
1.00 RX
1.00R
L
℄ SYMMETRY
OF LATCH
TYP 5 PLACES
2.02
1.84
.062(REF)
.150
.032
SECTION L-L
SCALE 2/1
.016 REF
VIEW J-J
SCALE 2/1
.50
1.00
Z_AN 2.00
Z_AN 0.00
Z_AN -8.00
VIEW
SCALE

FRAME

3,

BEST AVAILABLE COPY



4

BEST AVAILABLE COPY

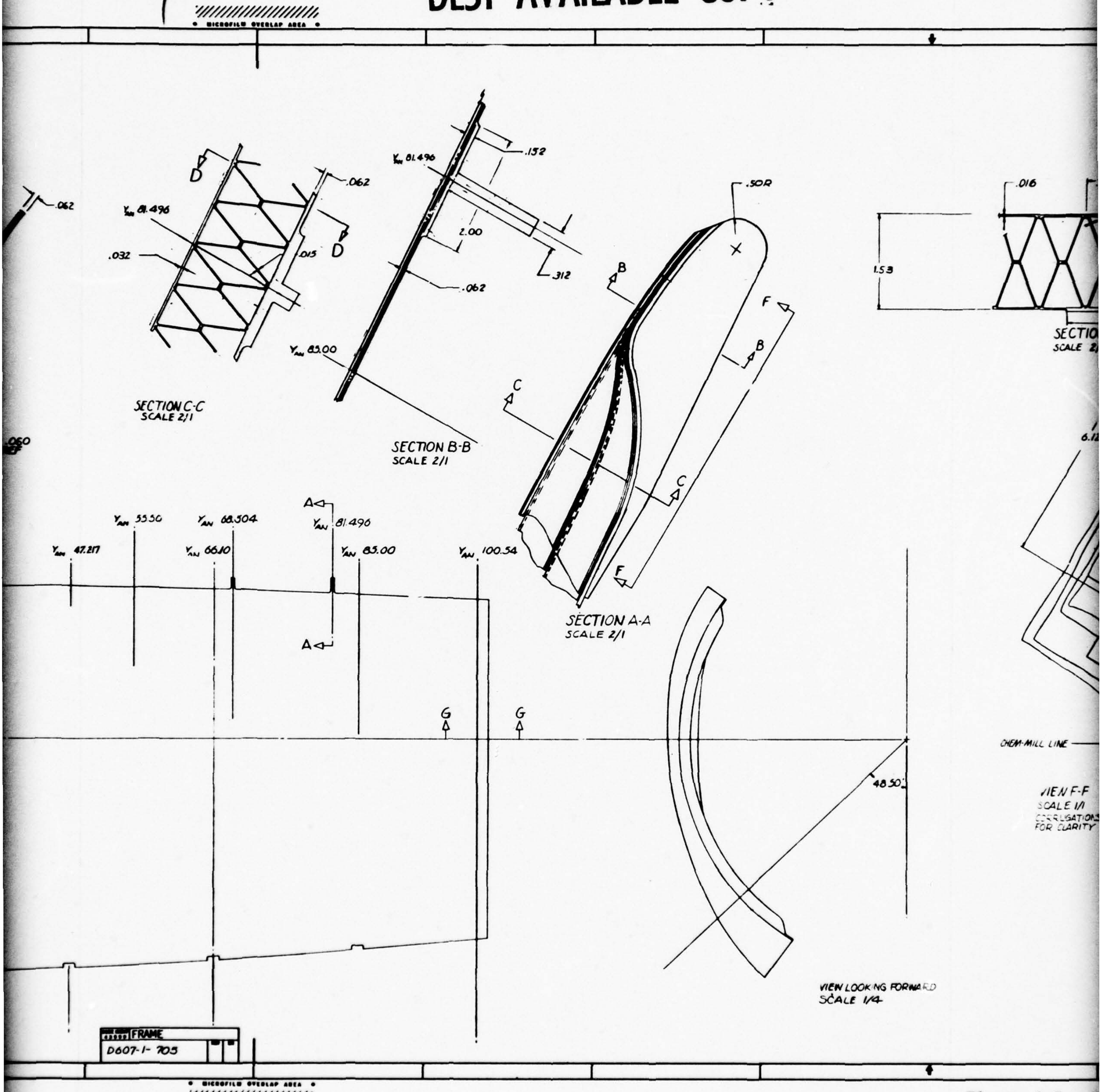


Figure A-5. E

BEST AVAILABLE COPY

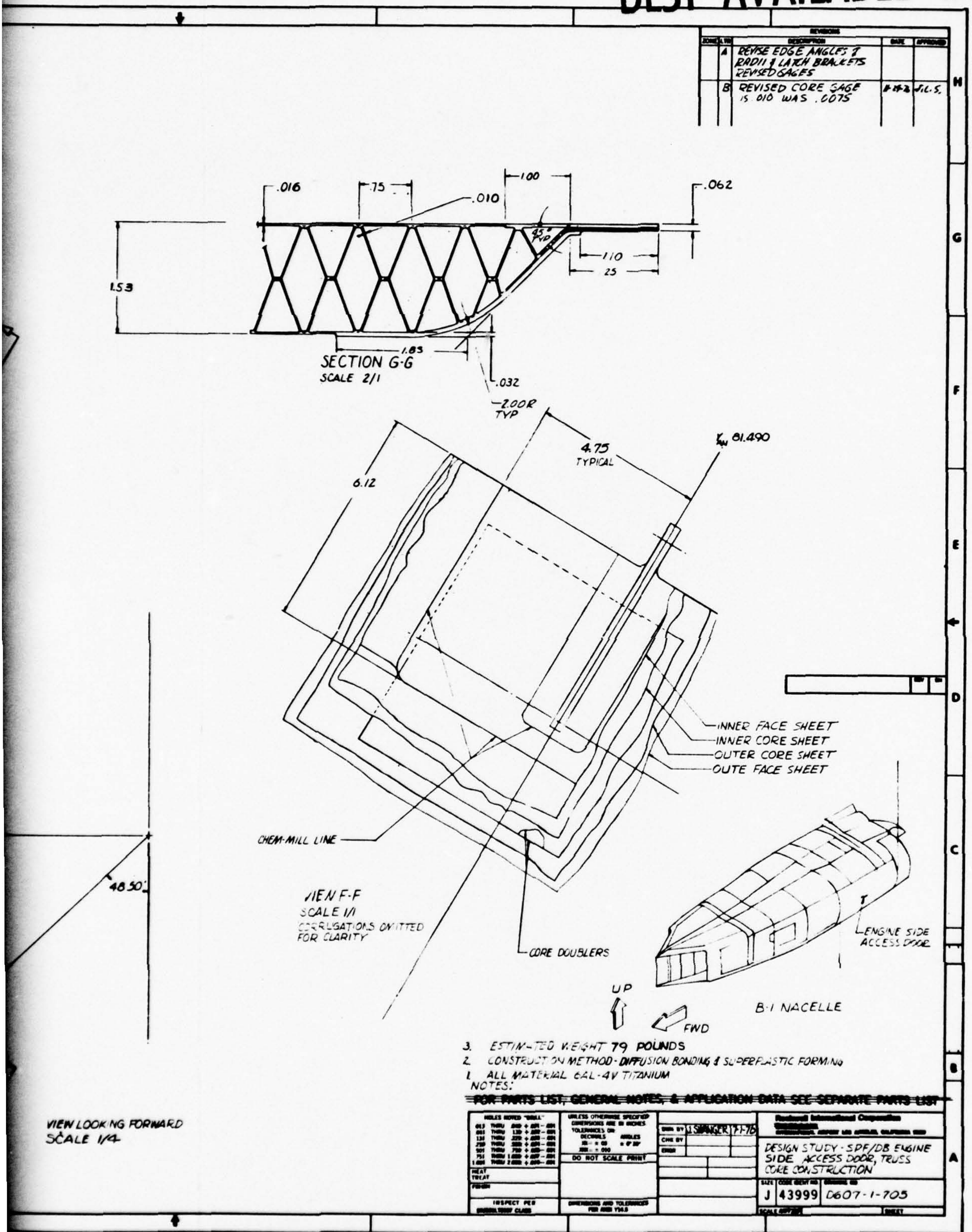
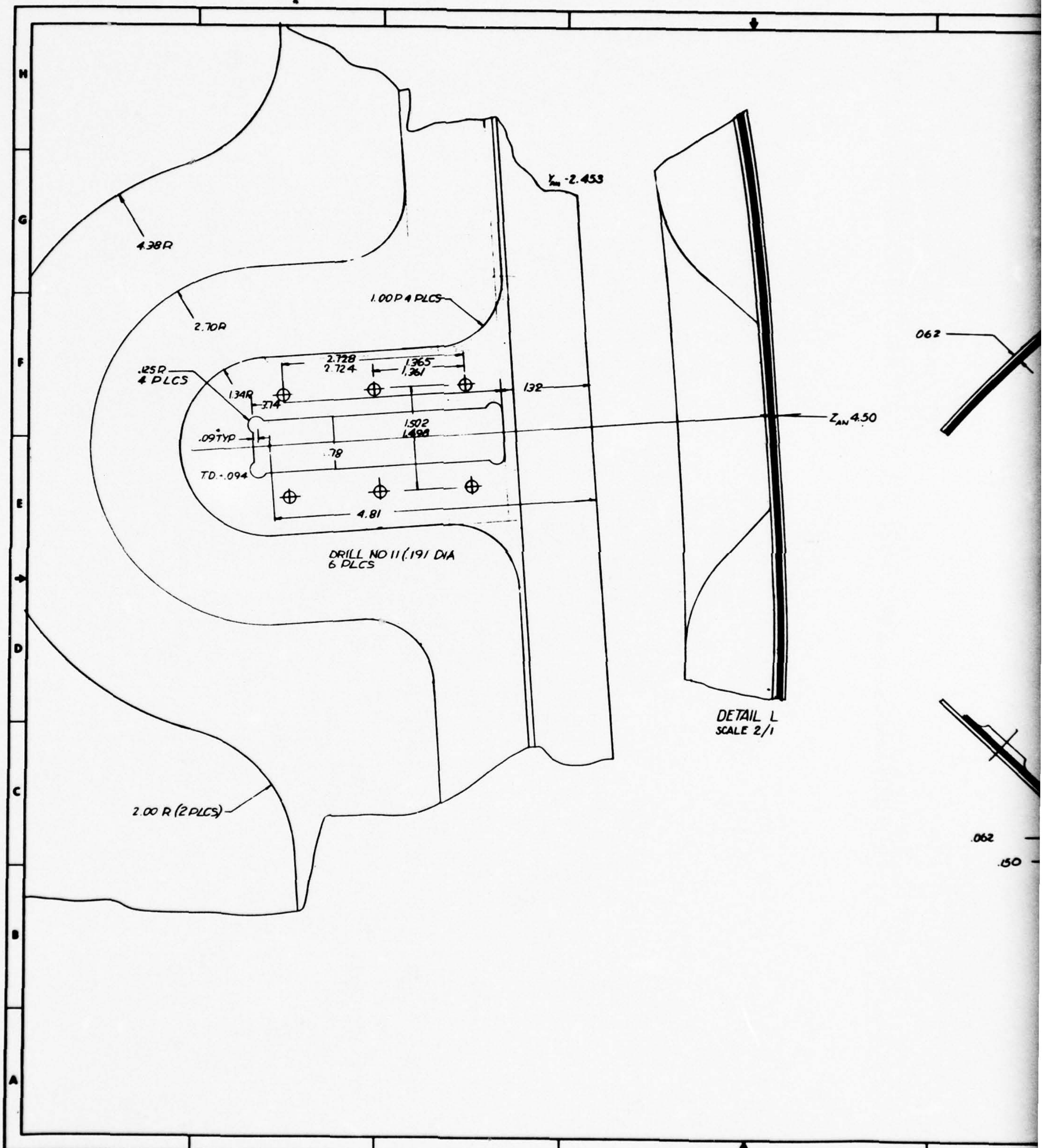


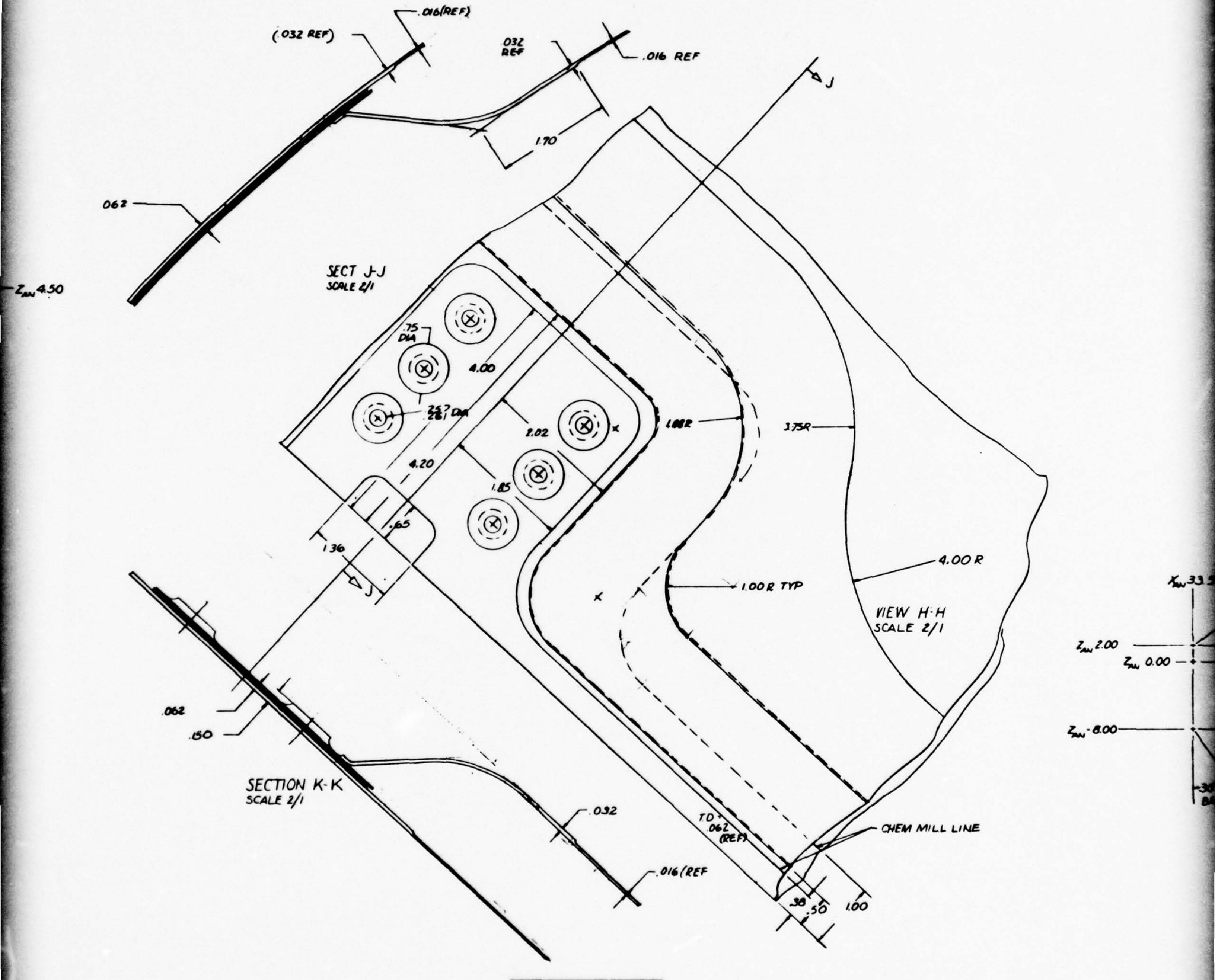
Figure A-5. Engine side access door - double-truss sandwich.

BEST AVAILABLE COPY

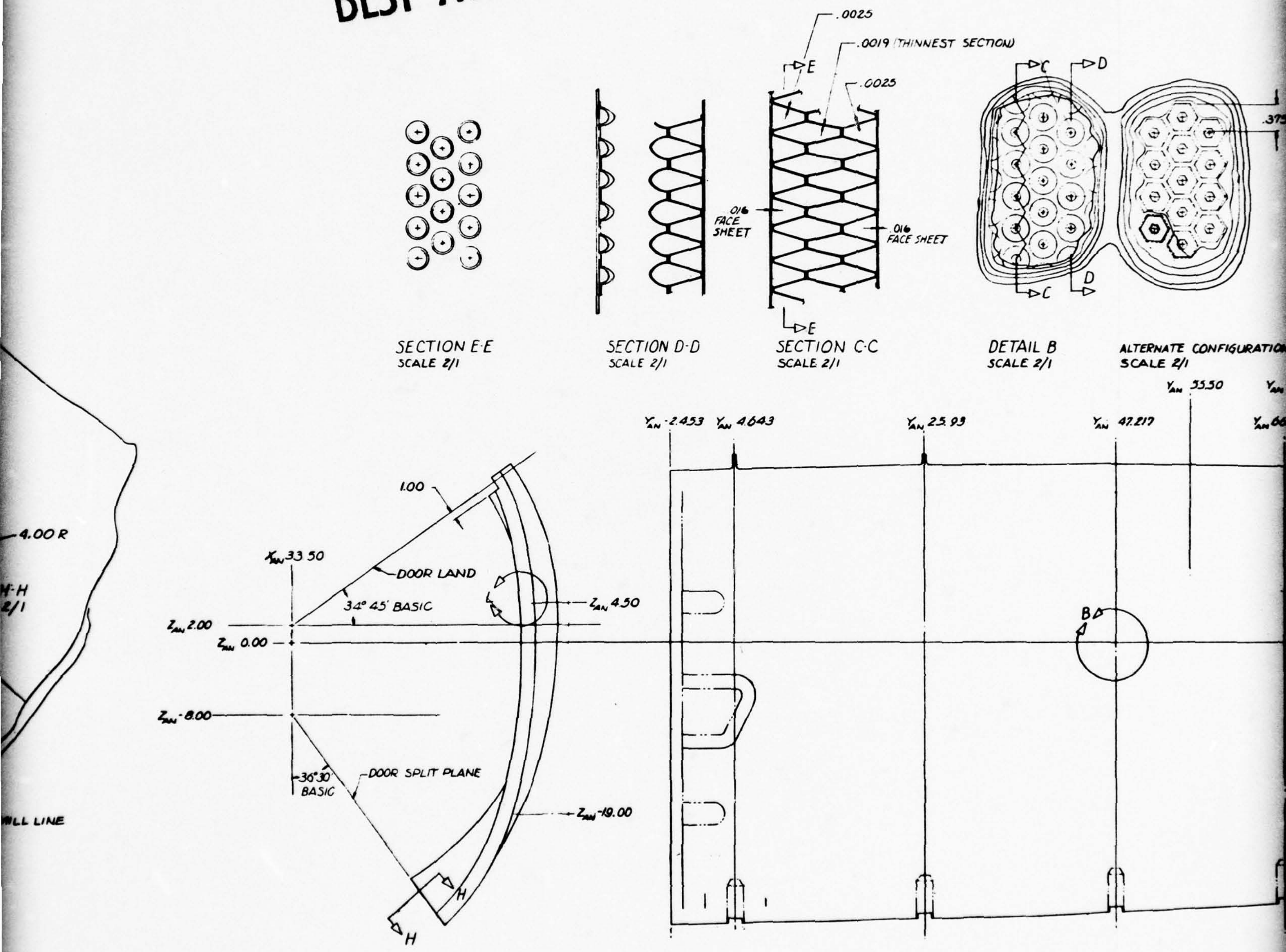


2

BEST AVAILABLE COPY



3


.0025
.0019 (THINNEST SECTION)
.0025
.016 FACE SHEET
.016 FACE SHEET
.375
SECTION E-E
SCALE 2/1
SECTION D-D
SCALE 2/1
SECTION C-C
SCALE 2/1
DETAIL B
SCALE 2/1
ALTERNATE CONFIGURATION
SCALE 2/1
4.00 R
H-H
2/1
ILL LINE
1.00
DOOR LAND
34° 45' BASIC
X_{AN} 33.50
Z_{AN} 2.00
Z_{AN} 0.00
Z_{AN} -8.00
Z_{AN} 4.50
36°30' BASIC
DOOR SPLIT PLANE
Z_{AN} -19.00
Y_{AN} -2.453
Y_{AN} 4.643
Y_{AN} 25.93
Y_{AN} 47.217
Y_{AN} 55.50
FRAME
D607-1-704

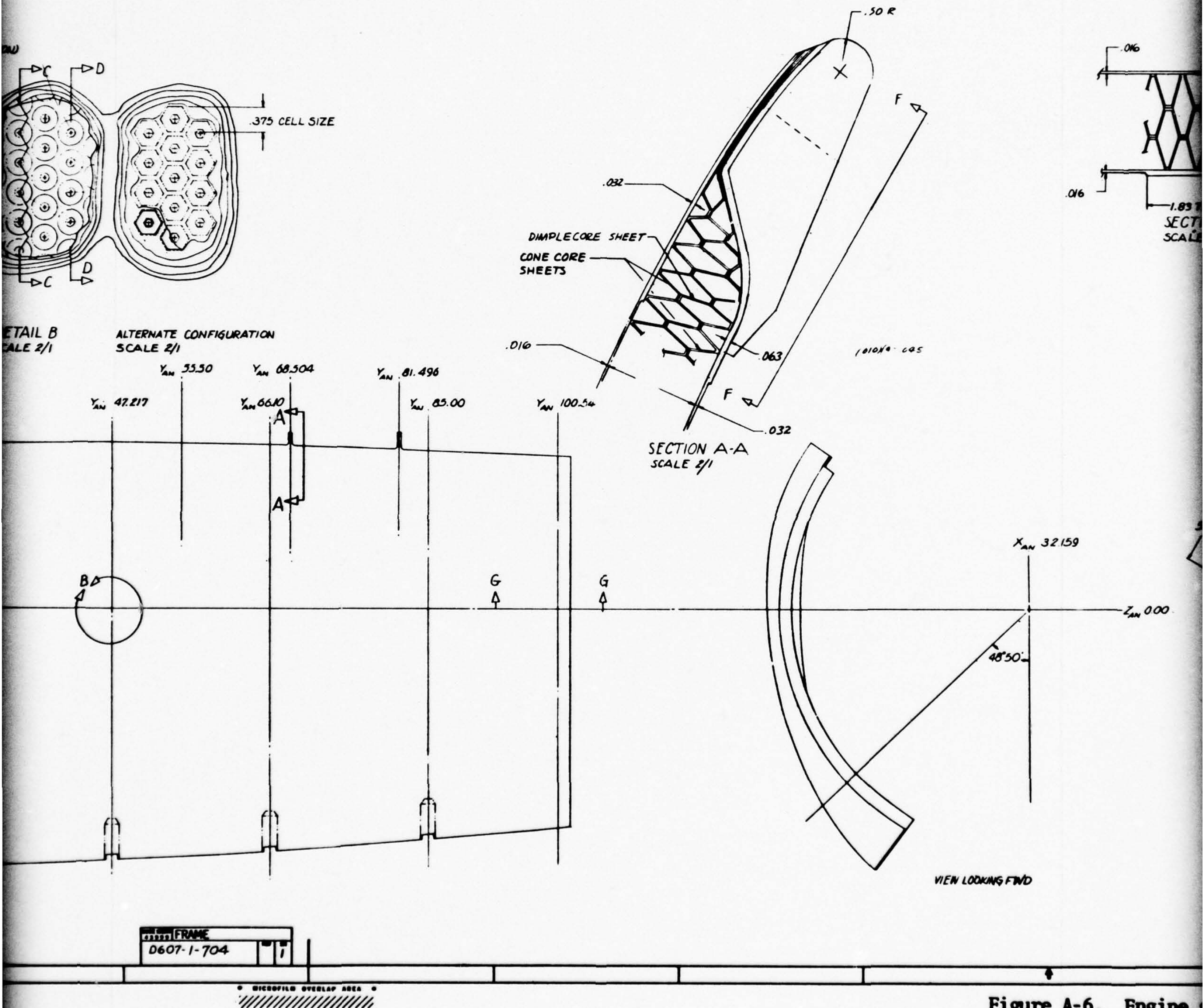


Figure A-6. Engine s

BEST AVAILABLE COPY

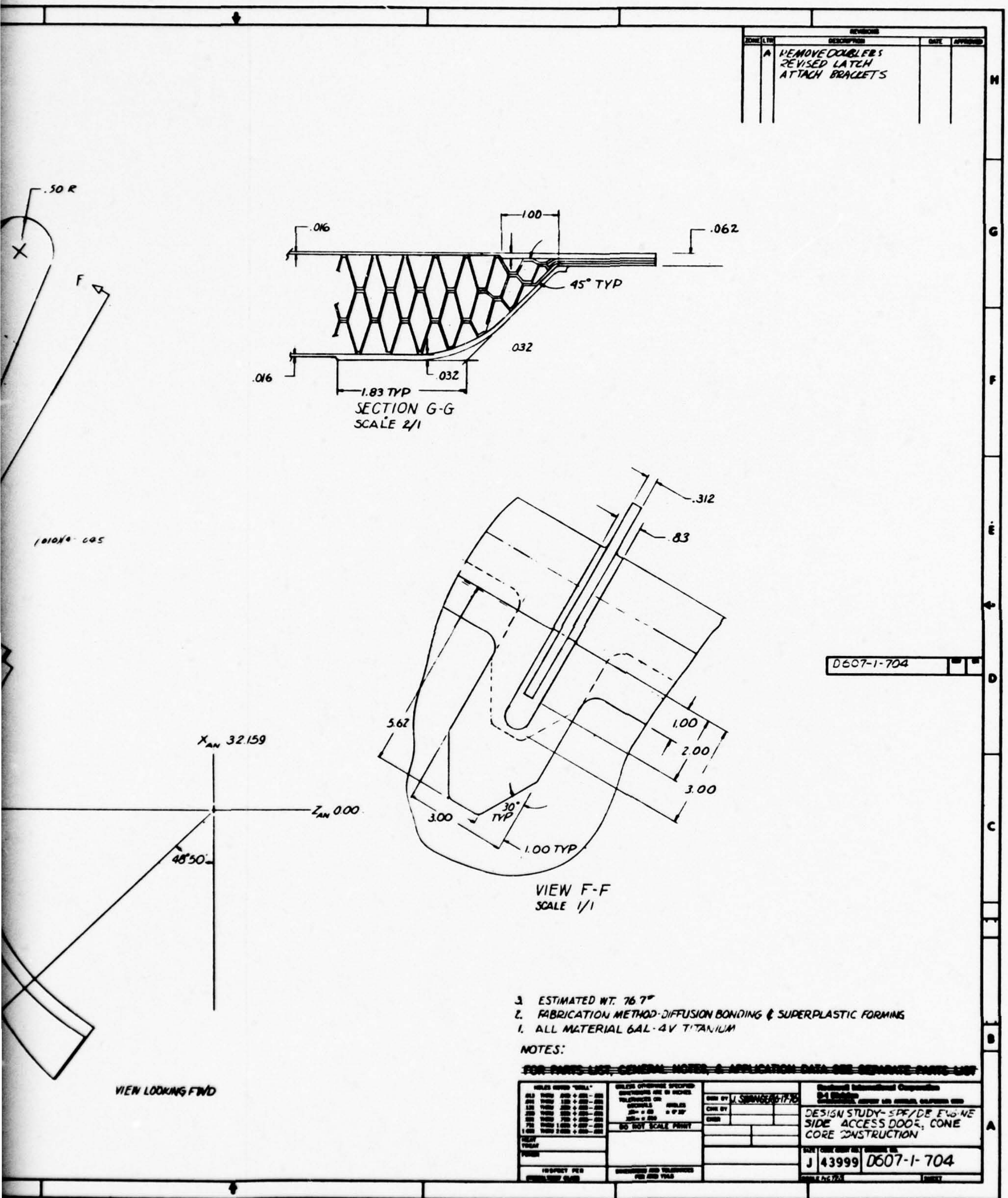
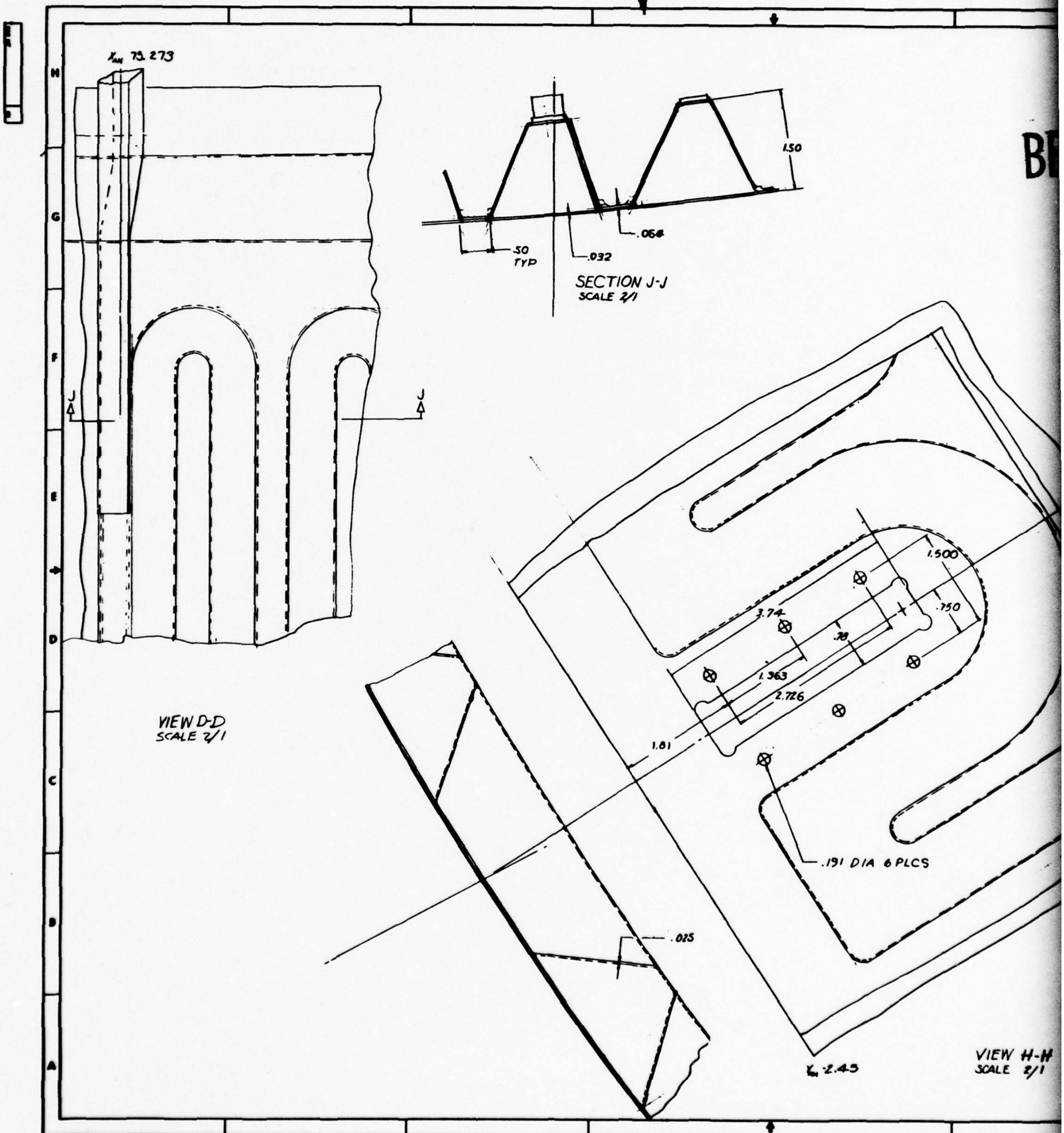
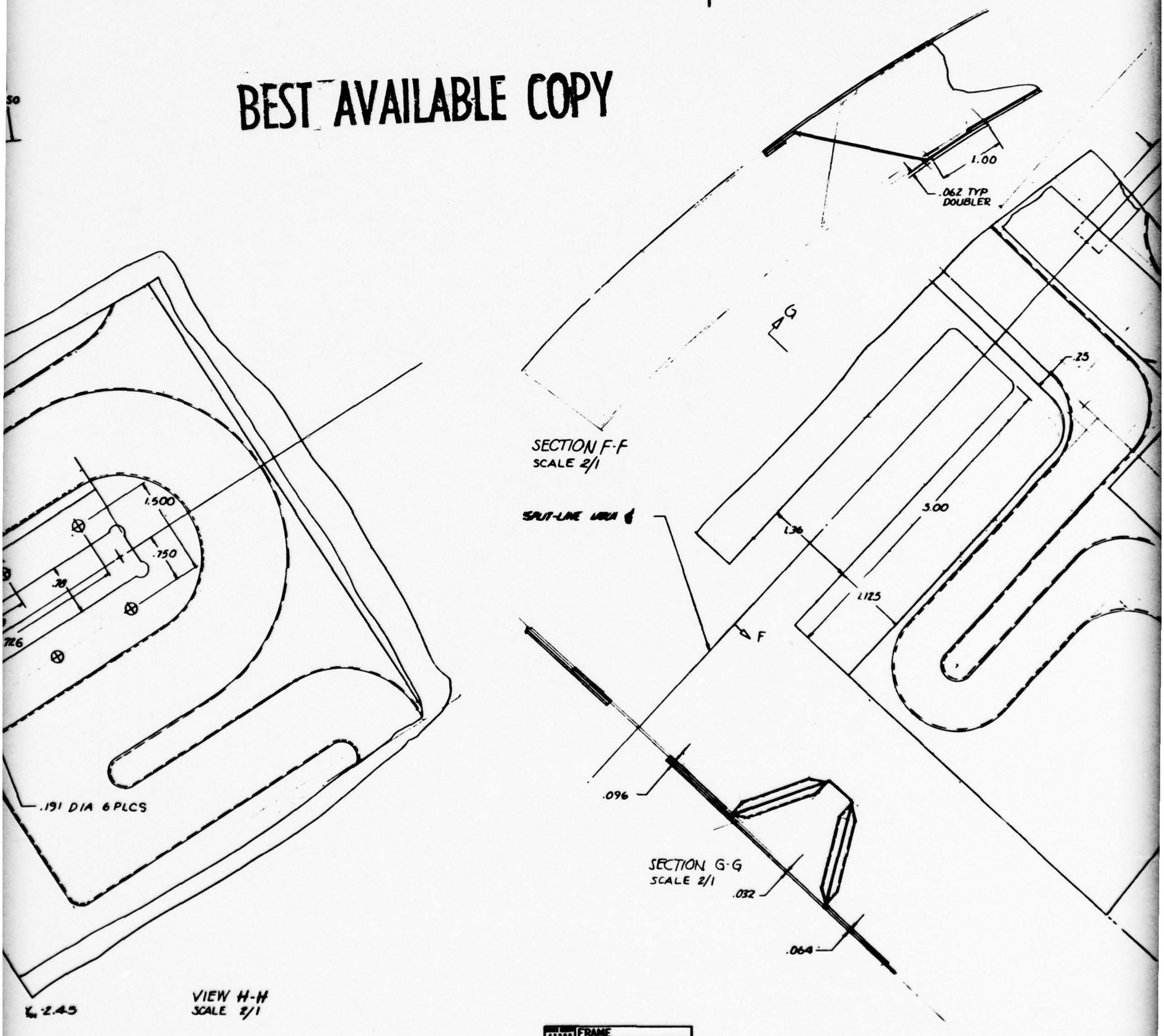


Figure A-6. Engine side access door - triple-sheet, cone core sandwich.

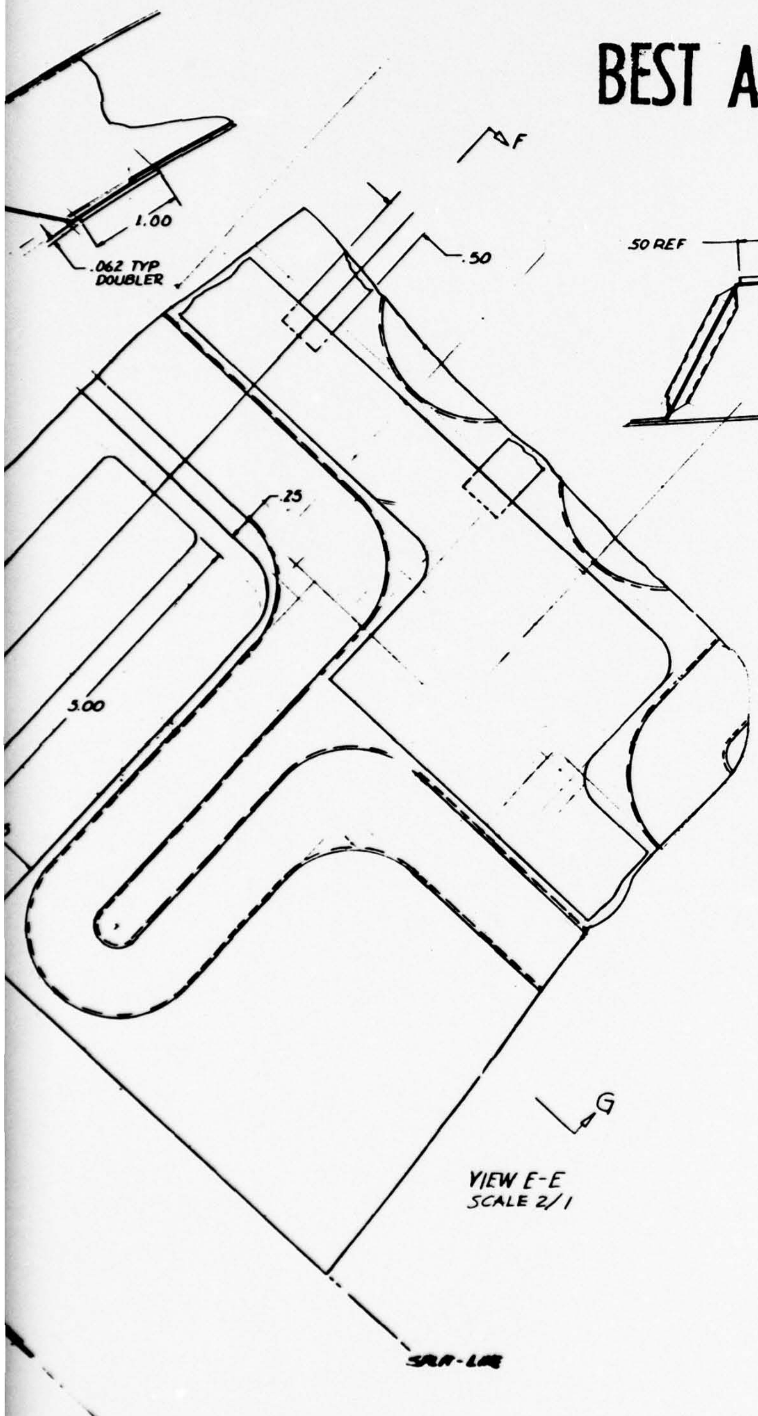

Y_AN 73.273
1.50
.50 TYP
.032
.064
SECTION J-J
SCALE 2/1
J
J
VIEW D-D
SCALE 2/1
1.500
.750
3.74
.78
1.363
2.726
1.81
.191 DIA 6 PLCS
.025
Y_AN -2.45
VIEW H-H
SCALE 2/1

2

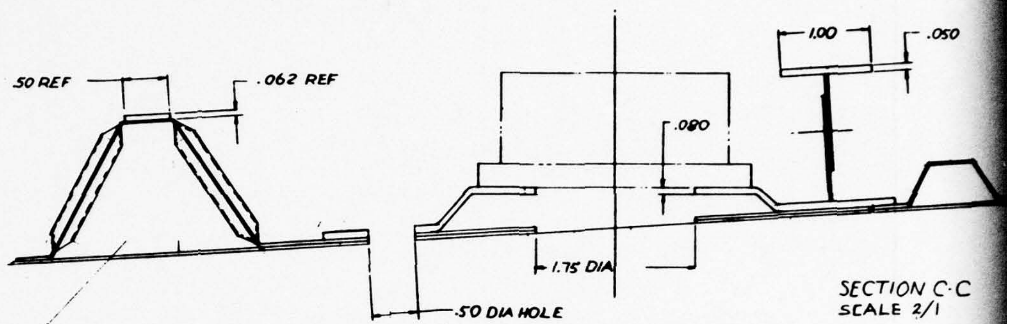

1.00
.062 TYP
DOUBLER
G
.25
SECTION F-F
SCALE 2/1
1.500
.750
.78
.726
3.00
1.36
1.125
F
.191 DIA 6 PLCS
.096
SECTION G-G
SCALE 2/1
.032
.064
VIEW H-H
SCALE 2/1
FRAME

3

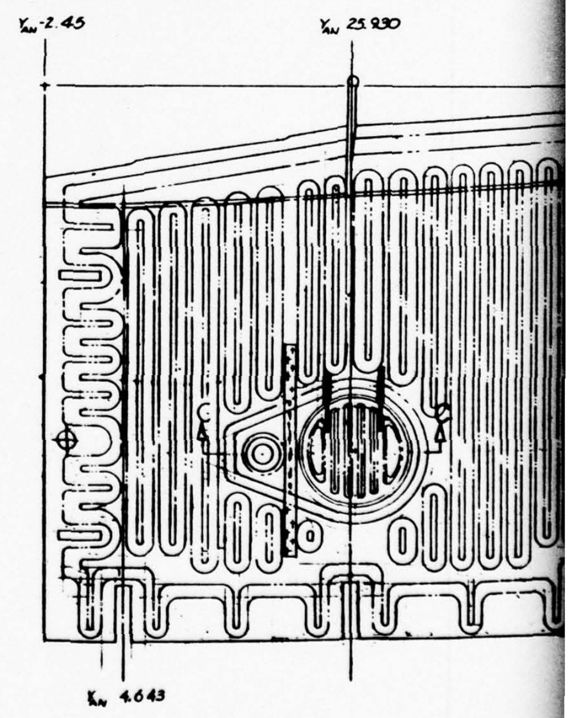
BEST AVAILABLE COPY



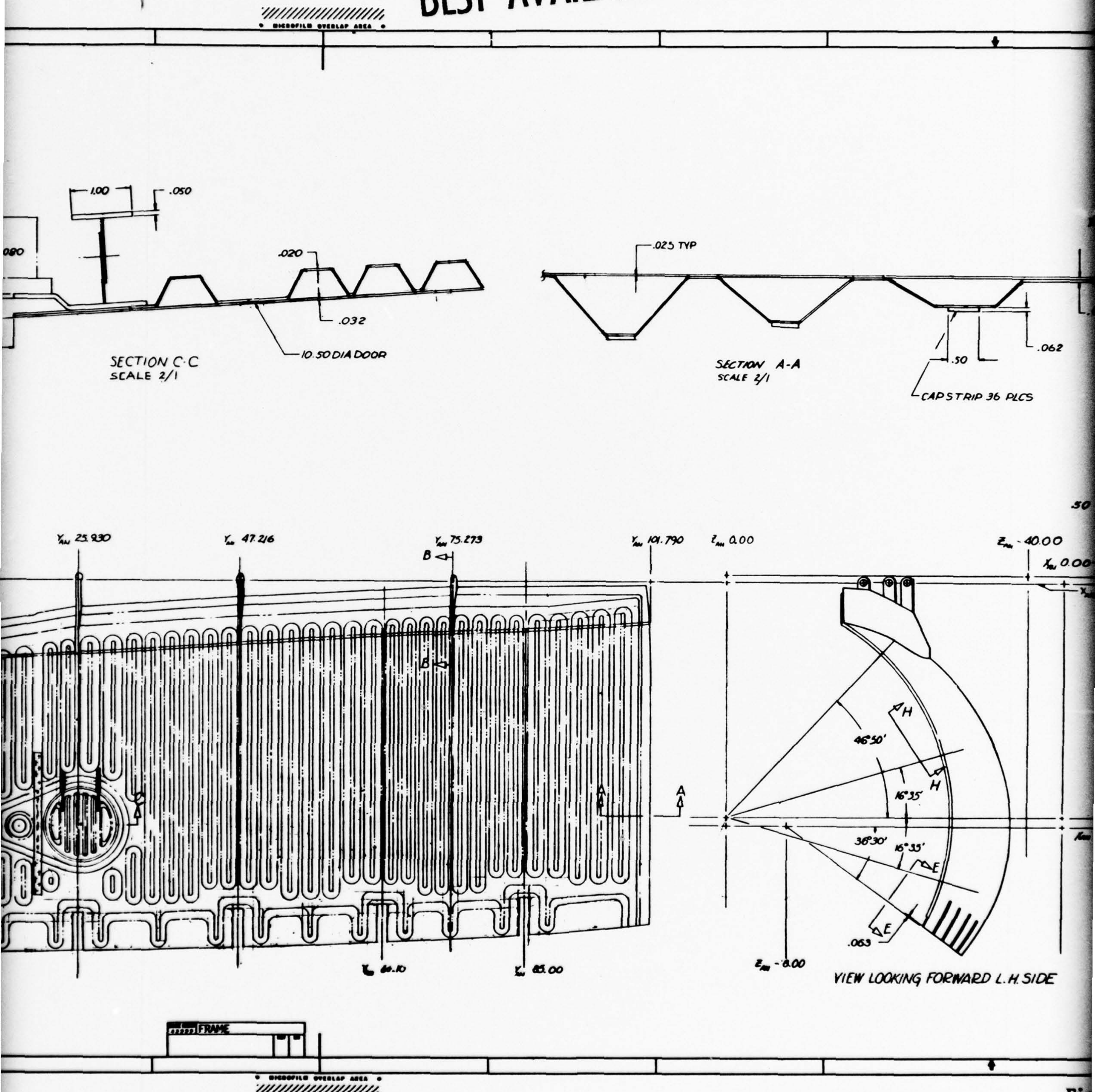
VIEW E-E
SCALE 2/1



SECTION C-C
SCALE 2/1



4



MICROFILM OVERLAP AREA
1.00
.050
.080
.020
.032
10.50 DIA DOOR
SECTION C-C
SCALE 2/1
.025 TYP
SECTION A-A
SCALE 2/1
.50
.062
CAPSTRIP 36 PLCS
Y_{AN} 25.930
Y_{AN} 47.216
Y_{AN} 75.273
Y_{AN} 101.790
Z_{AN} 0.00
Z_{AN} -40.00
X_{AN} 0.00
B
A
H
46°50'
16°35'
36°30'
16°35'
E
.063
Z_{AN} -8.00
VIEW LOOKING FORWARD L.H. SIDE
FRAME
MICROFILM OVERLAP AREA

Fi

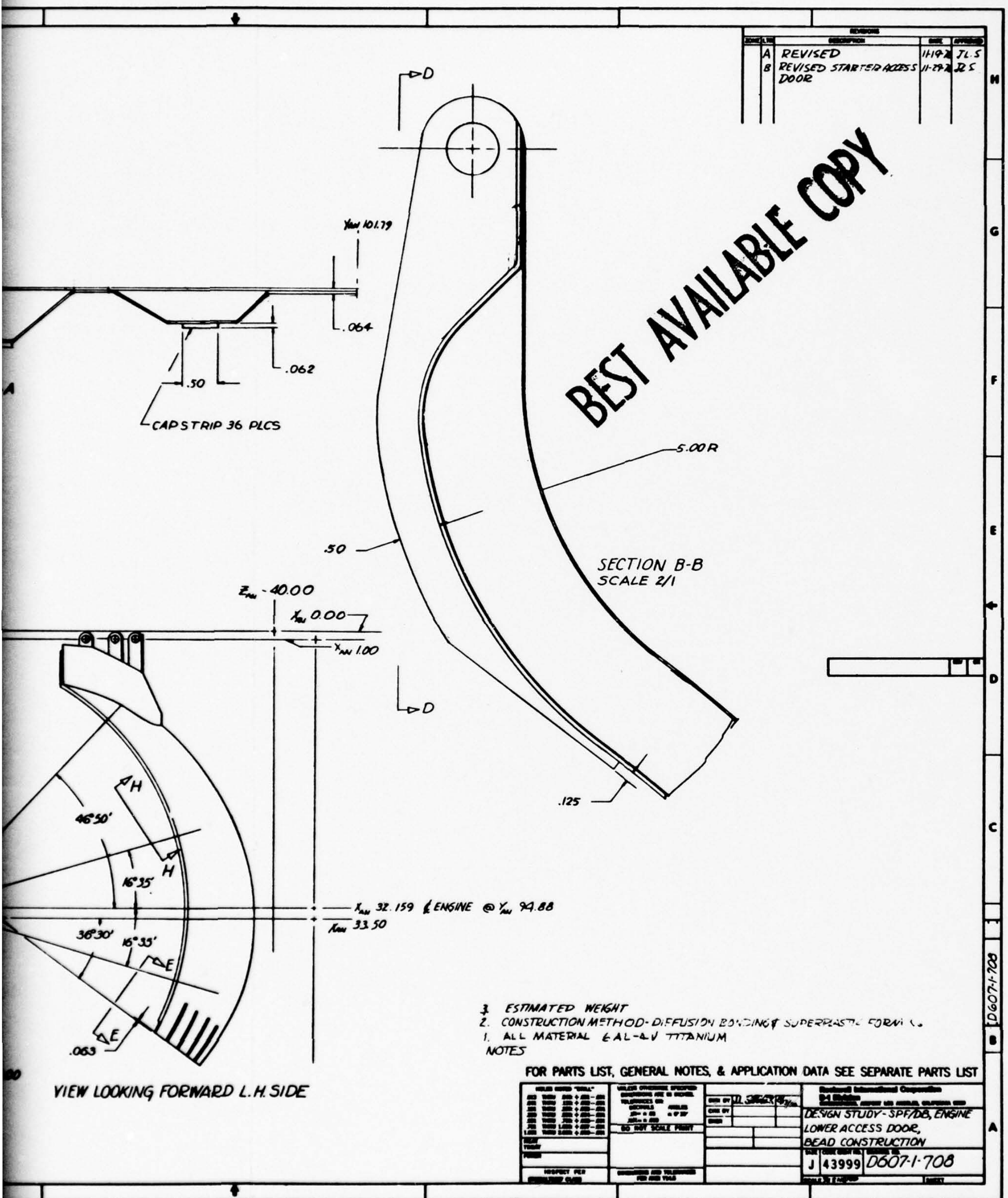


Figure A-7. Engine lower access door - stiffened skin.

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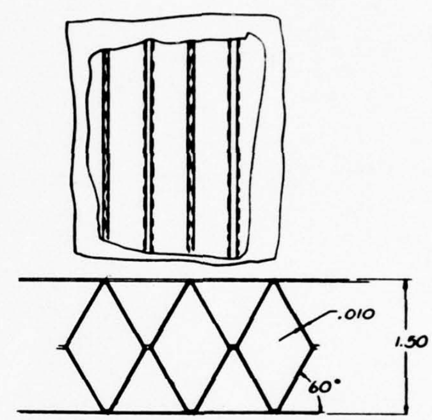
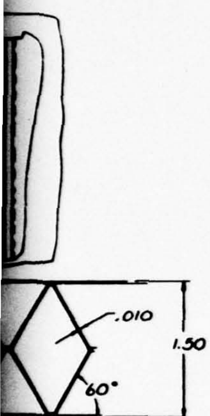


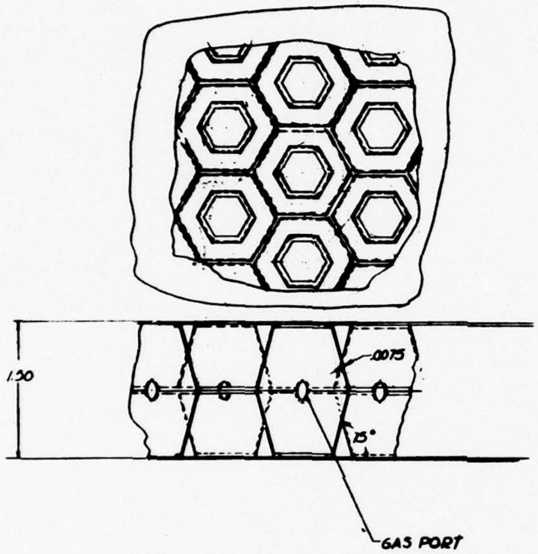
DETAIL G · TRUSS CORE · OPTIONAL
SCALE 2/1

2

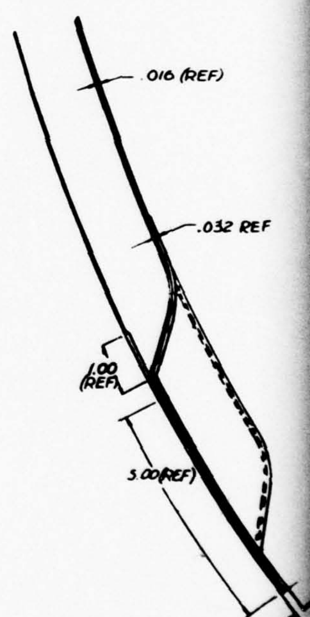
MICROFILM OVERLAP AREA



CORE - OPTIONAL



DETAIL F - CONE CORE - OPTIONAL
SCALE 2/1



SECTION
SCALE 1/1

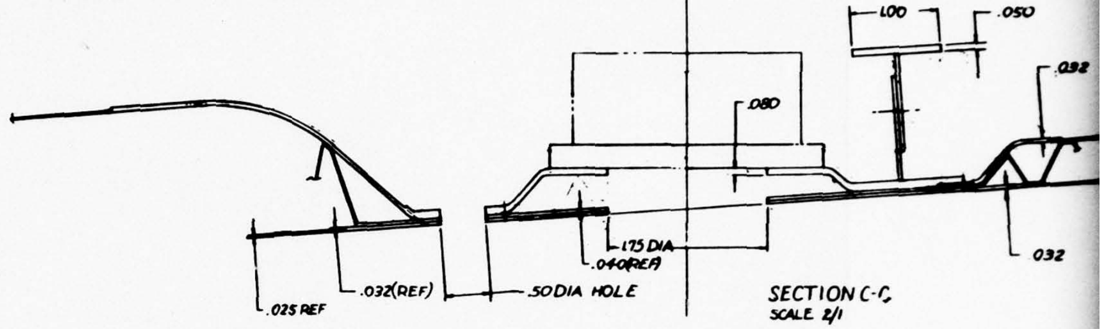
FRAME

MICROFILM OVERLAP AREA

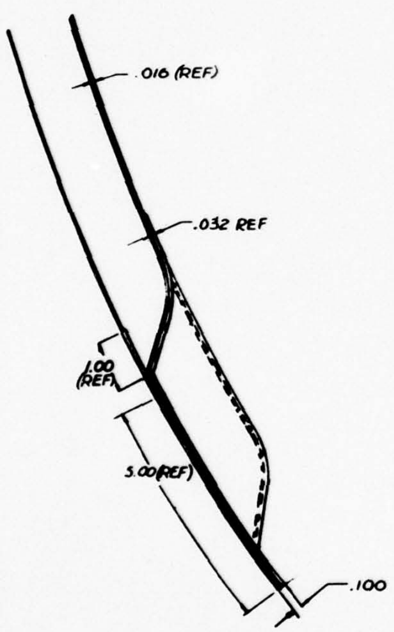
3

DPY

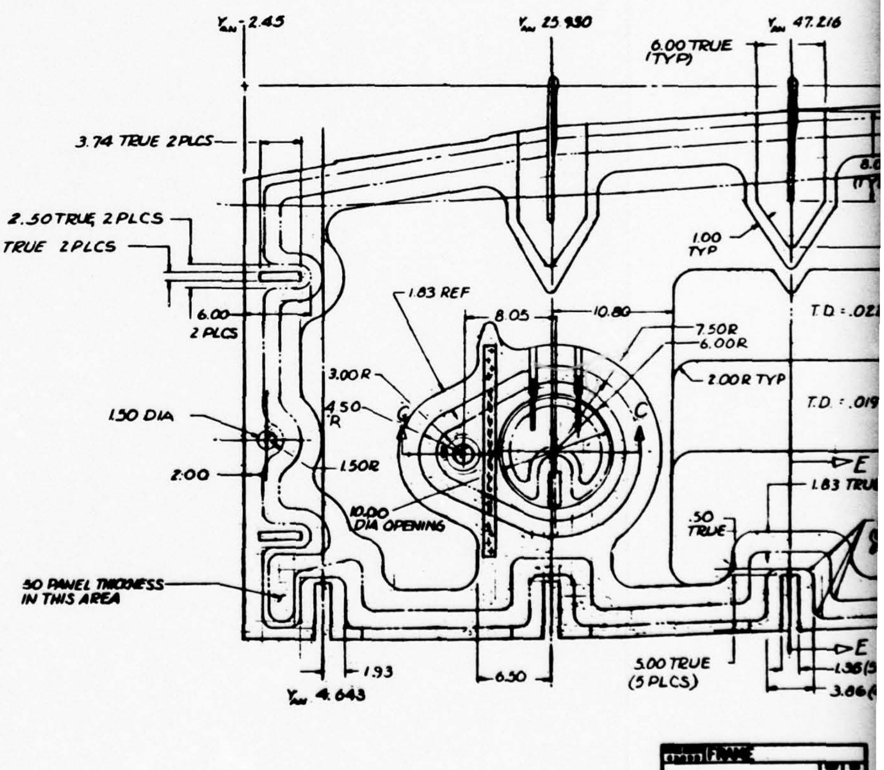
BEST AVAILABLE COPY



SECTION C-C
SCALE 2/1



SECTION E-E
SCALE 1/1



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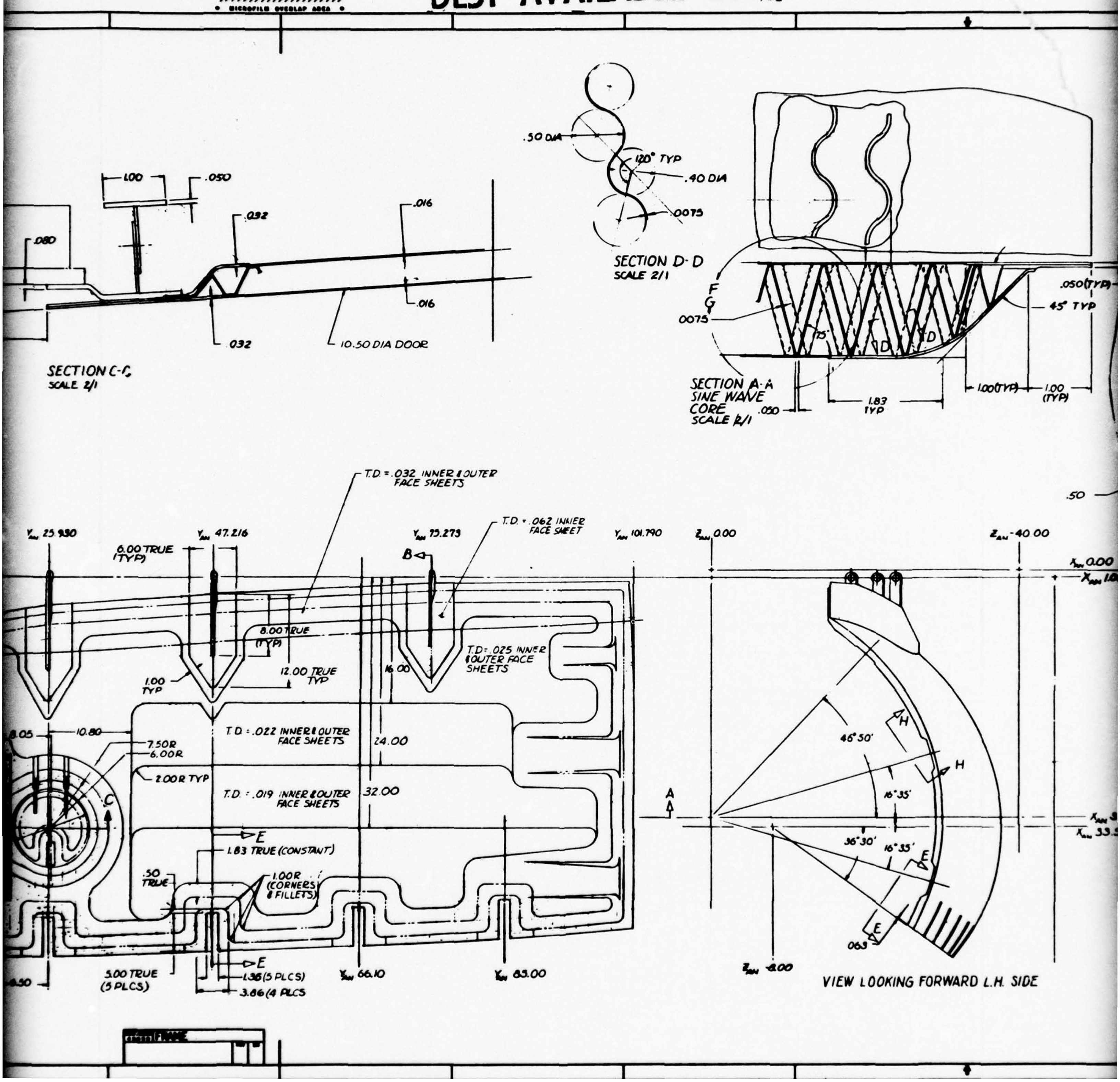


MICROFILM OVERLAP AREA
1.00
.050
.080
.032
.016
.016
.032
10.50 DIA DOOR
SECTION C-C
SCALE 2/1
.50 DIA
120° TYP
.40 DIA
.0075
SECTION D-D
SCALE 2/1
F
G
.0075
75°
D
D
.050(TYP)
45° TYP
SECTION A-A
SINE WAVE
CORE
SCALE 2/1
.050
1.83
TYP
1.00(TYP)
1.00
(TYP)
.50
T.D. = .032 INNER & OUTER
FACE SHEETS
T.D. = .062 INNER
FACE SHEET
Y 25.930
Y 47.216
Y 75.273
Y 101.790
Z 0.00
Z -40.00
X 0.00
6.00 TRUE
(TYP)
B
8.00 TRUE
(TYP)
T.D. = .025 INNER
& OUTER FACE
SHEETS
16.00
12.00 TRUE
TYP
1.00
TYP
8.05
10.80
7.50R
6.00R
T.D. = .022 INNER & OUTER
FACE SHEETS
24.00
2.00R TYP
T.D. = .019 INNER & OUTER
FACE SHEETS
32.00
C
E
1.83 TRUE (CONSTANT)
.50
TRUE
1.00R
(CORNERS
& FILLETS)
E
3.00 TRUE
(5 PLCS)
1.36(5 PLCS)
3.86(4 PLCS)
Y 66.10
Y 83.00
46°50'
H
H
16°35'
A
36°30'
16°35'
E
E
.063
Z -8.00
VIEW LOOKING FORWARD L.H. SIDE
FRAME

BEST AVAILABLE COPY

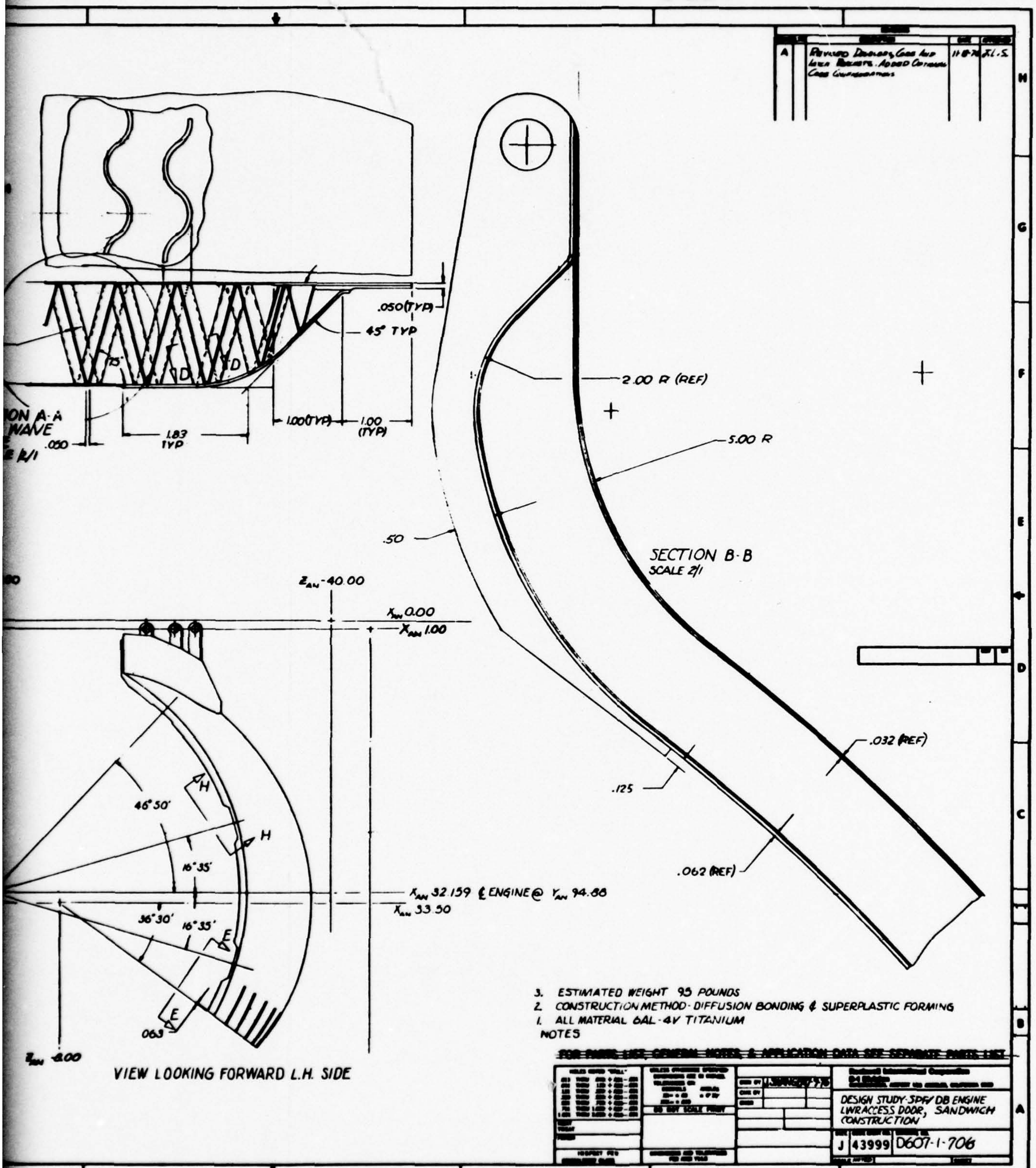
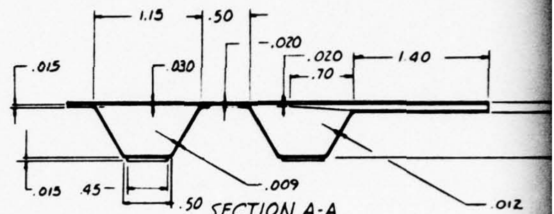
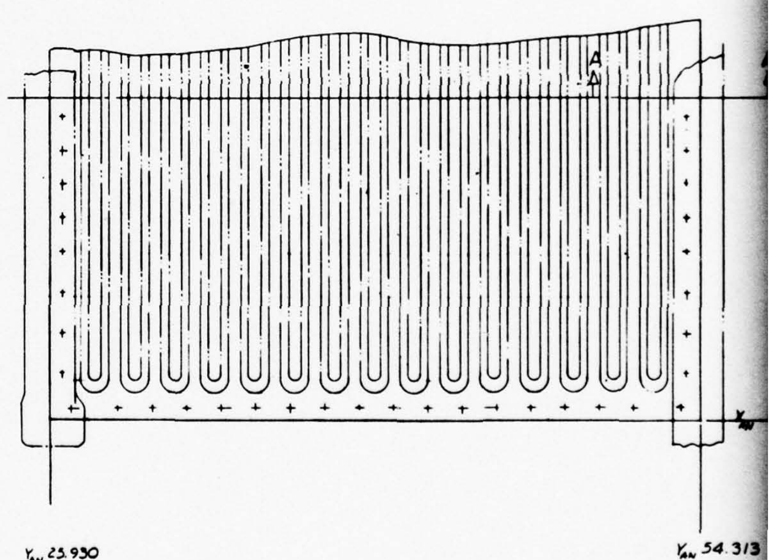


Figure A-8. Engine lower access door - double-sheet sandwich.

2



SECTION A-A
SCALE 2/1



FRAME

3

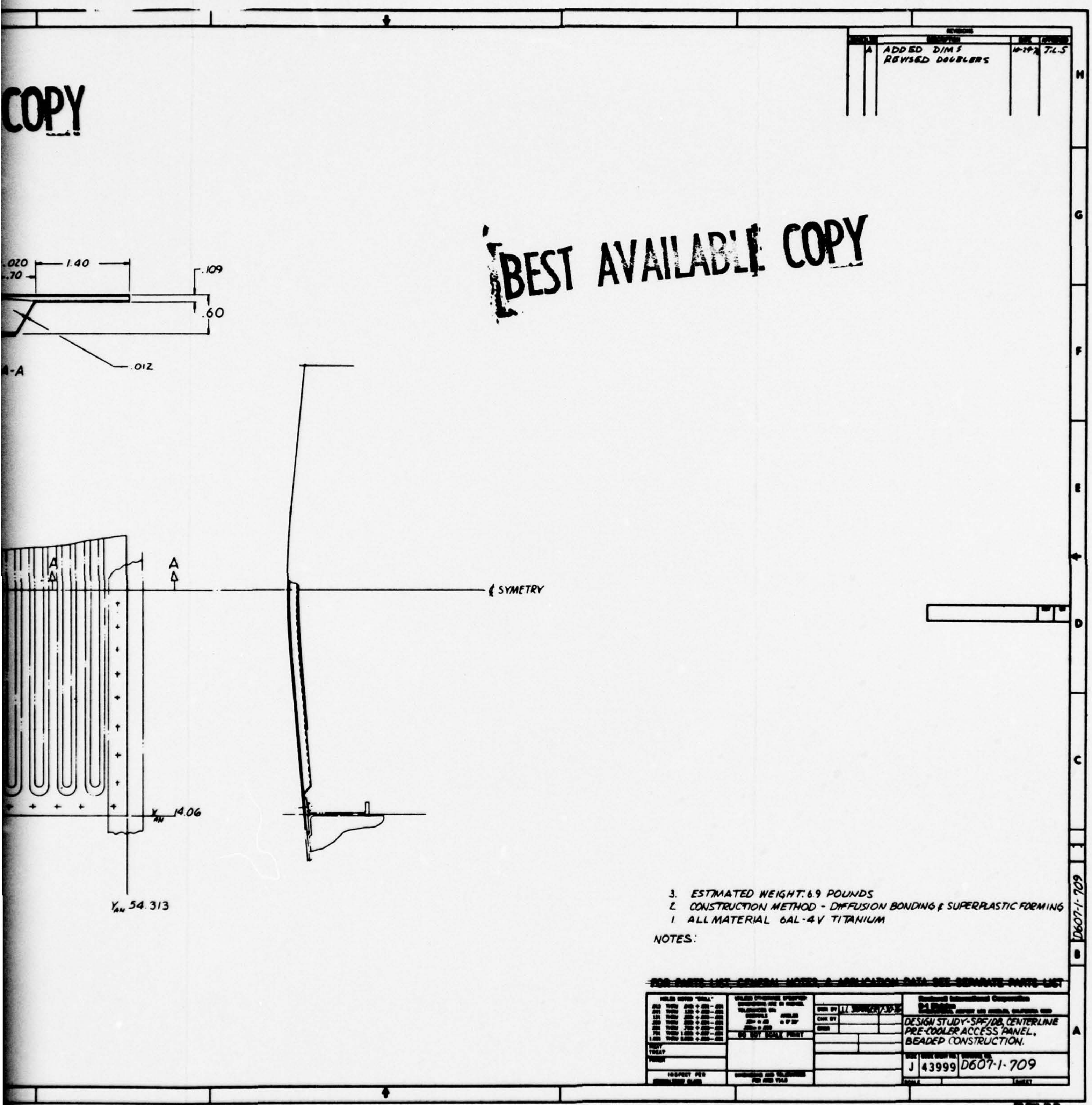


Figure A-9. Centerline precooler access panel - stiffened skin.

4

REVISIONS		
A	ADDED DIMS REVISED DOUBLERS	T.L.S

3. ESTIMATED WEIGHT: 6.9 POUNDS
2. CONSTRUCTION METHOD - DIFFUSION BONDING & SUPERPLASTIC FORMING
1. ALL MATERIAL 6AL-4V TITANIUM

NOTES:

FOR PARTS LIST, GENERAL NOTES & APPLICATION DATA SEE SEPARATE PARTS LIST

Rockwell International Corporation

DESIGN STUDY-SPF/DB, CENTERLINE PRE-COOLER ACCESS PANEL, BEADED CONSTRUCTION.

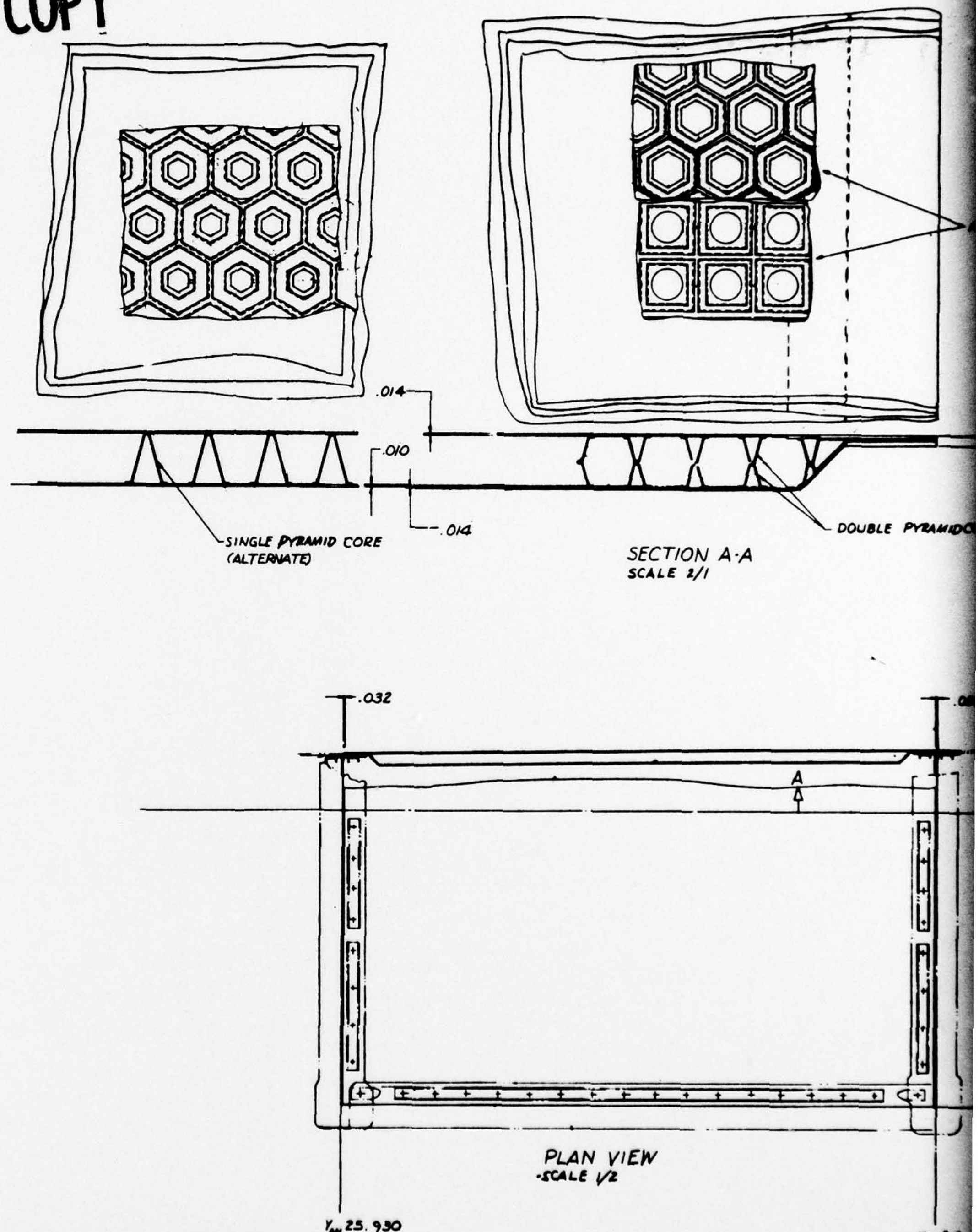
J 43999 D607-1-709

D607-1-709

recooler access panel - stiffened skin.

2

MICROFILM OVERLAP AREA



FRAME

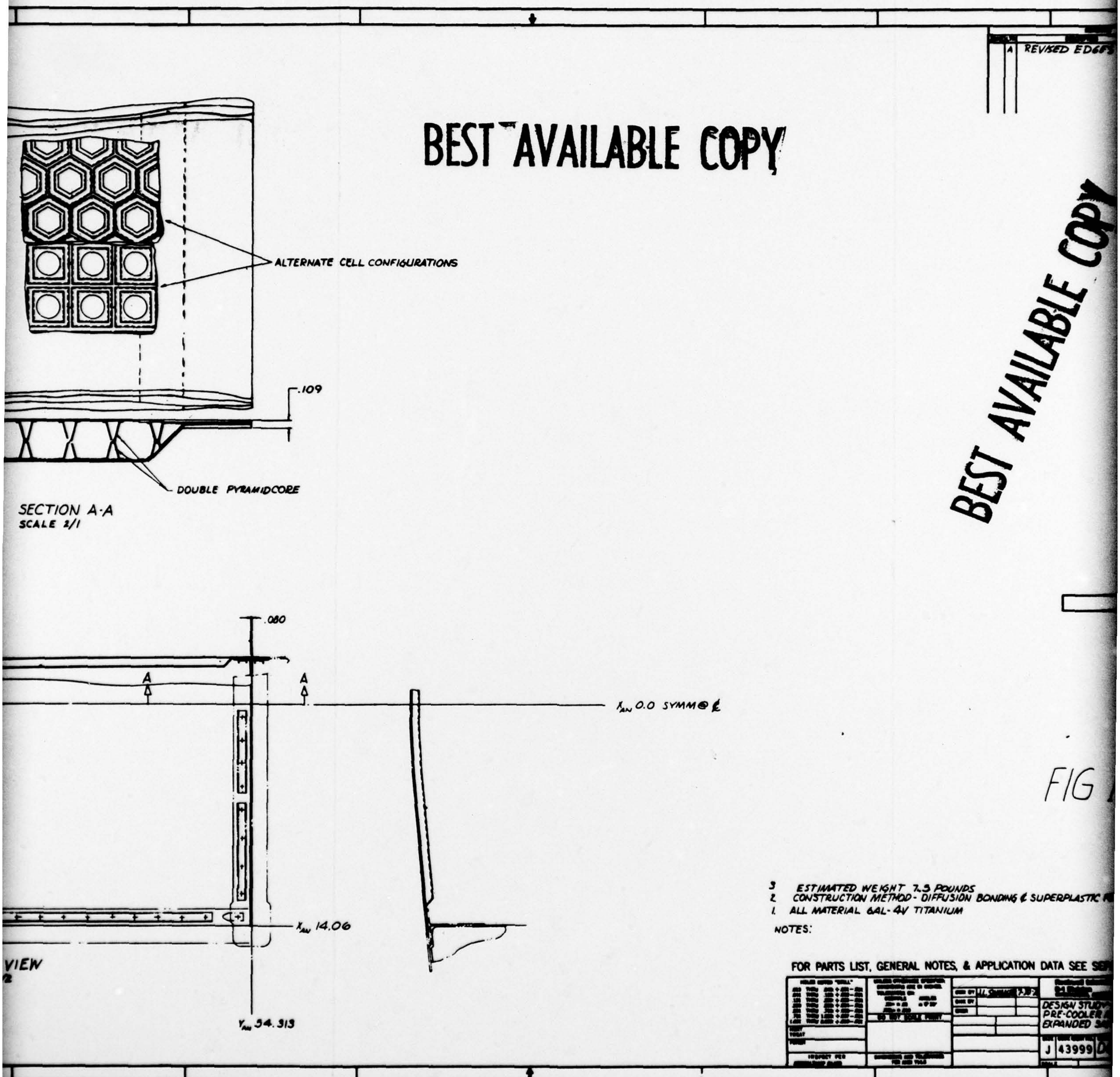


Figure A-10. Centerline precooler access panel - expanded s

4

A	REVISED EDGES	10-20-76	J.L.S.

FIG 1

3. ESTIMATED WEIGHT 7.3 POUNDS
2. CONSTRUCTION METHOD - DIFFUSION BONDING & SUPERPLASTIC FORMING
1. ALL MATERIAL 6AL-4V TITANIUM

TES:

FOR PARTS LIST, GENERAL NOTES, & APPLICATION DATA SEE SEPARATE PARTS LIST

DESIGN STUDY - SPF/DB, CENTERLINE PRE-COOLER ACCESS PANEL, EXPANDED SANDWICH CONSTRUCTION

J 43999 D607-1-710

D607-1-710

cooler access panel - expanded sandwich.

PRECEDING PAGE NOT FILMED
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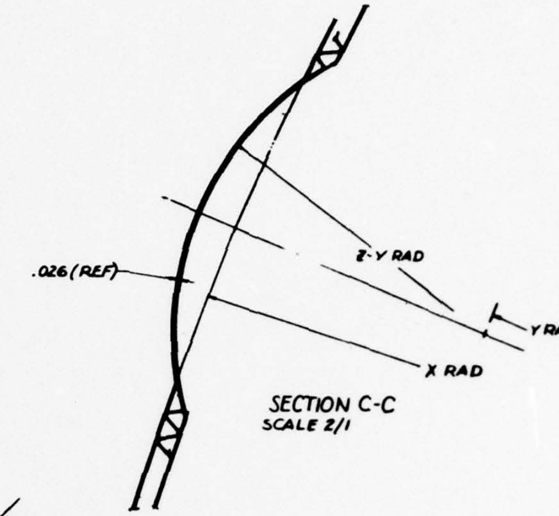
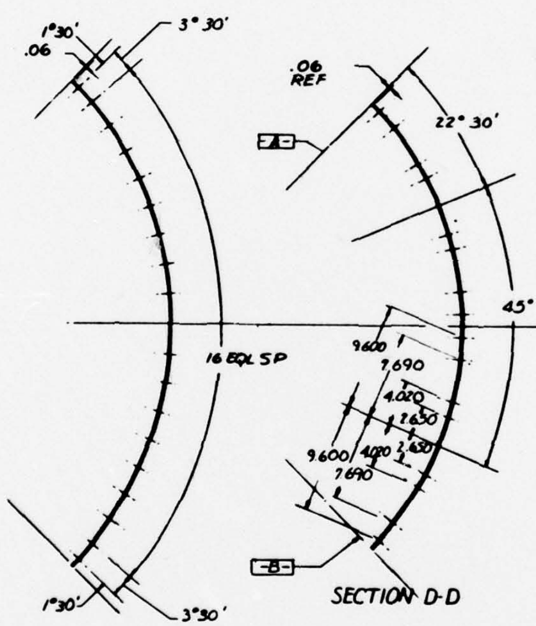
3

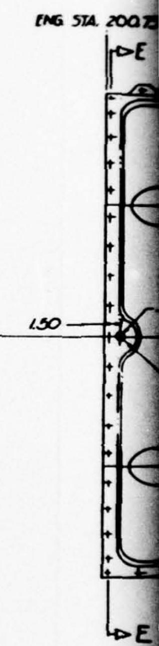


SECTION C-C
SCALE 2/1

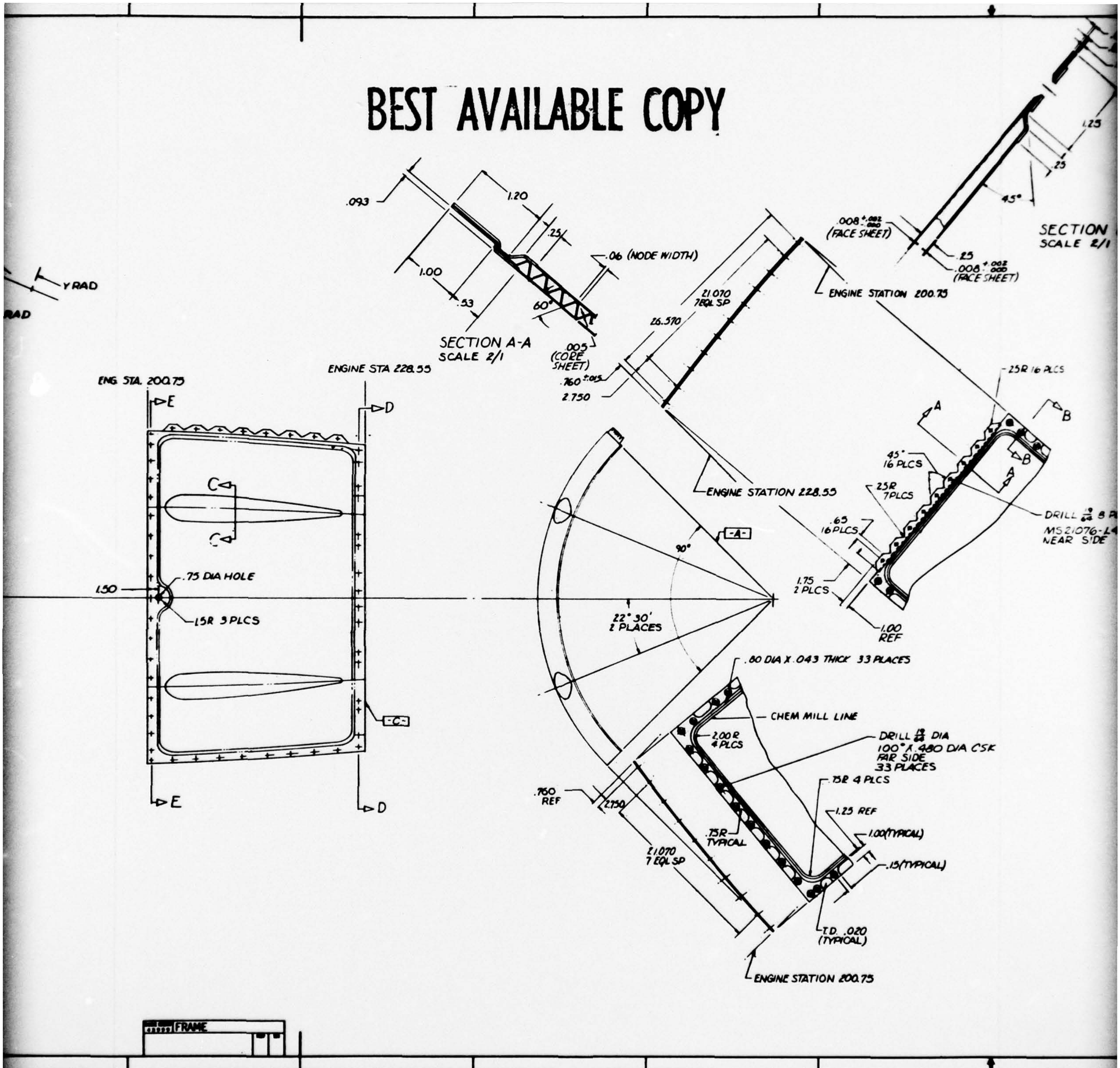


SECTION E-E

SECTION D-D



BEST AVAILABLE COPY



MICROFILM OVERLAP AREA

Figu

5

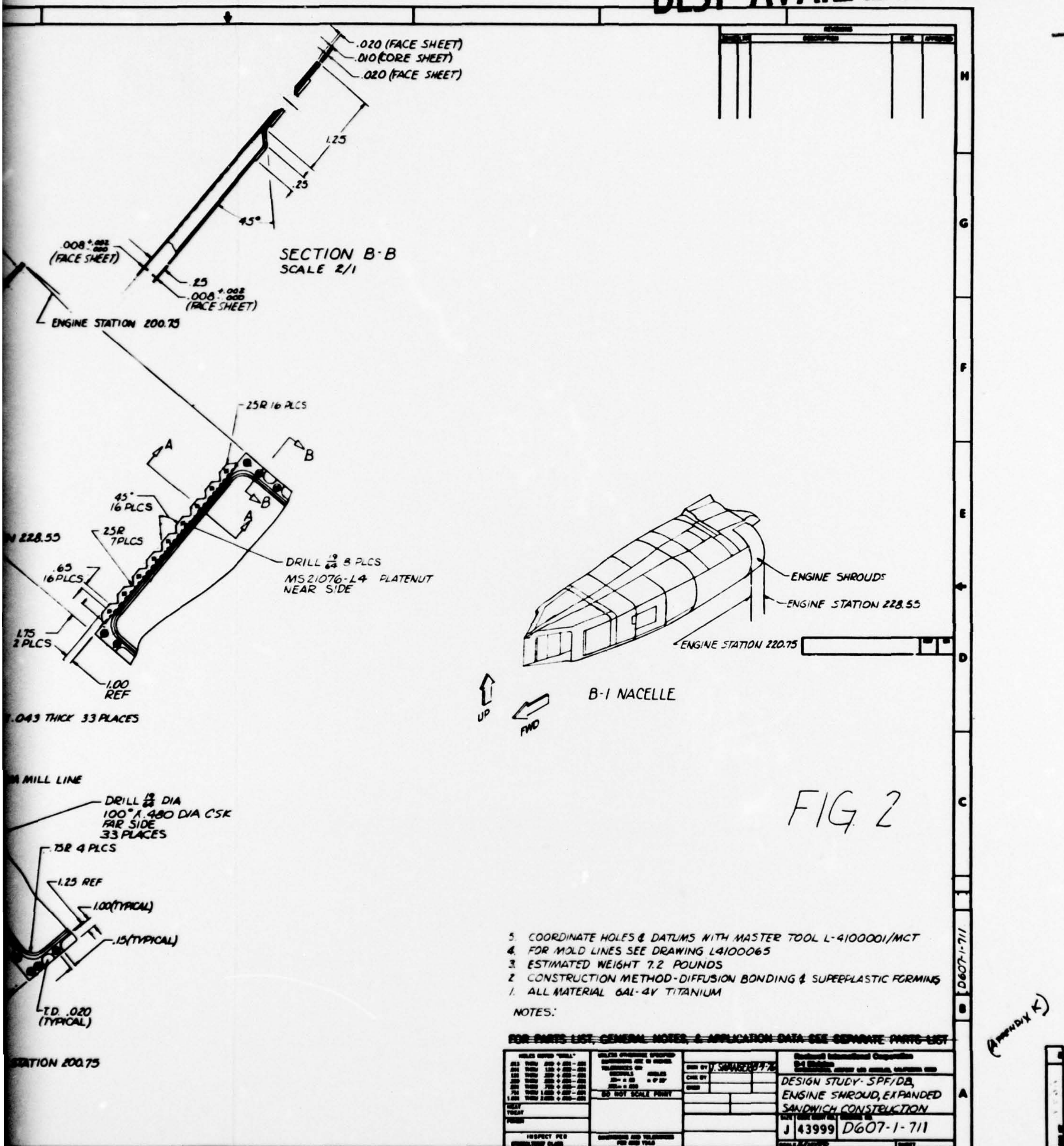


Figure A-11. Engine shroud - truss core sandwich.

1

[illegible]

H

G

F

E

D

C

B

A

MICROFILM OVERLAP AREA

MICROFILM OVERLAP AREA

3

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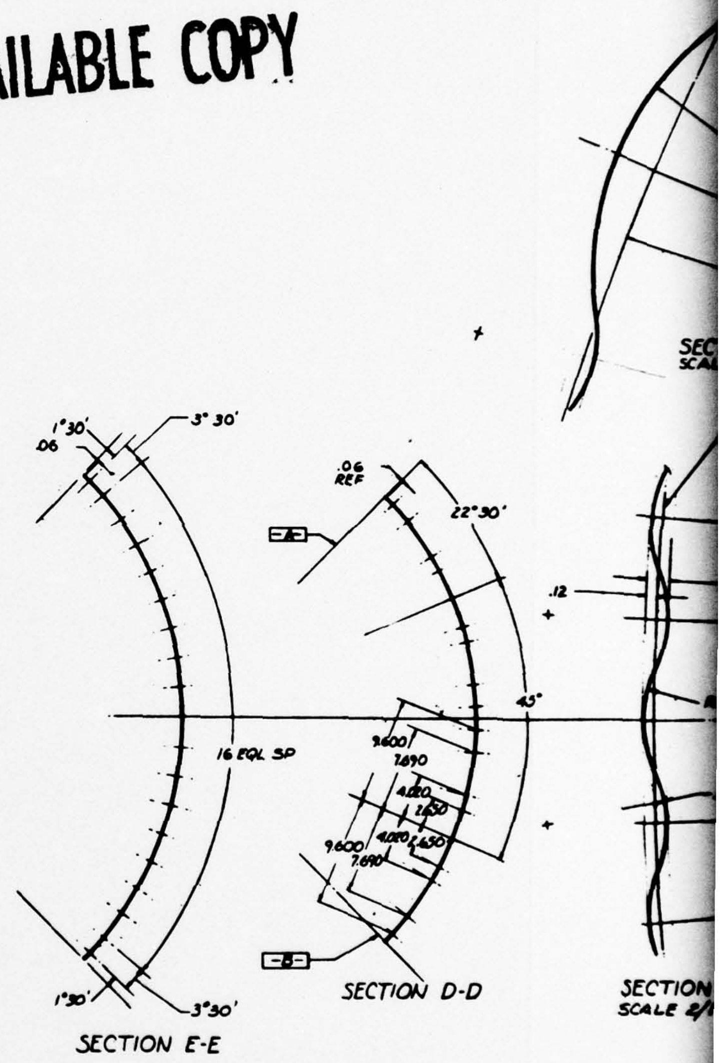

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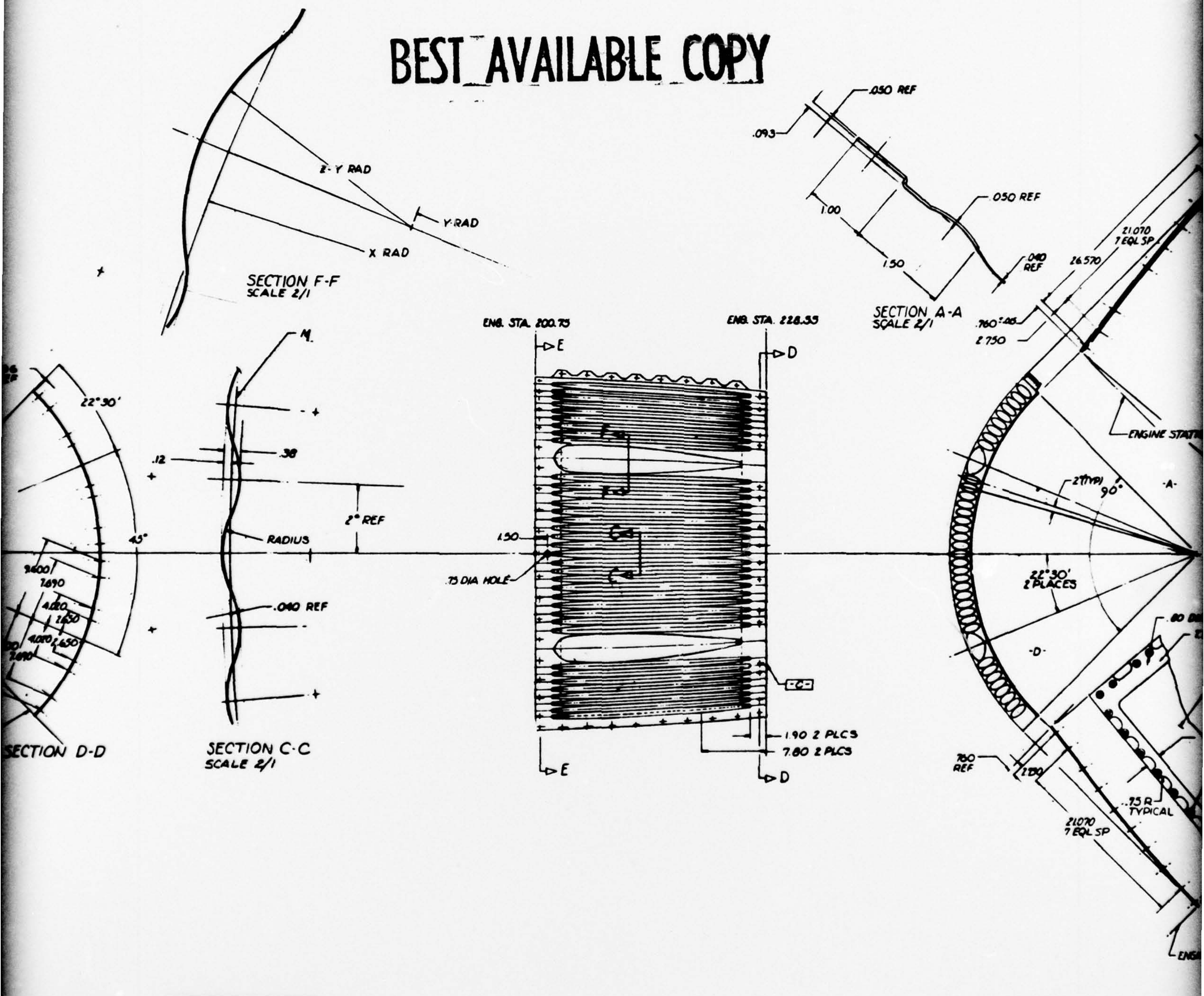

Figure A-12

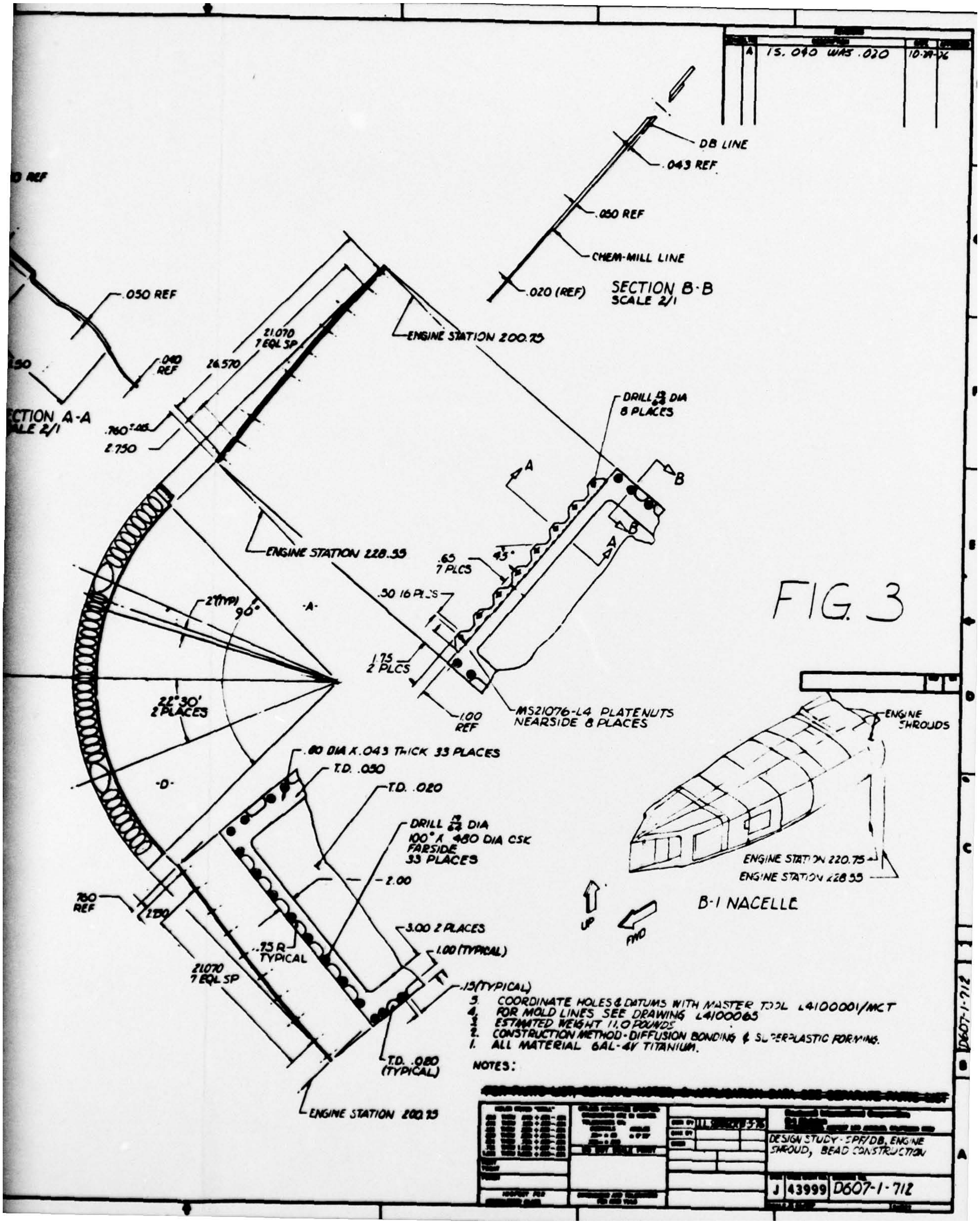
A 15. 040 WAS .020 10-29-76
DB LINE
.043 REF
.050 REF
CHEM-MILL LINE
.020 (REF)
SECTION B-B
SCALE 2/1
.050 REF
.040 REF
SECTION A-A
SCALE 2/1
.760
2.750
26.570
21.070
7 EQL SP
ENGINE STATION 200.75
DRILL 13/64 DIA
8 PLACES
ENGINE STATION 228.55
.65
7 PLCS
45°
.50 16 PLCS
1.75
2 PLCS
1.00
REF
MS21076-L4 PLATENUTS
NEARSIDE 8 PLACES
2°(TYP)
90°
-A-
22°30'
2 PLACES
.80 DIA X .043 THICK 33 PLACES
T.D. .050
T.D. .020
-D-
DRILL 13/64 DIA
100° X .480 DIA CSK
FARSIDE
33 PLACES
2.00
760
REF
2.750
3.00 2 PLACES
1.00 (TYPICAL)
.75 R
TYPICAL
21.070
7 EQL SP
.15 (TYPICAL)
T.D. .080
(TYPICAL)
ENGINE STATION 200.75
ENGINE SHROUDS
ENGINE STATION 220.75
ENGINE STATION 228.55
UP
FWD
B-1 NACELLE
5. COORDINATE HOLES & DATUMS WITH MASTER TOOL L4100001/MCT
4. FOR MOLD LINES SEE DRAWING L4100065
3. ESTIMATED WEIGHT 11.0 POUNDS
2. CONSTRUCTION METHOD - DIFFUSION BONDING & SUPERPLASTIC FORMING.
1. ALL MATERIAL 6AL-4V TITANIUM.
NOTES:
DESIGN STUDY - SPF/DB, ENGINE SHROUD, BEAD CONSTRUCTION
J 43999 D607-1-712
D607-1-712

FIG. 3

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