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ADVANCED COMPOSITE VERTICAL STABILIZER
FOR DC-10 TRANSPORT AIRCRAFT

CONTRACT NAS1-14869

FIFTH QUARTERLY TECHNICAL PROGRESS REPORT
27 MARCH 1978 THROUGH 25 JUNE 1978

DOUGLAS AIRCRAFT COMPANY

MCDONNELL DOUGLAS
CORPORATION

ACEE-03-PR-8484
26 JULY 1978

DRL ITEM NUMBER 005

FIFTH QUARTERLY TECHNICAL PROGRESS REPORT
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ADVANCED COMPOSITE VERTICAL STABILIZER FOR DC-10 TRANSPORT AIRCRAFT

PREPARED FOR LANGLEY RESEARCH CENTER
CONTRACT NAS1-14869

MCDONNELL DOUGLAS
CORPORATION

Douglas Aircraft Company
Contract NAS1-14869

ACEE-03-PR-8484

DRL Item Number 005

FIFTH QUARTERLY TECHNICAL PROGRESS REPORT

27 March through 25 June 1978

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FOREWORD

This report was prepared by the Douglas Aircraft Company, McDonnell Douglas Corporation, Long Beach, California, under Contract NAS1-14869. It is the fifth quarterly technical progress report covering work performed between 27 March 1978 and 25 June 1978. The program is sponsored by the National Aeronautics and Space Administration, Langley Research Center (NASA-LRC). Mr. Marvin B. Dow is the Project Manager for NASA-LRC.

The following Douglas personnel were the principal contributors to the program during the reporting period: G. M. Lehman, Project Manager; C. O. Stephens, Engineering Supervisor; A. V. Hawley, Structural Development Supervisor; J. O. Sutton, Stress and Loads Analysis; P. W. Scott, Weight Analysis; H. M. Toellner, Material and Producibility Engineering; B. Lyon and A. T. Tucci, Manufacturing Engineering; and R. B. Anderson, Engineering Test Supervisor.

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Douglas Aircraft Company
Contract NASI-14869

ACEE-03-8484

SUMMARY

The structural design, fabrication, and test activities performed during the fifth quarterly report period are documented in this report. The structural design configuration for the Composite Vertical Stabilizer is described and the structural design, analysis, and weight activities are presented. The status of fabrication and test activities for the development test portion of the program is described. Test results are presented for the skin panels, spar web, spar cap to cover, and laminate properties specimens. Engineering drawings of verification test panels and root fittings, rudder support specimens, titanium fittings, and the rear spar specimen analysis model are included in Appendix A.

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SECTION 1

INTRODUCTION

Advanced composite materials, if used extensively in airframe components, offer a high potential for reducing the structural weight and thus the direct operating costs of commercial transport aircraft. To achieve the goal of production commitments, advanced composite structures must convincingly demonstrate the potential weight reduction while maintaining equivalent durability and competitive costs with conventional metal structures.

The overall objective of this program is to accelerate the use of advanced composite structures by developing technology and processes for early progressive introduction of composite structures into production commercial transport aircraft. Key steps in accomplishing this objective are: (1) to develop low-cost design and manufacturing approaches which will produce a cost competitive structure, and (2) to initiate commercial airline service of a mid-sized composite primary structure, the DC-10 composite vertical stabilizer (CVS).

The program is being conducted under six major task headings as follows:

1. Preliminary Design
2. Detail Design
3. Manufacturing Process Development
4. Verification Tests
5. Serial Manufacture
6. Program Management and Plans Development

The Tasks 1 through 4, two prototype vertical stabilizers will be developed and ground tested, and one will be developed, flight tested, certified, and introduced into commercial airline service. In Task 5, five additional advanced composite vertical stabilizers will be produced in a serial production mode and introduced into commercial airline service. Task 6 includes program management functions and the formulation of the plans necessary for development, certification by the Federal Aviation Agency (FAA), and in-service inspection and maintenance of the CVS.

This report describes work accomplished during the fifth quarterly period of the program. Work continued on test component design activities, preliminary structural analysis, preliminary weight studies, and tooling, fabrication, and test of a number of structural development components and specimens. Detail design of skin panel and spar components was continued. Overall schedule status is summarized in Figure 1.

The activities during the quarterly period are described under the headings Detail Design, Concept Development Test Components, Joint Development Test Components, Mechanical Properties Specimens, Design Verification Test Components, and Quality Assurance. Engineering drawings of root fitting specimens, verification test panels, and a rear spar specimen are included in Appendix A. Supplementary analyses are included in Appendix B.

The measurement values in this report are expressed in the International System of Units (SI) and also U.S. Customary Units in some cases. U.S. Customary Units were used for the principal measurements and calculations.

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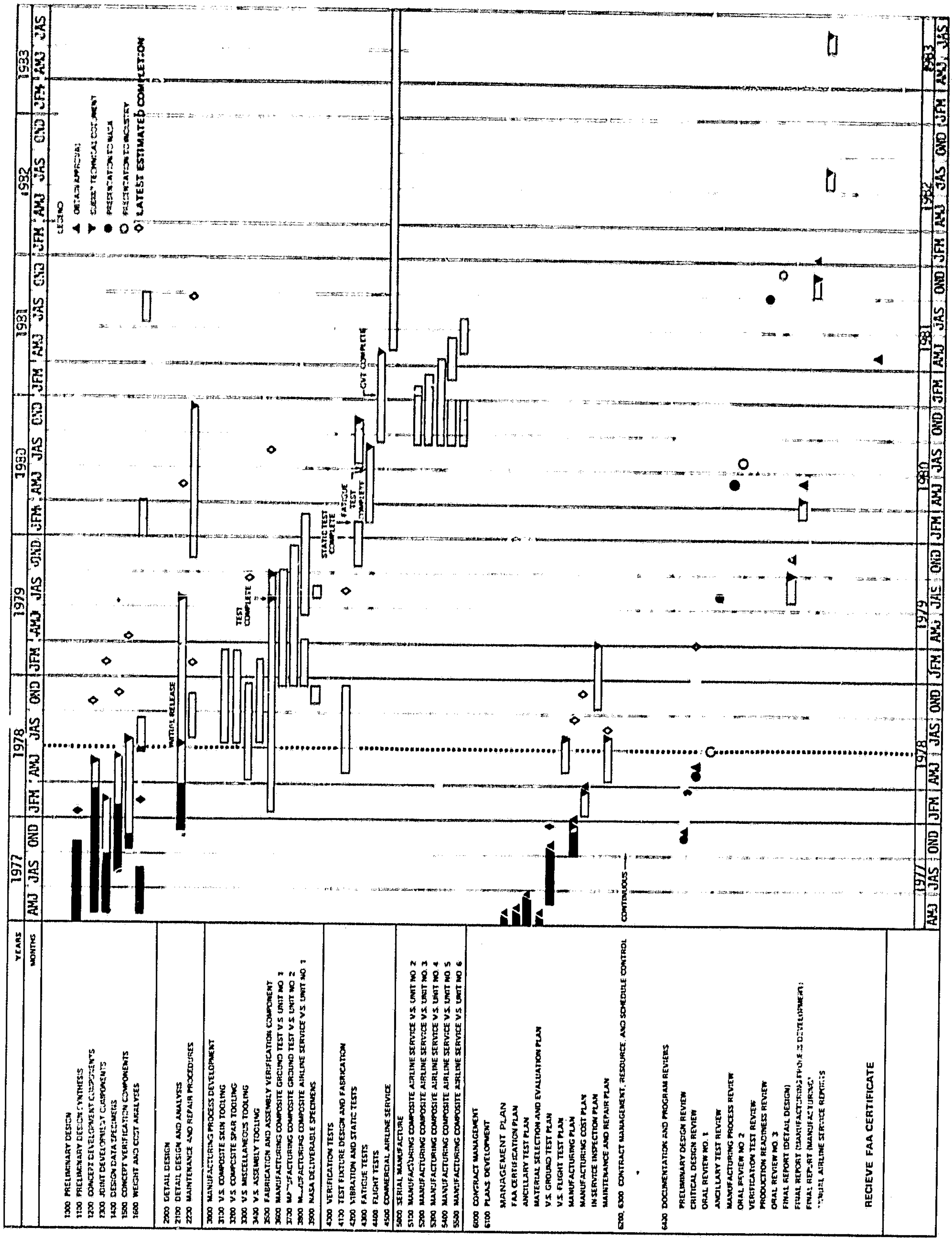

FIGURE 1. SUMMARY SCHEDULE

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SECTION 2
DETAIL DESIGN

Detail design activities on the Composite Vertical Stabilizer were devoted to the development of the sine-wave configuration for the substructure stiffening; detail development of the skin panel design; development of the spar designs; and analysis tasks including detail stress analysis and weight analysis.

Design Development

No significant changes have been made to the basic structural configuration as reported in the last quarterly progress report (Reference 1). This configuration includes one-piece honeycomb sandwich skin panels bolted to a substructure stiffened mainly by sine-wave construction.

Manufacturing considerations indicated that metal tooling would be preferable for fabrication of the sine-wave web elements. With metal tooling, the number of different waveforms would have to be kept to a minimum. With this in mind, an investigation was conducted into the feasibility of using a single waveform throughout the whole substructure. A circular arc wave was selected in preference to an actual sine-wave, because the constant curvature of this form increases the resistance to local buckling and eases the stretching of the layers which has to take place when folding the flanges.

An interactive (FASTBUCK) computer program was prepared to solve for local and general panel instability for any given panel size, laminate and waveform. With the aid of this program, a single waveform was selected for both spar and rib webs (Figure 2). For reasons of simplicity in layup and to keep the number of laminate types to a minimum it was decided to use only bi-weave cloth material. This led to the selection of three basic laminates for the entire substructure. Each rib and spar panel laminate has now been defined and the structural weights associated with the simplified approach are reflected in the latest weight estimates.

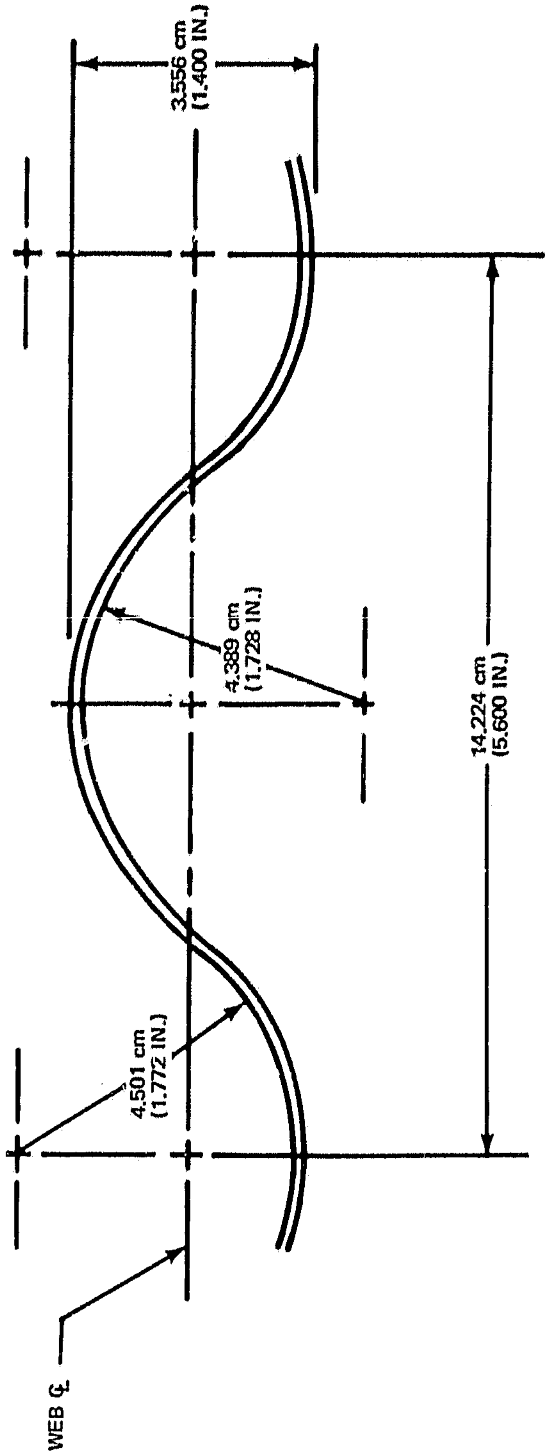

FIGURE 2. WAVE FORM FOR SPAR AND RIB WEB STIFFENING

Another general study which interacts with the design of the skin panels, ribs, and rear spar, concerned the rudder support brackets and their associated fittings within and external to the box structure. While retaining the basic features of the existing support brackets used on the metal stabilizer, most of these brackets have been redesigned in order to make them compatible with the composite design. Internal bathtub-type fittings have been replaced with shorter aluminum fittings, except in the case of the rudder tie-rod stations where fail-safe considerations dictated that the longer fittings be retained.

Skin Panels

Work is continuing on the detail refinement of the skin panel design. A major change is that the highly directional spar cap material within the skin thickness has been replaced with pseudo-isotropic layup. This enables spar cap and rib cap laminates to cross each other without interruption, although this is achieved only at the cost of a weight penalty due to the reduced modulus of the spar cap material. However, the pseudo-isotropic pattern provides good bolt bearing strengths in both spar and rib directions, and is particularly useful in regions of local input, such as at the attachments for the rudder support fittings.

Uni-directional cloth was selected for the caps to enable the spar/rib continuity to be achieved without incurring the waste which would be experienced if bi-weave material were to be used. The use of bi-weave cloth is still retained for the facing layers.

Ribs

Detail design of the ribs is being held in abeyance pending further development on the skin panel and spar components. Sine-wave webs have been selected for most rib elements, and these will have the standard waveforms for which laminate thicknesses have already been designated. The exceptions to sine-wave webs include the aft bays of ribs at tie-rod stations, where the design of bathtub fittings has dictated that thin honeycomb sandwich webs be used.

Spars

Most of the detail design problems at the root end of the spars have already been resolved for the rear spar beam test specimen (drawing Z5943446). It was originally intended that the titanium end fittings would be essentially similar for all four spars, differing only in sweepback and skin bevel angles. However, the front spar fittings are affected by constraints arising from the leading-edge attachment, which lead to differences in the location of the web flange. These final detail considerations are now being resolved.

Sine-wave web geometries and laminate thicknesses have been tentatively selected, including detail stiffening in the flange regions.

Preparation of detail design drawings for the front and aft center spars is now in progress and the design of the rear spar will follow immediately after completion of the rear spar beam specimen drawing.

Structural Analysis

The main emphasis of the structural analysis tasks on the composite stabilizer is on the expansion and improvement of the original redundant force analysis of the complete structure, incorporating the latest version of the stabilizer structural arrangement, more sophisticated finite analysis elements, and modeling a support system of realistic stiffness. The current analysis model is shown in Figure 3. It consists of four basic substructures: 1) the structural box, 2) the leading edge, 3) the forward and aft rudder systems, and 4) the lower vertical stabilizer/inlet duct structure.

Substructures (3) and (4) are existing aircraft components, and the finite element models for these structures are complete. Substructure (2) is an existing component and is in the process of being completed at this time. Substructure (1) has been defined geometrically and the physical and material properties will be defined in greater detail as the design effort progresses.

The analysis method presently contemplated is the MACAIR CADD/CGSA (Computer Aided Design Drafting/Computer Graphics Structural Analysis) System, which allows the structure to be modeled, analyzed, interpeted, edited and optimized entirely on an interactive graphics computer terminal. The system enjoys widespread use throughout the McDonnell Douglas Corporation. A parallel study is in progress using the rear spar beam test specimen analytical model (see Section 6) to determine the relative cost/benefit of using Nastran as the

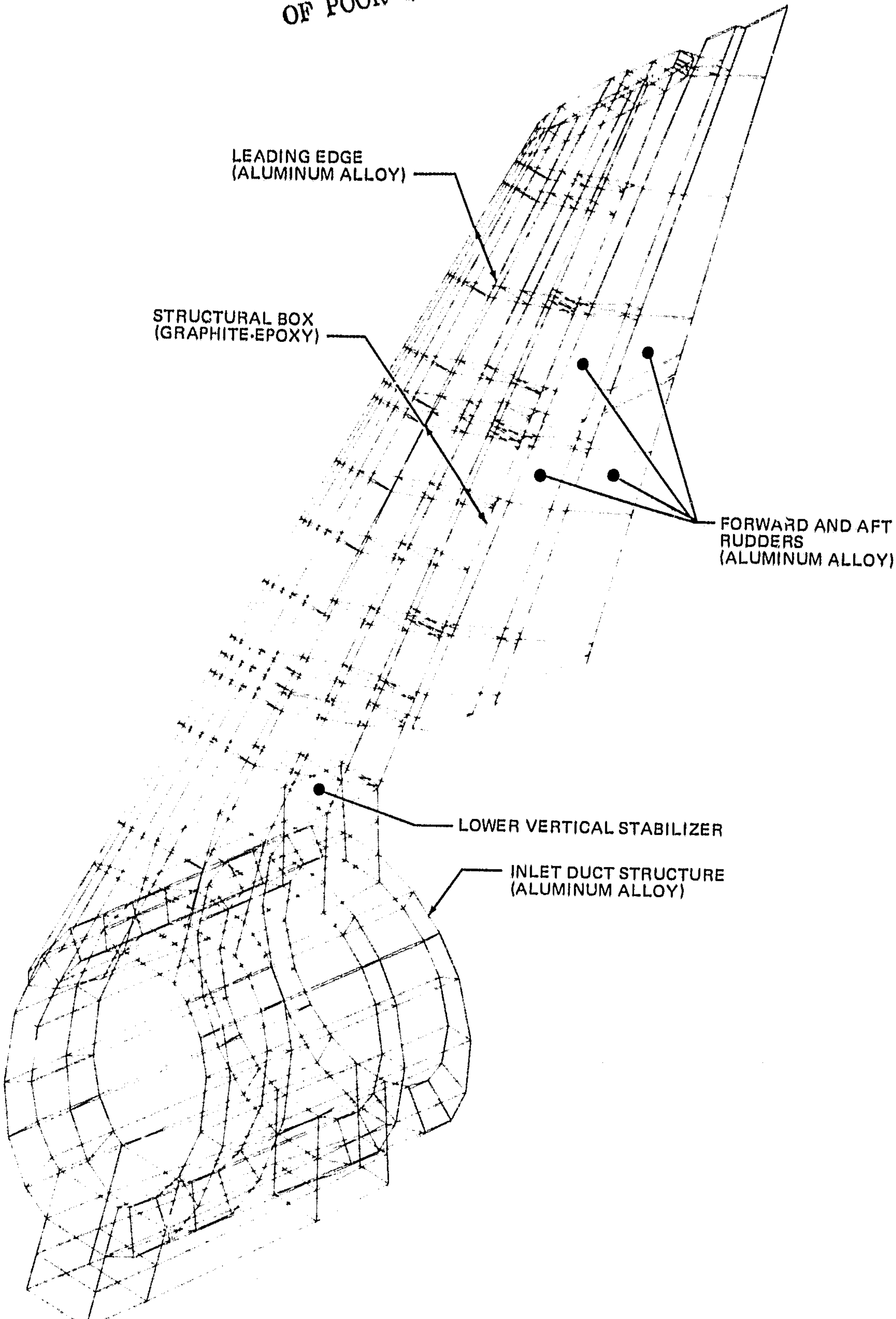

FIGURE 3. COMPOSITE STABILIZER ANALYSIS MODEL

analysis method. The analysis model is amenable to either system and the selection will be made in the near future.

The spar and rib web stiffening configurations were investigated using the FASTBUCK computer program mentioned previously. The derivation of the equations is given in Appendix B together with the assumptions used for limiting the maximum shear loading (N_{xy}) to a strain level of 0.003 cm/cm in the 45° direction.

A number of interesting studies were made with this program. For example, by varying wave radius R and amplitude H of a panel loaded only in shear, and for a given panel size and laminate, it is possible to derive a chart of boundary weight conditions as shown in Figure 4. Minimum values of R and H are determined from the required clearances for the installation of nut-plates, and an upper limit is provided when R is equal to H and the circular arc becomes a semi-circle. Maximum strain is another limit and yet another may be provided if it is desired to keep bolt spacing below a certain value.

However the boundary of most interest occurs when local and general buckling become equal since this represents a minimum weight condition. For a given panel size, a minimum weight boundary of the type shown in Figure 5 can be derived for a full range of possible practical laminates. In another study where waveform was kept constant, the effect of panel size was investigated for particular laminates as shown in Figure 6. Local buckling is seen to be only slightly affected by panel width B and completely independent of panel length A. General buckling on the other hand is greatly influenced by B, and to a lesser extent by A.

Weight Status

The composite stabilizer weights were revised to reflect the redesign of the spar caps, spar webs and rib webs as shown in Table 1. The revised weights are based on design curves and estimates since detailed layouts are not complete. The current predicted weight saving is 20.2 percent.

The most significant weight changes occurred in the spar caps as shown in Table 2. This weight increase was a result of changing the spar cap laminate layup from primarily unidirectional with a modulus of 103 gigapascals (15 MSI) to a pseudo-isotropic layup with a modulus of 55 gigapascals (8 MSI).

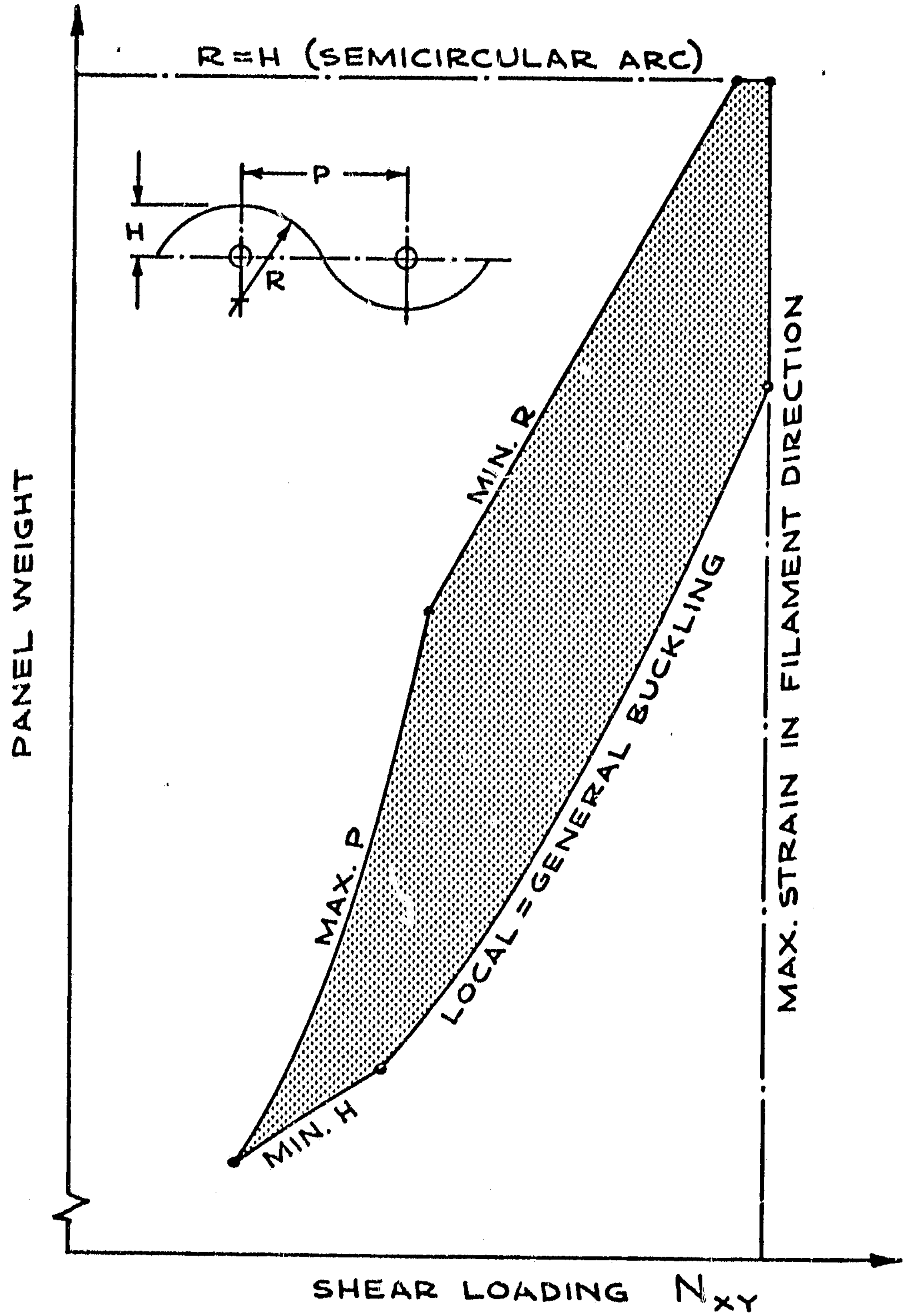

FIGURE 4. TYPICAL WEIGHT BOUNDARY FOR A PARTICULAR LAMINATE AND PANEL SIZE

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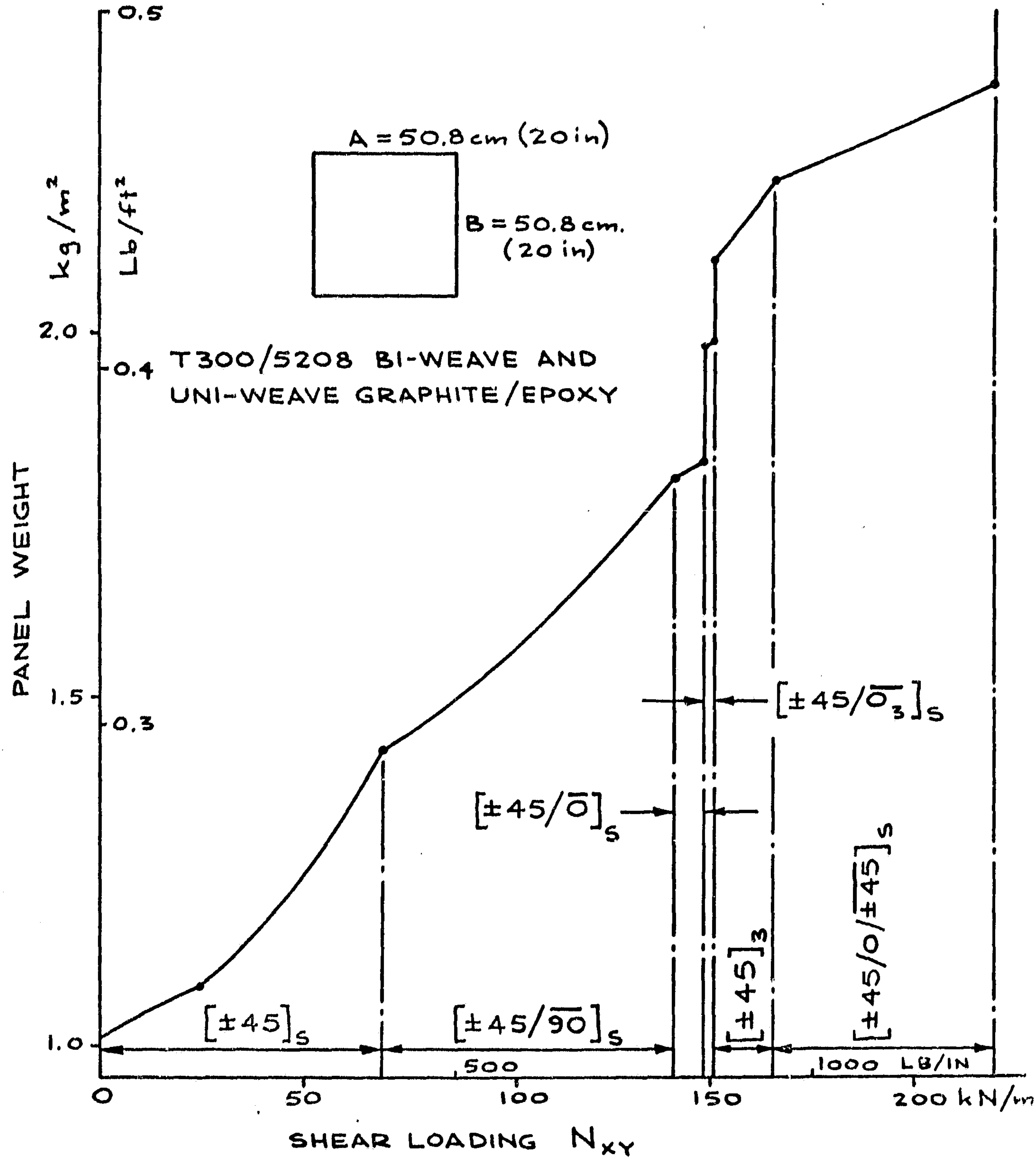

FIGURE 5. MINIMUM WEIGHT BOUNDARY FOR A PARTICULAR PANEL SIZE

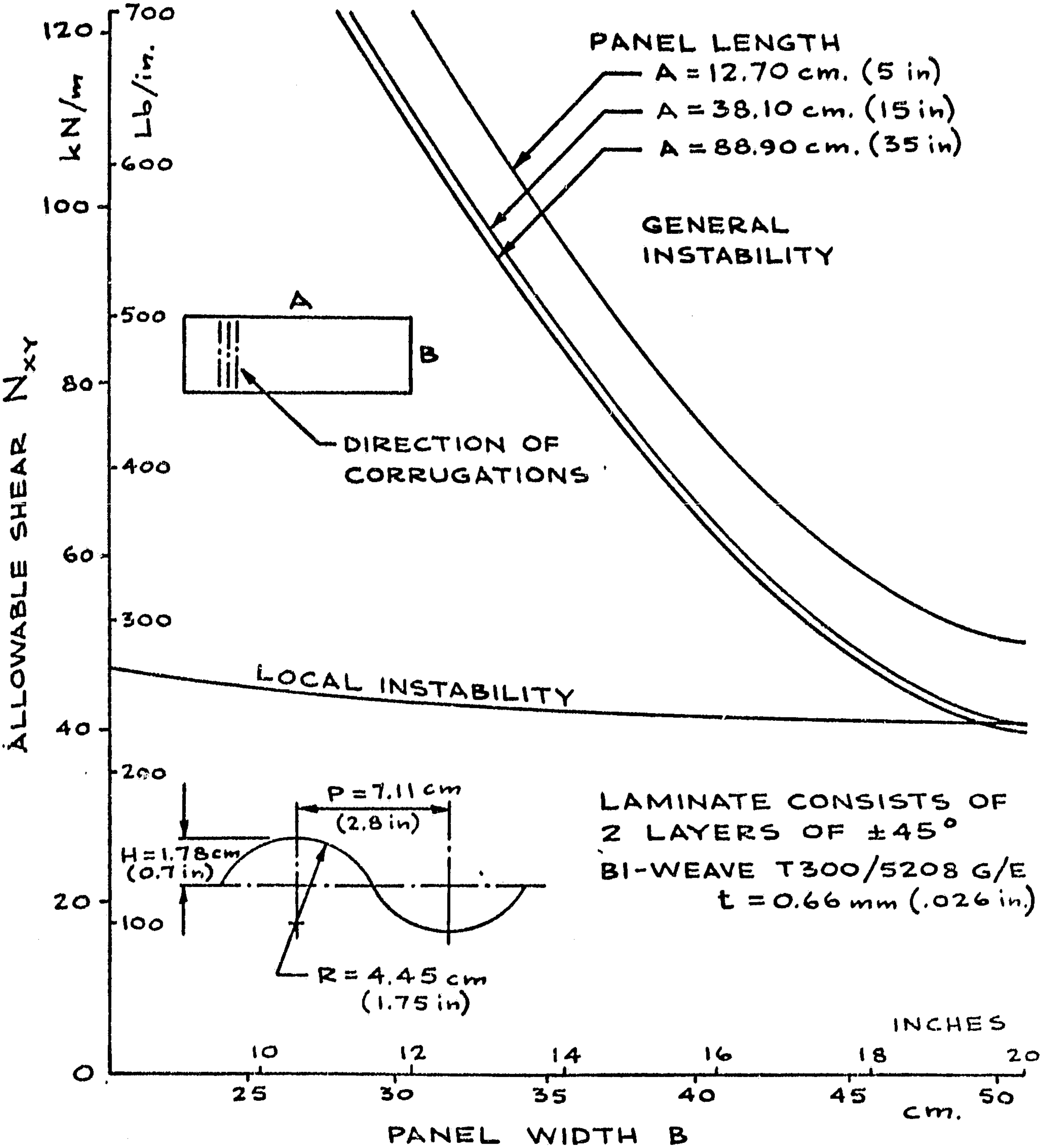

FIGURE 6. ALLOWABLE SHEAR FOR A PARTICULAR LAMINATE AND WAVE FORM

TABLE 1

PRELIMINARY WEIGHT COMPARISONS
COMPOSITE VERTICAL STABILIZER

ITEM	COMPOSITE STABILIZER				METAL STABILIZER	
	PREVIOUS ESTIMATE		LATEST ESTIMATE			
	KILOGRAMS	POUNDS	KILOGRAMS	POUNDS	KILOGRAMS	POUNDS
SPAR CAPS	107.3	236.6	150.0	330.6	158.4	349.2
INTERSPAR SKIN PANELS	78.5	173.1	61.7	136.1	87.5	192.8
SPAR WEBS	50.5	111.3	40.6	89.5	62.4	137.6
INTERSPAR RIBS	58.6	129.2	51.8	114.2	67.9	149.6
ACCESS DOORS	16.6	36.6	16.6	36.6	18.5	40.7
MISCELLANEOUS STRUCTURE	15.5	34.2	13.4	29.5	28.7	63.3
GROWTH/CONTINGENCY	10.7	23.5	4.5	10.0	–	–
BOX STRUCTURE	337.7	744.5	338.6	746.5	423.3	933.2
TRAILING EDGE SKIN AND RIBS	25.3	55.7	25.3	55.7	32.7	72.1
TOTAL – BOX AND TRAILING EDGE	363.0	800.2	363.9	802.2	456.0	1005.3
WEIGHT REDUCTION	93.0	205.1	92.1	203.1	–	–
PERCENT REDUCTION	20.4	20.4	20.2	20.2	–	–

TABLE 2

WEIGHT CHANGE SUMMARY
COMPOSITE VERTICAL STABILIZER

ITEM	WEIGHT CHANGE	
	KILOGRAMS	POUNDS
SPAR CAPS • CHANGE SPAR CAP MATERIAL TO PSEUDO-ISOTROPIC LAYUP • REALLOCATE FASTENERS TO SPAR CAPS	+42.6	+94.0
SKIN PANELS • REALLOCATE FASTENERS TO SPAR CAPS	–16.8	–37.0
SPAR WEBS • CHANGE SPAR WEB DESIGN FROM SANDWICH TO SINE-WAVE	–9.9	–21.8
RIBS • CHANGE RIB WEB DESIGN FROM SANDWICH TO SINE-WAVE	–6.8	–15.0
MISCELLANEOUS STRUCTURE • CHANGE TO SMALLER STEEL BUSHINGS FOR ATTACH FITTINGS	–2.1	–4.7
GROWTH/CONTINGENCY ALLOWANCE	–6.1	–13.5
TOTAL WEIGHT CHANGE	+0.9	+2.0

The sine-wave spar webs and rib webs resulted in a weight savings of 16.7 kilograms (36.8 pounds). The steel bushings in the titanium attach fittings are smaller than those previously required for the composite attach fittings resulting in a 2.1 kilogram (4.7 pound) weight saving that was not reported in the last quarterly progress report (Reference 1).

The growth and contingency allowance was partially absorbed reflecting the weight growth that has occurred. A 4.5 kilogram (10 pound) contingency allowance remains.

The weight distribution by material is summarized in Table 3. A weight-time history of the predicted weight and target weight is shown in Figure 7.

TABLE 3

WEIGHT DISTRIBUTION BY MATERIAL
COMPOSITE VERTICAL STABILIZER

ITEM	MATERIAL WEIGHT																			
	GRAPHITE-EPOXY		TITANIUM		ADHESIVE		NOMEX HONEYCOMB		SYNTACTIC FOAM		ALUMINUM		STEEL		FASTENERS		EXTERIOR FNISH		TOTAL	
	kg	LB	kg	LB	kg	LB	kg	LB	kg	LB	kg	LB	kg	LB	kg	LB	kg	LB	kg	LB
SPAR CAPS	96.6	213.0	46.1	101.6											7.3	16.0			155.0	330.6
SKIN PANELS	32.7	72.1			13.0	28.7	6.2	13.7	1.7	3.7	6.8*	15.1*			1.3	2.8			61.7	136.1
SPAR WEBS	37.5	82.6			1.5	3.4	1.0	2.2	0.6	1.3									40.6	89.5
RIBS	45.5	100.3			0.4	0.9	0.2	0.5	0.2	0.5	2.8	6.1			2.7	5.9			51.8	114.2
ACCESS DOORS	10.5	23.1			1.1	2.5	0.5	1.2	0.4	0.9	1.6*	3.5*			2.4	5.4			16.6	36.6
MISCELLANEOUS STRUCTURE	4.6	10.1			0.6	1.3					4.2	9.3	1.5	3.2	0.2	0.4	2.4	5.2	13.4	29.5
GROWTH/CONTINGENCY																			**	**
BOX SUBTOTAL	227.3	501.2	46.1	101.6	16.7	36.8	8.0	17.6	2.9	6.4	15.4	34.0	1.5	3.2	13.8	30.5	2.4	5.2	334.1	736.5
TRAILING EDGE	13.8	30.4			0.4	0.8	0.1	0.3	0.3	0.6	8.2	18.0	0.7	1.6	1.5	3.3	0.3	0.7	25.3	55.7
TOTAL WEIGHT	241.1	531.6	46.1	101.6	17.1	37.6	8.1	17.9	3.2	7.0	23.6	52.0	2.2	4.8	15.3	33.8	2.7	5.9	359.4	792.2

*ALUMINUM SPRAY COATING
**GROWTH/CONTINGENCY ALLOWANCE OF 10 POUNDS NOT INCLUDED

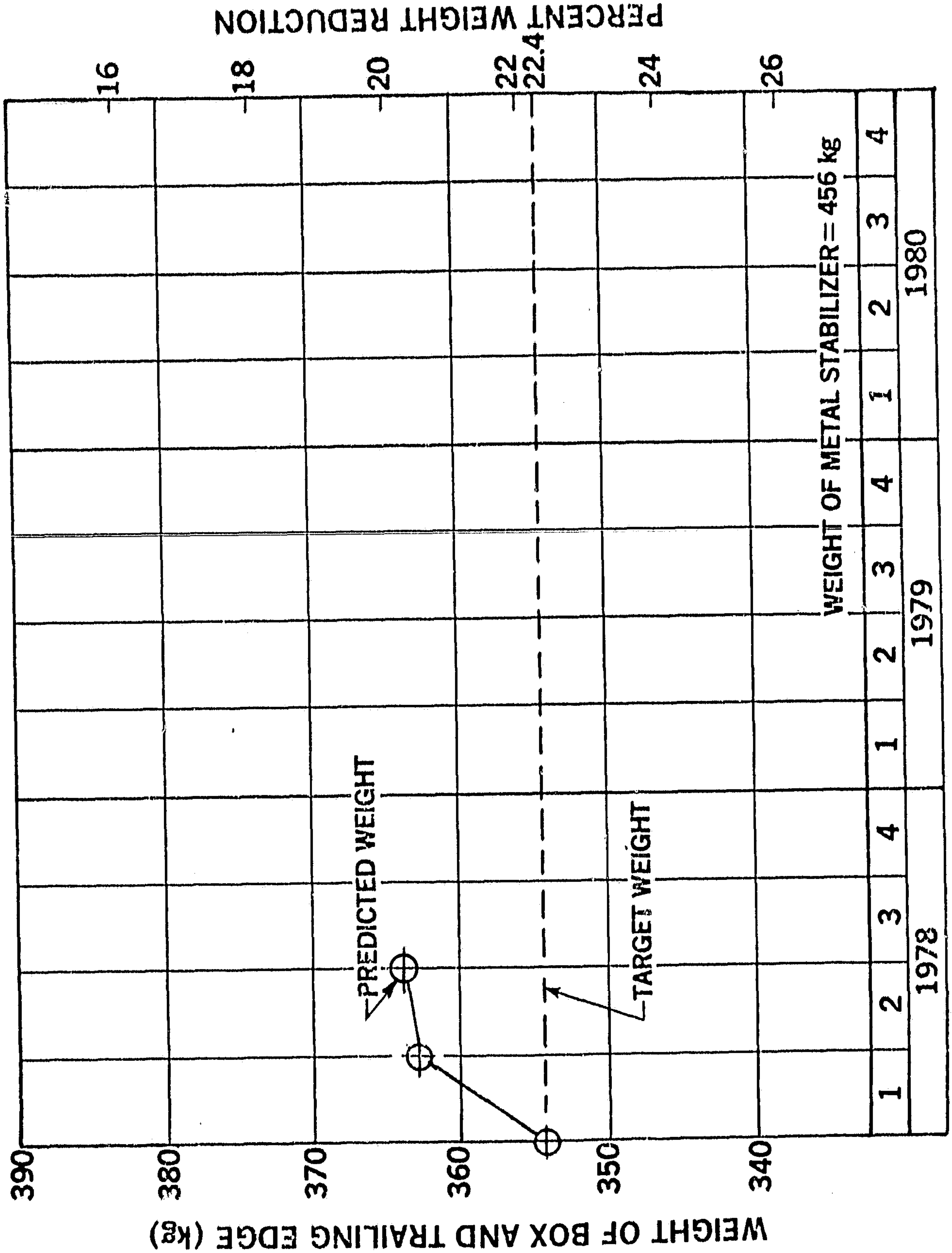

FIGURE 7. COMPOSITE VERTICAL STABILIZER WEIGHT TREND

SECTION 3

CONCEPT DEVELOPMENT TEST COMPONENTS

The candidate structural design concepts are being evaluated through a program of design, fabrication, and test of a series of development components representing critical elements of the structure. The current status of these activities is described in this section.

Skin Panel Components

Tests at ambient temperatures were completed on two of the remaining six honeycomb shear panels (P/N Z5943428-501). Both test panels exhibited failure loads well in excess of the maximum design ultimate shear loading of 132746 n/m (758 pounds per inch) based on the latest internal load analysis.

The first specimen was tested under in-plane shear with no pre-test moisture conditioning. Failure occurred at a load of 166808 Newtons (37,500 pounds) corresponding to a distributed shear loading of 255160 n/m (1457 pounds per inch). Failure apparently initiated near one corner of the panel adjacent to the support angle (Figure 8). The failure proceeded along the panel edge and then across the short side of the specimen. The failure was somewhat premature in that the predicted failure load in the basic sandwich was 257787 n/m (1472 pounds per inch) for the test panel size.

The second specimen was tested under in-plane shear after pre-test conditioning to approximately 1.2 percent moisture level. Failure occurred at a load of 182377 Newtons (41,000 pounds) corresponding to a distributed shear loading of 278977 n/m (1593 pounds per inch). Failure occurred across the specimen through the basic sandwich (Figure 9). The predicted failing load (disregarding moisture effects) was 257787 n/m (1472 pounds per inch) as before. This failure is considered to be typical of the level expected from the sandwich skin panels.

Testing of the remaining cover panels requires loading with the test panel under controlled temperature and humidity conditions. Tests will be conducted in the 733957 Newton (165,000-lb) Schenck Universal Test Machine utilizing the special

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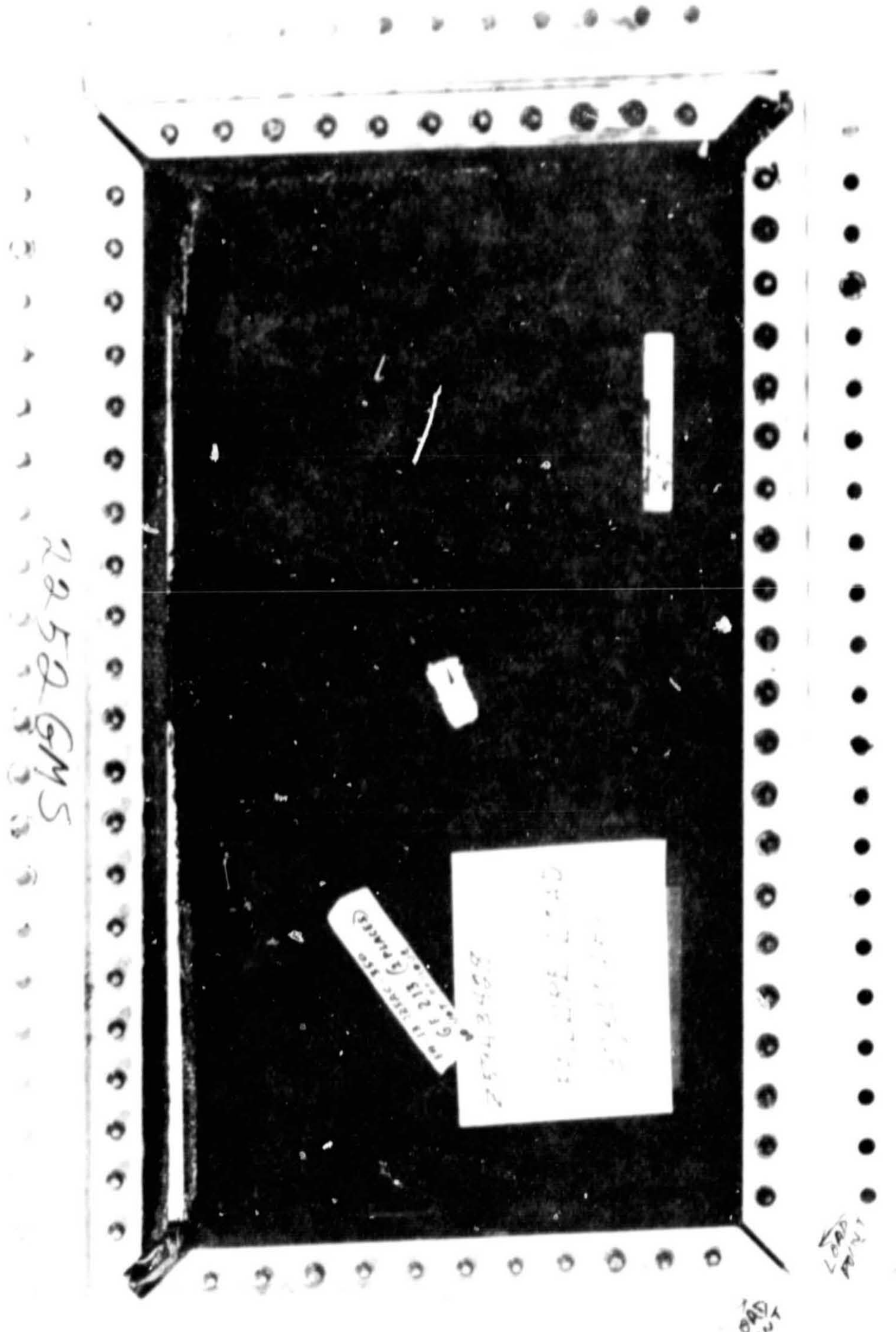

FIGURE 8. FIRST Z5943428-501 PANEL SHEAR TEST SPECIMEN

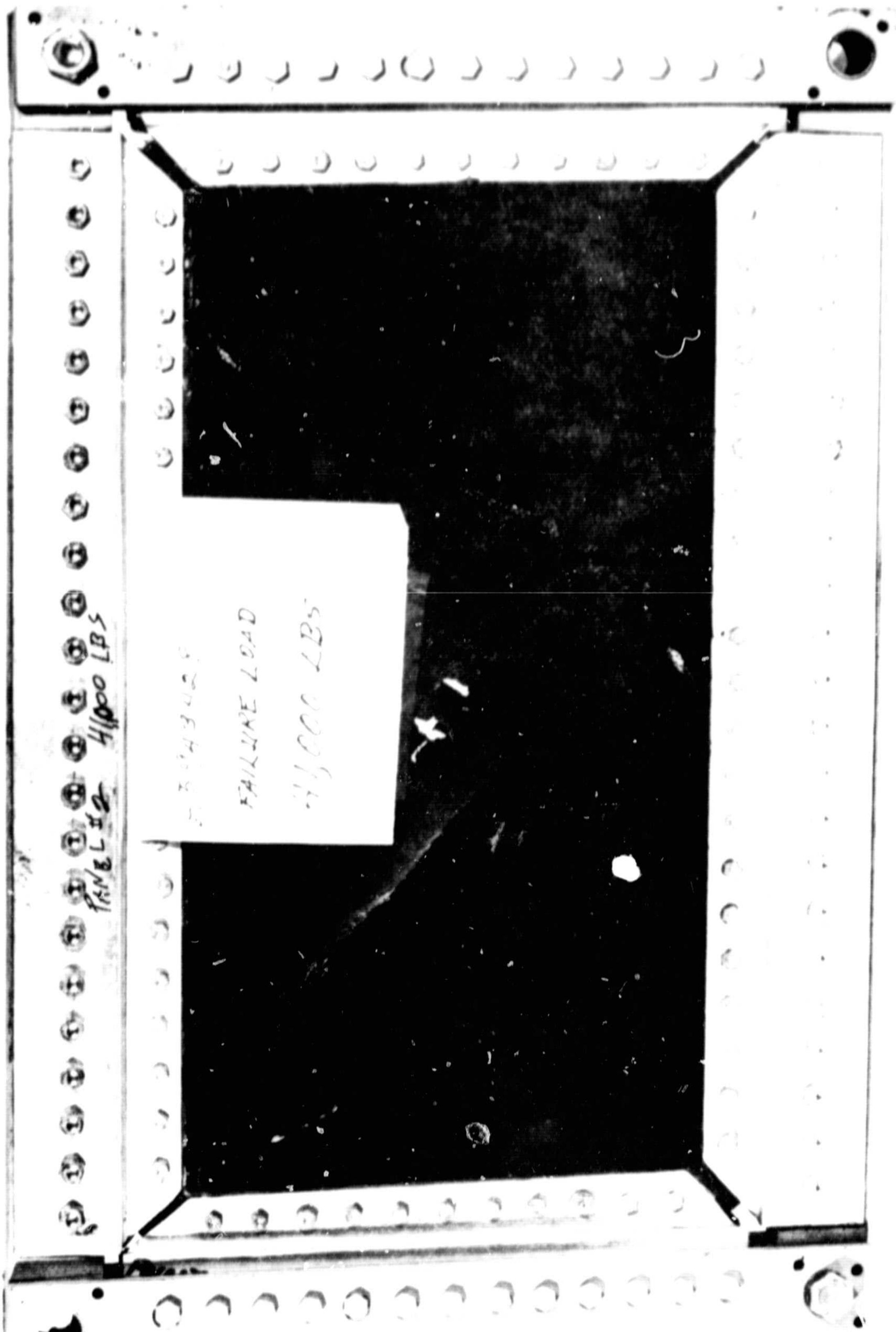

FIGURE 9. SECOND Z5943428-501 PANEL SHEAR TEST SPECIMEN

environmental chamber procured for tests in the 1.78 meganewton (400,000-lb) Baldwin Test Machine. Extenders were designed and fabricated to extend the upper and lower loading heads thru the chamber walls with provisions on the inside for applying load to the test panel. These extenders are of heat treated, corrosion resistant steel and were fabricated by a specialty machine shop having the capability to trepan core (hole-saw) the heavy steel billets. Delivery was made on 27 June, and the entire setup is currently being assembled in the test facility. A portable thermal conditioner is available for circulating the required hot/humid or cold air thru the chamber during the testing.

Spar Web Components

The Z5943435 honeycomb spar web component was tested during the report period. The component was tested at ambient temperatures with no pre-test moisture conditioning. Loads were applied to the component as a simply supported beam as shown in Figure 10. Failure occurred when the jack load reached 102487 Newtons (23,040 pounds) corresponding to a shear load in the sandwich web of 112081 n/m (640 pounds per inch). Failure occurred when the lower composite angle attaching the web to the spar cap separated from the web (Figure 11). The design ultimate load for the sandwich web portion of the specimen was 105076 n/m (600 pounds per inch).

Both halves of the fiberglass/epoxy tool for fabricating the Z5943434 sine-wave spar web test component have been completed. A rubber facing approximately 0.32 cm (1/8 inch) thick was provided on the tool surfaces to help distribute uniform curing pressure to the thin composite shear web. The surfaces of the tool were lightly sanded, cleaned, and primed with 1-100 silicone rubber primer. Two layers of uncured 0.157 cm (0.062 inch) thick silicone rubber sheet stock were rolled and pressed to the sine wave facing. After removing all air entrapments, a layer of Armalon cloth was applied to the uncured silicone rubber and held in place by cellophane tape. The sheet of silicone rubber was drape formed on the curved tool surfaces and held in place by cellophane tape. The tool was placed in a vacuum bag for the curing cycle. The finished tool is shown in Figure 12.

Once the tool was completed, the test component was laid-up, densified, and placed in the autoclave for cocuring and bonding. During the cure cycle the temperature recorder malfunctioned resulting in loss of the vacuum bag after the test component

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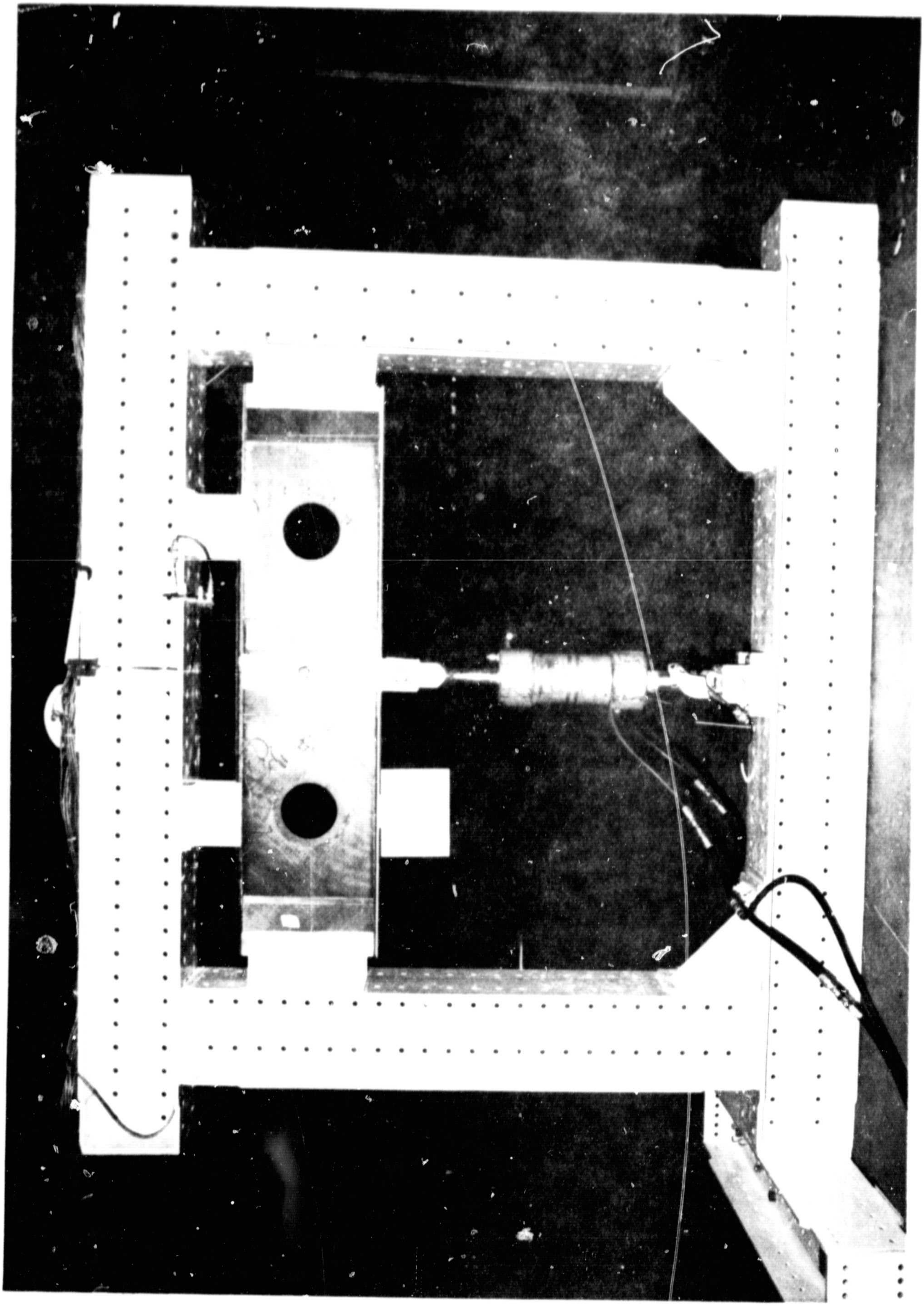

FIGURE 10. TEST SETUP FOR HONEYCOMB SPAR WEB COMPONENT

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FIGURE 11. FAILURE OF HONEYCOMB SPAR WEB COMPONENT

FIGURE 12. CURED SINE WAVE SPAR WEB COMPONENT PLM

had reached 450°K (350°F). Loss of the bag resulted in incomplete bonding over extensive portions of the web making the component unacceptable for test.

A second sine wave spar web component is currently being fabricated and is scheduled for completion on 21 July 1978.

Galvanic Corrosion Specimens

Fabrication activities were completed on six additional specimens. These additional specimens will be used to further evaluate RF bond continuity and to establish whether a fiberglass isolation layer between the aluminum and the graphite will be required.

The six specimens were prepared as follows:

(1) Abrade graphite surface, spray on aluminum, and apply a faying surface seal.
(2) Same as (1), except no faying surface seal.
(3) Abrade, spray, seal, and apply a Dacron scrim isolation layer.
(4) Same as (3) except no seal.
(5) Abrade, spray, seal and apply a fiberglass peel ply.
(6) Same as (5) except no seal.

These specimens will be placed in the salt spray chamber for a thirty day exposure period. This test should be complete early in August 1978.

Lightning Evaluation Panel

The composite portion of the panel has been completed and flame sprayed with aluminum. The metal details are complete and ready for assembly to the panel. Further fabrication activity will be postponed until the galvanic corrosion specimens are completed, tested, and evaluated.

SECTION 4
JOINT DEVELOPMENT TEST COMPONENTS

Structural joint concepts are being evaluated through a program of design, fabrication, and test of selected development components representing critical joints of the composite structure. Current status of these activities is detailed in the following paragraphs.

Rudder Fitting Design

Test specimens for the actuator and tie-rod stations have been redesigned in conformance with the latest design configuration. A copy of the drawing (Z5943453) is included in Appendix A. These specimens contain aluminum fittings which transfer loads from the rudder support brackets into the composite structure. In the case of the tie-rod specimen, where fail-safe requirements prohibit the loss of both tie-rods at any one station, separate bathtub fittings extend between the rear and the aft center spars. Shorter fittings are used at the actuator station, but the moment due to the offset of the bracket load from the skin line is reacted by a fitting which extends from one skin surface to the other. For this reason the specimen for this station includes both skins so that this moment reaction can be simulated.

Spar Cap to Cover Specimens

Tests were completed on the four Z5943444 spar cap-to-cover specimens. The specimens were tested under ambient laboratory conditions after pre-test moisture conditioning at 170°F and 95 percent relative humidity.

The four test results are summarized below.

Z5943444 Spar Cap-to-Cover Specimen Test Results

Specimen	Load at Failure		Moisture Level	Running Load	
	(Newtons)	(Pounds)		(n/m)	(Lb/In)
-1 Sine Wave Bolted	6316	1420	0.6%	41,505	237
-501 Sine Wave Cocured	3790	852	0.9%	24,868	142
-503 Plain Web Bonded	3336	750	1.0%	21,891	125
-505 Plain Web Cocured	4493	1010	1.0%	29,246	168

The stabilizer skin panels are subjected to a maximum joint tensile load from external lifting pressure of approximately 17,237 n/m^2 (2.50 psi) limit or 25,855 n/m^2 (3.75 psi) ultimate, equivalent to a spar cap-to-cover running load of approximately 7180 n/m (41 pounds per inch). This load requirement is well below the test results.

Figure 13 shows the failure of the -1 bolted sine-wave specimen, typical of all failures in this series.

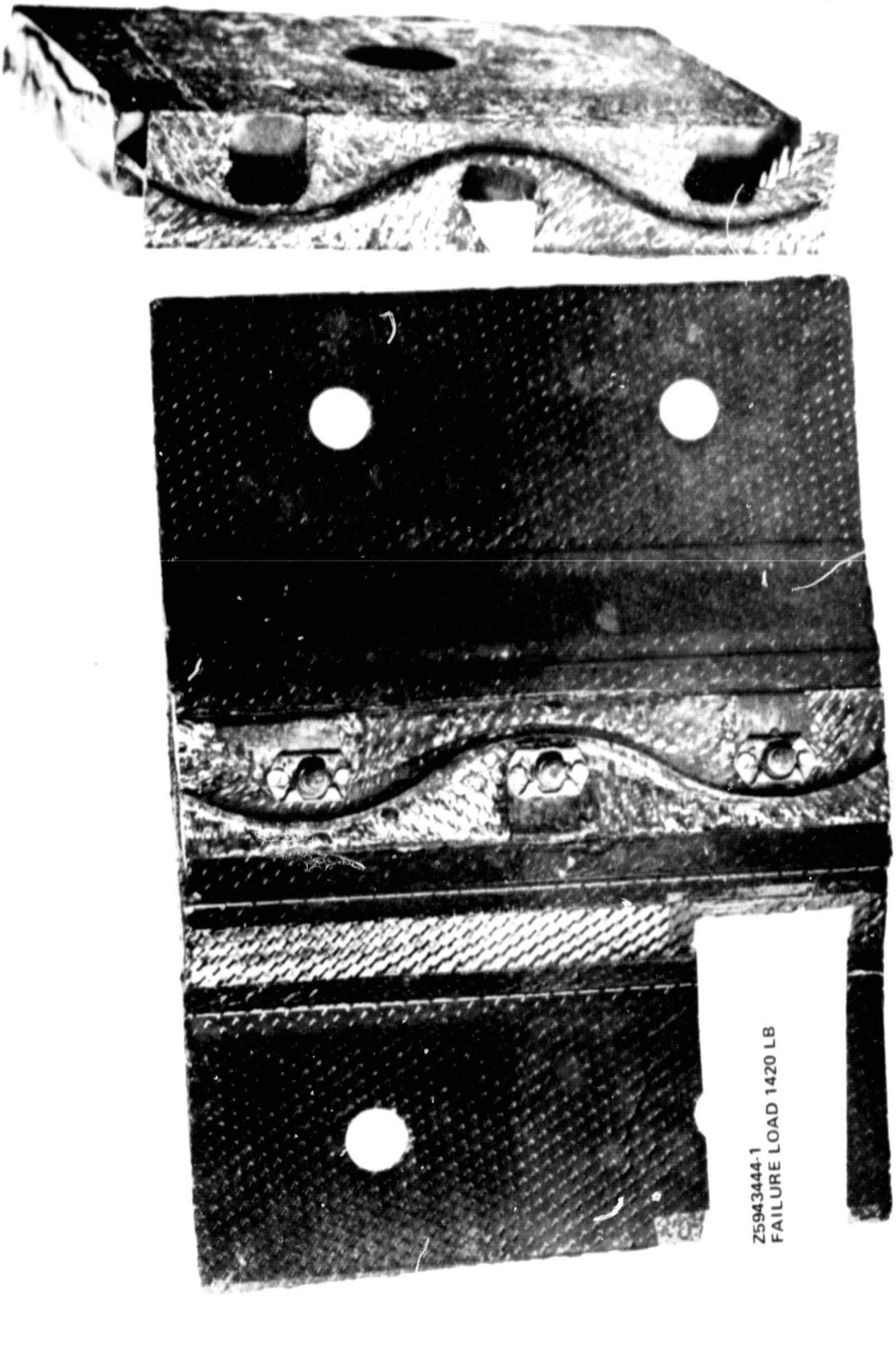


FIGURE 13. FAILURE OF SINE-WAVE BOLTED SPECIMEN

SECTION 5
MECHANICAL PROPERTIES SPECIMENS

Material design allowables and damage tolerance of the composite structure are being verified through a test program involving testing of sandwich beam specimens to determine laminate tension, compression and fatigue properties; testing of tension coupons to determine laminate bearing and shear-out values; testing of tension specimens in fatigue to evaluate flaw growth; and testing of sandwich panels to evaluate crack propogation and damage tolerance.

Laminate Properties Design Data

Testing of 66 of the 102 sandwich beam tension specimens and 42 of the 102 sandwich beam compression specimens (Drawing Z3943432) was completed during the report period.

Four of the fatigue test beams have been tested to cyclic levels greater than predicted values. Residual strengths were determined on three of these beams to help determine stress levels for subsequent tests. The fatigue test was continued on the fourth beam to achieve a fatigue failure if possible, since no additional tests were scheduled on the test machine in the near term. During testing of the fourth beam, the flexural pivots on the test machine failed so the test was suspended until repairs can be completed. Results achieved to date on the sandwich beams are shown in Tables 4 through 12.

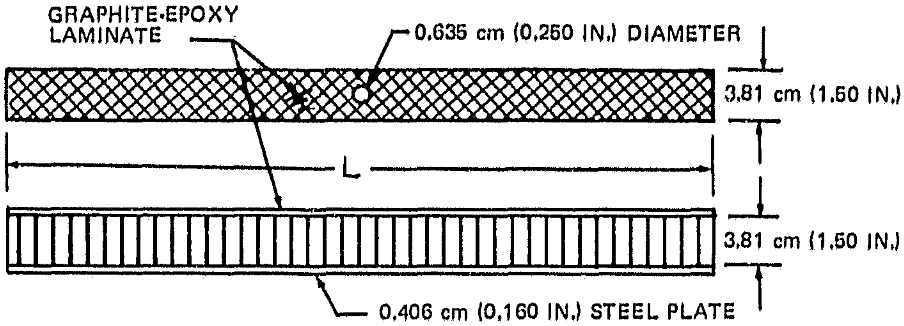
Shear-out tests on 24 of the 36 bearing and shear-out coupons were completed and the results are tabulated in Tables 13 through 16.

There are 176 sandwich beam specimens fabricated to date out of a total of 312. The remaining specimens are expected to be complete in July 1978. All of the 36 bearing and shear-out coupons are complete.

Figures 14 through 17 show a sandwich beam specimen and typical laminate failures. Figures 18 through 21 show a bearing and shear-out specimen and laminate failures from the shear-out tests.

TABLE 4

SANDWICH BEAM TEST SPECIMENS



DRAWING Z3943432
T300/5208 GRAPHITE-EPOXY

DRAWING DASH NO.	SPECIMEN TYPE	LENGTH L		LAMINATE PATTERN	NOMINAL LAMINATE THICKNESS	
		cm	IN.		cm	IN.
-1	STATIC	55.88	22.00	25/50/25	0.132	0.052
-501	STATIC	55.88	22.00	39/41/20	0.163	0.064
-503	STATIC	55.88	22.00	65/35/0	0.188	0.074
-505	FATIGUE	80.65	31.75	25/50/25	0.132	0.052
-507	FATIGUE	80.65	31.75	39/41/20	0.163	0.064
-509	FATIGUE	80.65	31.75	65/35/0	0.188	0.074

TABLE 5

SANDWICH BEAM STATIC TENSION TESTS

Z3943432-1
LAYUP: [25/50/25]

PERCENT MOISTURE CONTENT	TEST TEMPERATURE °K	TEST TEMPERATURE °F	SPECIMEN NUMBER	LAMINATE THICKNESS cm	LAMINATE THICKNESS IN.	STRESS ON NET SECTION AT FAILURE MPa	STRESS ON NET SECTION AT FAILURE PSI	STRAIN AT FAILURE μ cm/cm	MODULUS GPa	MODULUS MSI
AMBIENT	219	-65	BET 267	0,1455	0,0573	321,29	46,599	4700	57,02	8,27
			BET 268	0,1506	0,0593	308,89	44,800	4625	56,95	8,26
			BET 269	0,1494	0,0588	312,57	45,334	–	–	–
AMBIENT	AMBIENT	AMBIENT	BET 270	0,1435	0,0565	345,67	50,136	4400	65,43	9,49
			BET 387	0,1466	0,0577	336,44	48,797	4600	61,02	8,85
			BET 388	0,1481	0,0583	336,72	48,837	–	–	–
AMBIENT	350	170	BET 389	0,1499	0,0590	331,02	48,010	5250	52,61	7,63
			BET 390	0,1509	0,0594	321,42	46,618	5000	53,64	7,78
			BET 391	0,1473	0,0580	345,33	50,086	–	–	–
AMBIENT	394	250	BET 392	0,1438	0,0566	353,49	51,270	5200	56,74	8,23
			BET 393	0,1443	0,0568	326,93	47,417	4800	56,81	8,24
			BET 394	0,1473	0,0580	344,11	49,909	–	–	–
1,22	AMBIENT	AMBIENT	BET 249	0,1476	0,0581	333,52	48,373			
			BET 250	0,1450	0,0571	338,11	49,039			
			BET 251	0,1430	0,0563	374,22	54,276			
			BET 252	0,1417	0,0558	369,96	53,658			
			BET 253	0,1488	0,0586	353,98	51,341			
			BET 254	0,1494	0,0588	341,24	49,492			
1,69	350	170	BET 255	0,1486	0,0585	322,74	46,809	4600	58,54	8,49
			BET 256	0,1506	0,0593	320,47	46,480	4750	56,26	8,16
			BET 257	0,1486	0,0585	353,64	51,291	–	–	–
			BET 258	0,1400	0,0567	348,95	50,611	–	–	–
			BET 259	0,1471	0,0579	324,13	47,011	–	–	–
			BET 260	0,1455	0,0573	330,98	48,004	–	–	–
1,14	394	250	BET 261	0,1483	0,0584	326,47	47,350	4700	57,92	8,40
			BET 262	0,1400	0,0551	341,21	49,489	4900	58,05	8,42
			BET 263	0,1392	0,0548	327,62	47,517	–	–	–
			BET 264	0,1499	0,0590	317,12	45,995	–	–	–
			BET 265	0,1532	0,0603	312,69	45,352	–	–	–
			BET 266	0,1481	0,0583	325,89	47,267	–	–	–

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TABLE 6

SANDWICH BEAM STATIC TENSION TESTS

Z3943432-501
LAYUP: [39/41/20]

PERCENT MOISTURE CONTENT	TEST TEMPERATURE °K	TEST TEMPERATURE °F	SPECIMEN NUMBER	LAMINATE THICKNESS cm	LAMINATE THICKNESS IN.	STRESS ON NET SECTION AT FAILURE MPa	STRESS ON NET SECTION AT FAILURE PSI	STRAIN AT FAILURE μ cm/cm	MODULUS GPa	MODULUS MSI
1.19	AMBIENT	AMBIENT	BET 307	0.1666	0.0656	427.86	62,056	4750	75.01	10.88
			BET 308	0.1689	0.0665	412.40	59,814	4700	73.08	10.60
			BET 309	0.1669	0.0657	418.99	60,769	–	–	–
			BET 310	0.1689	0.0665	471.66	68,409	–	–	–
			BET 311	0.1742	0.0686	442.44	64,170	–	–	–
			BET 312	0.1730	0.0681	435.42	63,152	–	–	–
1.08	350	170	BET 319	0.1689	0.0665	409.92	59,454	4800	71.15	10.32
			BET 320	0.1676	0.0660	414.42	60,107	4725	73.08	10.60
			BET 321	0.1615	0.0636	464.03	67,302	–	–	–
			BET 322	0.1664	0.0655	476.54	69,116	–	–	–
			BET 323	0.1694	0.0667	409.91	59,452	–	–	–
			BET 324	0.1692	0.0666	430.03	62,370	–	–	–
0.57	394	250	BET 325	0.1697	0.0668	424.41	61,556	4250	83.15	12.06
			BET 326	0.1722	0.0678	423.77	61,462	4350	81.15	11.77
			BET 327	0.1704	0.0671	434.07	62,957	–	–	–
			BET 328	0.1750	0.0689	438.60	63,614	–	–	–
			BET 329	0.1730	0.0681	426.88	61,914	–	–	–
			BET 330	0.1712	0.0674	446.83	64,807	–	–	–

TABLE 7

SANDWICH BEAM STATIC TENSION TESTS

Z3943432-503
LAYUP: [65/35/0]

PERCENT MOISTURE CONTENT	TEST TEMPERATURE °K	TEST TEMPERATURE °F	SPECIMEN NUMBER	LAMINATE THICKNESS cm	LAMINATE THICKNESS IN.	STRESS ON NET SECTION AT FAILURE MPa	STRESS ON NET SECTION AT FAILURE PSI	STRAIN AT FAILURE μ cm/cm	MODULUS GPa	MODULUS MSI
1.10	219	−65	BET 361	0.2014	0.0793	595.47	86,365	4250	116.52	16.90
			BET 362	0.2009	0.0791	466.55	67,668	4000	97.35	14.12
			BET 363	0.2019	0.0795	499.35	72,424	–	–	–
			BET 364	0.2019	0.0795	552.19	80,089	–	–	–
			BET 365	0.2040	0.0803	471.37	68,367	–	–	–
			BET 366	0.1956	0.0770	545.71	79,149	–	–	–
1.12	AMBIENT	AMBIENT	BET 367	0.1951	0.0768	645.00	93,550	4850	110.80	16.07
			BET 368	0.1890	0.0744	607.04	88,043	4350	116.45	16.89
			BET 369	0.2060	0.0811	657.63	95,381	–	–	–
			BET 370	0.2007	0.0790	570.83	82,792	–	–	–
			BET 371	0.2002	0.0788	700.45	101,592	–	–	–
			BET 372	0.1938	0.0763	706.77	102,508	–	–	–
1.12	AMBIENT	AMBIENT	BET 373	0.1951	0.0768	774.49	112,330			
			BET 374	0.2007	0.0790	828.31	120,136			
			BET 375	0.2017	0.0794	690.34	100,125			
			BET 376	0.1976	0.0778	709.84	102,954			
			BET 377	0.1999	0.0787	701.65	101,766			
			BET 378	0.1920	0.0756	741.45	107,538			

TABLE 8

SANDWICH BEAM STATIC COMPRESSION TESTS

Z3943432-1
LAYUP: [25/50/25]

PERCENT MOISTURE CONTENT	TEST TEMPERATURE		SPECIMEN NUMBER	LAMINATE THICKNESS		STRESS ON NET SECTION AT FAILURE		STRAIN AT FAILURE	MODULUS	
	°K	°F		cm	IN.	MPa	PSI	μ cm/cm	GPa	MSI
AMBIENT	219	-65	BET 201	0,1415	0,0557	395,50	57,943	6450	51,64	7,49
			BET 202	0,1384	0,0545	388,97	56,516	–	–	–
			BET 203	0,1377	0,0542	412,30	59,799	–	–	–
AMBIENT	AMBIENT	AMBIENT	BET 204	0,1440	0,0567	366,99	53,228	5500	55,64	8,07
			BET 205	0,1397	0,0550	334,81	48,560	–	–	–
			BET 206	0,1443	0,0568	347,42	50,389	–	–	–
AMBIENT	350	170	BET 207	0,1476	0,0581	314,20	45,571	5400	48,54	7,04
			BET 208	0,1438	0,0566	322,23	46,736	–	–	–
			BET 209	0,1443	0,0568	314,51	45,616	–	–	–
AMBIENT	394	250	BET 210	0,1461	0,0575	306,16	44,403	5000	51,09	7,41
			BET 211	0,1453	0,0572	307,91	44,659	–	–	–
			BET 212	0,1440	0,0567	307,84	44,649	–	–	–
1,43	AMBIENT	AMBIENT	BET 225	0,1488	0,0586	382,58	55,488			
			BET 226	0,1501	0,0591	368,47	53,442			
			BET 227	0,1478	0,0582	349,34	50,667			
			BET 228	0,1488	0,0586	388,04	56,280			
			BET 229	0,1433	0,0564	374,35	54,295			
			BET 230	0,1400	0,0567	360,48	52,283			

TABLE 9

SANDWICH BEAM STATIC COMPRESSION TESTS

Z3943432-501
LAYUP: [39/41/20]

PERCENT MOISTURE CONTENT	TEST TEMPERATURE		SPECIMEN NUMBER	LAMINATE THICKNESS		STRESS ON NET SECTION AT FAILURE		STRAIN AT FAILURE	MODULUS	
	°K	°F		cm	IN.	MPa	PSI	μ cm/cm	GPa	MSI
1,21	219	-65	BET 271	0,1656	0,0652	490,53	71,146	5550	73,70	10,69
			BET 272	0,1684	0,0663	493,13	71,523	5490	74,95	10,87
			BET 273	0,1727	0,0680	476,34	69,087	–	–	–
			BET 274	0,1783	0,0702	483,16	70,076	–	–	–
			BET 275	0,1773	0,0698	511,97	74,255	–	–	–
			BET 276	0,1687	0,0664	516,86	74,964	–	–	–
1,21	AMBIENT	AMBIENT	BET 283	0,1735	0,0683	395,48	57,360			
			BET 284	0,1735	0,0683	407,40	59,089			
			BET 285	0,1720	0,0677	409,78	59,434			
			BET 286	0,1654	0,0651	416,44	60,400			
			BET 287	0,1707	0,0672	419,33	60,833			
			BET 288	0,1755	0,0691	442,28	64,147			

TABLE 10

SANDWICH BEAM STATIC COMPRESSION TESTS

Z3943432-503
LAYUP: [65/35/0]

PERCENT MOISTURE CONTENT	TEST TEMPERATURE		SPECIMEN NUMBER	LAMINATE THICKNESS		STRESS ON NET SECTION AT FAILURE*		STRAIN AT FAILURE	MODULUS	
	°K	°F		cm	IN.	MPa	PSI	μ cm/cm	GPa	MSI
1.31	219	−65	BET 331	0.1941	0.0764	532.96	77,299	4500	98.80	14.33
			BET 332	0.1974	0.0777	526.02	76,293	4300	97.15	14.09
			BET 333	0.1933	0.0761	–	(NO DATA)	–	–	–
			BET 334	0.1915	0.0754	523.62	75,945	–	–	–
			BET 335	0.1928	0.0759	536.05	77,748	–	–	–
			BET 336	0.1905	0.0750	569.35	82,577	–	–	–
1.57	350	170	BET 349	0.1880	0.0740	601.57	87,250	3800	131.97	19.14
			BET 350	0.1908	0.0751	616.58	89,427	4100	125.35	18.18
			BET 351	0.1902	0.0749	589.65	85,522	–	–	–
			BET 352	0.1976	0.0778	596.62	86,532	–	–	–
			BET 353	0.1971	0.0776	571.92	82,950	–	–	–
			BET 354	0.1935	0.0762	493.51	71,578	–	–	–

*INITIAL LAMINA FAILURE

TABLE 11

SANDWICH BEAM FATIGUE TESTS

Z3943432-509
LAYUP: [65/35/0]

R = −1.0

TEST TEMPERATURE		PERCENT MOISTURE CONTENT	SPECIMEN NUMBER	LAMINATE THICKNESS		NUMBER CYCLES ACCUMULATED	MAXIMUM CYCLIC STRESS		RESIDUAL STRENGTH	
°K	°F			cm	IN.		MPa	PSI	MPa	PSI
219	−65									
AMBIENT	AMBIENT	0.84	BET 467	0.1872	0.0737	2,843,000(1)	224.53	32,569	778.46	112,906
		0.98	BET 468	0.1920	0.0756	223,000(1)	272.97	39,591	771.19	111,852
AMBIENT	AMBIENT									
350	170									

(1) NO FATIGUE FAILURES

TABLE 12

SANDWICH BEAM FATIGUE TESTS

Z3943432-509
LAYUP: (55/35/0)

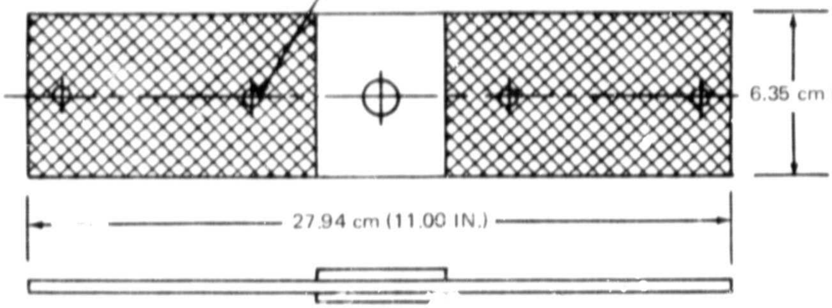
R = 0.05

TEST TEMPERATURE		PERCENT MOISTURE CONTENT	SPECIMEN NUMBER	LAMINATE THICKNESS		NUMBER CYCLES ACCUMULATED	MAXIMUM CYCLIC STRESS		RESIDUAL STRENGTH	
°K	°F			cm	IN.		MPa	PSI	MPa	PSI
219	-65									
AMBIENT	AMBIENT	1.26	BET 485 BET 486	0.1923 0.1933	0.0757 0.0761	2,597,000(1) 1,019,000(2)	345.72 361.48	50,142 52,428	726.30	105,341
AMBIENT	AMBIENT									
350	170									

(1) NO FATIGUE FAILURE
(2) TEST FIXTURE FAILED

TABLE 13

BEARING AND SHEAR-OUT TEST SPECIMENS



DRAWING Z3943433
T300/5208 GRAPHITE-EPOXY

DRAWING DASH NO.	LAMINATE PATTERN	NOMINAL LAMINATE THICKNESS	
		cm	IN.
-1	25/50/25	0.264	0.104
-501	39/41/20	0.325	0.128
-503	65/35/0	0.376	0.148

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TABLE 14

BEARING AND SHEAROUT SPECIMENS
SHEAROUT TEST RESULTS

Z3943433-1
LAYUP: [25/50/25]

TEST TEMPERATURE		PERCENT MOISTURE CONTENT	SPECIMEN NUMBER	LAMINATE THICKNESS		HOLE DIAMETER		EDGE DISTANCE		SHEAR STRESS		NET SECTION TENSILE STRESS	
^oK	^oF			cm	IN.	cm	IN.	cm	IN.	MPa	KSI	MPa	KSI
219	−65	1.04	BET 512	0.278	0.1093	0.634	0.2495	1.310	0.516	292.01	42.35	102.33	14.84
				0.279	0.1100	0.634	0.2495	1.244	0.490	277.33	40.22	89.88	13.04
		1.06	BET 513	0.287	0.1130	0.635	0.2500	1.252	0.493	273.58	39.68	88.89	12.89
				0.279	0.1100	0.635	0.2500	1.260	0.496	288.90	41.90	94.52	13.71
		1.12	BET 514	0.284	0.1120	0.638	0.2510	1.256	0.495	272.77	39.56	89.35	12.96
				0.282	0.1110	0.638	0.2510	1.238	0.488	279.69	40.57	90.40	13.11
AMBIENT	AMBIENT	1.01	BET 515	0.279	0.1100	0.634	0.2495	1.226	0.483	302.02	43.80	96.13	13.94
				0.284	0.1120	0.632	0.2490	1.223	0.482	278.11	41.64	91.07	13.21
		1.07	BET 516	0.277	0.1091	0.637	0.2508	1.256	0.494	297.14	43.10	98.64	14.31
				0.278	0.1096	0.632	0.2488	1.243	0.489	275.76	40.00	90.63	13.15
		1.08	BET 517	0.286	0.1125	0.634	0.2497	1.232	0.485	295.37	42.84	95.35	13.83
				0.278	0.1093	0.634	0.2496	1.234	0.486	296.18	42.96	95.84	13.90
		1.08	BET 518	0.282	0.1111	0.634	0.2497	1.252	0.493	276.57	40.11	91.18	13.23
				0.282	0.1112	0.634	0.2495	1.244	0.490	281.14	40.78	91.48	13.27
		1.06	BET 519	0.283	0.1116	0.634	0.2495	1.254	0.494	280.44	40.68	92.75	13.45
				0.280	0.1104	0.634	0.2497	1.247	0.491	287.52	41.70	93.90	13.62
		1.10	BET 520	0.283	0.1113	0.634	0.2495	1.234	0.486	296.87	43.06	95.07	13.79
				0.283	0.1115	0.634	0.2495	1.259	0.496	294.18	42.67	97.00	14.07
350	170	0.92	BET 521	0.285	0.1121	0.634	0.2497	1.254	0.494	269.19	39.04	88.16	12.79
				0.285	0.1121	0.634	0.2497	1.254	0.494	270.03	39.16	88.44	12.83
		0.92	BET 522	0.284	0.1118	0.634	0.2495	1.257	0.495	271.68	39.40	89.14	12.93
				0.278	0.1096	0.634	0.2497	1.257	0.495	265.23	38.47	87.11	12.63
		0.93	BET 523	0.278	0.1093	0.634	0.2498	1.244	0.490	282.57	40.98	91.63	13.29
				0.278	0.1094	0.634	0.2498	1.244	0.490	284.04	41.20	92.11	13.36

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TABLE 15

BEARING AND SHEAROUT SPECIMENS
SHEAROUT TEST RESULTS

Z3943433-501
LAYUP: [39/41/20]

TEST TEMPERATURE		PERCENT MOISTURE CONTENT	SPECIMEN NUMBER	LAMINATE THICKNESS		HOLE DIAMETER		EDGE DISTANCE		SHEAR STRESS		NET SECTION TENSILE STRESS	
°K	°F			cm	IN.	cm	IN.	cm	IN.	MPa	KSI	MPa	KSI
AMBIENT	AMBIENT	1.08	BET 527	0.344	0.1355	0.638	0.2511	1.252	0.493	256.50	37.20	83.05	12.05
				0.348	0.1369	0.636	0.2503	1.250	0.492	256.96	37.27	83.73	12.14
		1.05	BET 528	0.345	0.1357	0.636	0.2503	1.252	0.493	251.97	36.55	82.66	11.99
				0.345	0.1357	0.635	0.2500	1.250	0.492	242.97	35.24	78.98	11.46
		1.04	BET 529	0.344	0.1355	0.637	0.2508	1.255	0.494	232.01	33.65	76.40	11.08
				0.343	0.1350	0.636	0.2504	1.280	0.504	239.53	34.74	80.60	11.69
		1.04	BET 530	0.341	0.1341	0.635	0.2500	1.260	0.496	245.99	35.68	80.76	11.71
				0.343	0.1352	0.634	0.2498	1.262	0.497	236.13	34.25	77.80	11.28
		1.07	BET 531	0.345	0.1360	0.636	0.2504	1.247	0.491	249.33	36.16	81.13	11.77
				0.345	0.1359	0.634	0.2495	1.262	0.497	251.28	36.45	82.85	12.02
		1.06	BET 532	0.342	0.1348	0.638	0.2510	1.257	0.495	257.13	37.29	84.45	12.25
				0.341	0.1344	0.636	0.2504	1.250	0.492	245.32	35.53	79.79	11.57

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TABLE 16

BEARING AND SHEAROUT SPECIMENS
SHEAROUT TEST RESULTS

Z3943433-503
LAYUP: [65/35/0]

TEST TEMPERATURE		PERCENT MOISTURE CONTENT	SPECIMEN NUMBER	LAMINATE THICKNESS		HOLE DIAMETER		EDGE DISTANCE		SHEAR STRESS		NET SECTION TENSILE STRESS	
^oK	^oF			cm	IN.	cm	IN.	cm	IN.	MPa	KSI	MPa	KSI
AMBIENT	AMBIENT	1.14	BET 503	0.375	0.1475	0.635	0.2500	1.247	0.491	259.90	37.70	84.59	12.27
				0.373	0.1467	0.635	0.2500	1.260	0.496	274.58	39.82	90.27	13.09
		1.07	BET 504	0.362	0.1424	0.635	0.2500	1.255	0.494	269.97	39.16	88.43	12.83
				0.364	0.1434	0.635	0.2500	1.247	0.491	276.52	40.11	90.00	13.05
		1.13	BET 505	0.359	0.1414	0.635	0.2500	1.257	0.495	251.05	36.41	82.39	11.95
				0.367	0.1446	0.635	0.2500	1.267	0.499	256.26	37.17	84.89	12.31
		1.17	BET 506	0.370	0.1458	0.635	0.2500	1.237	0.487	257.35	37.33	82.74	12.00
				0.371	0.1460	0.634	0.2497	1.252	0.493	242.54	35.18	79.36	11.51
		1.17	BET 507	0.374	0.1472	0.634	0.2496	1.257	0.495	240.53	34.89	78.92	11.46
				0.378	0.1487	0.635	0.2500	1.245	0.490	239.46	34.73	77.62	11.26
		1.11	BET 508	0.362	0.1427	0.634	0.2497	1.240	0.488	240.25	34.85	77.37	11.22
				0.367	0.1444	0.634	0.2495	1.262	0.497	229.43	33.28	75.53	10.96

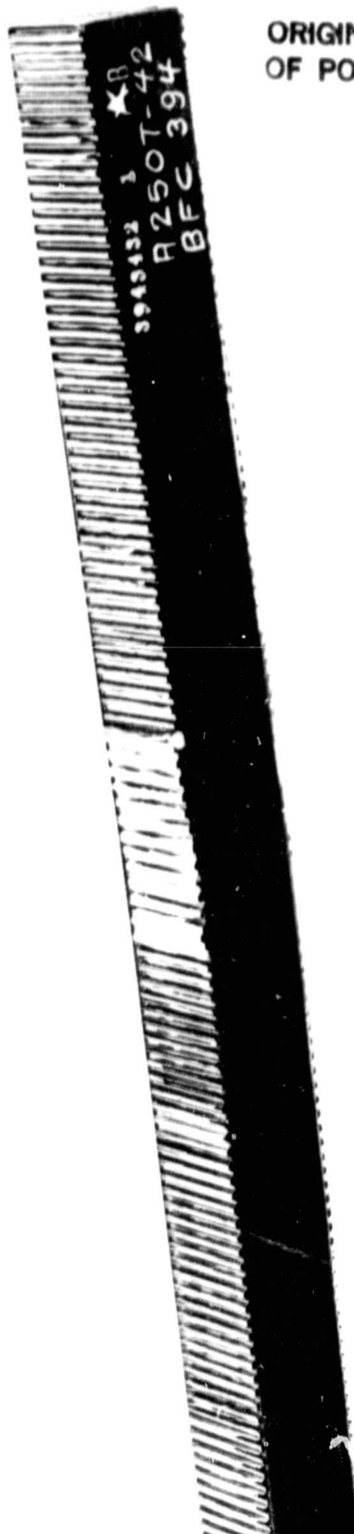

FIGURE 14. SANDWICH BEAM STATIC TENSION SPECIMEN

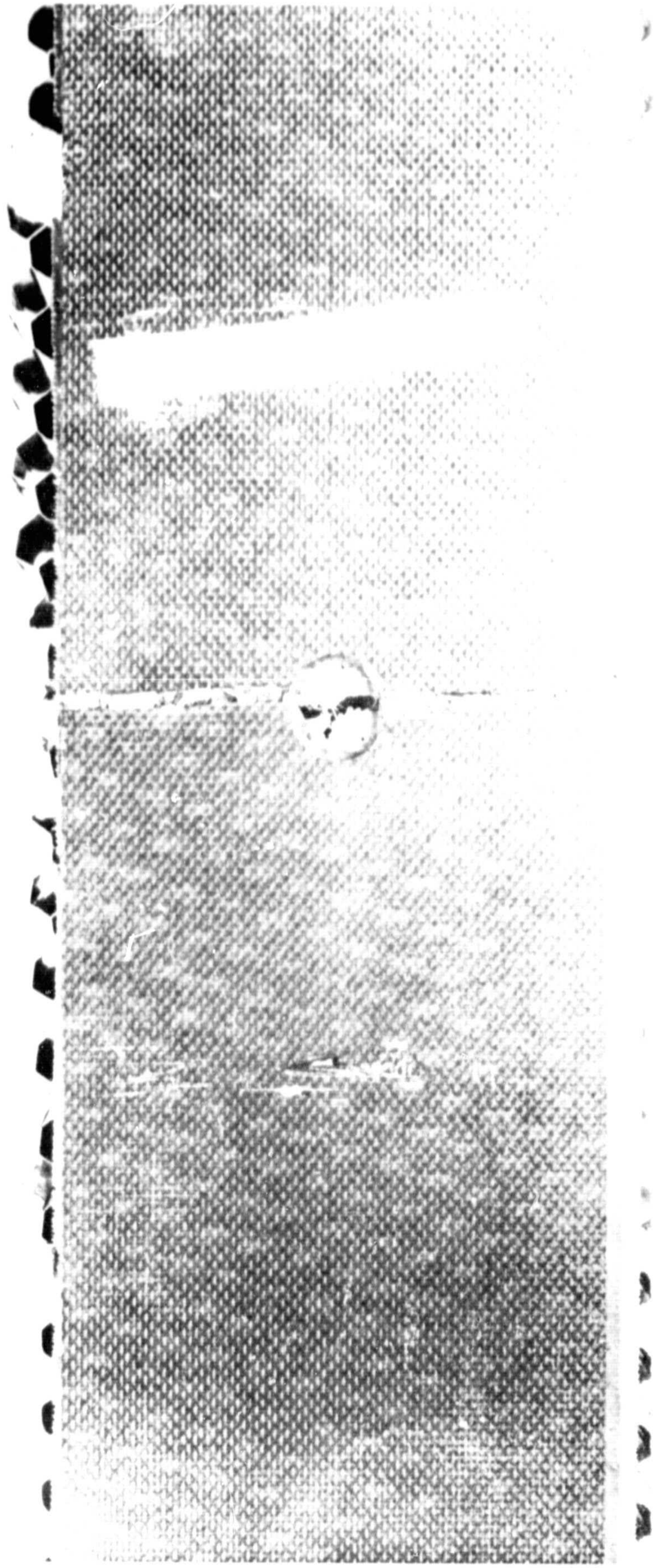

FIGURE 15. CLOSEUP OF STATIC TENSION FAILURE IN 25/50/25 LAMINATE
(TESTED AT 394^{o}K)

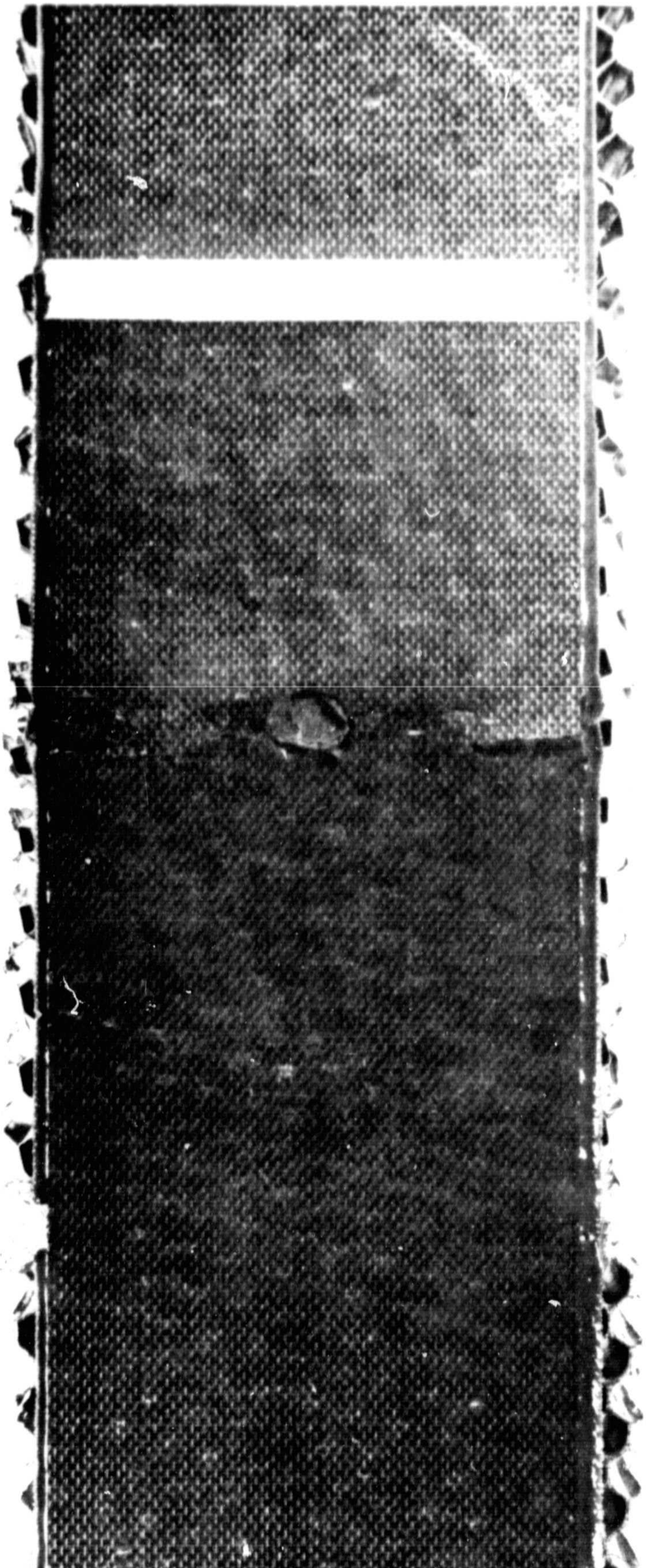

FIGURE 16. CLOSEUP OF STATIC COMPRESSION FAILURE IN 25/50/25 LAMINATE (TESTED AT 350°K)

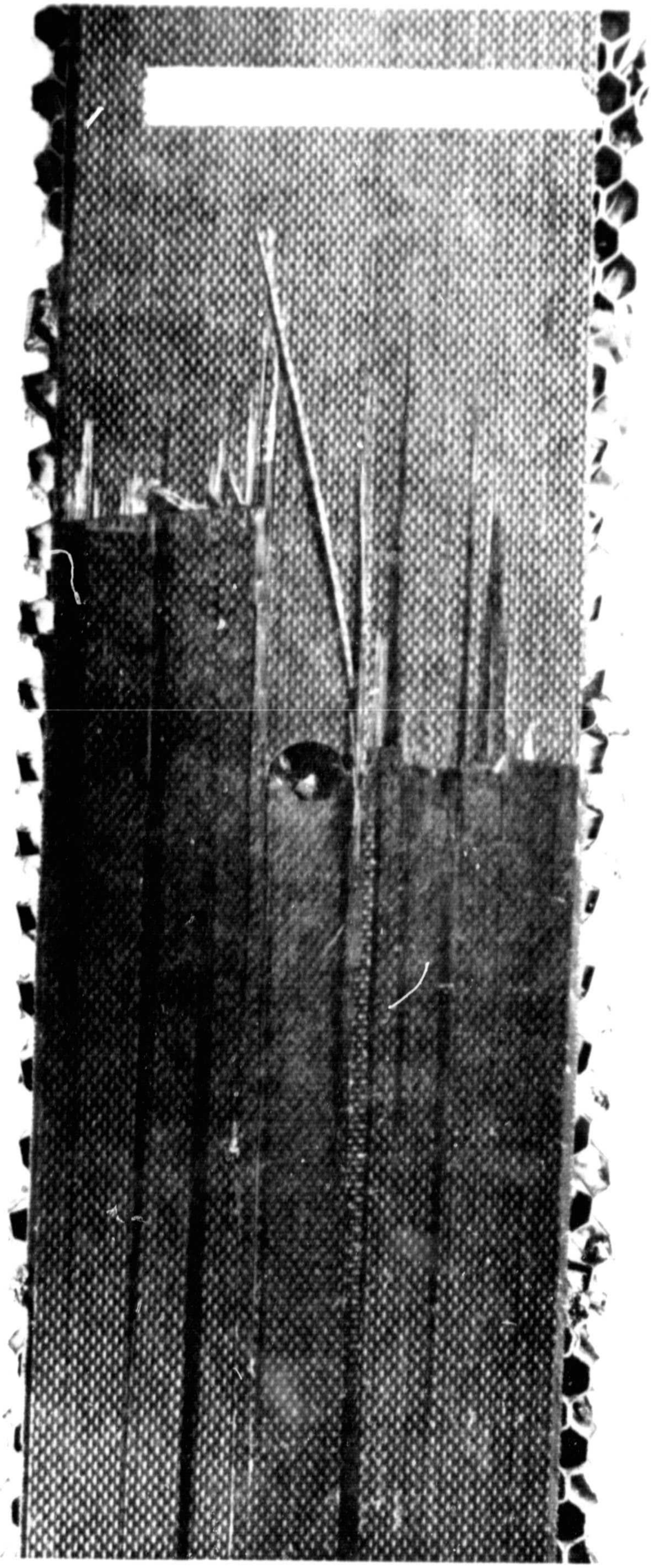

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FIGURE 17. CLOSEUP OF STATIC COMPRESSION FAILURE IN 65/35/0 LAMINATE (TESTED AT 219°K)

FIGURE 18. BEARING AND SHEAROUT SPECIMEN

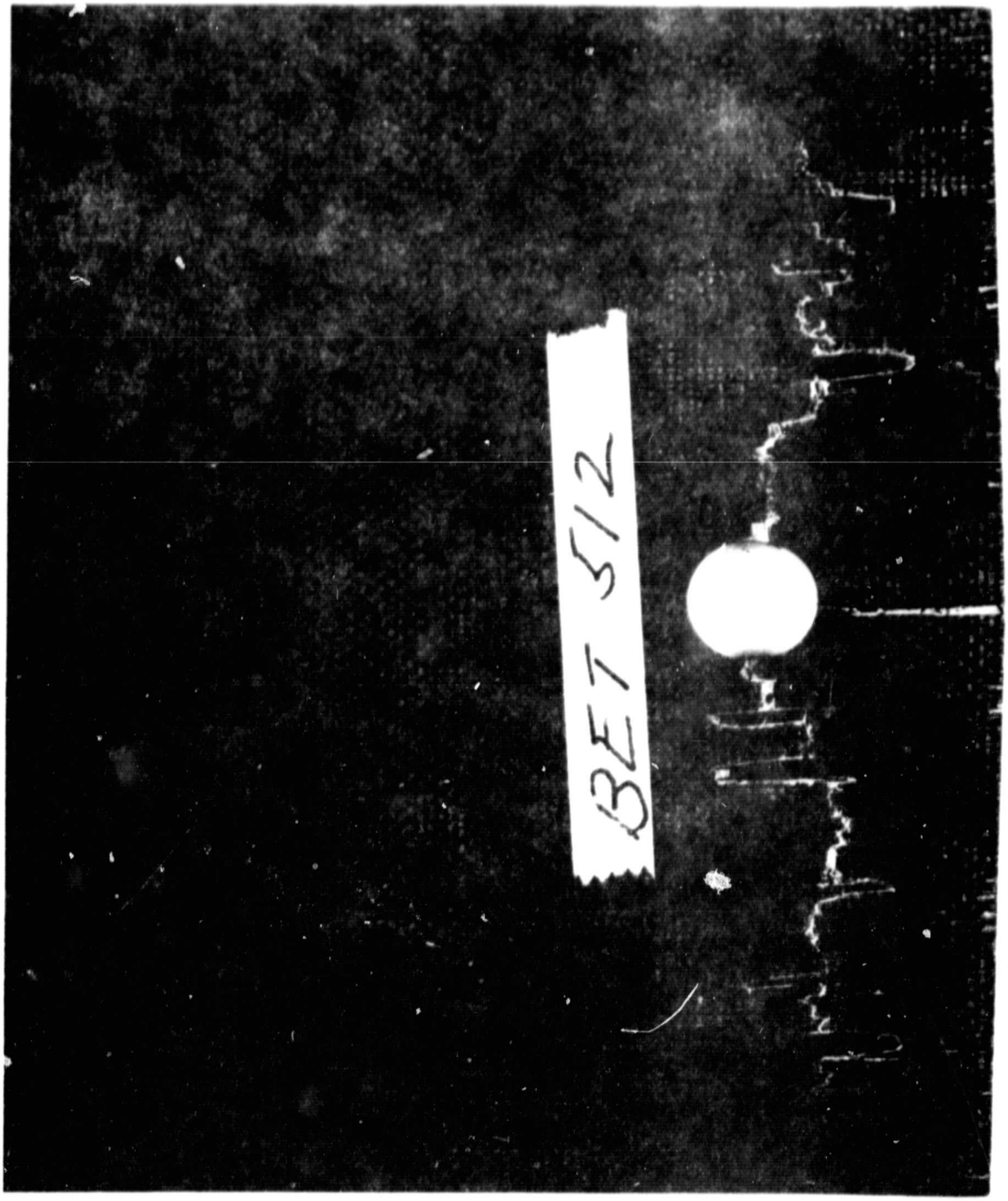

FIGURE 19. CLOSEUP OF FAILURE OF 25/50/25 LAMINATE (TESTED AT 219°K)

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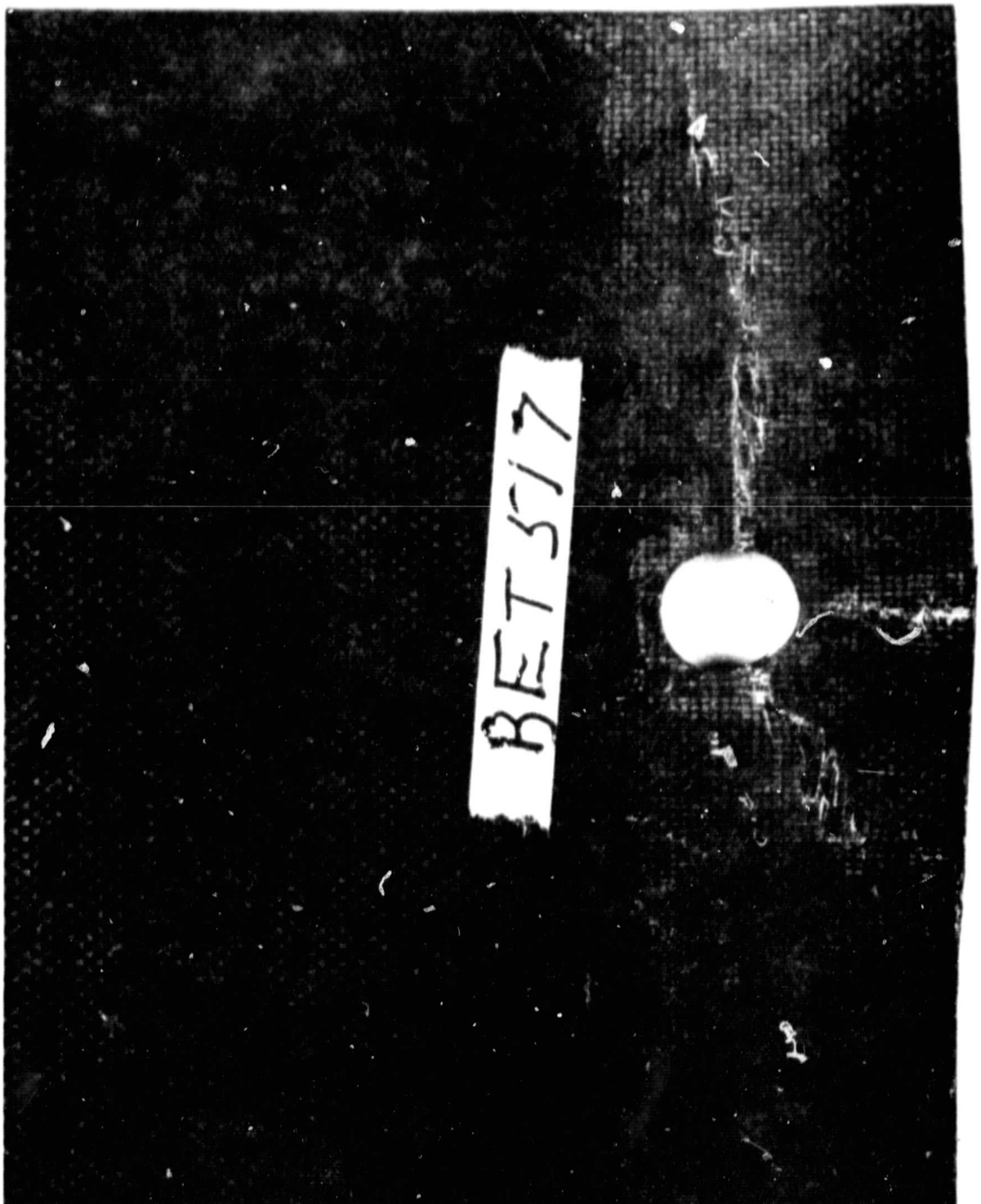

FIGURE 20. CLOSEUP OF FAILURE OF 25/50/25 LAMINATE (TESTED AT AMBIENT TEMPERATURE)

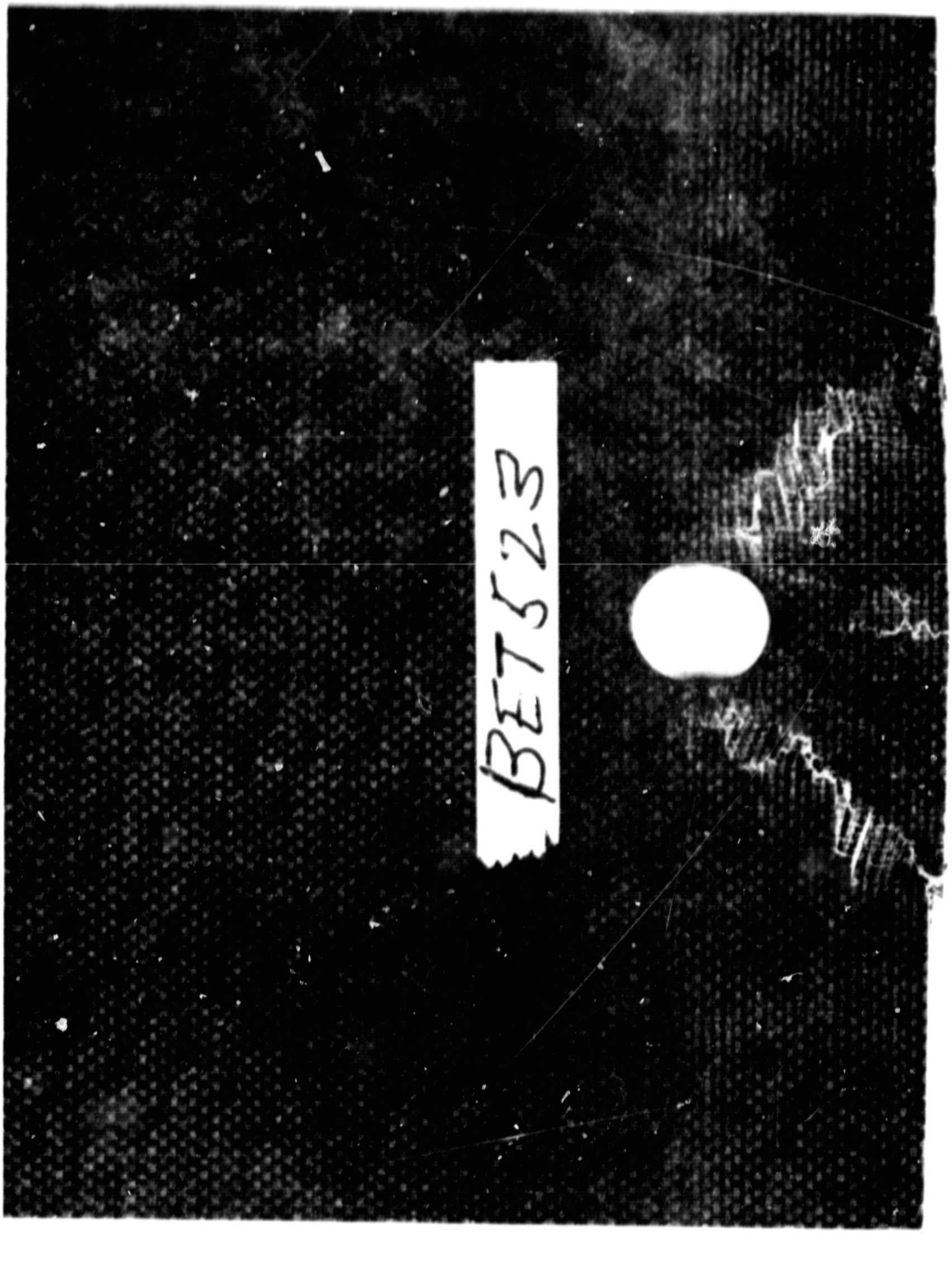

FIGURE 21. CLOSEUP OF FAILURE OF 25/50/25 LAMINATE (TESTED AT $350^{\circ}K$)

Fracture Mechanics Design Data

Fabrication of the Z3943442 Damage and Debond specimens is continuing. Laminating and curing is 70 percent complete.

Fabrication specifications and planning documents are in preparation for the fabrication of the Z3943443 center slit panels and the Z5943428-501 damage tolerance shear panels.

Testing of the fracture mechanics specimens (except for the shear panels) will be accomplished in a temperature/humidity environment under cyclic loading. These tests will require special test facilities. An environmental chamber designed to fit the 222,400 Newton (50,000 pound) MTS test machine was fabricated by a vendor and delivery made on 23 June 1978. Special extenders were also designed to permit load application to the specimen inside the chamber similar to the extenders for the Schenck test machine. These extenders were fabricated by a specialty machine shop and delivery made on 27 June 1978.

SECTION 6

DESIGN VERIFICATION TEST COMPONENTS

Subcomponents selected for design verification testing are the Z5943445 cover panel (Appendix A, Figure A2), the Z5943452 spar root bondline fitting (Appendix A, Figure A3), and the Z5943446 rear spar beam.

Cover Panel Verification Subcomponent

Planning paper has been released to initiate tooling and fabrication orders for the construction of the three test subcomponents. High temperature PLM's are being considered for the sine-wave spar and rib web elements.

Rear Spar Beam

The rear spar beam test specimen represents the lower six feet of the full-size rear spar component. Titanium attach fittings are embedded within the composite web molding at the root end, the drawing for these fittings (Z5943423-501) is shown in Appendix A (Figure A1). Load is transferred from the fittings into the composite spar cap by means of an adhesively bonded scarf joint, with the addition of bolted fasteners as a fail-safe load path. The joint design is being verified by the specimens defined by drawing Z5943452 (Appendix A, Figure A3).

The spar component consists essentially of a web and two skin caps connected by bolts to simulate the attachment of the skin panels to the substructure. All types of web construction are included in the web segment from honeycomb sandwich at the root end, through solid laminate doublers around the actuator cutout, to sine-wave construction at the upper end. Provision is made for the attachment of the test fixture at the end of the beam. The specimen drawing (Z5943446) is in the final stage of completion.

Six titanium forgings for the Z5943423 fittings have been received and four have been released to a subcontractor for machining. The fittings will be completed by 20 August 1978.

Spar Root Bondline Fittings

Fabrication orders have been released for machining the metal details. A fabrication TAD for the completion of the six test specimens is in preparation.

Rear Spar Specimen Analysis

Previous verification test specimens have suffered failures basically unrelated to the test region or the component design concept. In order to preclude this type of failure, a detailed redundant force model is being prepared of the entire specimen. Analysis of this model will be accomplished sufficiently in advance of the specimen construction to reveal and allow correction of any potential design defects. The definition of the model geometry and physical and material properties is virtually complete, except for the details of the interface between the specimen and the loading fixture which has not been completely defined at present. An arbitrary interim model of this region is being prepared and it is expected that the complete model will be operational by early July. A computer graphics sketch of the model layout is shown in Figure A5 of Appendix A.

In addition to the rear spar specimen model, a fine-grid model was prepared and run to examine the area around the lower rudder actuator cut-out (Figure 22). The results indicated an adequate structural margin in all regions of the cut-out panel. A plot of the limit cut-out boundary stresses for the critical design condition is shown in Figure 23.

Analyses using the "FASTBUCK" programs have been performed of the scarf joint splice region and have shown a high margin of safety for the bonded joint for all conditions. An analysis has been made of the back-up bolted joint for failsafe loads and the joint has adequate margins for the critical design conditions.

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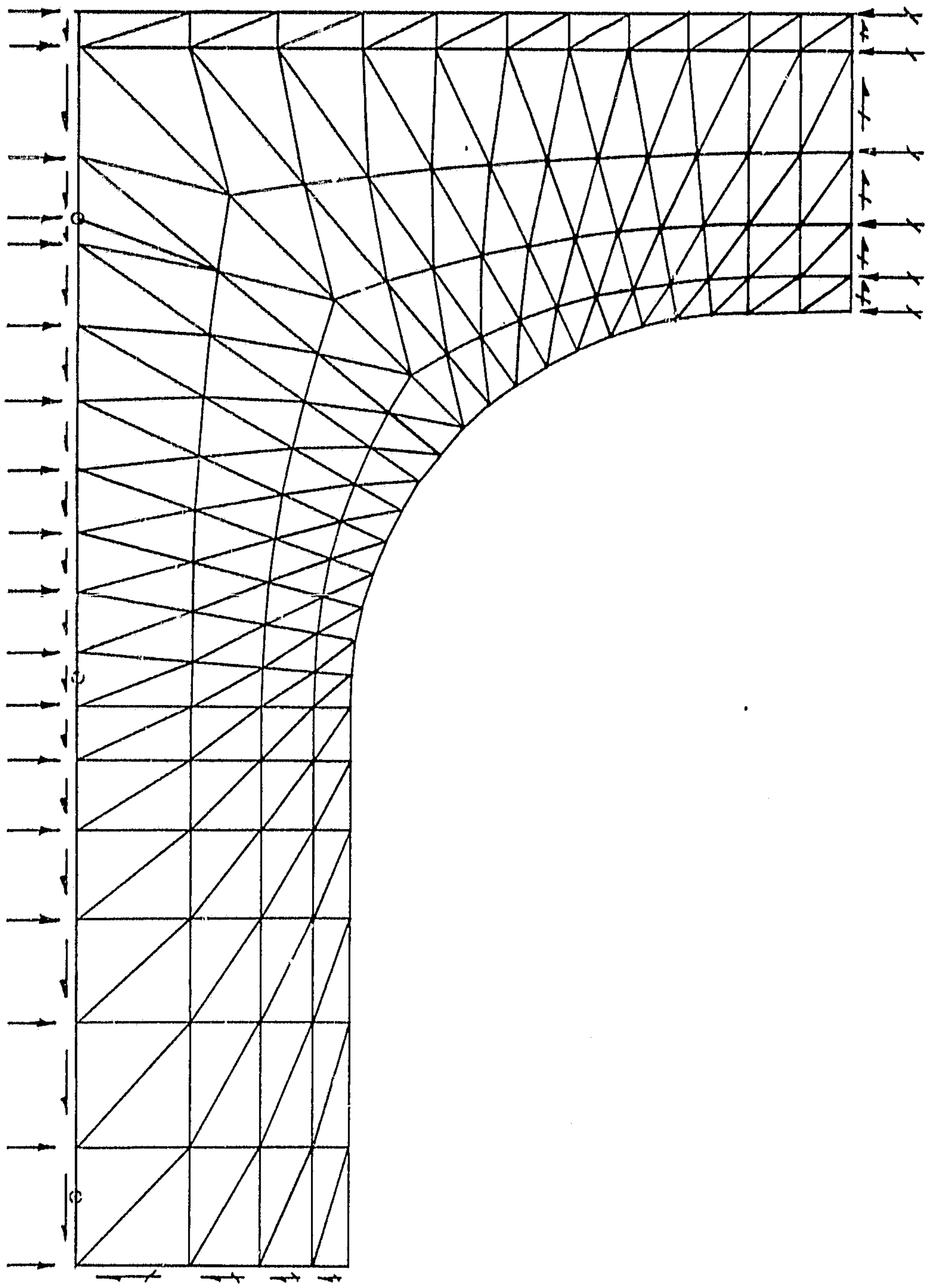

FIGURE 22. REAR SPAR ACTUATOR CUTOUT ANALYSIS MODEL

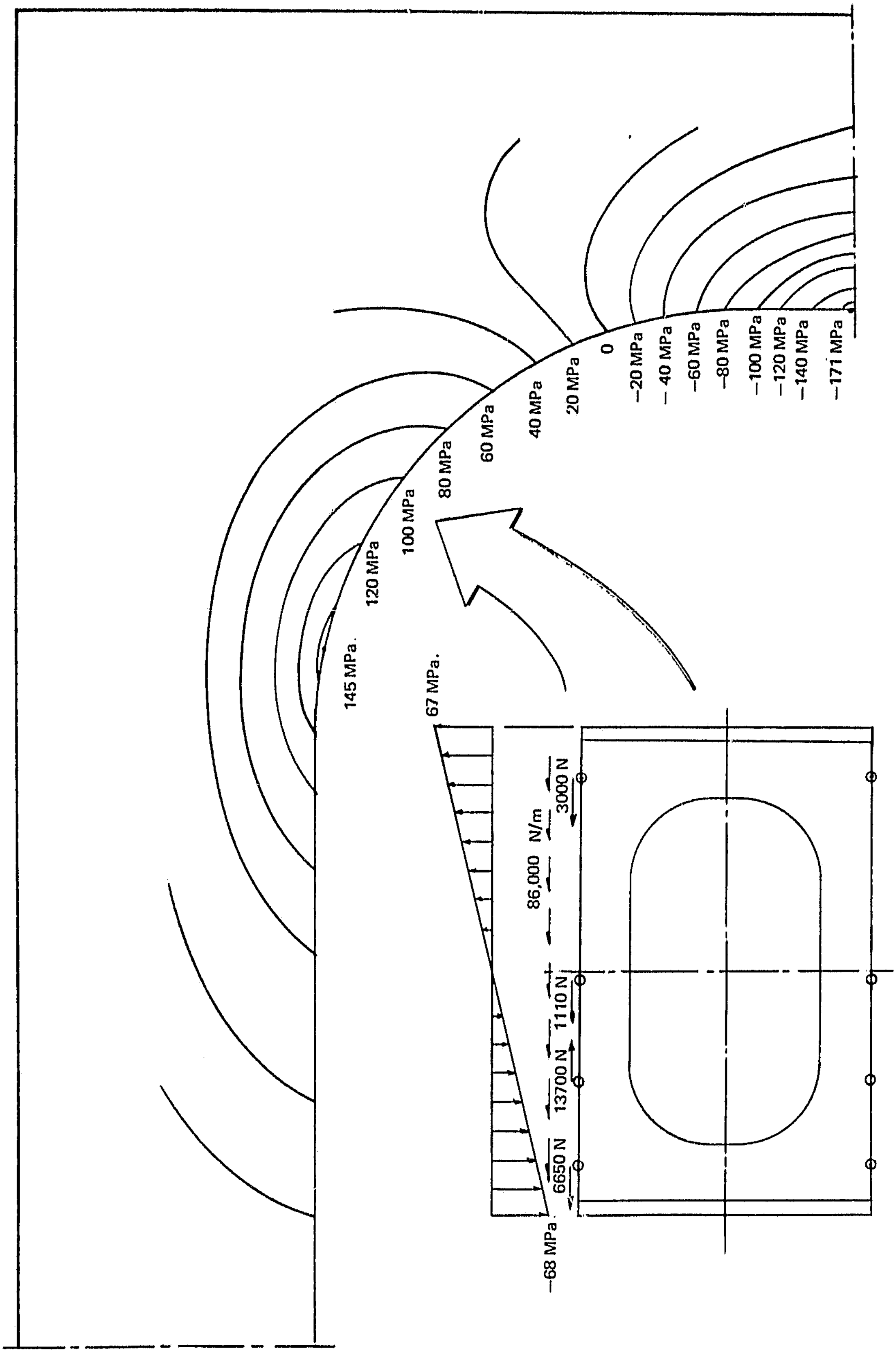

FIGURE 23. LIMIT CIRCUMFERENTIAL STRESS AT ACTUATOR CUTOUT (PSD CONDITION 207405)

SECTION 7

QUALITY ASSURANCE

Receiving Quality Control

Receiving quality control tests were conducted on 97.9 pounds of bi-woven T300/5208 (Batch 154), 50.4 pounds of which are allocated to the CVS program. All material met specifications as shown in Table 17.

TABLE 17
QUALITY CONTROL RECEIVING INSPECTION TEST RESULTS
T300/5208 GRAPHITE-EPOXY
BI-DIRECTIONAL WOVEN MATERIAL

BATCH NO.	QUANTITY		UNIT IDENTITY	PREPREG PROPERTIES			LAMINATE PROPERTIES							
				RESIN CONTENT WEIGHT (%)	VOLATILE CONTENT WEIGHT (%)	GEL TIME (MIN)	FLEXURAL STRENGTH		FLEXURAL MODULUS		INTERLAMINAR SHEAR STRENGTH		THICKNESS PER PLY	
	(kg)	(LB)					(MPa)	(KSI)	(GPa)	(MSI)	(MPa)	(KSI)	(mm)	(MILS)
–	–	–	DMS 2163 REQMT	42 ± 3.0	3.0 MAX	17 TO 27	896.3 MIN	130.0 MIN	68.9 MIN	10.0 MIN	68.9 MIN	10.0 MIN		
154		97.9	1	43.3	1.36	18.9	926.7	134.4	75.2	10.9	68.3	9.9	0.330	13.0
				43.3			937.0	135.9	80.7	11.7	78.6	11.4	0.328	12.9
							987.3	143.2	83.4	12.1	69.6	10.1	0.328	12.9
				43.3			950.1	137.8	80.0	11.6	72.4	10.5	0.328	12.9
			2	44.7	2.53	20.2	945.3	137.1	80.7	11.7	67.6	9.8	0.328	12.9
				43.8			1051.5	152.5	78.6	11.4	64.8	9.4	0.325	12.8
							1014.2	147.1	81.4	11.8	67.6	9.8	0.325	12.8
				44.3			1003.9	145.6	80.0	11.6	66.9	9.7	0.325	12.8
			3	44.5	1.40	20.4	1046.6	151.8	81.4	11.8	77.2	11.2	0.323	12.7
				42.9			1010.8	146.6	81.4	11.8	67.6	9.8	0.323	12.7
							1035.6	150.2	80.7	11.7	75.2	10.9	0.323	12.7
				43.4			1030.8	149.5	81.4	11.8	73.1	10.6	0.323	12.7
			AVERAGE				994.9	144.3	80.7	11.7	73.8	10.7	0.325	12.8

SECTION 8
REFERENCES

1. "Advanced Composite Vertical Stabilizer Program for DC-10 Transport Aircraft", Fourth Quarterly Technical Progress Report, Douglas Aircraft Company Report Number ACEE-03-PR-8394, Contract NAS1-14869, 24 April 1978.

2. "Optimization of Multirib and Multiweb Box Structures Under Shear and Moments", D.H. Emero, L. Spunt, AIAA 6th Structures and Materials Conference, Palm Springs, California, April 1965.

APPENDIX A

ENGINEERING DRAWINGS

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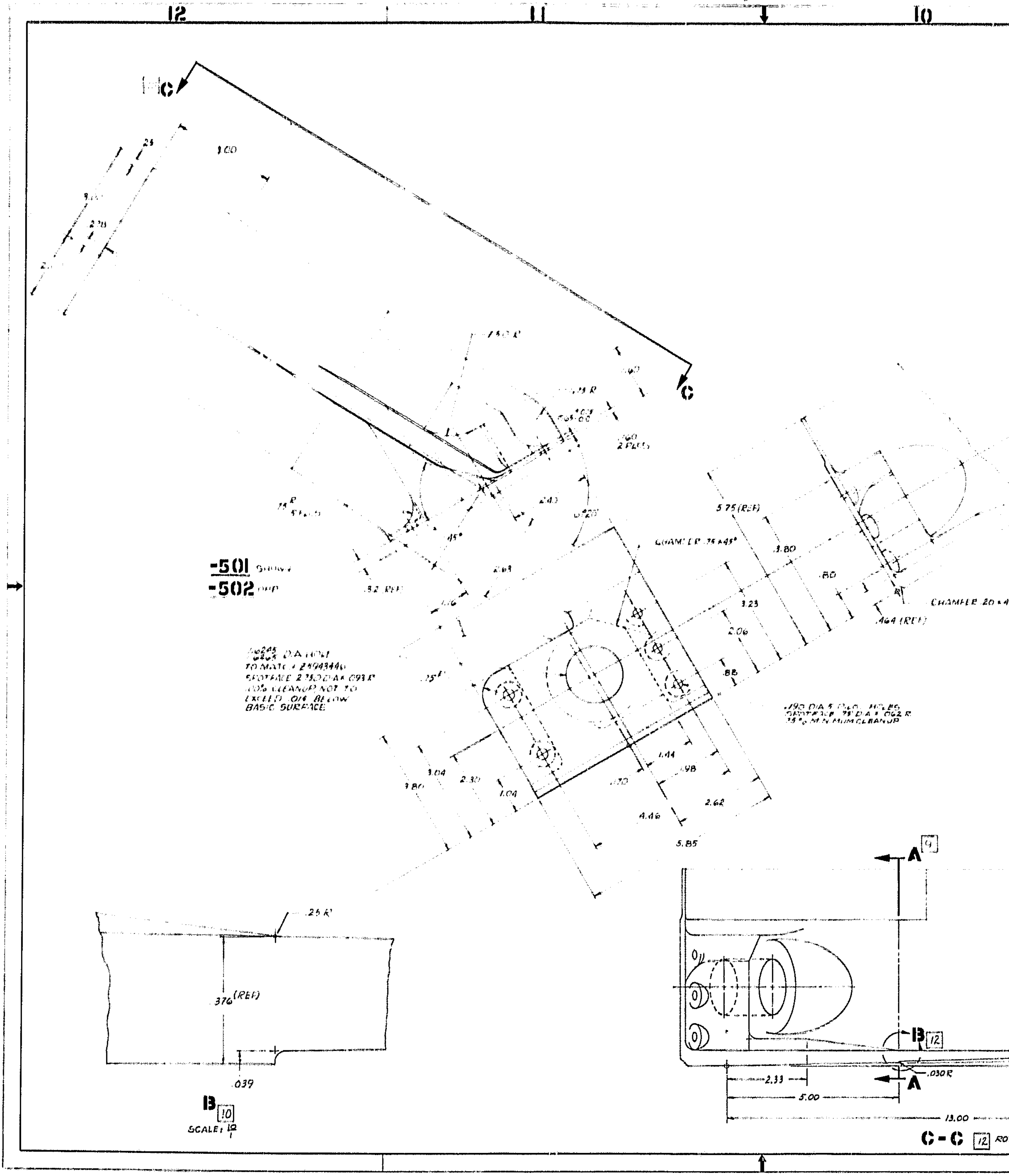
12
11
10
C
C
-501 SHOWN
-502 OPP
5.75 (REF)
3.80
3.23
2.06
.88
.80
.464 (REF)
2.63
.32 REF
45°
2.43
1.44
.98
2.62
4.46
5.85
3.04
3.80
2.30
1.04
.25 R
.376 (REF)
.039
B 10
SCALE: 10/1
A 9
B 12
.030 R
2.33
5.00
13.00
C - C 12

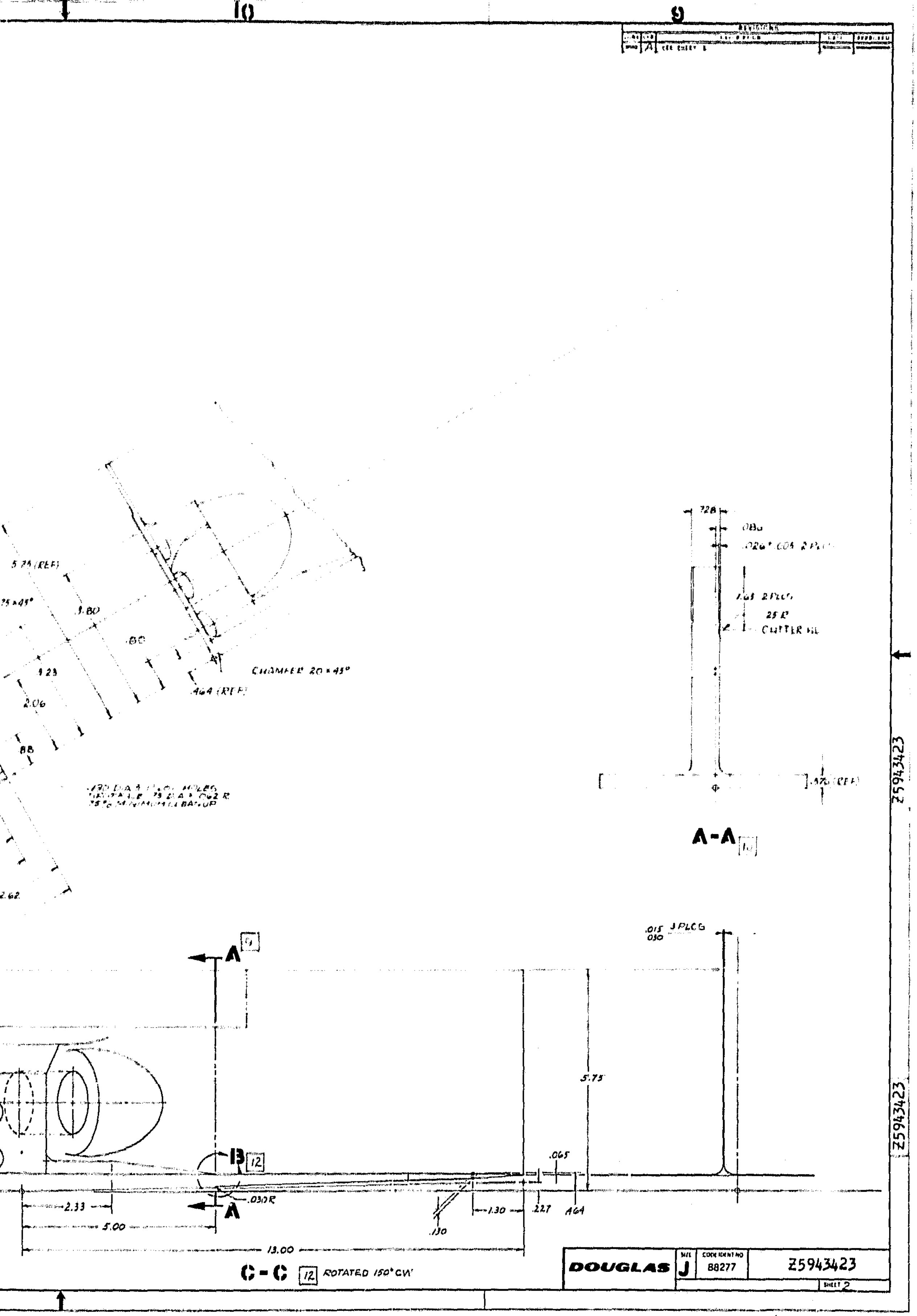

FIGURE A1. DRAWING Z5943423-501 – TITANIUM FITTING

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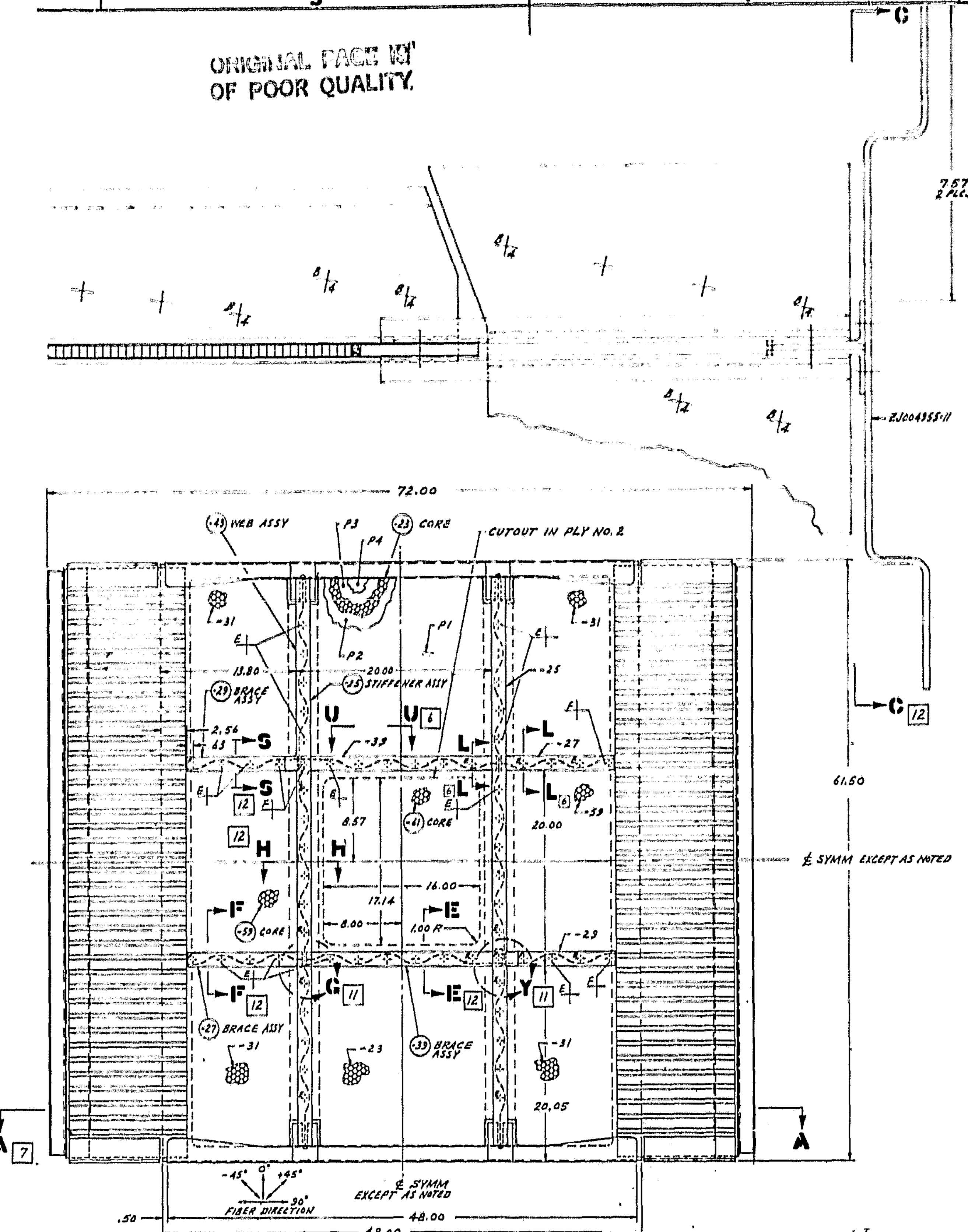

GEN NOTES (CONT)

17 ASSEMBLY SHOP PRACTICE PER DPS 1.70.1
18 INSTALL RIVETS AND FLUSH SCREWS PER 5307...
19 INSTALL HI-LOK PINS PER 1.79, 1631 AND LOCK BOLTS PER 5793... STANDARD INTERFERENCE FITS APPLY UNLESS OTHERWISE INDICATED BY SYMBOL DESIGNATION
20 ATTACH NUTPLATES WITH MS20426AD RIVETS
21 HEAT TREAT 2024-0 TO 2024-T42, 2014-0 & -T3 TO 2014-T6 & 7075-0 TO 7075-T6 PER DPS 7.00
22 ATTACHMENTS LOCATED FROM PART EDGES .30 + .06 FOR DETAILS .30 MIN. ACCEPTABLE ON ASSEMBLY
23 ATTACHMENTS LOCATED .30 FROM JOGGLES AND ADJACENT STRUCTURE
24 "EQL SPACED" TOLERANCE TO BE WITHIN .06
25 PANEL IS TO BE ASSEMBLED IN A JIG (C 151-Z...) WHICH WILL CONTROL THE LOCATION OF ALL AT... BETWEEN THE PANEL & THE TEST FIXTURE
26
(27) -21 TO BE ASSEMBLED TO -3, -4, -5, & -6... EA 9320 ADHESIVE APPLIED TO ALL MAT...
28 SCALE MISSING DIMS
(29) POT HONEYCOMB IN AREA OF FASTENERS... TYPE 2
30 USE A WASHER UNDER THE COLLAR OR N... WHEN THE COLLAR OR HEAD IS AGAINST A...
31 FOR ADDITIONAL NOTES FOR -601 (UNDIM... SEE ZONE 13.
32 WHEN QUANTITY IN L/M IS GIVEN IN YARDS, THIS ... LENGTH OF 42 IN WIDE MATERIAL REQUIRED.
33 PREPARE HONEYCOMB PANELS USING FM... PER DPS 1.966.

PLY NO (P)	[illegible]	NEXT ASSY	THICKNESS (REF)	MAKE FROM	FIBER DIRECTION	ZONE
1	1	-21	.013	-35	±45	5
2	1					5
3	1					5
4	1	-21			±45	5
5	1	-25			0/90	12
6	1				±45	
7	1				±45	
8	1				0/90	
9	1				±45	
10	1				±45	
11	1	-25			0/90	
12	1	-27			0/90	
13	1				±45	
14	1				±45	
15	1				0/90	
16	1				±45	
17	1				±45	
18	1	-27			0/90	
19	1	-39			0/90	
20	1				±45	
21	1				±45	
22	1	-39			0/90	12
23	[illegible]	-41			0/90	6
24					0/90	
25					0/90	
26					±45	
27			.013	-35	±45	
28			.006	-33	0	
29			.006	-33	0	
30			.006	-33	0	
31			.006	-33	0	
32			.013	-35	±45	
33			.006	-33	0	
34			.006	-33	0	
35			.006	-33	0	
36			.006	-33	0	
37			.013	-35	±45	
38			.006	-33	0	
39			.006	-33	0	
40			.006	-33	0	
41			.006	-33	0	
42			.013	-35	±45	
43			.006	-33	0	
44			.006	-33	0	
45			.006	-33	0	
46			.006	-33	0	
47			.013	-35	±45	
48			.006	-33	0	
49			.006	-33	0	
50			.006	-33	0	
51			.006	-33	0	
52			.013	-35	±45	
53					±45	
54					0/90	
55						
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[illegible]						
[illegible]						
78						
79						6
[illegible]	1	[illegible]	[illegible]	-35	[illegible]	[illegible]

Z5943445 | A | 1

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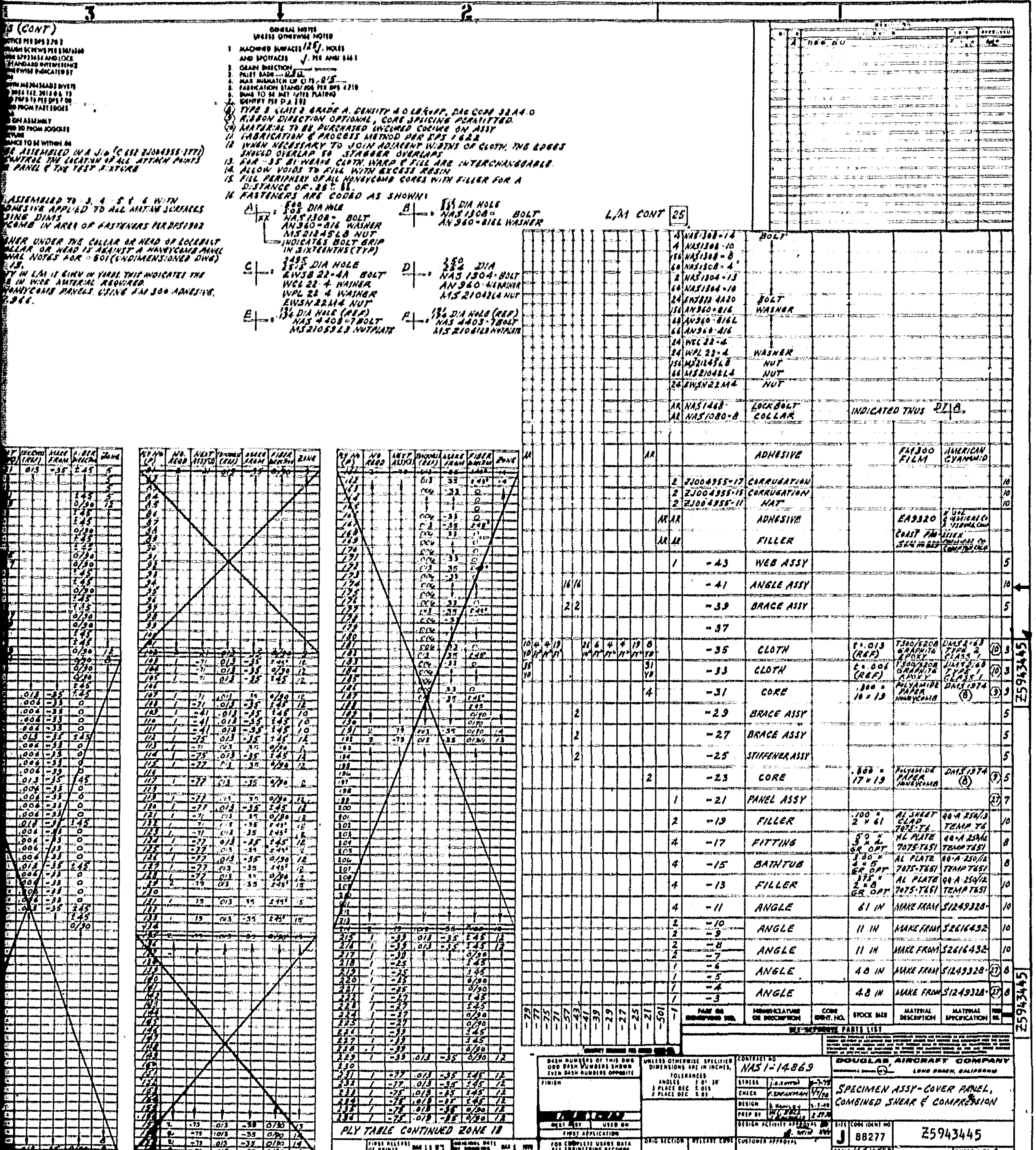

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FIGURE A2. DRAWING Z5943445 – SPECIMEN ASSY – COVER PANEL, COMBINED SHEAR AND COMPRESSION (SHEET 1)

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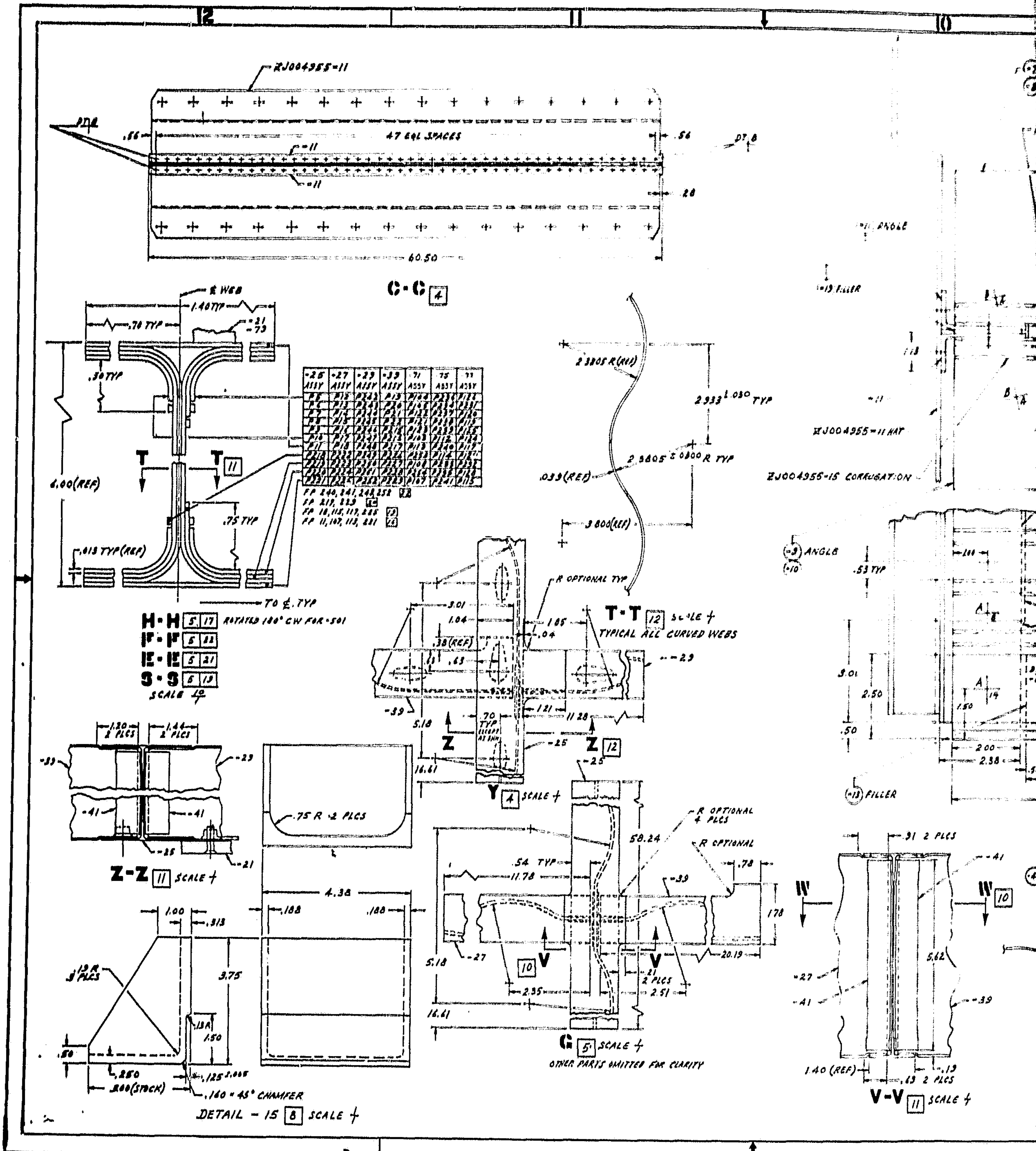

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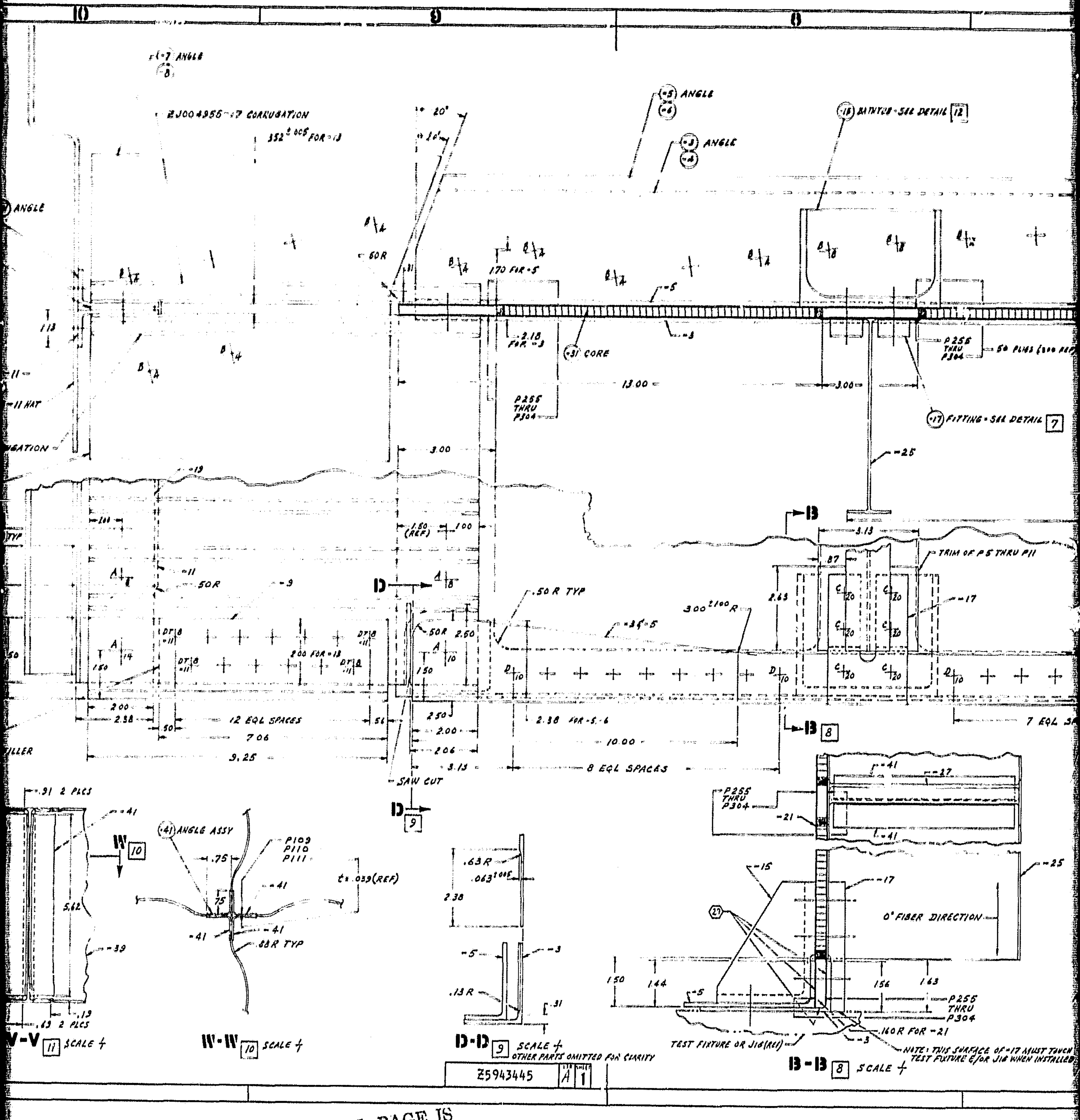

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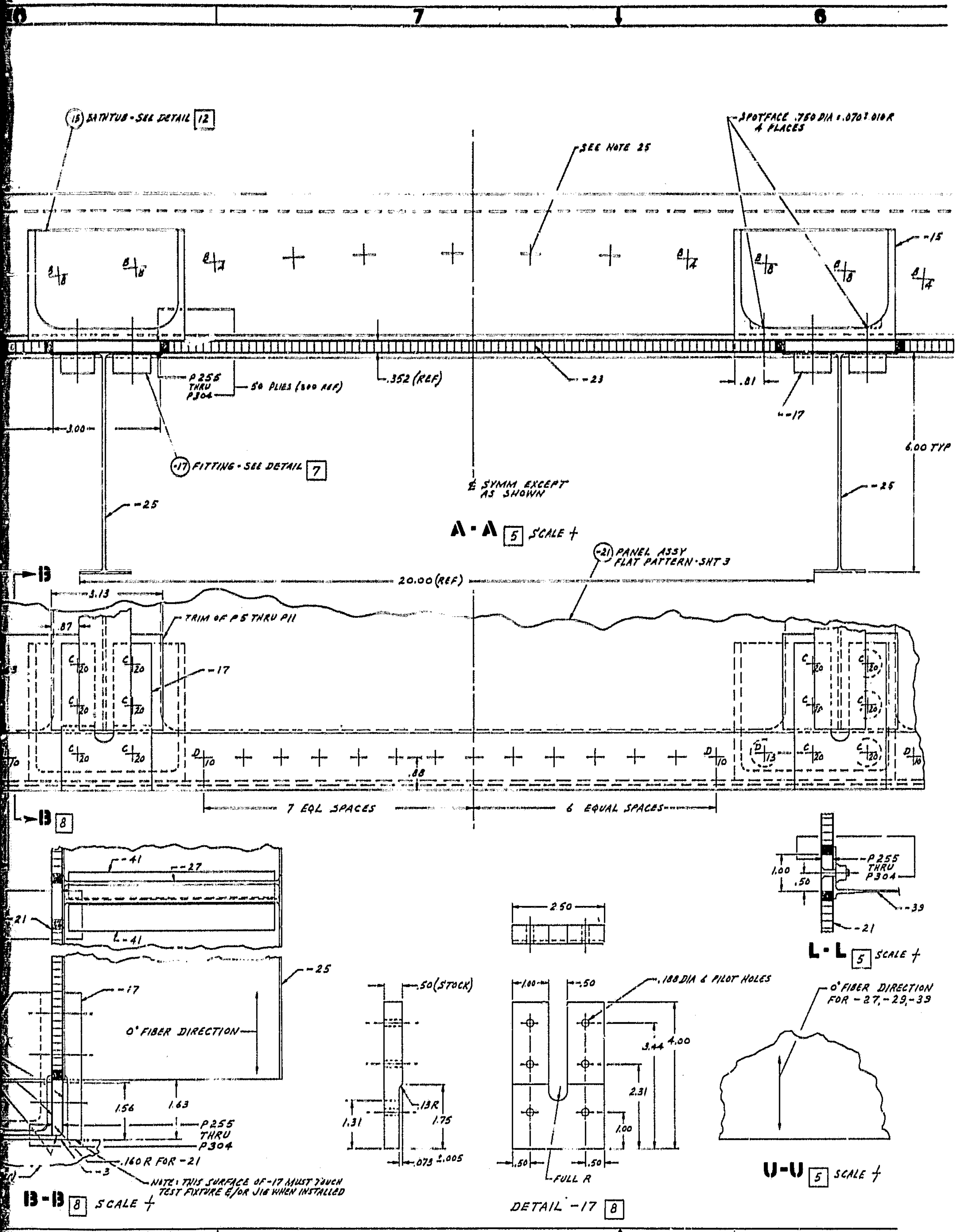

FIGURE A2. DRAWING Z5943445 – SPECIMEN ASSY – COVER PANEL, COMBINED SHEAR AND COMPRESSION (SHEET 1 CONCLUDED)

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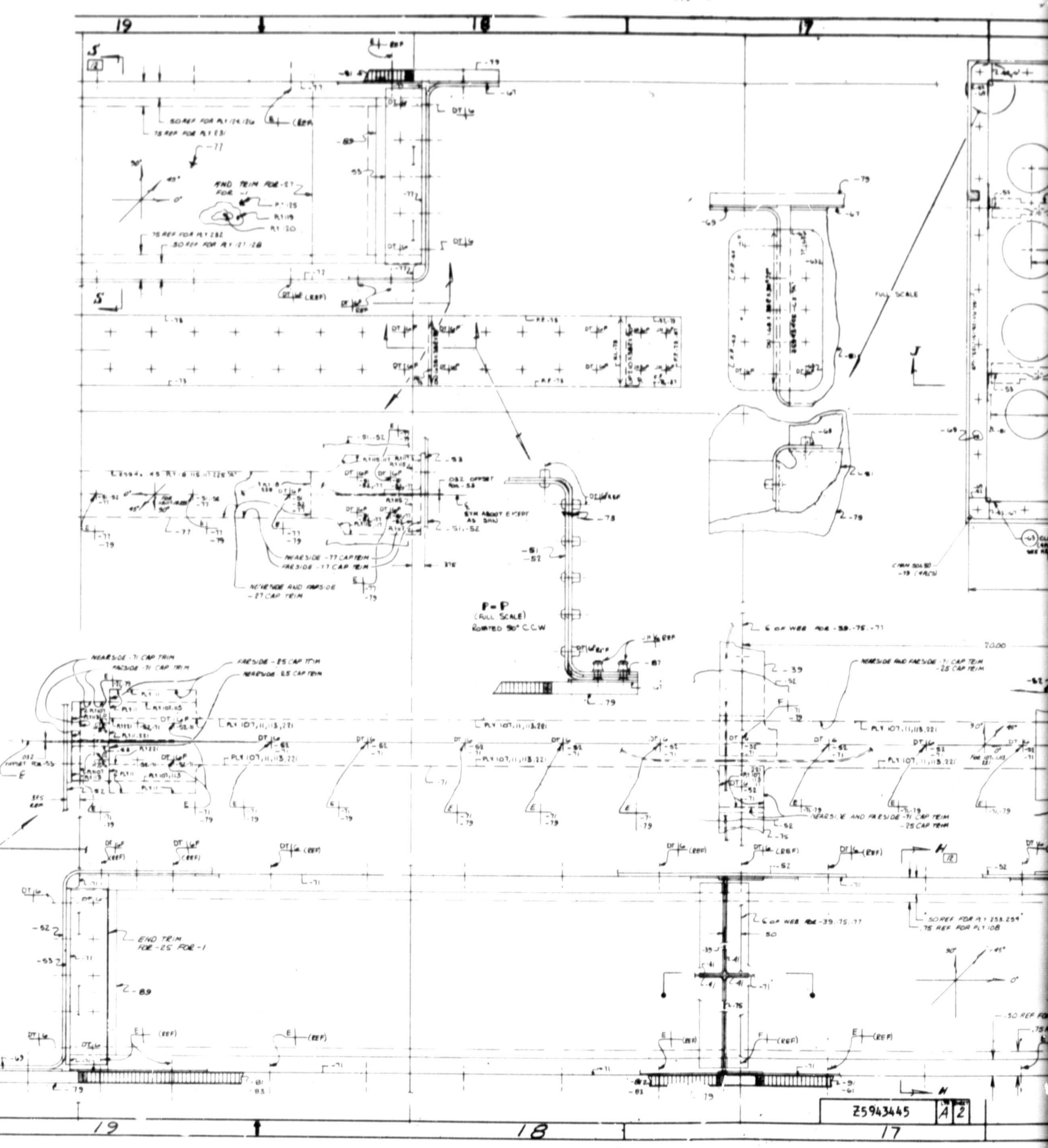

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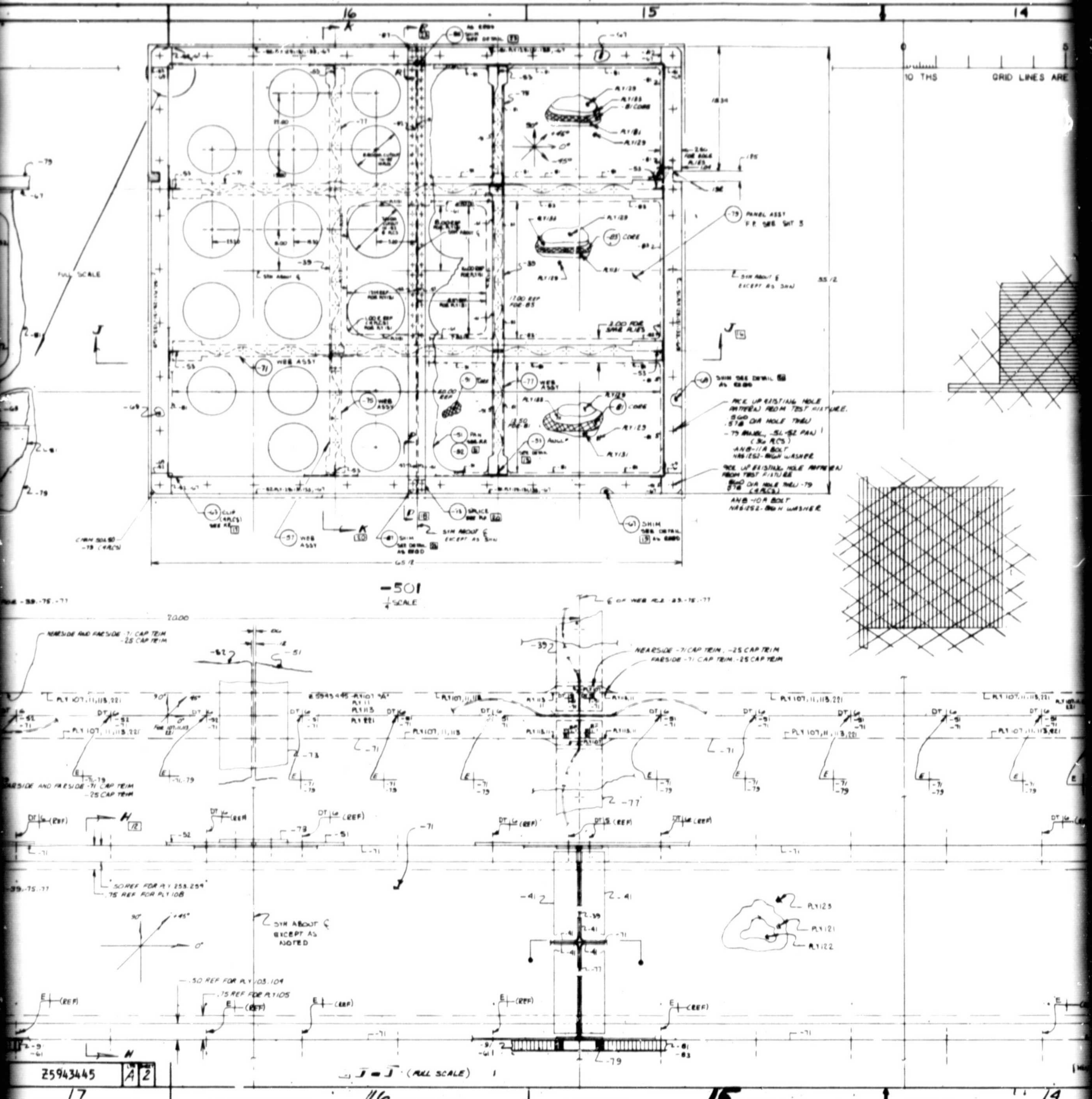

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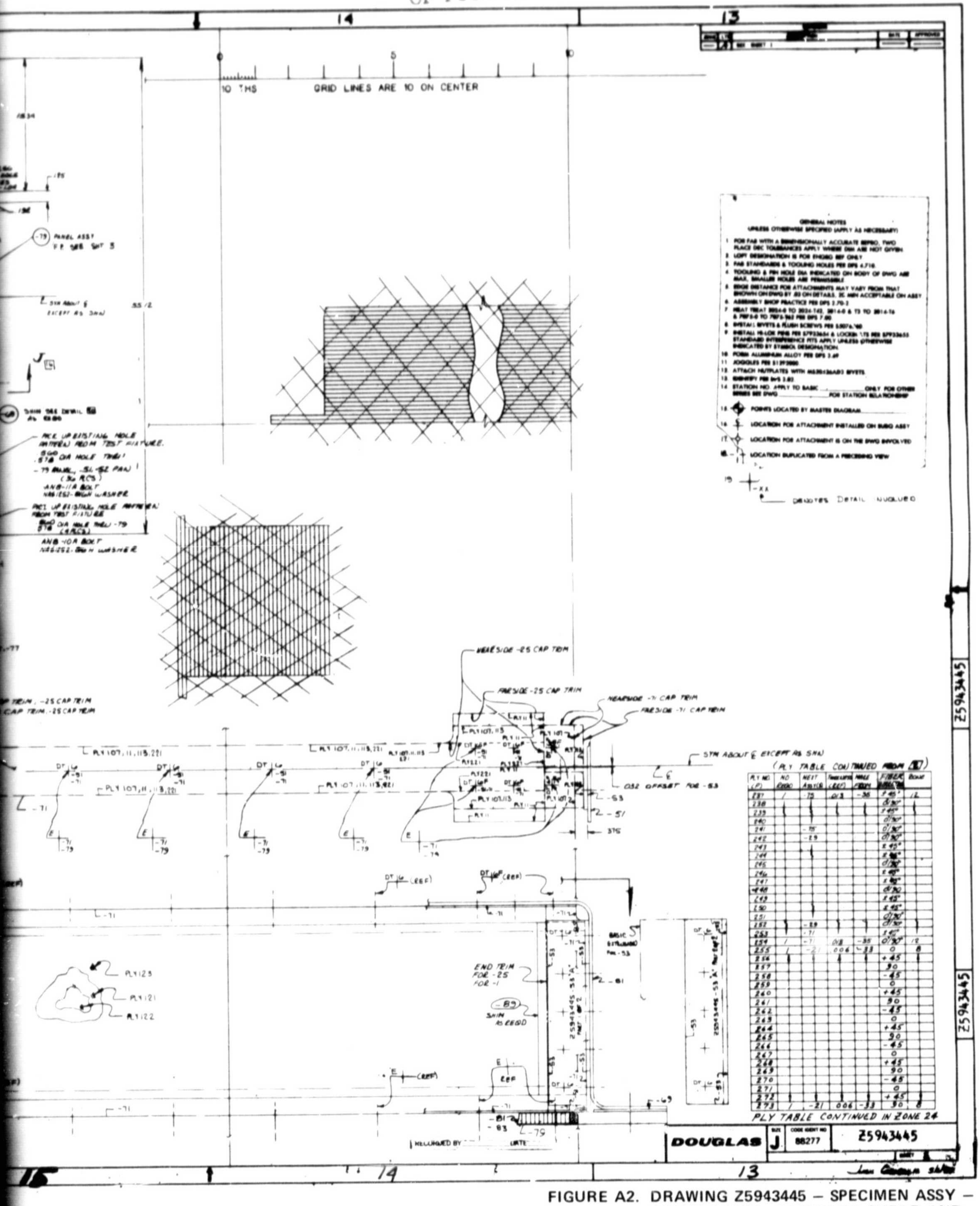
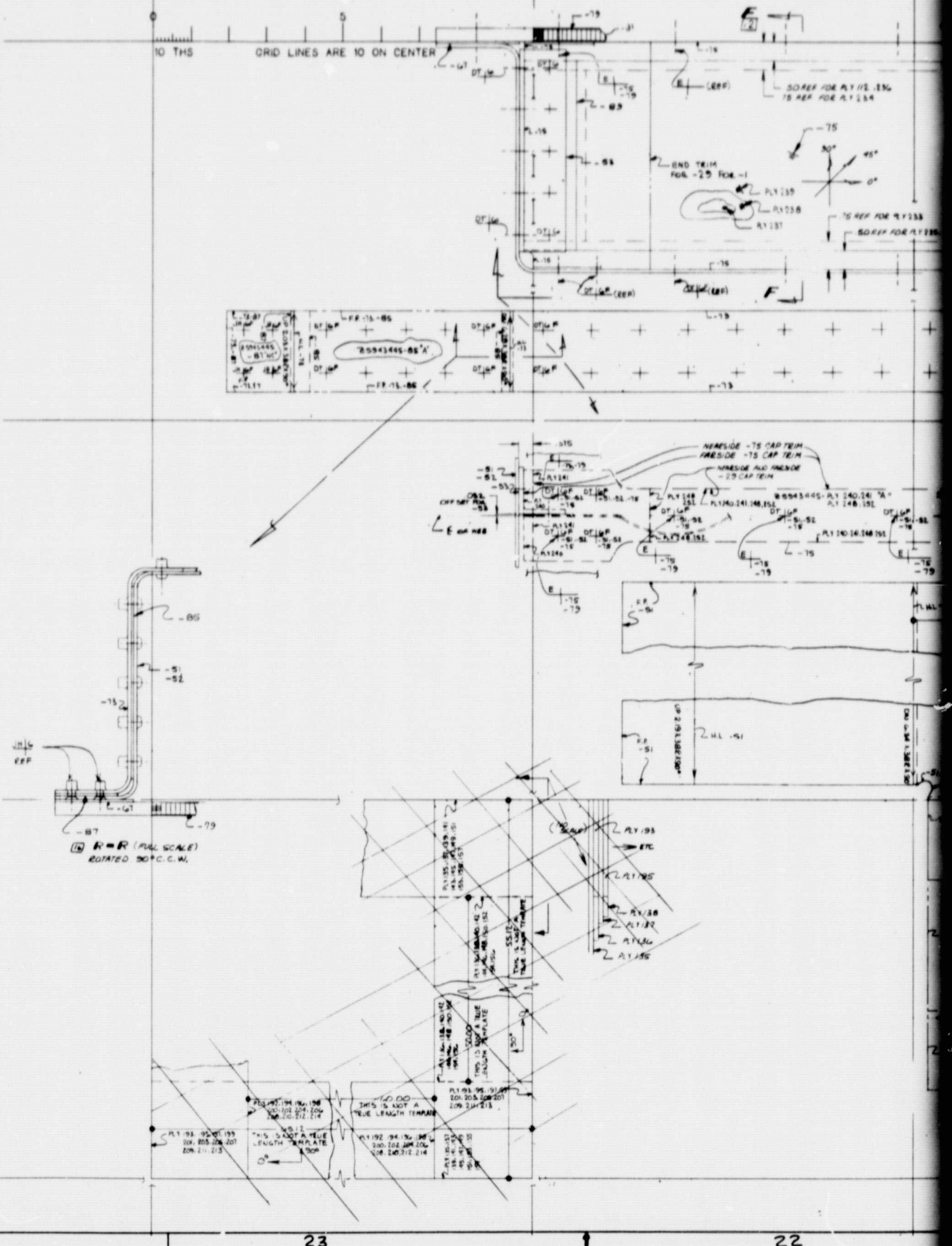


FIGURE A2. DRAWING Z5943445 – SPECIMEN ASSY – COVER PANEL, COMBINED SHEAR AND COMPRESSION (SHEET 2)

24 23 22

PLY TABLE CONTINUED FROM ZONE 18

PLY NO (P)	NO REQD	NEXT ASSY	THICKNESS (REF)	MAKE FROM	FIBER DIRECTION	ZONE
274	1	-21	.006	-33	-45	8
275					0	
276					+45	
277					90	
278					-45	
279					0	
280					90	
281					0	
282					-45	
283					90	
284					+45	
285					0	
286					-45	
287					90	
288					+45	
289					0	
290					-45	
291					90	
292					+45	
293					0	
294					-45	
295					90	
296					+45	
297					0	
298					-45	
299					90	
300					+45	
301					0	
302					-45	
303					90	
304	1	-21	.006	-33	+45	8
305		-19	.006	-33	0	15
306					+45	
307					90	
308					-45	
309					0	
310					+45	
311					90	
312					-45	
313					0	
314					+45	
315					90	
316					-45	
317					0	
318					+45	
319					90	
320					-45	
321					0	
322					+45	
323					90	
324					-45	
325					0	
326					+45	
327					90	
328					-45	
329					0	
330					90	
331					0	
332					-45	
333					90	
334					+45	
335					0	
336					-45	
337					90	
338					+45	
339					0	
340					-45	
341					90	
342					+45	
343					0	
344					-45	
345					90	
346					+45	
347					0	
348					-45	
349					90	
350					+45	
351					0	
352					-45	
353					90	
354	1	-79	.006	-33	+45	15



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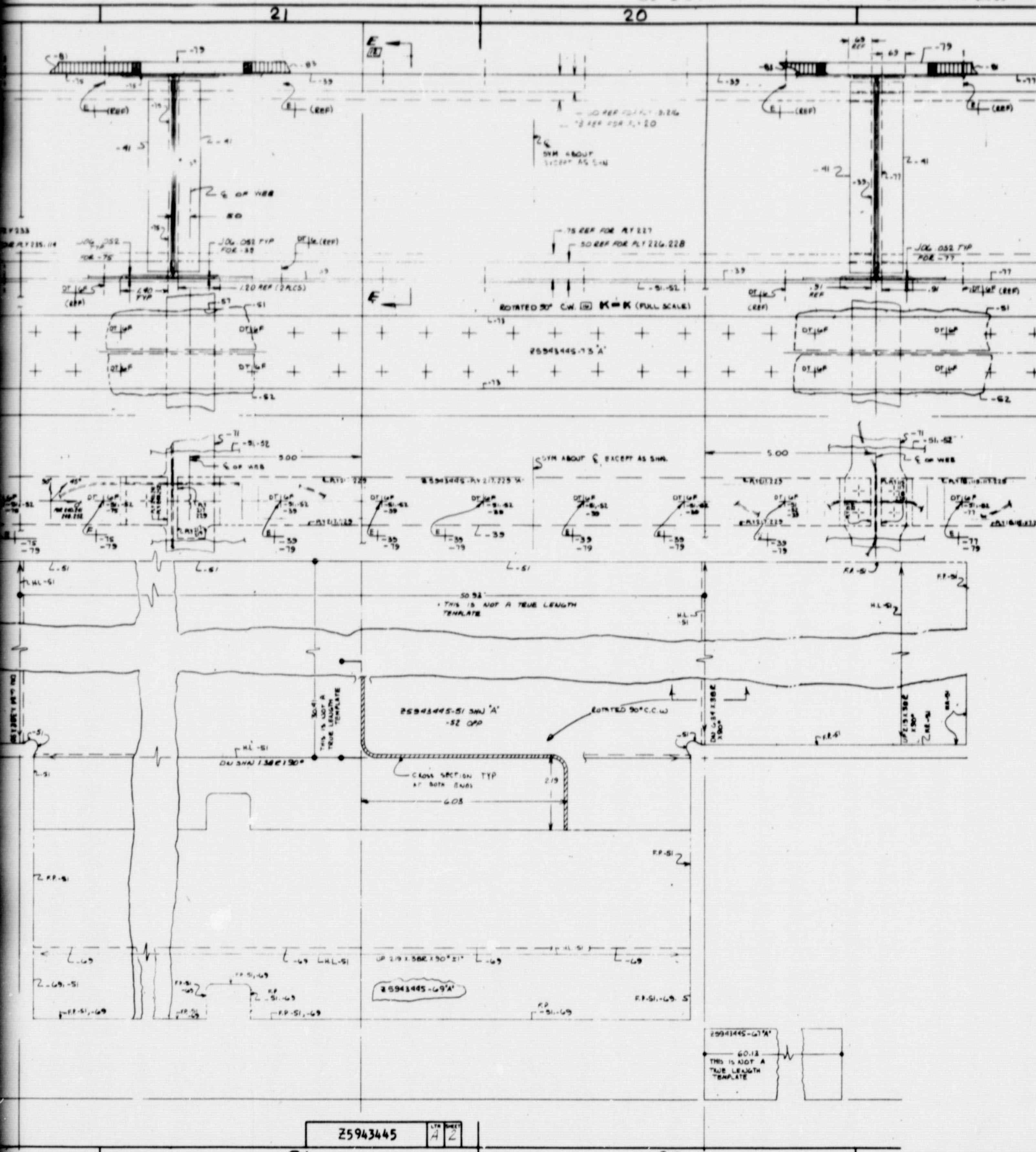

FIGURE A2. DRAWING Z5943445 – SPECIMEN ASSY – COVER PANEL, COMBINED SHEAR AND COMPRESSION (SHEET 2 CONTINUED)

					PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	STOCK SIZE	MATERIAL DESCRIPTION	MATERIAL SPECIFICATION	ZONE	PLANNING COORDINATION

PARTS LIST SEGMENT – [redacted]

					PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	STOCK SIZE	MATERIAL DESCRIPTION	MATERIAL SPECIFICATION	ZONE	PLANNING COORDINATION
	2				-91	CORE	300×14 19	POLYAMIDE PAPER HONEYCOMB	DMS 1974	16	(9)(8) SEE SHT 1 G/N'S
			8		-89	SHIM	THICKNESS AS REQD 1½×5	AL SHT CLAD 2024-T3	QQ-A-250/5 TEMP T3	14	
			AE	AE	NAS4403-7	BOLT					
			AE	AE	MS21261L3	NUTPLATE					
			AE	AE	MS21059L3	NUTPLATE					
			AE		NAS1476	LOCKBOLT	DENOTED BY	JH/6			
			AE		NAS1080-6	COLLAR					
			AE		NAS1466	LOCKBOLT	DENOTED BY	DT/6			
			40		NAS1252-816H	WASHER					
			4		AN8-11A	BOLT					
			8		AN8-10A	BOLT					
			2		-87	SHIM	THICKNESS AS REQD 2½×2	AL SHT CLAD 2024-T3	QQ-A-250/5 TEMP T3	16	
			1		-85	SHIM	THICKNESS AS REQD 2½×6½	AL SHT CLAD 2024-T3	QQ-A-250/5 TEMP T3	16	
	2				-83	CORE	301×17 ×20	POLYAMIDE PAPER HONEYCOMB	DMS 1974	15	(9)(8) SEE SHT 1 G/N'S
	4				-81	CORE	301×14 ×20	POLYAMIDE PAPER HONEYCOMB	DMS 1974	15	(9)(8) SEE SHT 1 G/N'S
			1		-79	PANEL				15	
2					-77	WEB ASSY				16	-77 WEB ASSY IS IDENTICAL TO -27 WEB ASSY EXCEPT FOR END TRIM, -77 IS LONGER
2					-75	WEB ASSY				16	-75 WEB ASSY IS IDENTICAL TO -29 WEB ASSY EXCEPT FOR END TRIM -75 IS LONGER
			1		-73	SPLICE	.090×3 ×70	AL SHT CLAD 2024-T3	QQ-A-250/5 TEMP T3	16	
2					-71	WEB ASSY				16	-71 WEB ASSY IS IDENTICAL TO -25 WEB ASSY EXCEPT FOR END TRIM -71 IS LONGER
			2		-69	SHIM	THICKNESS AS REQD 2½×50½	AL SHT CLAD 2024-T3	QQ-A-250/5 TEMP T3	15	
			2		-67	SHIM	THICKNESS AS REQD 2½×60	AL SHT CLAD 2024-T3	QQ-A-250/5 TEMP T3	15	
					-65 (DELETED NOT USED)						
			4		-63	CLIP	.090×3 ×6	AL SHT CLAD 2024-T3	QQ-A-250/5 TEMP T3	16	
	1	1			-61	CORE	301× ×19	POLYAMIDE PAPER HONEYCOMB	DMS 1974	5	(9)(8) SEE SHT 1 G/N'S
		2			-59	CORE	300×15 ×19	POLYAMIDE PAPER HONEYCOMB	DMS 1974	5	(9)(8) SEE SHT 1 G/N'S
			1		-57	WEB ASSY				16	
					-55 (DELETED NOT USED)						
			8		-53	ANGLE	6 IN	MAKE FROM 6124932B-		16	
			1		-52	PAN	.09×40 ×69	AL SHT CLAD 2024-T3	QQ-A-250/5 TEMP T3	16	
			1		-51						

PARTS LIST SEGMENT – [redacted]

FIGURE A2. DRAWING Z5943445 – SPECIMEN ASSY – COVER PANEL, COMBINED SHEAR AND COMPRESSION (SHEET 2 CONCLUDED)

FOLDOUT FRAME 1

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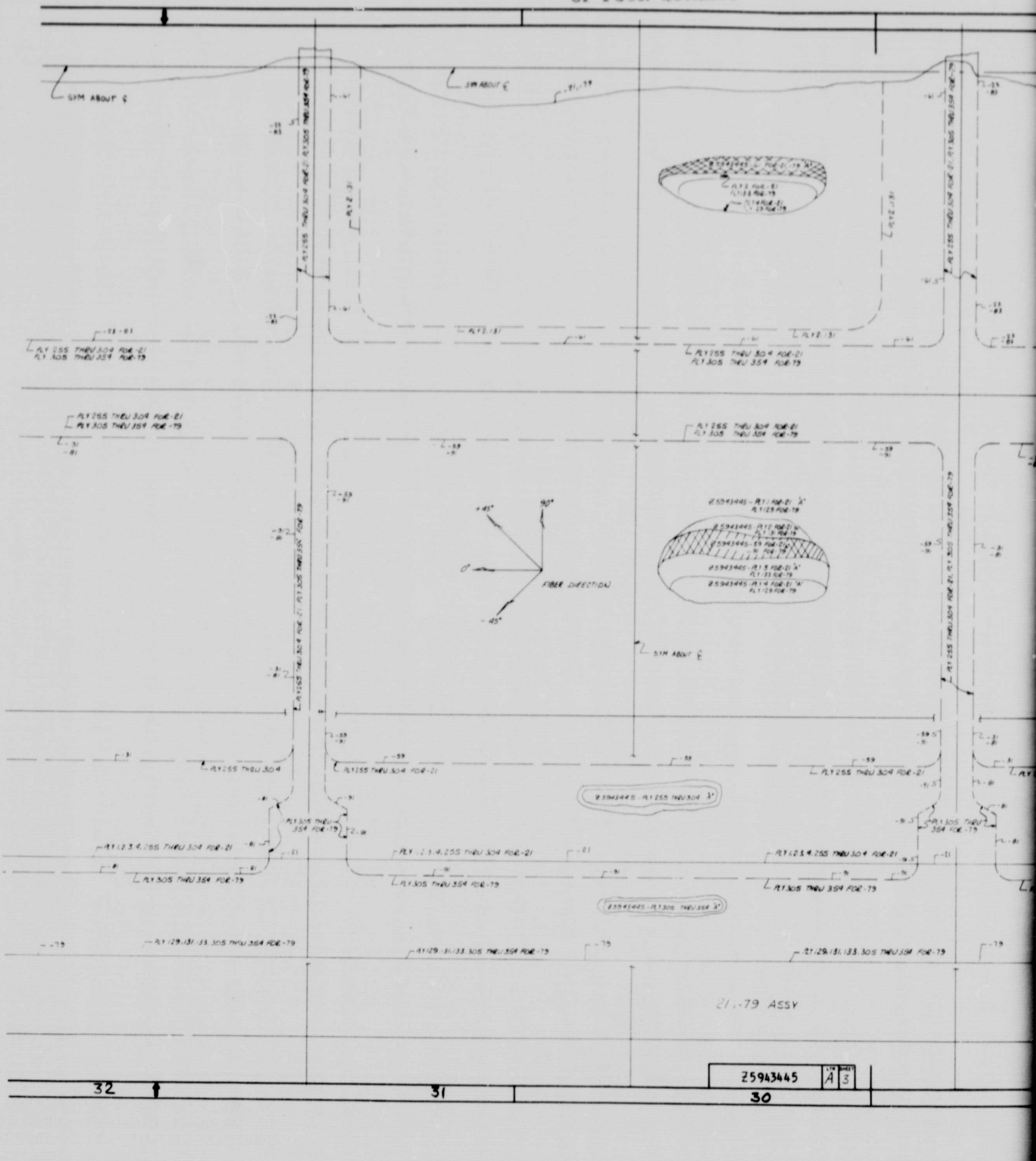

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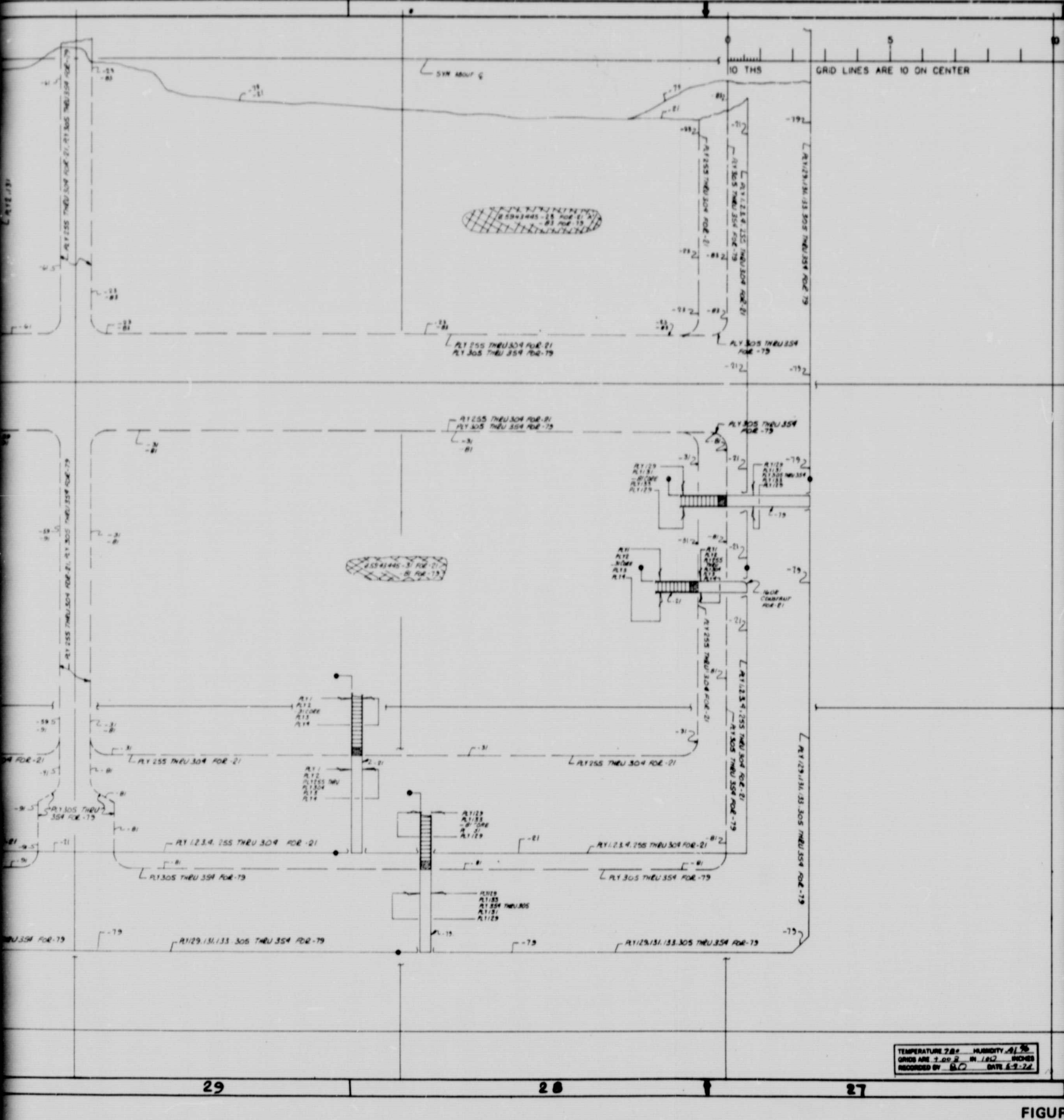
Douglas Aircraft Company
Contract NAS1-14869



FIGURE

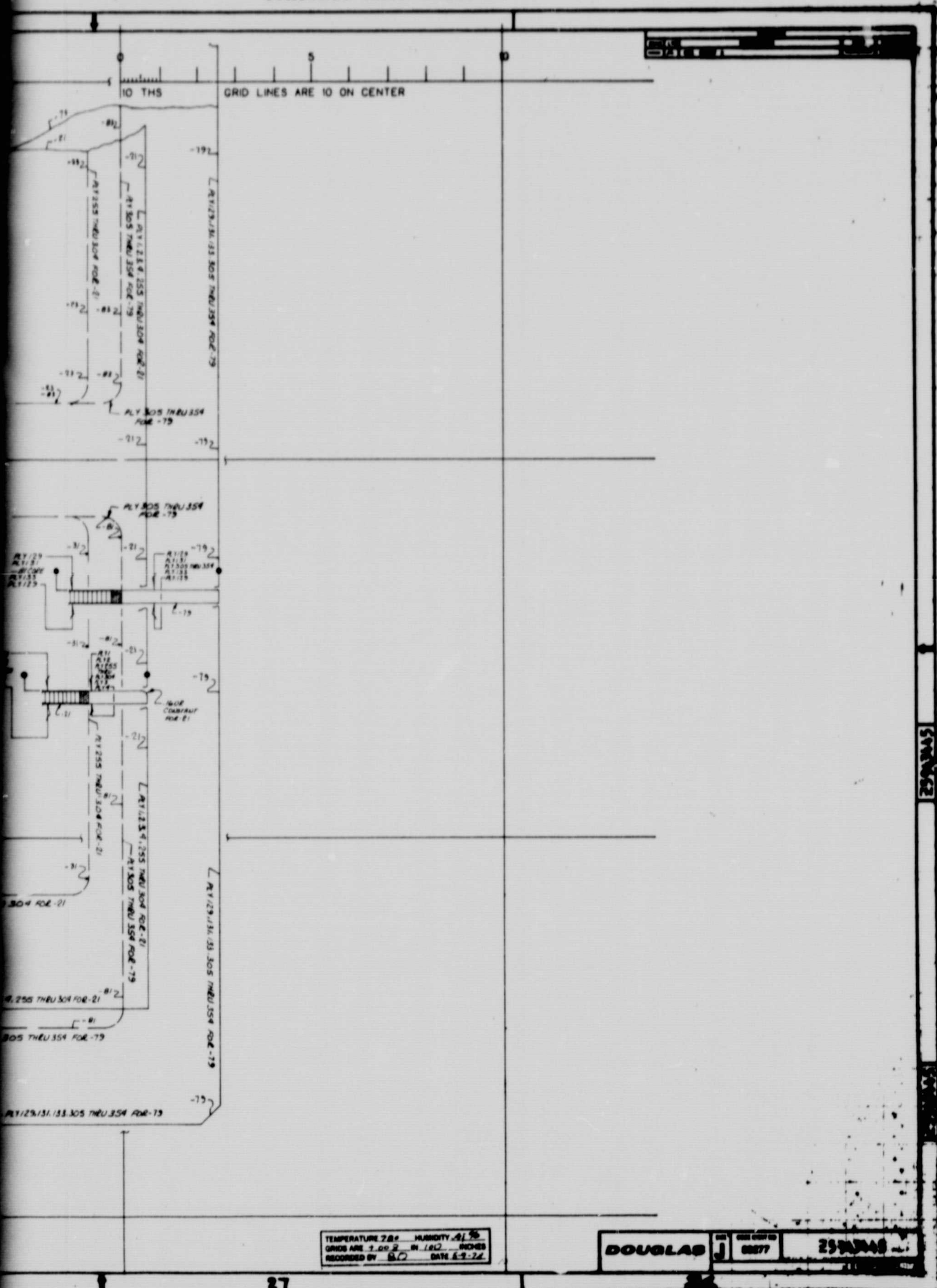


FIGURE A2. DRAWING Z5943445 – SPECIMEN ASSY – COVER PANEL, COMBINED SHEAR AND COMPRESSION (SHEET 3)

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0 5 10

10 THS GRID LINES ARE 10 ON CENTER

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37 36

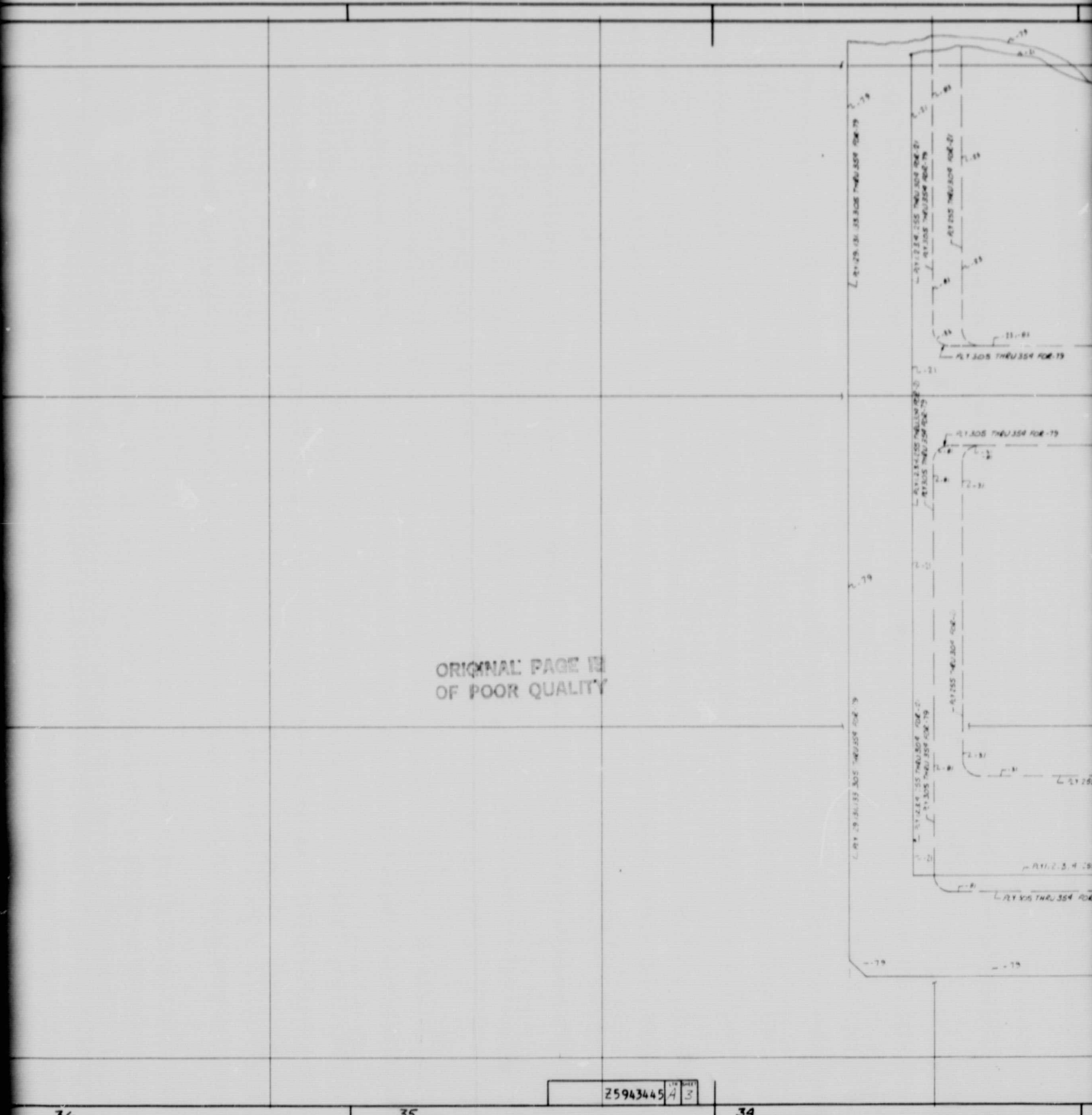

FIGURE A2. DRAWING Z594[...]
COVER PANEL, [...]
COMPRESSION [...]

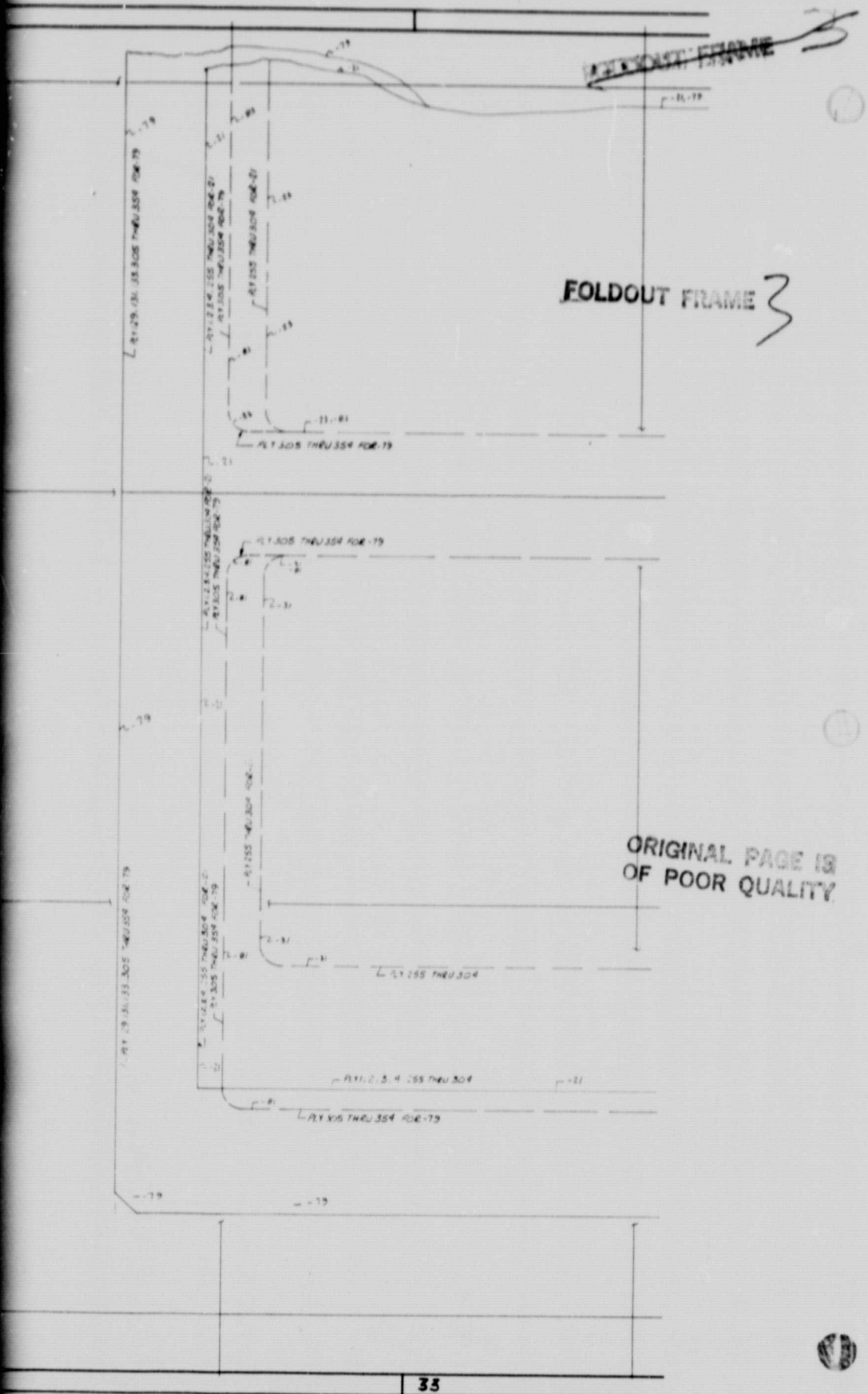

FIGURE A2. DRAWING Z5943445 – SPECIMEN ASSY – COVER PANEL, COMBINED SHEAR AND COMPRESSION (SHEET 3 CONCLUDED)

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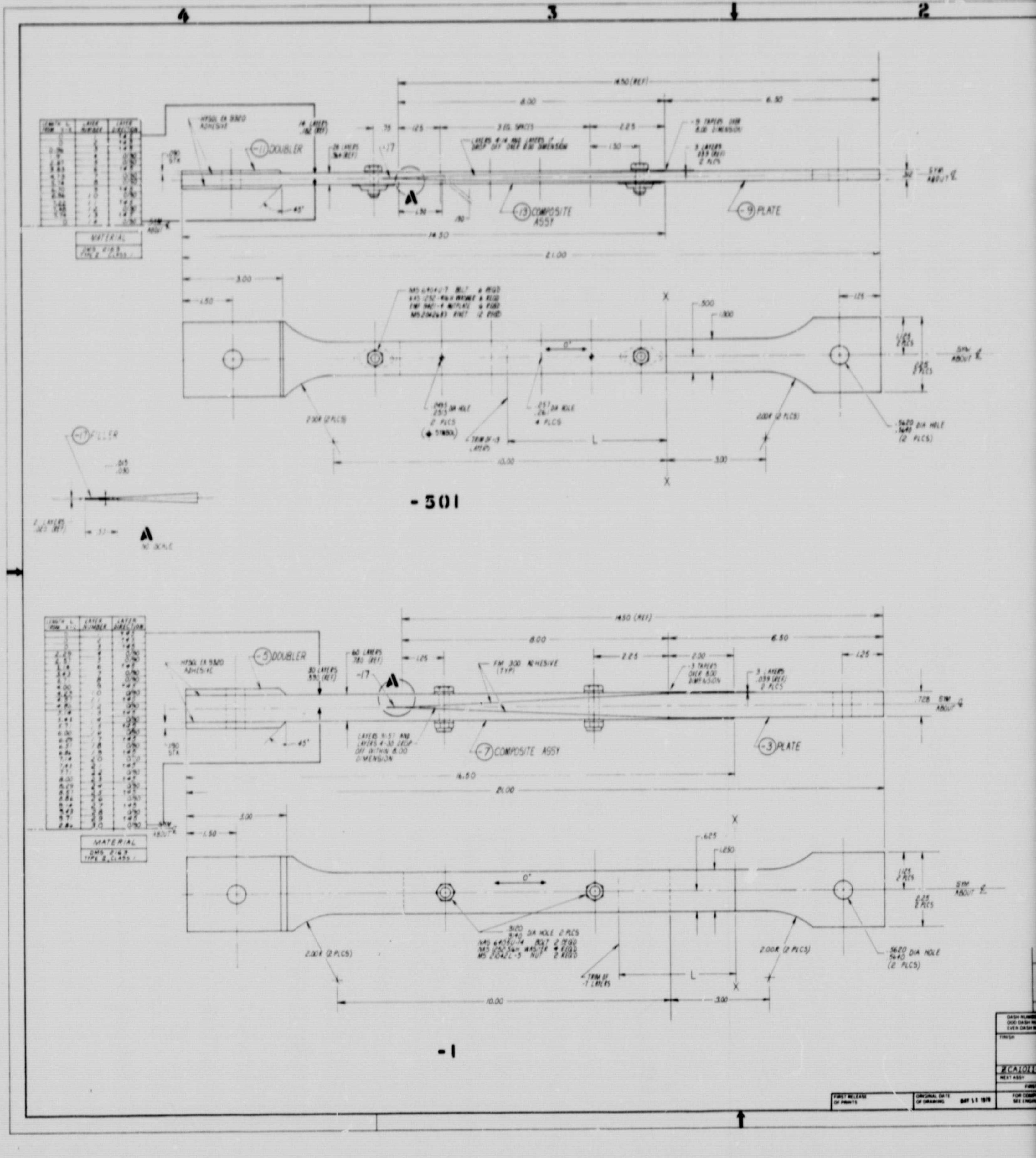
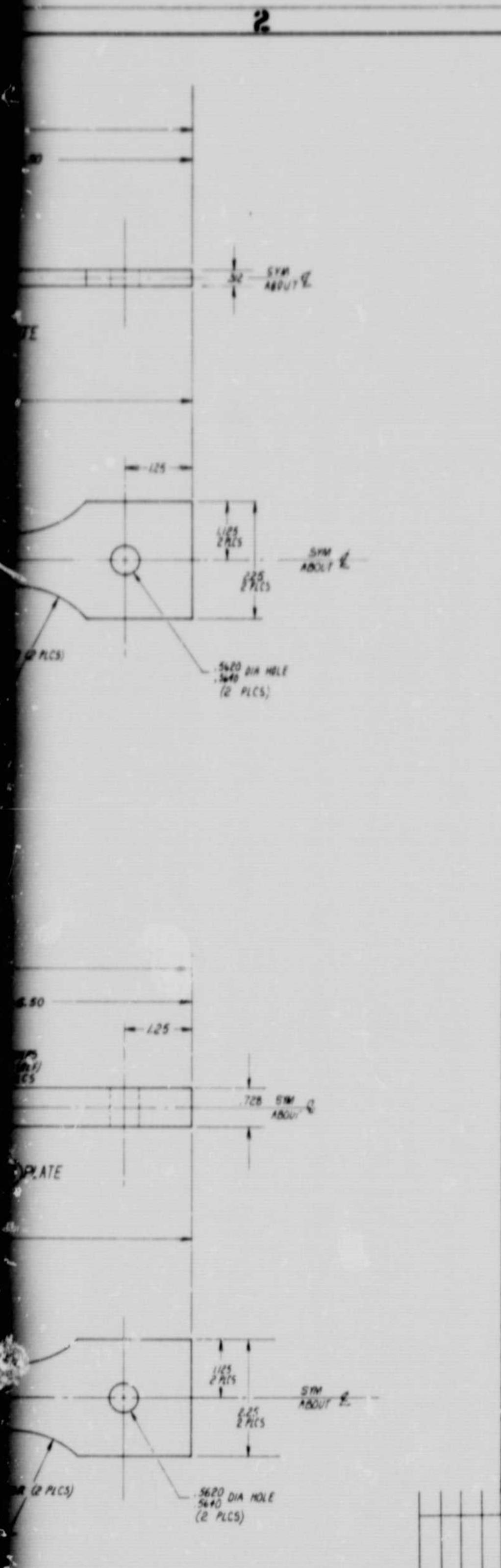
Douglas Aircraft
Contract NAS1-14





GENERAL NOTES: UNLESS OTHERWISE SPECIFIED

1. IDENTIFY PER DPS 3.02.
2. PROCESS TITANIUM PER DPS 4.801.
3. MACHINE SURFACES 125 PER ANSI B46.1.
4. GRAIN DIRECTION LENGTHWISE.
5. PENETRANT INSPECT TITANIUM PER DPS 4.707.
6. FABRICATION STANDARDS PER DPS 4.710
7. ASSEMBLY SHOP PRACTICE PER DPS 2.70-2.
8. INSTALL RIVETS PER S5076260.
9. ATTACH NUTPLATES WITH MS20426AD3 RIVETS.
10. "EQL SPACED" TOLERANCE TO BE WITHIN .06.
11. HEAT TREAT 4130 STEEL 125-145 KSI PER DPS 5.00.
12. COCURE -3 PLATE TO -7 COMPOSITE ASSY AND -9 PLATE TO -13 COMPOSITE ASSY WITH FM 300 ADHESIVE DURING CYCLE.
13. BOND -5 DOUBLER TO -7 COMPOSITE ASSY AND -11 DOUBLER TO -13 COMPOSITE ASSY WITH HYSOL EA 9320 ADHESIVE.
14. WARP AND FILL DIRECTIONS ARE INTERCHANGEABLE.
15. FABRICATION AND PROCESS METHOD PER [illegible] 5943683 AND DPS [illegible].
16. MEASURE RESIN & VOID CONTENT PER DMS 1936 OR DMS 2163 AND VERIFY CONFORMITY TO REQUIREMENT.
    RESIN CONTENT, BY WEIGHT: BETWEEN 24.2 & 34.2
    VOID CONTENT, BY VOLUME: 2% MAX
17. INSTALL RIVETS & BOLTS USING WET SEALANT PER DPS 4.025

-13	-7	-501	-1	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	CODE IDENT NO	STOCK SIZE	MATERIAL DESCRIPTION	MATERIAL SPECIFICATION	FIND NO	ZONE
		1	1	— 17	FILLER		2 LAYERS x .50 x WIDTH	181 TYPE GLASS FAB. 5208 IMPREGNATED			
		6		KAF9421-4	NUTPLATE						3
		6		NAS6404U-7	BOLT						3
		12		MS20426 B3	RIVET						3
		6		NAS1252-416H	WASHER						3
0.5 M	1.0 M			— 15	CLOTH			T300/5208 GRAPHITE/EPOXY	DMS 2163 TYPE I CLASS		
		1		— 13	COMPOSITE ASSY						3
		2		— 11	DOUBLER		.090 x 2.50 x 3.00	STEEL PLATE 4130	MIL-S-18729 COND N		4
		1		— 9	PLATE		1/2 x 2.50 x 15	TITANIUM 6AL-4V ANNEALED	DMS 1592		2
			4	NAS1252-516H	WASHER						3
			2	MS21042L-5	NUT						3
			2	NAS6405U-14	BOLT						3
		AR	AR	HYSOL EA 9320	ADHESIVE				HYSOL CHEMICAL CO PITTSBURG CALIF		4
		AR	AR	FM 300	ADHESIVE				AMERICAN CYANAMID		3
			1	— 7	COMPOSITE ASSY						3
		2		— 5	DOUBLER		.190 x 2.50 x 3.00	STEEL PLATE 4130	MIL-S-18729 COND N		4
			1	— 3	PLATE		3/4 x 2.50 x 15	BAR 6AL-4V TITANIUM ALLOY ANNEALED	DMS 1570C		2

QUANTITY REQUIRED PER NOTED DASH NO.

PARTS LIST

DOUGLAS AIRCRAFT COMPANY
LONG BEACH, CALIFORNIA

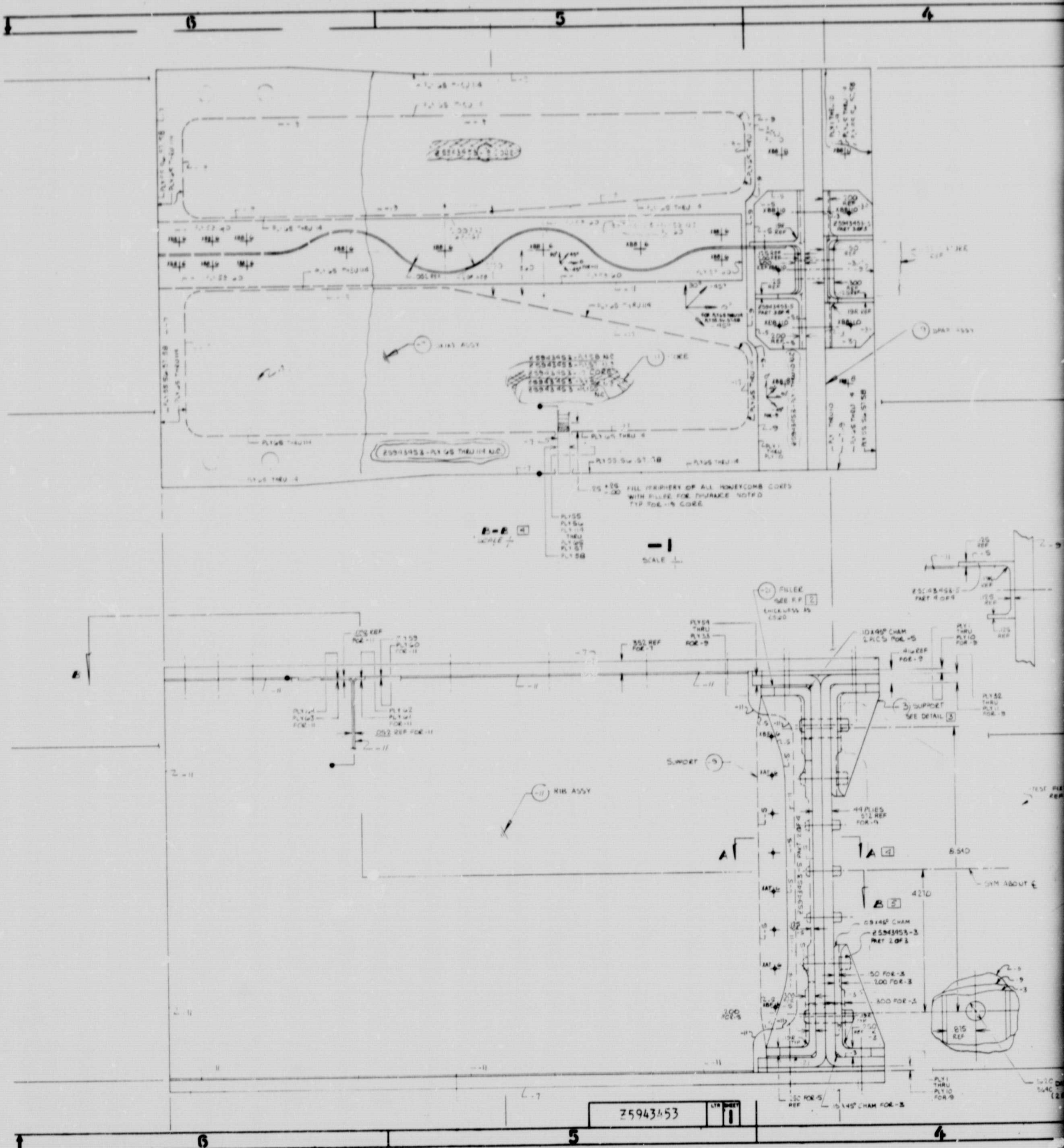
CONTRACT NO NAS 1-14869

SPECIMEN ASSY — SPAR-ROOT FITTING, BONDLINE

SIZE J | CODE IDENT NO 88277 | Z5943452

FIGURE A3. DRAWING Z5943452 – SPECIMEN ASSY, SPAR-ROOT FITTING, BONDLINE

FOLDOUT FRAME 1



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Douglas Aircraft Company
Contract NAS1-14869

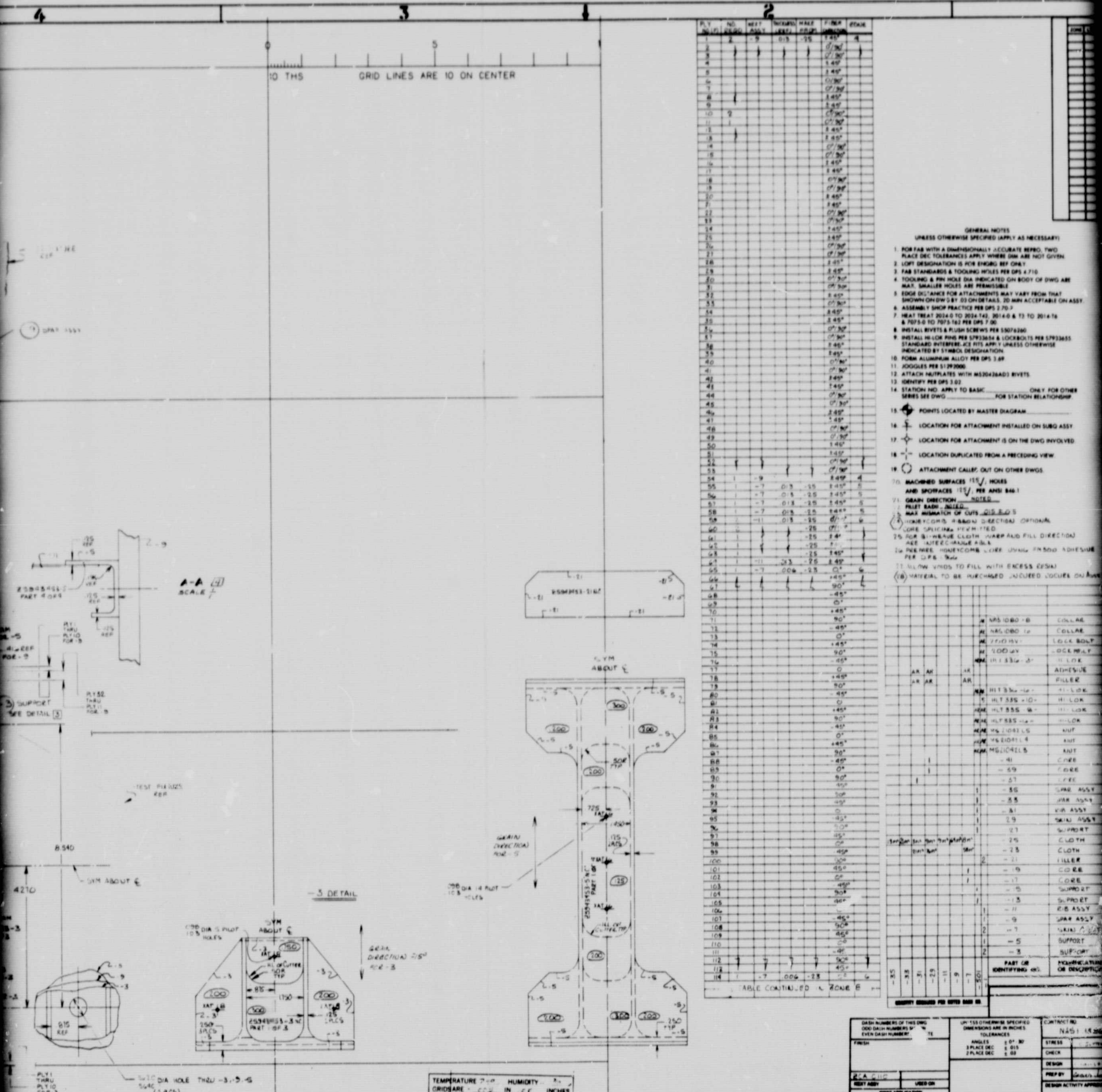

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FIGURE A4. DRAWING Z5943453
HINGE SUPPORT RI

FOLDOUT FRAME 3

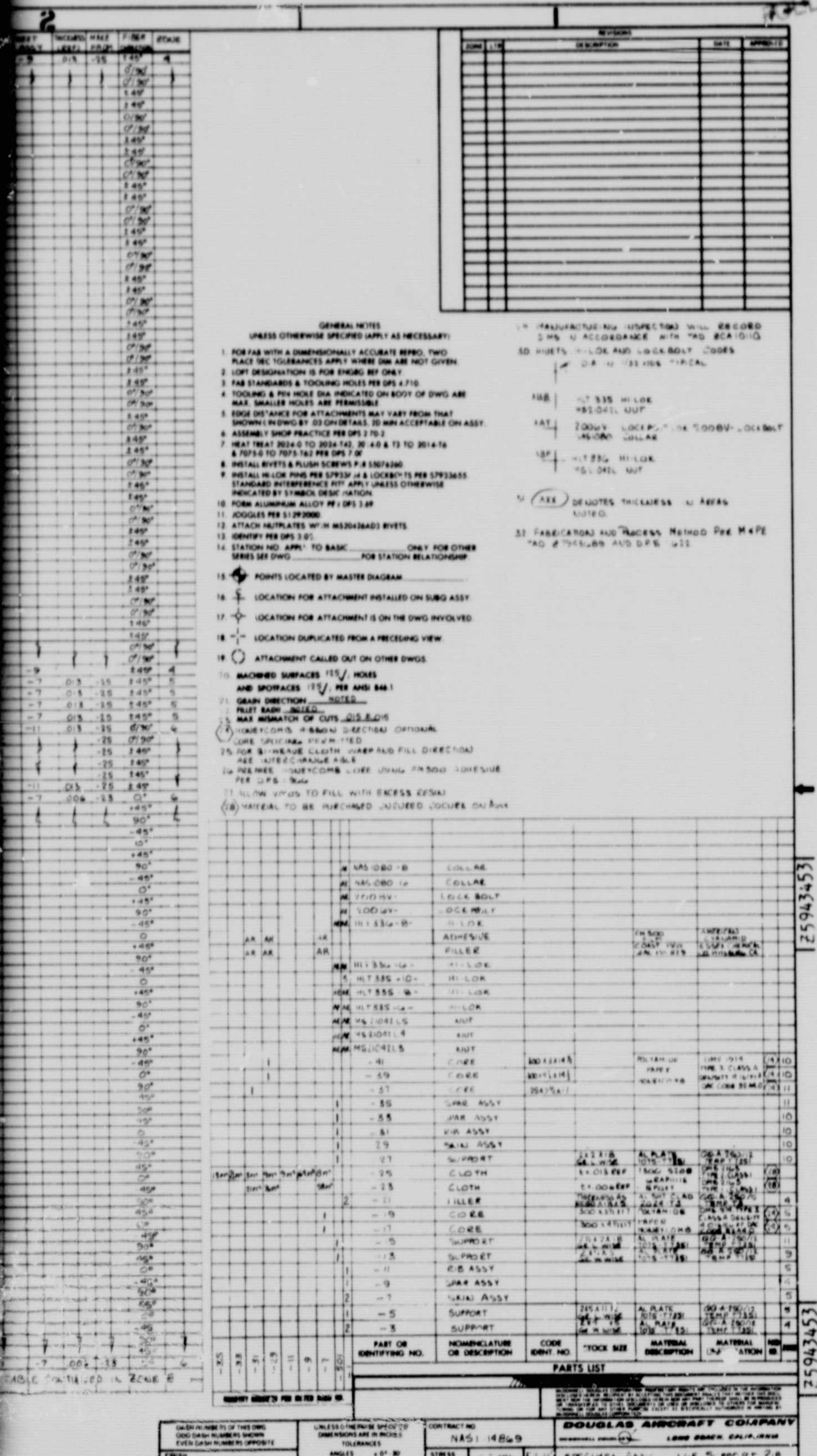

FIGURE A4. DRAWING Z5943453 – SPECIMEN ASSEMBLY – HINGE SUPPORT RIB, ACTUATOR AND TIE ROD

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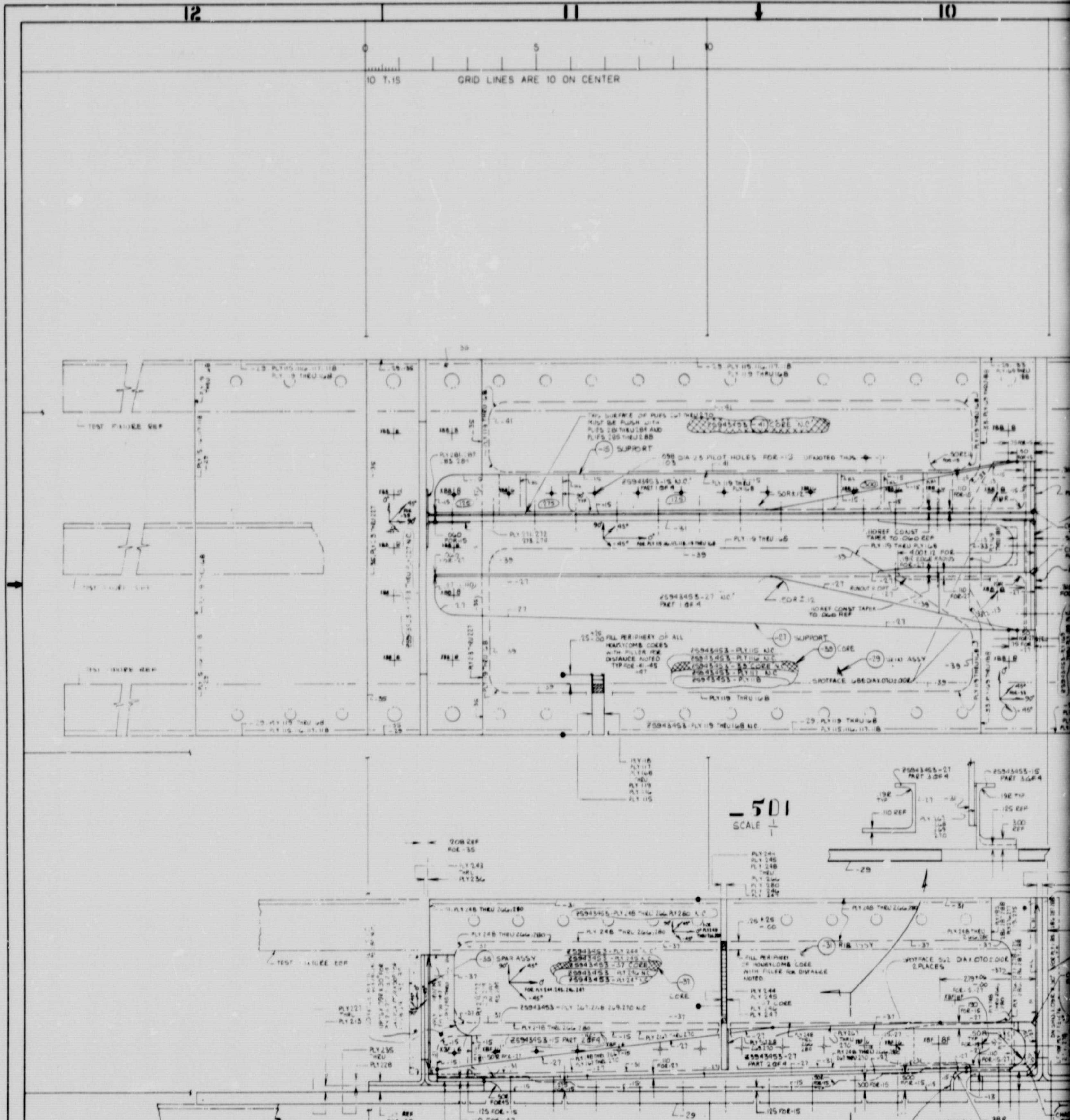

FIGURE A4. DRAWING Z5943453 – SPE
HINGE SUPPORT RIB, ACT
(CONCLUDED)

8 7

PLY SEQ'N	NO. REQ'D	NEXT ASSY	THICKNESS (REF)	MAKE FROM	FIBER DIRECTION	ZONE
115	1	-29	.013	-25	±45°	10
116	1	-29	.013	-25	±45°	
117	1	-29	.013	-25	±45°	
118	1	-29	.013	-25	±45°	
119			.006	-23	0°	
120					45°	
121					90°	
122					-45°	
123					0°	
124					45°	
125					90°	
126					-45°	
127					0°	
128					45°	
129					90°	
130					-45°	
131					0°	
132					45°	
133					90°	
134					-45°	
135					0	
136					45°	
137					90°	
138					-45°	
139					0°	
140					45°	
141					90°	
142					-45°	
143					0°	
144					90°	
145					45°	
146					90°	
147					45°	
148					0	
149					-45°	
150					90°	
151					45°	
152					0°	
153					45°	
154					90°	
155					[illegible]	
156					0°	
157					-45°	
158					90°	
159					45°	
160					0°	
161					-45°	
162					90°	
163					45°	
164					0°	
165					45°	
166					90°	
167					45°	
168		-29	.006	-23	0°	
169		-33	.013	-25	0°/90°	
170					±45°	
171					±45°	
172					0°/90°	
173					0°/90°	
174					±45°	
175					±45°	
176					0°/90°	
177					0°/90°	
178					±45°	
179					±45°	
180					0°/90°	
181					0°/90°	
182					±45°	
183					±45°	
184					0°/90°	
185					0°/90°	
186					±45°	
187					±45°	
188					0°/90°	10
189					0°/90°	9
190					±45°	
191					0°/90°	
192					0°/90°	
193					±45°	
194					±45°	
195					±45°	
196					0°/90°	
197					0°/90°	
198					±45°	
199					±45°	
200					0°/90°	
201					0°/90°	
202					±45°	
203					±45°	
204					0°/90°	
205					0°/90°	
206					±45°	
207					±45°	
208					0°/90°	
209					0°/90°	
210					±45°	
211					±45°	
212		-33			0°/90°	9
213		-35			0°/90°	11
214					±45°	
215					±45°	
216					0°/90°	
217					0°/90°	
218					±45°	
219					±45°	
220					0°/90°	
221					0°/90°	
222					±45°	
223					±45°	
224					0°/90°	
225					0°/90°	
226					±45°	
227					±45°	11
228					0°/90°	12
229					±45°	
230					±45°	
231					0°/90°	
232					0°/90°	
233					±45°	
234					±45°	12
235					0°/90°	
236					0°/90°	11
237					±45°	
238					±45°	
239					0°/90°	
240					0°/90°	
241					±45°	
242					±45°	
243	1	-35	.013	-25	0°/90°	11

PLY SEQ'N	NO. REQ'D	NEXT ASSY	THICKNESS (REF)	MAKE FROM	FIBER DIRECTION	ZONE
244	1	-31	.013	-25	±45°	11
245	1	-31	.013	-25	±45°	
246	1	-31	.013	-25	±45°	
247	1	-31	.013	-25	±45°	
248			.006	-23	0°	
249					45°	
250					90°	
251					-45°	
252					0°	
253					45°	
254					90°	
255					-45°	
256					0°	
257					[illegible]	
258					1?	
259					[illegible]	
260					[illegible]	
261					[illegible]	
262					[illegible]	
263					[illegible]	
264					[illegible]	
265					[illegible]	
266			.006	-23	[illegible]	11
267			.013	-25	±45°	12
268						12
269						12
270						12
271						11
272						11
273						11
274						11
275						10
276						10
277						10
278	1	-31	.013	-25	±45°	10
279		-35	.013	-25	0°/90°	11
280	1	-31	.006	-23	45°	
281		-31	.013	-25	±45°	12
282					±45°	12
283					±45°	12
284					±45	12
285					±45°	9
286					±45°	9
287					±45°	9
288	1	-31	.013	-25	±45°	9

8 7

FIGURE A4. DRAWING Z5943453 – SPECIMEN ASSEMBLY – HINGE SUPPORT RIB, ACTUATOR AND TIE ROD (CONCLUDED)

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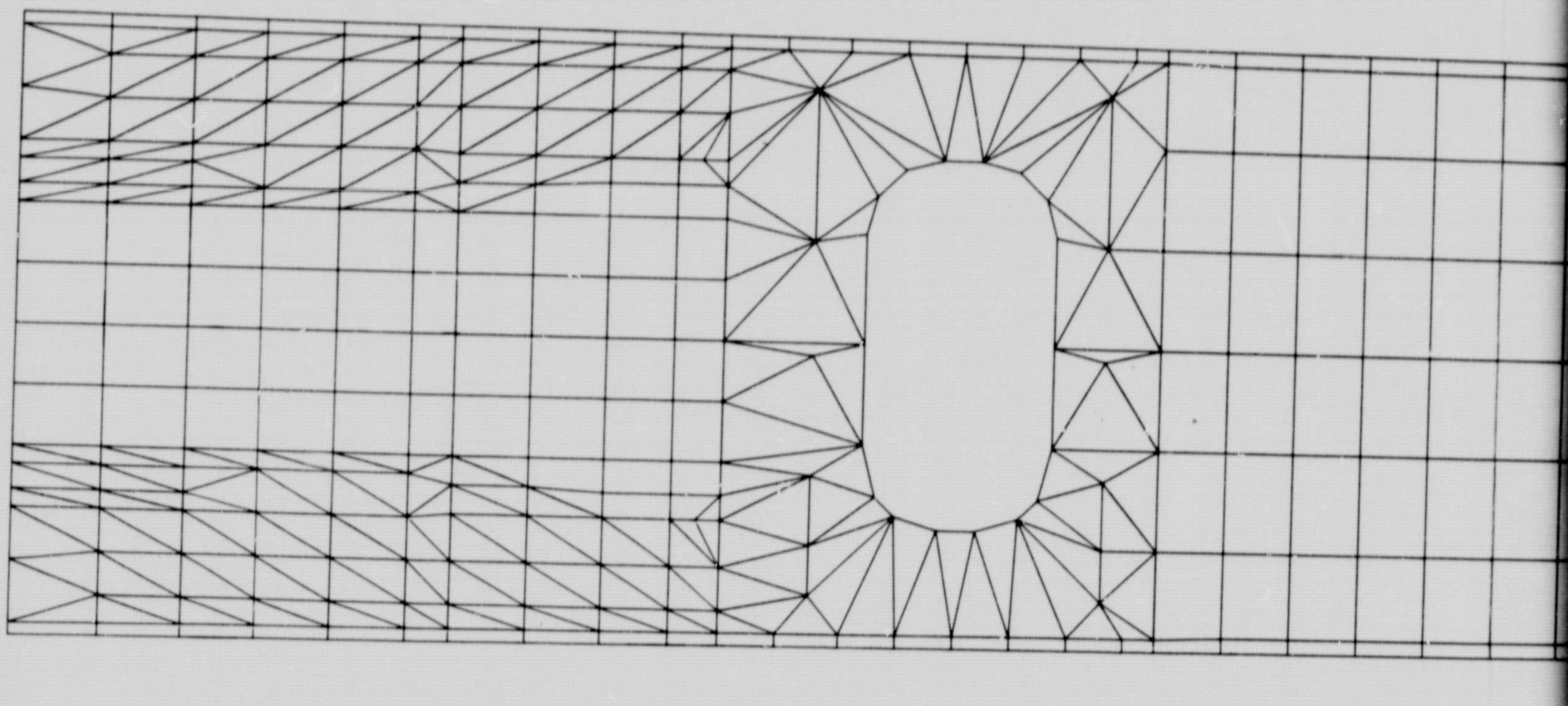


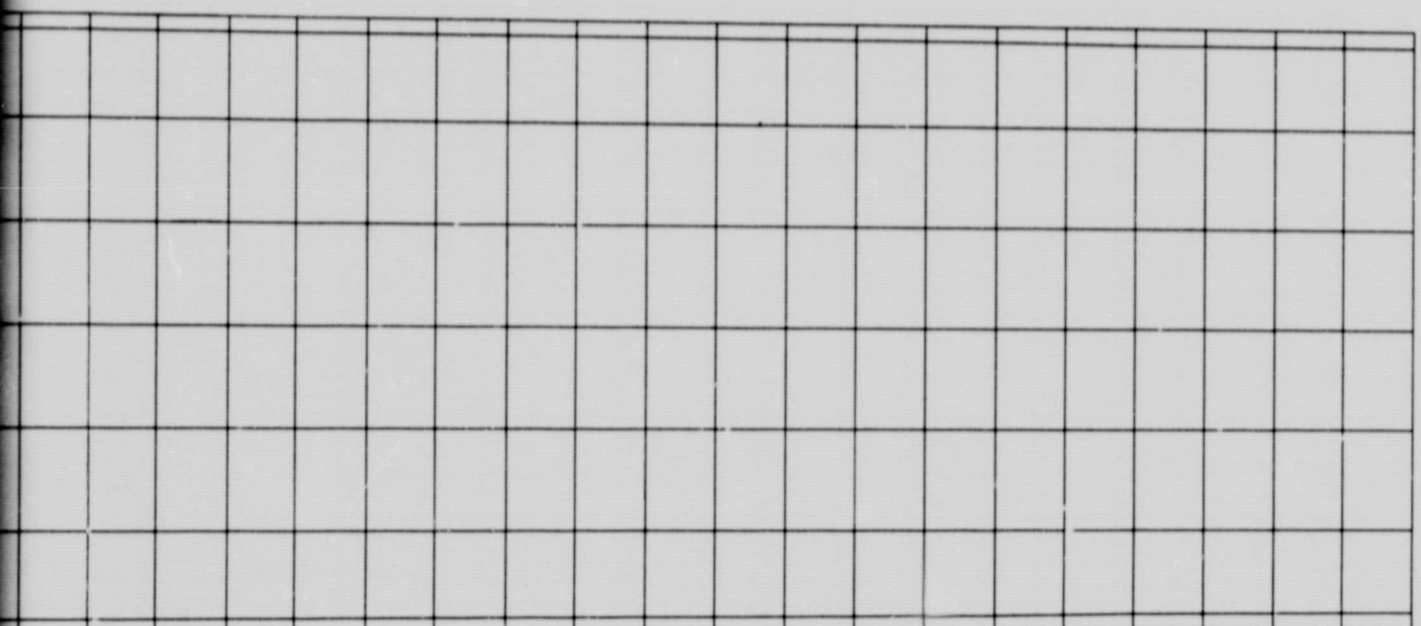


FIGURE A5 DRAWING Z5943446 – REAR SPAR TEST SPECIMEN, ANALYSIS MODEL

APPENDIX B

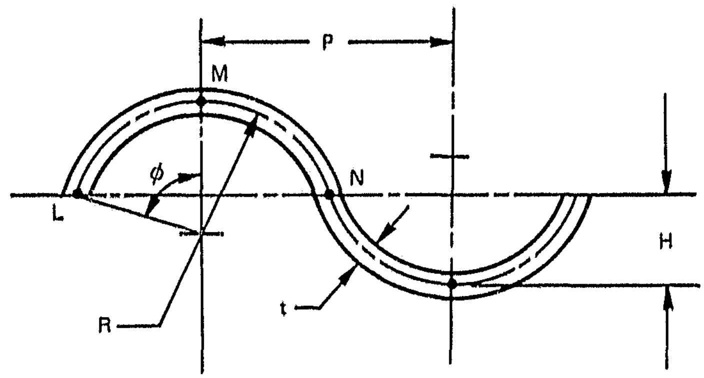
SUPPLEMENTARY ANALYSES

- BUCKLING OF SINE-WAVE WEBS
- ALLOWABLE SHEAR BASED ON STRAIN

APPENDIX B

SUPPLEMENTARY ANALYSES

Buckling of Sine-wave Webs



Amplitude $H = R\,(1 - \cos\phi)$

Pitch $P = 2\,R\,\sin\phi$

Arc Length $\overline{LMN} = S = 2\,R\,\phi$

Length Ratio $L = S/P = \phi/\sin\phi$

The normal panel stiffness terms are modified as follows:

$$D_{11} = \left(\frac{E_x\,t^3}{12\,\lambda}\right)/L$$

$$D_{12} = \left(\frac{\nu_{yx}\,E_x\,t^3}{12\lambda}\right)/L$$

$$D_{66} = \left(\frac{G_{xy}\,t^3}{12}\right)/L$$

$$D_{22} = \frac{Ey}{\lambda}\left\{tR^2\left[1/2 - \frac{3\,\sin 2\phi}{4\phi} + \cos^2\phi\right] + \frac{t^3}{8}\left[1 + \frac{\sin 2\phi}{2\phi}\right]\right\}L$$

where the laminate is assumed to be homogeneous throughout the thickness.

Evaluation of local buckling is based on the semi-empirical equation

$$N_{xy} = 1.55\ t\ E\left(\frac{t}{2R}\right)^{1.5}$$

given in Reference 2. Since this expression was derived for isotropic material for which $\nu = 0.3$ may be assumed, it has been modified for nonisotropic material as follows

$$N_{xy} = 1.4105 \left(\frac{K_s\ t}{\lambda}\right) \left(E_x\ E_y{}^3\right)^{1/4} \left(\frac{t}{2R}\right)^{1.5}$$

where K_s is a function of θ and β

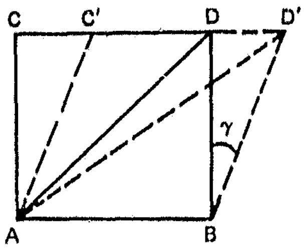
$$\theta = \frac{D_{12} + 2\ D_{66}}{(D_{11}\ D_{22})^{1/2}}$$

$$\beta = \frac{b}{a}\left(\frac{D_{11}}{D_{22}}\right)^{1/4}$$

as is normal practice for nonisotropic panel solution.

Allowable Shear Based on Strain

The adopted policy for the design of the stabilizer is to achieve a damage-tolerant structure by imposing a limit on the allowable strain. If this maximum strain is regarded as being appropriate to any filament direction, shear panels which contain layers at $\pm 45^{\circ}$ can be considered as follows:



Consider square element of unit side length

Diagonal $\overline{AD} = \sqrt{2}$

For strain on diagonal $= \varepsilon$

$$\overline{AD'} = (1 + \varepsilon)\sqrt{2}$$

$$\overline{CD'} = \left[2(1 + \varepsilon)^2 - 1\right]^{1/2}$$

$$= \left[2\varepsilon\,(2 + \varepsilon) + 1\right]^{1/2}$$

$$\overline{DD'} = \left[2\varepsilon\,(2 + \varepsilon) + 1\right]^{1/2} - 1$$

Shear Strain $\quad \gamma = \tan^{-1} \overline{DD'}$

Allowable Shear Stress $F_s = \gamma\, G_{xy}$

Allowable Shear Loading $N_{xy} = \gamma\, G_{xy}\, t$

For example, if $\varepsilon = 0.003$ $\quad \gamma = 0.005991$ radians

If for 100% $\pm 45^{\circ}$ $\quad G_{xy} = 5.5 \times 10^6$

$F_s = 32{,}950$ psi

If for 0% $\pm 45^{\circ}$ $\quad G_{xy} = 0.65 \times 10^6$

$F_s = 3894$ psi

Linear interpolation may be used between these two values for other percentages of $\pm 45^{\circ}$. For general buckling, the above expressions are substituted into the normal compression and shear buckling equations for nonisotropic panels.