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DESIGN AND FABRICATION AND DELIVERY OF FIBERGLASS BOX BEAM ASSEMBLY

FINAL REPORT
March 1965

Contract No. NAS 8-11749
Control No. DCN 2-4-04-001070-1
CPB 04-46139-64 (1F)

by
William H. Gottwald

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National Aeronautics and Spqce Administration
George C. Marshall Space Flight Center
Huntsville, Alabama

by
William H. Gottwald

WHITTAKER CORPORATION
Narmco Research & Development Division
San Diego, California

FOREWORD

This report was prepared by Whittaker Corporation, Narmco Research & Development Division, San Diego, California, under Contract No. NAS-8-11749, Control No. 2-4-04-001070-1, CPB 04-46139-64(1F), entitled "Design and Fabrication and Delivery of Fiberglass Box Beam Assembly," for the George C. Marshall Space Flight Center, National Aeronautics and Space Administration, Huntsville, Alabama. The work was administered under the direction of PR-RM, George C. Marshall Space Flight Center, with Mr. William J. McKinney as contracting officer. This report covers work performed from 30 June 1964 to 15 March 1965.

The author wishes to acknowledge the valuable analytical assistance given by Mr. V. G. Grinius, Narmco Research Engineer, in the development of this design.

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SUMMARY

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This report describes work on a program whose objective was to design and fabricate a fiberglass box beam to be tested and compared, by the National Aeronautics and Space Administration (NASA), with metallic box beams. A complete stress analysis is presented which contains (1) a summary of the design loads, margins of safety for the shear webs and the top panel compression member and a theoretical weight analysis for the beam; (2) an analysis of the predicted failing load of NASA's aluminum box beam; (3) a basic stress analysis for the fiberglass reinforced box beam; and (4) a description of modifications in the basic design of the fiberglass reinforced box beam. In addition, this report describes results of tests performed on test specimens of the major load-carrying components. Fabrication details along with the materials and processing data used to construct the box beam are given, and quality assurance testing data are delineated.

AUTHOR

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I. INTRODUCTION

Several candidate materials for application to box beam construction are presently under consideration by the National Aeronautics and Space Administration (NASA). These are being designed to common load-carrying capacity to provide a valid weight-to-efficiency comparison. This report describes work on a program whose goal was to design and fabricate a box beam which will demonstrate the potential of fiberglass reinforced construction through comparison with the metallic materials under consideration.

Narmco believes that the two box beams fabricated for this test program will demonstrate not only the feasibility of composite construction procedures, but also the high potential of this construction medium for space applications.

II. DISCUSSION

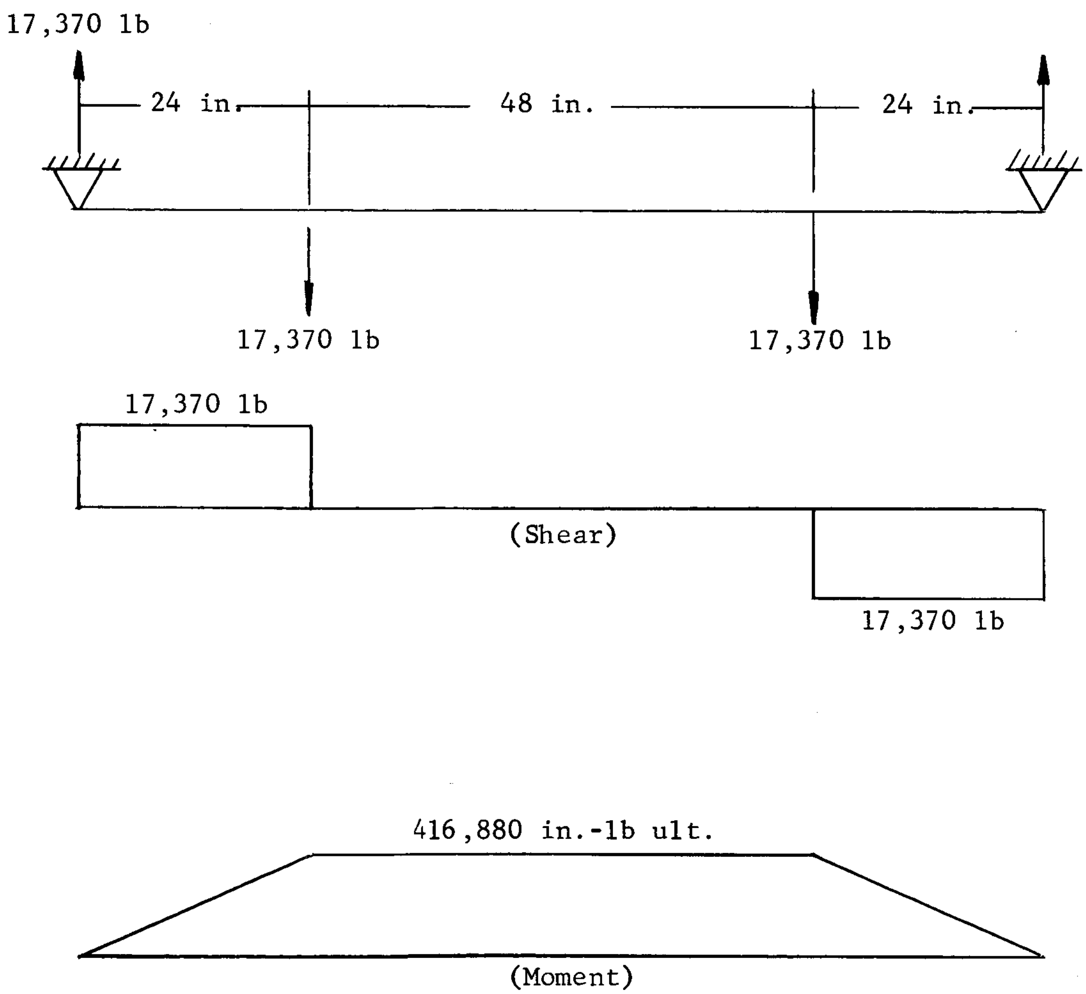
A. Structural Analysis

Narmco's version of a fiberglass reinforced box beam is shown in Figures 1 and 2. Narmco Drawing No. NR63-050, presented as Appendix A to this report, gives the basic design details of the beam. The fiberglass reinforced beam shown has been designed to the same overall external geometry and load-carrying capacity as the NASA aluminum beam; however, its total weight is less.

A complete structural analysis for the fiberglass reinforced beam is presented in the subsequent paragraphs.

1. Summary of the Fiberglass Reinforced Box Beam Criteria

   a. Loads



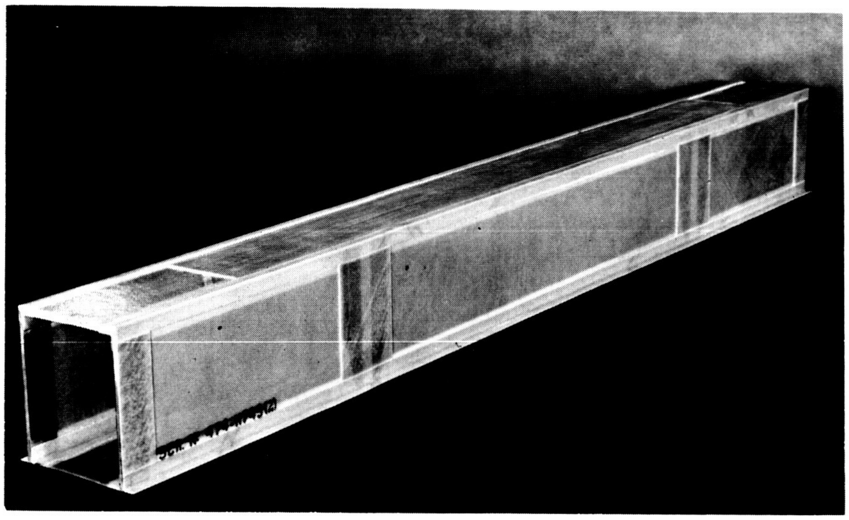


Figure 1. A Completed Assembly of the Fiberglass Reinforced Box Beam

Figure 2. End View of a Completed Fiberglass Reinforced Box Beam

b. Margins of Safety

Shear webs from end of beam to load points:

M.S. = +0.13 (See Appendix B)

Compression in the top panel between load points:

M.S. = +0.27 (See Appendix C)

c. Weight Analysis

Weight of the basic fiberglass reinforced beam design:

26.02 lb (See Appendix B)

Increased weight due to removing inserts and adding magnesium slugs:

1.59 lb (See Appendix D)

Increased weight due to adding doublers to the upper sandwich panel:

2.102 lb (See Appendix C)

Total weight of the fiberglass reinforced beam:

29.71 lb

2. Analysis of Predicted Failing Load of the NASA Aluminum Box Beam

The aluminum alloy version of the NASA box beam was analyzed to predict the failing load of this beam. These loads were determined for the purpose of establishing design data for the fiberglass reinforced box beam. The analysis for the predicted failing load is presented in Appendix E to this report.

3. Basic Stress Analysis for the Fiberglass Reinforced Box Beam

Narmco's task was to design and fabricate a fiberglass reinforced box beam which would demonstrate the potential of fiberglass reinforced construction. A fiberglass reinforced beam was designed to support the predicted failing load of the aluminum beam. The stress analysis for this beam is presented in Appendix B.

4. Basic Design Modification of the Fiberglass Reinforced Box Beam

Two major modifications were made on the basic design of the fiberglass reinforced box beam. The first modification was made to simplify the fabrication task and at the same time improve the quality of the beam. The second modification was a result of tests performed on sandwich specimens representative of the upper box beam panel. Tests and analytical studies indicated that face wrinkling of the upper sandwich facing could occur, depending on edge conditions at loads approaching that of design.

a. Hardware Installation Points (Modification 1)

In the process of establishing the fabrication schedule and building fastener pattern test specimens, it was found that fabrication complexity as well as fabrication time could be reduced by replacing the inserts used for fastening the hardware with magnesium slugs. This simplifies the fabrication task so that a definite increase in beam load-carrying capacity can be expected. This change improves the quality of the beam without jeopardizing beam strength. In addition, this change improves the procedure for properly positioning and fastening the loading hardware to the beams by eliminating the need to match the insert patterns to the hole patterns of the loading hardware. The magnesium slugs in the sandwich box beams will not be drilled at the time of beam fabrication. The magnesium slugs will be match-drilled to the actual loading hardware after the beams have been delivered to MSFC.

The original stress analysis for the inserts is based on a load path whereby the vertical web shear loads are transferred to the insert by the web facings through bearing. The loads are then transferred from the inserts to the fasteners and are ultimately carried to the loading hardware reaction.

With solid magnesium slugs used in place of the individual inserts, an additional load path becomes the primary load transfer mechanism. Web shear loads are transferred, predominately, to the magnesium slug by the slug-to-facing bondlines, then through bearing to the fastener, and finally to the load hardware reaction.

Considering the area between the magnesium slugs and the shear web facings, the final design actually has an ultimate load-carrying capacity greater than the original design at the cost of a slight weight increase. In the original design, shear web loads were primarily transferred to the inserts by bearing of the shear web facings and doublers. The primary purpose of the doublers was to increase the amount of shear web bearing area through which shear web loads could be transferred.

In the final design, shear web loads are primarily being transferred through the bondline between the slug and the shear web facings, in which case the doublers only serve to increase the beam weight. Therefore, the inner doublers were removed in the interest of reducing beam weight. However, the outer doublers were not removed since they act as a spacer between the assembly angles, thus providing a uniform mating surface for installing loading hardware. The analytical calculations for the insert to magnesium slug modification are presented in Appendix D.

b. Face Wrinkling of the Upper Sandwich Facings (Modification 2)

In the process of performing program quality assurance tasks, test values for sandwich specimens representative of the upper panel of the box beam appeared marginal. The initial edgewise compression tests were performed in accordance with MIL STD 401, "Sandwich Construction and Core Materials; General Test Methods." The test values obtained were lower than expected. Apparently the specimens had a premature buckling failure as a result of the loading fixture design.

It was determined that the test fixture was inducing loads on the test specimen which were not representative of those the upper panel would experience in the final beam test. Therefore, an analytical study was made on the upper panel and a specially designed test fixture was built to determine the stress and the mode of failure occurring in the upper sandwich test specimens. The additional tests and analytical studies indicated that face wrinkling could occur at loads approaching that of design. This in turn indicated the advisability of modifying the beams slightly by adding 0 030-in. thick doublers (over the critical area only) to the exposed surfaces of each of the upper panel facings. The analytical calculations supporting this modification are presented in Appendix C

The marginal strength of the upper compression panel in the initial design of the fiberglass reinforced box beam is basically due to insufficient strength of the core selected for this panel. The additional margin of strength designed into the upper panel could have been accomplished by adding doublers as done, increasing core depth and density, or both. The trade off was marginal and therefore additional studies in this area would be recommended for future designs

B. Fabrication

Fabrication details for the overall construction of the fiberglass reinforced box beam are given below.

1. Materials

The following materials were utilized in fabricating the fiberglass reinforced box beam:

a. Composite Laminate Material

(1) Scotchply type 1009-26S is a high-strength unidirectional tape made from epoxy resin reinforced with continuous glass filaments of high-tensile-strength S994 glass. The manufacturer will not disclose the resin system components; however, the resin content of this material is 26% and is compatible with the epoxy resin system shown for S-901/81.

(2) S-901/81 (HTS epoxy finish) is a high-strength bidirectional fabric made from S994 glass. The material was purchased in a 38-in. width roll and impregnated with the following resin system:

Epon 828	50 parts
Epon 1031	50 parts
MNA	90 parts
BDMA	0.5 parts

The resin content of this material was 35%. Because of resin consistency during the prepregging process, a lower resin content was not obtainable.

b. Adhesive

Metlbond 324 adhesive was used throughout the beam for bonding. This is a low-temperature-curing, modified epoxy adhesive supported by a synthetic fabric carrier.

c. Sandwich Core

Aluminum alloy (111-A, 1/4, 3003, 0.001P, 2.3 lb/ft^3) core material was used in the upper sandwich panel and shear webs of the beam.

d. Magnesium Slugs

The magnesium slugs bonded into the shear webs of the beam are made from AZ 31 B H-24 magnesium.

2. Processing Data and Procedures

a. Press-Cured Laminates (With Alpha Cellulose)

(1) The laminate layup was prepared as shown below and placed between the heating platens of the press.

Caul plate (Aluminum ≈ 1/4-in. thick)

Alpha-cellulose pad (1/16-in. thick)

Release (cellophane, 600 PD)

Laminate layup

Release

Alpha cellulose pad

Caul plate

Note: The alpha-cellulose pad acts as a pressure equalizer and is used to prevent resin-lean areas at the lap joints of the bidirectional fabric.

(2) The following cure cycle was utilized:

(a) The laminate was placed in a 325°F press at zero contact pressure for 3 minutes.

(b) 30-35 psi pressure was applied and the laminate cured for 1 hour at 325°±10°F.

(c) The laminate was removed and cooled on a flat surface.

(d) Postcure was accomplished at 350°F for 4 hours.

b. Autoclave-Cured Laminates

The angular-shaped laminates used in the assembly of the box beam were laid-up and cured between mating aluminum angles according to the subsequent schedule.

(1) Cellophane release (600 PD) was placed over the lower aluminum angle.

(2) The laminate was laid up over the cellophane release.

(3) The cellophane release was applied over the layup.

(4) The upper aluminum angle was placed over the above composite.

(5) A vacuum bag polyvinyl alcohol (PVA) was placed around the entire assembly.

(6) The assembly was placed in an autoclave and held under vacuum to 180°F.

(7) The assembly was vented to atmosphere and the vacuum gradually removed; autoclave pressure was applied until 40 psi was reached.

(8) The assembly was cured 1 hour at 325°±10°F.

(9) Postcure took place at 350°F for 4 hours.

c. Press-Cured Laminate (Without Alpha Cellulose)

(1) The laminate layup was prepared as shown below and placed between the heating press platens:

Caul Plate (Aluminum ≈ 1/8-in. thick)

Release (TFE Teflon film)

Laminate layup

Release

Caul Plate

(2) The following cure cycle was utilized:

(a) The layup was placed in a 325°F press.

(b) 30-35 psi was applied and the layup was cured 1 hour at 325°±10°F.

(c) The layup was removed and cooled on a flat surface.

(d) Postcure took place at 350°F for 4 hours.

d. Bonding Procedure for 324 Metlbond Adhesive

(1) Laminate Surface Preparation:

(a) The surface to be bonded was washed with a clean cloth that was wet, but not dripping, with methyl ethyl ketone (MEK) and the solvent allowed to evaporate.

(b) The clean surface was abraded with 80- to 120-grit emery cloth.

(c) Step (a) was repeated to remove all loose abraded particles from the surface.

(d) The abraded surface was covered with a clean film of PVA to provide protection against contamination.

Note: Following cleaning, the laminates were handled only with clean, white cotton gloves or clean rubber gloves.

(2) Aluminum core preparation:

(a) The core was vapor-degreased.

(b) The core was cleaned by spraying with MEK and air-dried.

(c) Following cleaning, the core was placed in a PVA bag to provide protection against contamination.

Note: Following cleaning, the core was handled only with clean, white cotton gloves or clean rubber gloves.

(3) Magnesium preparation:

(a) The part was cleaned with Dow-7 solution.

(b) The Dow-7 was brought to a boil.

(c) The magnesium part was submerged for 30 minutes.

(d) The part was rinsed for 5 minutes with tapwater and for 1 minute with distilled water.

Note: Following cleaning, the part was handled only with clean, white cotton gloves or clean rubber gloves.

(4) Layup procedure:

(a) One layer of Metlbond 324 adhesive was placed flush against one of the cleaned surfaces to be bonded.

(b) The cleaned surface of the part to be bonded was placed directly against the adhesive.

(c) One ply of 1500 style fabric boat cloth was placed around the assembly to act as an air bleeder.

(d) The part was vacuum-bagged and a vacuum of 8- to 10-in. Hg pulled. This was kept under vacuum for at least 15 minutes, before curing, and checked for leaks.

(5) Cure cycle:

(a) The part was cured for 1 hour at 235°±10°F under 8 to 10 in. of vacuum.

(b) The part was then cooled to 180°F in the oven, under vacuum.

(c) The vacuum bag and bleeder cloth were removed and adhesive flash removed.

3. Fabrication of Components

a. Laminates

(1) The upper sandwich facings, the shear web facings, and the bottom laminate were laid-up as specified by Narmco Drawing NR 63-050 (see Appendix A). Each laminate was processed according to Sections II.B.2.a.(1) and (2) of this report.

(2) The fillers located at the hardware installation points were laid up as specified by Narmco Drawing NR 53-050 (see Appendix A). They were processed according to Sections II.B.2.c.(1) and (2).

(3) The assembly angles which join the upper panel and the bottom laminate to the shear webs were each laid up, as specified by Engineering Drawing NR 63-050, between a pair of mating aluminum angles and processed according to Section II.B.2.b. The aluminum angles were 9 ft long and had 2-in. wide x 1/4-in. thick legs. The lower angle served as a layup tool and the other was nested over the layup to apply uniform pressure during cure.

b. Subassemblies

The upper panel and the shear webs were fabricated on an aluminum caul plate with vacuum pressure. The location of details and the end of part reference lines were accurately scribed on the caul plate (see Figure 3) for purposes of prefitting and making the final layup. The panel fabrication steps followed were as follows:

(1) Upper panel fabrication:

(a) Laminate facings and core were cut slightly oversize, to allow for trim after assembly cure.

(b) A dry-run of the layup was made without adhesive and then disassembled.

(c) The facings were abraded and cleaned according to Section II.B.2.d.(1).

(d) The core was cleaned according to Section II.B.2.d.(2).

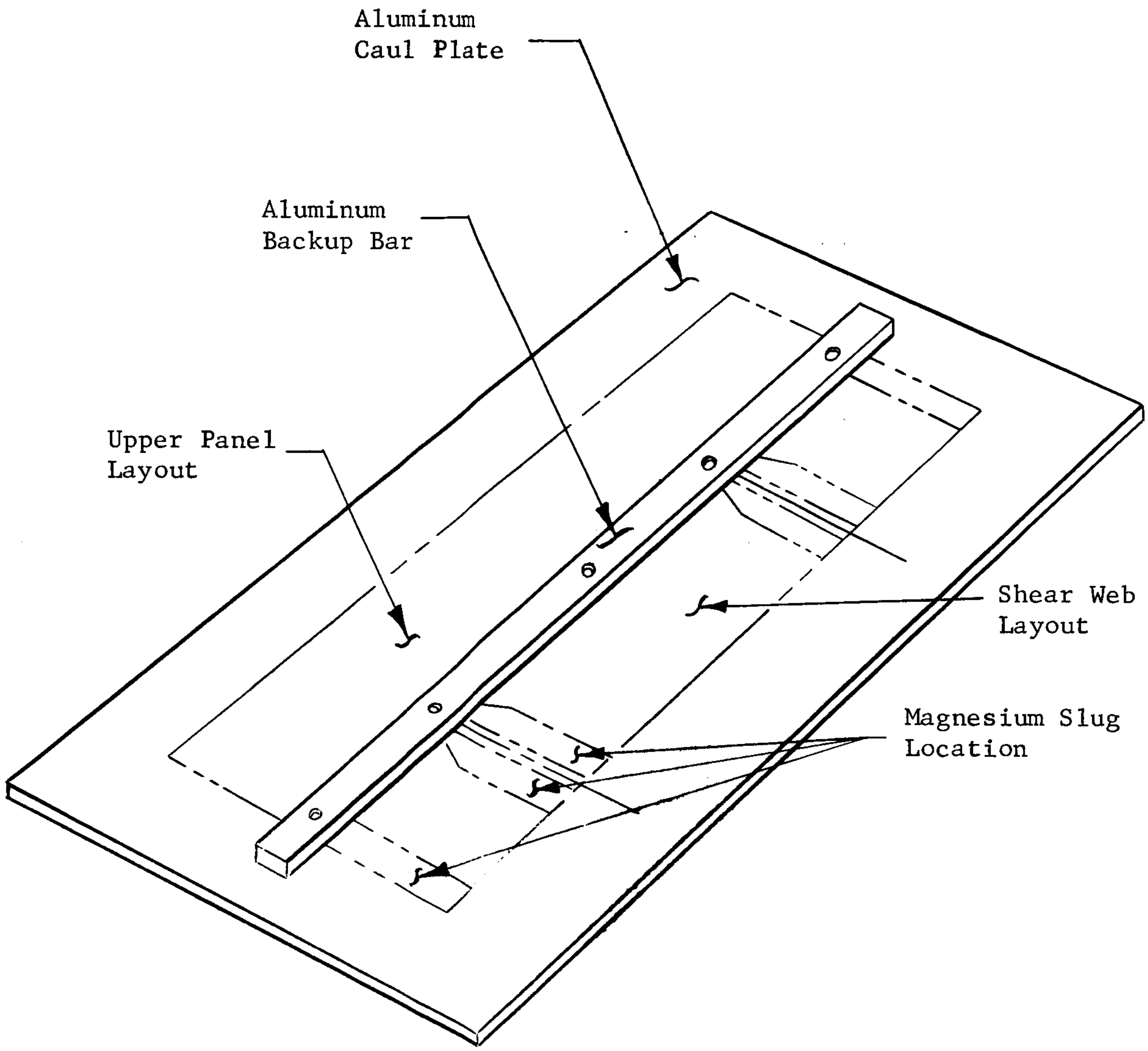


Figure 3. Sandwich Panel Assembly Tool

(e) The fabrication tool was cleaned with MEK.

(f) The panel was laid-up according to Section II.B.2.d.(4).

(g) The assembly was cured according to Section II.B.2.d.(5).

(2) Shear web panel fabrication:

(a) Laminate facings were cut slightly oversize to allow for trim following assembly.

(b) The core and magnesium slug details were prefit; the core was left oversize on the outer periphery for trim following assembly cure.

(c) A dry run of the layup was made without adhesive and then disassembled.

(d) The facings were abraded and cleaned according to Section II.B.2.d.(1).

(e) The core was cleaned according to Section II.2.d.(2).

(f) The magnesium slugs were prepared according to Section II.B.2.d.(3).

(g) The fabrication tool was cleaned with MEK.

(h) The panel was laid up according to Section II.B.2.d.(4).

(i) The assembly was cured according to Section II.B.2.d.(5).

(j) The panel was trimmed to the dimensions in Narmco Drawing No. NR 63-050.

4. Beam Assembly

Final assembly of the beam was accomplished using a double vacuum bag in conjunction with a fixture that held the beam components in their respective positions. The double vacuum bag technique provided a simple method for getting the correct pressure on the internal and external bond areas of the beam.

The assembly fixture (see Figure 4) was constructed from four aluminum bars and threaded rods which held the fixture in shape while providing means for adjustment of the fixture's rectangular cross section. In addition, four slip out bars were incorporated so that the fixture could be removed from the finished part.

The general assembly steps for the beam are illustrated by Figures 4 through 9. The final assembly steps for the box beam are outlined in the subsequent text.

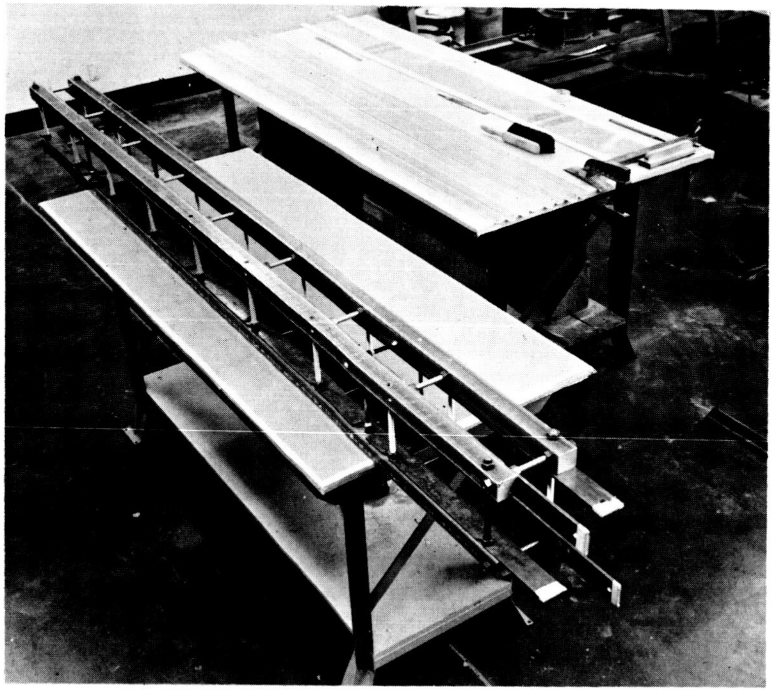


Figure 4. Fiberglass Reinforced Box Beam Assembly Fixture, Adjusted and Ready for Use

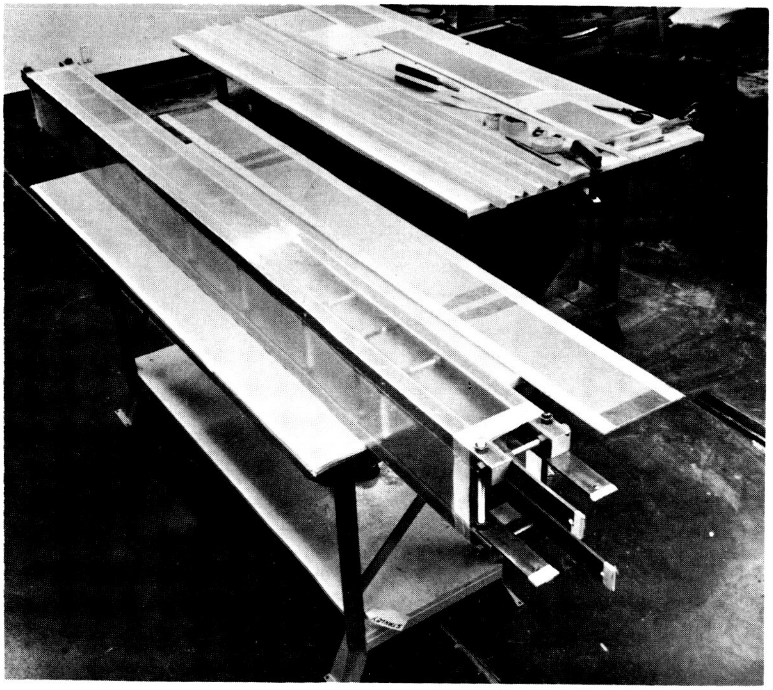


Figure 5. Fiberglass Reinforced Box Beam Assembly Fixture with the Internal Polyvinyl Alcohol Vacuum Bag Installed

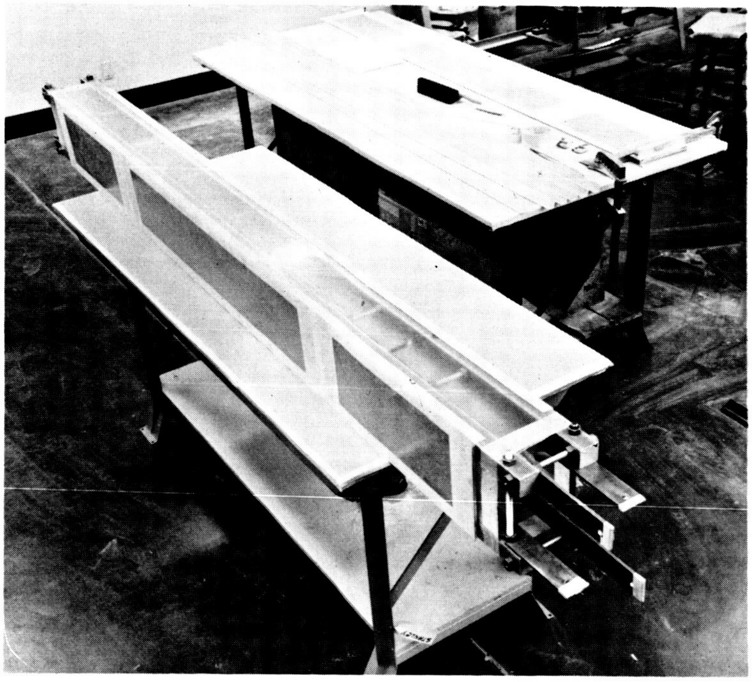


Figure 6. Fiberglass Reinforced Box Beam Assembly Fixture, Showing a Shear Web and Two Assembly Angles in Position

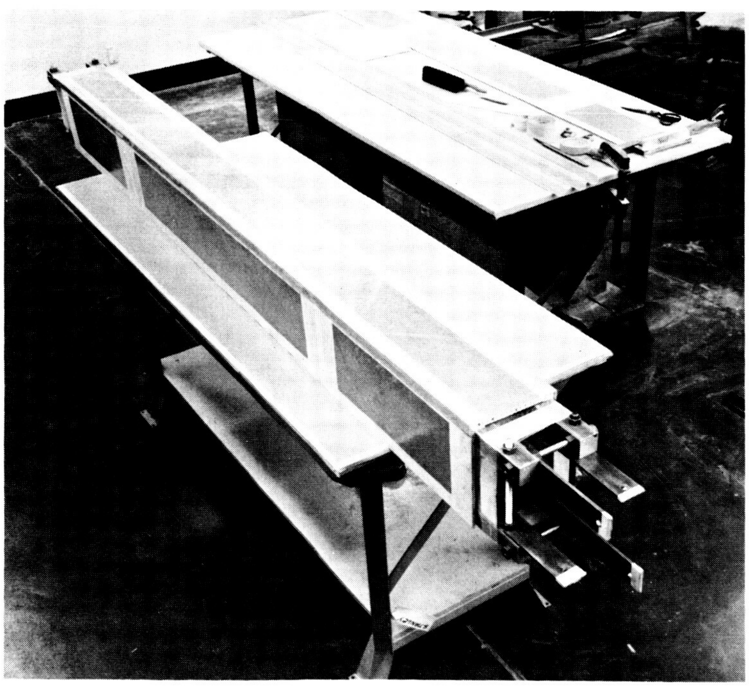


Figure 7. Fiberglass Reinforced Box Beam Assembly Fixture, Showing a Shear Web, Upper Panel, and Two of the Assembly Angles in Position

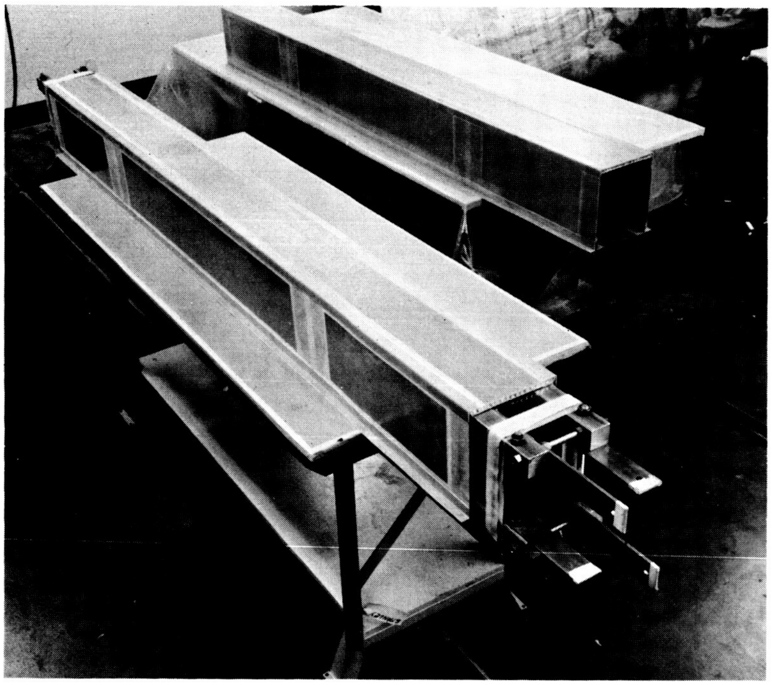


Figure 8. Fiberglass Reinforced Box Beam Assembly Fixture, with Beam Assembly Components in Position (A completed box beam assembly is shown in the background)

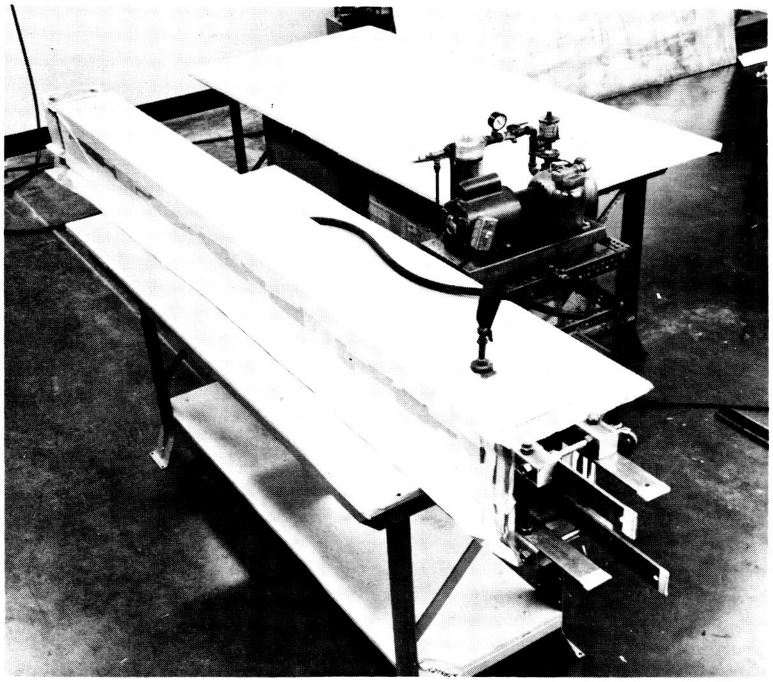


Figure 9. Fiberglass Reinforced Box Beam Assembly Vacuum-Bagged and Ready to be Placed in the Oven for Bonding

a. The assembly fixture was adjusted to the internal dimensions of the beam, taking into account the PVA vacuum bag.

b. All bond area surfaces in the final assembly were prepared according to Section II.B.2.d.(1).

c. A vacuum bag (PVA) was neatly wrapped around the assembly fixture (see Figure 5).

d. Metlbond 324 adhesive was applied to the bond area according to Sections II.B.2.d.(4)(a) and (b).

e. The assembly components were placed onto the fixture.

f. The assembly was vacuum-bagged according to Sections II.B.2.d.(4)(c) and (d).

g. The assembly was cured according to Sections II.B.2.d.(5).

5. Modification to Upper Panel — Doubler Addition

A 0.030-in. thick doubler was bonded to the exposed facings of the upper sandwich after the beam was assembled. Fabrication and installation of the doubler is given below.

a. Doubler Fabrication

(1) The laminate was laid up, with respect to number of plies and orientation, as specified by Narmco Drawing NR 63-050.

(2) The laminate was processed in accordance with Section II.B.2.c.(1) and (2).

b. Doubler Installation

(1) The inner and outer doublers were cut to size and hand-fitted between the assembly angles.

(2) Bleed holes (#60 diameter) were drilled through the laminate as specified by Narmco Drawing NR 63-050.

Note: The bleed holes help remove air which may be trapped between the bond surfaces.

(3) The bond areas for both the doubler and the upper panel were prepared according to Section II.B.2.d.(1).

(4) The doublers were laid up according to Section II.B.2.d.(4)(a) and (b) and heat-tacked to hold them in place while the vacuum bag was installed.

(5) The assembly was vacuum-bagged, according to Section II.B.2.d.(4)(c) and (d), on the inside and outside.

(6) The assembly was cured according to Section II.B.2.d.(5).

C. Quality Assurance

The Quality Assurance tasks performed on the fiberglass box beam were primarily tests on specimens representative of the components that make up the subassemblies or the final assembly. In addition, process and dimensional inspection tasks were performed. A record of the final dimensional inspection and weight of each beam is given in Appendix F.

Tests were performed on the major load-carrying components according to their most likely mode of failure. Thus, the bottom laminate had to demonstrate tensile strength, the shear webs had to demonstrate shear strength, and the upper panel had to demonstrate compressive strength.

1. Tests and Major Load-Carrying Components

a. Bottom Laminate Tensile Test

The tensile specimens for this test were cut from excess bottom laminate material. Three standard dogbone type tensile specimens were tested; however, these specimens had a test section width of 0.250 in. instead of the standard 0.400-in. width. The narrower test section reduced the problem of specimens failing in the jaws. The ultimate tensile strength and the design allowable for this material were

Average test value:	133,408 psi
Design allowable (Appendix B):	130,408 psi

b. Shear Web and Fastener Pattern Test

The ability of the shear webs to carry a shear load was demonstrated by the fastener pattern test performed on the specimens shown in Figures 10 and 11. Figure 10 shows the test specimen which represents half of one of the beam's end support points. Figure 11 shows the test specimen which represents one of two load application points for a shear web.

The two specimens shown supported loads 1000 lb over their design value without either specimen experiencing a shear failure in the sandwich cross section or a bearing failure at the fastener points. The loads supported by the test specimen were

By end support point (Figure 10):	9,980 lb
By load application point (Figure 11):	9,960 lb
Minimal design load (Appendix B stress analysis):	8,685 lb

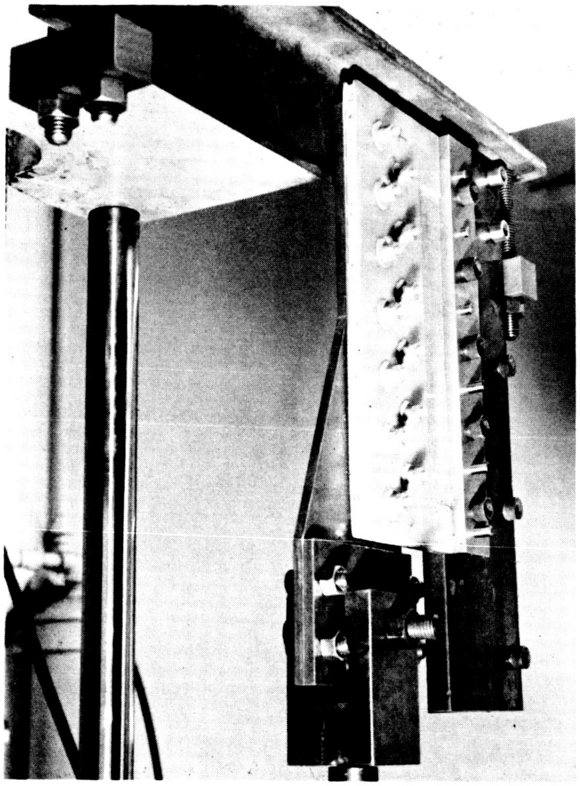


Figure 10. Fastener Pattern Test Specimen of Half of One of the Beam's End Support Points

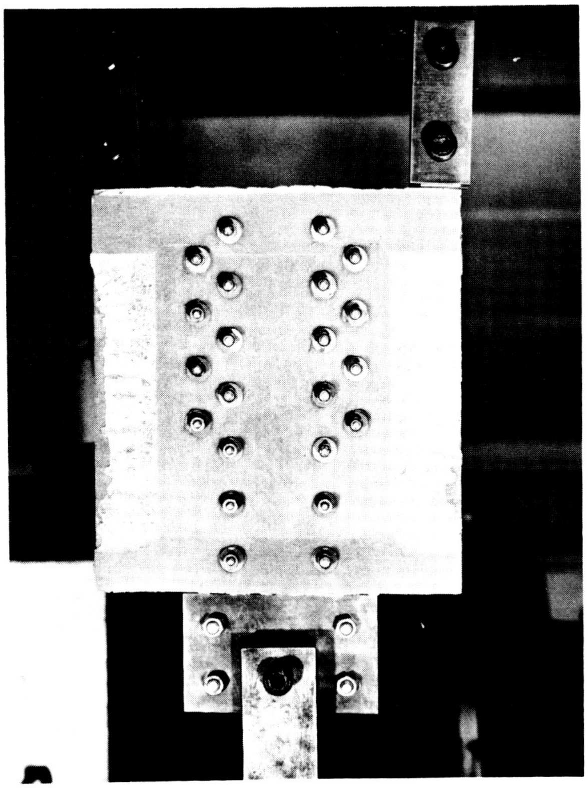


Figure 11. Fastener Pattern Test Specimen of One of Two Load Application Points for a Shear Web

c. Upper Sandwich Compression Tests

(1) Initial edgewise compressive tests were performed according to MIL STD 401A. The values obtained were lower than expected. Apparently the test specimens were undergoing a buckling failure due to eccentric loads induced by the fixture (see Figures 12 and 13). The average edgewise compressive value obtained with this fixture was 27,500 psi. It was determined that the test fixture was inducing loads on the test specimens which were not representative of those that the upper panel would experience in the final test. In the box beam the upper sandwich panel has edge fixity which helps to stabilize the panel. Specimens tested according to MIL STD 401A are not supported or stabilized on the sides, and thus, test results do not necessarily reflect load-carrying capacity of the upper sandwich panel.

A special test fixture (see Figures 14 through 18) was designed to support and load the specimen as if it were simply supported on all edges. The round, slotted bars in Figure 17 apply the load to the specimen and are free to rotate on the bearing plate of the test machine. The sides of the fixture are shimmed so that the specimen is free to slide between the angles. Also, the edges of the angle have been rounded so the specimen is not restrained, as in a fixed end condition.

The analytical studies indicated that a marginal condition existed in the upper sandwich panel, and therefore two types of specimens were tested. One type of specimen was the same as those tested initially, and the other type had a 0.030-in. doubler bonded to each of the facings. Edgewise compressive strengths for the two types of specimens were

Specimens without doublers (Figure 17):	33,500 psi (average)
Specimens with doubler (Figure 18):	44,000 psi (average)
Theoretical compressive stress in upper panel (Appendix C):	32,665 psi

(2) Tensile Test

Tensile tests were performed on specimens cut from a 12-in. x 12-in. press laminate which was representative of the bottom box beam laminate. Due to the high strength and thinness of the laminate, it was difficult to obtain good test results without modifying the test specimen. The standard size dogbone specimens were failing in the holding jaws (see Figure 19, Specimens Nos. 1-1 and 2-1).

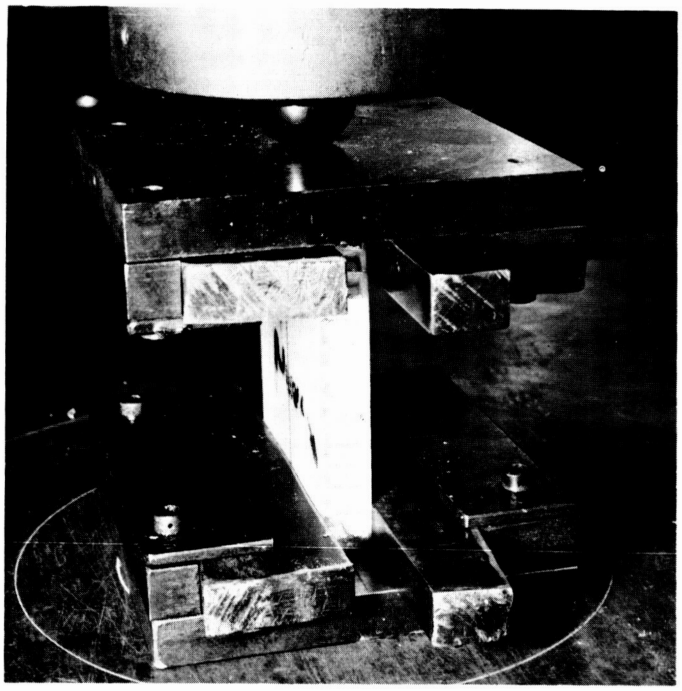


Figure 12. Standard Test Fixture and Upper Sandwich Panel Test Specimen ready to be Tested in Edgewise Compression

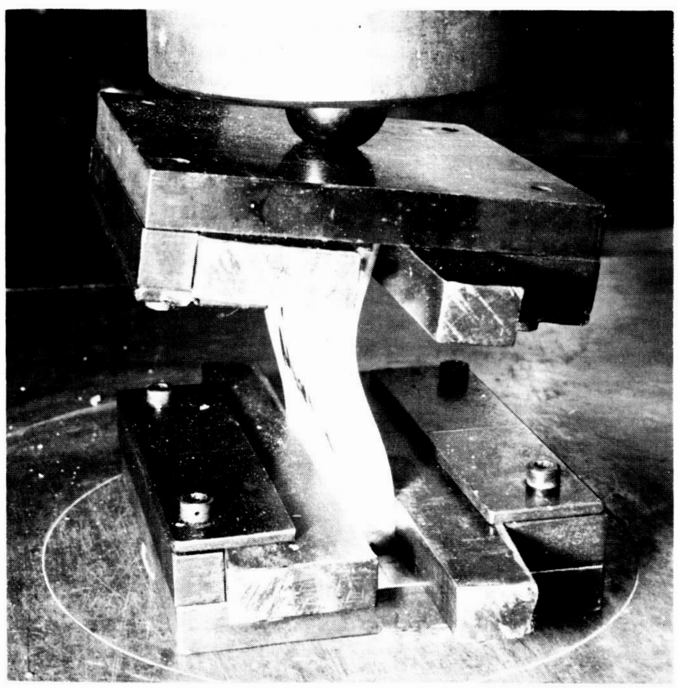


Figure 13. Standard Test Fixture and Upper Sandwich Panel Test Specimen Following Loading in Edgewise Compression

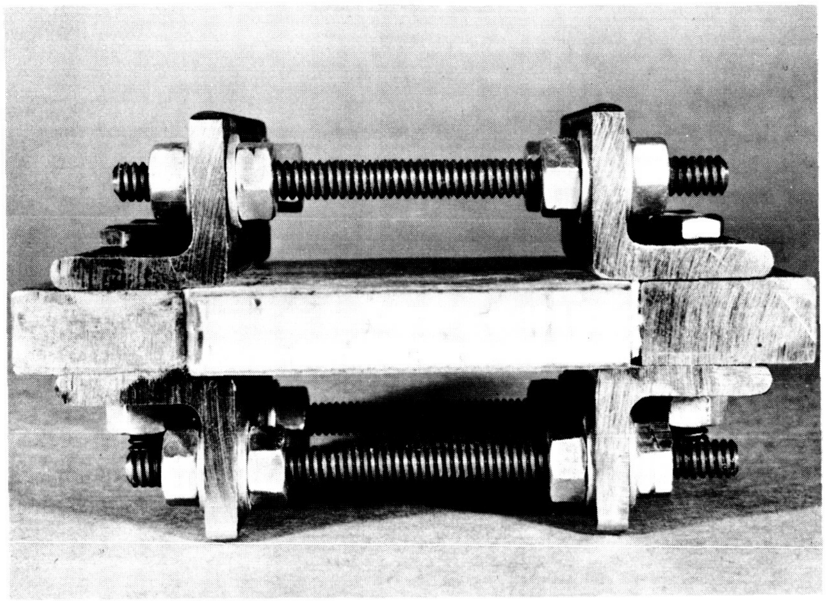


Figure 14. Specially Designed Test Fixture for Testing Upper Sandwich Panel in Edgewise Compression

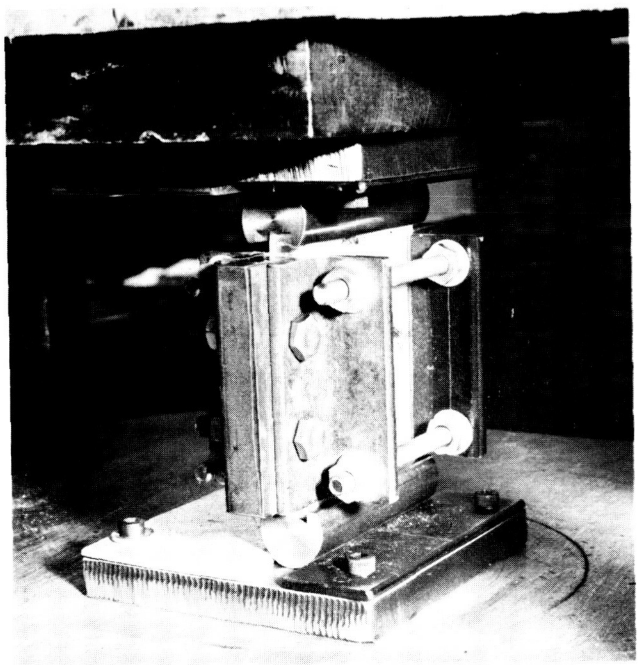


Figure 15. Specially Designed Test Fixture and Upper Sandwich Panel Test Specimen Ready to be Tested in Edgewise Compression

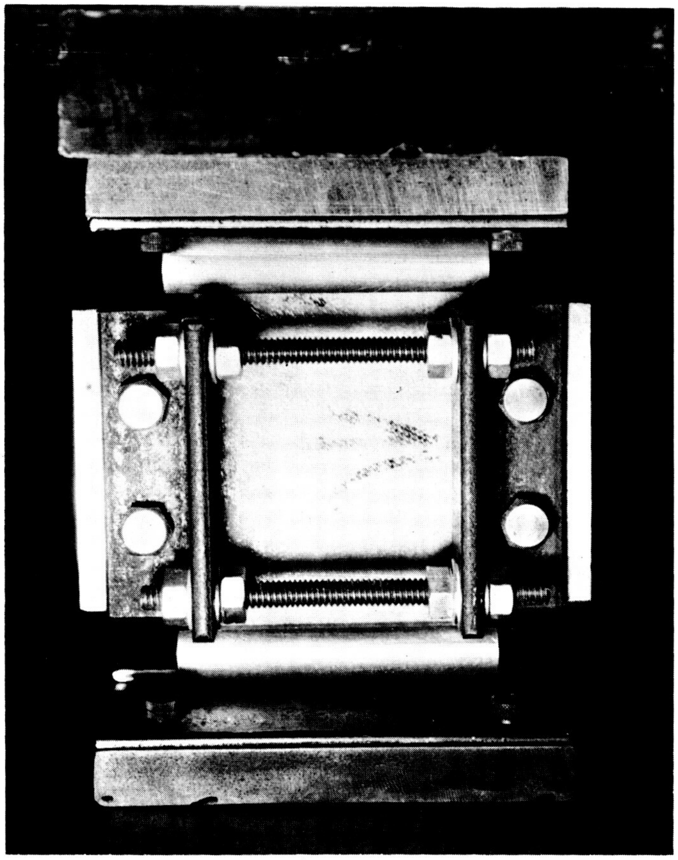


Figure 16. Specially Designed Test Fixture and Upper Sandwich Panel Test Specimen Ready to be Tested in Edgewise Compression

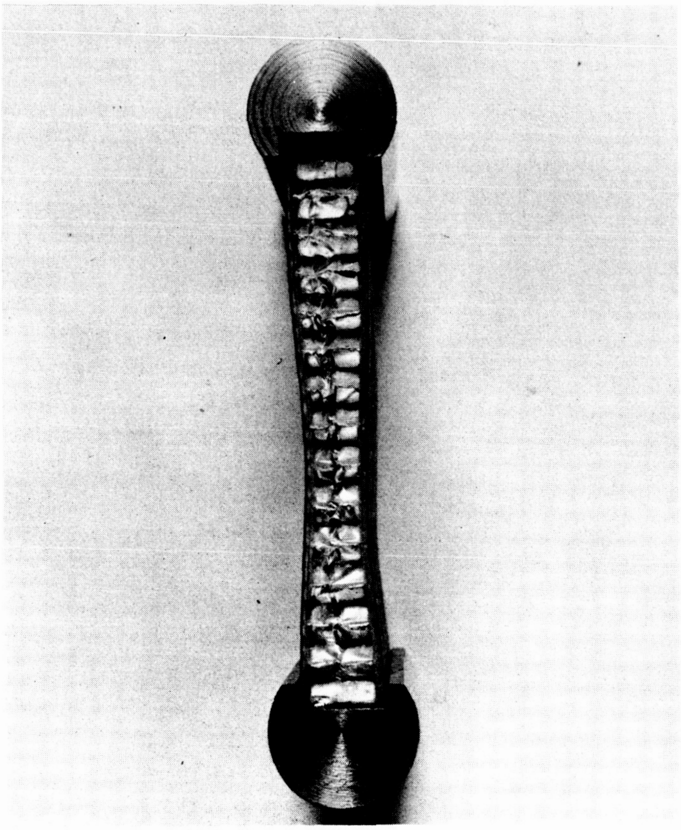


Figure 17. Edge View of Upper Sandwich Panel Test Specimen, without Doublers, following Edgewise Compression Test

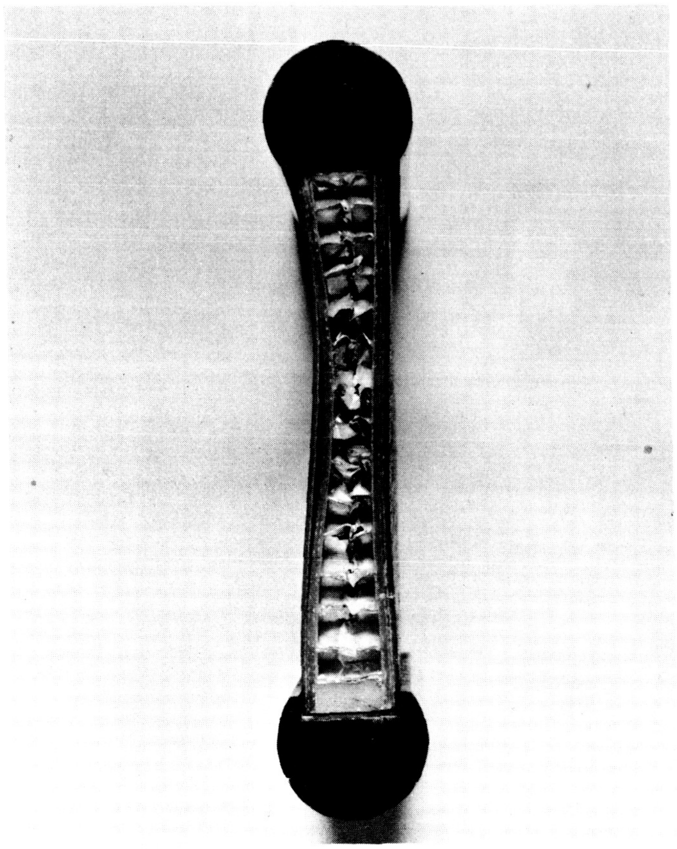


Figure 18. Edge View of Upper Sandwich Panel Test Specimen, with Doublers, following Edgewise Compression Test

Figure 19. Dogbone Tensile Test Specimens Showing Failure in the Area of the Holding Jaw

The standard size dogbone is 4/10 in. wide at the test section (see Figure 20). By reducing the dogbone test section to a 1/4-in. width, it was possible to get satisfactory test results (see Figure 19, Specimen No. 2-2). Ultimate tensile strengths for the standard and modified test specimens along with the design allowable were as follows:

Standard dogbone tensile specimen (Figure 19):

Specimen 1-1	106,122 psi
Specimen 2-1	97,458 psi

(Strength values shown are based on the load at the time the specimen failed in the holding jaws.)

Modified dogbone tensile specimen (Figure 19):

Specimen 2-2	145,458

Design allowable for bottom laminate (see Appendix B):

130,500 psi

(3) Compression Test

As in the case of the tensile test, difficulty was encountered in trying to perform compressive tests on the box beam laminates. However, this time the problem was one of buckling due to the thinness of the laminates.

The standard size compression specimen is 1 in. wide, 3 in. long, and is at least 1/10 in. thick to prevent buckling. Thus, due to the thinness of the box beam laminates, it was impossible to get compressive test values for the 1-in. x 3-in. specimen size.

It was decided to make two different types of specimens. One type was cut to microspecimen size, having very little unsupported column area, and the other consisted of 3 plies of the laminate bonded together and cut to the standard 1-in. x 3-in. dimensions. The compressive test results obtained from both types of specimen were acceptable; however, in the case of 1-in. x 3-in. specimen it was possible to obtain a compressive modulus (see Figures 21 through 23). The average compressive strength values and theoretical ultimate for upper sandwich facings and doubler were as follows:

Upper sandwich facing:	70,692 psi (average)
Upper doubler:	63,200 psi (ultimate) 4.20×10^6 (modulus)
Theoretical ultimate for upper doubler:	60,700 psi

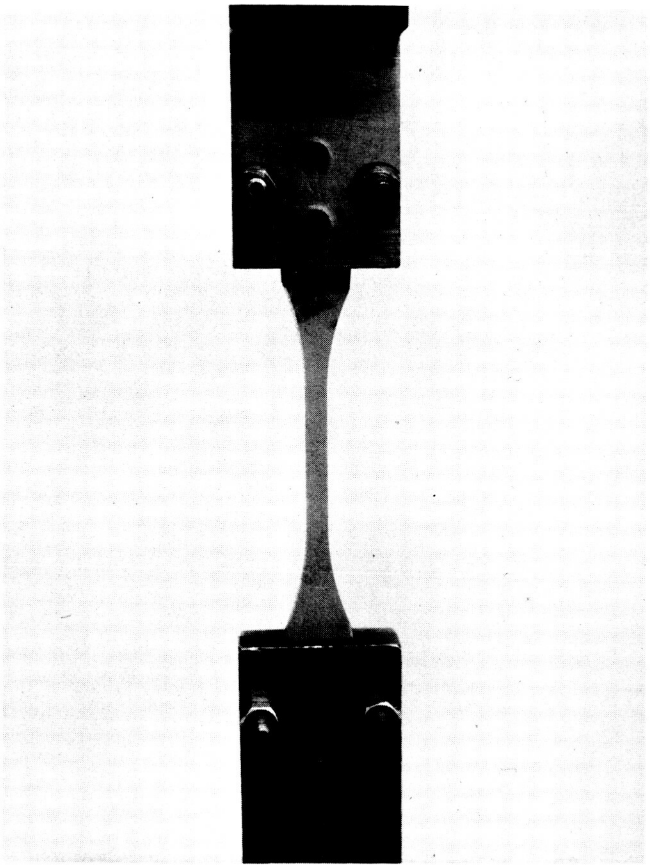


Figure 20. Holding Jaws and Dogbone Tensile Test Specimen Ready to be Tested

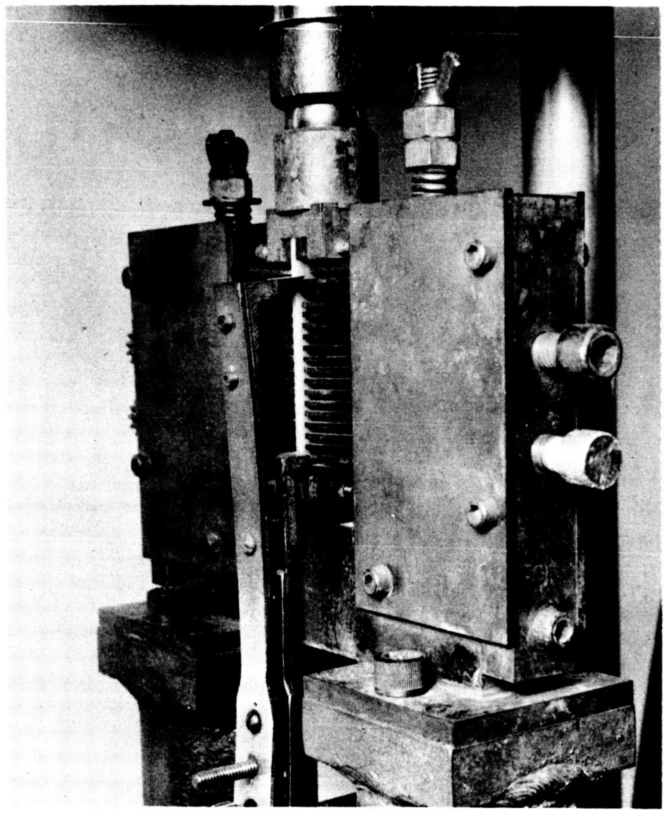


Figure 21. Standard Compression Fixture for Determining Compressive Modulus and Ultimate Compressive Strength of Laminate Materials

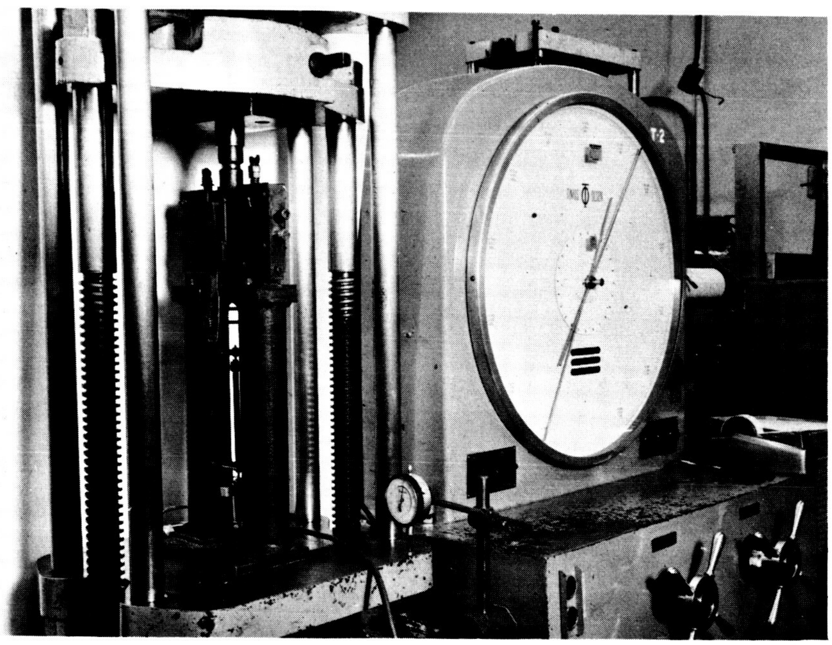


Figure 22. Standard Compression Fixture for Determining Compressive Modulus and Ultimate Compressive Strength of Laminate Materials

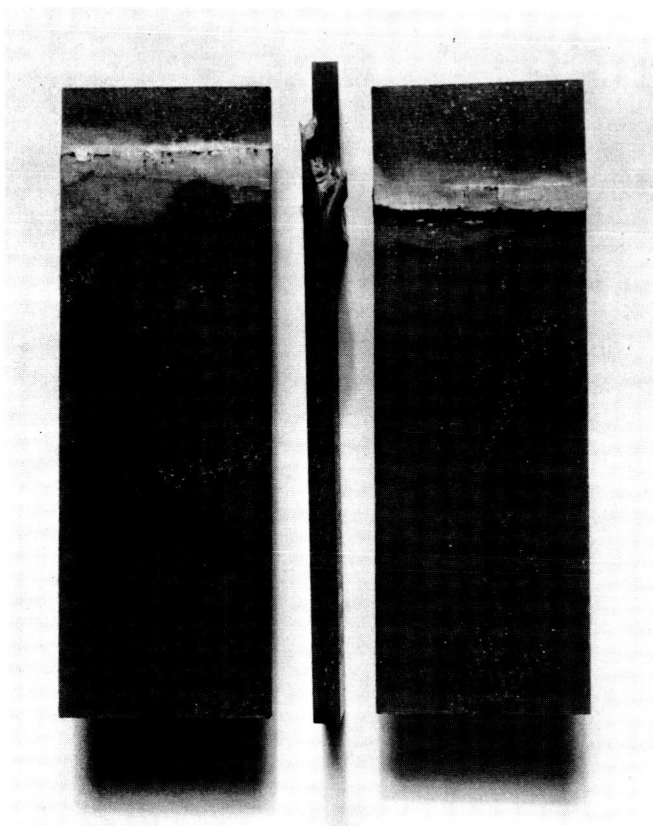


Figure 23. Three Compressive Test Specimens of the Upper Sandwich Doubler after Testing

(4) Adhesive Bond Shear Test

The Metlbond 324 adhesive was tested for shear strength in accordance with MIL Spec. A-5090D. The adhesive shear strength results of eight tensile lap shear specimens tested are shown below:

Minimum value	3,600 psi
Maximum value	4,286 psi
Average value	3,959 psi
Design Allowable	1,250 psi (Appendix B)

(5) Resin Content

Resin content tests were performed on specimens from the upper sandwich facings, the shear web facings, and the assembly angles. The tests were performed according to FTM 406, Method 7061. The average resin content values were as follows:

Upper sandwich facings:	30.27%
Shear web facings:	33.16%
Assembly angles:	29.25%

Note: A desirable resin content range from a strength-to-weight-ratio basis is 26%±2%. In general, increased resin contents decrease the efficiency but not the load-carrying capacity of a laminate.

III. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

With the exception of supervising the installation of beam loading hardware, Narmco considers that all requirements of the box beam contract have been satisfied. A box beam was designed and fabricated from fiberglass reinforced epoxy to withstand the same loads as an aluminum box beam, and the weight has been held to a minimum: 31.6 and 31.9 lb for the two fiberglass reinforced beams vs. 33 lb for the aluminum box beam.

Because of the prototype nature of the contract and the delivery requirements, it was not possible to fully optimize the design, or the fabrication or assembly of the beam. Improvement in the quality of the final part, based on the existing design, lies in the further development of processing techniques, specialized testing equipment, and a more sophisticated tooling approach.

B. Recommendations

Based on the program just completed, sufficient experience and knowledge have been gained that could effectively be utilized to design and fabricate a similar type box beam with an increase in efficiency.

To accomplish this task, the following schedule is recommended.

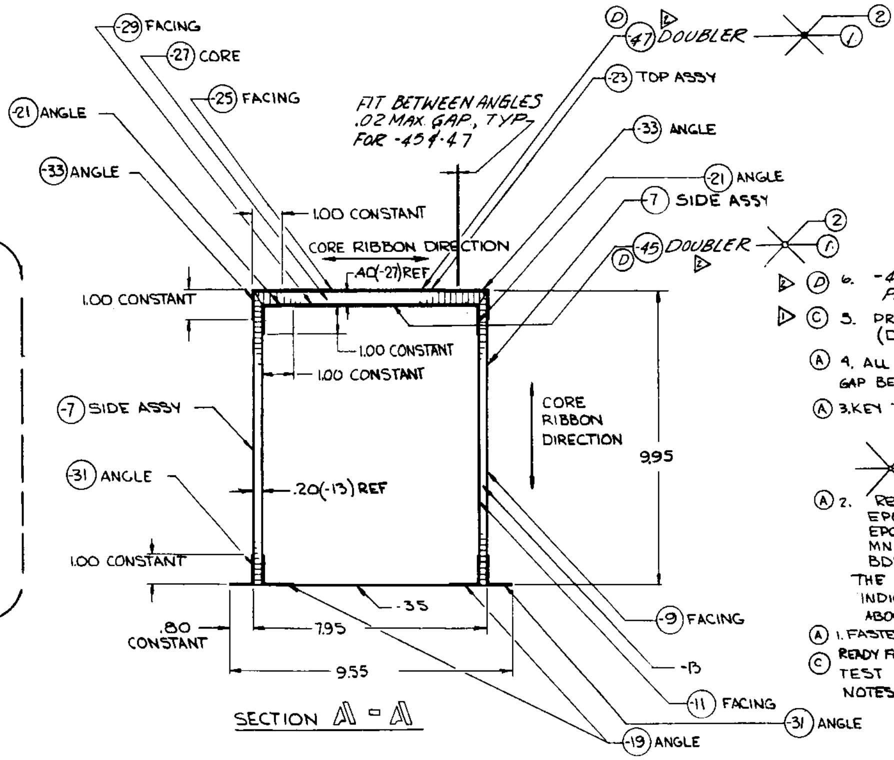
1. Optimize sandwich panel design by varying core density panel depth and facing thickness within the same panel.
2. Orient the fibers throughout a laminate to obtain maximal use of their strength as accomplished in this program.
3. Taper laminates according to their strength requirements.
4. Utilize inserts to carry loads into or away from the structure.
5. Provide closer control of the laminate resin content through more efficient tooling.

APPENDIX A

BOX BEAM DRAWING

(Narmco Drawing NR 63-050)

CHG	REVISION	BY	
A	ADD NOTES 2,3 & 4. CHG NOTE 1. ADD VIEWS C & D; REMOVE FASTENER CALLOUTS FROM P/D. REMOVE JOGS FROM ANGLES. ADD -37, -39, -41 & -43. REMOVED DELRIN INSERTS	JLR	9-15-64 9/14/64
B	AZ31B MAG ALY WAS 2024 T6 AL ALY (-37,-39)	JLR	10-6-64 10-6-64
C	IN B/M ADDED SPEC FOR AZ31 B MAG ALY. ADDED NOTE 5. REVISED NOTE 1, MS 21043-1032 UNF 3B & MS 21042-1032 NF 3B WAS MS 20362 1032 NUT. AN 173-7 WAS AN 3-7 BOLT	JLR	
D	ADD -45 & -47 DOUBLER IN B/M & FACE OF DWG. NOTE #6 ADDED	S.Y.	2-1-65
E	ADD VIEW E-E SHOWING BLEED HOLES IN -45 & -47 ALTERNATE NUT WAS MS 21042 1032 NF 3B (B/M)	JLR	



(D) 6. -45 & -47 TO BE LAYED-UP WITH STRONG FIBERS PARALLEL TO UNIDIRECTIONAL TAPE

(C) 5. PREPARE -37 & -39 PARTS WITH DICHROMATE ETCH PER MIL-M-3171 TYPE 3 (DOW 7)

(A) 4. ALL FILLERS TO BE TRIMMED TO FIT WITH MINIMUM GAP BETWEEN ADJACENT ANGLES.

(A) 3. KEY TO LAMINATING SYMBOL

(N) NUMBER OF 5901/81/HTS FABRIC PLIES
(N) NUMBER OF 1009-26S UNIDIRECTIONAL TAPE PLIES

(A) 2. RESIN SYSTEM TO BE

EPON 828 — 50
EPON 1031 — 50
MNA — 90
BDMA — 0.5

THE RESIN CONTENT BY WEIGHT SHALL BE 26% ± 2%. THE FABRICS INDICATED IN NOTE 3 ARE TO BE USED PREIMPREGNATED WITH THE ABOVE MENTIONED RESIN SYSTEM.

(A) (C) 1. FASTENER HOLES ARE NOT TO BE DRILLED UNTIL ASSEMBLY IS COMPLETE AND READY FOR TEST AND ARE TO BE DRILLED TO MATCH MSFC TEST EQUIPMENT. ALL TEST HARDWARE TO BE INSTALLED AT MSFC.

NOTES:

-23	-7		DWG. NO.	OPP DASH / SHN DASH NO.	PART NAME	
1				-47	DOUBLER	GLASS LAMINATE
1				-45	DOUBLER	GLASS LAMINATE
	1			-43	CORE	HEXCEL 1/4 2.3 LB/FT³ AL ALY 3003
	2			-41	CORE	HEXCEL 1/4 2.3 LB/FT³ AL ALY 3003
	4			-39	SLUG	.200 x 2.5 x 10.0 AZ 31 B H-24 MAG ALY QQ-M-44
	2			-37	SLUG	.200 x 2. x 10.0 AZ 31 B H-24 MAG ALY QQ-M-44
✓	✓	✓	ADHESIVE		NARMCO 324	
		212	WASHER		AN 960 10	L WASHER
		212	NUT		MS 21043	1032 UNF-3B (AN 345-10 ALTERNATE)
		212	BOLT		AN 173-7	BOLT
		1		-35	BOTTOM	GLASS LAMINATE
		2		-33	ANGLE	
		2		-31	ANGLE	
1				-29	FACING	GLASS LAMINATE
1				-27	CORE	HEXCEL 1/4 2.3 LB/FT³ AL ALY 3003 (.40)
1				-25	FACING	GLASS LAMINATE
		1		-23	TOP ASSY	
	1			-21	ANGLE	GLASS LAMINATE
	1			-19	ANGLE	
	2			-17	FILLER	
	2			-15	FILLER	GLASS LAMINATE
	2			-13	CORE	HEXCEL 1/4 2.3 LB/FT³ AL ALY 3003 (.20)
	1			-11	FACING	GLASS LAMINATE
	1			-9	FACING	GLASS LAMINATE
		2		-7	SIDE ASSY	

REQUIREMENTS PER ASSEMBLY

MANUFACTURING TOLERANCES ARE UNLESS OTHERWISE NOTED: FRACTIONS ± .031; DECIMALS .XX ± .020, .XXX ± .005; ANGLES ± 1/2 DEG. ALL MACHINED SURFACES & AS NOTED REF. NAS 30

DESIGN J. Robinson 3-3-64

NOTICE!

EVERY EFFORT WILL BE MADE TO INSURE THAT THE TOLERANCES INDICATED ON THIS DRAWING WILL BE HELD. HOWEVER, DUE TO THE DEVELOPMENTAL NATURE OF THE ARTICLE DEPICTED, NO GUARANTEE CAN BE GIVEN THAT THE FINISHED SPECIMEN WILL FALL WITHIN THESE TOLERANCES.

NARMCO RESEARCH & DEVELOPMENT

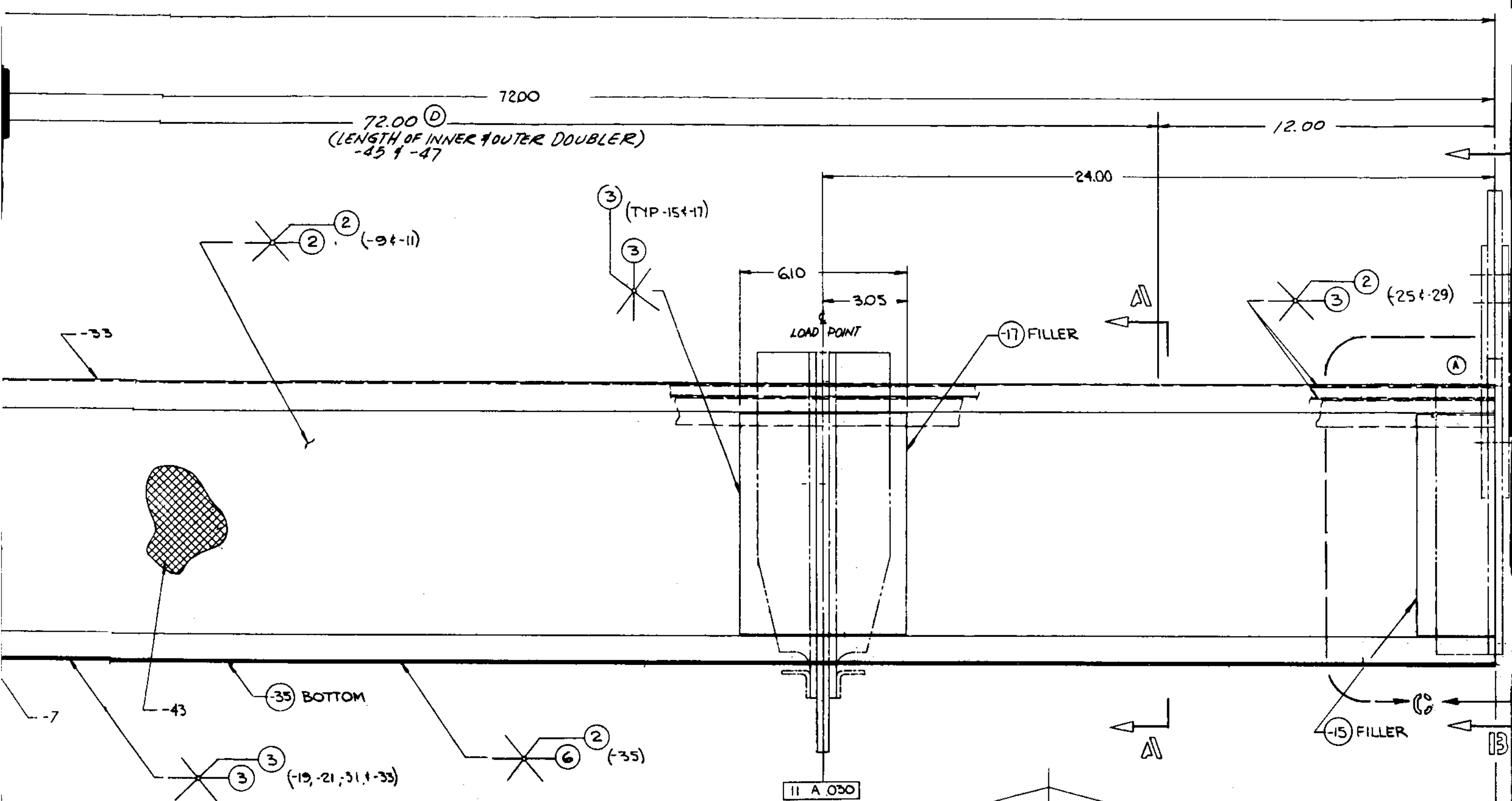
TITLE: BOX BEAM

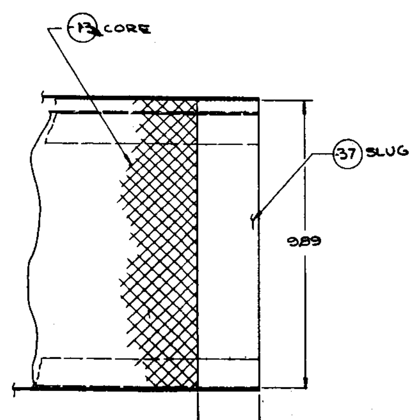
SCALE HALF — 100-2159

R — DWG NO NR 63-050 — E

SHEET 1 OF 1

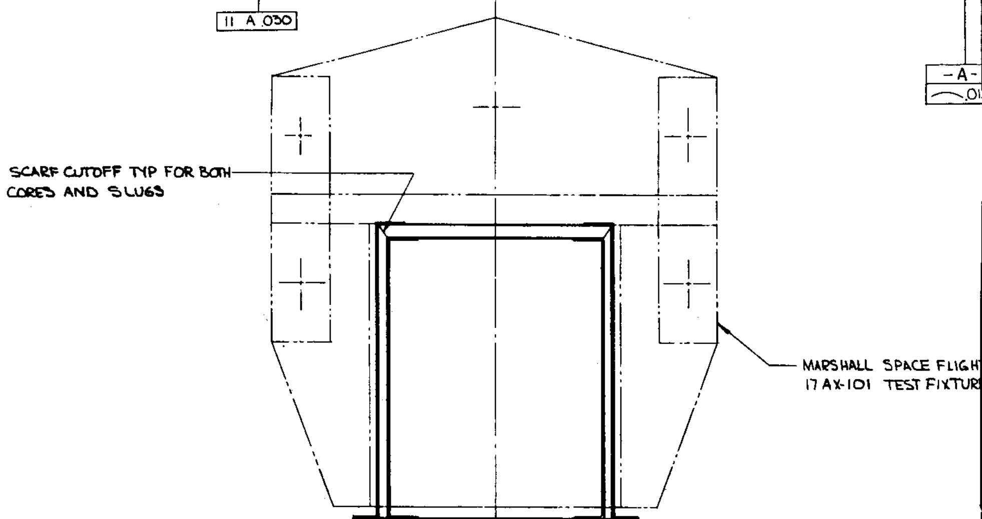
LENGTH OF -45 & -47
TOP ASSY.
ON



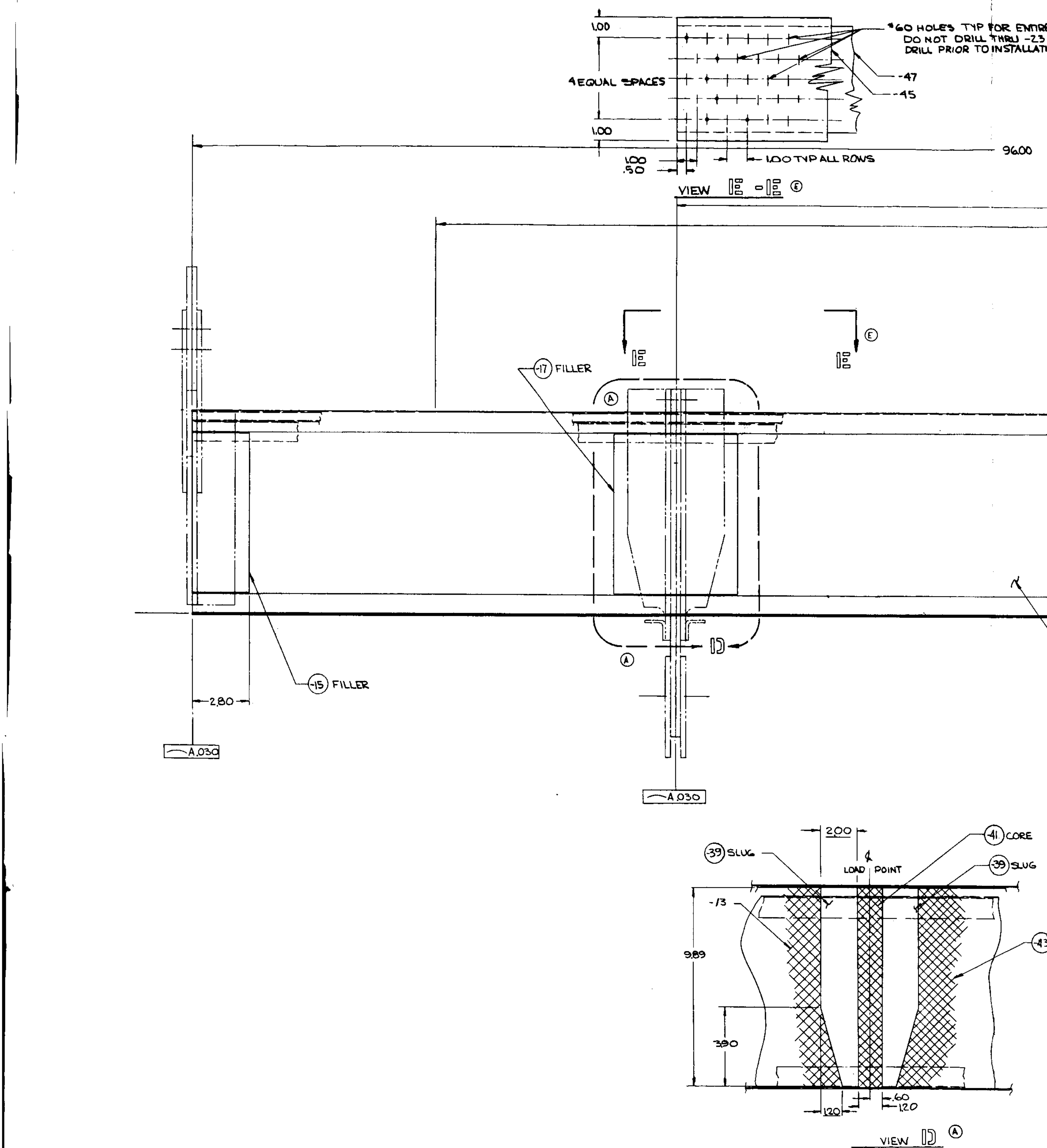


VIEW C Ⓐ

SHOWING -37 SLUG WITH -9 OUTER FACING REMOVED FOR CLARITY. TYP BOTH ENDS AND BOTH SIDES.



SECTION B - B



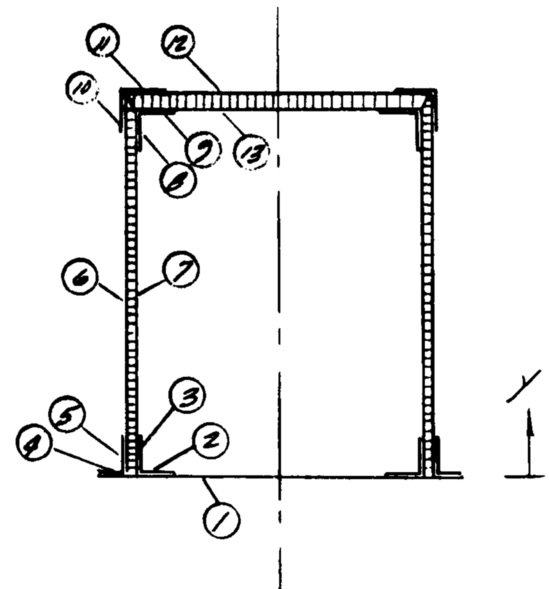
SHOWING -39 SLUG WITH -9 OUTER FACING REMOVED FOR CLARITY. TYP ALL LOADING POINTS BOTH SIDES.

APPENDIX B

BASIC STRESS ANALYSIS OF THE FIBERGLASS REINFORCED BOX BEAM

THE BASIC STRESS ANALYSIS OF THE FIBERGLASS REINFORCED BOX BEAM

NASA BOX BEAM ANALYSIS:



ITEM		A	Y	Ay	Ay²	I_o
1	4.8 × .057 =	.274	.0285	.0078	.0002	.0001
2	1.0 × .046 =	.046	.088	.0040	.0004	—
3	1.0 × .046 =	.046	.565	.0260	.0147	.0038
4	0.8 × .046 =	.037	.088	.0033	.0003	—
5	1.0 × .046 =	.046	.565	.0260	.0147	.0038
6	10.0 × .030 =	.300	5.0	1.5000	7.5000	2.5000
7	9.5 × .030 =	.285	4.25	1.2113	5.1478	2.1434
8	1.0 × .046 =	.046	9.01	.4145	3.7343	.0038
9	1.0 × .046 =	.046	9.49	.4365	4.1428	—
10	1.0 × .046 =	.046	9.50	.4370	4.1515	.0038
11	1.0 × .046 =	.046	9.98	.4591	4.5816	—
12	4.0 × .037 =	.148	9.93	1.4696	14.9535	—
13	3.7 × .037 =	.137	9.68	1.3262	12.8372	—
		1.503		7.3213	57.079	4.6587

$$\bar{Y} = \frac{7.3213}{1.503} = 4.871 \text{ IN.}, \quad A_{TOT} = 1.503(2) = 3.006 \text{ IN}^2$$

$$I = 2\left[57.079 + 4.659 - (7.3213)(4.871)\right] = 52.15 \text{ IN}^4$$

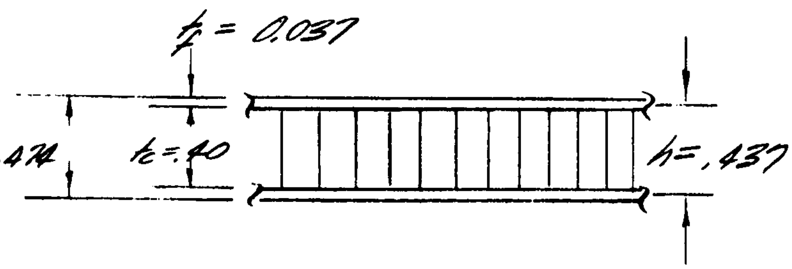
NASA BOX BEAM ANALYSIS (CONT.)

UPPER SURFACE SANDWICH PANEL ~

$$f_b = \frac{MY}{I} \qquad Y = 10.00 - 4.87 = 5.13$$

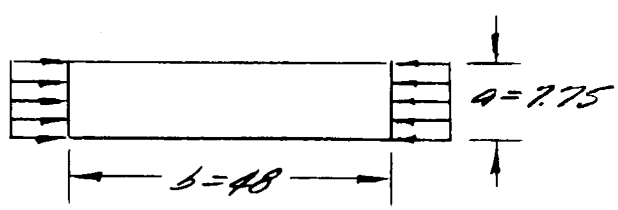
$$= \frac{416{,}880\,(5.13)}{52.15}$$

= 41,000 psi ULT. (COMPRESSION IN UPPER SURFACE)



$$V = \frac{t_c t_f^2}{t - t_c} \; \frac{\pi^2}{a^2} \; \frac{\sqrt{E_{fa} E_{fb}}}{\lambda_F \, G_{c_{bz}}}$$

REF. FPL REPORT NO 1867



UPPER PANEL FACINGS ARE:

2 PLYS 181E-HTS @ 45° (X)

3 PLYS 1009-26S @ 0° (=)

$$E_{fa} = \left[\frac{2.25(2) + 1.04(3)}{5}\right](10^6)$$

$$= 1.52 \times 10^6$$

NASA BOX BEAM ANALYSIS (CONT)

UPPER SURFACE SANDWICH PANEL (CONT.)

$$E_{F_b} = \left[\frac{2.25(2) + 6.71(3)}{5}\right] \times 10^6$$

$$= 4.92 \times 10^6$$

$$\left[E_{F_a} E_{F_b}\right]^{1/2} = \left[(1.52)(4.92)\right]^{1/2} \times 10^6$$

$$= 2.73 \times 10^6$$

.24 .123

$$\mu_{ba} = \frac{0.12(2) + .041(3)}{5}$$

$$= .073$$

$$\mu_{ab} = \frac{0.12(2) + 0.264(3)}{5}$$

$$= 0.206$$

$$\lambda_F = 1 - \mu_{ab}\mu_{ba}$$

$$= 1 - (.073)(.206)$$

$$= 0.985$$

$G_{c_{bz}} = 14{,}000$ (2.3 #/FT³ HEXCEL CORE ⊥ TO RIBBON)

NASA BOX BEAM ANALYSIS (CONT.)

UPPER SURFACE SANDWICH PANEL (CONT.)

$$V = \frac{0.40(.037)^2}{0.474 - 0.400} \times \frac{\pi^2}{7.25^2} \times \frac{2.73 \times 10^6}{(0.985)(14{,}000)}$$

$$= 0.238$$

$$r = \frac{G_{c_{bz}}}{G_{c_{az}}}$$

$G_{c_{az}} = 27{,}000$ (2.3 #/FT³ HEXCEL CORE // TO RIBBON)

$$= \frac{14{,}000}{27{,}000}$$

$$= 0.52$$

$$\alpha = \left[\frac{E_{F_a}}{E_{F_b}}\right]^{1/2} = \left[\frac{1.52 \times 10^6}{4.92 \times 10^6}\right]^{1/2} = 0.556$$

$$\gamma = \frac{G_{F_{ab}}\,\lambda_F}{\sqrt{E_{F_a} E_{F_b}}}$$

$$G_{F_{ab}} = \frac{1.4(2) + .389(3)}{5} \times 10^6$$

$$= 0.79 \times 10^6$$

$$= \frac{0.79 \times 10^6 (.995)}{2.73 \times 10^6}$$

$$= 0.288$$

NASA BOX BEAM ANALYSIS (CONT.)

UPPER SURFACE SANDWICH PANEL (CONT.)

$$\beta = \alpha \mu_{fab} + 2\gamma$$

$$= 0.556(.206) + 2(.288)$$

$$= 0.69$$

$$b/a = \frac{48.}{7.75} = 6.2$$

$K_M = 2.5$ (REF. FPL REPORT NO. 1867 FIG. 2)

$$F_{CR} = K \frac{\pi^2}{4} \frac{t_f^{\,2}}{a^2} \left[\frac{t+t_c}{t-t_c}\right]^2 \frac{\sqrt{E_{fa} E_{fb}}}{\lambda_f}$$

$$= 2.5 \frac{\pi^2}{4} \frac{(.037)^2}{(7.75)^2} \left[\frac{.474+.40}{.474-.40}\right]^2 \frac{2.73 \times 10^6}{.945}$$

$$= 53{,}800 \text{ psi.}$$

$$M.S. = \frac{F_{CR}}{f_c} - 1$$

$$= \frac{53{,}800}{41{,}000} - 1 = \text{———————} \underline{\underline{+0.31}}$$

NASA BOX BEAM ANALYSIS (CONT.)

SHEAR FLOW DISTRIBUTION IN BOX:

@ UPPER CORNER

Q ~

ITEM	A	y	Ay
9	.046	4.62	.2125
11	.046	5.11	.2351
12	.148	5.06	.7489
13	.137	4.81	.6590
		Σ	1.856

$Q_{UPPER\ CORNER} = 2(1.856) = 3.712$

@ N.A.

Q ~

ITEM	A	y	Ay
9,11,12,13			1.856
8	.046	4.14	.190
10	.046	4.63	.213
PORTION 6	.154	2.57	.396
PORTION 7	.139	2.32	.322
		Σ =	2.977

$Q_{N.A.} = 2(2.977) = 5.954$

NASA BOX BEAM ANALYSIS (CONT.)

SHEAR FLOW DISTRIBUTION IN BOX (CONT.)

④ LOWER CORNER

ITEM	A	Y	AY
1	.274	4.84	1.326
2	.046	4.78	.220
4	.037	4.78	.177
		Σ =	1.723

$$Q = 2(1.723) = 3.446$$

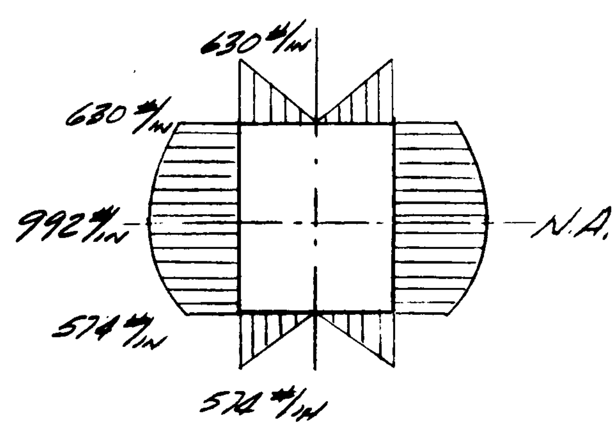
$$q_{℄} = 0$$

$$q_{\text{UPPER CORNER}} = \frac{VQ}{I(2)} = \frac{17370(3.712)}{52.15(2)} = 630\ \#/_{IN}\ \text{ULT.}$$

$$q_{N.A.} = \frac{VQ}{2I} = \frac{17370(5.954)}{52.15(2)} = 992\ \#/_{IN}\ \text{ULT.}$$

$$q_{\text{LOWER CORNER}} = \frac{VQ}{2I} = \frac{17370(3.446)}{52.15(2)} = 574\ \#/_{IN}\ \text{ULT.}$$

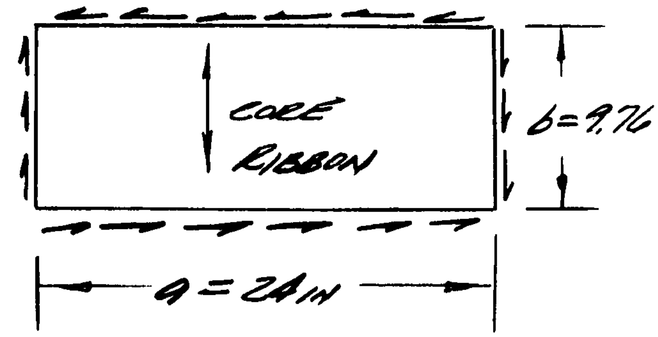
SHEAR FLOW DIAGRAM



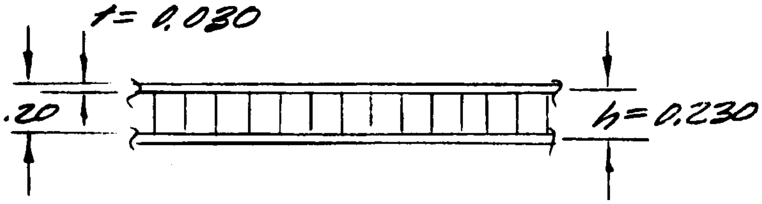
NASA BOX BEAM ANALYSIS (CONT.)

SHEAR STRESS IN WEBS FROM END SUPPORTS TO LOAD PTS. ~

$b/a = \frac{9.76}{24} = 0.407$



$V = \frac{\pi^2 t_c E' t}{2 \lambda b^2 G_c}$ (REF. MIL HDBK 23, PART III)



$= \frac{\pi^2 (.20)(2.71 \times 10^6)(.030)}{2(0.985)(9.76)^2(14{,}000)}$

$= \frac{160{,}480}{2627 \times 10^3}$

$= .061$

$E' = \left[E_{Fa} \times E_{Fb}\right]^{1/2}$

$= (4.48 \times 1.64)^{1/2} \times 10^6$

$= 2.71 \times 10^6$

$\lambda_F = 1 - \mu_{ab}\,\mu_{ba}$

$= 1 - (.192)(.080) = 0.985$

$G_c = 14{,}000$ psi.

$K_M = 5.2$ (REF. FIG. 3-7, MIL. HDBK 23, PART III)

NASA BOX BEAM ANALYSIS (CONT.)

SHEAR STRESS IN WEBS (CONT.)

$$F_{s_{cr}} = \frac{\pi^2 K E' h^2}{4 \lambda b^2}$$

$$= \frac{\pi^2 (5.2)(2.71 \times 10^6)(.230)^2}{4(.985)(9.76)^2}$$

$$= 19{,}600 \text{ psi}$$

$$F_{su} = 18{,}600 \text{ psi}$$

$$f_s = \frac{q}{t} = \frac{992}{2(.030)} = 16{,}530 \text{ psi}$$

$$M.S. = \frac{F_{su}}{f_s} - 1 = \frac{18600}{16{,}530} - 1 = \text{———— ————} \ \underline{\underline{+0.13}}$$

TENSION STRESS IN LOWER SHEET:

$$f_t = \frac{My}{I} = \frac{416{,}880(4.87)}{52.15} = 38{,}930 \text{ psi ULT.}$$

$$F_{tu} = 130{,}500 \text{ psi ULT.}$$

$$M.S. = \frac{F_{tu}}{f_t} - 1 = \frac{130{,}500}{38{,}930} - 1 \text{ ——— ————} \ \underline{\underline{+2.35}}$$

NASA BOX BEAM ANALYSIS (CONT.)

SHEAR STRESS IN LOWER SHEET AT CORNERS:

$$f_s = \frac{q}{t} = \frac{574}{.057} = 10{,}100 \text{ psi. ULT.}$$

$$F_{SU} = 14{,}300 \text{ psi}$$

$$M.S. = \frac{14{,}300}{10{,}100} - 1 = \text{———— ———— ————} +0.41$$

BOND SHEAR STRESS, BOTTOM SHEET TO ∡'S.

$$Q = 2(1.326) = 2.652$$

$$q = \frac{VQ}{2I} = \frac{17370(2.652)}{2(52.15)} = 441 \text{ LB/IN ULT.}$$

$$f_s = \frac{q}{w} \qquad w = \text{BOND WIDTH} = 1.8 \text{ IN}$$

$$= \frac{441}{1.8}$$

$$= 245 \text{ psi ULT.}$$

$F_{S_{BOND}}$ = 1250 psi (SPECIFICATION REQUIREMENT @ 180°F, MIL-A-5090D)

$$M.S. = \frac{F_{S_{BOND}}}{f_s} - 1 = \frac{1250}{245} - 1 = \text{———— ————} \underline{\underline{+4.1}}$$

NASA BOX BEAM ANALYSIS (CONT.)

BOND SHEAR STRESS, LOWER ∡'S TO SIDE WEBS

$Q = 3.446 + 2[(.046)(4.306) + (.046)(4.306)]$

$= 4.238$

$q = \frac{VQ}{2I} = \frac{17370(4.238)}{2(52.15)} = 705 \text{ \#/IN}$

$f_s = \frac{q}{w} = \frac{705}{2(1.0)} = 353 \text{ psi}$

$M.S. = \frac{F_{s\,BOND}}{f_s} - 1 = \frac{1250}{353} - 1 = \text{———} \quad \underline{\underline{+2.55}}$

BOND SHEAR STRESS, UPPER FACINGS TO ∡'S

$Q = 2[.148(5.06) + .137(4.81)] = 2.816$

$q = \frac{VQ}{2I} = \frac{17370(2.816)}{2(52.15)} = 469 \text{ LB/IN ULT.}$

$f_s = \frac{q}{w} = \frac{469}{2.0} = 235 \text{ psi ULT.}$

$M.S. = \frac{F_{s\,BOND}}{f_s} - 1 = \frac{1250}{235} - 1 = \text{———} \quad \underline{\underline{+4.3}}$

NASA BOX BEAM ANALYSIS (CONT.)

BOND SHEAR STRESS, UPPER ∡'S TO WEBS

$Q = 3.712 + 2[.046(4.14) + .046(4.63)]$

$= 4.519$

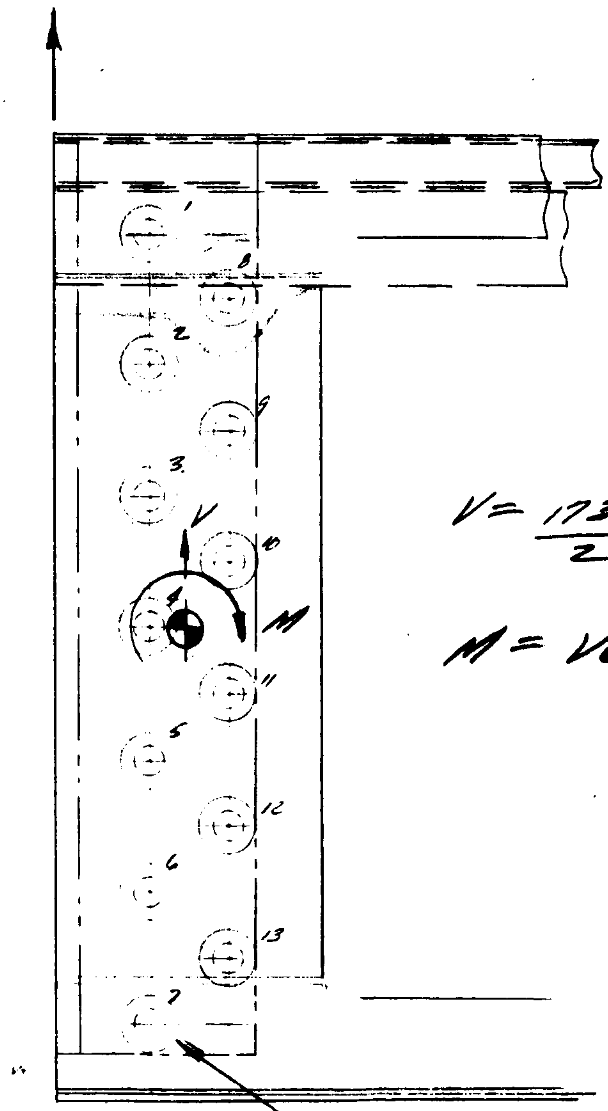
$q = \frac{VQ}{2I} = \frac{17370(4.519)}{2(52.15)} = 753$ LB/IN ULT.

$f_s = \frac{q}{w} = \frac{753}{2.0} = 377$ PSI ULT.

$M.S. = \frac{F_{s\,BOND}}{f_s} - 1 = \frac{1250}{377} - 1 =$ —— —— $\underline{\underline{+2.3}}$

NASA BOX BEAM ANALYSIS (CONT.)

END FITTING ATTACHMENTS



$V = \frac{17370}{2} = 8685$ LB. ULT.

$M = Ve = 8685(1.369)$

$= 11890$ IN. LB. ULT.

DELRON INSERTS (13)

S-102F 10-06

P 102F 10-0

NASA BOX BEAM ANALYSIS (CONT.)

END FITTING ATTACHMENTS:

BOLT NO.	x	y	x^2	y^2	P_{cy}	P_{ey}	P_y	P_{ex}	P
1	-.369	4.125	.136	17.02	-668	-50	-718	556	907
2		2.750	.136	7.56				371	
3		1.375	.136	1.89				185	
4		0	.136	0				0	
5		-1.375	.136	1.89				-185	
6		-2.750	.136	7.56				-371	
7	-.369	-4.125	.136	17.02		-50	-718	-556	907
8	.431	3.438	.186	11.82		58	-610	464	
9		2.063	.186	4.26				278	
10		.688	.186	.47				93	
11		-.688	.186	.47				-93	
12		-2.063	.186	4.26				-278	
13	.431	-3.438	.186	11.82	-668	58	-610	-464	
Σ			2.068	86.04					

$$\bar{x} = \frac{7(1.0) + 6(1.8)}{13} = 1.369$$

$$P_{ey} = \frac{Mx}{\Sigma(x^2+y^2)} = \frac{11890\,x}{2.068 + 86.04} = 134.9x$$

$$P_{ex} = \frac{My}{\Sigma(x^2+y^2)} = 134.9y$$

$$P_{MAX} = \left[718^2 + 556^2\right]^{1/2} = 907 \text{ LBS. ULT.}$$

NASA BOX BEAM ANALYSIS (CONT.)

END FITTING ATTACHMENTS (CONT.)

BEARING STRESS IN SANDWICH WEB FACINGS ~

$$f_{br} = \frac{P}{A} = \frac{907}{2(.309)(.046+.030)}$$

$$= 19{,}300 \text{ psi ULT.}$$

$F_{br} = 26{,}100$ psi (REF. TABLE 2-7, MIL HDBK 17)

$$M.S. = \frac{F_{br}}{f_{br}} - 1 = \frac{26100}{19300} - 1 = \text{———— ————} \underline{\underline{+0.35}}$$

SHEAR STRESS ON NET SECTION @ END FITTING ATTACHMENTS:

CONSIDERING SINGLE ROW

$$C_R = 1 - \frac{d_e}{P}$$

$$= 1 - \frac{0.309}{1.375} = 0.775$$

d_e = EFFECTIVE FASTNER DIA.
= 0.309

P = FASTNER SPACING
= 1.375

NASA BOX BEAM ANALYSIS (CONT.)

SHEAR STRESS ON NET SECTION @ END FITTING ATTACHMENTS (CONT.)

CONSIDERING STAGGERED ROW

$$C_R = 1 - \frac{d_e}{P} + \frac{S^2}{4P^2}$$

$d_e = 0.309$

$P = \frac{1.375}{2} = .688$

S = STAGGER = 0.80

$$= 1 - \frac{.309}{.688} + \frac{0.80^2}{4(.688)^2}$$

(.449) (.338)

$$= 0.889$$

SINGLE ROW IS MORE CRITICAL ~

$$f_{s_{NET}} = \frac{q}{t C_R} = \frac{792}{2(.030+.046)(.775)}$$

$$= 8420 \text{ psi.}$$

FOR STRESS CONCENTRATION FACTOR:

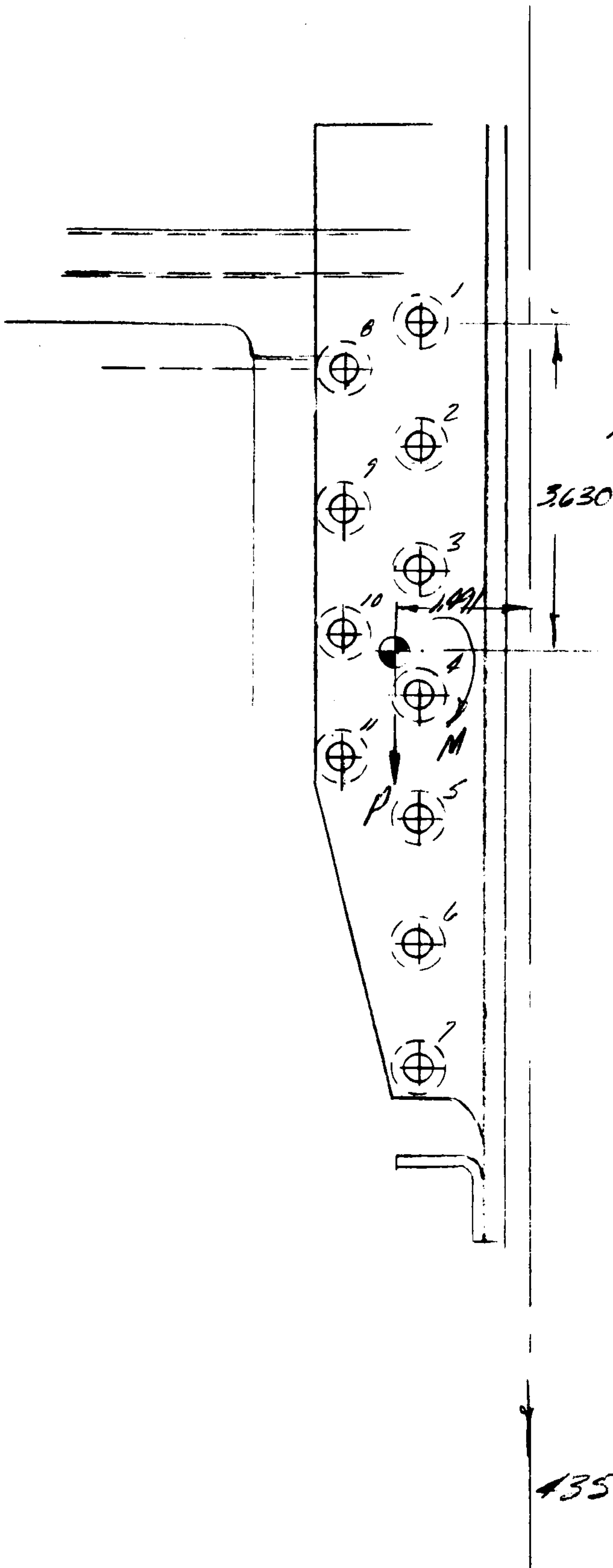
$$F_{s_{NET\,SEC}} = 0.8 \, F_{s_{GROSS\,SEC}}$$ (REF. TABLE 2-10, MIL HDBK 17)

$$= 0.8(18,600)$$

$$= 14,880 \text{ psi}$$

$$M.S. = \frac{F_s}{f_s} - 1 = \frac{14880}{8420} - 1 = \text{———— ————} \; \underline{\underline{+0.77}}$$

NASA BOX BEAM ANALYSIS (CONT.)



$$P = \frac{17370}{4}$$

$$= 4350 \text{ LB. ULT.}$$

ASSUME $M = \frac{P\ell}{8}$ (FIXED END BEAM)

$$= \frac{4350(2 \times 1.491)}{8}$$

$$= 1620 \text{ IN}^{\#} \text{ ULT.}$$

NASA BOX BEAM ANALYSIS (CONT.)

LOAD PT. FITTING ATTACHMENTS:

BOLT NO	x	y	x^2	y^2	P_{cy}	P_{ey}	P_y	P_x	P
1	.291	3.630	.0847	13.177	395	7	402		
2		2.255		5.085					
3		0.880		.774					
4		-.495		.245					
5		-1.870		3.497					
6		-3.245		10.530					
7	.291	-4.620	.0847	21.344		7	402	109	416
8	-.509	2.943	.2591	8.661		-12	383		
9		1.568		2.458					
10		0.193		.0372					
11	-.509	-1.183	.2591	1.399	395	-12	383		
Σ			1.629	67.207					

$$P_{cy} = \frac{4350}{11} = 395$$

$$P_{ey} = \frac{Mx}{\Sigma(x^2+y^2)} = \frac{1620}{(1.629+67.207)}x = 23.53x$$

$$P_{ex} = \frac{My}{\Sigma(x^2+y^2)} = 23.53y$$

$$P_{MAX} = \left[P_y^2 + P_x^2\right]^{1/2} = \left[402^2 + 109^2\right]^{1/2} = 416 \text{ LB. ULT.}$$

NASA BOX BEAM ANALYSIS (CONT.)

LOAD PT FITTING ATTACHMENTS (CONT.)

BEARING STRESS IN SANDWICH WEB FACINGS ~

$$f_{br} = \frac{P}{A} = \frac{416}{2(.309)(.046+.030)}$$

$$= 8850 \text{ psi ULT.}$$

$$F_{BR} = 26,100 \text{ psi}$$

$$M.S. = \frac{F_{br}}{f_{br}} - 1 = \frac{26100}{8850} - 1 = \text{———— ————} \quad \underline{+1.95}$$

SHEAR STRESS ON NET SECTION:

ROW WITH 7 FASTNERS IS SAME AS END FITTING

$$M.S. = \text{————————————————} \quad \underline{+0.77}$$

NASA BOX BEAM ANALYSIS (CONT.)

WEIGHT ESTIMATE ~

UPPER PANEL:

SKINS

$96 \times 77 \times .037 \times 2 \times .067 = 3.66$

CORE

$\frac{96 \times 8 \times .40}{1728}(2.3) = 0.41$

ADHESIVE

$\frac{96 \times 8 \times 2}{144}(.07) = 0.75$

SIDE WEBS:

SKINS

$96 \times 19.5 \times 2 \times .030 \times .067 = 7.53$

CORE

$\frac{96 \times 9.8 \times .20}{1728} \times 2 (23) = 0.50$

ADHESIVE

$\frac{96 \times 10 \times 4}{144}(.07) = 1.87$

LOWER SHEET

$96 \times 9.6 \times .057 \times .067 = 3.52$

ANGLES

$15.6 \times .046 \times 96 \times .067 = 4.61$

∆ ADHESIVE

$\frac{15.6 \times 96}{144}(.07) = 0.73$

23.58 SUB TOTAL

NASA BOX BEAM ANALYSIS (CONT.)

WEIGHT ESTIMATE (CONT.)

LOAD PT. DOUBLERS

LAMINATES

$4 \times 8 \times .046 \times 6.2 \times .067$

$+ 4 \times 7.5 \times .046 \times 6.2 \times .067 \quad = \quad 1.18$

ADHESIVE

$\frac{4(8+7.5) \times 6.2}{144} (.07) \quad = \quad 0.19$

END DOUBLERS:

LAMINATES

$4(8+7.5).046 \times 2.8 \times .067 = 0.54$

ADHESIVE

$4 \frac{(8+7.5) \times 2.8}{144} (.07) \quad = 0.08$

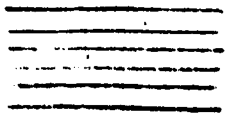
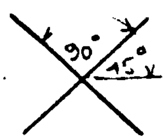
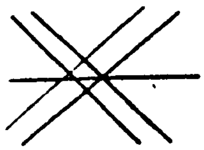
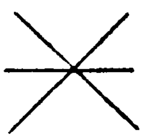
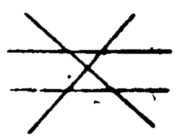
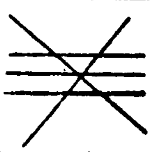
DELKON INSERTS

$[8(11) + 4(13)](.0032) \quad = \underline{0.45}$

SUB TOTAL = 2.44

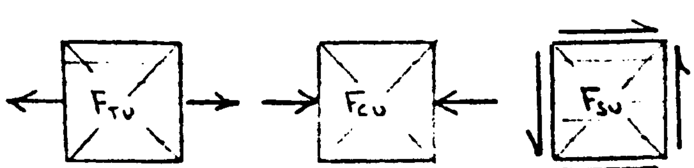
TOTAL = 2.44 + 23.58 = 26.02 LBS.

S-HTS GLASS WITH EPOXY RESIN (46% BY VOLUME) 181 GLASS FABRIC WITH EPOXY

ORIENTATION	TENSION (PSI)	COMPRESSION (PSI)	SHEAR (PSI)	POISON'S RATIO & DENSITY
(1)  (1 PLY) S-HTS .004 INCHES	$F_{TU} = 165000$ $E_L = 6.71 \times 10^6$ $E_T = 1.04 \times 10^6$	$F_{CU} = 92000$	$F_{SU} = 7800$ $G_{LT} = .389 \times 10^6$	$\mu_{LT} = .264$ $\mu_{TL} = .041$ $\rho = .069$ #/IN³
(2)  (1PLY) 181E .008 IN	$F_{TU} = 27000$ $E_L = 2.25 \times 10^6$ $E_T = 2.25 \times 10^6$	$F_{CU} = 27000$	$F_{SU} = 24000$ $G_{LT} = 1.4 \times 10^6$	$\mu_{LT} = .12$ $\mu_{TL} = .12$ $\rho = .067$ #/IN³
(3)  (1 PLY) S-HTS (2 PLY) 181E .020 IN	$F_{TU} = 73{,}000$ $E_L = 3.74 \times 10^6$ $E_T = 1.85 \times 10^6$	$F_{CU} = 48{,}600$	$F_{SU} = 20{,}760$ $G_{LT} = 1.06 \times 10^6$	$\mu_{LT} = .169$ $\mu_{TL} = .094$ $\rho = .067$ #/IN³
(4)  (1PLY) S-HTS (1PLY) 181E .012 IN	$F_{TU} = 96000$ $E_L = 4.48 \times 10^6$ $E_T = 1.64 \times 10^6$	$F_{CU} = 59{,}500$	$F_{SU} = 18600$ $G_{LT} = .894 \times 10^6$	$\mu_{LT} = .192$ $\mu_{TL} = .080$
(5)  (2 PLY) S-HTS (1PLY) 181E .016 IN	$F_{TU} = 119{,}000$ $E_L = 5.22 \times 10^6$ $E_T = 1.44 \times 10^6$	$F_{CU} = 70{,}300$	$F_{SU} = 15{,}900$ $G_{LT} = .726 \times 10^6$	$\mu_{LT} = .216$ $\mu_{TL} = .067$ $\rho = .068$ #/IN³
(6)  (3PLY) S-HTS (1PLY) 181E .020 IN	$F_{TU} = 130{,}500$ $E_L = 5.59 \times 10^6$ $E_T = 1.34 \times 10^6$	$F_{CU} = 75{,}750$	$F_{SU} = 14{,}300$ $G_{LT} = .642 \times 10^6$	$\mu_{LT} = .228$ $\mu_{TL} = .061$

LOAD ORIENTATION:

$E_{TENSION} \approx E_{COMPRESSION}$



APPENDIX C

MODIFICATION — UPPER SANDWICH DOUBLER ADDITION

Upper Panel Doubler Addition

The addition of a doubler on the upper sandwich panel of the box beam reduces the compressive stress to approximately 32,600 psi from the original stress of 41,000 psi.

Edgewise compression tests were performed on specimens of the original upper sandwich panel design. The test results show a face wrinkling type of failure. A study was made on face wrinkling, and the results are shown on the theoretical curve that follows, which applies only to the original sandwich design. The test results confirmed the face wrinkling theory for the core density used on the box beam.

Tests were performed on sandwich specimens with doublers added. The core, facings, and doublers were the same as on the final box beam design. Compressive buckling stresses varied from 46,300 psi to 41,700 psi. The minimum value (41,700 psi) was used to calculate the margin of safety in the analysis that follows.

Upper Sandwich Panel

Minimum M.S. = 27% (Compression)

Section Properties Change

Add doubler to items (12) and (13) : Reference: Amount 7-14-64 (See page 37.)

Doubler = 2 plies of 1581 at 0 degrees to load direction
1 ply of 1009-26S unidirectional

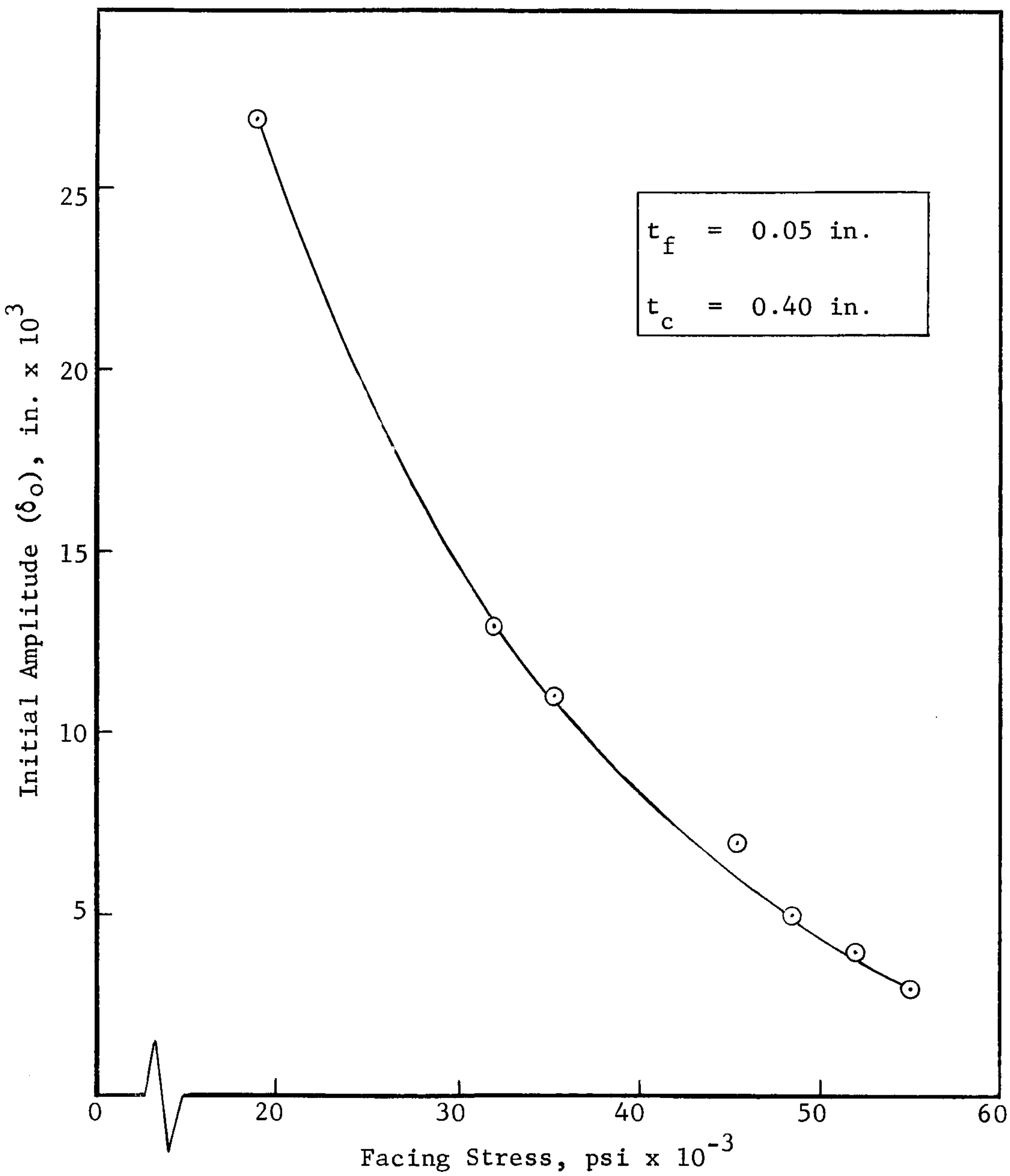
$$2 \times t_{1581} = 0.018 \text{ in.}$$

$$t_{1009} = 0.006 \text{ in.}$$

$$t_{total} = 0.024 \text{ in.}$$

Section properties: Reference: Amounts calculated 7-14-64 (See page 37.)

	A	Y	AY	AY^2	I_o
(12) $4.0 \times \left(0.037^{0.061} + 0.024\right)$	0.244	9.94	2.425	24.108	--
(13) 3.7×0.061	0.225	9.51	2.139	20.349	--
Total Items (1) → (13)	1.687		9.0895	73.7453	4.6587



Allowable Facing Stress vs. Initial Facing Amplitude (Unevenness)

$$\bar{Y} = \frac{9.0895}{1.687} = 5.388 \text{ in.}$$

$$A_{tot} = 2 \times 1.687 = 3.374 \text{ in.}^2$$

$$I = 2\left[73.7453 + 4.6587 - (9.0895)(5.388)\right]$$

$$I = 2\,[78.404 - 48.974]$$

$$I = \underline{58.86 \text{ in.}^4}$$

Upper Surface Sandwich Panel

$$\bar{Y}_{upper} = 10.00 - 5.388 = 4.612 \text{ in.}$$

at center section of beam:

$$M = 416{,}880 \text{ in. lb}$$

$$f_b = \frac{M\bar{Y}}{I} = \frac{416{,}880 \times 4.612}{58.86}$$

$$f_b = \underline{32{,}665 \text{ psi}}$$

This is a compressive stress in the upper surface.

Sandwich panels were tested in edgewise compression, with the same core and doubler arrangement.

Minimum Test Value:

$$\underline{F_{CR} = 41{,}700 \text{ psi}}$$

$$M.S. = \frac{41{,}700}{32{,}665} - 1 = \underline{0.27}$$

Weight Analysis

2 ply 1581 and 1 ply unidirectional

Doubler — Outside Surface:

72 in. long x 6.20 in. wide

$$A = 72 \times 6.20 = 446.4 \text{ in.}^2$$

$$V = 446.4 \times 0.030 = 13.39 \text{ in.}^3$$

$$WT_{doubler} = 13.39 \times 0.067 = 0.897 \text{ lb}$$

$$WT_{adhesive} = \frac{446.4}{144} \times 0.07 = 0.217 \text{ lb}$$

$$WT_{out} = 1.114 \text{ lb}$$

Doubler — Inside Surface:

72 in. long x 5.5 in. wide

$$A = 72 \times 5.5 = 396 \text{ in.}^2$$

$$V = 396 \times 0.030 = 11.88 \text{ in.}^3$$

$$WT_{doubler} = 11.88 \times 0.067 = 0.796 \text{ lb}$$

$$WT_{adhesive} = \frac{396}{144} \times 0.07 = 0.192 \text{ lb}$$

$$WT_{lower} = 0.988 \text{ lb}$$

Total Weight = 2.102 lb

Weight Analysis

2 ply 1581 and 1 ply unidirectional

Doubler — Outside Surface:

72 in. long x 6.20 in. wide

$$A = 72 \times 6.20 = 446.4 \text{ in.}^2$$

$$V = 446.4 \times 0.030 = 13.39 \text{ in.}^3$$

$$WT_{doubler} = 13.39 \times 0.067 = 0.897 \text{ lb}$$

$$WT_{adhesive} = \frac{446.4}{144} \times 0.07 = 0.217 \text{ lb}$$

$$WT_{out} = 1.114 \text{ lb}$$

Doubler — Inside Surface:

72 in. long x 5.5 in. wide

$$A = 72 \times 5.5 = 396 \text{ in.}^2$$

$$V = 396 \times 0.030 = 11.88 \text{ in.}^3$$

$$WT_{doubler} = 11.88 \times 0.067 = 0.796 \text{ lb}$$

$$WT_{adhesive} = \frac{396}{144} \times 0.07 = 0.192 \text{ lb}$$

$$WT_{lower} = 0.988 \text{ lb}$$

Total Weight = 2.102 lb

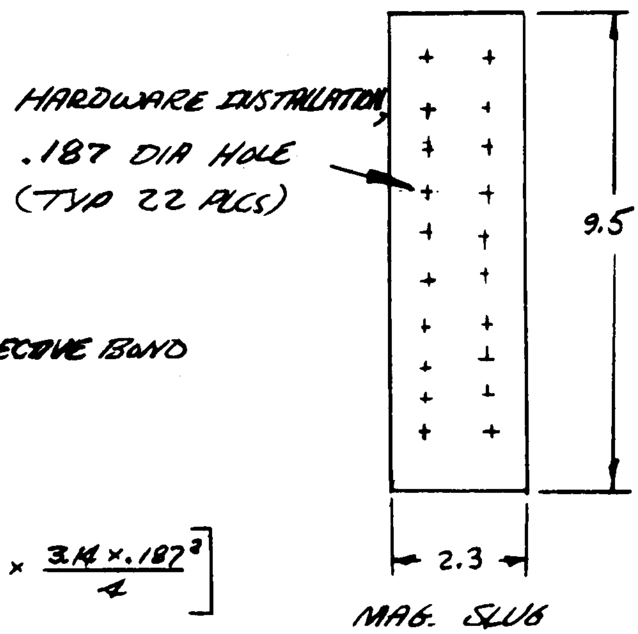
APPENDIX D

MODIFICATION IN THE HARDWARE INSTALLATION AREAS
OF THE FIBERGLASS REINFORCED BOX BEAM

MODIFICATION IN HARDWARE INSTALLATION AREAS

(CHANGE FROM DELRON INSERTS TO MAGNESIUM SLUGS)

1) BONDLINE SHEAR STRESS BETWEEN FACINGS & MAGNESIUM SLUGS AT END POINTS OF BEAM



USE 9.5 INCHES AS EFFECTIVE BOND AREA LENGTH

TOTAL BONDLINE AREA:

$$A_T = \left[2 \times 2.3 \times 9.5\right] - \left[2 \times 22 \times \frac{3.14 \times .187^2}{4}\right]$$

$$= 42.5 \text{ IN}^2$$

SHEAR FORCE ON EACH END SLUG:

$$F_S = \frac{17,370}{2}$$

$$= 8,685 \text{ LBS.}$$

BONDLINE SHEAR STRESS:

$$f_s = \frac{8,685}{42.5}$$

$$= 204 \text{ PSI}$$

MARGIN OF SAFETY:

$$M.S. = \frac{3959}{204}$$

$$= +19$$

AV. SHEAR VALUE FOR 329 ADHESIVE 3,959 PSI - BY TEST, REF TEST DATA SECTION OF THIS REPORT

MODIFICATION IN HARDWARE INSTALLATION AREAS

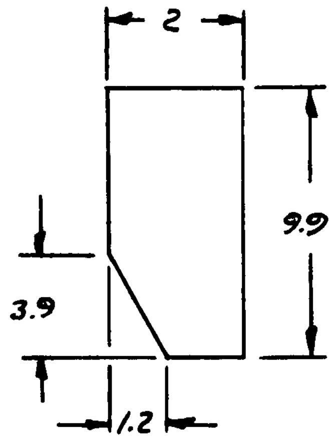
(CHANGE FROM DELRON INSERTS TO MAGNESIUM SLUGS)

2) MAGNESIUM SLUG WEIGHT:

a) LOAD POINTS:

$t = 0.2$

$MAG = 0.065\ \#/IN^3$



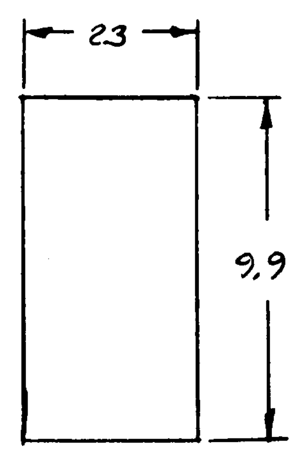
$$W_L = 8 \times .065 \times .2 \left[(2 \times 9.9) - (.5 \times 3.9 \times 1.2) \right]$$

$$= 1.81 \text{ LBS}$$

b) END POINTS:

$t = 0.2$

$MAG = 0.065\ \#/IN^3$



$$W_E = 4 \times .065 \times .2 (2.3 \times 9.9)$$

$$= 1.18 \text{ LBS}$$

C) TOTAL MAGNESIUM SLUG WEIGHT:

$$W_T = 1.81 + 1.18$$

$$= 2.99 \text{ LBS.}$$

INSERT MODIFICATION
NASA FIBERGLASS REINFORCED BOX BEAM

MODIFICATION IN HARDWARE INSTALLATION AREAS
(CHANGE FROM DELRON INSERTS TO MAGNESIUM SLUGS)

3) INNER DOUBLER WEIGHT AND ADHESIVE:

a) LOAD POINT:

1. LAMINATE, $4 \times 7.5 \times .046 \times 6.2 \times .067 = 0.57$

2. ADHESIVE, $\frac{4 \times 7.5 \times 6.2}{144}(.07) = 0.09$

b) END POINT:

1. LAMINATES, $4 \times 7.5 \times .046 \times 2.8 \times .067 = 0.25$

2. ADHESIVE. $\frac{4(7.5) \times 2.8}{144}(.07) = 0.04$

c) TOTAL WEIGHT:

$= 0.57 + 0.09 + 0.25 + 0.04$

$= 0.95$

4) TOTAL DELRON INSERT WEIGHT:

0.45 LB (REF. BASIC FIBERGLASS REINFORCED BOX BEAM STRESS ANALYSIS)

5) TOTAL WEIGHT INCREASE;

$= 2.99 - (.95 + .45)$

$= 1.59$ LBS.

APPENDIX E

ANALYSIS OF THE PREDICTED FAILING LOAD OF THE NASA ALUMINUM BOX BEAM

NASA BOX BEAM ANALYSIS

SUMMARY ~

THE ALUMINUM ALLOY VERSION OF THE NASA BOX BEAM TEST SPECIMEN WAS ANALYZED TO PREDICT THE FAILING LOAD ON THIS BEAM. THESE PREDICTED FAILING LOADS ARE SHOWN ON PG 78.

A REINFORCED PLASTIC/SANDWICH BOX BEAM WAS DESIGNED TO SUPPORT THE PREDICTED LOADS

MARGIN OF SAFETY IN PLASTIC/SAND. DESIGN ~

SHEAR WEBS FROM END OF BEAM TO LOAD PTS:

M.S. = +0.13 (SEE PG. 45)

COMPRESSION IN TOP PANEL BETWEEN LOAD PTS.:

M.S. = +0.27 (SEE PG. 62)

THEREFORE, IT IS PREDICTED THAT THE REINFORCED PLASTIC/SANDWICH BEAM IS 13% STRONGER THAN THE ALUMINUM BEAM.

WEIGHT COMPARISON ~

ALUM. BEAM WT. $= W_{AL} = 33^{\#}$

NASA BOX BEAM ANALYSIS (CONT.)

WEIGHT COMPARISON (CONT.) ~

FIBERGLASS REINFORCED PLASTIC BEAM WT. (BASIC BOX) = W_{FG} = 26.02 # (SEE PG. 57)

INCREASED WEIGHT DUE TO MODIFICATIONS:

CHANGE TO MAGNESIUM SLUGS (SEE PG 67), 1.59 #

DOUBLER ADDITION UPPER SANDWICH (SEE PG 63) 2.102 #

TOTAL WEIGHT: $W_{FG_{TOTAL}}$ = 29.71 LBS.

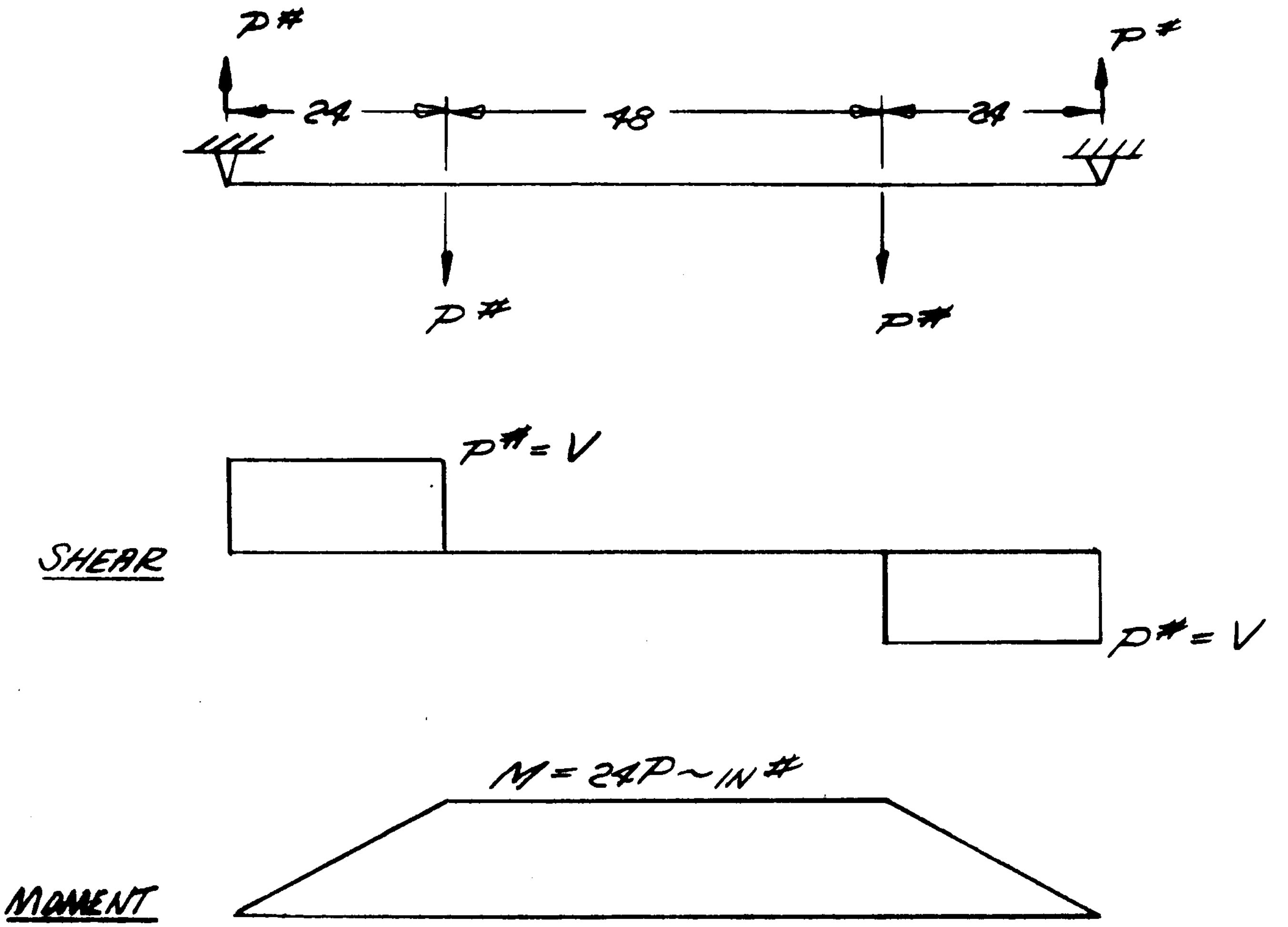
COMPARING ALUMINUM AND FIBERGLASS BOX BEAM WEIGHTS ~

$$\text{WT. SAVING} = \frac{W_{AL} - W_{FG}}{W_{AL}} \times 100$$

$$= \frac{33 - 29.71}{33}$$

$$= 10\%$$

NASA BOX BEAM ANALYSIS



NASA BOX BEAM ANALYSIS (CONT.)

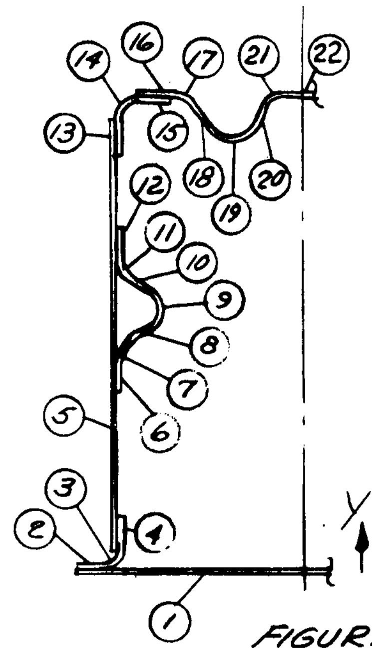


FIGURE 1

ITEM		A	y	Ay	Ay^2	I_o
1	4.8 × .050 =	.240	.025	.0060	.0002	—
2	0.6 × .050 =	.030	.075	.0023	.0002	—
3	$\frac{\pi}{2}$(.325)(.050) =	.026	.21	.0055	.0011	—
4	0.8 × .050 =	.040	.80	.0320	.0256	.002
5	9.0 × .050 =	.450	4.90	2.2050	10.8045	3.038
6	.57 × .050 =	.029	4.12	.1195	.4922	↑
7	$\frac{56}{360}$(2)π(.525)(.050) =	.026	4.64	.1206	.5600	
8	.45(.050 =	.023	4.95	.1139	.5636	
9	$\frac{112}{360}$(2π)(.525)(.050) =	.054	5.50	.2970	1.6335	.164
10	.45(.050) =	.023	6.05	.1392	.8419	
11	$\frac{56}{360}$(2)π(.525)(.050) =	.026	6.40	.1664	1.0650	↓
12	.57 × .050 =	.029	6.94	.2013	1.3967	
13	.50 × .10 =	.050	9.00	.4500	4.0500	.001
14	$\frac{\pi}{2}$(.65)(.10) =	.102	9.71	.9904	9.6170	—
15	.50 × .10 =	.050	9.90	.4950	4.9005	—
16	.75 × .050 =	.038	9.975	.3791	3.7810	—
17	$\frac{61}{360}$(2)π(.525)(.050) =	.028	9.91	.2775	2.7498	
18	.47 × .050 =	.024	9.50	.2280	2.1660	
19	$\frac{122}{360}$2π(.525)(.050) =	.056	9.15	.5124	4.6885	.008
20	.47 × .050 =	.024	9.50	.2304	2.1888	
21	$\frac{61}{360}$2π(.525)(.050) =	.028	9.91	.2775	2.7498	
22	.30(.050) =	.015	9.975	.1496	1.4925	—
		1.411		7.3986	55.7684	3.213

NASA BOX BEAM ANALYSIS (CONT.)

$$\bar{y} = \frac{\Sigma Ay}{\Sigma A} = \frac{7.3986}{1.411} = 5.244$$

$$I_{TOT} = 2\left[55.768 + 3.213 - (7.399)(5.244)\right]$$

$$= 40.36 \text{ IN}^4$$

$$A_{TOT} = 2(1.411) = 2.822 \text{ IN}^2$$

NASA BOX BEAM ANALYSIS (CONT.)

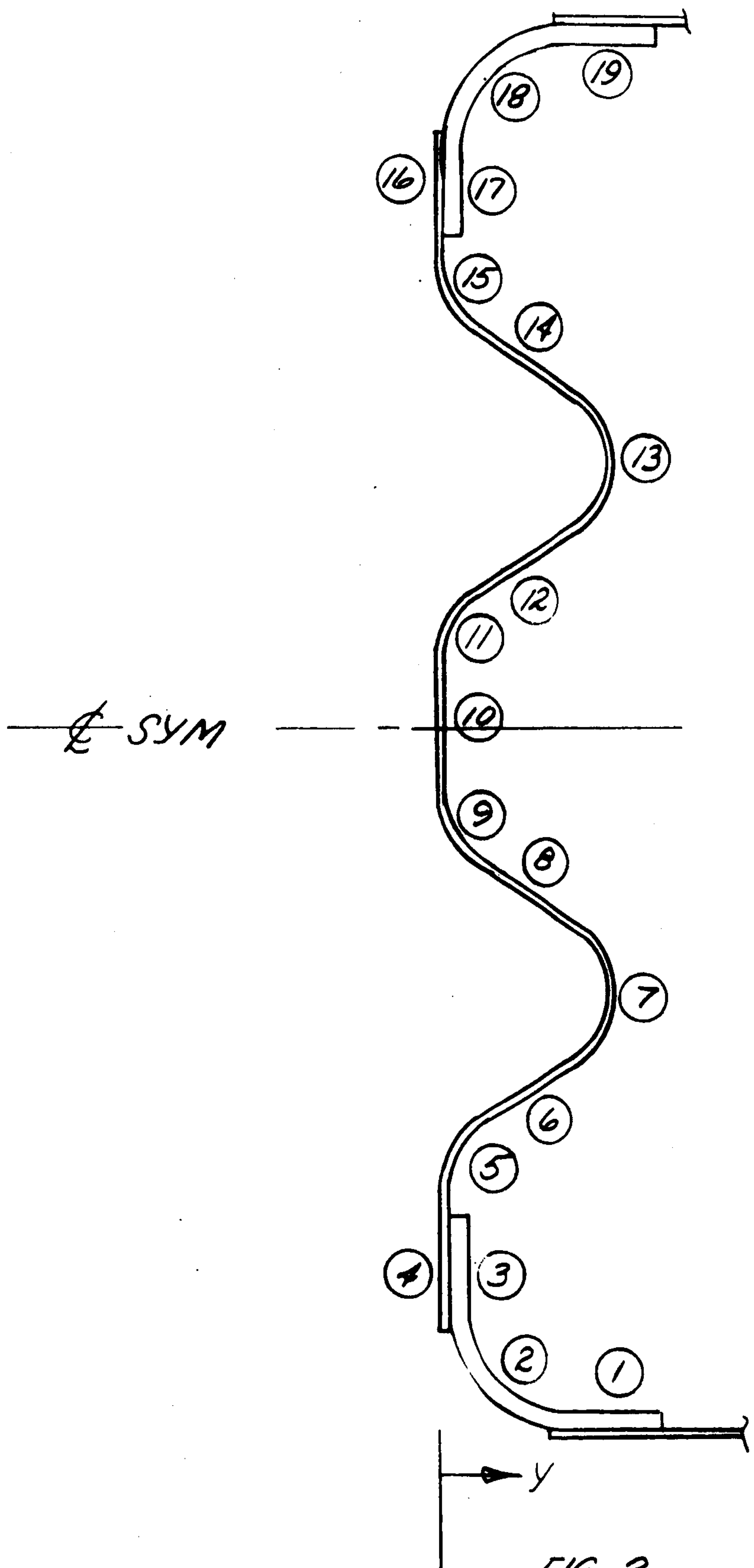


FIG. 2

NASA BOX BEAM ANALYSIS (CONT.)

$$F_{cc} = \frac{\Sigma A_n F_{cc_n}}{\Sigma A_n}$$

(REF. "STIFFNER CRIPPLING STRESSES FOR PANEL ALLOWABLE PREDICTION" ~ RYAN STRESS MAN.)

ITEM	A_n	b_n/t	R_n/t	F_{cc_n}	$F_{cc_n} A_n$
1	.050	15.2	—	17,000	850
2	.102	—	6.5	72,200	7364
3	.050	15.2	—	17,000	850
4	.038	—	—	17,000	646
5	.028	—	10.5	70,300	1968
6	.024	9.4	—	46,000	1104
7	.056	—	10.5	70,300	3937
8	.024	9.4	—	46,000	1104
9	.028	—	10.5	70,300	1968
10	.030	12.0	—	39,800	1194
11	.028	—	10.5	70,300	1968
12	.024	9.4	—	46,000	1104
13	.056	—	10.5	70,300	3937
14	.024	9.4	—	46,000	1104
15	.028	—	10.5	70,300	1968
16	.038	—	—	17,000	646
17	.050	15.2	—	17,000	850
18	.102	—	6.5	72,200	7364
19	.050	15.2	—	17,000	850
Σ	.830				40776

$$F_{cc} = \frac{40,776}{.830} = 49,130 \text{ PSI}$$ (BASED ON MIL HDBK 5, "B" VALUE)

NASA BOX BEAM ANALYSIS (CONT.)

CHECK UPPER WEB AS COLUMN BETWEEN STIFFENERS ~

$F_{CO} = F_{CY}\left(1+\sqrt{\frac{F_{CY}}{1333}}\right)$ REF MIL HDBK 5, TABLE 3.4.2.1

F_{CY} = 71,000 PSI (REF MIL HDBK 5, TABLE 3.2.7.0(b) "B" VALUE)

$F_{CO} = 71.0\left(1+\sqrt{\frac{71.0}{1333}}\right) = 87.4$ (VALUE IS HIGHER THAN F_{TU} ~ ∴ USE $F_{CO} = F_{TU}$ = 79,000 PSI

TRANSITIONAL $L'/\rho = 1.346\,\pi\left[\frac{E}{F_{CO}}\right]^{1/2}$

$= 1.346\,\pi\left[\frac{10.5\times10^6}{7.9\times10^4}\right]^{1/2}$

$= 48.8$

FROM FIG. 2

ITEM	A	y	Ay	Ay²	Io
1	.050	1.02	.0510	.0520	.0010
2	.102	.286	.0292	.0083	.0041
3	.050	.10	.0050	.0005	—
4	.038	.025	.0010	0	—
5	.028	.13	.0036	.0005	.0002
6	.024	.52	.0125	.0065	.0003
7	.056	.90	.0504	.0454	.0004
8	.024	.52	.0125	.0065	.0003
9	.028	.13	.0036	.0005	.0002
10/2	.015	.025	.0004	—	—
	.415		.1692	.1202	.0065

NASA BOX BEAM ANALYSIS (CONT.)

$$\bar{Y} = \frac{.1692}{.415} = .4077$$

$$I_{TOT} = 2\left[.1202 + .0065 - .1692(.4077)\right]$$

$$= .1154 \text{ IN}^4$$

$$\rho = \left[\frac{I}{A}\right]^{1/2} = \left(\frac{.1154}{.830}\right)^{1/2} = .373$$

L' = STIFFNER SPACING = 4.8

$$\frac{L'}{\rho} = \frac{4.8}{.373} = 12.9$$

12.9 < 48.8 ∴ SHORT COLUMN FORMULA APPLIES

$$F_C = F_{CO}\left[1 - \frac{0.333\left(L'/\rho\right)}{\pi\sqrt{E/F_{CO}}}\right]$$

$$= 79{,}000\left[1 - \frac{.333\,(12.9)}{\pi\left[\frac{10.5\times10^6}{7.9\times10^4}\right]^{1/2}}\right]$$

$$= 49{,}500 \text{ PSI}$$

F_{CC} IS SLIGHTLY MORE CRITICAL

NASA BOX BEAM ANALYSIS (CONT.)

FAILURE LOADS ON ALUM. BOX BEAM -

$$f_b = F_{cc} = \frac{My}{I}$$

$M = 24\,P$

$Y = 10.0 - 5.244$

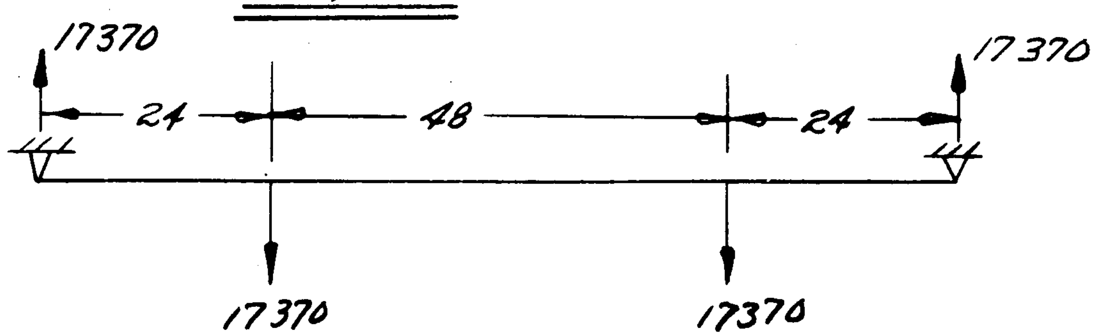
$\quad = 4.756$

$I = 40.36$

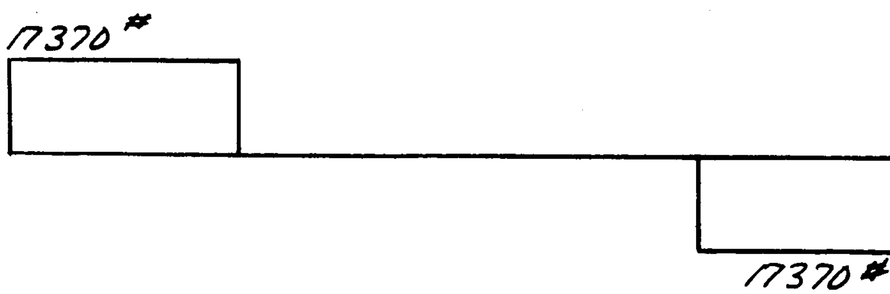
$$49{,}130 = \frac{24P(4.756)}{40.36}$$

$$P = \frac{49{,}130(40.36)}{24(4.756)}$$

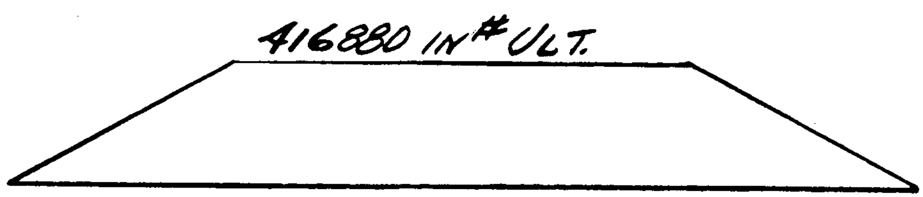
$$= 17{,}370\,\#\ \text{ULT.}$$



SHEAR



MOMENT



NASA BOX BEAM ANALYSIS (CONT.)

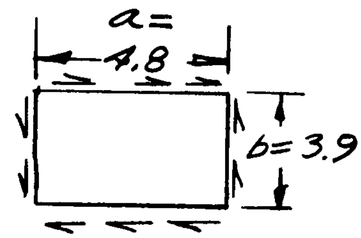
WEBS OF ALUMINUM BEAM:

$$f_s = \frac{V}{2ht} = \frac{17,370}{2(8.2)(.050)}$$

h = DISTANCE BETWEEN FLG. RIVET ℄'S

$$= 21,200 \text{ PSI}$$

$$F_{SCR} = KE\left(\frac{t}{b}\right)^2$$



$$a/b = \frac{4.8}{3.9} = 1.23$$

K_S = 7.1 (REF. FIG. 15.1, PEERY)

$$F_{SCR} = 7.1(10.3 \times 10^6)\left(\frac{.050}{3.9}\right)^2$$

$$= 12,000 \text{ PSI}$$

$$f_s / F_{SCR} = \frac{21,200}{12,000} = 1.765$$

F_{SW} = 32,000 PSI (REF. FIG. 15.16, PEERY)

F_{SW} = WEB SHEAR ALLOWABLE FOR SEMI-TENSION FIELD WEB

$$M.S. = \frac{32,000}{21,200} - 1$$

$$= \underline{\underline{+0.51}}$$

∴ BENDING IS MORE CRITICAL

APPENDIX F

BOX BEAM DIMENSIONAL INSPECTION AND FINAL WEIGHT

FIBERGLASS REINFORCED BOX BEAM

WEIGHT SUMMARY & DIMENSIONAL INSPECTION

BEAM SER. Nº 474-11749 (1)

WEIGHT WITHOUT DOUBLER:	30.03 POUNDS
WEIGHT WITH DOUBLER:	31.62 POUNDS

BEAM SER. Nº 474-11749 (2)

WEIGHT WITHOUT DOUBLER:	30.27 POUNDS
WEIGHT WITH DOUBLER	31.94 POUNDS

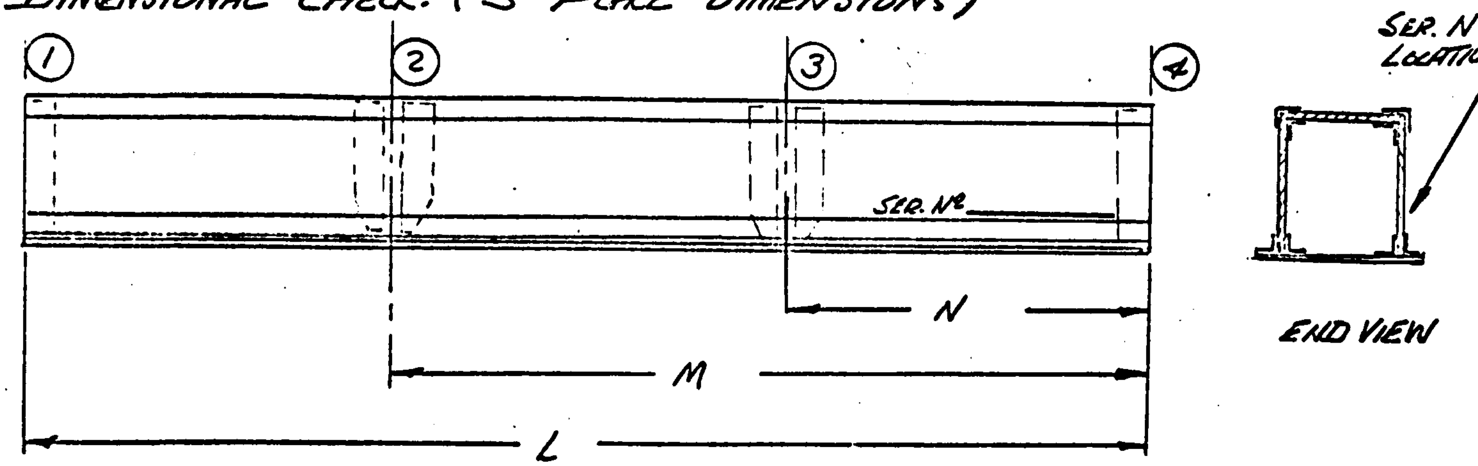
NOTE: THE THEORETICAL TOTAL WEIGHT OF THE BEAM IS 29.71 POUNDS (SEE PAGE 4)
EACH OF THE TWO BEAMS IS APPROXIMATELY 2 POUNDS OVER THE ESTIMATED WEIGHT OR 7 %,
THIS OVER WEIGHT CONDITION IS PRIMARILY ATTRIBUTED TO THE DIFFERENCE IN RESIN CONTENT.

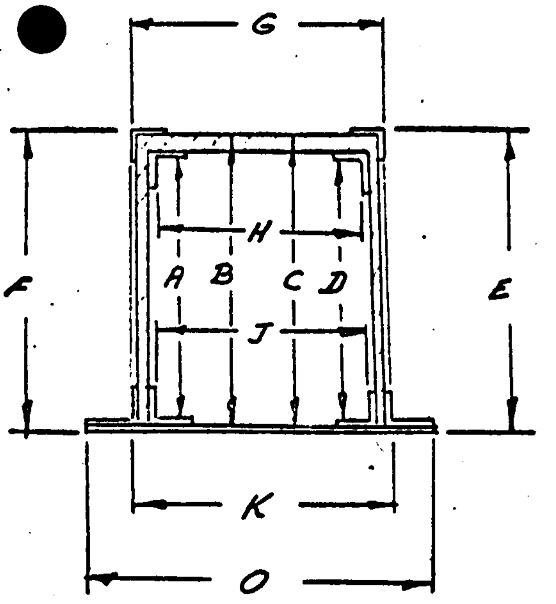
MJO 474 BOX BEAM PROGRAM (BEAM INSPECTION)

1) BEAM SER. Nº 474-11749 (1) INSPECTED BY PETER SANDOVAL

2) BEAM WEIGHT 13,620 GMS. DATE 1-6-65

3) DIMENSIONAL CHECK: (3 PLACE DIMENSIONS)





END VIEW

SECTION 1		SECTION 2		SECTION 3		SECTION 4	
A	9.392"					A	9.404"
B	9.996"					B	9.983"
C	9.982"					C	9.980"
D	9.394"					D	9.399"
E	10.116"	E	10.115"	E	10.117"	E	10.119"
F	10.112"	F	10.118"	F	10.120"	F	10.117"
G	8.143"	G	8.188"	G	8.171"	G	8.180"
H	7.376"					H	7.392"
J	7.360"					J	7.385"
K	8.139"	K	8.162"	K	8.165"	K	8.176"
O	9.614"	O	9.622"	O	9.611"	O	9.617"

L	95.95"
M	71.96
N	23.94"

4) VISUAL INSPECTION OF ALL GLUE LINES, NOTE ANY VOIDS OR POOR BOND AREAS. IF NONE, INDICATE NONE.

5) NOTE ANY AREAS WHICH EFFECT THE QUALITY OF THE BEAM FROM A STRUCTURAL STANDPOINT

MJO 474 BOX BEAM PROGRAM (BEAM INSPECTION)

MODIFICATION:

DOUBLER ADDITION TO UPPER SANDWICH PANEL

BEAM SER. Nº 474-11749 (1)

BEAM WEIGHT: 31.62 LBS.
(WITH DOUBLERS)

1) CHECK BEFORE BONDING:

INSIDE DOUBLER THICKNESS 0.0265"

OUTSIDE DOUBLER THICKNESS 0.0285"

2) VISUAL INSPECTION OF GLUE LINES:
INSIDE AND OUTSIDE DOUBLER
GLUE LINES APPEAR SATISFACTORY

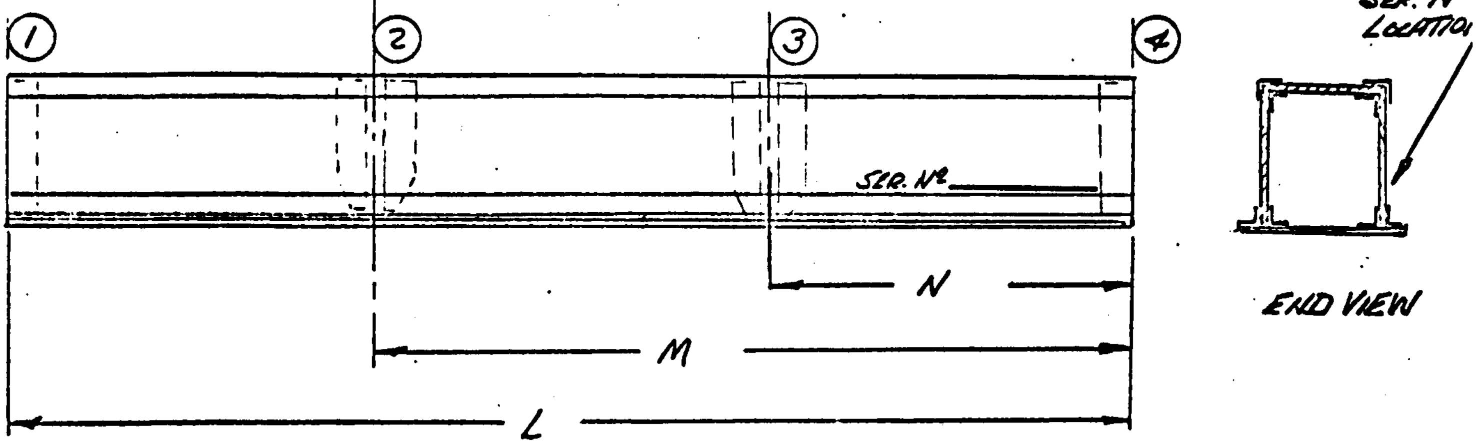
INSPECTED BY: Peter M. Sandorf
DATE: 2-16-65

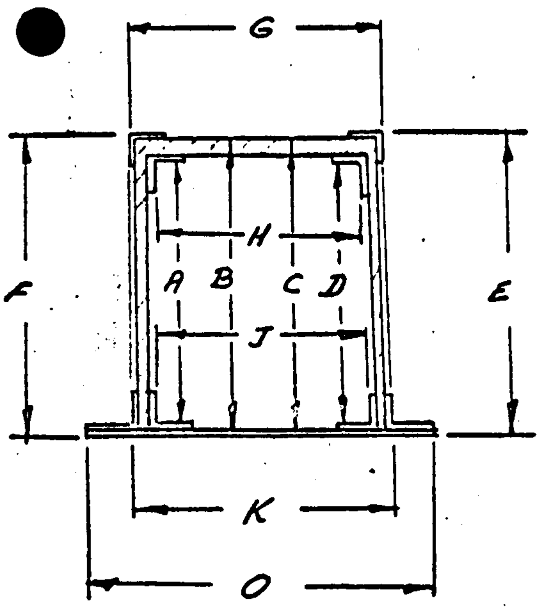
MJo 474 BOX BEAM PROGRAM (BEAM INSPECTION)

1) BEAM SER. Nº 474-11749 (2) INSPECTED BY Peter Sandavk[illegible]

2) BEAM WEIGHT 13,728 GMS. DATE 1-6-65

3) DIMENSIONAL CHECK: (3 PLACE DIMENSIONS)





END VIEW

	Section 1		Section 2		Section 3		Section 4
A	9.475"					A	9.383"
B	10.094"					B	9.956"
C	10.088"					C	9.996"
D	9.516"					D	9.452"
E	10.268"	E	10.216"	E	10.211"	E	10.202"
F	10.202"	F	10.155"	F	10.133"	F	10.115"
G	8.064"	G	8.060"	G	8.070"	G	8.065"
H	7.2[illegible]6"					H	7.274"
J	7.272"					J	7.304"
K	8.076"	K	8.073"	K	8.087"	K	8.087"
O	9.640"	O	9.538"	O	9.557"	O	9.546"

L	95.98
M	71.98
N	23.98

4) VISUAL INSPECTION OF ALL GLUE LINES, NOTE ANY VOIDS OR POOR BOND AREAS. IF NONE, INDICATE NONE.

5) NOTE ANY AREAS WHICH EFFECT THE QUALITY OF THE BEAM FROM A STRUCTURAL STANDPOINT

2 FEB 65

MJO 474 BOX BEAM PROGRAM (BEAM INSPECTION)

MODIFICATION:

DOUBLER ADDITION TO UPPER SANDWICH PANEL

BEAM SER. Nº 474-11749 (2)

BEAM WEIGHT: 31.94 LBS.
(WITH DOUBLERS)

1) CHECK BEFORE BONDING:

INSIDE DOUBLER THICKNESS 0.029"

OUTSIDE DOUBLER THICKNESS 0.026"

2) VISUAL INSPECTION OF GLUE LINES:
INSIDE AND OUTSIDE DOUBLER GLUE LINES ARE IN SATISFACTORY CONDITION.

INSPECTED BY: Peter M. Sandford

DATE: 2-16-65