(84)

NASA TECHNICAL
MEMORANDUM

REPORT NO. 53882

TITANIUM 8Al-Mo-IV CROSSBEAM REPAIR

By Ronald L. Nichols
Manufacturing Engineering Laboratory

September 12, 1969

NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER

INTERNAL NOTE

R-ME-IN-67-3

was changed to TM X-53882 on September 12, 1969

TITANIUM 8Al-1Mo-1V CROSSBEAM REPAIR

By

Ronald L. Nichols

MANUFACTURING ENGINEERING LABORATORY
RESEARCH AND DEVELOPMENT OPERATIONS

ACKNOWLEDGMENT

The welding, machining and chemical cleaning portions of this report were provided by personnel of the Manufacturing Engineering Laboratory's Welding Development Branch, Assembly Development Branch and the Chemical Processing Section, respectively. Information concerning the testing program was provided by the Launch Vehicle Section of the Propulsion and Vehicle Engineering Laboratory.

Particular recognition is due Mr. A. Bienert, Mr. L. Coker, Mr. G. Mincher and Mr. R. Sellers for their individual efforts in accomplishing this repair program. Special recognition is also due Mr. R. Denaburg who conducted metallurgical analysis of cracked areas and supplied technical information throughout the repair program.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Concluded)

LIST OF TABLES

TITANIUM 8Al-1Mo-1V CROSSBEAM REPAIR

SUMMARY

The propagation of cracks in the crossbeam member is attributed to non-homogeneous impurities or contaminants which result in unreliable areas of material. Tungsten impurities and relatively large voids are the contaminants found in the weld seams. The solution to this detrimental effect is obviously to eliminate the contamination. Skill in hand welding and utilization of optimum methods of machine welding 8-1-1 titanium are being developed in order to obtain dependable weld joints in future manufacture of complex titanium components.

INTRODUCTION

A structural member, simulating the crossbeam in the thrust structure of the S-IC vehicle, was manufactured from titanium alloy (8 percent aluminum, 1 percent molybdenum, 1 percent vanadium) by North American Aviation. The specific goals of this program were to develop the design and manufacturing parameters and to construct a titanium beam with load carrying capability equivalent to the current aluminum alloy center-engine supports used in the Saturn V vehicle.

A test program was initiated by the Propulsion and Vehicle Engineering Laboratory subsequent to completion of the above contract. The test program was designed to evaluate the performance of the beam under simulated flight load conditions. Prior to completion of this program, small cracks were noted at random locations in welded areas. A particularly heavy concentration of cracks was observed in the cable feed-through cylinder welds.

An agreement was reached between the Propulsion and Vehicle Engineering and the Manufacturing Engineering Laboratories to repair the defective areas. Two principal repairs were proposed. The first consisted of mechanically removing the cable feed-through ducts and replacing them with a patch butt welded into the sine wave webs. The second consisted of routing the cracks in other defective welds and rewelding by standard repair techniques. The procedures used and results obtained in making these repairs are outlined in this report.

HISTORY

North American Aviation was granted Contract NAS8-11768 to develop and construct a crossbeam for the S-IC thrust structure from the titanium alloy, 8Al-Mo-1V. The design of this member is shown in Figure 1. The specific purpose of this program was to determine the feasibility of fabricating and welding large structures of titanium alloy material. Subsequent to completing a portion of the program, the design was revised to include cable feed-through cylinders in the same positions as those on the aluminum crossbeam. This change was made to simulate more closely the aluminum structure which is presently flight hardware on the S-IC.

TESTING

A testing program has been initiated by the Propulsion and Vehicle Engineering Laboratory at Marshall Space Flight Center. The primary objective is verification of the structural integrity and spring rates of the critical design condition of the S-IC stage. The titanium test specimen, only a portion of a complete crossbeam, consists of one complete member and stub ends of the other member.

The applied test loads will be only those which would be carried by the complete member. The stub ends serve to provide lateral and rotational stability to the loaded member. The length of the beam is 9.677 meters (381 in.) and the height is 2.073 meters (81.6 in.). The total length of the stub ends is 3.048 meters (120 in.)

The following limit loads are to be applied to the crossbeam in five test conditions:

a. F1-Engine thrust carried by one-half of the crossbeam

b. F2-Engine thrust transmitted to the crossbeam through the alignment strut

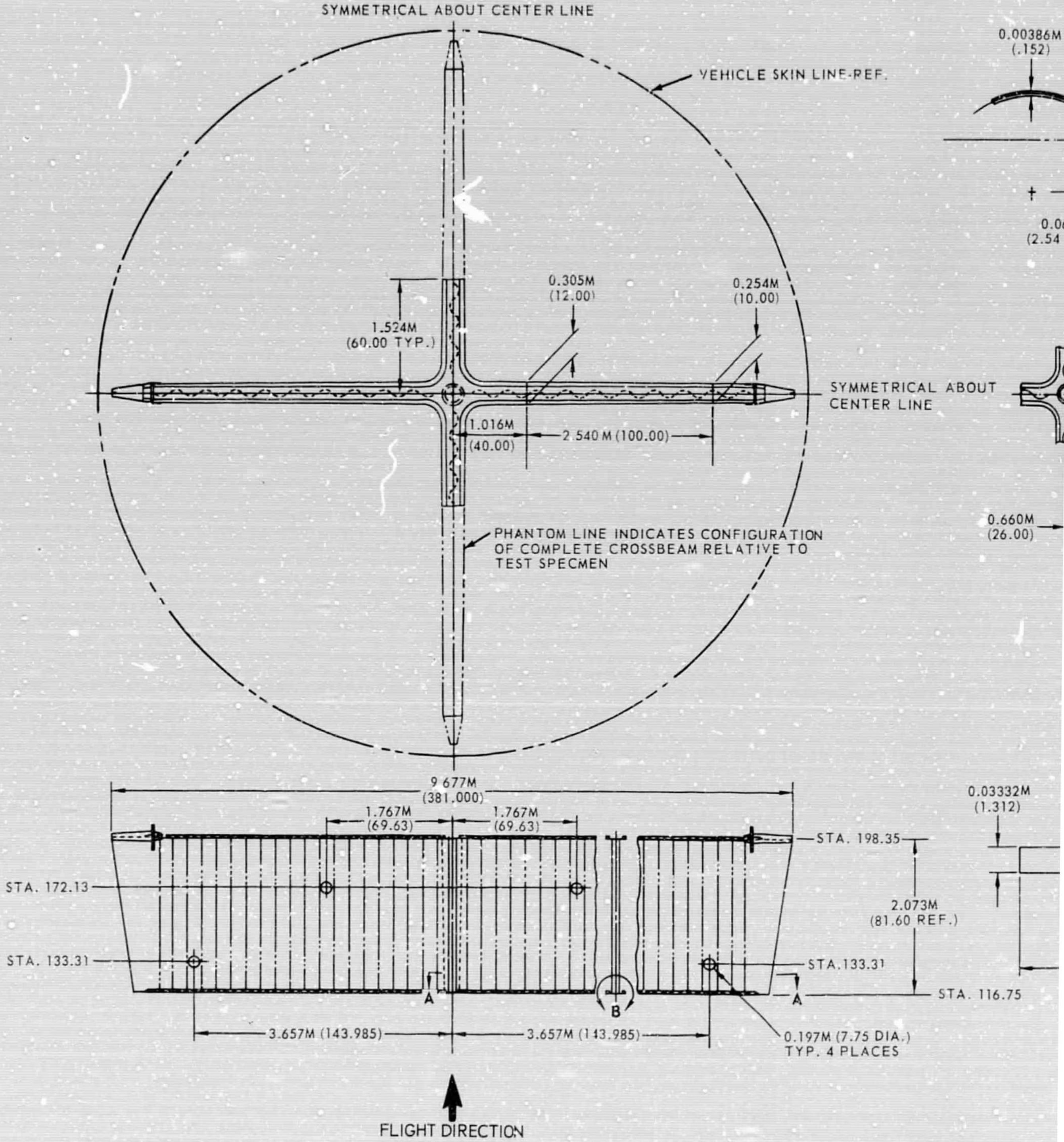
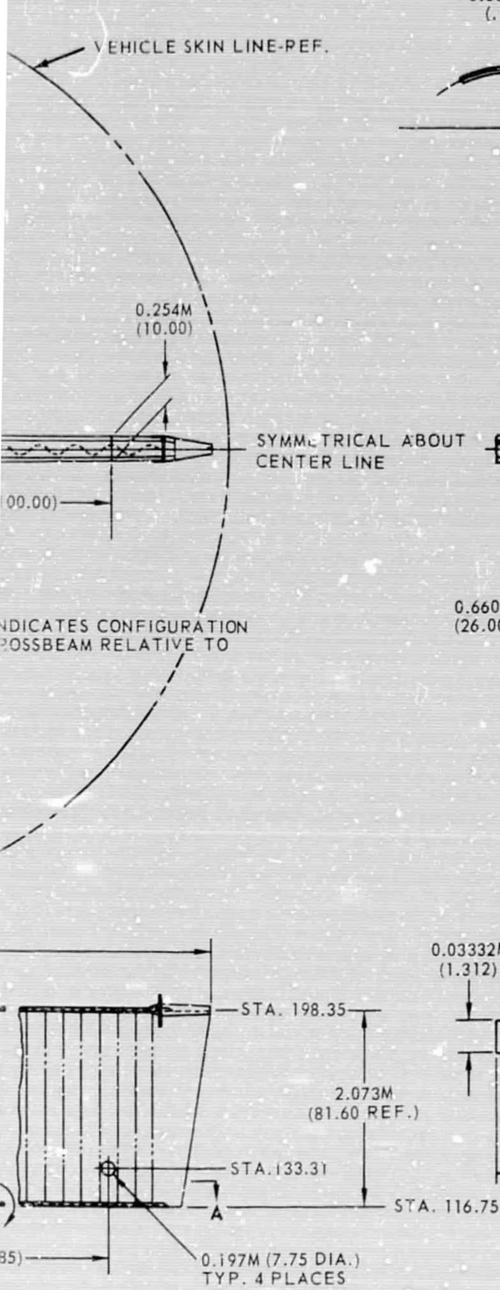
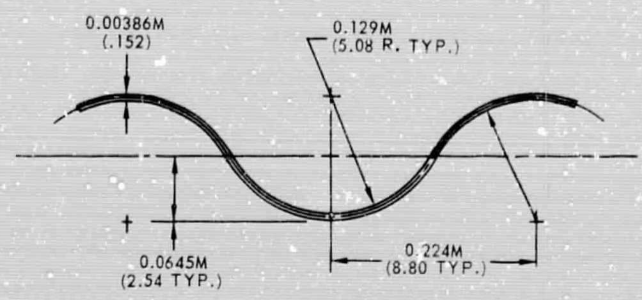


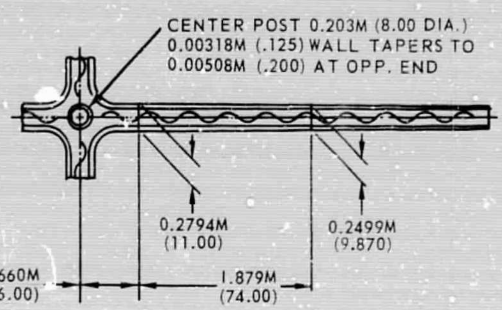
FIGURE 1. TEST SPECIMEN DETAIL

FOLDOUT FRAME 1

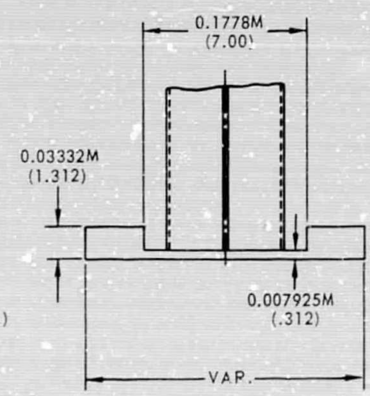




DETAIL CORRUGATED WEB



SECTION A-A



DETAIL B

MATERIAL PROPERTIES

8 AL-1 MO-IV TITANIUM (COND A)
LB 0170-177

$F_{TU} = 9.31 \times 10^8 N/M^2$ (135000 LBS./IN.^{2})

$F_{TY} = 8.62 \times 10^8 N/M^2$ (125000 LBS./IN.^{2})

$F_{CY} = 9.31 \times 10^8 N/M^2$ (135000 LBS./IN.^{2})

$F_{SU} = 6.21 \times 10^8 N/M^2$ (90000 LBS./IN.^{2})

$E = 1.24 \times 10^{10} N/M^2$ (18.0×10^6 LBS/IN.^{2})

$G = 4.55 \times 10^{10} N/M^2$ (6.6×10^6 LB./IN.^{2})

DENSITY 4.379 GM/CC (.158 LBS./IN.^{3})

MINIMUM GUARANTEED VALUES

STRESS RELIEVED AFTER WELDING

$F_{TU} = 7.93 \times 10^8 N/M^2$ (115000 LBS./IN.^{2})

$F_{TY} = 7.24 \times 10^8 N/M^2$ (105000 LBS./IN.^{2})

$F_{CY} = 7.86 \times 10^8 N/M^2$ (114000 LBS./IN.^{2})

$F_{SU} = 5.24 \times 10^8 N/M^2$ (76000 LBS./IN.^{2})

REF: N.A.A. REPORT NA-64-1153
NOV. 1, 1964

GURE 1. TEST SPECIMEN DETAIL

FOLDOUT FRAME 2

PRECEDING PAGE BLANK NOT FILMED.

c. F3-F4-Loads resulting from propellant V1, V2 lines support M1-M2 brackets

d. T-Engine induced torque load carried by one-half of the crossbeam

e. M3-M4-Loads which provide the constraints at the beam ends as induced by the thrust structure.

For each test condition, loads are to be applied simultaneously in percent increments of limit loads. Loads will be applied to the 140 percent limit load for test conditions I, II, III and IV. Test condition V loads will be to 200 percent limit load or to failure, whichever occurs first. The load schedule is shown in Table 1.

CRACK ANALYSIS

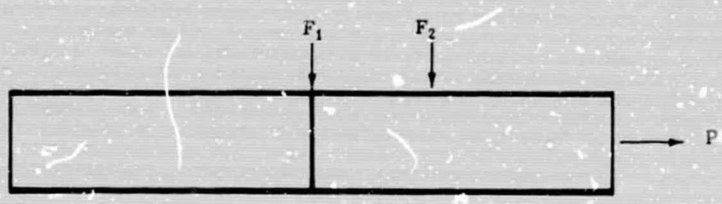
Subsequent to applying 40 percent maximum testing load, several cracks appeared on the crossbeam. After discovery of one large crack, dye penetrant was used for inspection of all weld seams and areas adjacent to welds. This inspection revealed cracks in weld seams on the periphery of three of the four cylindrical inserts. Also, cracks were observed in three positions along the burn-through welds and in one area on a vertical weld seam.

Microstructural analysis of the cracks in the vertical seams and burn-through welds indicates that the defects propagated from tungsten impurities or porosity in the welds, as shown in Figures 2 and 3.

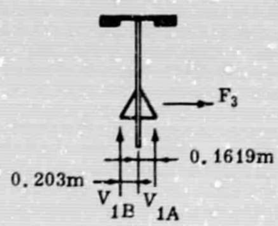
Cracks around the insert cylinders are attributed to a form of embrittlement. An α phase is observed in Figure 4 on the surface of the titanium removed from the crossbeam. The bright phase along the surface is the α phase. The presence of this phase indicates that embrittlement resulted from an influx of impurities into the titanium. The major crack shown in Figure 5 is surrounded by smaller microcracks. This type of fracture, characteristic of brittle materials, was evidently caused from a loss of ductility in the titanium.

TABLE I. LOAD SCHEDULE

Load	Cylinder Description	Push Pull	Area m^2 ($in.^2$)	Limit Load N (lb)	Pressure N/m^2 (psi)	Test Condition
F_1	0.762 m (30 in.) Bore Regent	Push	0.4554 (706.86)	3.95×10^6 (888,000)	8.66×10^6 (1256)	All
F_2	0.1778 m (7 in.) Bore Miller	Push	0.0248 (38.48)	[illegible]$.09 \times 10^5$ (47,000)	8.42×10^6 (1221)	II, III, IV, V
P	0.254 m (10 in.) Bore Miller	Pull	0.0353 (54.78)	3.34×10^5 (75,000)	9.44×10^6 (1369)	All



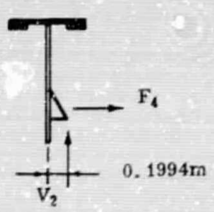
F_3	0.02857 m(1-1/ in.) Bore Tom Thumb	Pull	0.000571 (0.885)	2.11×10^3 (475)	3.70×10^6 (537)	II, III, IV
V_{1A}	0.0508 m (2 in.) Bore Miller	Push	0.00202 (3.14)	2.070×10^4 (4,656)	1.022×10^7 (1483)	II, III, IV
V_{1B}	0.152 m (6 in.) Bore Miller	Push	0.0182 (28.26)	1.229×10^5 (27,644)	6.805×10^6 (978)	II, III, IV



$$V_{1A} + V_{1B} = V_1$$

$$[illegible] \cdot V_{1B} - 7.628 \cdot V_{1A} = M_1$$

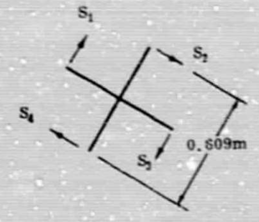
F_4	0.0285 m (1-1/8 in.) Bore Tom Thumb	Pull	0.000571 (0.885)	2.562×10^3 (576)	4.481×10^6 (650)	II, III, IV
V_2	0.1016 m (4 in.) Bore Miller	Push	0.00810 (12.56)	9.029×10^4 (20,300)	1.116×10^7 (1618)	II, III, IV



$$7.85 \cdot V_2 = M_2$$

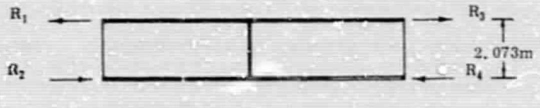
TABLE I. LOAD SCHEDULE (Concluded)

Load	Cylinder Description	Push / Pull	Area m^2 ($in.^2$)	Limit Load N (lb)	Pressure N/m^2 (psi)	Test Condition
S_{1-4}	0.08255 m ($3\frac{1}{4}$ in.) Bore Miller (4)	Pull	0.003315 (5.14)	3.039×10^4 (6833)	9.232×10^6 (1339)	III, V



$2 \cdot 24 \cdot S =$ Torque, T

Load	Cylinder Description	Push / Pull	Area m^2 ($in.^2$)	Limit Load N (lb)	Pressure N/m^2 (psi)	Test Condition
R_1	0.254 m (10 in.) Bore Hydroline (2)	Pull	0.0404 (62.64)	6.343×10^4 (14,261)	1.570×10^7 (2277)	I
				6.148×10^4 (13,822)	1.52[illegible] $\times 10^7$ (2206)	II, III, V
				6.587×10^4 (14,819)	1.630×10^7 (2364)	IV
R_2	0.254 m (10 in.) Bore Hydroline (2)	Push	0.05067 (78.54)	6.343×10^4 (14,261)	1.251×10^7 (1815)	I
				6.148×10^4 (13,822)	1.213×10^7 (1760)	II, III, V
				5.587×10^4 (14,810)	1.300×10^7 (1885)	IV
R_3	0.254 m (10 in.) Bore Hydroline (2)	Pull	0.0404 (62.64)	6.343×10^4 (14,261)	1.570×10^7 (2277)	I
				6.518×10^4 (14,654)	1.613×10^7 (2339)	II, III, V
				6.734×10^4 (15,140)	1.666×10^7 (2417)	IV
R_4	0.254 m (10 in.) Bore Hydroline (2)	Push	0.05067 (78.54)	6.343×10^4 (14,261)	1.251×10^7 (1815)	I
				6.518×10^4 (14,654)	1.286×10^7 (1865)	II, III, V
				6.734×10^4 (15,140)	1.329×10^7 (1928)	IV



$2 \cdot 81.6 \cdot R_1 = M_3$

$2 \cdot 81.6 \cdot R_3 = M_4$

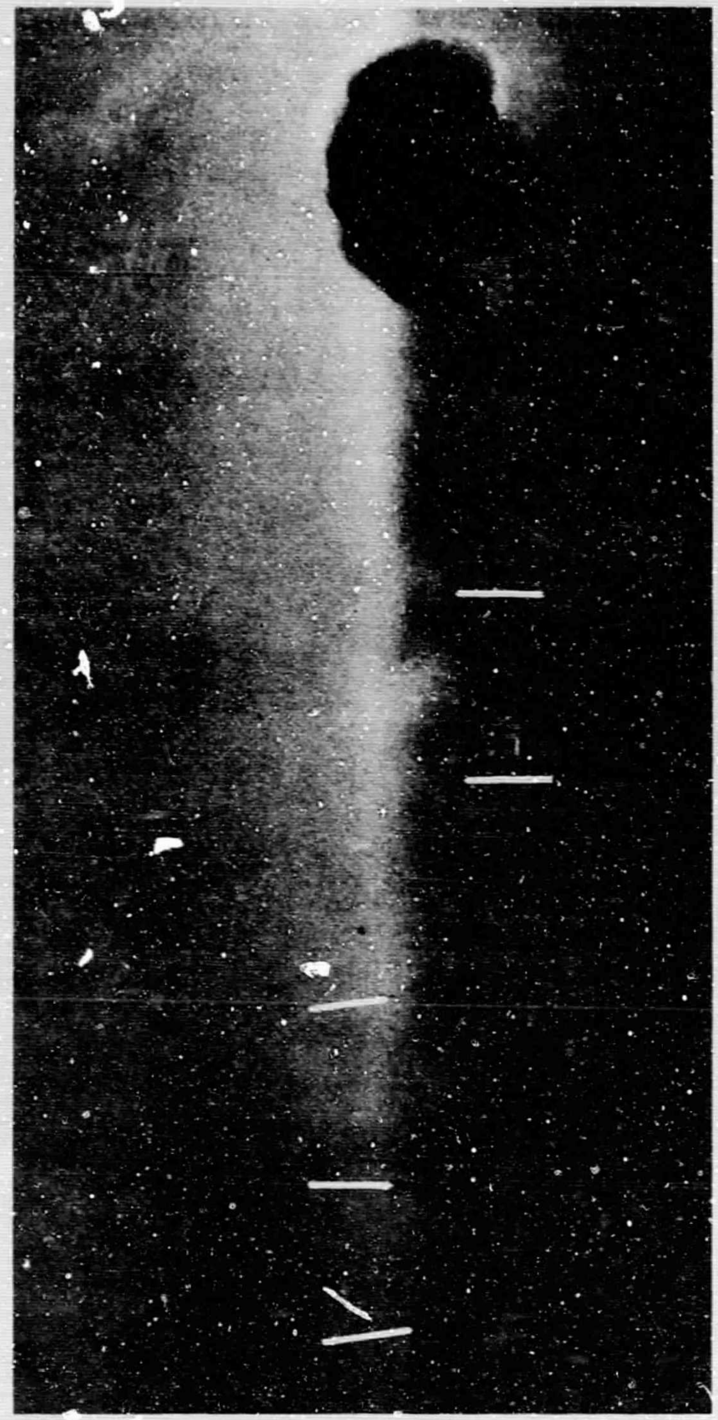


FIGURE 2. VERTICAL SEAM WELD WITH LARGE AMOUNT OF RESIDUAL TUNGSTEN IMPURITY DEPOSITED FROM THE WELDING ELECTRODE

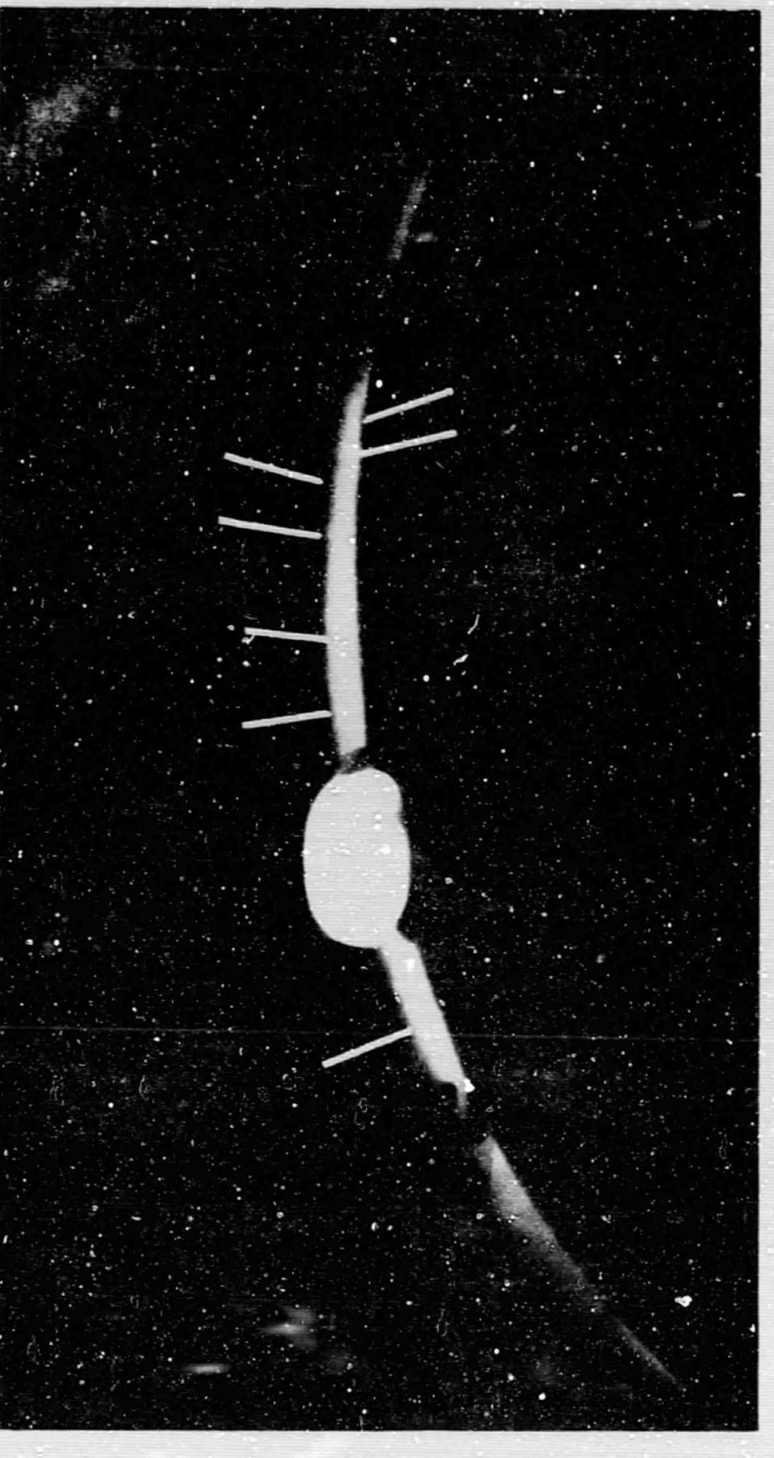


FIGURE 3. INCLUSIONS ON THE BOTTOM BURN-THROUGH WELD. NOTE THE TAILS EXTENDING FROM SEVERAL OF THE PORES

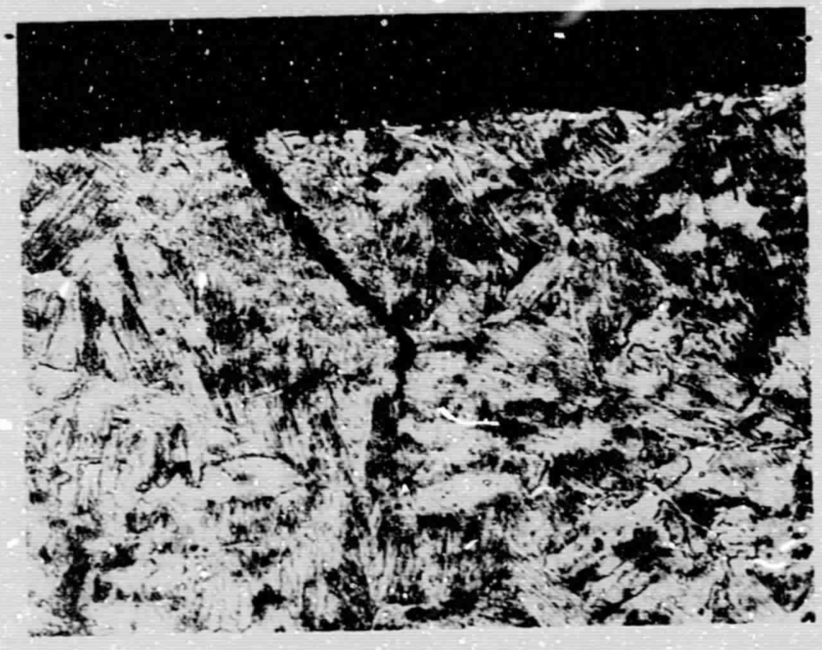


FIGURE 4. PHOTOMICROGRAPH OF α PHASE ALONG SURFACE

FIGURE 5. PHOTOMICROGRAPH OF BRITTLE FRACTURE

REPAIR

Machining and Cleaning

A method of repair was selected by joint action of the Propulsion and Vehicle Engineering and the Manufacturing Engineering Laboratories. The cable feed-through cylinders were removed by drilling a series of intersecting holes around each cylinder (Figs. 6 and 7.) Material for replacing the removed sections was obtained from test pieces of the 8-1-1 titanium alloy, formed to the sine wave configuration. This material was duplex annealed so that its metallurgical characteristics closely approximate those of the material in the cross-beam. The duplex annealing process is a heat treatment of 1003°K (1450° F) for 15 minutes followed by air cooling. This is in addition to the mill anneal.

The replacement parts were degreased before application of Turco pre-treat coating, an oxidation inhibitor. Subsequent to heat treatment, the oxide was removed in a 15 to 20 percent HNO_3 and 1 to 1.5 percent HF pickling bath at 308°K (95°F). The parts were submerged in this bath 15 minutes, removed, and then washed with a high pressure water spray. A small amount of etching was obtained during the process.

Each titanium replacement panel was placed against its respective hole, and a line was scribed on the part indicating the shape of the hole. The four panels were milled along the scribe line allowing an 0.254 millimeter (0.010 in.) oversize. The parts were then hand fitted to the beam by grinding the edges with a hand grinder. Panel 1 was fitted to its hole with 0.508 millimeter (0.020 in.) clearance between each side of the part and the walls of the hole. Panels 2, 3 and 4 were hand fitted with 1.016 millimeter (0.040 in.) clearance on each side to achieve better penetration during welding. Prior to welding, a jacking system (Fig. 8) was fabricated to maintain horizontal alignment of the beam at the positions where the cylinders were removed.

Welding

Upon completion of the machining processes, preparation began for welding the replacement parts into their respective positions. Strap clamps were utilized to ensure rigid placement of each part in position for welding as shown in Figure 9. The straps are cleaned in the same manner as the beam. The beam was prepared for welding by a combination of chemical and mechanical cleaning. It was hand cleaned with a 35 percent nitric acid and 5 percent hydrofluoric acid pickling solution and mechanically cleaned with a wire brush.

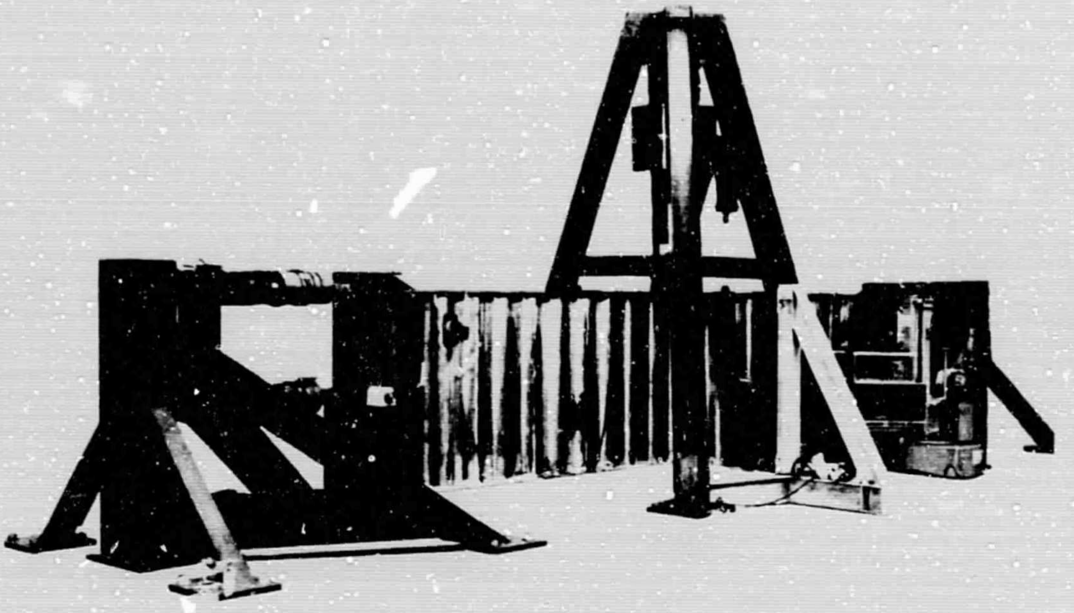


FIGURE 6. COMPLETE CROSSBEAM AND TESTING FIXTURE WITH ONLY ONE CYLINDER REMAINING

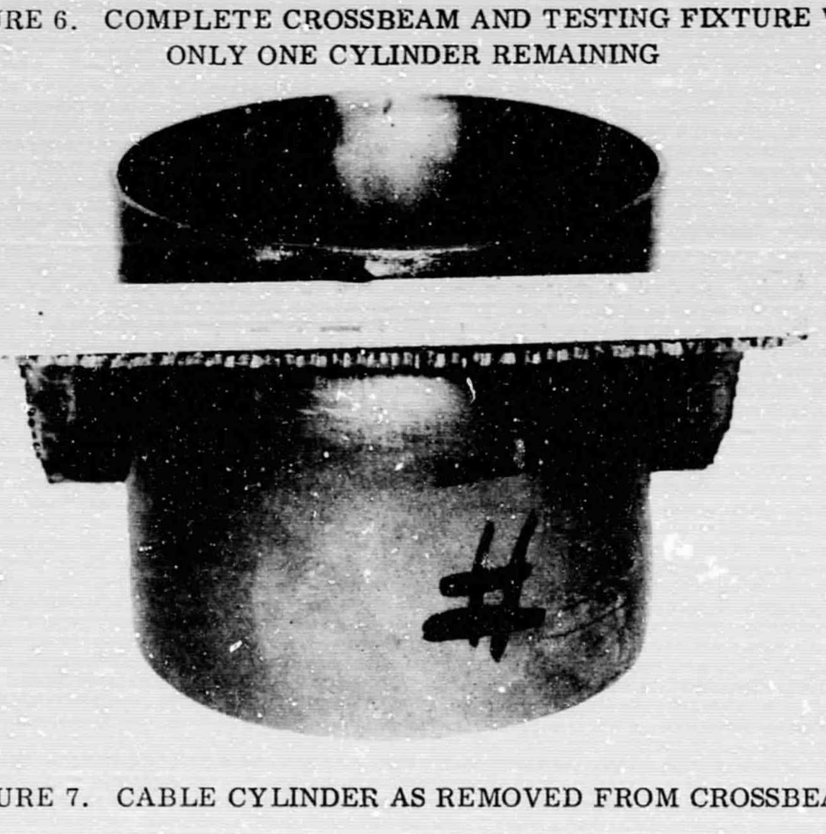


FIGURE 7. CABLE CYLINDER AS REMOVED FROM CROSSBEAM

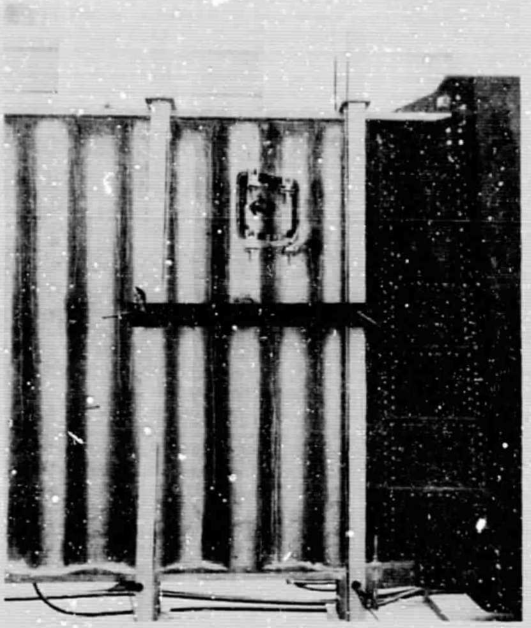


FIGURE 8. CROSSBEAM SECTION SHOWING JACKING SYSTEM USED TO ELIMINATE HORIZONTAL DEFORMATION DUE TO THE WEIGHT OF THE BEAM

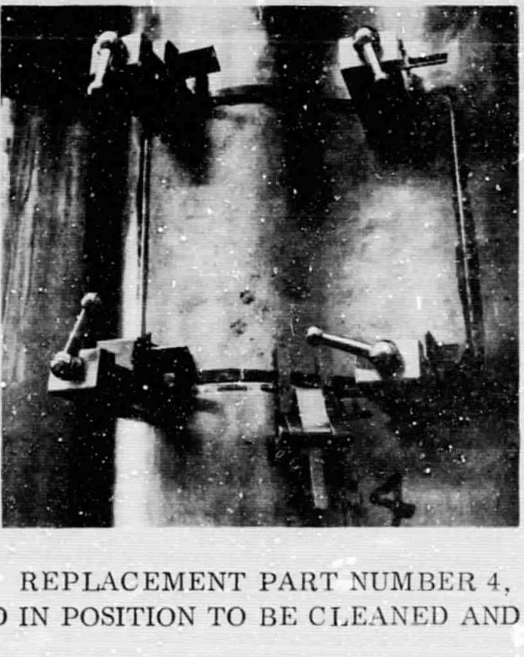


FIGURE 9. REPLACEMENT PART NUMBER 4, PRECISELY PLACED IN POSITION TO BE CLEANED AND WELDED

After the parts were thoroughly cleaned and precisely fit to the beam with little or no mismatch, a plastic bag completely covering the area to be welded was taped on each side of the beam, as shown in Figure 10. The bag

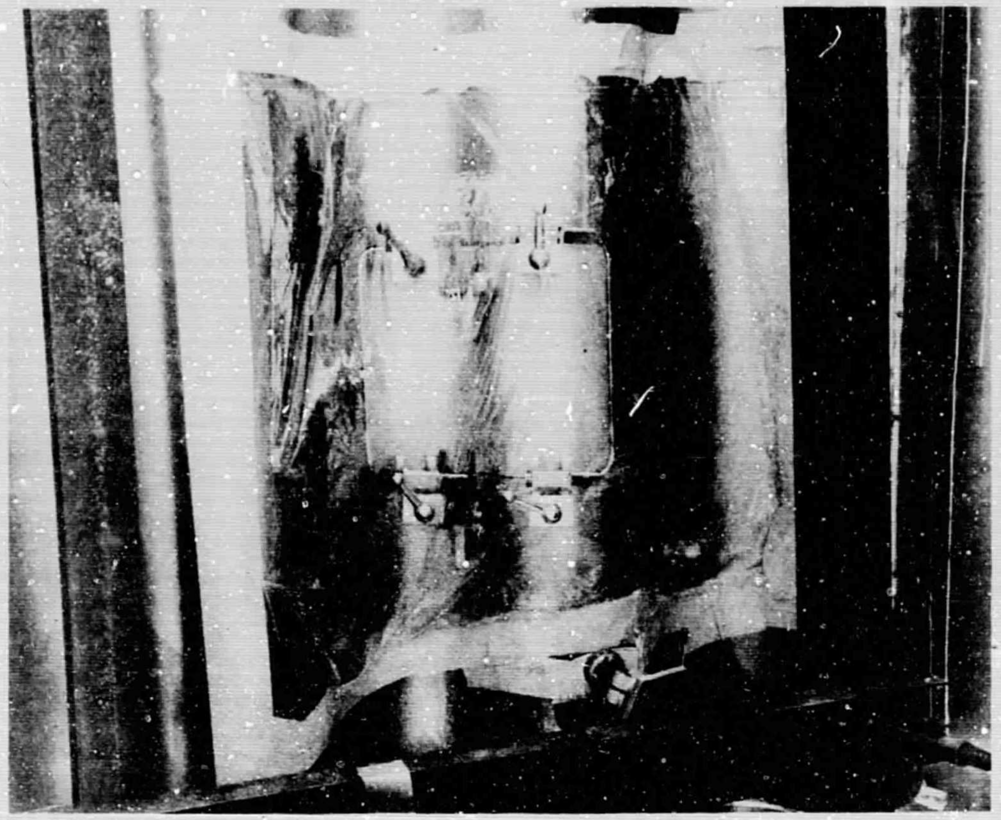


FIGURE 10. REPLACEMENT PANEL IN POSITION TO BE WELDED - CLEANING AND BAGGING IS COMPLETE

was purged with argon for a period of one hour to remove all oxygen and hydrogen from the bagged area. A tungsten electrode and titanium filler rod was inserted through the bag to the welding area for use with TIG welding equipment. Welding in this manner is slow because of the limited area that can be welded without repositioning the electrode in the bag.

All four corners of the panel were tacked as an initial welding step. One side of the patch was completely welded into place obtaining as good penetration as possible. The bagging was then removed from the side opposite the weld and the groove routed to remove all inclusions in the penetrated weld. This side of the patch was again bagged and purged. It was then welded in the same manner as the previously welded side.

Each weld was X-ray analyzed with a portable X-ray machine. If unacceptable porosity was found, the weld around the inclusion was removed and the area welded again. This process continued until the weld was found acceptable. Unacceptable porosity or impurities were those with a diameter greater than 1.60 millimeter (0.040 in.)

Figures 11 through 15 show the finished repair panels and filler welds.

CONCLUSIONS

The repair welds were completed with no apparent oxide contamination because the welding area was completely bagged with an inert gas-filled diaphragm. X-ray analysis indicates that all repair areas are acceptable. No unacceptable porosity or impurity appeared during the repair procedure; therefore, no repair weld required removal and replacement.

FIGURE 11. COMPLETELY WELDED REPAIR PANEL NUMBER 1

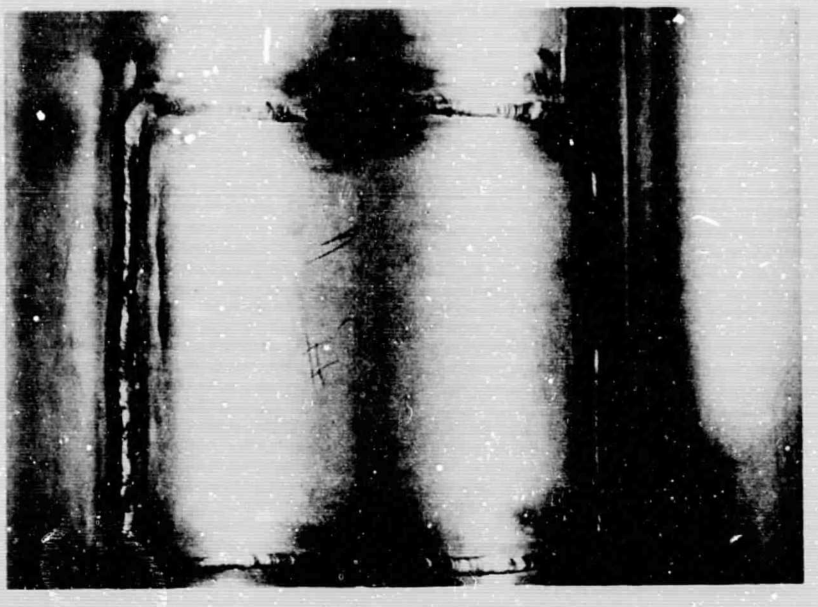


FIGURE 12. REPAIR PANEL NUMBER 2 AFTER COMPLETION

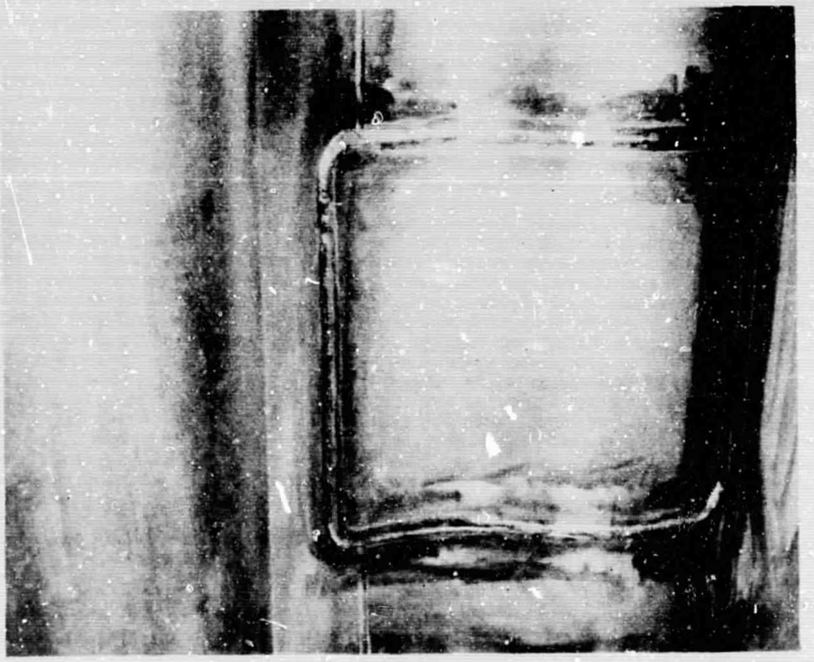


FIGURE 13. REPAIR PANEL NUMBER 3 WELDED INTO POSITION

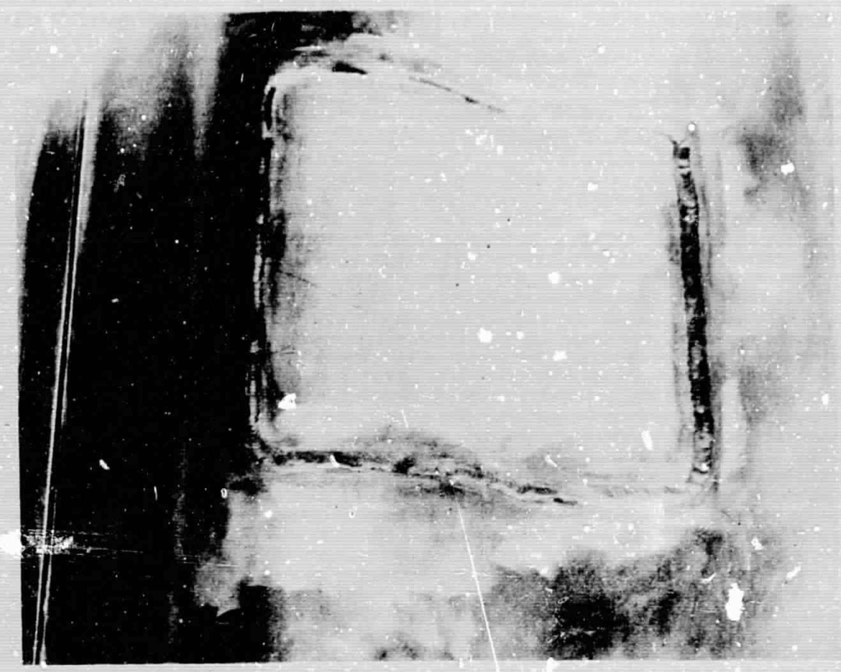


FIGURE 14. REPAIR PANEL NUMBER 4 COMPLETED

FIGURE 15. REPAIR WELDS AFTER REMOVAL OF TUNGSTEN IMPURITIES AND INCLUSIONS