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DEVELOPMENT OF THE ALL-WELDED COMMON BULKHEAD

MONTHLY REPORT

1 NOVEMBER - 30 NOVEMBER 1964
DOUGLAS ~~REPORT~~ SM-48094

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MISSILE & SPACE SYSTEMS DIVISION
DOUGLAS AIRCRAFT COMPANY, INC.
SANTA MONICA/CALIFORNIA

DOUGLAS

DEVELOPMENT OF THE ALL-WELDED COMMON BULKHEAD

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PREPARED FOR
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION,
GEORGE C. MARSHALL SPACE FLIGHT CENTER
CONTRACT NO. NAS 8-11696

APPROVED BY
A.C. ROBERTSON
MANAGER
ALL-WELDED COMMON
BULKHEAD PROJECT

PREFACE

This is the fifth monthly progress report on the program for "Development of the All-Welded Common Bulkhead." This work is being done for the National Aeronautics and Space Administration, George C. Marshall Space Flight Center, Huntsville, Alabama, under Contract Number NAS 8-11696, dated 30 June 1964. This report covers the period from 1 November through 30 November 1964.

CONTENTS

Section 1
INTRODUCTION

The objective of this program is to develop an alternate manufacturing concept in which both faces of the common bulkhead are simultaneously welded from honeycomb sandwich segments to simplify manufacturing of common bulkheads for Saturn V upper stages. The general approach that will be followed is to fabricate gore segments and a dollar segment (skins plus core) and simultaneously weld the inside and outside seams for all welds (the meridian weld, the dollar weld, and the bulkhead attach-angle weld). Simultaneous welding of the inside and outside skins is essential to the minimization or elimination of distortions.

The program will follow a three-phase approach.

> Phase I - Joint Design and Development--The objective of Phase I of the program is to thoroughly analyze the theoretical and practical aspects of the all-welded segmented bulkhead concept and to develop the attendant fabrication and inspection processes and techniques.
>
> Phase II - Manufacturing and Test of the 18-Ft. Bulkhead--The objectives of Phase II are (1) design, fabrication, and modification of manufacturing tools and (2) fabrication and inspection of a common bulkhead 18 ft. in diameter.
>
> Phase III - Preparation of the Test Plan and Manufacturing Specifications--The objectives of Phase III are (1) preparation of a bulkhead test plan to establish the reliability of the all-welded bulkhead with bonded honeycomb core and (2) initiation of manufacturing specifications to define the manufacturing techniques and limitations that will be used for the manufacture of the 18-ft.-dia. bulkhead.

The following sections of this report describe the work accomplished to date (Section 2) and the work planned for the coming month (Section 3). Within each of these sections, the discussions are arranged according to the phases and tasks outlined in the contract work statement. The accomplishments for the report period and the results obtained are discussed and those results are analyzed and interpreted. The problems encountered and their possible effects on the performance of the program are also discussed, along with proposed corrective actions.

The purpose of this report is to describe the progress that has been made on the program during the past month.

Section 2

WORK ACCOMPLISHED DURING REPORT PERIOD

The schedule for the entire program is shown in Figure 1. The solid black bars represent the progress to date on each task. Only Task 1.2.1, Flat-Panel Tests; Task 1.2.2, Sandwich-Panel Tests; and Task 1.4, Establishment of Manufacturing Plan were scheduled to be under way at this time. As of 1 December 1964, as shown in Figure 1, Tasks 1.2.1 and 1.4 were on schedule, Task 1.2.2 was three weeks ahead of schedule, and Task 1.2.1.5 was completed. As indicated in last month's report, Task 1.2.1.7 is complete.

The progress to date is discussed in more detail in the following paragraphs, which are arranged according to the task numbers shown in Figure 1.

Task 1.2.1--Flat-Panel Tests

Photomacrographs were prepared from specimens of TIG welds (Configuration B, integral chill), using a grooved joint and added filler metal. These specimens, which include several variations in tooling and fit-up conditions, are shown in Figure 2. Photomacrographs were also prepared from specimens of TIG welds (Configuration D, backing strip). Three such photomacrographs, showing typical defects, make up Figure 3.

MIG weld tests in Configuration D (backing strip) have been completed. Welds were prepared with varying degrees of fit-up between the workpiece and the backing strip. Nondestructive testing indicated that the joint is unsuitable for fabricating the all-welded common bulkhead. Porosity, even under ideal fit-up conditions, was prohibitive. Furthermore, where poor fit existed between the test parts and the backup strip, excessive penetration through the backup strip occurred, causing underbead suckback. Problems related to the tooling of three-joint pieces rather than two (experienced with the TIG process in this joint) were similar to these MIG weld tests. Further testing in this joint was discontinued. Table I summarizes welding conditions and procedures and

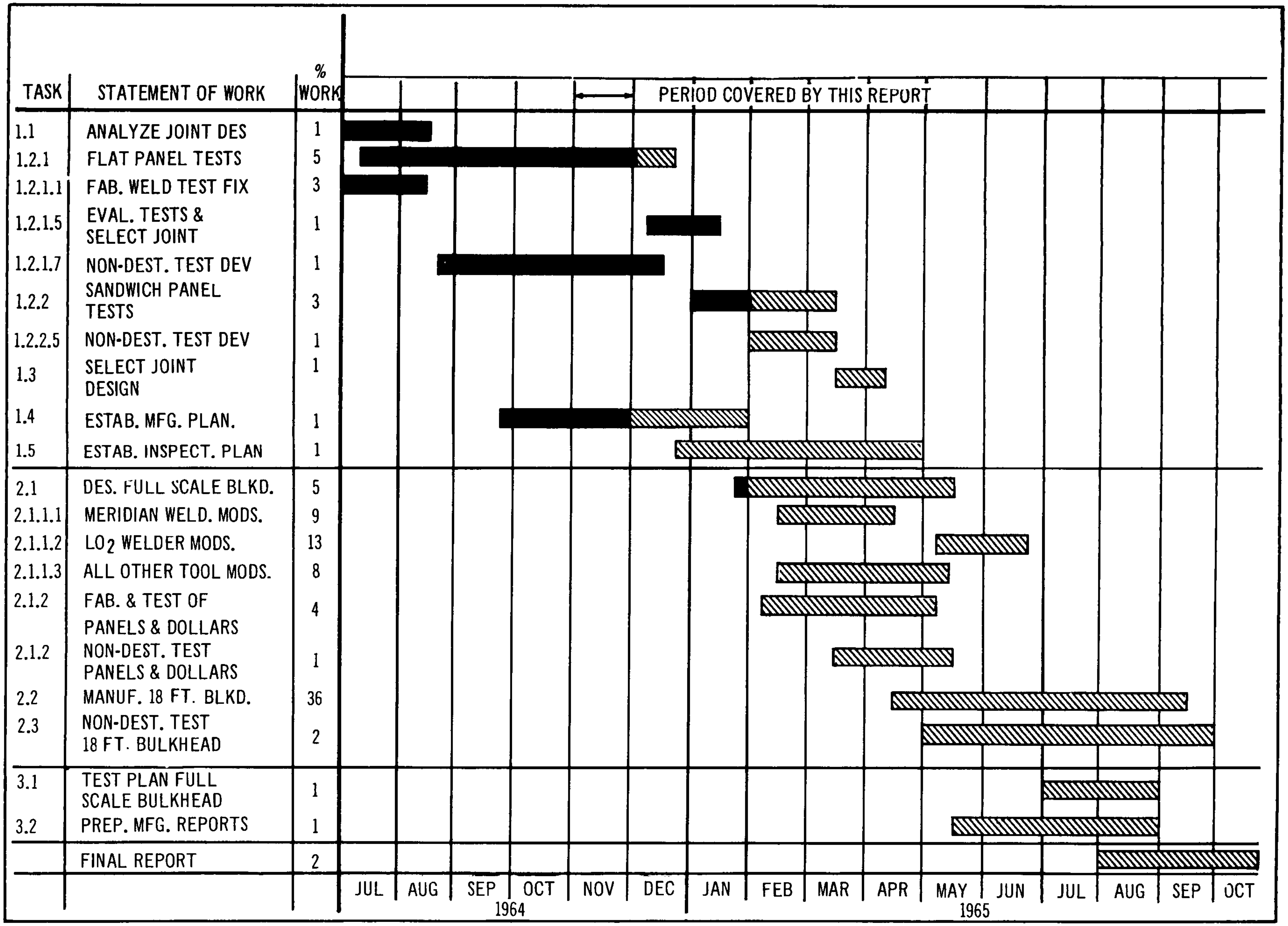
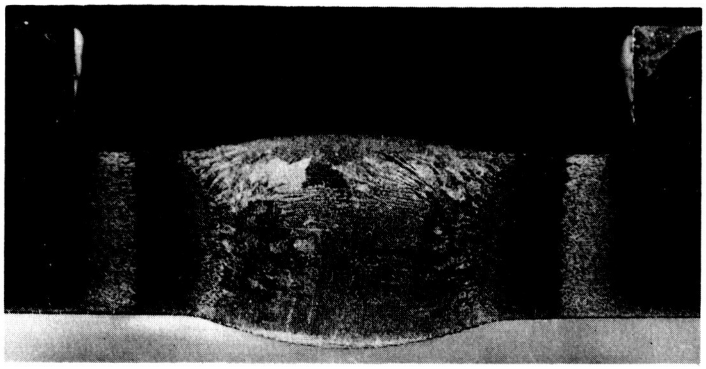
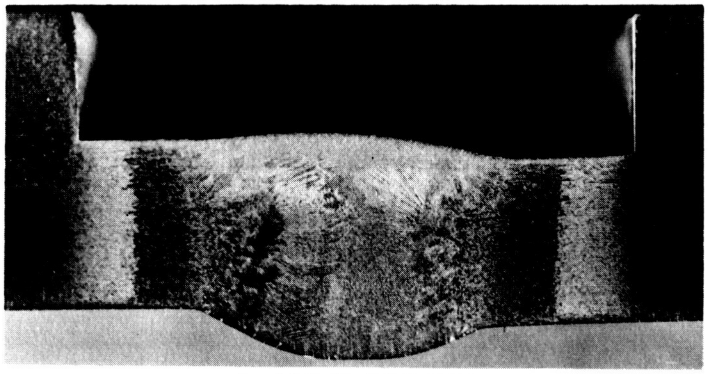


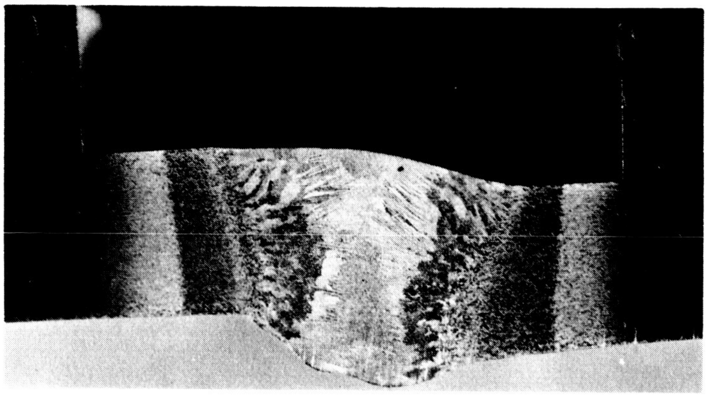
Figure 1 Task Progress Report



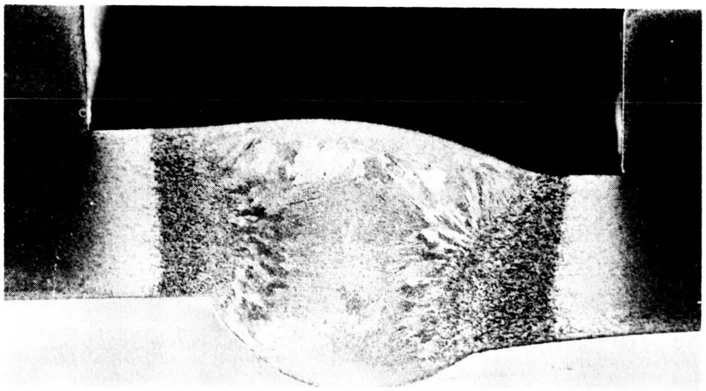
A. TYPICAL WELD



B. 0.025-IN. MISMATCH

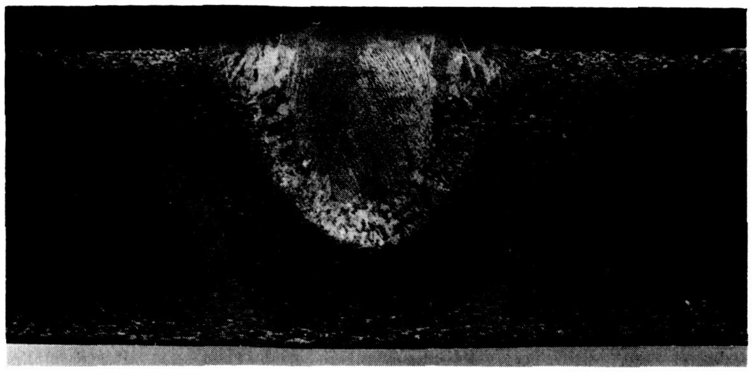


C. 0.060-IN. MISMATCH, AS-WELDED

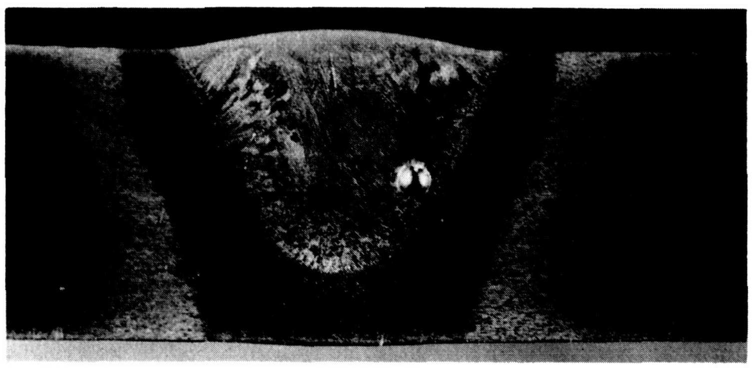


D. 0.060-IN. MISMATCH, REWELDED (2 PASSES)

Figure 2 6X Photomacrograph of Vertical-Position Tig Welds in 1/4-In. 2014-T6 Aluminum Alloy (Tig, Configuration B) (Keller's Etch)

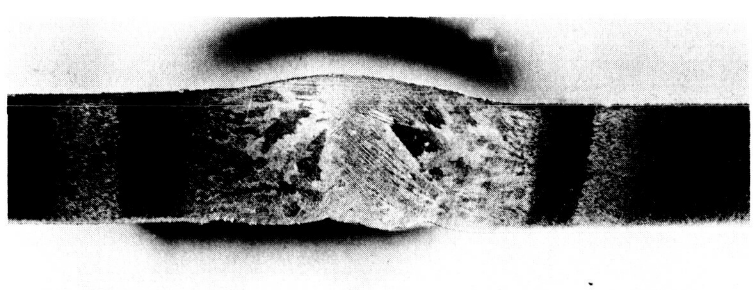


A. TYPICAL WELD



B. 0.020-IN. GAP BETWEEN TEST PLATES. TIGHT FIT WITH BACKING STRIP

(TOP)



(BOTTOM)

C. 0.020-IN. MISMATCH BETWEEN TEST PLATES AND BACKING STRIP (NOT SHOWN). WELD DID NOT FUSE TO BACKING STRIP, RESULTING IN UNDERBEAD SUCKBACK

Figure 3 5X Photomacrographs of Vertical-position Tig Welds in 1/8-In. 2014-T6 Aluminum Alloy With 1/8-In. 2014-T6 Backing Strip (Tig, Configuration D) (Keller's Etch)

Table I

SUMMARY OF WELDING PROCEDURES AND OPERATING CONDITIONS, AND NONDESTRUCTIVE INSPECTION RESULTS FOR VERTICAL MIG WELDS IN 1/8-IN. 2014-T6 ALUMINUM ALLOY WITH A 1/8-IN. BACKING STRIP

Joint:	MIG, backed (butt-strap) (Figure 6, SM-48068*)
Equipment:	Linde Missile Maker, MIG-TIG SEH-2 welding head (Linde) ST-5 torch No. 8 (5/8-in. I.D.) nozzle Vertical position fixture (Figure 4, SM-48068*)
Shielding Gas:	Argon plus 0.1% oxygen (Linde)
Filler Wire:	3/64-in.-dia. 4043 (Linde HQ)
Cleaning:	Chem-etch followed by stainless steel wire brush. Abutting edges draw filed.
Torch Angle:	Perpendicular to joint
Weld Direction:	Vertical, up

Weld No.	Arc Current (amp)	Arc Voltage (v)	Weld Speed (ipm)	Gas Flow Rate (cfh)	Nondestructive Inspection Results		
					Visual	Dye Penetrant	X-ray
84-55	200	22	23	60	Very high crowned narrow bead with approximately 50% penetration into backing strip where tight fit-up existed. Where gap existed between workpiece and backing strip, excessive penetration, suckback, and undercutting resulted.	No indications.	Porosity approximately equivalent to ABMA-PD-R-27A Class III in all welds.
84-56							
84-57							
84-58							

*"Development of the All-Welded Common Bulkhead," Monthly Report dated 1 October - 31 October 1964.

nondestructive inspection results for vertical MIG welds with a backing strip. Figure 4 shows typical photomacrographs of MIG welds in Configuration D.

On the basis of the results of the flat-panel tests, the three most promising joint process techniques were selected for tension test. These are MIG, Configuration B (integral chill); TIG, Configuration A (external chill); and TIG, Configuration B (integral chill). The required 81 tensile specimens (27 of each joint) were machined.

Ultimate tension testing of the 81 specimens at room temperature, -321°F, and -423°F has been completed. The resulting data are listed in Table II.

Task 1.2.1.5--Evaluation of Tests and Selection of Two Joint Concepts

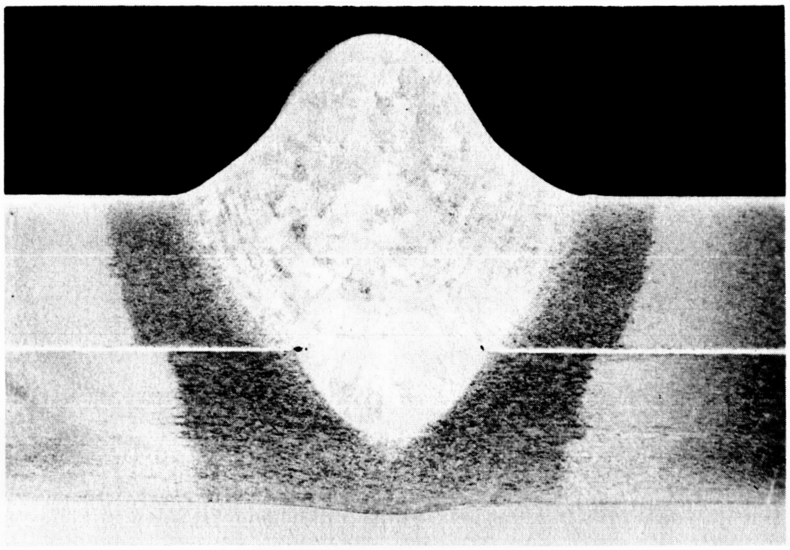
On the basis of the test results summarized in Table II, two joint concepts were selected for further development. The test results indicate consistently better properties for the TIG-welded joints than for the MIG-welded joint. The yield and ultimate strengths are better and the all-weld-metal longitudinal elongations, which are the measure of weld ductility, are also better for the TIG welds than for the MIG welds. On the basis of these results, the two TIG joints (TIG-welded integral chill and TIG-welded external chill) were selected for further testing and development.

Eighteen transverse tensile specimens, nine each of TIG, Configuration A (external chill), and TIG, Configuration B (integral chill), have been fabricated for the purpose of conducting tension fatigue tests.

Task 1.2.1.7--Nondestructive Test Development

As reported in SM-48068, "Development of the All-Welded Common Bulkhead," Monthly Report dated 1 October - 31 October 1964, Task 1.2.1.7, the work on this task is essentially complete. However, ultrasonic testing techniques will be refined and improved by tests to be carried out on sandwich panels. The results of these tests will be reported as information becomes available.

Weld samples (1-1/2 in. x 8 in. x 1/8 in.) with fatigue cracks of 0.050 in. to 0.200 in. long, were stressed in bending and immersed in liquid nitrogen. Ultrasonic tests were then performed to determine if crack growth occurred from the cryogenic shocking. Ultrasonic detection showed no increase in crack length.



A. TYPICAL WELD

B. 0.030-IN. GAP BETWEEN TEST PART AND BACKING STRIP
NOTE: UNDERBEAD SUCKBACK, LARGE VOIDS, AND SCATTERED MICROPOROSITY

Figure 4 6X Photomacrographs of Vertical-position Mig Welds in 1/8-In. 2014-T6 Aluminum Alloy With 1/8-In. 2014-T6 Backing Strip (Mig, Configuration D) (Keller's Etch)

Table II

MECHANICAL PROPERTY SUMMARY OF TENSION TEST RESULTS FROM VERTICAL POSITION MIG AND TIG WELDS IN 2014-T6 ALUMINUM ALLOY

Test Temp.	Specimen Type		MIG, Integral Chill (Configuration B)			TIG, External Chill (Configuration A)			TIG, Integral Chill (Configuration B)		
			YS Fty	US Ftu	E(1) (%)	YS Fty	US Ftu	E(1) (%)	YS Fty	US Ftu	E(1) (%)
Room Temperature	Transverse	1	32.8	39.8	3.0	34.7	48.3	2.0	37.4	50.9	5.0
		2	32.0	38.6	3.0	31.9	48.0	2.0	38.3	45.7	3.0
		3	30.7	43.0	4.0	34.3	50.5	2.0	35.9	52.8	5.0
		Avg.	31.8	40.5	3.3	33.6	48.9	2.0	37.2	49.8	4.3
	All-Weld-Metal Longitudinal	1	22.8	40.6	10.0	23.4	43.2	16.0	24.5	43.8	12.0
		2	20.2	38.4	10.0	25.0	47.5	13.0	24.8	44.4	14.0
		3	19.6	38.0	10.0	25.9	44.5	12.0	26.2	45.1	9.0
		Avg.	20.9	39.0	10.0	25.1	45.1	13.7	25.2	44.4	11.7
	Joint Longitudinal (1 1/2 in. Wide)	1	35.2	55.0	5.0	46.7	62.9	8.0(2)	42.6	65.8	5.0(2)
		2	31.9	50.8	12.0	44.0	61.4	7.0	48.6(3)	62.1(3)	8.0(2)(3)
		3	37.2	57.1	11.0	43.7	61.2	7.0(2)	44.1	63.5	10.0
		Avg.	34.8	56.3	9.3	44.8	61.8	7.3	45.1	63.8	7.7
-321°F	Transverse	1	41.5	47.2	0	38.7	59.5	2.0	46.1	50.6	1.0
		2	37.0	50.1	1.0	40.7	56.6	1.0	54.8	54.9	0
		3	37.4	40.7	1.0	41.4	61.1	2.0	44.2	49.3	0
		Avg.	38.6	46.0	0.7	40.3	59.1	1.7	48.4	51.6	0.3
	All-Weld-Metal Longitudinal	1	No Yield(4)	44.1	4.0	29.9	50.6	8.0	31.8	55.6	11.0
		2	22.5	41.1	4.0	34.2	52.1	5.0	30.2	55.9	10.0
		3	26.6	41.8	4.0	32.2	56.9	9.0	31.3	53.2	14.0
		Avg.	24.5	42.3	4.0	32.1	53.2	7.3	31.1	56.6	11.7
	Joint Longitudinal (1 1/2 in. Wide)	1	48.4	64.6	6.0	51.4	71.2	6.0	58.9	77.9	8.0
		2	49.4	65.9	6.0	56.2	70.4	6.0	56.8	72.7	8.0
		3	49.2	63.5	7.0	56.9	69.7	4.0(3)	56.8	74.6	8.0
		Avg.	49.0	64.7	6.3	54.8	70.4	5.3	57.5	75.1	8.0
-423°F	Transverse	1	No Yield(4)	45.1	1.0	55.4	66.0	2.0	No Yield(4)	49.4(5)	1.0
		2	45.7	48.8	1.0	49.8	63.2	2.0	62.2	63.0	1.0
		3	No Yield(4)	48.9	1.0	53.1	61.9	2.0	58.3	63.9	1.0
		Avg.	45.7	47.6	1.0	52.8	63.7	2.0	60.2	63.4	1.0
	All-Weld-Metal Longitudinal	1	34.7	48.4	2.0	36.3	54.6	5.0	37.9	61.9	5.0
		2	33.2	46.5	3.0	37.3	57.8	5.0	39.7	58.5	3.0
		3	33.4	48.3	3.0	38.4	49.1	2.0	41.7	59.3	3.0
		Avg.	33.8	48.3	2.7	37.3	53.8	4.0	39.8	59.9	3.7
	Joint Longitudinal (1 1/2 in. Wide)	1	55.8	70.2	4.0	65.4	75.6	3.0	56.8	73.8	5.0
		2	56.4	69.3	4.0	56.3	74.8	3.0	59.6	80.2	5.0
		3	55.9	67.8	3.0	63.8	75.4	3.0	65.3	80.6	5.0
		Avg.	56.0	69.1	3.7	61.8	75.2	3.0	60.8	78.2	5.0

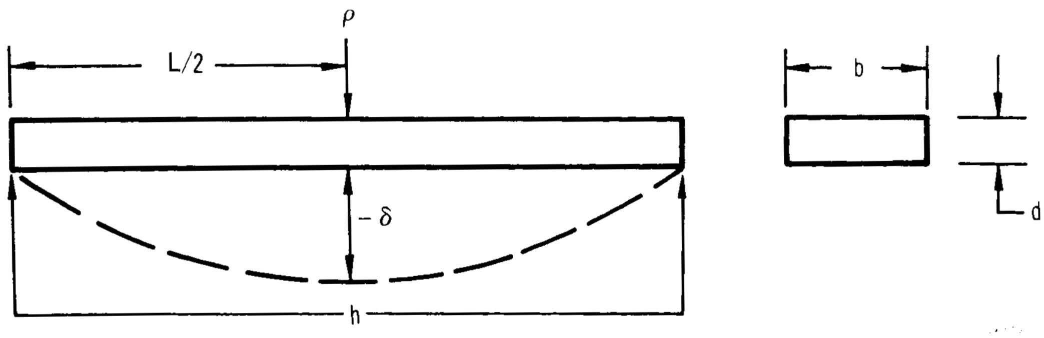
(1) Elongation measured over 2-in. gage length for transverse and longitudinal joint specimens; 1-in. gage used for all-weld-metal specimens.

(2) Specimen failed outside gage marks.

(3) Specimen failed in weld defect.

(4) Extensometer failed. No yield value obtained.

(5) Specimen failed in weld deposit. No defects noted.



The following equation was used to determine the exact stress level:

Given: 2014-T6 aluminum beam

$b = 1.50$ in. $\quad d = 0.100$ in.

$I = \frac{bd^3}{12} = 0.000125 \quad c = \frac{0.100 \text{ in.}}{2}$

$L = 8$ in. $\quad E = 10.6 \times 10^6$ psi

Find: deflection δ required at L/2 by application of concentrated load P to cause a binding stress f_b of 43,700 psi.

$$f_b = \frac{Mc}{I} \text{ or } M = \frac{I f_b}{c} = \frac{(0.000125)(43,700)}{\left(\frac{0.100}{2}\right)} = 109.2 \text{ m - } \mu$$

where M is the maximum binding moment at L/2 midspan of the beam.

$$M = \frac{Pl}{4} \text{ or } P = \frac{4M}{L} = \frac{4(109.2)}{8} = 54.6 \text{ lb.}$$

that is: a force of 54.6 lb. must be applied to deflect the beam.

The required deflection is $\delta = \frac{Pl^3}{48 EI}$

$$\delta = \frac{(54.6)(8)^3}{(48)(10.6 \times 10^6)(0.000125)} = 0.440 \text{ in.}$$

The fixture used for applying these stresses is shown in Figure 5. Ultrasonic signal response of the before and after quench condition is shown in Figure 6.

Earlier in the program, two 1/4-in.-thick MIG-welded samples with tight lack of fusion defects were sent to the W.W. Dickinson Corporation, San Francisco, for unique ultrasonic testing and to Automation Industries, Boulder, Colorado, for thermal infrared tests. Unfortunately, the dimensions of the samples sent

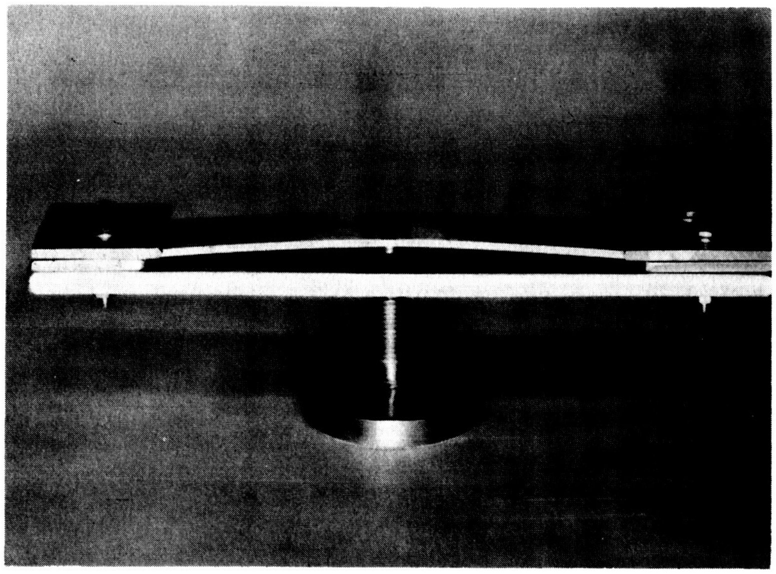


Figure 5 Hold-down Fixture for Applying Bending Stress to Weld Sample (Bending Stress Applied With Screw Adjustment Deflection Measured With Micrometer)

A. BEFORE LN_2 QUENCH

B. AFTER LN_2 QUENCH

Figure 6 Ultrasonic Responses From .100-In. Long Fatigue Crack In 1/8-In. 2014-T6 Aluminum Weld (Instrument Set at Constant Gain 5.0 mc $\times$ 45° Angle Transducer) to these companies were too small to avoid interfering edge effects. However, Dickinson Corporation stated that they have larger weld samples with lack of fusion, which was readily detected by ultrasonic techniques. Since a complete evaluation of Dickinson's equipment would take considerable time, no further evaluation will be made at present.

Larger weld samples, with and without lack of fusion, have been sent to Automation Industries for further infrared tests. The results of this testing will be reported at a later date.

Task 1.2.2--Sandwich-Panel Tests

As noted in SM-48068, referenced above, the drawings of the sandwich-panel configurations to be used in the simultaneous welding phase of this program and the test specimens that will be machined from these panels were released to the shop.

All planning and scheduling of manufacturing has been completed; the necessary materials have been procured and the fabrication of parts has been initiated. The panels are expected to be ready for welding by the end of December.

Task 1.4--Establishment of Manufacturing Plan

A preliminary manufacturing plan is being prepared. Obviously, this plan cannot be completed in detail until the final joint concept has been selected and the design of the full-scale bulkhead has reached the point where preparation of production drawings can begin. However, this preliminary plan will be useful for preparing the inspection plan and for scheduling the tooling and manufacturing tasks. Therefore, it will be completed as quickly as possible. Completion will, however, be delayed until the end of January to incorporate the information resulting from the fabrication of the sandwich-panel test parts.

Task 2.1--Design of the Full-Scale Bulkhead

The design of the full-scale bulkhead has been completed with the exception of the common bulkhead-to-aft dome attachment and the selection of the final joint concept to be used (Task 1.3). Major problems regarding the attachment of the common bulkhead to the aft dome and various possible solutions to these problems have been discussed. The problem is under investigation, but it is felt that a detailed design will be complete long before construction of the bulkhead is scheduled to begin.

Section 3

WORK TO BE ACCOMPLISHED DURING COMING MONTH

Task 1.2.1--Flat-Panel Tests

During the next month, an attempt will be made to complete the fatigue testing. However, this effort may run into January, depending on the workload of the cryogenic laboratory and the priority which will be given to this project. This will complete Task 1.2.1.

Task 1.2.2--Sandwich-Panel Tests

During the coming month, fabrication of the sandwich panels will continue. These parts are expected to be complete by the end of December.

Task 1.4--Establishment of Manufacturing Plan

During the coming month, the preparation of the preliminary manufacturing plan will continue.

Task 2.1--Design of the Full-Scale Bulkhead

During the coming month, the design of the attachment rings will be complete. This will leave the selection of the final joint concept (Task 1.3) as the only design detail to be established before the production drawings of the bulkhead are prepared.

Appendix

COMPARISON OF RESULTS OF VERTICAL-POSITION WELD STUDIES

This appendix contains a tabulated comparison (Table A-I) of the summarized results of vertical-position MIG and TIG weld tests in the several joints. This table will be completed as additional data are compiled during the coming months.

Table A-I

COMPARISON OF RESULTS OF VERTICAL-POSITION WELD TESTS RELATED TO ALL-WELDED COMMON BULKHEAD

Test No.	1	2	3	4A[1]	4B[1]	5	6
Joint/Process	MIG External Chill	MIG Integral Chill	TIG External Chill	TIG Integral Chill	TIG Integral Chill	TIG-Backed	MIG-Backed
Weld Energy Input[2]	117	328	136	180	142	168	196
Mismatch Tolerance	Not determined	< 0.015 in.	0.020	< 0.015 in.	0.20 in.	<0.010 in.	0.010 in.
Gap Tolerance	Not determined	0.020 in.	0.030	< 0.020 in.	0.030 in.	<0.010 in.	0.010 in.
Avg. Weld Deposit Hardness - Rockwell 30T	39	43	48	50	50	Not determined	Not determined
Avg. Width of Heat-Affected Zone	5/8 in.	3/4 in.	5/8 in.	11/16 in.	9/16 in.	Not determined	Not determined
Avg. Yield Tensile Fty (ksi)	30.9	29.8	31.5	33.6	34.6	Not determined	Not determined
Avg. Ultimate Tensile Ftu (ksi)	42.6	40.4	44.6	49.9	47.4	Not determined	Not determined
Avg. Elongation % E in 2-in.	2.0	1.4	1.4	3.0	1.0	Not determined	Not determined
Temp. Gradient Distance from Weld ℄						Not determined	
700°F	1/2 in.	1/2 in.	3/8 in.	3/8 in.	5/16 in.		
600°F	1/2 in.	5/8 in.	7/16 in.	7/16 in.	3/8 in.		
500°F	3/4 in.	1 in.	9/16 in.	5/8 in.	1/2 in.		
400°F	1 in.	1-5/8 in.	7/8 in.	7/8 in.	11/16 in.		

[1]Joint 4A is square-butt joint utilizing no additional filler metal. Joint 4B is a grooved joint, as shown in Fig. 8b,* and includes the addition of filler material in the form of cold wire. Both joints are examples of the TIG process with integral chill.

[2]Weld energy input is determined as the product of arc current-x-arc voltage divided by weld speed, or arc power per unit speed. The values are meaningless in themselves, but provide a comparison of the relative rate at which welding heat is applied to the workpiece in the various combinations of process and joint.

*Douglas Report SM-48035, "Development of the All-Welded Common Bulkhead," monthly report dated 1 September - 30 September 1964.