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By
W. D. Bixler And W. L. Engstrom

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Contract NAS 9-11435
&
Contract NAS 9-10364, Task 24

THE BOEING COMPANY

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Final Report

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Technical Management

NASA Manned Spacecraft Center
Houston, Texas

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THE BOEING COMPANY
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CRACK GROWTH OF D6 STEEL IN AIR AND HIGH PRESSURE OXYGEN

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ABSTRACT

Fracture and subcritical flaw growth characteristics were experimentally determined for electroless nickel plated D6 steel in dry air and high pressure oxygen environments as applicable to the Lunar Module/Environmental Control System (LM/ECS) descent gaseous oxygen (GOX) tank. The material tested included forgings, plate, and actual LM/ECS descent GOX tank material. Parent metal and TIG welds were tested. Tests indicate that proof testing the tanks at 4000 psi or higher will insure safe operation at 3060 psi. Although significant flaw growth can occur during proofing, subsequent growth of flaws during normal tank operation is negligible.

KEY WORDS

D6 steel alloy

High pressure gaseous oxygen

Fracture characteristics

Lunar Module/Environmental Control System

Pressure vessels

Weldments

Apollo Program

Electroless nickel plating

Electrical discharge machining

Threshold stress intensity

SUMMARY

The experimental work described herein was undertaken to investigate the fracture and flaw growth characteristics of forging, plate and TIG welded D6 steel alloy, primarily in environments of dry air, lab air, and high pressure gaseous oxygen. The objective was to determine the failure mode and sustained load growth characteristics applicable to the LM/ECS descent GOX tank.

The program was conducted using precracked surface flawed specimens made from forgings, plates, and actual LM/ECS GOX tanks. Tank fabrication processes, thicknesses, and service conditions were simulated. Static, sustained, cyclic and combination loaded specimens were tested with flaws located in the base metal, in the weld nugget centerline and in the weld heat affected zone.

Flaw growth tests were conducted in dry air, lab air and 3000 psi gaseous oxygen at 70°F. Some tests included proofing, cycling and sustained loading a specimen in order to simulate maximum operating conditions of the LM/ECS descent GOX tanks. Welded specimens were nominally 0.21 or 0.18 inches thick and base metal specimens were nominally 0.375, 0.21, 0.125 or 0.11 inches thick.

An actual LM/ECS descent GOX tank was pressure tested to evaluate tanks with flaws growing through-the-thickness during operation.

The following observations and conclusions were made from this study.

1. The predicted failure mode of the weld area of the LM/ECS descent GOX tank is leakage at 2520 psi. This was demonstrated by cycling a surface flawed tank to leakage at 2520 psi and then loading to as high as 4550 psi with a 1.15 inch long crack without catastrophic failure.

2. The sustained load threshold of D6 steel (electroless nickel plated on one side followed by 28 hours of bake-out at 375°F, is above 75% of the critical stress intensity in dry air or high pressure oxygen. A limited amount of data for specimens that were baked for 4 hours indicated the same result.

3. Proof testing a LM/ECS descent GOX tank can cause flaw growth if a large flaw is present. However, negligible further growth will occur during the intended service life after proofing.

4. The failure mode of a LM/ECS descent GOX tank during proof test to 4000 psi could either be catastrophic or leakage depending upon (1) the actual fracture toughness of the tank material, (2) the area of the tank containing the flaw and (3) the flaw shape. If a flaw was screened by the proof test because of combinations of low toughness, highly stressed area relative to the thickness and/or long flaws, safe operation would be guaranteed for 20 MDOP cycles at 3060 psi. If a flaw was not screened by the proof test because of combinations of high toughness, lowly stressed area relative to the thickness and/or short flaws, functional operation would not be guaranteed at 3060 psi. The failure mode in this case would be leakage rather than catastrophic.

FOREWORD

NASA requested the Aerospace Group of The Boeing Company to perform an experimental study to determine the crack growth behavior of electroless nickel plated D6AC steel alloy in air and high pressure gaseous oxygen environments as applicable to the Apollo Lunar Module/Environmental Control System (LM/ECS) descent gaseous oxygen (GOX) tank. This program was performed under NASA Contract NAS 9-11435, and NASA Contract NAS 9-10364, Task 24 from October 7, 1970 through May 7, 1971 and the results are reported herein. The work was administered under the direction of S. V. Glorioso at NASA/MSC.

In addition to the D6 steel testing reported in this document, additional test work on 5Al-2.5Sn titanium was performed under Contract NAS 9-11435. The titanium test work was applicable to the Apollo Service Module/Electrical Power System cryo-hydrogen tank and is reported in NASA CR-114859 (Boeing Document D180-12854-1), "Crack Growth of 5Al-2.5Sn Titanium in Hydrogen".

Boeing personnel who participated in this investigation include J. N. Masters, Program Leader, and W. D. Bixler/W. L. Engstrom, Technical Leaders. Structural testing of specimens was conducted by A. A. Ottlyk, C. C. Mahnken, and G. E. Vermillion. Metallurgical and welding support was provided by E. C. Roberts, J. Scott, H. A. Johnson and T. J. Bosworth. Don Good prepared the art work.

The information contained in this report is also released as Boeing Document D180-12928-1.

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1.0 INTRODUCTION

The objective of this investigation was to determine the crack growth behavior of D6 steel in air and high pressure oxygen as applicable to the Apollo Lunar Module/Environmental Control System (LM/ECS) descent gaseous oxygen (GOX) tank. Fracture specimen testing included static fracture tests, sustained tests, growth-on-loading tests, cyclic tests, proof tests, proof tests with subsequent cycling, and proof tests with subsequent cycling plus sustained loading.

Much of the testing was conducted to simulate typical life spectrums of LM/ECS tanks. A typical tank life might include proof loading to a nominal pressure of 4000 psi (4170 psi maximum) followed by 3 cycles to MDOP of 3000 psi nominal (3060 psi maximum) and 4 or 5 cycles to 2520 psi nominal. During flight service a tank would spend 4 to 5 days at sustained pressure.

During the course of this investigation, it was found that electric discharge machining (EDM) of D6 steel (to introduce crack starter notches) affected the sustained load results. Significant flaw growth observed in early sustained load testing was at first believed to be caused by hydrogen introduced during electroless nickel plating and inadequately removed during a 4 hour bake-out process. Further testing showed that the sustained load flaw growth was reduced to essentially zero when the specimens were baked after EDM. It was initially thought that the free surface provided by the EDM starter notch and precrack permitted the hydrogen to escape more readily in the vicinity of the flaw. This idea was later discarded when specimens which were mechanically flawed by a high speed cutter after being baked had no sustained load flaw growth. It was finally determined that the EDM process was introducing hydrogen into the flaw area. Hydrogen would be provided by the dielectric fluid (kerosene) when ionized by the electric discharge (Reference 1). EDM specimens which were not subsequently baked are reported in the Appendices, except for Tank S/N 0041 and cycle through-the-thickness tests. Static fracture and end-point fracture values which were EDM without subsequent baking are reported in Appendices A and B, and those from Appendix A are summarized in the main body of this report.

Various bake out cycles were investigated to remove hydrogen; however, only the data applicable to the tanks used on Apollo 14 and subsequent missions are shown in the plots. These spacecraft employ tanks which have been baked 3 to 4 hours at 375°F in Argon plus 24 hours at 375°F in a vacuum.

2.0 MATERIALS

Two complete LM/ECS GOX descent tanks and half of a fractured tank were provided by NASA/MSC, Houston, Texas. The tanks were approximately 22 inches in diameter, 0.205 inches thick in the weld area and 0.123 inches thick in the base metal. Prior to receipt by Boeing, the D6 steel tanks were heat treated at 1650°F for 1 hour, carbon dioxide quenched, and then tempered at 1040°F for 3 hours plus 1040°F for 3 hours. An Argon atmosphere was maintained during heat treatment. Following final finish machining, the tanks were stress relieved in Argon at 950°F for 3 hours. The tanks were then electroless nickel plated on the inside and baked for 3 to 4 hours at 375°F (S/N 0010) or at 3 to 4 hours at 375°F plus 24 hours at 375°F in vacuum (S/N 0032, 0041).

Grumman Aerospace Corporation supplied the following pieces of D6 plate material:

a. Four pieces 0.21 in. x 14 in. x 18 in.
b. Six pieces 0.375 in. x 12 in. x 18 in.
c. Twenty pieces 0.21 in. x 8 in. x 24 in. which were fabricated by welding together 8 in. x 12 in. pieces.

Prior to receipt by Boeing, the material was electroless nickel plated by Chemplate Corp., Los Angeles, Calif., and subsequently baked for 4 hours at 375°F, except for one plate 0.375 in. x 12 in. x 18 in. which was not plated or baked and one welded plate 0.21 in. x 8 in. x 24 in. which was not baked after plating.

The Boeing Company supplied 54 pieces of annealed forging 0.30 in. x 4 in. x 6 in. Heat treatment and processing information of this material is described in Section 3.0.

3.0 PROCEDURES

3.1 SPECIMEN FABRICATION

Specimens were fabricated from D6 steel flat forging material, flat plate material and material from LM/ECS GOX tanks.

3.1.1 Boeing Processed Specimens (DBM-XX, DWM-XX)

The forging material used was in the form of pieces, 0.30 in. thick by 4 in. wide by 6 in. long. These were normalized and machined into the configurations shown in Figure 1 . The weld specimen halves were then welded together from one side only, using a tungsten arc in an Argon atmosphere (TIG). Welding parameters for the weld specimens (DWM-XX) duplicated actual tank parameters whenever possible and they are as follows:

a. Preheat and interpass temperature - 400°F to 430°F.

b. Electrode - 3/32 diameter tungsten (2% thorated with pointed tip)

c. Filler wire - 0.062 dia. D6AC (annealed)

d. Inert shield - 75% Argon + 25% Helium head gas, 100% Argon backup gas.

e. Weld Schedule

Parameter	Pass Sequence				
	Fusion	Filler			
	1	2	3	4	5
Voltage + 2V	10	10	13	13	13
Amps + 4A	52	70	80	100	112
Weld Speed + 0.5 imp	2.6	2.6	2.6	2.6	2.6
Wire Feed + 0.4 ipm	N/A	5.1	5.1	7.6	7.6

f. Post weld heat treat - 600°F for 1½ hour, cool to 300°F, stress relieve at 1250°F for 1½ hours (Argon internal purge)

All weld specimens were radiographically inspected. The base metal specimens (DBM-XX) underwent a similar welding process, however, they were welded from both sides.

After being welded, the specimens were drilled and cut to width and thickness. The weld specimens were cut to 0.215/0.210 inches thick in the test section and the base metal specimens were cut to 0.133/0.128 inches thick in the test section (located outside the weld area per Figure 2). The specimens were then heat treated to 220-240 ksi as follows:

a. Austenitize - 1625°F to 1675°F for 1 hour in Argon.

b. Air Quench - fan cooled in air.

c. Temper in air - 1000°F for 2 hours + 1000°F for 2 hours.

The weld specimens were then ground to a thickness of 0.210/0.205 inches and the base metal specimens were ground to a thickness of 0.128/0.123 inches. Finished specimens are shown in Figures 2 and 3. Grinding was followed by a stress relief cycle of 950°F to 975°F for 3 hours in an Argon atmosphere. Most of the specimens were then electroless nickel plated by Heath Tecna Corporation in Kent, Washington, and baked at 375°F for 4 hours in air.

Tensile specimens were made by reducing the width of fracture specimens to 0.5 inches in a 2.0 inch long test section.

3.1.2 0.21 Inch Thick Longitudinal Grain Plate Specimens (G-XX)

D6 steel was provided by Grumman Aerospace Corporation (GAC), Bethpage, New York, in the form of plates 0.21 in. x 14 in. x 18 in. with the grain direction parallel to the 18 in. length. The plate was heat treated by GAC at 1650°F for $1\frac{1}{4}$ hours, oil quenched, tempered at 1000°F for 2 hours and air cooled plus 1015°F for 2 hours and air cooled. After heat treating the plates were electroless nickel plated on one side and baked at 375°F for 3 to 4 hours by Chemplate Corporation, Los Angeles, California. Longitudinal grain blanks were cut from the plate and fabricated into specimens as shown in Figure 4. The tensile specimen was made by reducing the width of a fracture specimen to 0.50 inches in a 2.25 inch long test section.

3.1.3 0.21 Inch Thick Welded Plate Specimens (GW-XX), Longitudinal Grain Plate Specimens (GBM-X), and Long Transverse Grain Plate Specimens (GB-XX, SG-XX)

Material for these specimens was provided by GAC in the form of welded plates 0.21 in. x 8 in. x 24 in. with the longitudinal grain direction parallel to the 24 inch length. Each plate was made by welding together two 0.21 in. x 8 in. x 12. in. pieces of material which had previously been prepared with "J" grooves as shown previously in Figure 1. After being welded, the plates were radiographically inspected and stress relieved at 1250°F for 1 1/2 hours. The weld bead was then machined flat and the plates were heat treated as described in Section 3.1.2. The plates were then electroless nickel plated on the underside by Chemplate Corporation, and with the exception of one plate, were baked at 375°F for 3 to 4 hours. The longitudinal grain specimens (GBM-X) and welded specimens (GW-XX) were cut from the plates and fabricated as shown in Figure 4. The long transverse grain specimens (GB-XX, SG-XX) were fabricated as shown in Figures 4 and 5. Tensile specimens were made by reducing the width of fracture specimens to 0.5 inches in a 2.25 inch test section.

3.1.4 0.375 Inch Thick Longitudinal Grain Plate Specimens (GTB-XX)

Material for these specimens was provided by GAC in the form of plates 0.375 in. x 12 in. x 18 in. with the longitudinal grain direction parallel to the 12 inch length. The plates were heat treated as described in Section 3.1.2 and then all but one plate were electroless nickel plated on one side and baked at 375°F for 3 to 4 hours by Chemplate Corporation. Longitudinal grain specimens were fabricated as shown in Figure 6. Tensile specimens were reduced in width to 0.50 in. in a 2.25 in. long test section.

3.1.5 Base Metal (TB-XX) and Weldment Specimens (TW-XX, SN 41-X) from LM/ECS GOX Descent Tanks

The tanks from which these specimens were fabricated were supplied by NASA. Processing is described in Section 3.0. One of the tanks (S/N 0041) was flawed and pressure tested prior to being cut up and fabricated into fracture specimens. Weldment specimens were cut from S/N 0010, 0032 and 0041 tanks. Base metal specimens were cut only from S/N 0010 tank. Typical locations of specimen blanks are shown in Figure 7. Specimens were fabricated from the blanks by flattening and straightening outside the test section. The steps involved in fabrication of weldment specimens are described in Figure 8. Base metal specimens were fabricated in a similar manner. Finished specimen dimensions are shown in Figures 9 and 10. Tensile specimens were fabricated by making the largest size flat specimen that could be made without straightening the material. This resulted in specimens that were 0.25 inches wide and 1.25 inches long in the test section.

After fabrication and before flawing the specimens were strain gaged and loaded to determine bending stresses. Because specimens displayed different amounts of bending, it was necessary to perform this calibration on each specimen. A typical bending stress curve is shown in Figure 11.

3.1.6 Machining and Precracking of Flaws

Those flaws which were electrically discharge machined (EDM) were cut on an Eleroda D1 or D1-S machine. Kerosene was used as the dielectric and coolant fluid. The electrodes used were copper or copper-tungsten alloy. The mechanically cut flaws were made using a high speed tool steel cutting wheel with Rapid-Tap oil as the lubricant.

Fatigue extension of the starter notches was accomplished by precracking at 200 to 400 cpm in room temperature air. EDM flaws were precracked at a maximum stress of 30 to 40 ksi for 3000 to 29,000 cycles. Mechanically cut flaws were precracked at a maximum stress of 60 to 70 psi for 2,000 to 34,000 cycles.

Flaws were introduced on either the nickel plated or the nonplated side of the specimens. Weldment specimens had flaws in both the centerline (C_L) and the heat affected zone (HAZ) of the weld. The flaws were located in the middle of the HAZ which was 0.17 inches from the weld centerline; this location was determined from measurements of a tank weld micrograph provided by NASA/MSC.

3.2 STATIC AND FLAW GROWTH TEST SETUPS AND SPECIMEN INSTRUMENTATION

Hazardous sustained tests involving room temperature gaseous oxygen at 3000 psi were conducted at Boeing's remote Tulalip Test Site using load machines of 100,000 lb capacity. A specimen installed in a test machine is shown in Figure 12. A schematic of the system is shown in Figure 13. Gaseous oxygen in bottles at 500 to 2000 psi was pumped up to a pressure of 3000 psi before being introduced into a small cup mounted on the specimen. A cup with a pressure transducer was mounted on the back side of the specimen to sense any pressure rise that might occur if the flaw grew through-the-thickness. A set of pressure cups is shown in Figure 14.

Pressure tests of an actual LM/ECS Descent GOX tank containing an EDM surface flaw were conducted at the Tulalip Test Site also. The tank was pressurized with Texaco R and O HD-A hydraulic oil and utilized the 3000 psi hydraulic power supply of a Research Incorporated test machine during the first two loading sequences (precrack, cycle and sustain). The remainder of the tests utilized a 5000 psi, 35 gallon per minute, Sprague hydraulic bench with MIL-H-5606 hydraulic oil as the working fluid. Cooling was maintained by partially submerging the tank in a bath of R and O hydraulic oil. Cooling coils utilizing liquid nitrogen were introduced into the bath to absorb heat. In addition, gaseous nitrogen was bubbled into the bath to stir the oil for more efficient heat transfer. Several thermocouples were used to monitor temperature. The flaw was kept dry during precracking by covering it with a plexiglass shield. Silica gel was used as a dessicant. Because of the inherent dangers involved, all testing was monitored via closed circuit television. Remote controlled movies were also taken of some parts of the testing. A schematic of the test setup is shown in Figure 15 and a photograph is shown in Figure 16.

Nonhazardous tests were conducted in an environmentally controlled laboratory at the Boeing Space Center. Temperature and relative humidity in this lab are maintained at 70°F and 35% respectively. Static testing was done in a Baldwin 160,000 lb Universal test machine or a 150,000 lb hydraulic test machine manufactured by Boeing. Cyclic tests were conducted in the 150,000 lb machine. Nonhazardous sustained tests were run in the 150,000 lb machine, in another Boeing-built hydraulic test machine with a capacity of 60,000 lb, in the 160,000 lb Baldwin test machine, or in a 30,000 lb Boeing-built dead weight machine. A dry air environment was obtained by surrounding the specimens with a polyethylene bag containing silica gel dessicant.

Tests which required measurements of crack opening displacement (COD) were conducted using a clip gage. Small brackets were micro-spot welded to the specimen, and the clip gage was spring loaded between the brackets. Figure 17 illustrates a clip gage installation.

3.3 EXPERIMENTAL APPROACH

Surface flaw specimens were tested with initial targeted flaw shapes $(a/2c)_i$ ranging from about 0.2 to 0.4 with the majority of the tests conducted with an $(a/2c)_i$ of 0.25. Static specimens were tested in laboratory air at 70°F and 35% relative humidity. Unless stated otherwise, they were loaded to failure in one to one and a half minutes. Some static specimens were instrumented with the clip gages discussed in the previous section.

Specimens having various flaw sizes were sustained loaded at various stress levels. Specimens were also cycled or cycled and sustained tested at simulated operating stress levels after being proof tested. Sustained test durations varied from 45 minutes to 30 days. Several specimens were instrumented with clip gages to detect flaw growth during the cyclic and sustained tests.

After the cyclic and sustained tests were completed, specimens were low stress cycled in air to mark the flaw front and subsequently static loaded to failure. Evidence of growth was indicated by a separation between the initial fatigue crack extension and final marking. In conjunction with this procedure, separation of environmental caused growth and growth-on-loading was accomplished by loading surface flawed specimens to predetermined stress levels, immediately dropping the load to zero, marking and failing the specimen, and then observing the fracture face for growth. The specimen specifically utilized to determine growth-on-loading is termed a load/unload specimen. However, load/unload tests were also conducted on specimens which were previously sustained loaded. This was accomplished by fatigue marking the specimens between the sustained load test and the load/unload test.

Proof tests were conducted by instrumenting specimens with clip gages and loading them to a point at which failure was imminent. This point was determined by examining load versus crack opening displacement curves of static fracture tests. Typical curves for a static fracture test and a proof test are shown in Figure 18. Crack growth during subsequent cycling and sustained loading was determined by employing clip gages and by examining the fracture face of each specimen after testing.

3.4 STRESS INTENSITY SOLUTION

For surface flawed specimens loaded in tension, the following expression for stress intensity was used:

$$K_I = \underbrace{1.1 \; \sigma_A \left(\frac{\pi a}{Q}\right)^{1/2}}_{\text{Irwin Stress Intensity}} \; M_K \tag{1}$$

K_I = plane strain stress intensity

σ_A = axial gross stress

a = flaw depth

Q = flaw shape parameter (see Figure 19)

M_K = deep flaw magnification factor from Reference 2. (see Figure 20)

The Irwin critical stress intensity for a large group of D6 steel specimens are plotted as a function of flaw depth-to-thickness ratio (a/t) in Figure 21. The flaw depth-to-length ratio (a/2c) for these specimens ranged from about 0.20 to 0.40. Figure 21 data indicates a slight decrease in Irwin critical stress intensity as the a/t increases indicating that a magnification factor should be applied to the Irwin stress intensity solution. Because of program constraints, no systematic approach to determining M_K effects in D6 steel was undertaken. The 2219-T87 aluminum M_K curves presented in Figure 20 (Reference 2) approximates the M_K effect observed in the D6 steel. These aluminum M_K curves were used in calculating the stress intensities for the D6 steel specimens presented in this report.

The specimens fabricated from LM/ECS tanks were subjected to bending stresses as well as tension stresses when loaded axially. (These specimens were straightened outside the test area prior to testing to eliminate the major part of the bending.) To account for the bending stress contribution on the surface flaw stress intensity calculations, the following equation was used:

$$(K_I)_B = \sigma_B \left(\frac{\pi a}{Q}\right)^{1/2} M_B \tag{2}$$

where

$(K_I)_B$ = plane strain stress intensity due to bending

σ_B = maximum outer fiber bending stress

M_B = bending stress magnification factor from Reference 3 (see Figure 22)

The resultant stress intensity for a surface flaw subjected to combined tension and bending is:

$$K_I = (K_I)_{TENSION} + (K_I)_{BENDING} \quad (3)$$

The bending contribution is either added or subtracted, depending upon the orientation of the bending loads.

4.0 TEST RESULTS AND ANALYSIS

4.1 MECHANICAL PROPERTIES

Mechanical property tests were conducted for D6 steel forging, plate and weldment material used in evaluating the fracture characteristics of the LM/ECS gaseous oxygen tank. These tests were run at a temperature of 70°F in laboratory air. The results of these tests are presented in Tables 1 through 5. The yield strength (0.2 percent offset) ranged from 192.2 to 221.7 ksi for 0.375 inch thick plate and tank weldment, respectively. The thicker material exhibited the lowest strength while the heat treated weldments were in general, stronger than the parent material.

4.2 STATIC AND END POINT FRACTURE TESTS

Static fracture tests were conducted in air at 70°F and 35% relative humidity. Additional K_{Ic} values were obtained using end point fracture data from specimens which were previously tested. These latter values are called end point K_{Ic} values. Static and end point values are shown in Figures 23 through 28. A summary of tabulated fracture values is found in Table 6, [1] while individual values are presented in Tables 7 through 36. Many of the K_{Ic} values were taken from tests of nickel plated, 0.21 inch thick, long transverse grain D6 steel plate. (Specimen Code: GB-XX). These K_{Ic} values ranged between 97.1 ksi $\sqrt{in}$ and 112.6 ksi $\sqrt{in}$. The range of K_{Ic} values for all materials tested was from as low as 75.6 ksi $\sqrt{in}$ for a 0.21 in. thick longitudinal grain flat plate specimen (G-27) to as high as 124.0 ksi $\sqrt{in}$ for a 0.21 in. thick weldment specimen (GW-9). In general, most K_{Ic} values were in the 97.1 to 112.6 ksi $\sqrt{in}$ range displayed by the GB specimens.

Variations in bake temperatures and times in excess of 375°F and 24 hours respectively, did not appear to influence static and end point K_{Ic} values. Likewise, machining or EDM the flaws did not appear to influence the fracture toughness data. Any variations with these parameters were smaller than the scatter in the data.

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[1] Many of the values shown in the K_{Ic} summary table are taken from the appendix.

The fracture tests show that the failure mode of the tank weldment area at proof stress could either be catastrophic or leakage depending upon the actual fracture toughness of the tank material and the flaw shape.

4.3 SUSTAINED LOAD AND GROWTH-ON-LOADING TESTS

Sustained load tests were conducted in 3000 psi gaseous oxygen and dry air at room temperature. The results of these tests are presented in Figures 23, 24 and 25 for specimens that received a total 28 hours of bake time. Flaw growth was observed on these specimens when the K level exceeded about 60 ksi $\sqrt{in.}$ Additional tests were conducted to determine if this flaw growth was time dependent (and, therefore, a function of the environment) or if the flaw growth was due to loading the specimens (and independent of environment). Load/unload and proof specimens were tested and the results of these tests are presented in Figure 29. As Figure 29 indicates, flaw growth due to loading was observed above an initial K level of 60 ksi $\sqrt{in.}$ The amount of scatter observed with these tests was comparable with the scatter obtained with corresponding K_{Ic} tests. The amount of flaw growth observed with the sustain loaded specimens fell generally within the scatter band presented in Figure 29. This observation was true for all sustain loaded specimens regardless of bake time or material heat. The detailed data for all specimens that were sustain loaded are presented in Tables 11 through 18.

A limited number of specimens with a 4 hour bake were sustain loaded and the results are presented in Tables 14, and 16. The amount of growth observed fell within the scatter band of the growth-on-loading results as presented in Figure 29. From this limited amount of data it appears that a 4 hour bake time would be sufficient to eliminate any hydrogen due to plating.

4.4 EFFECT OF PROOF TEST ON SUBSEQUENT FLAW GROWTH

4.4.1 Proof Tests, Proof/MDOP Tests and Proof/MDOP/20 Hour Sustained Tests

Surface flawed specimens fabricated from 0.21 inch thick long transverse grain plate material (GB-XX) were subjected to multiple load cycles to determine the relative amounts of flaw growth due to proof, MDOP and sustained loads. Some specimens were proof tested in lab air, some proof tested and then subjected to 10 MDOP cycles in dry air to 76% of the proof stress and others were proof tested, MDOP cycled and then subjected to a sustained load for about 20 hours in dry air to 76% of the proof stress. [1] A trapezoidal loading profile for the MDOP cycles was used and is shown in Figure 30. Each cycle consisted of a one minute period with a 10 second load time, a 10 second unload time, and a 40 second hold time. The results of these tests are presented in Figure 27 while the detailed data is contained in Tables 19, 20, and 21.

As discussed in Paragraph 4.3, considerable growth-on-loading can occur during a proof test if the maximum stress intensity exceeds about 60 ksi $\sqrt{in.}$ From 0.002 to 0.009 inch of flaw growth was observed with these proof test specimens. No flaw growth was observed during the 10 MDOP cyclic portion of the proof/MDOP loaded specimen tests. Likewise, no flaw growth was observed during the sustain load portion of the proof/MDOP/sustain loaded specimen tests.

Retardation of subsequent growth after high load cycles has been documented by several investigators (References 4, 5, 6, 7, 8 and 9). This retardation could be caused by a number of mechanisms. Among them are the following (Reference 9):

1. Production of local yielding which leaves a residual stress pattern and so reduces the stress at the tip of a crack under a given external load.

2. Reduction of the sharpness of the crack tip by local yielding.

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[1] The proof test cited was to a stress level exceeding that which a tank would normally experience; the test was targeted at a stress intensity that the specimen would just pass without failure with flaws that were no deeper than 60% of the thickness to minimize deep flaw magnification effects. It is assumed that the data generated from these tests are applicable to other flaw size and stress level combinations (in particular deeper, lower stressed flaws) as long as the same stress intensity levels are considered.

4.4.2 MDOP Cycle Test

After the tests discussed in Paragraph 4.4.1 were run, a single specimen (GB-28) was subjected to 10 MDOP cycles (to about the same load level as the Paragraph 4.4.1 tests) in dry air without undergoing a previous proof. The data for this specimen (GB-28) is shown in Table 22. Cyclic growth totaled 0.003 inch for this specimen; however, examination of Figure 29 shows that about 0.001 inch of this growth was probably due to growth-on-loading caused during the first load cycle. This specimen emphasizes the growth retardation that a proof load would cause on subsequent subcritical flaw growth characteristics.

4.4.3 Proof/MDOP/Cycle to Failure Test

One specimen (GB-17) was proofed (see [1▷] page 15) and cycled at MDOP (stressed to about 76% of the proof stress), to failure. The loading spectrum for this specimen is shown in Figure 30 and the data is shown in Table 23 and Figure 27. The flaw in this specimen grew 0.002 inch during proof loading. No growth occurred during cycling until the 85th cycle, as indicated by the clip gage, and breakthrough occurred at the 672nd cycle. Failure occurred at 695 cycles. The exact crack length, 2c, could not be determined at breakthrough and at failure; however, the a/2c ratios were approximately 0.35 and 0.25, respectively. [1▷] This uniaxial specimen illustrated the fact that a through-flaw with an aspect ratio less than 0.25 will cause leakage in the weld area of a tank at a MDOP stress of about 80 ksi.

4.4.4 Multiple Proof Tests

Two multiple proof test specimens (see [1▷] page 15) were tested. The crack measurement data for these specimens (GB-22 and GB-23) are included in Table 24. Load summaries are found in Tables 25 and 26, and a load versus crack opening displacement curve for specimen GB-22 is shown in Figure 31.

[1▷] These a/2c ratios were calculated using the longest crack lengths. If crack lengths on the surface were measured, a/2c ratios were approximately 0.40 and 0.30 respectively.

Specimen GB-22 was tested in laboratory air. It was first loaded to approximately 80% of proof load to check out the instrumentation equipment. The load was then dropped to zero and the first proof test was run. The specimen fracture face showed a change in flaw depth of 0.003 inch during this proof test and during each of three subsequent proof tests. During the fifth proof test (the sixth loading cycle), 0.008 inch of growth was observed. The specimen was held at the proof loads for times varying from 1.75 minutes to 4.25 minutes. Failure occurred on the seventh loading cycle. As the load was increased during proof loading, the specimen was held at 75% and 85% of the previous proof load for times ranging from 1.50 minutes to 2.75 minutes. No growth occurred during these subsequent loadings to 75% and 85% of proof.

Specimen GB-23 was tested similarly to specimen GB-22, but the test on GB-23 was conducted in dry air. Specimen GB-23 was subjected to 9 loading cycles, 7 of which were proof tests. Hold times for the proof tests varied from less than 10 seconds to 14 minutes. As the load was increased during proof loading, the specimen was held for 1 to $3\frac{1}{4}$ minutes at 75% or 85% of the previous proof load. No growth occurred at 75% or 85% of proof. The amount of growth during each proof load could not be determined; however, the total growth during the 7 proof cycles consisted of a change of 0.030 inch in flaw depth and 0.025 inch in flaw length.

These two tests demonstrated that after proofing, no significant growth will occur at loads up to 85% of the proof load.

4.4.5 Multiple Proof/MDOP Tests with Wide Specimens

Two specimens (SG-4 and SG-5) were subjected to combinations of multiple proof (see [1]▷ page 15) and MDOP cyclic loading (to about 76% of the proof stress). Results from the first proof loading and subsequent MDOP cycling are shown in Figure 28. Complete crack growth information is shown in Table 27, and load summaries are found in Tables 28 and 29.

The fracture face of specimen SG-4 indicated that the flaw grew 0.008 inch during proof loading and then grew 0.001 inch during 10 cycles at MDOP. The MDOP cyclic test of this specimen differed from the MDOP cyclic tests reported in Section 4.4.1 in that one minute was used to reach MDOP, the specimen was held at MDOP for 2 1/2 minutes, and one minute was taken to drop the load back down to zero. The MDOP cyclic test was also conducted at a higher stress intensity level than those described in Section 4.4.1 (82.2 ksi $\sqrt{in}$ versus a maximum K level of 75.2 ksi $\sqrt{in}$). During six proof cycles following the MDOP cyclic test, the specimen grew a total of 0.010 inch. During some of the proof loading, the specimen was held for 2 1/2 minutes at MDOP, and 85% and 95% of proof without showing growth as indicated by the clip gage.

Specimen SG-5 grew 0.011 inch in depth during proof loading to 121.9 ksi $\sqrt{in}$. Subsequent cycling for 50 cycles at MDOP produced total growth of 0.006 inch in depth. The initial K level during the MDOP testing was high at 95.3 ksi $\sqrt{in}$, because of the high proof load. After being cycled, the specimen was loaded to 90% of the original proof load and held for 2 1/2 minutes with no growth. When the load was increased to 95% of the original proof load, 0.003 inch of growth occurred. No growth occurred during a final MDOP sustained load for 2 1/2 minutes.

These two specimens aided in confirming data presented in Section 4.4.1, although specimen SG-4 showed that a slight amount of growth (0.001 inch) may occur during 10 MDOP cycles after proofing. Specimen SG-5 showed that cycling for much more than the normal operational amount would produce additional growth, approximately at a d(a/Q)/dN of 60 micro-inches/cycle.

4.4.6 Proof/MDOP/30 Day Sustained Tests

Proof/MDOP/30 day sustained tests were conducted on a total of eleven specimens. These specimens were taken from a variety of forgings and plates. Five specimens were made from three LM/ECS descent GOX tanks. Specimen TW-19 came from S/N 0010, TW-36 and 37 came from S/N 0032 and SN 41-4 and -5 came from S/N 0041. Specimens G-28 and G-29 were longitudinal grain specimens from 0.21 inch thick flat plate. Specimen GB-24 was a long transverse grain specimen from 0.21 inch thick flat plate (not the same plate that G-28 and -29 were taken from). Specimens GWIP-6 and GW-38 and -47 were weldment specimens taken from welded 0.21 inch thick plate material (the same plates as GB-24).

The specimens were proofed (see 1▷ page 15) and subjected to 20 MDOP cycles in dry air to about 76% of the proof stress. The MDOP waveform was as described in Section 4.4.1 and as shown in Figure 30. After proofing and cycling at MDOP, the specimens were sustained loaded for 30 days in gaseous oxygen at 3000 psi or dry air. Test results are tabulated in Tables 30, 31, 32, 33, 34, 35 and 36 and are shown graphically in Figures 23, 24, 25 and 27.

Examination of the data further shows that proofing retards growth in subsequent loading to MDOP. During the 20 MDOP cycles, five specimens did not exhibit growth, one specimen grew 0.001 inch and the other five specimens grew 0.002 inch. None of the specimens showed growth during the 30 day sustained tests.

4.5 CYCLE THROUGH-THE-THICKNESS TESTS

Cycle through-the-thickness tests were conducted at 70°F in lab air; refer to Tables 37, 38 and 39. Specimen DBM-5 (Table 37) shows that a flaw can grow through-the-thickness in the tank base metal without causing catastrophic failure. This specimen was tested at 130 ksi. The tank operating stress at 3060 psi pressure is approximately 132 ksi. Specimens G-15 and G-16 (Table 38) show that a flaw can grow through-the-thickness in the thicker area near the weld without catastrophic failure. These specimens were tested at 95.7 ksi and 86.25/88.95 ksi. The tank stress is approximately 79 ksi in the weld area at 3060 psi operating pressure.

4.6 TANK TEST

The LM/ECS descent GOX tank (S/N 0041) was tested at various pressure levels. A flaw was introduced into the tank outer surface, parallel to and 0.25 inches from the girth weld ℄ by EDM. The initial flaw was precracked for 2500 cycles at a pressure of 1340 psi and at a frequency of 20 cycles per minute. When it had been established that a good precrack existed, cycling at 2520 psi and 10 cpm was commenced. This pressure level corresponds with the pressure level used in the LM/ECS GOX descent tank on the Apollo 14 mission. After 1530 cycles at this operating pressure, the flaw grew through-the-thickness without catastrophic failure, and the tank was held at pressure for 20 minutes. The tank was then subsequently pressurized three times to 4000 psi and once to 4150 psi with cyclic marking at 3050 or 3030 psi between high pressure cycles. These pressure levels approximately corresponded to the tank proof pressures of 3990 psi and the maximum design operating pressure of 3060 psi. The testing was completed with one cycle to 4550 psi which was followed immediately by one cycle to 4500 psi. Burst tests were not conducted because the hydraulic pump capacity would be exceeded. The tank was then sawcut and the flawed area was made into a fracture specimen which was pulled to failure. A complete summary of tank tests is shown in Figure 32 and a photo of the fracture face is shown in Figure 33 along with the loading sequences. A photograph of the crack in the tank at the completion of testing is shown in Figure 34. Movies taken during testing have been delivered to NASA/MSC, Houston, Texas.

Testing this tank demonstrated that (1) a leakage mode of failure occurs at a pressure of 2520 psi in the weld area when a flaw is cycled through-the-thickness, (2) the tank could sustain a proof pressure cycle to 4000 psi or multiple MDOP cycles to 3060 psi without catastrophic failure, after a surface flaw had grown through-the-thickness and, (3) the tank could sustain a pressure cycle to 4550 psi without catastrophic failure after a surface flaw had penetrated the thickness and grown considerably in the length direction.

5.0 OBSERVATIONS AND CONCLUSIONS

Some of the major observations and conclusions from this study are presented below:

1. The predicted failure mode of the girth weld area of the LM/ECS descent GOX tank is leakage at a pressure of 2520 psi based on the fracture data developed. Test of an actual tank demonstrated that a tank with a surface flaw could be cycled to leakage at 2520 psi, then proof tested to 4000 psi followed by multiple cycles to about 3000 psi. After the through-crack had extended approximately 1.15 inches, the tank sustained a pressure of 4550 psi without catastrophic failure.

2. The sustained load threshold of D6 steel (that has been electroless nickel plated on one side and received about 28 hours of bake time at 375°F) is above 75% of the critical stress intensity when tested in either high pressure gaseous oxygen or dry air at room temperature.

3. Proof testing a LM/ECS descent GOX tank can cause significant flaw growth if a flaw is present. However, post proof cycling to maximum design operating pressures will cause negligible flaw growth (0.001 to 0.002 inch) for (20) cycles. Subsequent sustained pressure at MDOP will cause no growth during the tank intended service life.

4. The failure mode of a LM/ECS descent GOX tank during proof test to 4000 could either be catastrophic or leakage depending upon (1) the actual fracture toughness of the tank material, (2) the area of the tank containing the flaw and (3) the flaw shape. If a flaw was screened by the proof test because of combinations of low toughness, highly stressed area relative to the thickness and/or long flaws, safe operation would be guaranteed for 20 MDOP cycles at 3060 psi. If a flaw was not screened by the proof test because of combinations of high toughness, lowly stressed area relative to the thickness and/or short flaws, functional operation would not be guaranteed at 3060 psi. The failure mode in this case would be leakage rather than catastrophic.

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APPENDIX A - EDM SPECIMENS

INTRODUCTION

At the onset of this fracture program, surface flaws were introduced into D6 steel specimens [1] by EDM. Sustained load tests of these specimens demonstrated that various amounts of flaw growth occurred. The flaw growth observed in base metal specimens (0.125 inches thick) and weld metal specimens (0.205 inch thick) was about 0.002 inch and 0.010—0.020 inch, respectively. It was initially thought that the sustained load growth was a result of hydrogen being present in the steel caused by the electroless nickel plating process (Reference A-1). A flawed weld metal specimen was baked out for 24 hours at 375°F and then sustain loaded for 20 hours. No flaw growth was observed on this specimen. It was later determined that whether or not sustained load flaw growth was present, was dependent upon whether or not the flaw was EDM after or prior to the bake out procedure. It was initially thought that the free surface provided by the EDM starter notch and precrack permitted the hydrogen to escape more readily in the vicinity of the flaw. This idea was later discarded when specimens which were mechanically flawed by a high speed cutter after being baked were sustained loaded and had no sustained load flaw growth. Apparently, hydrogen was being pumped into the steel material by the EDM process. Ionized hydrogen is formed between the EDM electrode and part being EDM when there is a discharge of electricity in the dielectric fluid. The dielectric fluid used for most of the EDM was a hydrocarbon-kerosene. Once the sustain load flaw growth problem was determined to be related to the EDM process, all surface flaws were introduced by mechanical machining.

RESULTS AND DISCUSSION

The data generated using EDM flaws is presented in the following paragraphs.

Static fracture values are tabulated in Tables A-1, A-2, A-3, and A-4. Load/unload tests are shown in Tables A-5 and A-6. Sustained load tests are shown in Tables A-7 through A-19. Sustained load times ranged from 4.9 to 504.7 hours. End-point static fracture values are reported with the primary test data for each specimen.

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[1] Electroless nickel plated and bake for 4 hours at 375°F.

Most K_{Ic} values are in the 97.1 to 112.6 ksi $\sqrt{in}$ range reported in the main body of this report. Notable exceptions are the base metal specimens from the S/N 0010 tank (TB-XX) reported in Tables A4, A6 & A11. All but one (TB-18) of these specimens had K_{Ic} or end-point values ranging from 71.3 to 80.7 ksi $\sqrt{in}$. These specimens with low toughness values were all 0.8 inch wide. Net section effects would be magnified in subsize specimens such as these. Therefore, the K_{Ic} values produced by these small specimens are not considered to be representative of the true K_{Ic} of the tank base metal. Specimen TB-18 was 1.0 inch wide in the test section. While this specimen is still too small for a valid test, the K_{Ic} value of 94.1 ksi $\sqrt{in}$ produced from this specimen is probably a better representation of the tank base metal toughness. EDM specimens without baking afterward did not appear to effect K_{Ic} values. However, it is conceivable that hydrogen introduced during EDM could cause more growth-on-loading to occur during the loading of these specimens, thereby producing lower calculated K_{Ic} values.

Although most load/unload and sustained data could not be used, there were still some data points of interest. An overall examination of all of the sustained load specimens showed that, in general, those specimens which showed the most growth had a relatively smooth surface on the EDM cut. This indicates that more hydrogen absorption occurs during a slow (smooth) cut than during a fast (rough) cut.

Examination of data from similarly baked specimens in Table A19 shows that the EDM depth can have an effect on the sustained load results. Specimens GW-14 and GW-20 had normal EDM with precrack extensions of 0.015 and 0.007 inch, respectively. Specimens GW-16, GW-21 had shallow EDM flaws with precrack extensions of 0.027 and 0.075 inch respectively. All four specimens had relatively smooth EDM. The specimens with the shallow EDM had less sustained growth than those with deep EDM. EDM sustained load specimens which were instrumented for COD measurements showed that the sustained growth rate as a function of time decreased with an increase in crack length. This would be a result of the crack moving away from the EDM area and/or using up the available hydrogen in the material.

CONCLUSIONS

Removal of material from a high strength steel of the D6 or 4340 class by electric discharge machining appears to cause hydrogen embrittlement of the material surface and could thereby affect the service life of such parts.

APPENDIX A - REFERENCES

A-1 Buzzard, R. W. and Cleaves, H.E.; "Hydrogen Embrittlement of Steel: Review of the Literature", National Bureau of Standards Circular 511, September 24, 1951

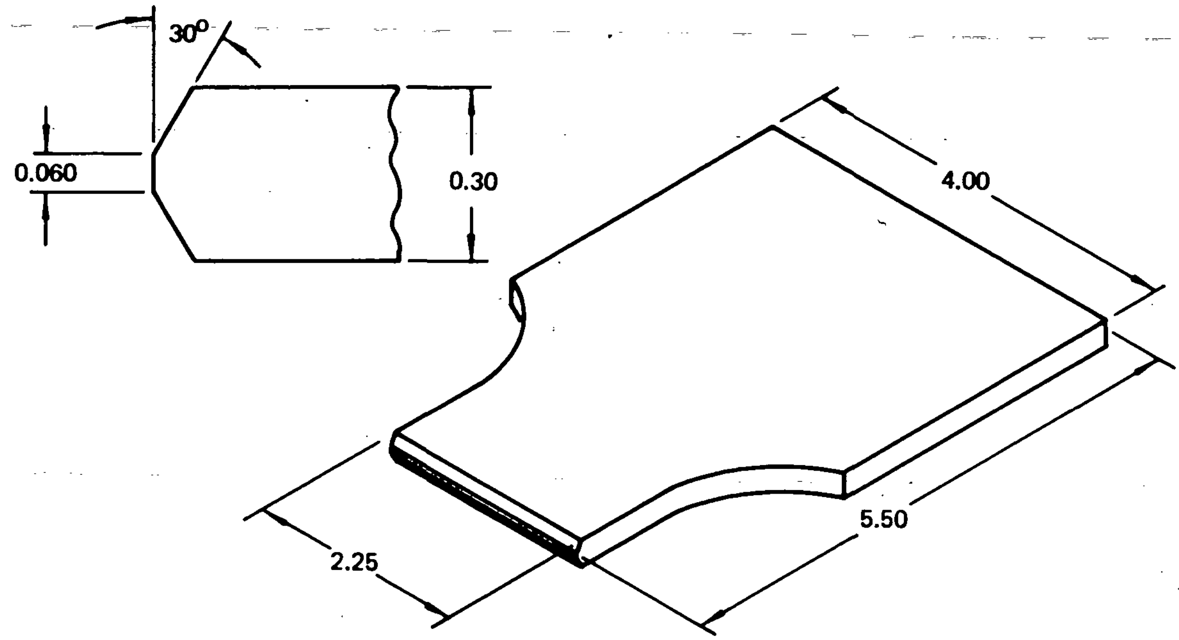
APPENDIX B - CONTROLLED EDM STUDY

Controlled EDM Study

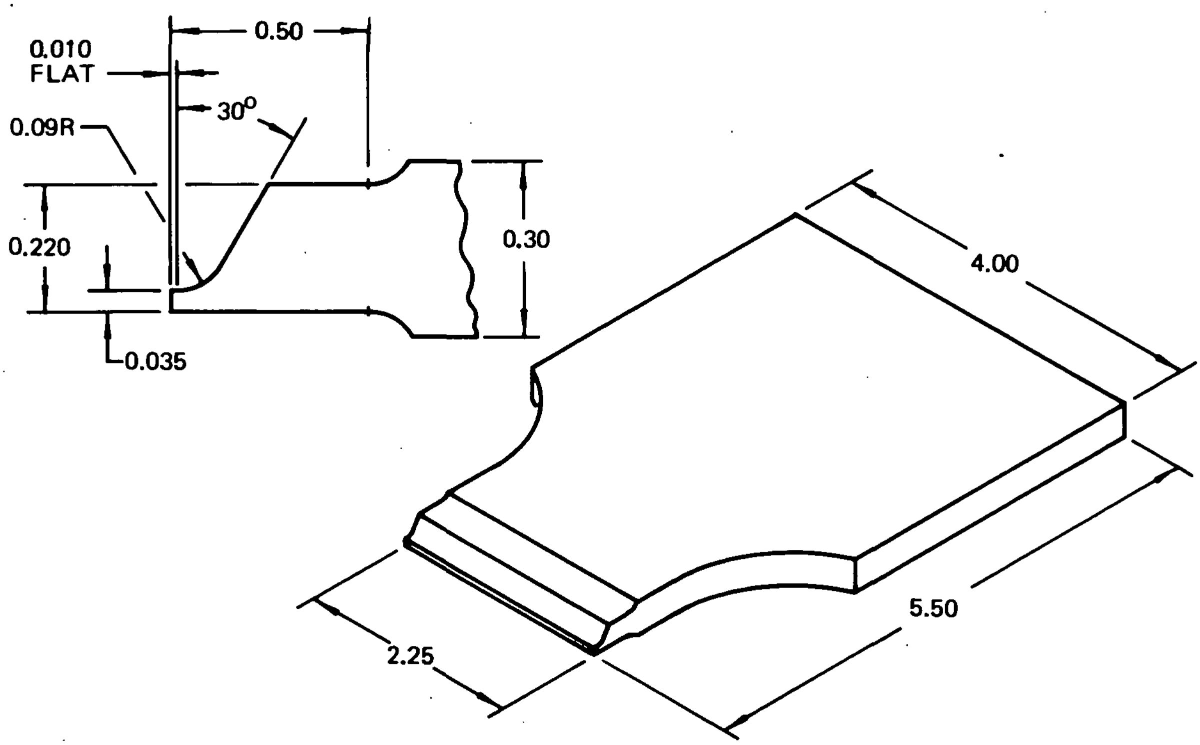
Five D6 steel specimens were EDM and sustained loaded for about 20 hours. EDM settings and cutting times were recorded to see if a correlation could be made between settings and the amount of sustained growth observed. Three different machines were used. All were manufactured by Eleroda and were Models D1, D1-S, and D4. The D1 and D1-S machines employed kerosene as a dielectric fluid, whereas the D4 machine employed hydraulic oil. Copper-Tungsten electrodes were used. The specimens were previously nickel plated and baked 4 hours at 375°F in air and then baked 180 hours at 600°F in flowing nitrogen. After EDM and precracking, the specimens were sustain loaded in dry air to 140 ksi. The detailed test data are shown in Table B1.

GW-32 and GW-33 were both EDM in the D1 machine with a fast and slow EDM respectively. GW-32 showed 0.001" growth in the Δa direction and GW-33 showed 0.004" growth. GW-34 and GW-35 were both EDM in the D1-S machine with a fast and slow EDM respectively. GW-34 showed 0.002" growth and GW-35 showed 0.017" growth. Comparison of these 4 data points indicates that there may be a variation in hydrogen input caused by different machine characteristics, as well as cutting times. It appears that a slower EDM cut will introduce more hydrogen into the notch, thereby causing more sustained load growth (or growth-on-loading).

Specimen GW-36 was supposedly cut at a relatively slow speed in the D4 machine (using hydraulic fluid), however, the actual total cutting time was much less than any of the other specimens (30 minutes vs. 45 to 190 minutes). This specimen showed 0.003" growth.



BASE METAL SPECIMEN HALVES



WELD METAL SPECIMEN HALVES

Figure 1: WELD PREPARATION OF BOEING PROCESSED SPECIMENS

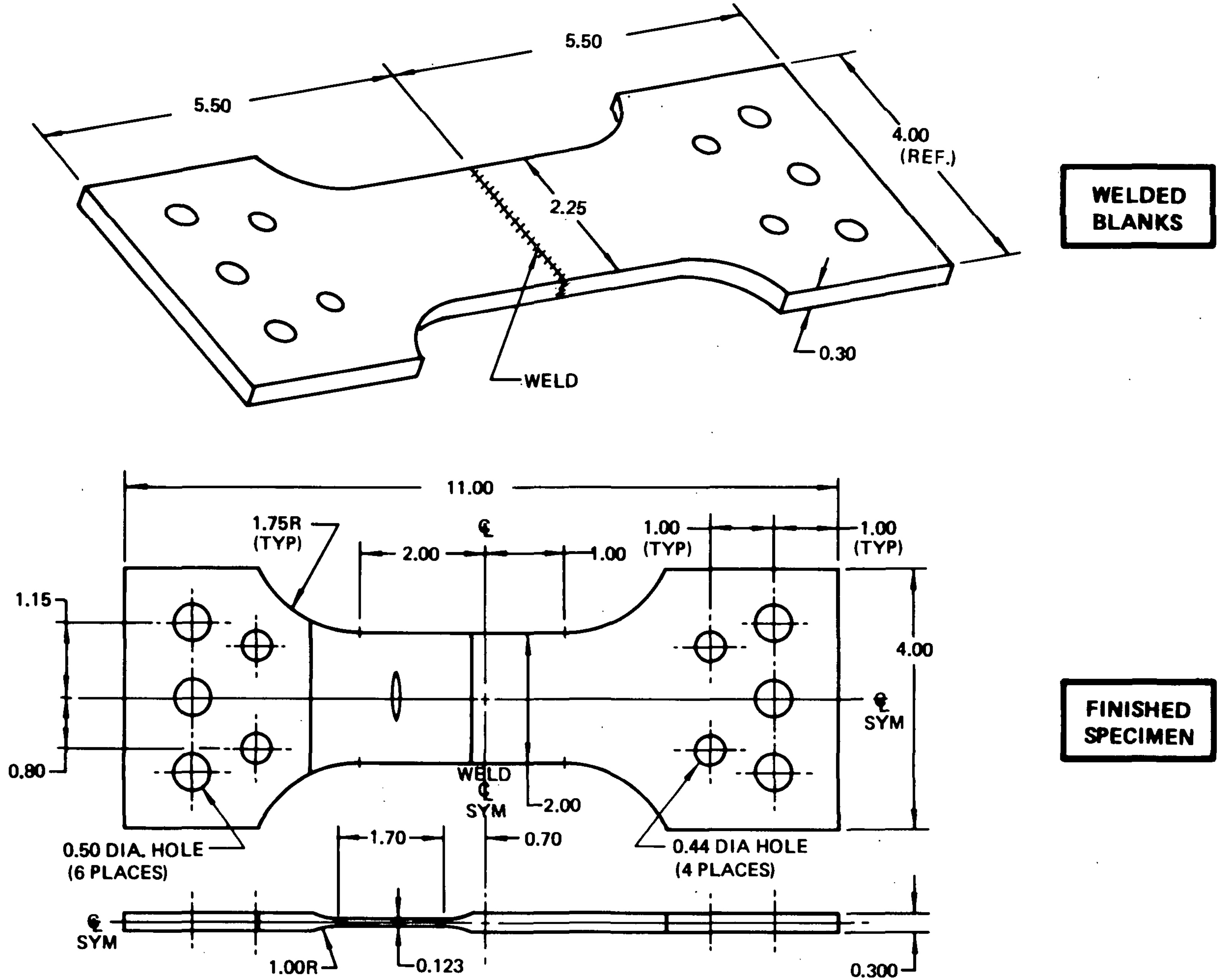


Figure 2: BOEING PROCESSED D6 STEEL FORGING BASE METAL SPECIMEN (DBM-XX)

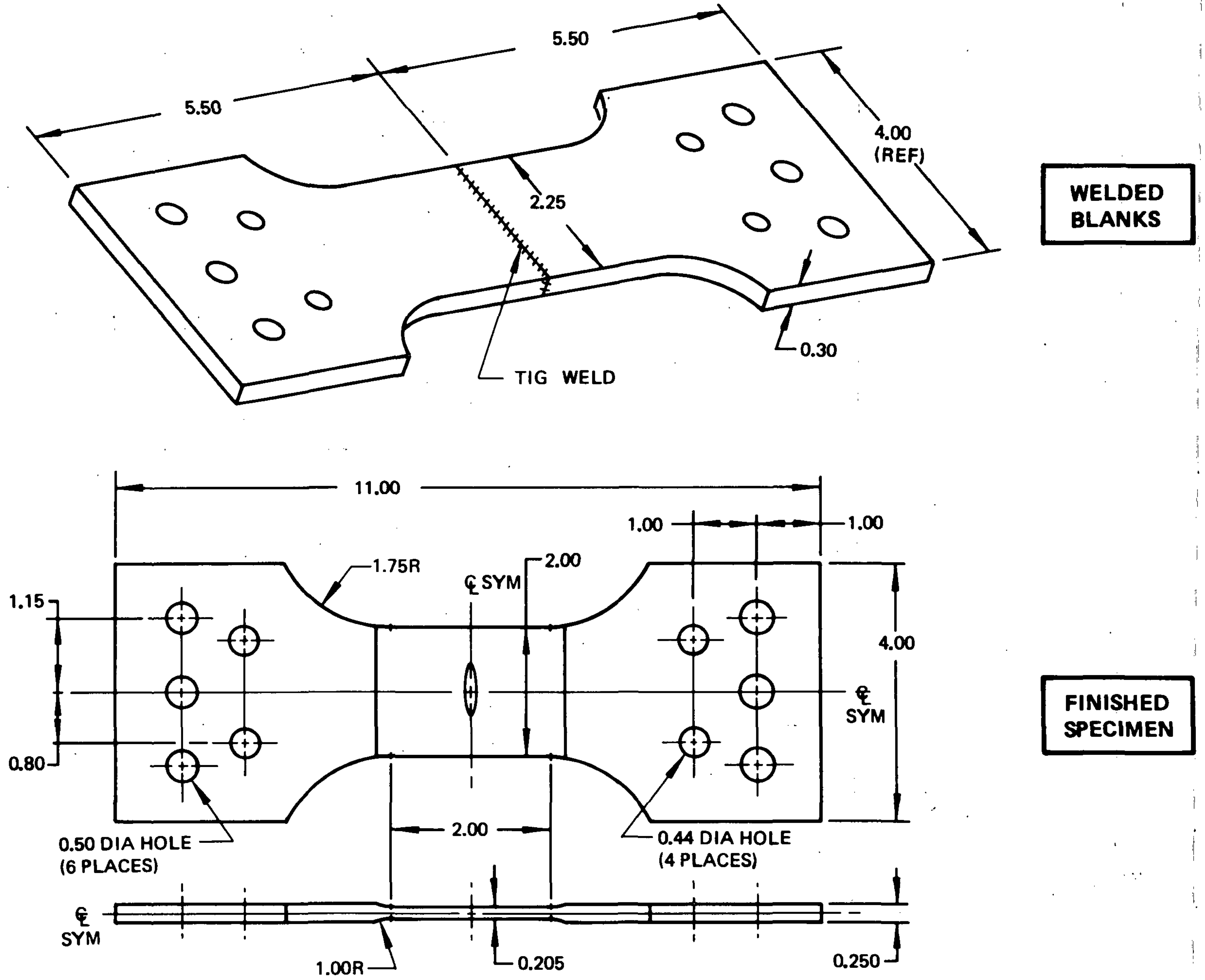


Figure 3: BOEING PROCESSED D6 STEEL FORGING WELD METAL SPECIMEN (DWM-XX)

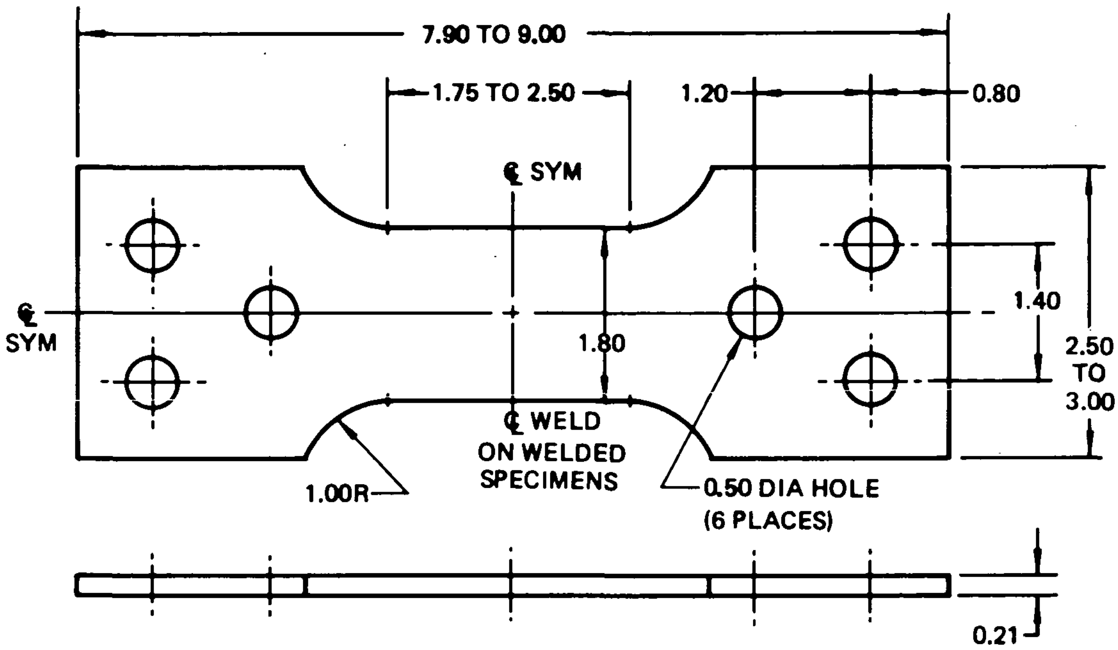


Figure 4: 0.21 THICK PLATE SPECIMENS (G-XX, GBM-XX, GW-XX, GB-XX)

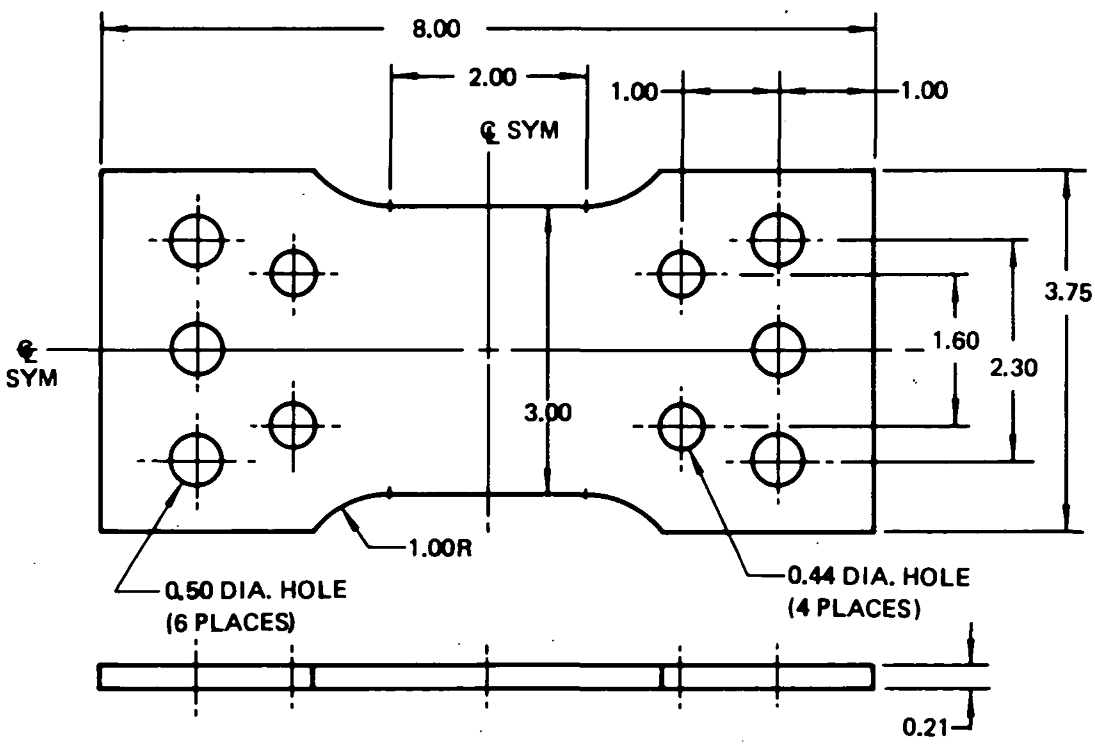


Figure 5: WIDE 0.21 THICK PLATE SPECIMEN (SG-XX)

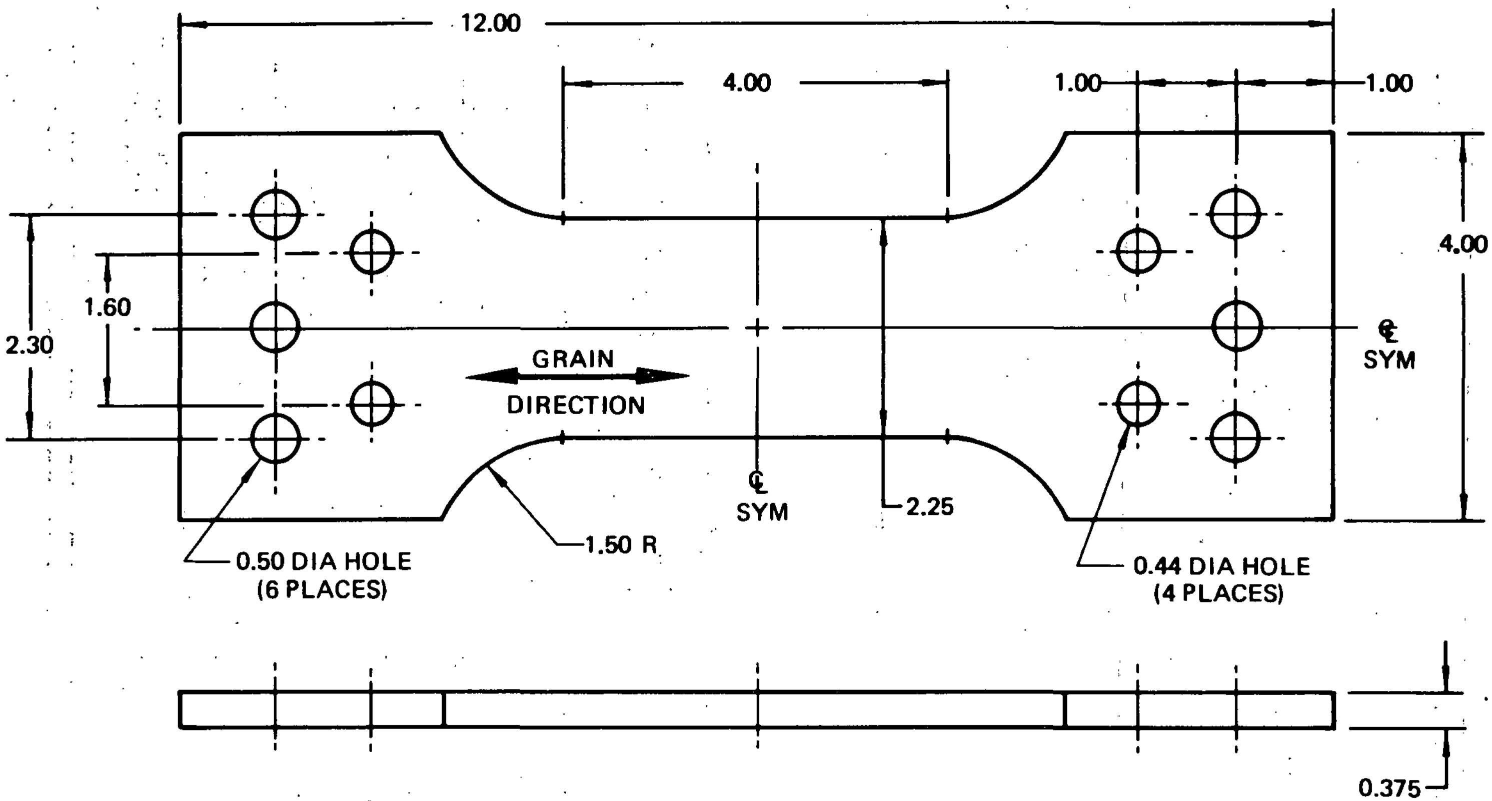


Figure 6: 0.375 THICK PLATE SPECIMEN (GTB-XX)

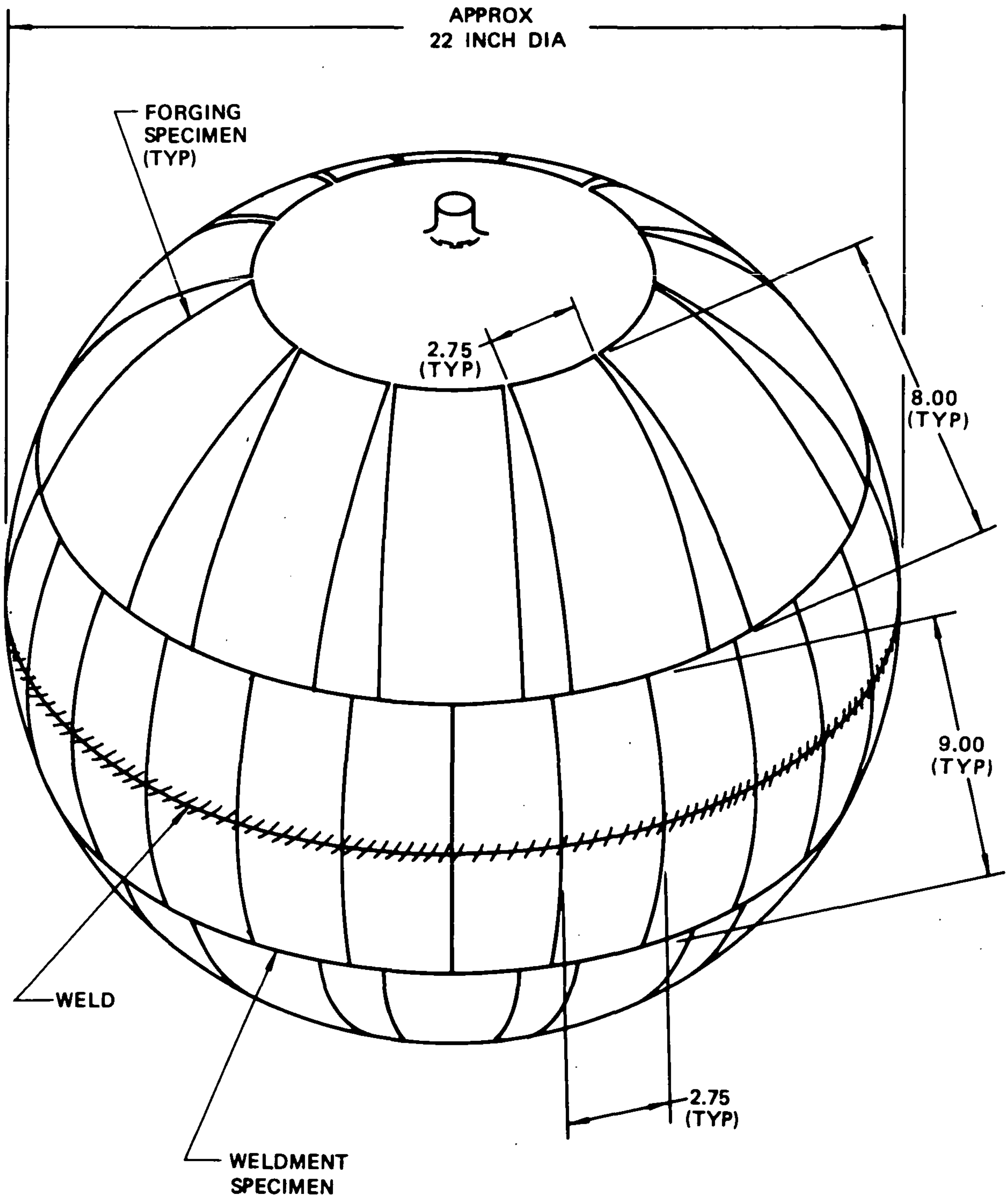


Figure 7: LOCATION OF SPECIMENS TAKEN FROM TANKS

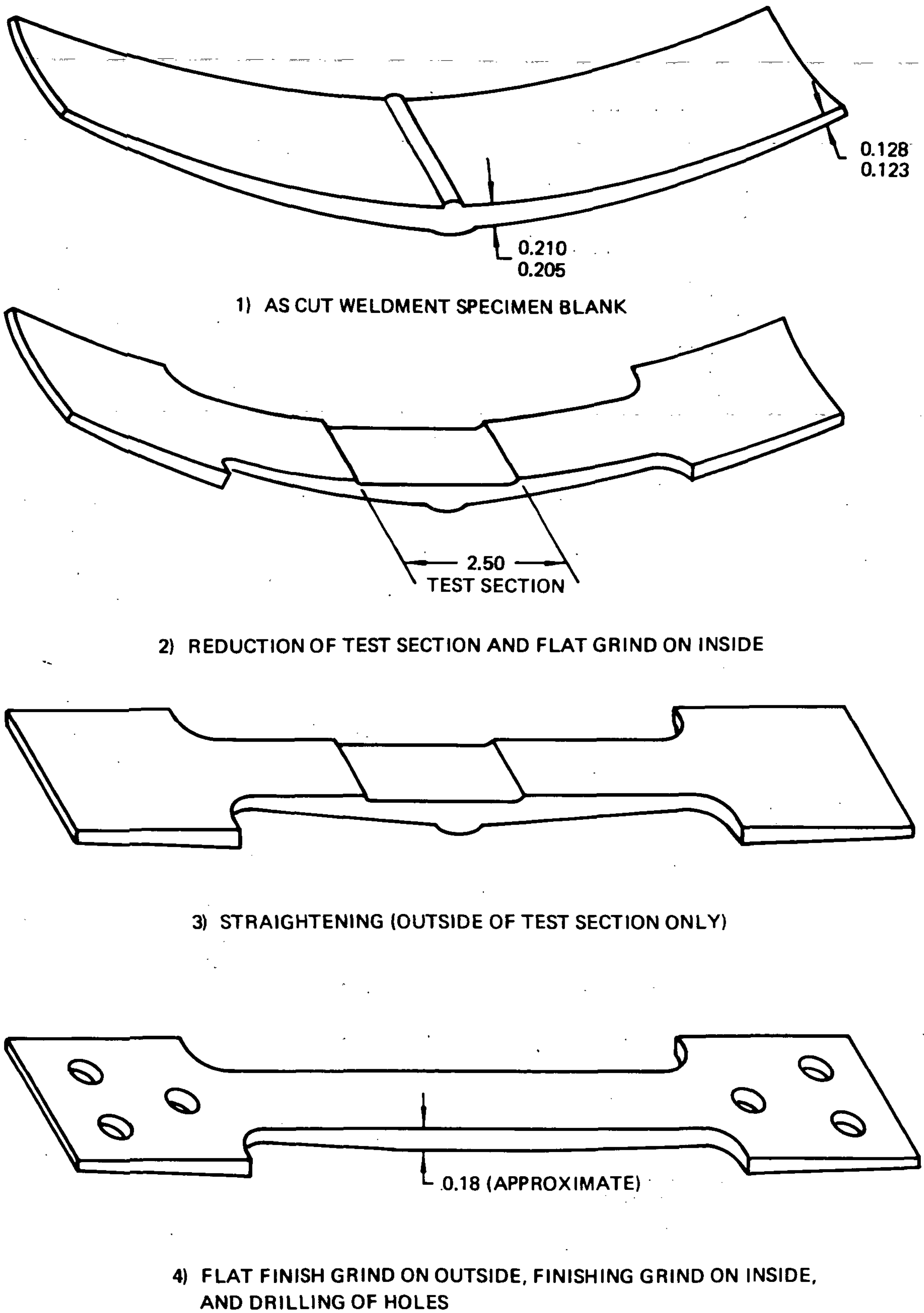


Figure 8: **STEPS IN FABRICATION OF WELDMENT SPECIMENS FROM TANK**

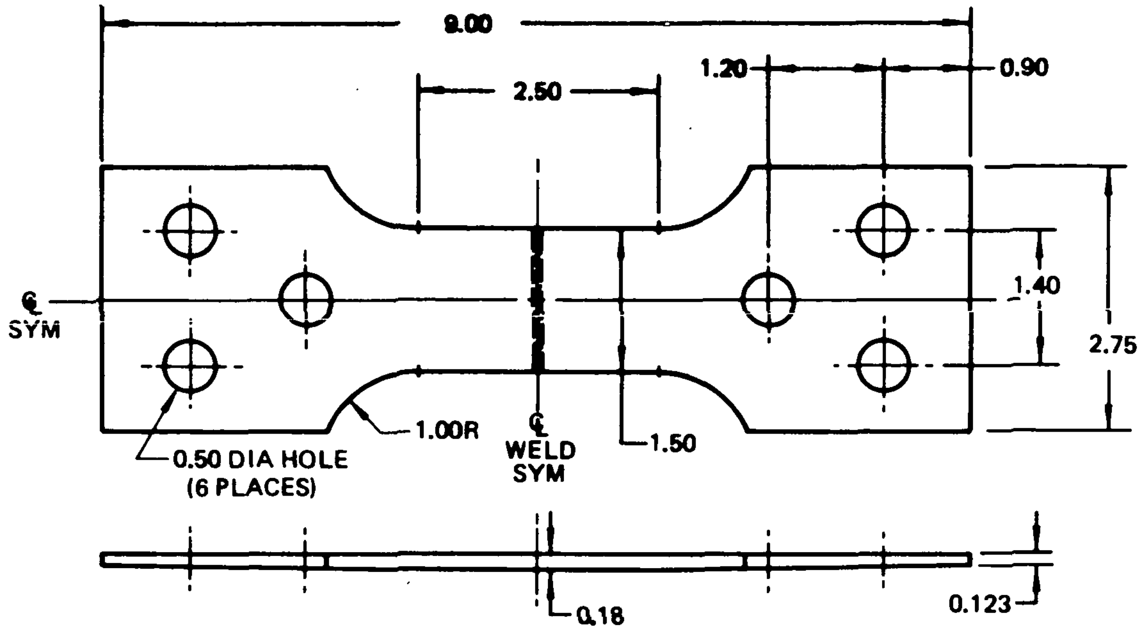


Figure 9: WELDMENT SPECIMENS FROM LM/ECS GOX DESCENT TANKS (TW-XX, SN41-X)

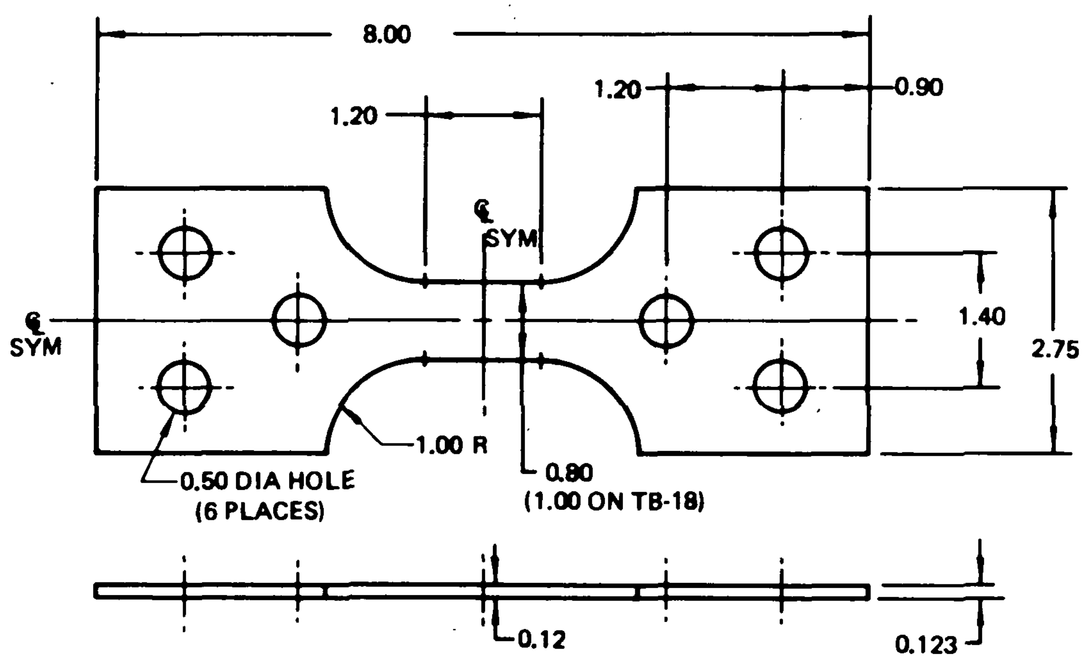


Figure 10: BASE METAL SPECIMENS FROM LM/ECS GOX DESCENT TANK (TB-XX)

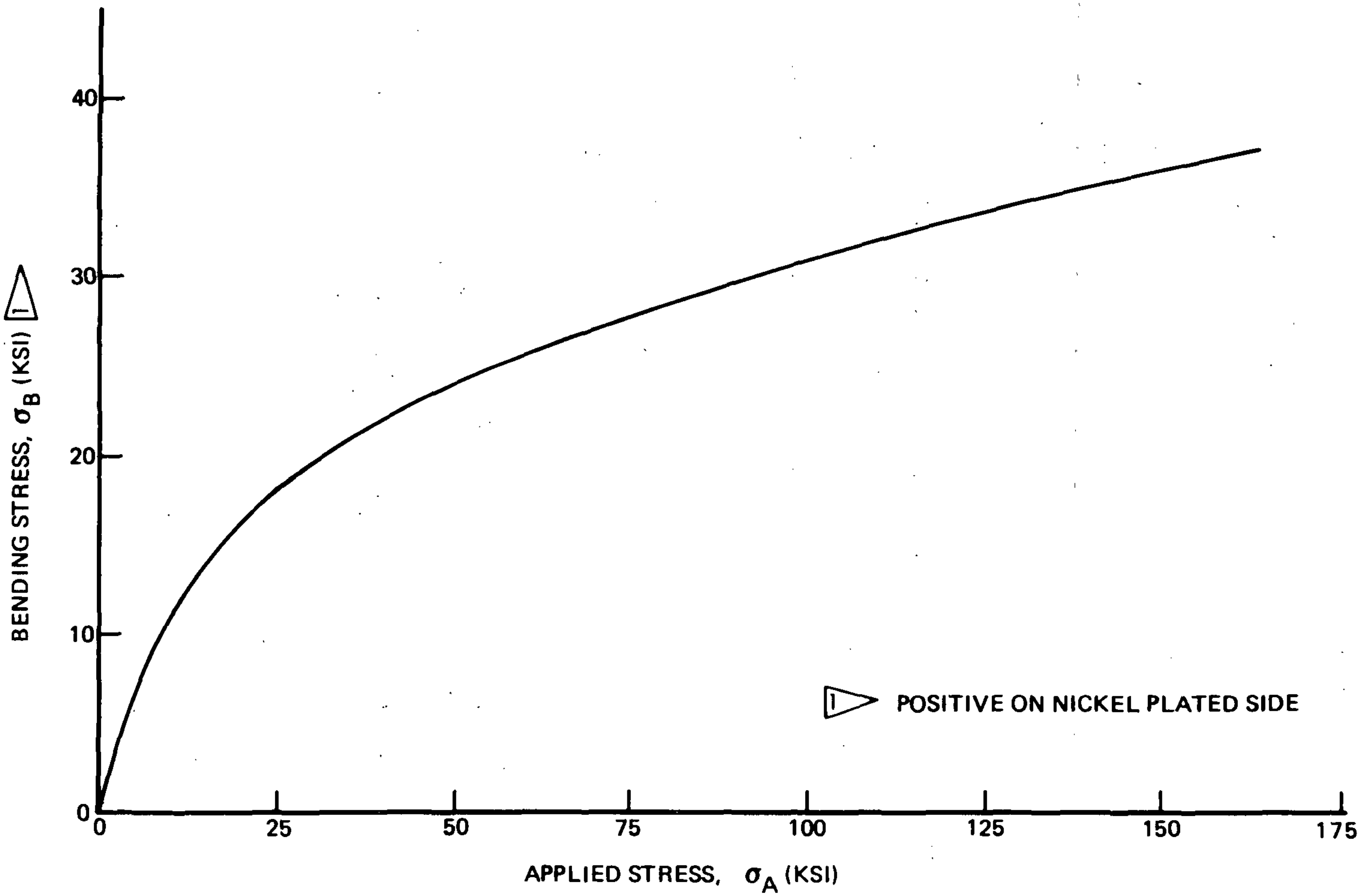


Figure 11: BENDING STRESSES IN A TYPICAL TANK WELDMENT SPECIMEN (TW-13)

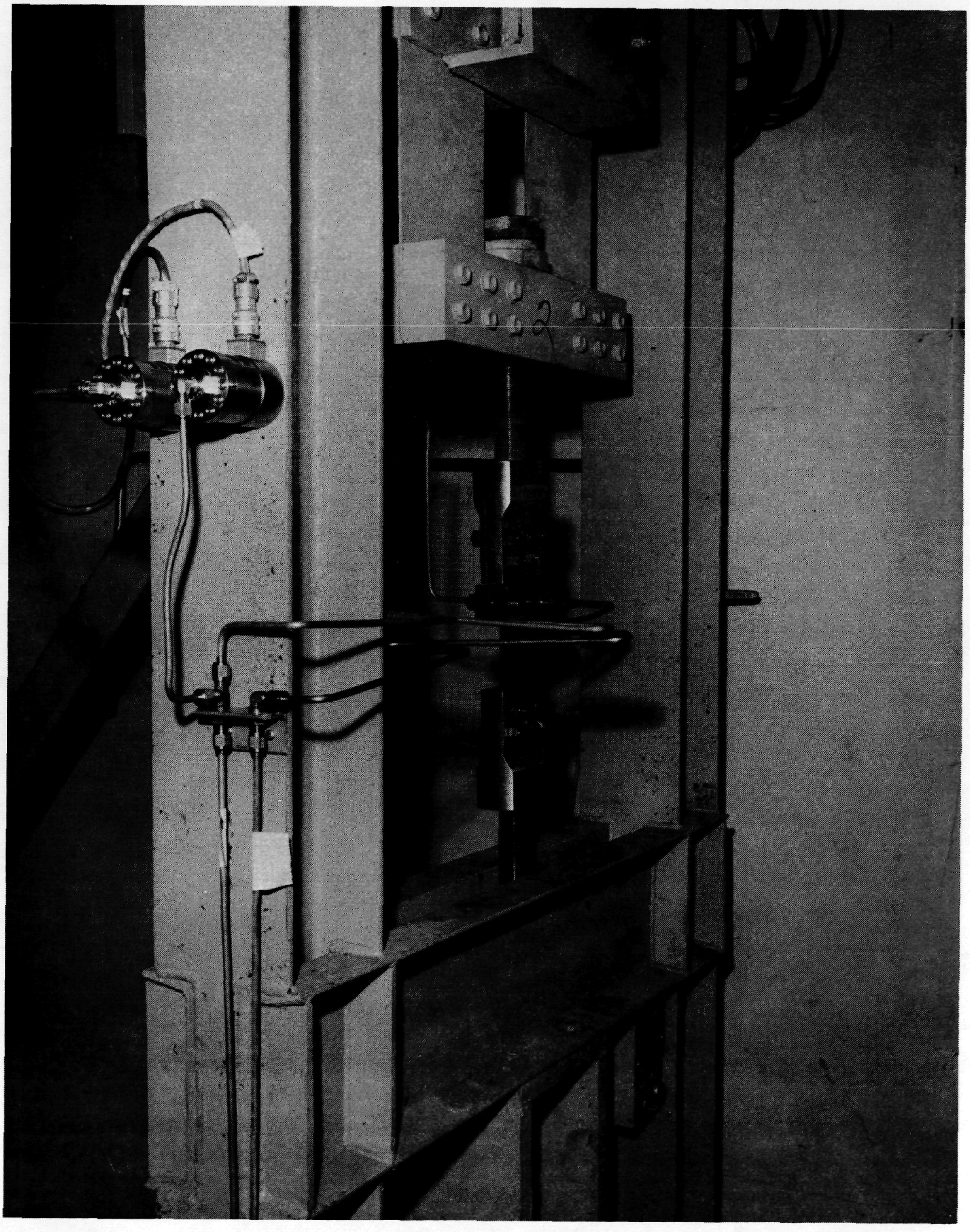


Figure 12: SPECIMEN WITH GOX PRESSURE CUPS INSTALLED IN TEST MACHINE

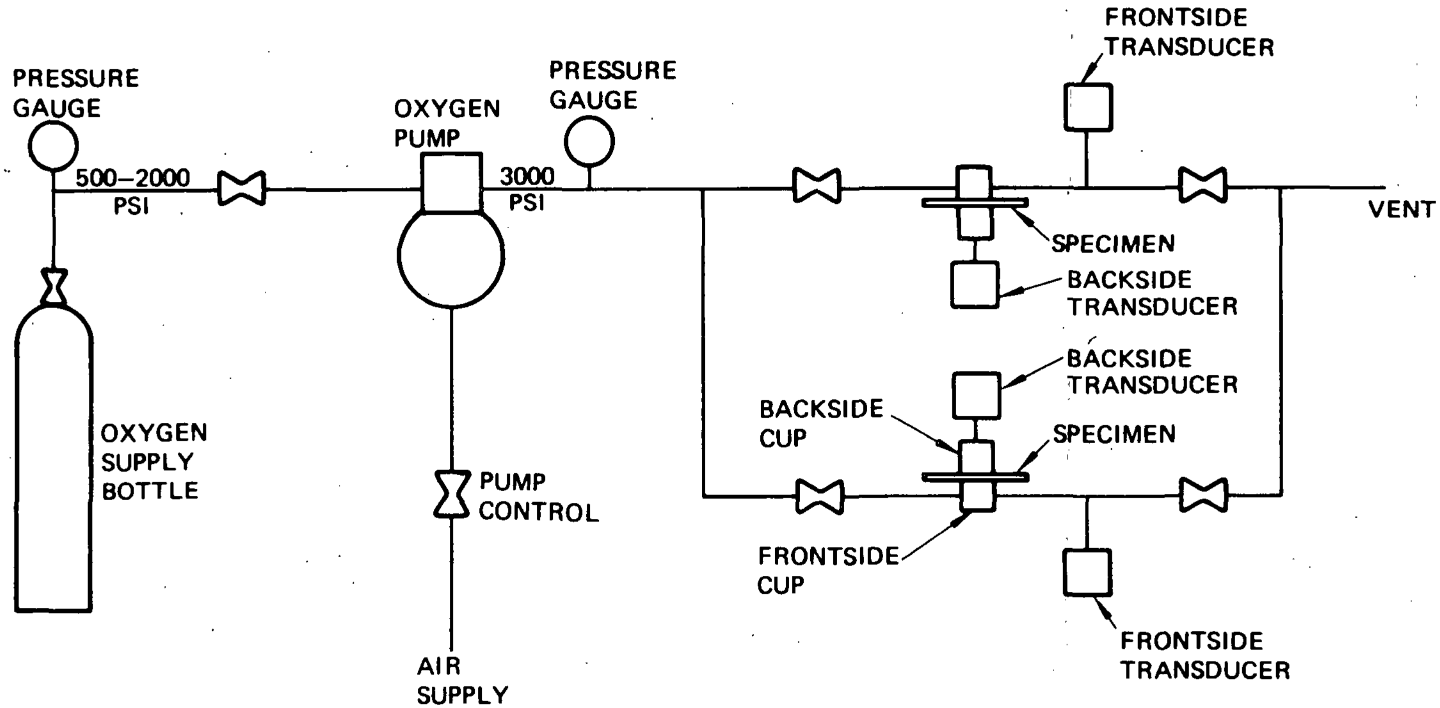


Figure 13: 3000 PSI GOX TEST SETUP SCHEMATIC

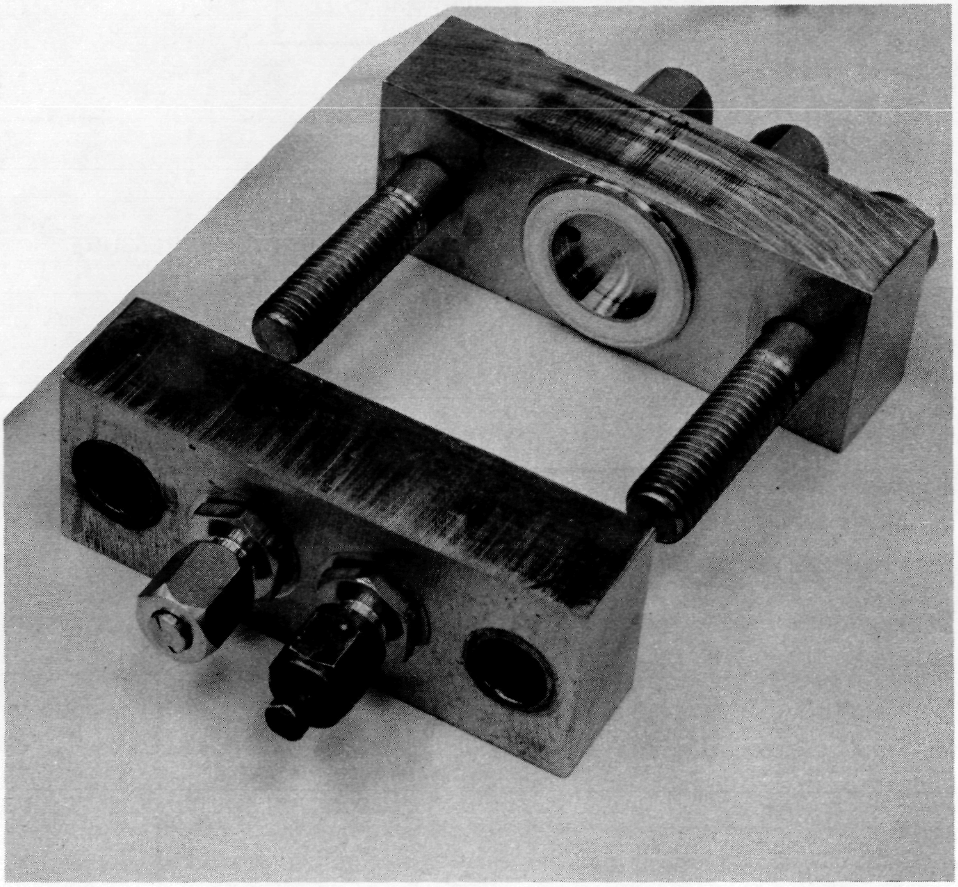


Figure 14 : PRESSURE CUPS

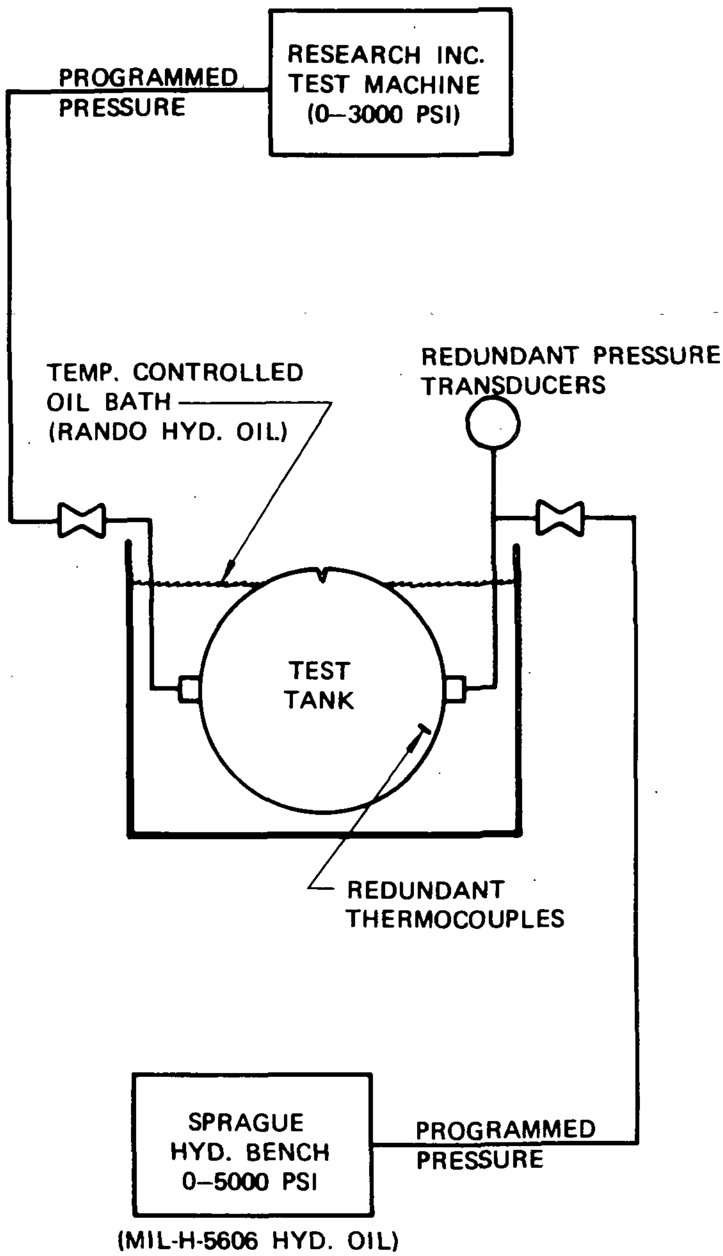


Figure 15: SERIAL NUMBER 0041 TANK TEST PRESSURE SYSTEMS SCHEMATIC

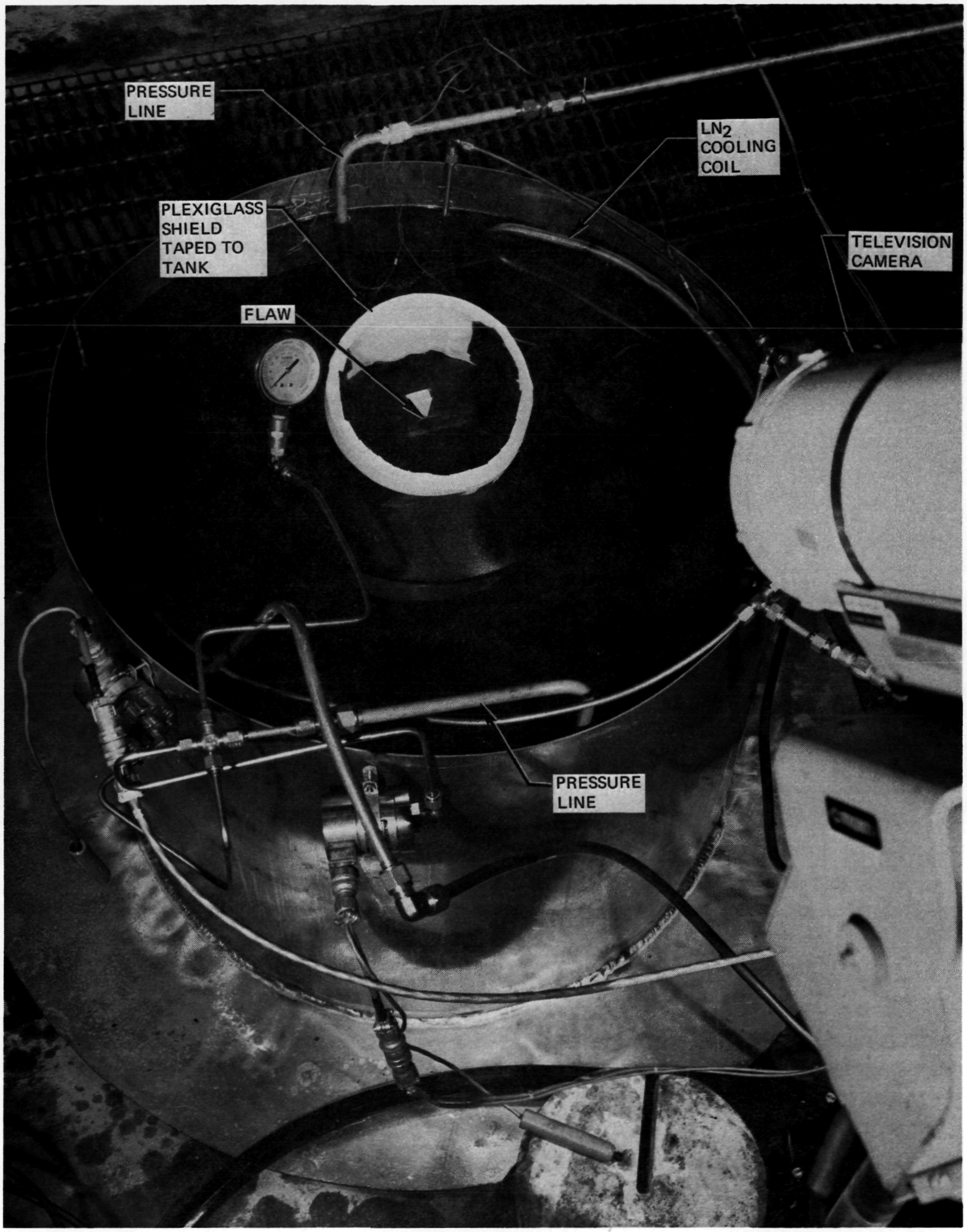


Figure 16: S/N 0041 TANK TEST SETUP

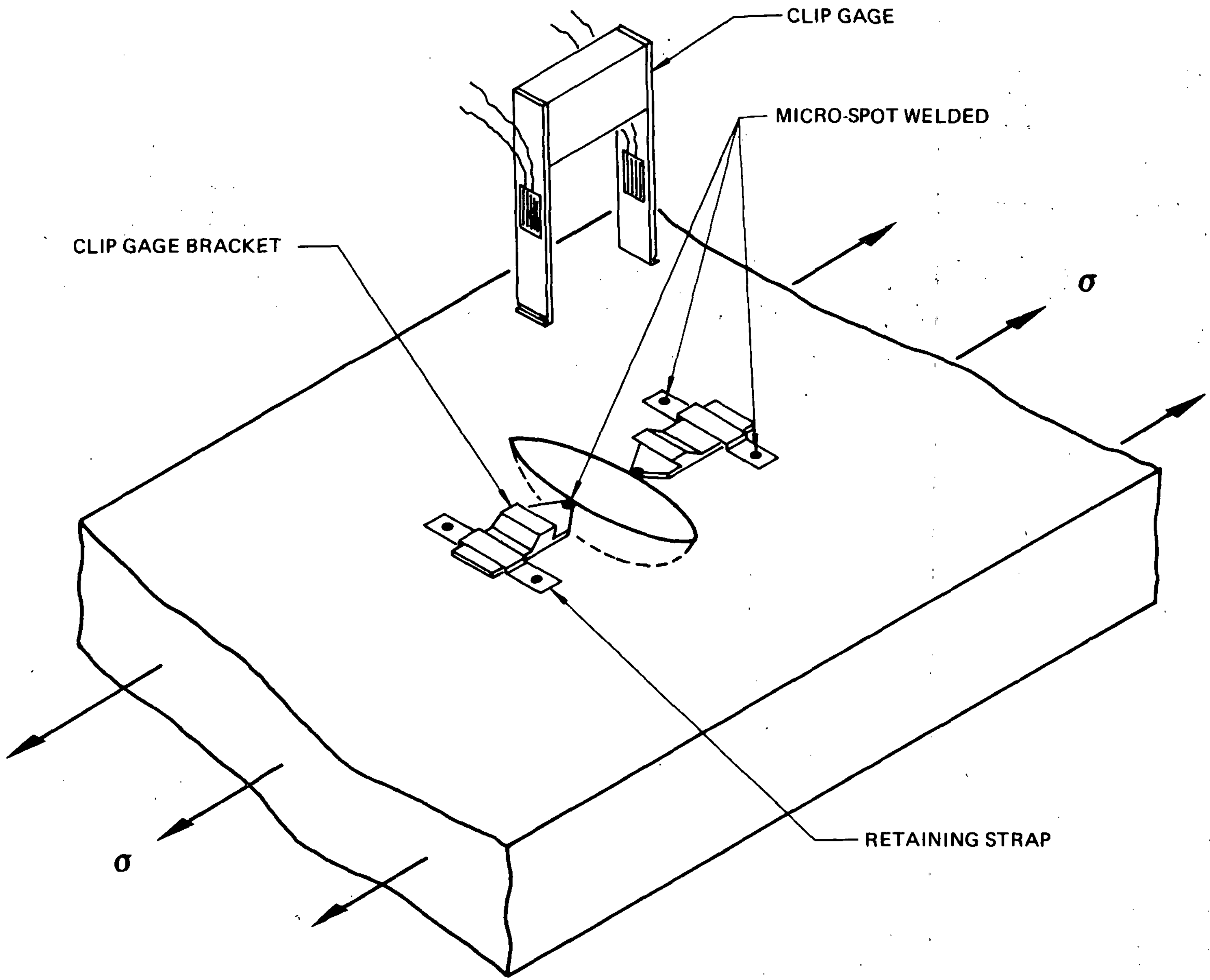


Figure 17: FLAW OPENING MEASUREMENT OF SURFACE FLAWED SPECIMENS

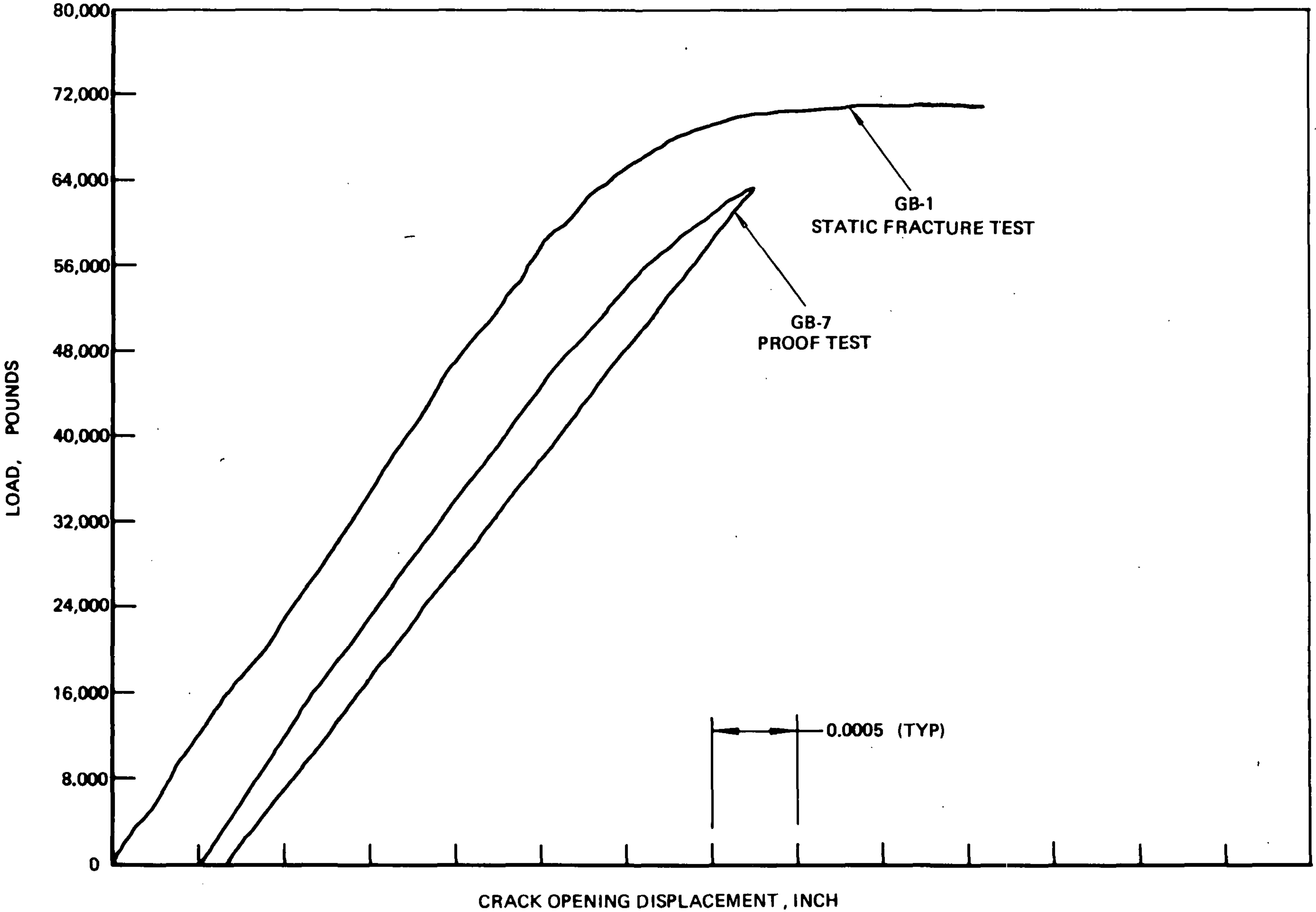


Figure 18: TYPICAL STATIC FRACTURE & PROOF TEST FOR LONG TRANSVERSE GRAIN D6 STEEL PLATE

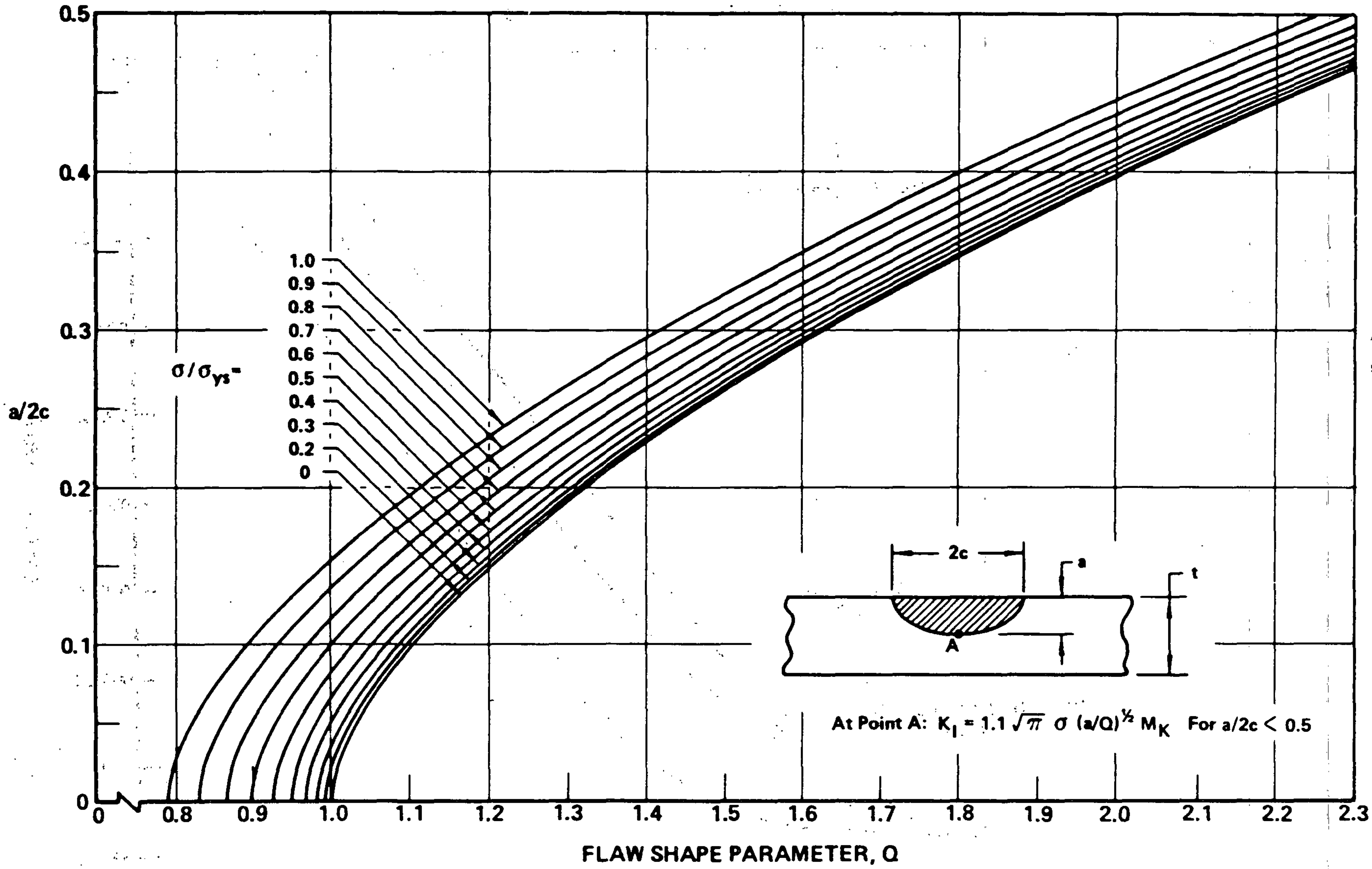


Figure 19: SHAPE PARAMETER CURVES FOR SURFACE AND INTERNAL FLAWS

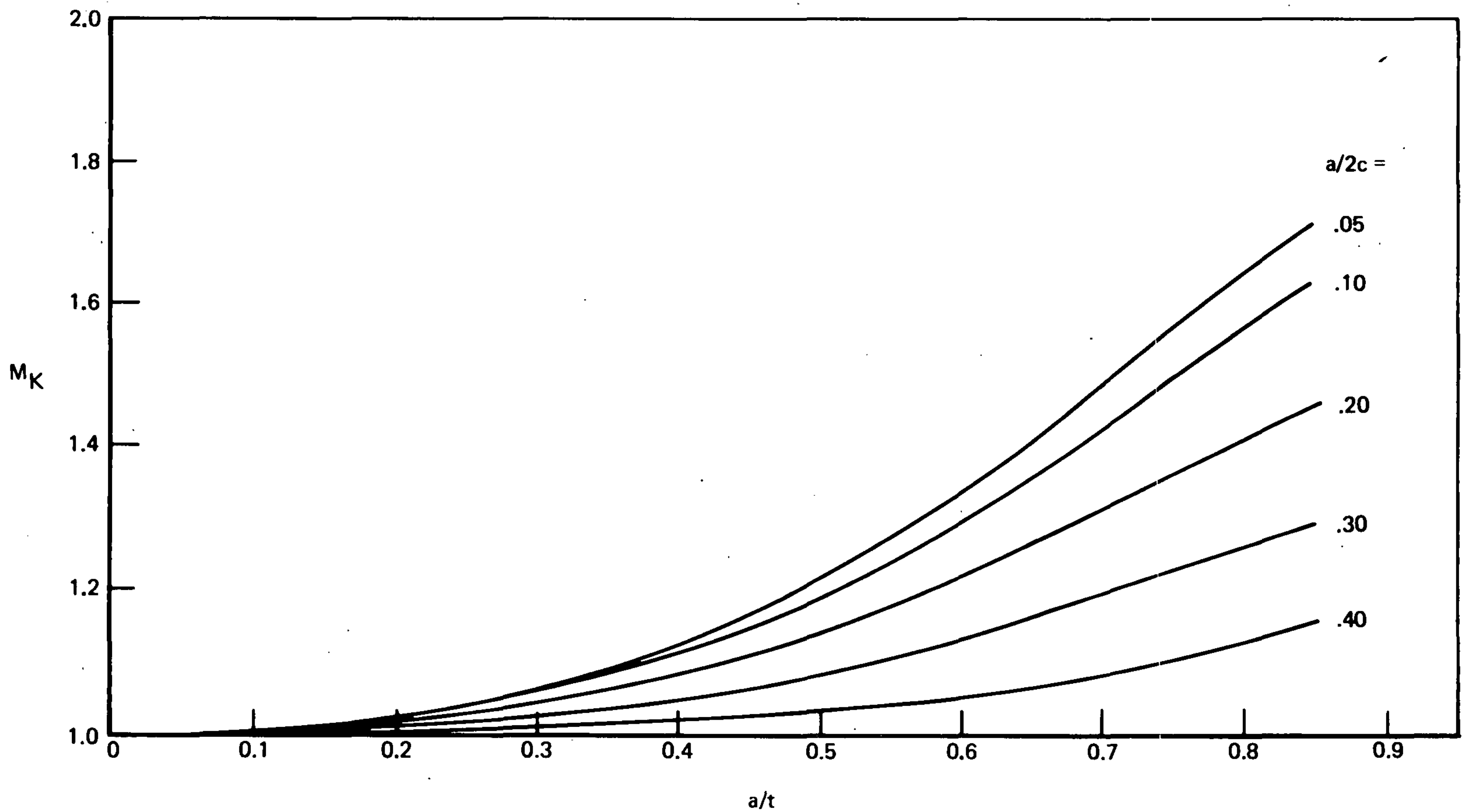


Figure 20: DEEP FLAW MAGNIFICATION CURVES (t = 0.625", 2219-T87 Aluminum Base Metal, Longitudinal Grain, At R. T., -320°F & -423°F) (Reference 2)

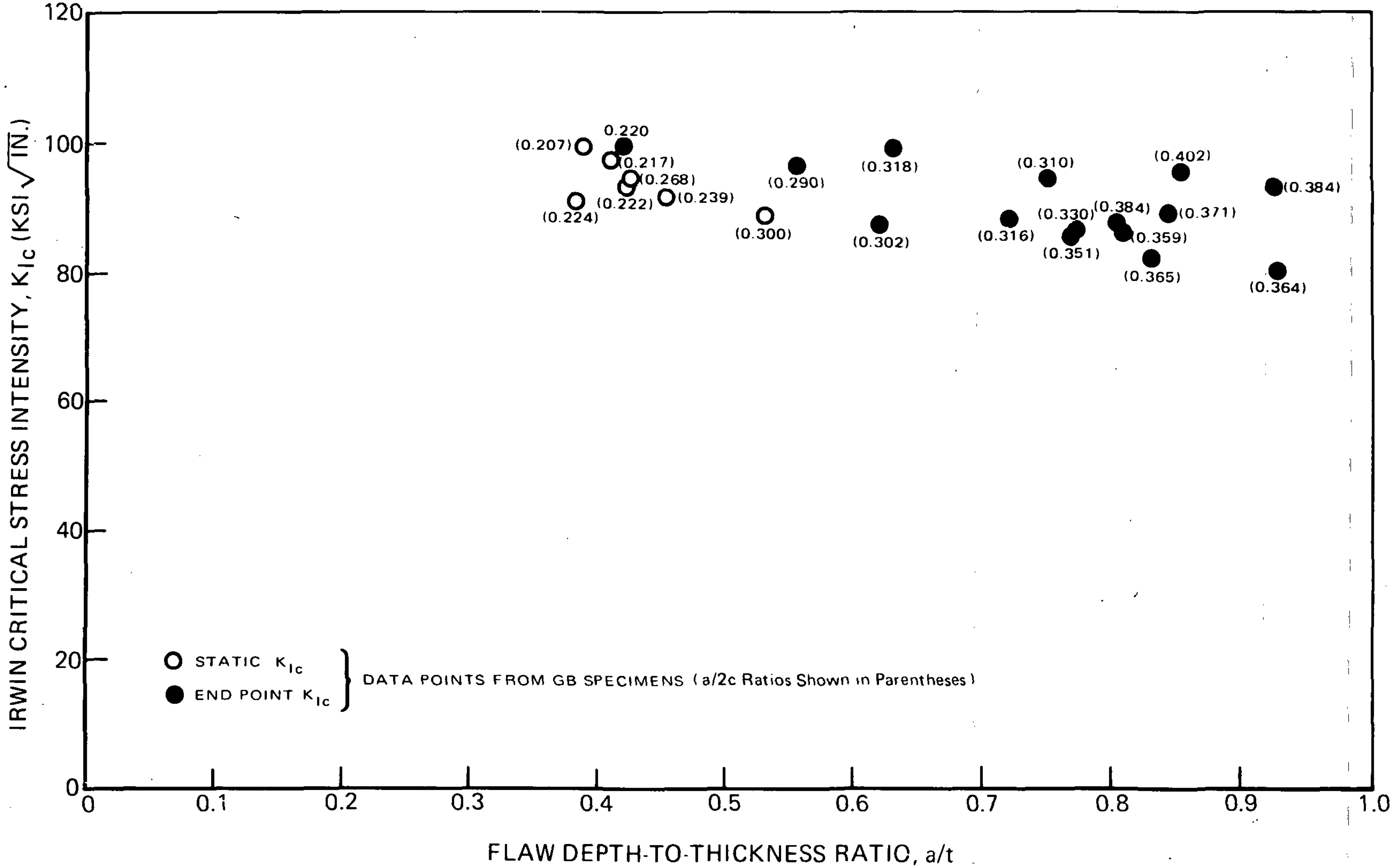


Figure 21: IRWIN CRITICAL STRESS INTENSITY AS A FUNCTION OF a/t

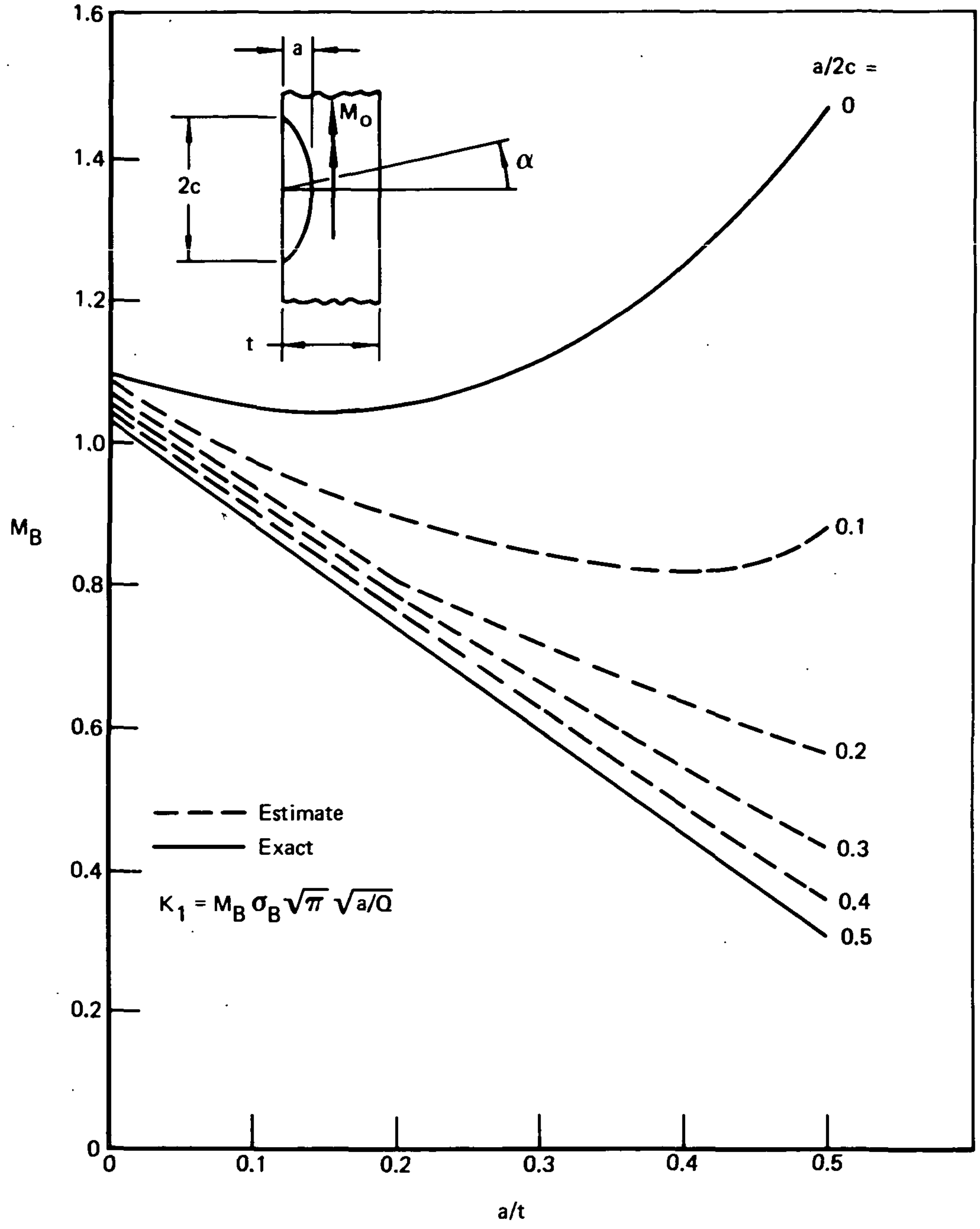


Figure 22: APPROXIMATE STRESS INTENSITY FACTORS FOR SEMI-ELLIPTICAL SURFACE FLAWS IN BENDING AT $\alpha = 0$ (Reference 3)

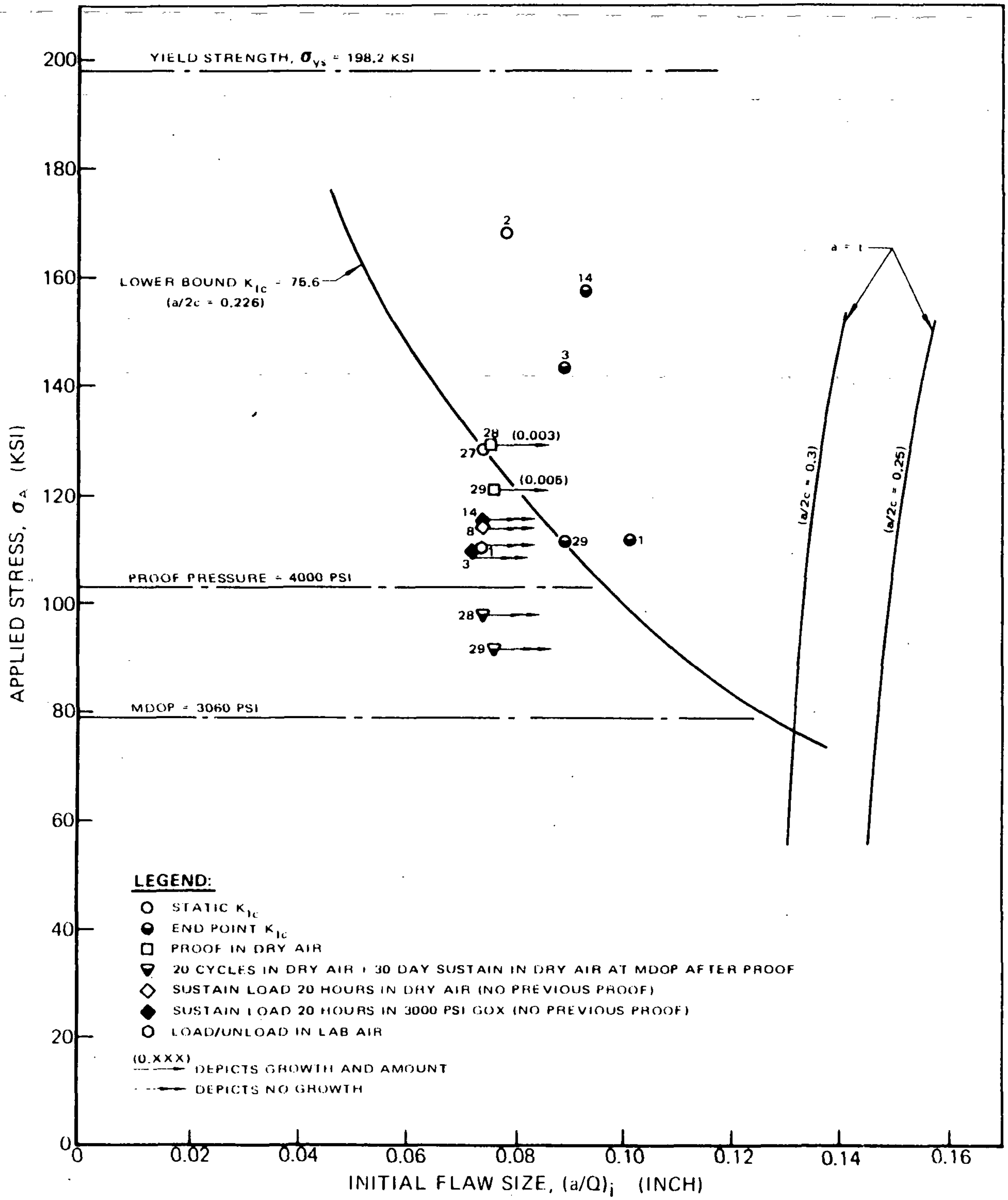


Figure 23: TEST RESULTS OF NICKEL PLATED, 0.21 INCH THICK, LONGITUDINAL GRAIN D6 STEEL PLATE (CODE: G-XX)

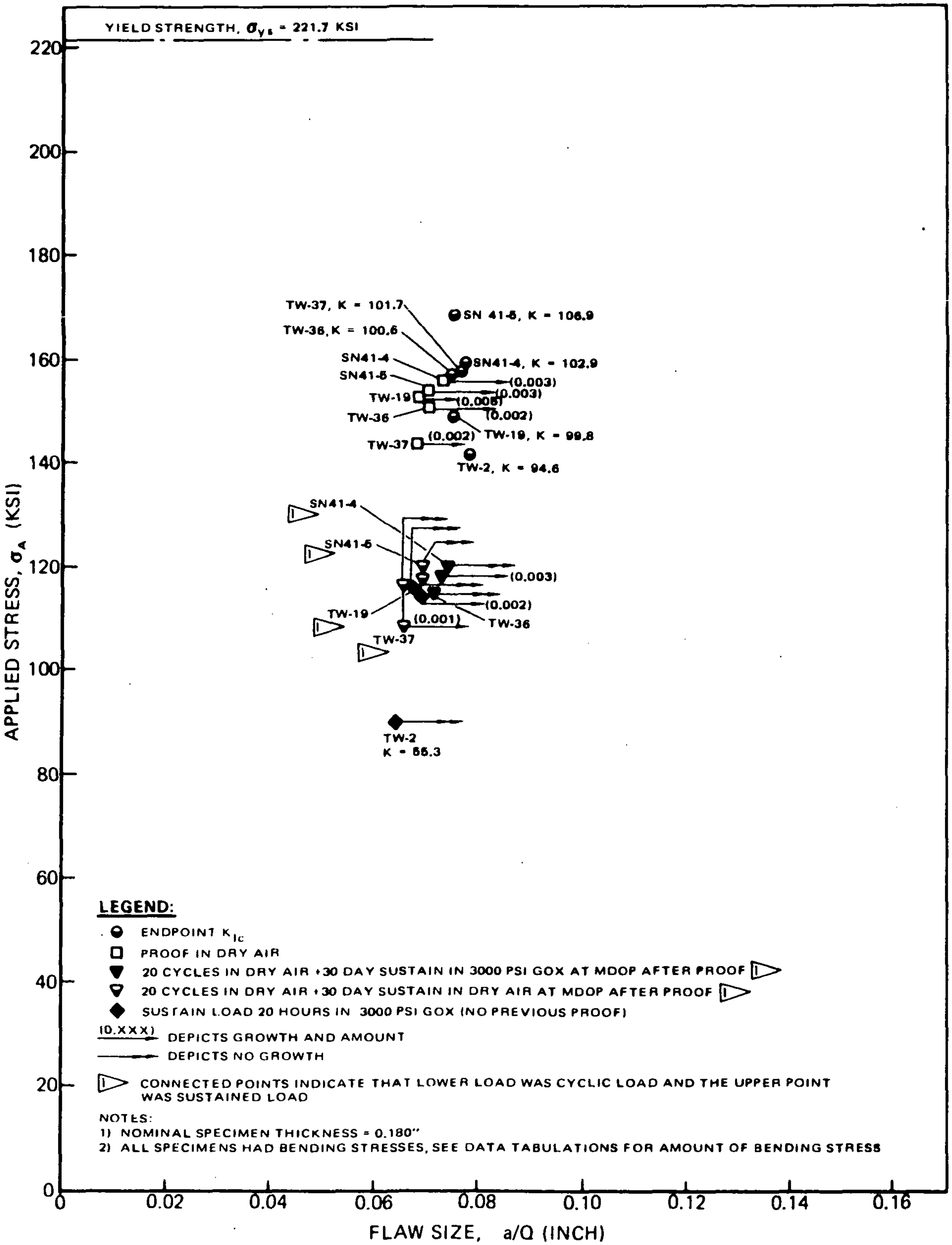


Figure 24: TEST RESULTS OF D6 STEEL WELDMENT SPECIMENS FROM LM/ECS DESCENT GOX TANKS, FLAWS ON INSIDE (CODE: TW-XX, SN 41-XX)

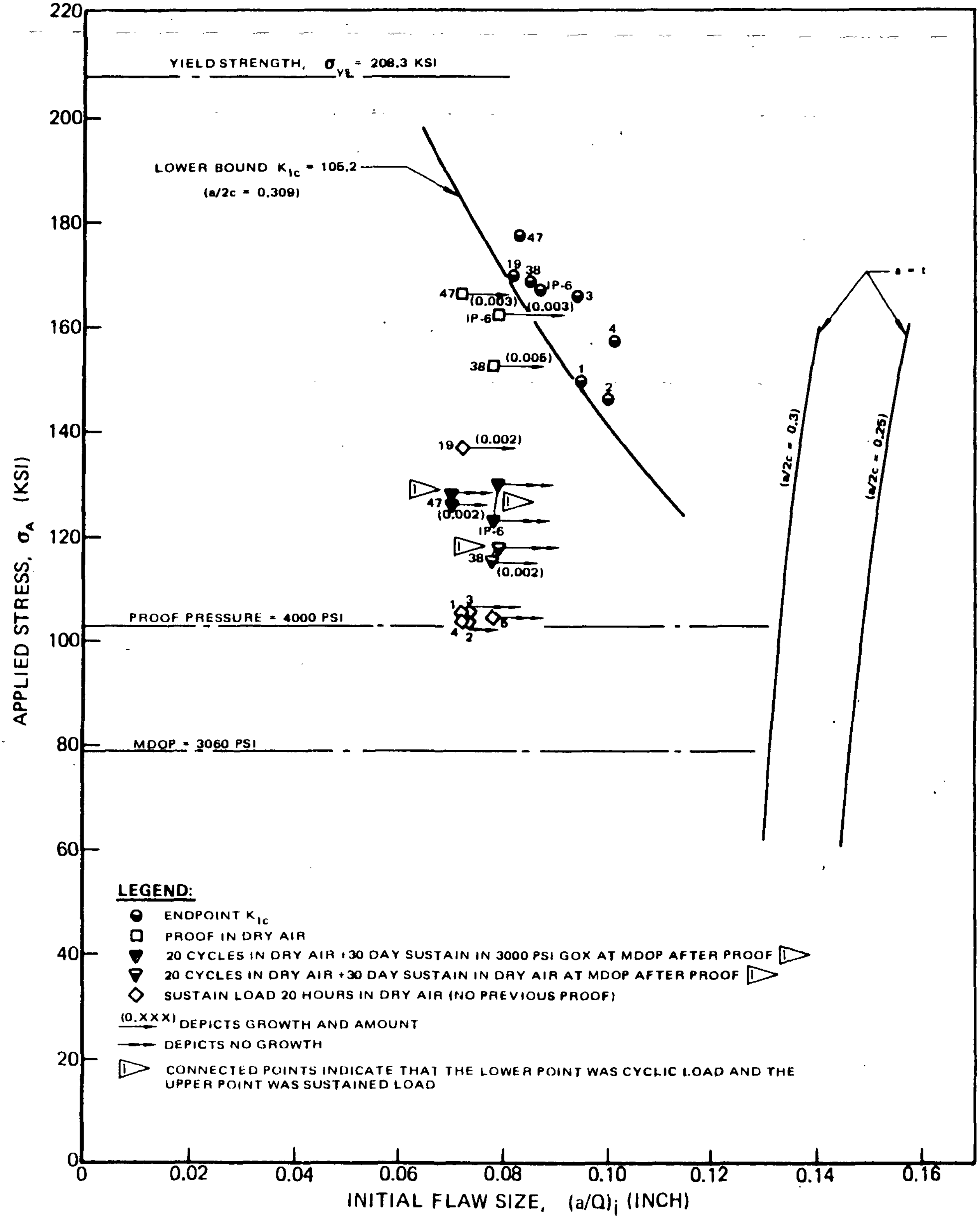


Figure 25: TEST RESULTS OF NICKEL PLATED, 0.21 INCH THICK, WELDMENT OF D6 STEEL PLATE (CODE: GW – XX)

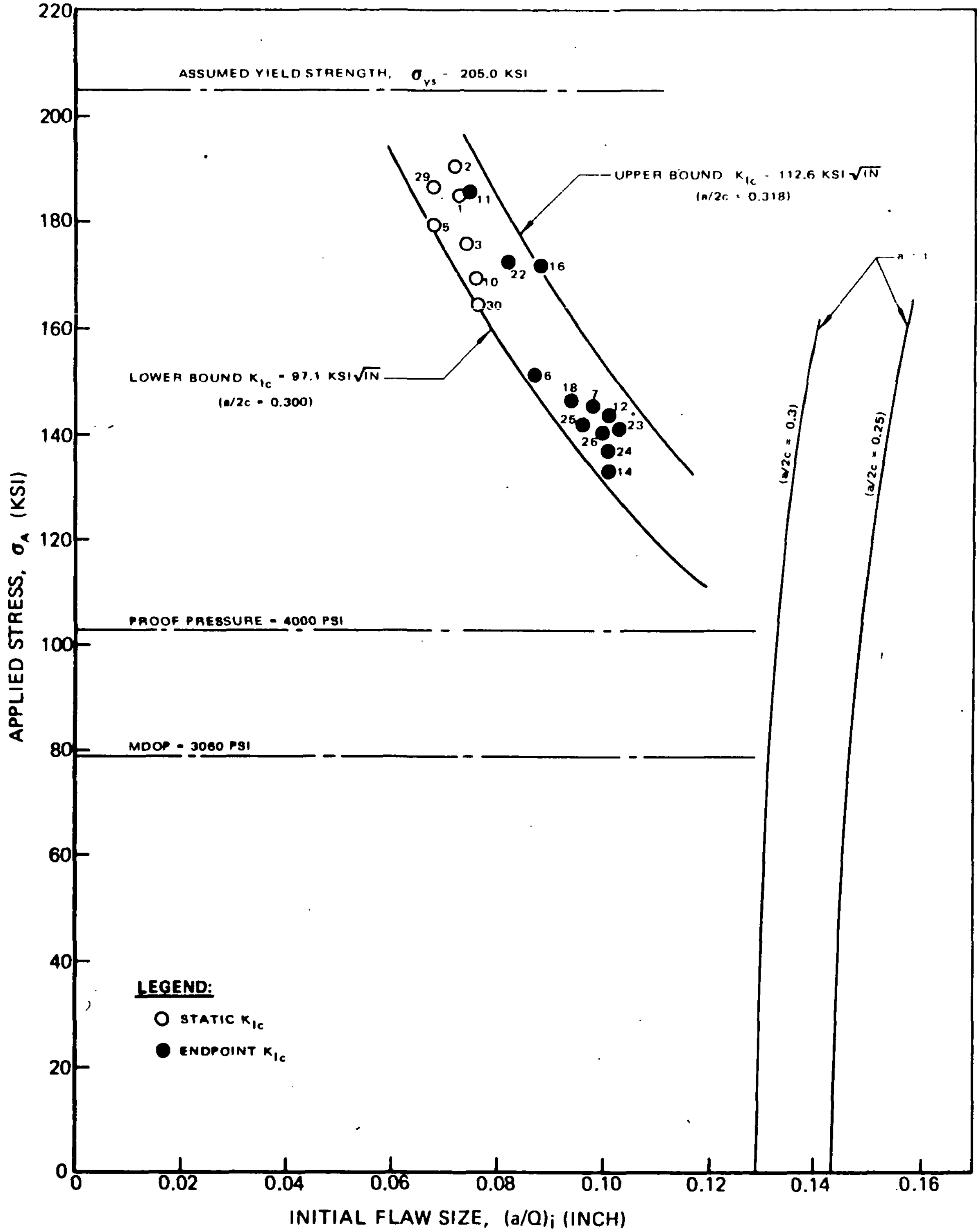


Figure 26: STATIC FRACTURE AND ENDPOINT TESTS OF NICKEL PLATED, 0.21 THICK LONG TRANSVERSE GRAIN D6 STEEL PLATE (CODE: GB-XX)

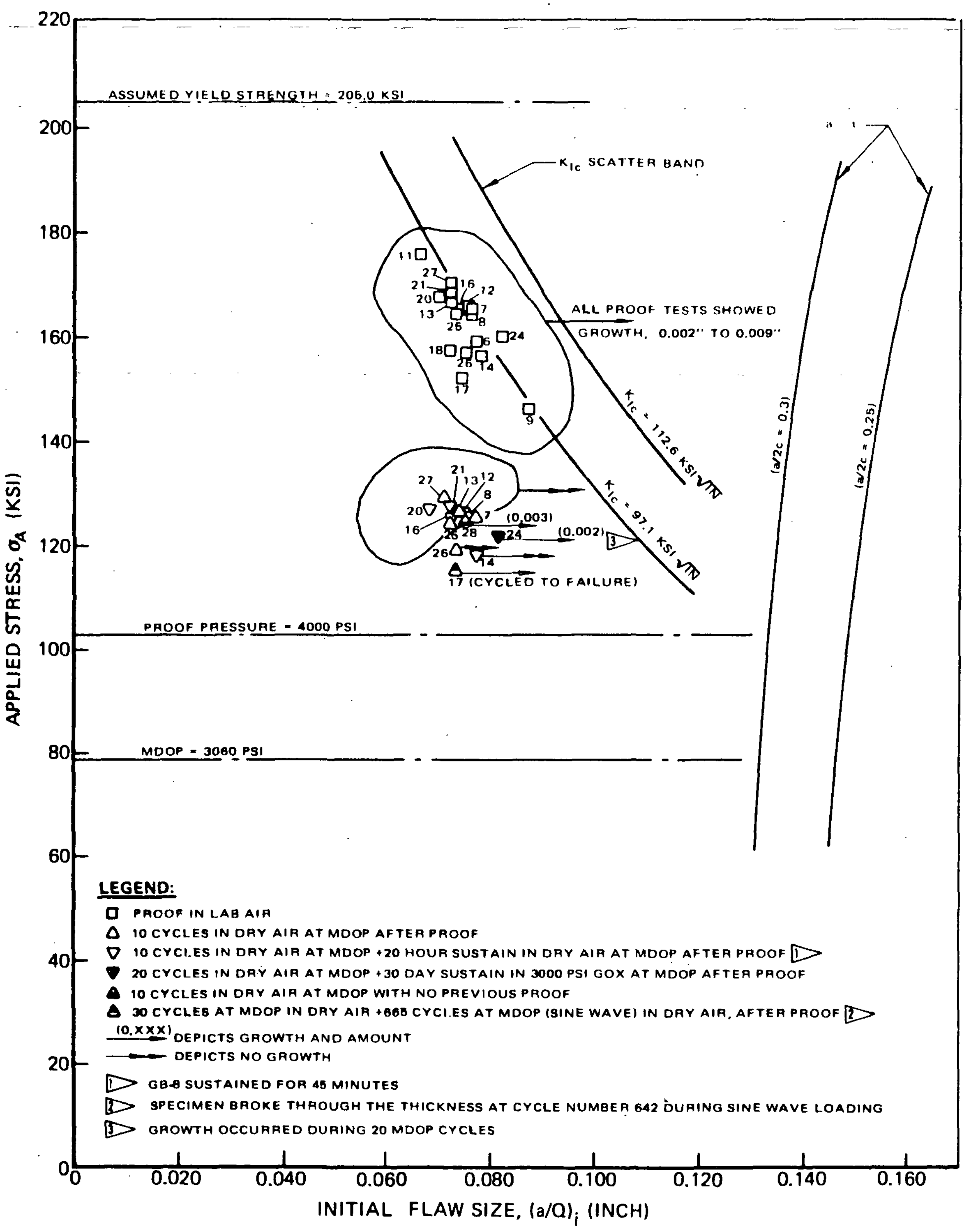


Figure 27: PROOF, MDOP, AND SUSTAINED TESTS OF NICKEL PLATED, 0.21 THICK LONG TRANSVERSE GRAIN D6 STEEL PLATE (CODE GB-XX)

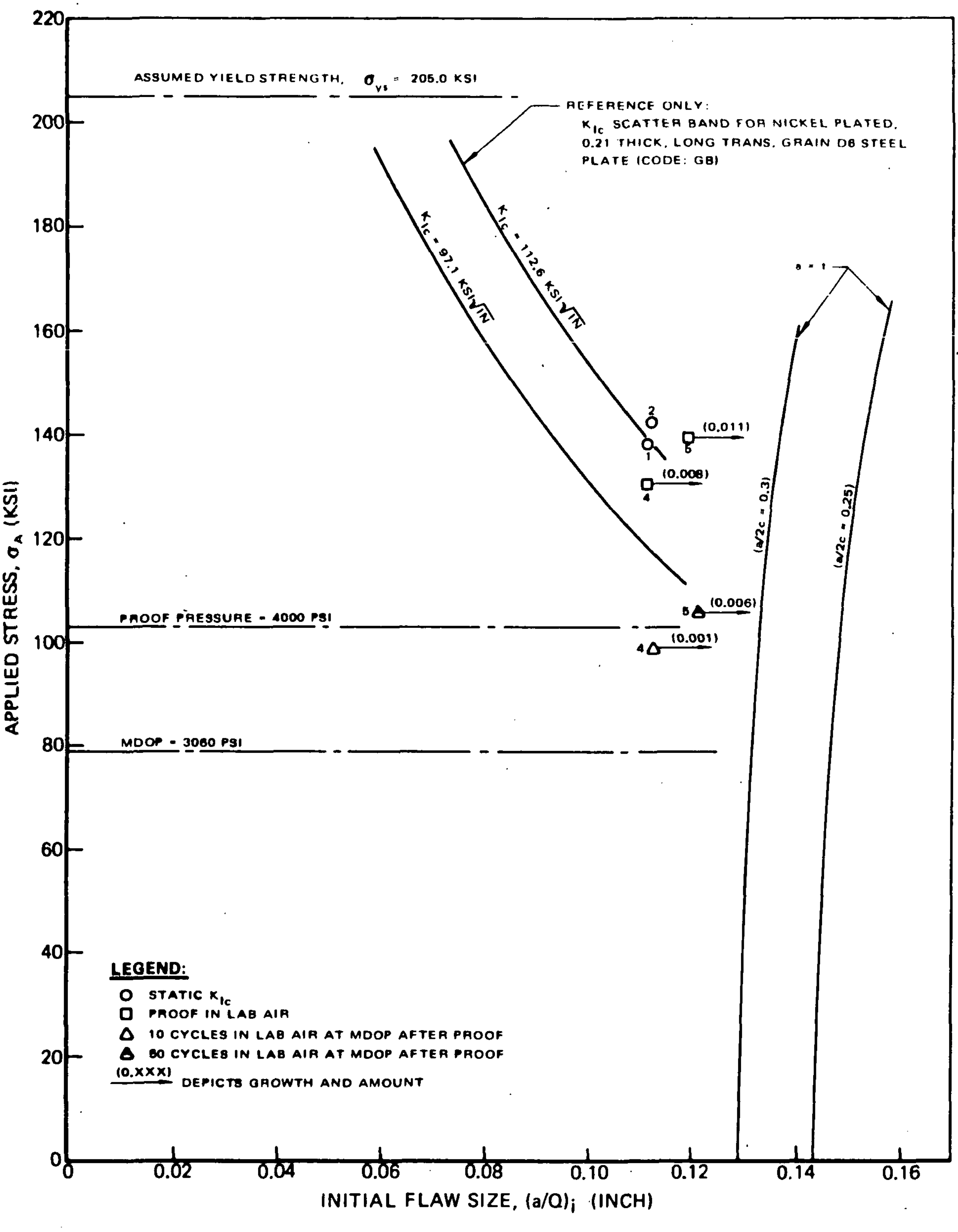


Figure 28: TESTS OF NICKEL PLATED, 0.21 THICK LONG TRANSVERSE GRAIN D6 STEEL PLATE (WIDE SPECIMENS, CODE: SG-XX)

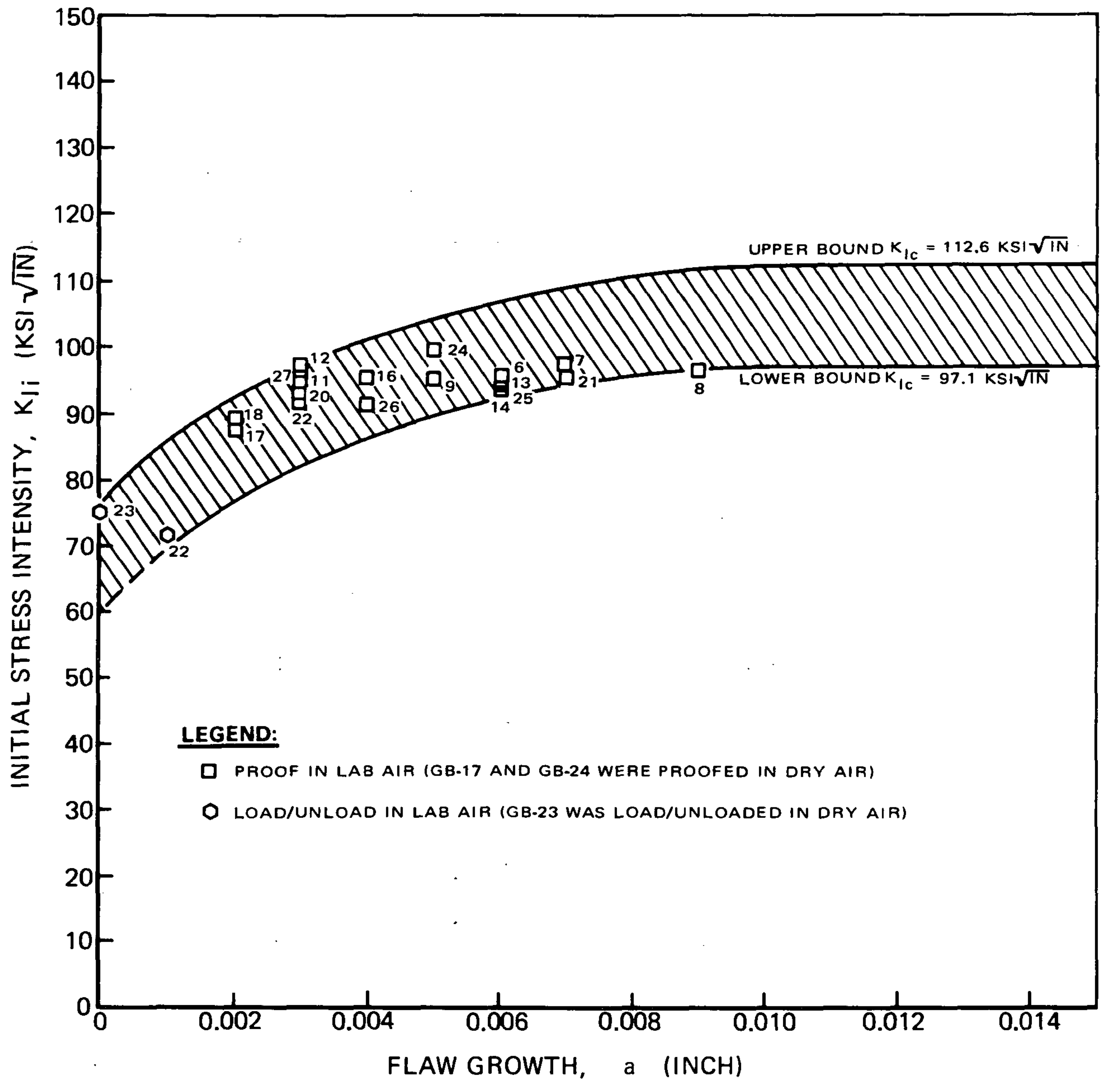


Figure 29: GROWTH-ON-LOADING OF NICKEL PLATED 0.21 THICK LONG TRANSVERSE GRAIN D6 STEEL PLATE (CODE: GB-XX)

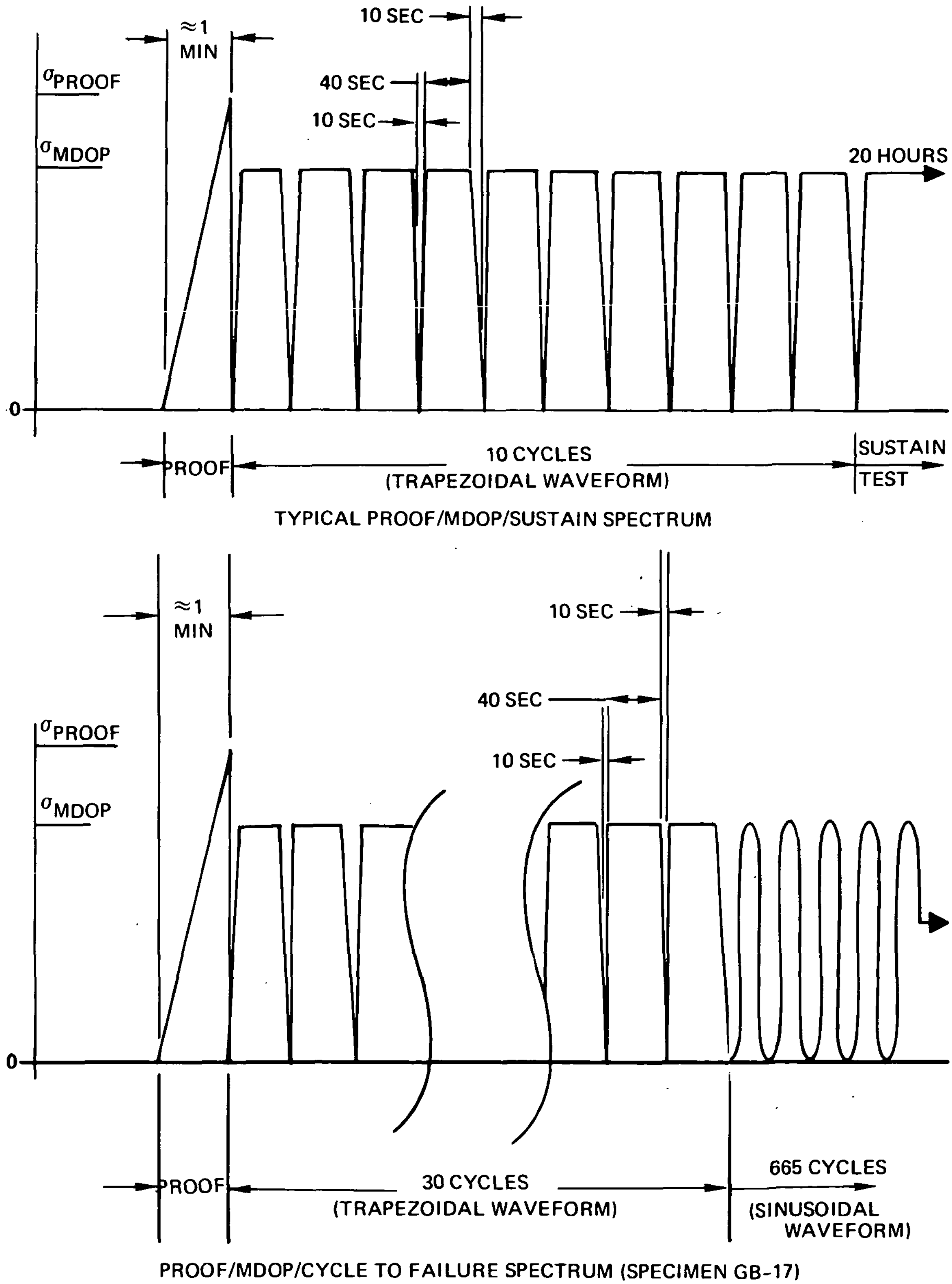


Figure 30: LOADING SPECTRUMS

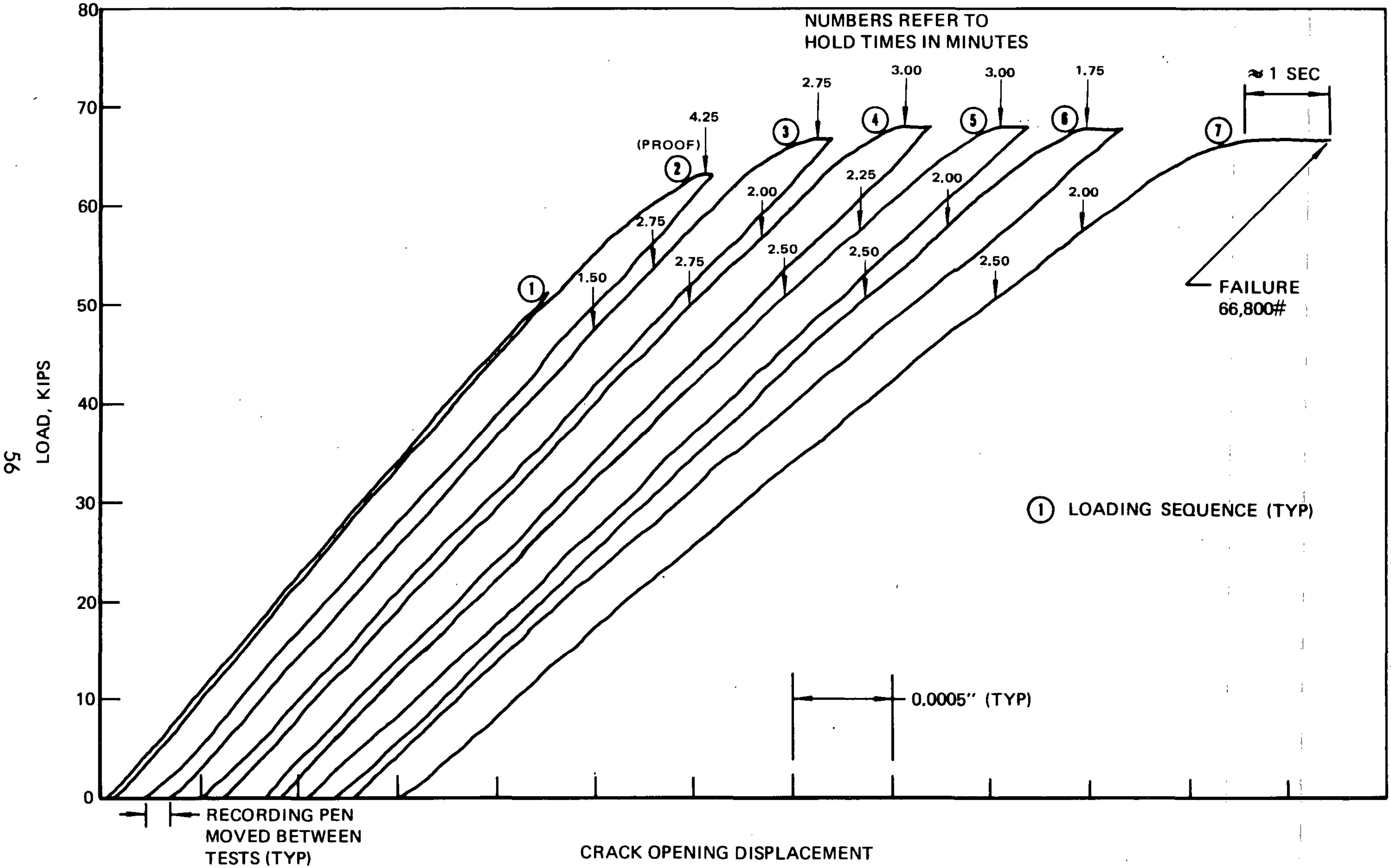


Figure 31: LOAD-OPENING TRACE (SPECIMEN GB-22)

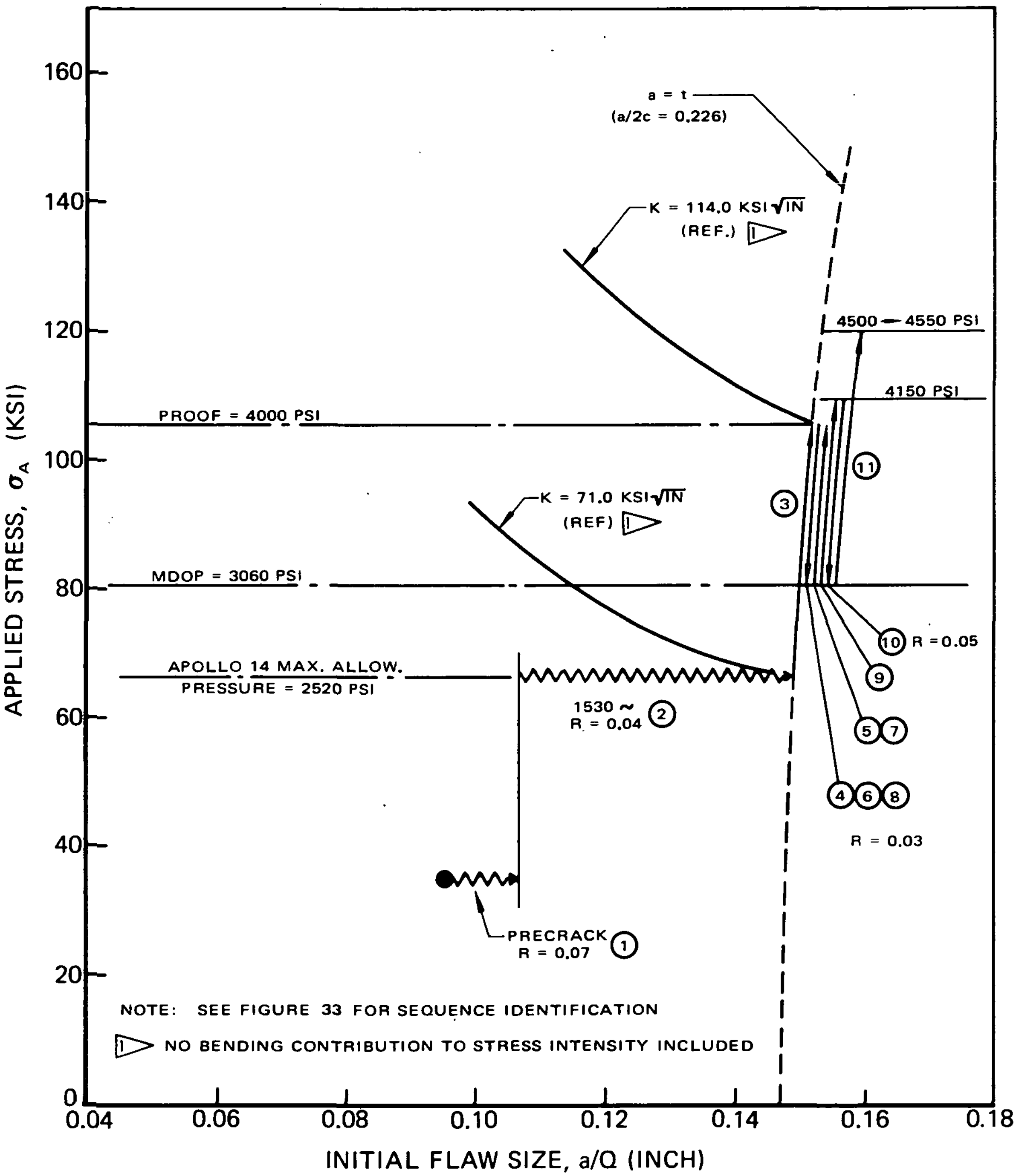
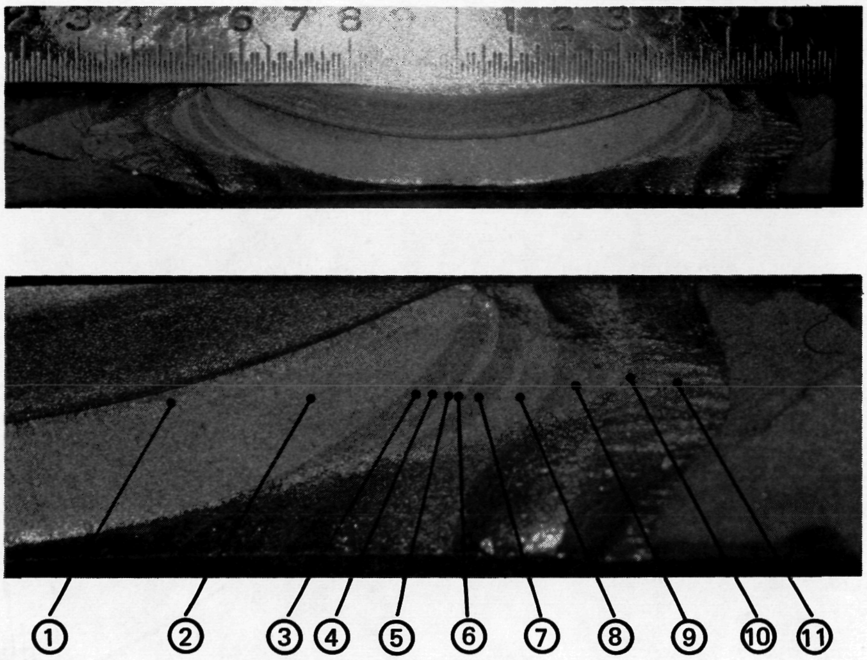


Figure 32: S/N 41 TANK TEST SEQUENCE



LOADING SEQUENCE		a_{max}	$(2c)_{max}$	LOAD PARAMETERS
① PRECRACK	START	0.108	0.890	2500 CYCLES @ 1340psi, R = .07
	STOP	0.126	0.890	
② CYCLE & SUSTAIN	START	0.126	0.890	1530 CYCLES AT 2520 PSI, R = .04 THEN HOLD AT 2520 PSI FOR 20 MIN.
	STOP	0.205	0.907	
③ HIGH PRESSURE	START	0.205	0.920	1 CYCLE TO 4000 PSI
	STOP		0.920	
④ CYCLE	START		0.920	20 CYCLES AT 3050 PSI, R = .03
	STOP		0.923	
⑤ HIGH PRESSURE	START		0.923	1 CYCLE TO 4000 PSI
	STOP		0.937	
⑥ CYCLE	START		0.937	106 CYCLES AT 3050 PSI, R = .03
	STOP		0.947	
⑦ HIGH PRESSURE	START		0.947	1 CYCLE TO 4000 PSI
	STOP		0.982	
⑧ CYCLE	START		0.982	222 CYCLES AT 3050 PSI, R = .03
	STOP		1.037	
⑨ HIGH PRESSURE	START		1.037	1 CYCLE TO 4150 PSI
	STOP		1.105	
⑩ CYCLE	START		1.105	199 CYCLES AT 3030 PSI, R = .05
	STOP		1.136	
⑪ HIGH PRESSURE	START	↓	1.136	1 CYCLE TO 4550 PSI
	STOP	0.205	1.330	1 CYCLE TO 4500 PSI

Figure 33: LOAD SUMMARY OF S/N 41 TANK TEST

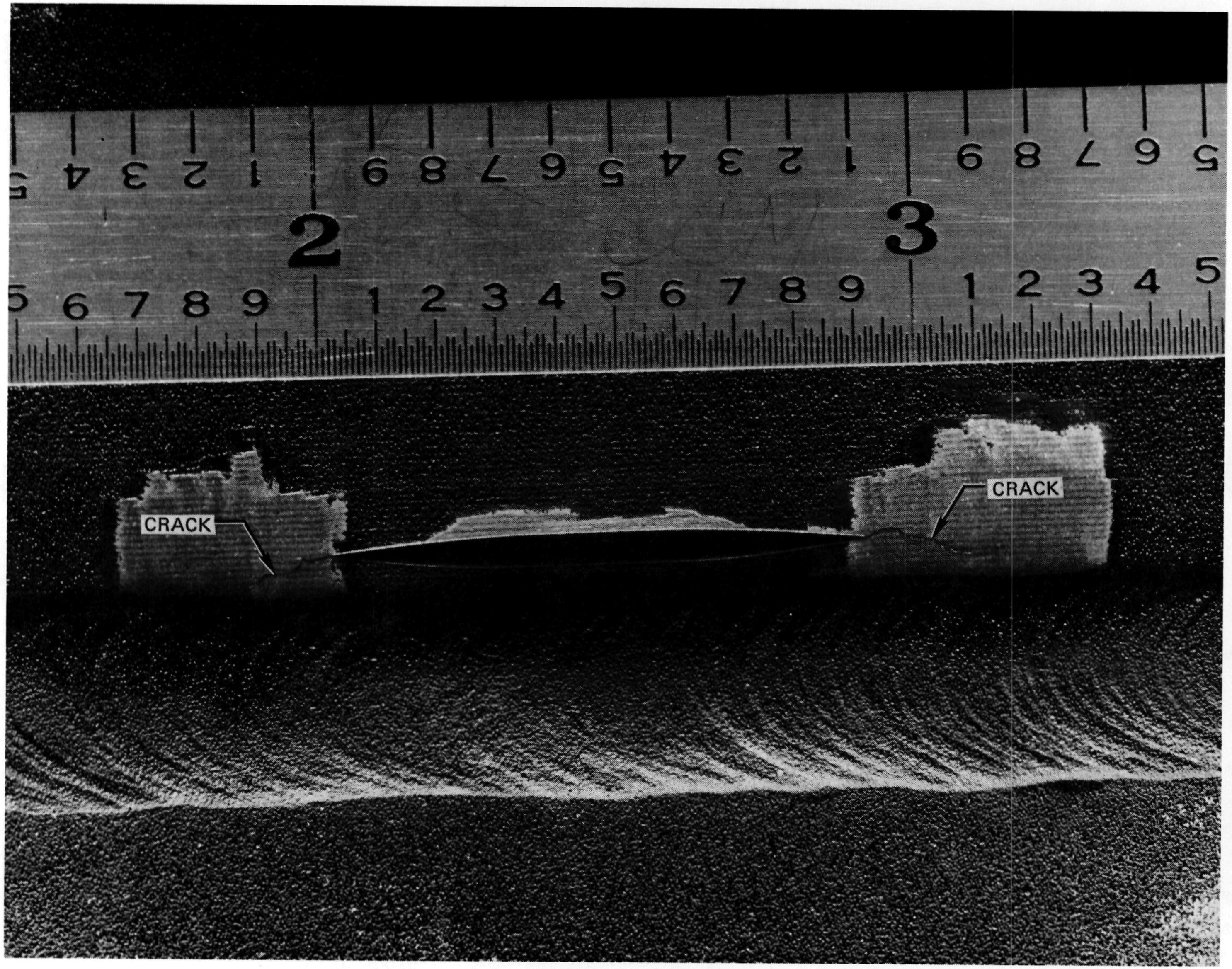


Figure 34: FLAW IN S/N 0041 TANK AT COMPLETION OF PRESSURE TESTS

Table 1: MECHANICAL PROPERTIES OF D6 STEEL FROM LM 2 ECS TANK (S/N 0010) [1]

MATERIAL	SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	ENVIRONMENT	TEMPERATURE (°F)	YIELD STRENGTH 0.2% OFFSET IN 1.0 INCH LENGTH (Ksi)	ULTIMATE STRENGTH (ksi)	ELONGATION % IN 1.0 INCHES	REDUCTION IN AREA %
FORGING	TB-20	0.0538	0.2528	AIR	70	220.5	236.0	8.0	N/A
WELDMENT	TW-20	0.1258	0.2504	AIR	70	221.7	236.1	6.0	44

[1] SPECIMENS WERE BAKED ADDITIONAL 24 HRS AT 375°F IN VACUUM PRIOR TO FABRICATION AND TEST

Table 2: MECHANICAL PROPERTIES OF NICKEL PLATED, 0.21 THICK, LONGITUDINAL GRAIN D6 STEEL PLATE

MATERIAL	SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	ENVIRONMENT	TEMPERATURE (°F)	YIELD STRENGTH 0.2% OFFSET IN 2.0 INCH LENGTH (Ksi)	ULTIMATE STRENGTH (Ksi)	ELONGATION % IN 1.0 INCHES	REDUCTION IN AREA %
PLATE	G-32	0.2080	0.5048	AIR	70	198.2	217.7	16.0	36

[1] SPECIMEN WAS BAKED ADDITIONAL 24 HRS AT 375°F IN VACUUM AND PAINTED PRIOR TO FABRICATION AND TEST

Table 3: MECHANICAL PROPERTIES OF 0.21 THICK NICKEL PLATED D6 STEEL PLATE [1]

MATERIAL	SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	ENVIRONMENT	TEMPERATURE (°F)	YIELD STRENGTH 0.2% OFFSET IN 2.0 INCH LENGTH (ksi)	ULTIMATE STRENGTH (ksi)	ELONGATION % IN 1.0 INCHES	REDUCTION IN AREA %
PLATE LONG GRAIN	GBM-4	0.204	0.502	AIR	70	205.0	224.6	20	51
	GBM-5	0.204	0.501	AIR	70	204.7	224.2	20	51
					AVG	204.8	224.4		
WELD–MENT	GW-7	0.201	0.504	AIR	70	209.4	227.4	15	41
	GW-8	0.194	0.507	AIR	70	207.3	225.6	18	45
					AVG	208.3	226.5		

[1] AS RECEIVED (4 HOUR BAKE AT 375°F IN AIR)

Table 4: MECHANICAL PROPERTIES OF 0.375 THICK NICKEL PLATED D6 STEEL PLATE [1]

MATERIAL	SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	ENVIRONMENT	TEMPERATURE (^{o}F)	YIELD STRENGTH 0.2% OFFSET IN 2.0 INCH LENGTH (ksi)	ULTIMATE STRENGTH (ksi)	ELONGATION % IN 1.0 INCHES	REDUCTION IN AREA %
PLATE	GTB-16	0.381	0.497	AIR	70	192.8	216.0	23	46
LONG	GTB-17	0.381	0.504	AIR	70	192.2	214.6	22	46
GRAIN					AVG.	192.5	215.3		

[1] AS RECEIVED (4 HOUR BAKE AT 375^{o}F IN AIR)

Table 5: MECHANICAL PROPERTIES OF BOEING PROCESSED D6 STEEL [1]

MATERIAL	SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	ENVIRONMENT	TEMPERATURE (^{o}F)	WELD NUGGET YIELD STRENGTH 0.2% OFFSET IN 0.25 INCH LENGTH (ksi)	YIELD STRENGTH 0.2% OFFSET IN 2.0 INCH LENGTH (ksi)	ULTIMATE STRENGTH (ksi)	ELONGATION % IN 1.0 INCHES	REDUCTION IN AREA (%)
FORGING	DBM-10	0.1253	0.5020	AIR	70	N/A	212.4	232.1	4.0	33
WELD-MENT	DWM-12	0.2082	0.4654	AIR	70	216.7	218.7	238.3	2.2	7

[1] UNPLATED AND UNBAKED

Table 6: SUMMARY OF STATIC FRACTURE AND ENDPOINT K_{Ic} TESTS OF NICKEL-PLATED AND BARE D6 STEEL

MATERIAL	SPECIMEN CODE	THICKNESS, t (inch)	AVERAGE STATIC FRACTURE, K_{Ic} (ksi $\sqrt{in.}$) ▷1	AVERAGE END POINT, K_{Ic} (ksi $\sqrt{in.}$) ▷1	OVERALL AVERAGE, K_{Ic} (ksi $\sqrt{in.}$) ▷1	RANGE OF K_{Ic} (ksi $\sqrt{in.}$)	Notes
BOEING-SUPPLIED FORGING BASE METAL	DBM	0.123	110.8 (2)	105.9 (4)	107.5 (6)	99.5–123.1	▷2
BOEING-SUPPLIED FORGING WELDMENT	DWM	0.205	99.5 (2)	100.9 (10)	100.6 (12)	88.9–114.8	▷2
LM/ECS TANK BASE METAL	TB	0.11	94.1 (1)	———	———	———	▷2 ▷4
LM/ECS TANK WELDMENT	TW/SN	0.18	100.2 (5)	99.9 (18)	99.9 (23)	86.7–109.0	▷3
LONGITUDINAL GRAIN PLATE	G	0.21	87.5 (3)	98.0 (13)	96.0 (16)	75.6–113.5	▷3
LONGITUDINAL GRAIN PLATE	GTB	0.375	102.7 (1)	101.4 (6)	101.6 (7)	98.0–104.7	▷3
LONGITUDINAL GRAIN PLATE	GBM	0.21	107.2 (1)	———	107.2 (1)	107.2	▷2
WELDMENT (PLATE)	GW	0.21	106.1 (3)	112.8 (23)	112.0 (26)	97.6–124.0	▷3
LONG TRANSVERSE GRAIN PLATE	GB	0.21	101.3 (7)	104.3 (12)	103.2 (19)	97.1–112.6	
LONG TRANSVERSE GRAIN PLATE (WIDE)	SG	0.21	113.8 (2)	———	113.8 (2)	111.6–116.0	

▷1 CIRCLED NUMBERS INDICATE NUMBER OF SAMPLES

▷2 ALL VALUES TAKEN FROM APPENDIX A

▷3 SOME VALUES TAKEN FROM APPENDIX A

▷4 MOST SPECIMENS TESTED WERE NOT LARGE ENOUGH TO PROVIDE A TRUE REPRESENTATIVE K_{Ic} VALUE

Table 7: STATIC FRACTURE TESTS OF NICKEL-PLATED, 0.21 THICK LONG TRANSVERSE GRAIN D6 STEEL PLATE (1) (2)

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	$\sigma A/\sigma ys$	FLAW SIZE a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I ($ksi\sqrt{in}$)	
GB-1	0.213	1.802	OUT-SIDE	0.087	0.400	0.217	185.1	(3) ↓	0.902	0.073	0.409	1.082	70	LAB AIR	105.2	
GB-2	0.213	1.804	OUT-SIDE	0.083	0.400	0.207	190.6		0.929	0.072	0.391	1.078	70	LAB AIR	107.2	
GB-3	0.215	1.798	OUT-SIDE	0.091	0.410	0.222	176.1		0.859	0.074	0.423	1.087	70	LAB AIR	101.6	
GB-5	0.216	1.800	OUT-SIDE	0.083	0.370	0.224	179.6		0.876	0.068	0.384	1.071	70	LAB AIR	97.5	(4)
GB-10	0.216	1.804	OUT-SIDE	0.098	0.410	0.239	169.4		0.826	0.076	0.454	1.094	70	LAB AIR	99.7	
GB-29	0.214	1.803	OUT SIDE	0.091	0.340	0.268	186.7		0.911	0.068	0.425	1.068	70	LAB AIR	101.1	(5)
GB-30	0.215	1.801	OUT-SIDE	0.114	0.380	0.300	164.5	↑ (3)	0.802	0.076	0.530	1.095	70	LAB AIR	97.1	

(1) AS REC'D (4 HOUR BAKE AT 375°F IN AIR) + 24 HOUR BAKE AT 400°F IN FLOWING NITROGEN

(2) ALL FLAWS MECHANICALLY CUT AFTER ALL BAKING

(3) ASSUMED σ_{ys} = 205.0 KSI

(4) TEST MACHINE FAILED AT 145.4 KSI ON FIRST LOADING, SPECIMEN RELOADED

(5) SLOW TEST (3 MIN TO FAILURE VS 1-1 1/2 MIN TO FAILURE)

Table 8: STATIC FRACTURE TESTS OF NICKEL-PLATED, 0.21 THICK LONG TRANSVERSE GRAIN D6 STEEL PLATE (WIDE SPECIMENS) [1] [2]

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST TEMPERATURE °F	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi $\sqrt{in.}$)
SG-1	0.215	3.003	OUT-SIDE	0.130	0.730	0.178	138.1	[3]	0.673	0.111	0.606	1.243	70	LAB AIR	111.6
SG-2	0.215	3.003	OUT-SIDE	0.131	0.730	0.179	142.5	[3]	0.695	0.112	0.610	1.246	70	LAB AIR	116.0

[1] AS RECEIVED (4-HOUR BAKE AT 375°F IN AIR) + 24-HOUR BAKE AT 350°F IN FLOWING NITROGEN

[2] FLAWS EDM'D BEFORE EXTRA BAKE, PRECRACKED AFTER EXTRA BAKE

[3] ASSUMED σ_{ys} = 205.0 KSI

Table 9 : STATIC FRACTURE TESTS OF NICKEL PLATED, 0.21 THICK LONGITUDINAL GRAIN D6 STEEL PLATE

SPECIMEN NUMBER	THICKNESS, t, (inch)	WIDTH, w (inch)	FLAW LOCATION	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi $\sqrt{in.}$)	
G-2	0.207	1.800	INSIDE	0.093	0.447	0.208	168.4	198.2	0.850	0.078	0.449	1.107	70	LAB AIR	101.6	[1]
G-27	0.207	1.804	INSIDE	0.097	0.430	0.226	128.3	198.2	0.648	0.074	0.470	1.109	70	LAB AIR	75.6	[2]

[1] AS RECEIVED (4 HOUR BAKE AT 375°F IN AIR) + BAKED 24 HOURS AT 375°F IN VACUUM AND PAINTED BY BOEING. FLAW WAS EDM'D BETWEEN BAKE CYCLES AND PRECRACKED AFTER PROCESSING.

[2] AS RECEIVED + BAKED 24 HOURS AT 375°F IN VACUUM AND PAINTED BY GRUMMAN. FLAW MECHANICALLY CUT.

Table 10: LOAD/UNLOAD TEST OF NICKEL-PLATED, 0.21 THICK LONGITUDINAL GRAIN D6 STEEL PLATE [1] [2]

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi$\sqrt{\text{in.}}$)	K_I/K_{Ic}	REMARKS
G-1	0.207	1.798	IN-SIDE	START	0.095	0.455	0.209	110.0	198.2	0.555	0.074	0.459	1.112	≈ 1 MIN	70	LAB AIR	65.0	0.677	NO GROWTH
				STOP	0.095	0.455	0.209	110.0	↕	0.555	0.074	0.459	1.112				65.0	0.677	
				FAIL	0.163	0.520	0.313	112.0	198.2	0.565	0.101	0.787	1.234	STATIC			85.8	—	

[1] AS RECEIVED (4-HOUR BAKE AT 375°F IN AIR) + BAKED 24 HOURS AT 375°F IN VACUUM AND PAINTED BY BOEING

[2] FLAW EDM'D AND PRECRACKED BEFORE EXTRA BAKE CYCLE

Table 11: SUSTAINED LOAD TESTS OF D6 STEEL WELDMENT SPECIMENS FROM LM 2 ECS DESCENT GOX TANK (S/N 0010)

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED AXIAL STRESS, σ_A (ksi)	σ_A/σ_{ys} (4)	APPLIED BENDING STRESS, σ_B (ksi)	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	BENDING STRESS MAGNIFICATION FACTOR, M_B	TEST DURATION (hours)	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY DUE TO TENSION K_{IK} (ksi$\sqrt{in.}$)	STRESS INTENSITY DUE TO BENDING K_{IB} (ksi$\sqrt{in.}$)	$K_{IK} + K_{IB} = K_I$	K_I/K_{Ic}	REMARKS (NOTES ARE CHRONOLOGICAL)
TW-6	0.182	1.507	OUT-	START	0.093	0.380	0.245	140.0	0.632	-44.4	0.068	0.512	1.121	0.50	20.0	70	DRY AIR	79.9	-10.3	69.6	0.697	Δa = 0.001″
			SIDE	STOP	0.094	0.380	0.247	140.0	0.632	-44.4	0.068	0.517	1.122	0.49				80.2	-10.1	70.1	0.702	(1) (2) (3A)
			HAZ	FAIL	0.165	0.410	0.402	150.4	0.679	-46.3	0.086	0.908	(5)	–	STATIC		LAB AIR	(5)	–	(5)	–	
TW-2	0.181	1.503	IN-	START	0.089	0.375	0.237	90.0	0.406	25.2	0.064	0.493	1.114	0.52	20.0	70	3,000 PSI GOX	49.4	5.9	55.3	0.554	NO GROWTH
			SIDE	STOP	0.089	0.375	0.237	90.0	0.406	25.2	0.064	0.493	1.114	0.52				49.4	5.9	55.3	0.554	(1) (2) (3B)
			HAZ	FAIL	0.118	0.406	0.291	141.5	0.639	32.0	0.078	0.653	1.174	0.26	STATIC		LAB AIR	90.5	4.1	94.6	—	
TW-15	0.179	1.502	OUT-	START	0.093	0.400	0.232	120.0	0.542	-32.2	0.069	0.518	1.133	0.52	5.0	70	TEXACO R AND O HD - A OIL	69.6	-7.8	61.8	0.619	NO GROWTH
			SIDE	STOP	0.093	0.400	0.232	120.0	0.542	-32.2	0.069	0.518	1.133	0.52				69.6	-7.8	61.8	0.619	(1) (2) (3C)
			HAZ	FAIL		(CYCLED THROUGH-THE-THICKNESS)									STATIC		LAB AIR	–	–	–	—	

(1) RECEIVED WITH 4-HOUR BAKE AT 375° IN ARGON, PAINT REMOVED BY SANDBLASTING

(2) FLAW EDM'D BY BOEING

(3A) BAKED 24 HOURS AT 375° IN VACUUM AND REPAINTED BY BOEING

(3B) BAKED 24 HOURS AT 375° IN VACUUM BY BOEING. NOT REPAINTED

(3C) BAKED 24 HOURS AT 375°F IN VACUUM AND REPAINTED BY GRUMMAN

(4) σ_{ys} = 221.7 ksi

(5) a/t > 0.85, M_K CURVE NOT APPLICABLE

Table 12: SUSTAINED LOAD TESTS OF NICKEL PLATED, 0.21 THICK, LONGITUDINAL GRAIN D6 STEEL PLATE [1] [2]

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION (hours)	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi$\sqrt{in.}$)	K_I/K_{Ic}	REMARKS
G-8	0.207	1.804	OUT-SIDE	START	0.093	0.455	0.204	115.0	198.2	0.580	0.074	0.450	1.109	19.0	70	DRY AIR	67.5	0.704	NO GROWTH
				STOP	0.093	0.455	0.204	115.0	↓	0.580	0.074	0.450	1.109				67.5	0.704	
				FAIL	0.183	0.555	0.330	109.4		0.552	0.110	0.885	[3]	STATIC		LAB AIR	[3]	—	
G-3	0.207	1.803	IN-SIDE	START	0.091	0.455	0.200	110.0		0.555	0.072	0.440	1.106	20.0	70	3,000 PSI GOX	63.8	0.665	NO GROWTH
				STOP	0.091	0.455	0.200	110.0		0.555	0.072	0.440	1.106				63.8	0.665	
				FAIL	0.128	0.460	0.278	143.6		0.725	0.089	0.618	1.162	STATIC		LAB AIR	96.9	—	
G-14	0.207	1.799	IN-SIDE	START	0.095	0.450	0.211	115.0		0.580	0.074	0.460	1.111	20.0	70	3,000 PSI GOX	67.9	0.708	NO GROWTH
				STOP	0.095	0.450	0.211	115.0	↑	0.580	0.074	0.460	1.111				67.9	0.708	
				FAIL	0.134	0.468	0.286	157.9	198.2	0.797	0.093	0.648	1.175	STATIC		LAB AIR	110.1	—	

[1] AS RECEIVED (4 HOUR BAKE AT 375°F IN AIR) + BAKED 24 HOURS AT 375°F IN VACUUM AND PAINTED BY BOEING

[2] ALL FLAWS EDM'D AND PRECRACKED BEFORE EXTRA BAKE CYCLE

[3] $a/t > 0.85$, M_K CURVE NOT APPLICABLE

Table 13: SUSTAINED LOAD TESTS OF BARE, 0.375 THICK LONGITUDINAL GRAIN D6 STEEL PLATE [1] [2]

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION (hours)	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi $\sqrt{in.}$)	K_I/K_{Ic}	REMARKS
GTB-2	0.385	2.253	–	START	0.124	0.490	0.253	126.0	↓	0.655	0.090	0.322	1.052	20.0	70	DRY	77.4	0.762	Δa = 0.002″
				STOP	0.126	0.490	0.257	126.0	↓	0.655	0.090	0.328	1.052			AIR	77.6	0.764	
				START	0.175	0.540	0.324	126.0	↓	0.655	0.108	0.455	1.055	≈ 1		LAB	85.1	0.838	Δa = 0.003″
				STOP	0.178	0.540	0.330	126.0	192.5	0.655	0.108	0.463	1.055	MIN		AIR	85.3	0.840	
				FAIL	(CYCLED THROUGH THE THICKNESS)									STATIC			–	—	

[1] BAKED 20 HOURS AT 900°F IN VACUUM
[2] FLAW MECHANICALLY CUT AFTER BAKE CYCLE

Table 14: SUSTAINED LOAD TESTS OF NICKEL PLATED, 0.375 THICK, LONGITUDINAL GRAIN D6 STEEL PLATE [1] [2]

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION (hours)	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi $\sqrt{in.}$)	K_I/K_{Ic}	REMARKS
GTB-5	0.386	2.248	IN-SIDE	START	0.112	0.500	0.224	130.0	192.5	0.675	0.087	0.290	1.052	20.3	70	DRY	78.5	0.773	Δa = 0.002″
				STOP	0.114	0.500	0.228	130.0	↑	0.675	0.087	0.295	1.053			AIR	78.9	0.786	
				START	0.159	0.530	0.300	152.1	↑	0.790	0.106	0.412	1.050	≈ 1		LAB	101.5	0.999	Δa = 0.008″
				STOP	0.167	0.530	0.315	152.1	↑	0.790	0.108	0.433	1.052	MIN		AIR	102.4	1.009	
				FAIL	0.199	0.550	0.362	150.1	↑	0.780	0.115	0.516	1.054	STATIC			104.7	—	
GTB-6	0.386	2.251	OUT-SIDE	START	0.136	0.460	0.296	126.0	↓	0.655	0.089	0.353	1.044	20.0	70	DRY	76.7	0.755	Δa = 0.003″
				STOP	0.139	0.460	0.302	126.0	↓	0.655	0.090	0.360	1.043			AIR	76.9	0.757	
				START	0.156	0.500	0.312	126.0	↓	0.655	0.099	0.405	1.044	≈ 1		LAB	80.6	0.793	Δa = 0.002″
				STOP	0.158	0.500	0.316	126.0	192.5	0.655	0.099	0.410	1.045	MIN		AIR	80.8	0.795	
				FAIL	(CYCLED THROUGH-THE-THICKNESS)									STATIC			–	–	

[1] AS RECEIVED (4 HOUR BAKE AT 375°F IN AIR)
[2] FLAWS MECHANICALLY CUT

Table 15: SUSTAINED LOAD TESTS OF NICKEL PLATED, 0.375 THICK, LONGITUDINAL GRAIN D6 STEEL PLATE 1 2

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION (hours)	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi$\sqrt{in.}$)	K_I/K_{Ic}	REMARKS	EXTRA BAKE TIME (HOURS)
GTB-3	0.386	2.254	OUT-SIDE	START	0.119	0.525	0.227	129.8	192.5	0.675	0.091	0.309	1.056	20.3	70	DRY AIR	80.8	0.795	Δa = 0.003"	-24-
				STOP	0.122	0.525	0.232	129.8		0.675	0.093	0.316	1.056				81.4	0.801		
				START	0.159	0.535	0.297	151.9		0.789	0.107	0.412	1.051	≈1 MIN.		LAB AIR	101.8	1.002	Δa = 0.014"	
				STOP	0.173	0.535	0.323	151.9		0.789	0.110	0.449	1.054				103.3	1.018		
				FAIL	0.224	0.590	0.380	136.6		0.710	0.123	0.581	1.061	STATIC			99.2	—		
GTB-7	0.382	2.246	OUT-SIDE	START	0.114	0.500	0.228	130.0		0.675	0.087	0.299	1.054	20.0	70	DRY AIR	79.0	0.777	Δa = 0.001"	48
				STOP	0.115	0.500	0.230	130.0		0.675	0.088	0.301	1.054				79.2	0.780		
				FAIL	0.238	0.620	0.384	136.3		0.709	0.129	0.624	1.071	STATIC		LAB AIR	102.5	—		
GTB-9	0.382	2.243	OUT-SIDE	START	0.118	0.480	0.246	130.0		0.675	0.087	0.309	1.052	20.0	70	DRY AIR	78.7	0.775	Δa = 0.001"	120
				STOP	0.119	0.480	0.248	130.0		0.675	0.087	0.311	1.052				78.8	0.776		
				FAIL	0.208	0.530	0.392	152.0		0.790	0.113	0.544	1.044	STATIC		LAB AIR	103.8	—		
GTB-10	0.382	2.248	OUT-SIDE	START	0.110	0.490	0.224	130.0		0.675	0.085	0.288	1.051	20.0	70	DRY AIR	77.7	0.765	Δa = 0.002"	144
				STOP	0.112	0.490	0.229	130.0		0.675	0.086	0.293	1.052				78.1	0.769		
				FAIL	0.287	0.720	0.399	120.1	192.5	0.624	0.149	0.752	1.107	STATIC		LAB AIR	100.1	—		

1 AS RECEIVED (4 HOUR BAKE AT 375°F IN AIR) AND BAKED AT 400°F IN FLOWING NITROGEN FOR TIME INDICATED

2 ALL FLAWS MECHANICALLY CUT AFTER EXTRA BAKE CYCLE

Table 16: SUSTAINED LOAD TESTS OF NICKEL-PLATED, 0.21 THICK D6 STEEL WELDMENT [1] [2]

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION (hours)	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi$\sqrt{in.}$)	K_I/K_{Ic}	REMARKS
GW -39	0.222	1.795	IN-SIDE HAZ	START	0.098	0.360	0.272	140.0	208.3	0.671	0.068	0.442	1.073	20.0	70	DRY AIR	76.4	0.679	Δa = 0.002"
				STOP	0.100	0.360	0.278	140.0		0.671	0.069	0.451	1.074				76.8	0.685	
				START	0.113	0.380	0.297	140.0		0.671	0.074	0.510	1.087	≈1 MIN		LAB AIR	80.8	0.721	Δa = 0.002"
				STOP	0.115	0.380	0.303	140.0		0.671	0.075	0.519	1.088				81.1	0.724	
				FAIL	0.137	0.400	0.342	157.7		0.756	0.083	0.619	1.105	STATIC			97.6	—	
GW -44	0.222	1.801	OUT-SIDE HAZ	START	0.107	0.380	0.282	133.8		0.642	0.072	0.483	1.085	20.0	70	DRY AIR	76.1	0.679	TOTAL Δa = 0.004"
				STOP	[3]	–	–	133.8		0.642	–	–	–				–	–	
				START	[3]	–	–	133.8		0.642	–	–	–	≈1 MIN		LAB AIR	–	–	
				STOP	0.111	0.380	0.292	133.8		0.642	0.073	0.501	1.085				76.6	0.684	
				FAIL	0.115	0.410	0.280	188.8	208.3	0.906	0.083	0.519	1.102	STATIC			116.8	—	

[1] AS RECEIVED (4-HOUR BAKE AT 375°F IN AIR)

[2] FLAW MECHANICALLY CUT

[3] CRACK GROWTH FOR EACH LOADING COULD NOT BE DETERMINED BECAUSE OF INSUFFICIENT FATIGUE MARKING

Table 17: SUSTAINED LOAD TESTS OF NICKEL-PLATED, 0.21 THICK, GRUMMAN-PROCESSED D6 STEEL WELDMENT (8)

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION (hours)	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi$\sqrt{in.}$)	K_I/K_{Ic}	REMARKS (NOTES ARE CHRONOLOGICAL)
GW -1	0.217	1.803	OUT-SIDE HAZ	START	0.092	0.457	0.201	104.8	208.3	0.503	0.072	0.424	1.096	20.0	70	DRY AIR	60.2	0.538	NO GROWTH (1) (2) (4) (5)
				STOP	0.092	0.457	0.201	104.8		0.503	0.072	0.424	1.096				60.2	0.538	
				FAIL	0.147	0.475	0.309	149.9		0.719	0.095	0.677	1.170	STATIC		LABAIR	105.2	—	
GW -2	0.219	1.801	OUT-SIDE HAZ	START	0.094	0.460	0.204	104.8		0.503	0.073	0.429	1.097	20.0	70	DRY AIR	60.8	0.543	NO GROWTH (1) (2) (3) (4) (5)
				STOP	0.094	0.460	0.204	104.8		0.503	0.073	0.429	1.097				60.8	0.543	
				FAIL	0.156	0.500	0.312	146.5		0.703	0.100	0.712	1.189	STATIC		LABAIR	107.1	—	
GW -3	0.212	1.810	OUT-SIDE HAZ	START	0.093	0.465	0.200	104.8		0.503	0.073	0.438	1.105	20.1	70	DRY AIR	61.1	0.545	NO GROWTH (1) (5) (6)
				STOP	0.093	0.465	0.200	104.8		0.503	0.073	0.438	1.105				61.1	0.545	
				FAIL	0.134	0.477	0.281	166.1		0.797	0.094	0.631	1.169	STATIC		LABAIR	115.9	—	
GW -4	0.222	1.801	OUT-SIDE HAZ	START	0.092	0.450	0.204	104.8		0.503	0.072	0.414	1.089	20.1	70	DRY AIR	59.6	0.532	NO GROWTH (1) (5) (6)
				STOP	0.092	0.450	0.204	104.8		0.503	0.072	0.414	1.089				59.6	0.532	
				FAIL	0.158	0.500	0.316	157.4		0.755	0.101	0.711	1.182	STATIC		LABAIR	115.4	—	
GW -5	0.217	1.800	OUT-SIDE HAZ	START	0.105	0.460	0.228	104.8		0.503	0.078	0.483	1.114	20.1	70	DRY AIR	63.6	0.568	NO GROWTH (1) (5) (6)
				STOP	0.105	0.460	0.228	104.8		0.503	0.078	0.483	1.114				63.6	0.568	
				FAIL	0.187	0.555	0.337	132.5	208.3	0.636	0.112	0.861	(7)	STATIC		LAB AIR	(7)	—	

(1) FLAW EDM'D BY BOEING
(2) PAINTED BY NULINE
(3) NO PRIMER USED
(4) PAINT REMOVED BY SANDBLASTING
(5) BAKED 24 HOURS AT 375°F IN VACUUM AND PAINTED BY GRUMMAN
(6) ZYGLO AND ULTRASONIC INSPECTION BETWEEN 24-HOUR BAKE AND PAINTING
(7) $a/t > 0.85$, M_K CURVE NOT APPLICABLE
(8) SPECIMENS INITIALLY HAD A 4-HOUR BAKE AT 375°F IN AIR

Table 18: **SUSTAINED LOAD TESTS OF NICKEL PLATED, 0.21 THICK D6 STEEL WELDMENT** (1) (2)

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION (hours)	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi $\sqrt{in.}$)	K_I/K_{Ic}	REMARKS	EXTRA BAKE TIME (HOURS)
GW-19	0.217	1.800	OUT-SIDE HAZ	START	0.099	0.395	0.251	137.0	208.3	0.658	0.072	0.456	1.089	19.5	70	DRY AIR	78.1	0.697	Δ a = 0.002"	24
				STOP	0.101	0.395	0.256	137.0		0.658	0.073	0.465	1.091				78.5	0.701		
				FAIL	0.119	0.408	0.292	170.3		0.817	0.082	0.548	1.110	STATIC		LAB AIR	105.3	—		
GW-22	0.220	1.793	OUT-SIDE HAZ	START	0.104	0.380	0.274	137.0		0.658	0.072	0.473	1.085	20.0	70	DRY AIR	77.6	0.693	Δ a = 0.001"	48
				STOP	0.105	0.380	0.276	137.0		0.658	0.072	0.477	1.085				77.8	0.695		
				START	0.156	0.440	0.355	137.0		0.658	0.090	0.709	1.136	≈ 1 MIN.		LAB AIR	91.0	0.812	Δ a = 0.002" Δ 2c = 0.010"	
				STOP	0.158	0.450	0.351	137.0		0.658	0.092	0.718	1.145				92.7	0.828		
				FAIL	0.193	0.525	0.368	141.1		0.677	0.108	0.877	(3)	STATIC			(3)	—		
GW-24	0.214	1.800	OUT-SIDE HAZ	START	0.084	0.380	0.221	137.0		0.658	0.065	0.393	1.073	20.0	70	DRY AIR	73.2	0.653	Δ a = 0.001"	72
				STOP	0.085	0.380	0.224	137.0		0.658	0.066	0.398	1.073				73.4	0.655		
				START	0.094	0.380	0.247	137.0		0.658	0.069	0.440	1.084	≈ 1 MIN.		LAB AIR	75.9	0.678	Δ a = 0.001"	
				STOP	0.095	0.380	0.250	137.0		0.658	0.069	0.445	1.085				76.2	0.680		
				FAIL	0.153	0.456	0.336	162.0		0.777	0.094	0.716	1.163	STATIC			112.7	—		
GW-25	0.201	1.802	OUT-SIDE HAZ	START	0.106	0.375	0.283	137.0		0.658	0.072	0.527	1.106	20.0	70	DRY AIR	79.1	0.706	NO GROWTH	96
				STOP	0.106	0.375	0.283	137.0		0.658	0.072	0.527	1.106				79.1	0.706		
				START	0.111	0.375	0.296	137.0		0.658	0.073	0.552	1.110	≈ 1 MIN.		LAB AIR	80.0	0.714	NO GROWTH	
				STOP	0.111	0.375	0.296	137.0		0.658	0.073	0.552	1.110				80.0	0.714		
				FAIL	0.136	0.395	0.344	192.4	208.3	0.923	0.085	0.677	1.131	STATIC			123.5	—		

Table 18: SUSTAINED LOAD TESTS OF NICKEL PLATED, 0.21 THICK D6 STEEL WELDMENT (CONTINUED)

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION (hours)	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi$\sqrt{in.}$)	K_I/K_{Ic}	REMARKS	EXTRA BAKE TIME (HOURS)
GW-26	0.212	1.802	OUT-SIDE HAZ	START	0.088	0.420	0.210	140.0	208.3	0.671	0.070	0.416	1.088	20.0	70	DRY AIR	78.7	0.703	TOTAL Δa = 0.004"	120
				STOP	(4)	—	—	140.0	↕	0.671	—	—	—				—	—		
				START	(4)	—	—	140.0	↕	0.671	—	—	—	≈1 MIN.		LAB AIR	—	—		
				STOP	0.092	0.420	0.219	140.0	↕	0.671	0.072	0.435	1.095				80.1	0.715		
				FAIL	0.094	0.430	0.219	189.8	↕	0.910	0.078	0.444	1.099	STATIC			114.0	—		
GW-27	0.213	1.802	OUT-SIDE HAZ	START	0.090	0.410	0.220	140.0	↕	0.671	0.070	0.422	1.087	20.0	70	DRY AIR	78.7	0.703	Δa = 0.001"	144
				STOP	0.091	0.410	0.222	140.0	↕	0.671	0.071	0.427	1.089				79.0	0.705		
				FAIL	0.126	0.435	0.290	183.6	↕	0.881	0.088	0.591	1.135	STATIC		LAB AIR	120.6	—		
GW-28	0.213	1.795	OUT-SIDE HAZ	START	0.090	0.415	0.217	140.0	↕	0.671	0.071	0.423	1.089	20.0	70	DRY AIR	79.0	0.705	Δa = 0.001"	168
				STOP	0.091	0.415	0.219	140.0	↕	0.671	0.071	0.427	1.090				79.3	0.708		
				FAIL	0.116	0.425	0.273	186.0	↕	0.892	0.085	0.545	1.122	STATIC		LAB AIR	118.5	—		
GW-29	0.214	1.797	OUT-SIDE HAZ	START	0.091	0.400	0.227	139.1	↕	0.667	0.070	0.425	1.086	20.0	70	DRY AIR	77.8	0.694	Δa = 0.001"	192
				STOP	0.092	0.400	0.230	139.1	↕	0.667	0.070	0.430	1.087				78.1	0.697		
				FAIL	0.123	0.430	0.286	183.0	208.3	0.879	0.087	0.575	1.129	STATIC		LAB AIR	118.7	—		

(1) AS REC'D (4HOUR BAKE AT 375°F IN AIR) AND BAKED AT 400°F IN FLOWING NITROGEN FOR TIME INDICATED

(2) ALL FLAWS MECHANICALLY CUT AFTER ALL BAKING

(3) $a/t > 0.85$, M_K CURVE NOT APPLICABLE

(4) CRACK GROWTH FOR EACH LOADING COULD NOT BE DETERMINED BECAUSE OF INSUFFICIENT FATIGUE MARKING

Table 19: PROOF TESTS OF NICKEL-PLATED, 0.21 THICK LONG TRANSVERSE GRAIN D6 STEEL PLATE [1] [2]

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi$\sqrt{in.}$)	K_I/K_{Ic}	REMARKS
GB-6	0.216	1.795	OUT-SIDE	START	0.102	0.420	0.243	159.4	[3]	0.778	0.077	0.473	1.102	≈ 1 MIN	70	LAB AIR	95.3	0.922	PROOF Δa = 0.006" Δ2c = 0.010"
				STOP	0.108	0.430	0.251	159.4	↓	0.778	0.080	0.501	1.110				97.9	0.949	
				FAIL	0.133	0.440	0.302	151.1		0.737	0.087	0.617	1.139	STATIC			99.2	—	
GB-9	0.216	1.807	OUT-SIDE	START	0.138	0.430	0.321	146.4		0.714	0.087	0.639	1.135	≈ 1 MIN	70	LAB AIR	95.4	0.924	PROOF Δa = 0.005" Δ2c = 0.010"
				STOP	0.143	0.440	0.325	146.4		0.714	0.089	0.662	1.144				97.4	0.943	
				FAIL		(CYCLED THROUGH THE THICKNESS)											–	—	
GB-11	0.215	1.798	OUT-SIDE	START	0.079	0.380	0.208	175.9		0.858	0.066	0.368	1.073	≈ 1 MIN	70	LAB AIR	94.9	0.919	PROOF Δa = 0.003"
				STOP	0.082	0.380	0.216	175.9		0.858	0.068	0.382	1.073				95.9	0.929	
				FAIL	0.090	0.410	0.220	185.7		0.906	0.075	0.419	1.086	STATIC			107.6	—	
GB-18	0.215	1.804	OUT-SIDE	START	0.120	0.350	0.343	157.6		0.769	0.072	0.558	1.080	≈ 1 MIN	70	LAB AIR	89.3	0.865	PROOF Δa = 0.002" Δ2c = 0.005"
				STOP	0.122	0.355	0.344	157.6	↓	0.769	0.073	0.567	1.083				90.2	0.873	
				FAIL	0.173	0.450	0.384	146.5	[3]	0.715	0.094	0.805	1.152	STATIC			100.9	—	

[1] AS RECEIVED (4-HOUR BAKE AT 375°F IN AIR) + 24-HOUR BAKE AT 400°F IN FLOWING NITROGEN

[2] ALL FLAWS MECHANICALLY CUT AFTER ALL BAKING

[3] ASSUMED σ_{ys} = 205.0 KSI

Table 20: PROOF/ MDOP TESTS OF NICKEL-PLATED , 0.21 THICK LONG TRANSVERSE GRAIN D6 STEEL PLATE [1] [2] [5]

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi$\sqrt{in.}$)	K_I/K_{Ic}	REMARKS
GB-7	0.215	1.798	OUT-SIDE	START	0.095	0.430	0.221	165.2	[3]	0.806	0.076	0.442	1.097	≈1 MIN	70	LAB AIR	97.7	0.946	PROOF Δa = 0.007" Δ2c = 0.010"
				STOP	0.102	0.440	0.232	165.2		0.806	0.080	0.475	1.109				101.0	0.978	
				START	0.102	0.440	0.232	125.7		0.613	0.077	0.475	1.109	10 CYCLES		DRY AIR	75.2	0.729	MDOP, f = 1 CPM, R = 0 (TRAPEZOIDAL WAVE)
				STOP	0.102	0.440	0.232	125.7		0.613	0.077	0.475	1.109				75.2	0.729	
				FAIL	0.155	0.490	0.316	145.1		0.708	0.098	0.722	1.189	STATIC		LAB AIR	105.4	—	NO GROWTH
GB-13	0.215	1.805	OUT-SIDE	START	0.116	0.350	0.331	166.6		0.813	0.072	0.539	1.080	≈1 MIN	70	LAB AIR	94.5	0.915	PROOF Δa = 0.006" Δ2c = 0.020"
				STOP	0.122	0.370	0.330	166.6		0.813	0.077	0.567	1.093				98.2	0.951	
				START	0.122	0.370	0.330	126.3		0.616	0.074	0.567	1.093	10 CYCLES		DRY AIR	73.1	0.708	MDOP, f = 1 CPM, R = 0 (TRAPEZOIDAL WAVE)
				STOP	0.122	0.370	0.330	126.3		0.616	0.074	0.567	1.093				73.1	0.708	
				FAIL			(CYCLED THROUGH THE THICKNESS)									LAB AIR	—	—	NO GROWTH
GB-25	0.215	1.805	OUT-SIDE	START	0.090	0.415	0.217	164.5		0.803	0.073	0.419	1.087	≈1 MIN	70	LAB AIR	94.2	0.912	PROOF Δa = 0.006" Δ2c = 0.005"
				STOP	0.096	0.420	0.229	164.5		0.803	0.076	0.447	1.096				96.8	0.937	
				START	0.096	0.420	0.229	124.6		0.608	0.072	0.447	1.096	10 CYCLES		DRY AIR	71.7	0.694	MDOP, f = 1 CPM, R = 0 (TRAPEZOIDAL WAVE)
				STOP	0.096	0.420	0.229	124.6		0.608	0.072	0.447	1.096				71.7	0.694	
				FAIL	0.165	0.470	0.351	141.9	[3]	0.692	0.096	0.768	1.174	STATIC		LAB AIR	100.9	—	NO GROWTH

Table 20: PROOF/MDOP TESTS OF NICKEL-PLATED, 0.21 THICK LONG TRANSVERSE GRAIN D6 STEEL PLATE (CONTINUED)

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi$\sqrt{\text{in.}}$)	K_I/K_{Ic}	REMARKS
GB-26	0.215	1.803	OUT-SIDE	START	0.097	0.410	0.237	157.1	3	0.766	0.075	0.450	1.093	≈1 MIN	70	LAB AIR	91.5	0.886	PROOF Δa = 0.004" $\Delta 2c$ = 0.005"
				STOP	0.101	0.415	0.243	157.1		0.766	0.076	0.469	1.099				93.1	0.902	
				START	0.101	0.415	0.243	119.1		0.581	0.073	0.469	1.099	10 CYCLES		DRY AIR	69.2	0.670	MDOP, f = 1 CPM, R = 0 (TRAPEZOIDAL WAVE)
				STOP	0.101	0.415	0.243	119.1		0.581	0.073	0.469	1.099				69.2	0.670	
				FAIL	0.174	0.485	0.359	140.1		0.683	0.100	0.808	1.188	STATIC		LAB AIR	102.5	—	NO GROWTH
GB-27	0.214	1.804	OUT-SIDE	START	0.092	0.390	0.236	170.5		0.832	0.072	0.430	1.084	≈1 MIN	70	LAB AIR	96.8	0.937	PROOF Δa = 0.003" $\Delta 2c$ = 0.005"
				STOP	0.095	0.395	0.241	170.5		0.832	0.074	0.444	1.089				98.2	0.951	
				START	0.095	0.395	0.241	129.3		0.631	0.070	0.444	1.089	10 CYCLES		DRY AIR	72.8	0.705	MDOP, f = 1 CPM, R = 0) (TRAPEZOIDAL WAVE)
				STOP	0.095	0.395	0.241	129.3		0.631	0.070	0.444	1.089				72.8	0.705	
				FAIL	0.198	0.515	0.384	146.4	3	0.714	0.108	0.926	4	STATIC		LAB AIR	4	—	NO GROWTH

1. AS REC'D (4 HOUR BAKE AT 375°F IN AIR) + 24 HOUR BAKE AT 400°F IN FLOWING NITROGEN
2. ALL FLAWS MECHANICALLY CUT AFTER ALL BAKING
3. ASSUMED σ_{ys} = 205.0 KSI
4. a/t > 0.85, M_K CURVE NOT APPLICABLE
5. SEE FIGURE 30 FOR TYPICAL LOADING SPECTRUM

Table 21: PROOF/MDOP/SUSTAINED TESTS OF NICKEL PLATED, 0.21 THICK LONG TRANSVERSE GRAIN D6 STEEL PLATE [1] [2] [5]

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi$\sqrt{in.}$)	K_I/K_{Ic}	REMARKS
GB-8	0.215	1.797	OUT-SIDE	START	0.101	0.400	0.252	164.7	[3] ↓	0.803	0.076	0.470	1.095	≈1 MIN.	70	LAB AIR	96.7	0.937	PROOF Δa = 0.009″ Δ2c = 0.010″
				STOP	0.110	0.410	0.268	164.7		0.803	0.079	0.512	1.106				100.1	0.969	
				START	0.110	0.410	0.268	125.3		0.611	0.076	0.512	1.106	10 CYCLES		DRY AIR	74.6	0.723	MDOP, f = 1 CPM, R = 0 (TRAPEZOIDAL WAVE) NO GROWTH
				STOP	0.110	0.410	0.268	125.3		0.611	0.076	0.512	1.106				74.6	0.723	
				START	0.110	0.410	0.268	125.3		0.611	0.076	0.512	1.106	45 MIN.			74.6	0.723	SUSTAIN NO GROWTH
				STOP	0.110	0.410	0.268	125.3		0.611	0.076	0.512	1.106				74.6	0.723	
				FAIL	0.200	0.550	0.364	123.5		0.602	0.112	0.931	[4]	STATIC		LAB AIR	[4]	—	
GB-12	0.213	1.800	OUT-SIDE	START	0.106	0.385	0.275	165.6		0.808	0.075	0.497	1.094	≈1 MIN.	70	LAB AIR	96.9	0.939	PROOF Δa = 0.003″ Δ2c = 0.020″
				STOP	0.109	0.405	0.269	165.6		0.808	0.079	0.511	1.105				100.0	0.969	
				START	0.109	0.405	0.269	125.6		0.613	0.075	0.511	1.105	10 CYCLES		DRY AIR	74.3	0.720	MDOP, f = 1 CPM, R = 0 (TRAPEZOIDAL WAVE) NO GROWTH
				STOP	0.109	0.405	0.269	125.6		0.613	0.075	0.511	1.105				74.3	0.720	
				START	0.109	0.405	0.269	125.6		0.613	0.075	0.511	1.105	20.0 HOURS			74.3	0.720	SUSTAIN NO GROWTH
				STOP	0.109	0.405	0.269	125.6		0.613	0.075	0.511	1.105				74.3	0.720	
				FAIL	0.180	0.485	0.371	143.9	[3]	0.702	0.101	0.844	1.195	STATIC		LAB AIR	106.4	—	

Table 21: PROOF/MDOP/SUSTAINED TESTS OF NICKEL PLATED, 0.21 THICK LONG TRANSVERSE GRAIN D6 STEEL PLATE (Continued)

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi$\sqrt{in.}$)	K_I/K_{Ic}	REMARKS
GB-14	0.215	1.799	OUT-SIDE	START	0.110	0.405	0.272	156.4	[3]	0.763	0.078	0.511	1.104	≈1 MIN.	70	LAB AIR	94.0	0.911	PROOF Δa = 0.006" Δ2c = 0.005"
				STOP	0.116	0.410	0.283	156.4		0.763	0.080	0.539	1.112				96.0	0.930	
				START	0.116	0.410	0.283	118.5		0.578	0.077	0.539	1.112	10 CYCLES		DRY AIR	71.5	0.693	MDOP, f = 1 CPM, R = 0 (TRAPEZOIDAL WAVE) NO GROWTH
				STOP	0.116	0.410	0.283	118.5		0.578	0.077	0.539	1.112				71.5	0.693	
				START	0.116	0.410	0.283	118.5		0.578	0.077	0.539	1.112	20.0 HOURS			71.5	0.693	SUSTAIN NO GROWTH
				STOP	0.116	0.410	0.283	118.5		0.578	0.077	0.539	1.112				71.5	0.693	
				FAIL	0.179	0.490	0.365	132.9		0.649	0.101	0.832	1.195	STATIC		LAB AIR	98.2	—	
GB-16	0.214	1.801	OUT-SIDE	START	0.095	0.400	0.237	165.5		0.808	0.074	0.445	1.091	≈1 MIN.	70	LAB AIR	95.5	0.925	PROOF Δa = 0.004" Δ2c = 0.010"
				STOP	0.099	0.410	0.241	165.5		0.808	0.076	0.463	1.098				97.7	0.947	
				START	0.099	0.410	0.241	125.4		0.612	0.073	0.463	1.098	10 CYCLES		DRY AIR	72.4	0.692	MDOP, f = 1 CPM, R = 0 (TRAPEZOIDAL WAVE) NO GROWTH
				STOP	0.099	0.410	0.241	125.4		0.612	0.073	0.463	1.098				72.4	0.692	
				START	0.099	0.410	0.241	125.4		0.612	0.073	0.463	1.098	20.3 HOURS			72.4	0.692	SUSTAIN NO GROWTH
				STOP	0.099	0.410	0.241	125.4		0.612	0.073	0.463	1.098				72.4	0.692	
				FAIL	0.135	0.425	0.318	172.0	[3]	0.839	0.088	0.632	1.135	STATIC		LAB AIR	112.6	—	

Table 21: PROOF/MDOP/SUSTAINED TESTS OF NICKEL PLATED, 0.21 THICK LONG TRANSVERSE GRAIN D6 STEEL PLATE (Continued)

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi$\sqrt{in.}$)	K_I/K_{Ic}	REMARKS
GB-20	0.212	1.801	OUT-SIDE	START	0.093	0.370	0.251	167.6	3	0.817	0.070	0.438	1.081	≈ 1 MIN.	70	LAB AIR	93.5	0.906	PROOF $\Delta a = 0.003''$ $\Delta 2c = 0.005''$
				STOP	0.096	0.375	0.256	167.6		0.817	0.071	0.452	1.085				94.8	0.919	
				START	0.096	0.375	0.256	127.1		0.620	0.068	0.452	1.085	10 CYCLES		DRY AIR	70.4	0.682	MDOP, f = 1 CPM, R = 0 (TRAPEZOIDAL WAVE) NO GROWTH
				STOP	0.096	0.375	0.256	127.1		0.620	0.068	0.452	1.085				70.4	0.682	
				START	0.096	0.375	0.256	127.1		0.620	0.068	0.452	1.085	20.0 HOURS			70.4	0.682	SUSTAIN NO GROWTH
				STOP	0.096	0.375	0.256	127.1		0.620	0.068	0.452	1.085				70.4	0.682	
				FAIL	0.181	0.450	0.402	158.5		0.773	0.096	0.853	4	STATIC		LAB AIR	4	—	
GB-21	0.214	1.801	OUT-SIDE	START	0.092	0.390	0.236	168.5		0.822	0.072	0.429	1.084	≈ 1 MIN.	70	LAB AIR	95.5	0.925	PROOF $\Delta a = 0.007''$ $\Delta 2c = 0.010''$
				STOP	0.099	0.400	0.247	168.5		0.822	0.075	0.462	1.094				98.6	0.955	
				START	0.099	0.400	0.247	127.7		0.623	0.072	0.462	1.094	10 CYCLES		DRY AIR	73.1	0.708	MDOP, f = 1 CPM, R = 0 (TRAPEZOIDAL WAVE) NO GROWTH
				STOP	0.099	0.400	0.247	127.7		0.623	0.072	0.462	1.094				73.1	0.708	
				START	0.099	0.400	0.247	127.7		0.623	0.072	0.462	1.094	20.1 HOURS			73.1	0.708	SUSTAIN NO GROWTH
				STOP	0.099	0.400	0.247	127.7	3	0.623	0.072	0.462	1.094				73.1	0.708	
				FAIL		(CYCLED THROUGH-THE-THICKNESS)								STATIC		LAB AIR	–	—	

1. AS RECEIVED (4-HOUR BAKE AT 375°F IN AIR) + 24-HOUR BAKE AT 400°F IN FLOWING INTROGEN
2. ALL FLAWS MECHANICALLY CUT AFTER ALL BAKING
3. ASSUMED σ_{ys} = 205.0 ksi
4. a/t > 0.85, M_K CURVE NOT APPLICABLE
5. SEE FIGURE 30 FOR TYPICAL LOADING SPECTRUM

Table 22: MDOP CYCLIC TEST OF NICKEL PLATED, 0.21 THICK LONG TRANSVERSE GRAIN D6 STEEL PLATE (1) (2) (4)

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi$\sqrt{in.}$)	K_I/K_{Ic}	REMARKS
GB-28	0.214	1.803	OUT-SIDE	START	0.122	0.380	0.321	125.0	(3)	0.610	0.075	0.569	1.100	10 CYCLES	70	DRY AIR	73.5	0.712	MDOP, f = 1 CPM, R = 0 (TRAPEZOIDAL WAVE) Δa = 0.003"
				STOP	0.125	0.385	0.325	125.0	(3)	0.610	0.076	0.583	1.103				74.3	0.720	
				FAIL	(SPECIMEN FAILED IN GRIPS AND HAD TO BE SAWCUT)												–	—	

(1) AS RECEIVED (4-HOUR BAKE OUT AT 375°F IN AIR) + 24-HOUR BAKE AT 400°F IN FLOWING NITROGEN
(2) FLAW MECHANICALLY CUT AFTER ALL BAKING
(3) ASSUMED σ_{ys} = 205.0 ksi
(4) SEE FIGURE 30 FOR MDOP WAVEFORM

Table 23: PROOF/MDOP/CYCLE TO FAILURE TEST OF NICKEL PLATED, 0.21 THICK LONG TRANSVERSE GRAIN D6 STEEL PLATE (1) (2) (5)

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi$\sqrt{in.}$)	K_I/K_{Ic}	REMARKS
GB-17	0.215	1.804	OUT-SIDE	START	0.126	0.360	0.350	152.2	(3) ↕	0.743	0.074	0.585	1.085	(1) MIN.	70	DRY AIR	87.8	0.851	PROOF Δa = 0.002" $\Delta 2c$ = 0.005"
				STOP	0.128	0.365	0.351	152.2		0.743	0.075	0.595	1.087				88.7	0.860	
				START	0.128	0.365	0.351	115.4		0.563	0.073	0.595	1.087	30 CYCLES			66.3	0.643	MDOP,1 CPM,R=0 (TRAPEZOIDAL WAVE) NO GROWTH
				STOP	0.128	0.365	0.351	115.4		0.563	0.073	0.595	1.087				66.3	0.643	
				START	0.128	0.365	0.351	115.4	(3)	0.563	0.073	0.595	1.087	665 CYCLES			66.3	0.643	MDOP, 40 CPM, R = 0 (SINE WAVE) (4)
				STOP		(CYCLED TO FAILURE)											–	—	

(1) AS RECEIVED (4-HOUR BAKE AT 375°F IN AIR) + 24-HOUR BAKE AT 400°F IN FLOWING NITROGEN
(2) FLAW MECHANICALLY CUT AFTER ALL BAKING
(3) ASSUMED σ_{ys} = 205.0 ksi
(4) GROWTH STARTED AT 55 CYCLES, BREAKTHROUGH OCCURRED AT 642 CYCLES
(5) SEE FIGURE 30 FOR LOADING SPECTRUM

Table 24: MULTIPLE PROOF TESTS OF NICKEL PLATED, 0.21 THICK LONG TRANSVERSE GRAIN D6 STEEL PLATE [1] [2]

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION (hours)	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi$\sqrt{in.}$)	K_I/K_{Ic}	REMARKS
GB-22	0.214	1.804	OUT-SIDE	START	0.098	0.370	0.265	129.3	[3]	0.631	0.069	0.457	1.083	[4]	70	LAB AIR	71.5	0.693	Δa = 0.001"
				STOP	0.099	0.370	0.268	129.3		0.631	0.069	0.462	1.084				71.7	0.695	CYCLE NO. 1
				START	0.099	0.370	0.268	162.7		0.794	0.071	0.462	1.084				91.8	0.889	PROOF Δa = 0.003"
				STOP	0.102	0.370	0.276	162.7		0.794	0.072	0.476	1.085				92.5	0.896	CYCLE NO. 2
				START	0.102	0.370	0.276	171.5		0.837	0.073	0.476	1.085				98.0	0.950	Δa = 0.003" Δ2c = 0.010"
				STOP	0.105	0.380	0.276	171.5		0.837	0.075	0.490	1.090				99.8	0.967	CYCLE NO. 3
				START	0.105	0.380	0.276	174.8		0.853	0.075	0.490	1.090				101.9	0.988	Δa = 0.003" Δ2c = 0.010" CYCLE NO. 4
				STOP	0.108	0.390	0.277	174.8		0.853	0.077	0.504	1.096				103.9	1.007	
				START	0.108	0.390	0.277	174.8		0.853	0.077	0.504	1.096				103.9	1.007	Δa = 0.003" Δ2c = 0.010" CYCLE NO. 5
				STOP	0.111	0.400	0.277	174.8		0.853	0.079	0.518	1.104				106.0	1.027	
				START	0.111	0.400	0.277	174.8		0.853	0.079	0.518	1.104				106.0	1.027	Δa = 0.008" Δ2c = 0.010" CYCLE NO. 6
				STOP	0.119	0.410	0.290	174.8		0.853	0.083	0.555	1.115				109.2	1.059	
				FAIL	0.119	0.410	0.290	172.7	[3]	0.843	0.082	0.555	1.115	[4]			107.8	—	FAILURE CYCLE NO. 7

Table 24: MULTIPLE PROOF TESTS OF NICKEL PLATED, 0.21 THICK LONG TRANSVERSE GRAIN D6 STEEL PLATE (Continued)

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION (hours)	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi$\sqrt{in.}$)	K_I/K_{Ic}	REMARKS
GB-23	0.214	1.799	OUT-SIDE	START	0.096	0.420	0.229	129.6	▷3	0.632	0.073	0.448	1.096	▷5	70	DRY AIR	74.8	0.724	NO GROWTH CYCLE NO. 1
				STOP	0.096	0.420	0.229	129.6	↕	0.632	0.073	0.448	1.096	↕			74.8	0.724	
				START	0.096	0.420	0.229	164.4		0.802	0.076	0.448	1.096				96.8	0.938	PROOF CYCLE NO. 2
				STOP	▷6	–	–	▷5		–	–	–	–				–	–	
				START	▷6	–	–	▷5		–	–	–	–				–	–	CYCLES NO. 3 THROUGH 8
				STOP	0.126	0.445	0.283	165.4		0.807	0.088	0.588	1.138				108.9	1.056	
				START	0.126	0.445	0.283	140.5		0.685	0.086	0.588	1.138				91.3	0.884	NO GROWTH CYCLE NO. 9
				STOP	0.126	0.445	0.283	140.5	↕	0.685	0.086	0.588	1.138	↕			91.3	0.884	
				FAIL	0.161	0.520	0.310	141.3	▷3	0.690	0.103	0.751	1.138	▷5			107.6	–	

▷1 AS RECEIVED (4-HOUR BAKE AT 375°F IN AIR) + 24-HOUR BAKE AT 400°F IN FLOWING NITROGEN

▷2 FLAWS MECHANICALLY CUT AFTER ALL BAKING

▷3 ASSUMED σ_{ys} = 205.0 ksi

▷4 SEE TABLE 25 FOR COMPLETE LOAD TIME SUMMARY OF GB-22

▷5 SEE TABLE 26 FOR COMPLETE LOAD TIME SUMMARY OF GB-23

▷6 ONLY TOTAL GROWTH COULD BE DETERMINED FOR CYCLES 2-8 OF GB-23

Table 25: LOAD-TIME SUMMARY OF SPECIMEN GB-22

LOADING CYCLE	APPLIED STRESS, σ_A (ksi)	TIME AT LOAD	GROWTH?
1	129.3	≈1 SEC	YES
	0	–	–
2	162.7	4¼ MIN	YES
	0	–	–
3	122.1	1½ MIN	NO
	138.1	2¾ MIN	NO
	171.5	2¾ MIN	YES
	0	–	–
4	128.3	2¾ MIN	NO
	146.1	2 MIN	NO
	174.8	3 MIN	YES
	0	–	–
5	131.1	2½ MIN	NO
	148.7	2¼ MIN	NO
	174.8	3 MIN	YES
	0	–	–
6	131.1	2½ MIN	NO
	148.7	2 MIN	NO
	174.8	1¾ MIN	YES
	0	–	–
7	131.1	2½ MIN	NO
	148.7	2 MIN	NO
	172.7	≈1 SEC	YES, FAILURE

Table 26: LOAD-TIME SUMMARY OF SPECIMEN GB-23

LOADING CYCLE	APPLIED STRESS, σ_A (ksi)	TIME AT LOAD	GROWTH?
1	129.6	≈1 SEC	NO
	0	–	–
2	164.4	14 MIN	YES
	0	–	–
3	123.2	2½ MIN	NO
	164.6	3½ MIN	YES
	167.2	3 MIN	YES
	0	–	–
4	125.7	3 MIN	NO
	167.2	1½ MIN	YES
	0	–	–
5	125.7	2½ MIN	NO
	166.7	2¼ MIN	YES
	169.3	5¼ MIN	YES
	0	–	–
6	127.0	2½ MIN	NO
	143.9	1 MIN	NO
	160.7	2 MIN	YES
	168.5	3½ MIN	YES
	171.1	<10 SEC	YES
	0	–	–
7	128.3	3¼ MIN	NO
	145.2	1½ MIN	NO
	162.8	3 MIN	YES
	167.0	<10 SEC	YES
	0	–	–
8	125.5	2½ MIN	NO
	142.6	2½ MIN	NO
	158.2	3 MIN	YES
	162.8	2 MIN	YES
	164.1	1¾ MIN	YES
	165.4	<10 SEC	YES
	0	–	–
9	123.9	2½ MIN	NO
	140.5	2½ MIN	NO
	0	–	–

Table 27: MULTIPLE PROOF/MDOP TESTS OF NICKEL-PLATED, 0.21 THICK, LONG TRANSVERSE GRAIN D6 STEEL PLATE (WIDE SPECIMENS) 1 2

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi $\sqrt{in.}$)	K_I/K_{Ic}	REMARKS
SG-4	0.215	2.998	OUT-SIDE	START	0.132	0.730	0.181	130.5	3	0.637	0.111	0.614	1.249	4	70	LAB AIR	106.0	0.851	PROOF Δa = 0.008"
				STOP	0.140	0.730	0.192	130.5		0.637	0.115	0.651	1.275				110.0	0.883	CYCLE NO. 1
				START	0.140	0.730	0.192	98.9		0.482	0.112	0.651	1.275				82.2	0.660	MDOP Δa = 0.001"
				STOP	0.141	0.730	0.193	98.9		0.482	0.112	0.656	1.277				82.5	0.662	CYCLES NO. 2-11
				START	0.141	0.730	0.193	124.2		0.606	0.115	0.656	1.277				104.8	0.841	
				STOP	5	—	—	124.2		0.606	—	—	—				—	—	CYCLES NO.12-16
				START	5	—	—	125.0		0.610	—	—	—				—	—	Δa = 0.010
				STOP	0.151	0.730	0.207	125.0		0.610	0.120	0.703	1.305				110.0	0.883	CYCLE NO. 17
				START	0.151	0.730	0.207	98.9		0.482	0.117	0.703	1.305				86.0	0.690	NO GROWTH
				STOP	0.151	0.730	0.207	98.9	3	0.482	0.117	0.703	1.305	4			86.0	0.690	CYCLE NO. 18
				FAIL	(CYCLED THROUGH– THE THICKNESS)												—	—	

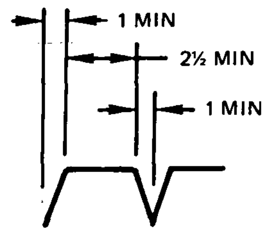
Table 27: MULTIPLE PROOF/MDOP TESTS OF NICKEL-PLATED, 0.21 THICK LONG TRANSVERSE GRAIN D6 STEEL PLATE (WIDE SPECIMENS) (CONTINUED)

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi $\sqrt{in.}$)	K_I/K_{Ic}	REMARKS
SG-5	0.213	2.997	OUT-SIDE	START	0.145	0.740	0.196	139.3	3 ↓	0.679	0.119	0.682	1.299	6 ↓	70	LAB AIR	121.9	0.979	PROOF Δa = 0.011" $\Delta 2c$ = 0.005"
				STOP	0.156	0.745	0.209	139.3		0.679	0.125	0.734	1.332				127.8	1.026	CYCLE NO. 1
				START	0.156	0.745	0.209	105.6		0.515	0.121	0.734	1.332				95.3	0.765	MDOP Δa = 0.006" $\Delta 2c$ = 0.005"
				STOP	0.162	0.750	0.216	105.6		0.515	0.124	0.762	1.349				97.7	0.784	CYCLES NO. 2-51
				START	0.162	0.750	0.216	132.3		0.645	0.127	0.762	1.349				123.9	0.995	Δa = 0.003"
				STOP	0.165	0.750	0.220	132.3		0.645	0.128	0.776	1.357				125.2	1.005	CYCLE NO. 52
				START	0.165	0.750	0.220	105.6		0.515	0.125	0.776	1.357				98.7	0.792	NO GROWTH
				STOP	0.165	0.750	0.220	105.6		0.515	0.125	0.776	1.357	6			98.7	0.792	CYCLE NO. 53
				FAIL	0.170	0.760	0.224	149.5	3	0.729	0.133	0.800	1.373	STATIC			7	—	

1. AS REC'D (4 HOUR BAKE AT 375°F IN AIR) + 24 HOUR BAKE AT 350°F IN FLOWING NITROGEN
2. FLAWS EDM'D BEFORE EXTRA BAKE, PRECRACKED AFTER EXTRA BAKE
3. ASSUMED σ_{ys} = 205.0 KSI
4. SEE TABLE 28 FOR COMPLETE LOAD-TIME SUMMARY OF SG-4
5. ONLY TOTAL GROWTH COULD BE DETERMINED FOR CYCLES 12-17 ON SG-4
6. SEE TABLE 29 FOR COMPLETE LOAD-TIME SUMMARY OF SG-5
7. M_K BELIEVED TO BE EXCESSIVELY HIGH FOR THIS SPECIMEN. NO ENDPOINT REPORTED

Table 28: LOAD-TIME SUMMARY OF SPECIMEN SG-4

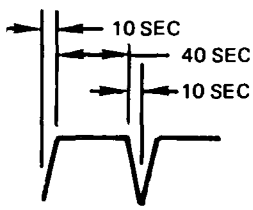
LOADING CYCLE	APPLIED STRESS, σ_A (ksi)	TIME AT LOAD	GROWTH?
1	130.5 0	≈1 SEC –	YES, 0.008" –
2–11	98.9 0	2½ MIN ON EACH CYCLE	YES, 0.001" TOTAL
12	98.9 111.0 117.7 124.2 0	2½ MIN 2½ MIN 2½ MIN 2½ MIN –	NO NO NO YES –
13	117.7 124.2 0	2½ MIN 2½ MIN –	NO YES –
14, 15, 16	124.2 0	2½ MIN –	YES, ON EACH CYCLE
17	98.9 125.0 0	2½ MIN 2½ MIN –	NO YES –
18	98.9 0	2½ MIN –	NO –



CYCLES 2-11

Table 29: LOAD-TIME SUMMARY OF SPECIMEN SG-5

LOADING CYCLE	APPLIED STRESS, σ_A (ksi)	TIME AT LOAD	GROWTH?
1	139.3 0	≈1 SEC –	YES, 0.011" –
2–51	105.6 0	40 SEC ON EACH CYCLE	YES, 0.006" TOTAL
52	125.4 132.3 0	2½ MIN 2½ MIN –	NO YES, 0.003" –
53	105.6 0	2½ MIN –	NO –



CYCLES 2-51

Table 30: PROOF/MDOP/30-DAY SUSTAINED TEST OF D6 STEEL WELDMENT SPECIMEN FROM LM2/ECS DESCENT GOX TANK (S/N 0010) [1] [2]

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED AXIAL STRESS, σ_A (ksi)	σ_A/σ_{ys} [3]	APPLIED BENDING STRESS, σ_B (ksi)	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	BENDING STRESS MAGNIFICATION FACTOR, M_B	TEST DURATION	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY DUE TO BENDING K_{IB} (ksi$\sqrt{in}$)	STRESS INTENSITY DUE TO TENSION K_{IK} (ksi$\sqrt{in}$)	$K_{IK} + K_{IB} = K_I$	K_I/K_{Ic}	REMARKS
TW-19	0.180	1.504	IN-SIDE HAZ	START	0.086	0.395	0.218	153.0	0.690	38.1	0.068	0.479	1.118	0.56	≈ 1 MIN	70	DRY AIR	86.8	9.9	96.7	0.968	PROOF Δ a = 0.005" Δ 2c = 0.005"
				STOP	0.091	0.400	0.227	153.0	0.690	38.1	0.070	0.507	1.128	0.53				89.1	9.5	98.6	0.987	
				START	0.091	0.400	0.227	116.0	0.524	34.4	0.068	0.507	1.128	0.53	20 CYCLES			66.5	8.4	74.9	0.750	MDOP NO GROWTH
				STOP	0.091	0.400	0.227	116.0	0.524	34.4	0.068	0.507	1.128	0.53				66.5	8.4	74.9	0.750	
				START	0.091	0.400	0.227	116.0	0.524	34.4	0.068	0.507	1.128	0.53	30 DAYS		3,000 PSI GOX	66.5	8.4	74.9	0.750	SUSTAIN NO GROWTH
				STOP	0.091	0.400	0.227	116.0	0.524	34.4	0.068	0.507	1.128	0.53				66.5	8.4	74.9	0.750	
				FAIL	0.104	0.410	0.254	148.9	0.672	37.7	0.075	0.579	1.159	0.41	STATIC		LAB AIR	92.3	7.5	99.8	–	

[1] AS RECEIVED (4-HOUR BAKE AT 375°F IN ARGON) + 24-HOUR BAKE AT 375°F IN FLOWING NITROGEN

[2] FLAW MECHANICALLY CUT

[3] σ_{ys} = 221.7 ksi

Table 31: PROOF/MDOP/30-DAY SUSTAINED TESTS OF D6 STEEL WELDMENT SPECIMENS FROM LM/ECS DESCENT GOX REQUALIFICATION TANK (S/N 0032) [1] [2]

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED AXIAL STRESS, σ_A (ksi)	σ_A/σ_{ys} [3]	APPLIED BENDING STRESS, σ_B (ksi)	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	BENDING STRESS MAGNIFICATION FACTOR, M_B	TEST DURATION	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY DUE TO BENDING K_{IB} (ksi$\sqrt{in}$)	STRESS INTENSITY DUE TO TENSION K_{IK} (ksi$\sqrt{in.}$)	$K_{IK} + K_{IB} = K_I$	K_I/K_{Ic}	REMARKS
TW-37	0.180	1.495	IN-SIDE ℄	START	0.093	0.375	0.248	143.3	0.647	20.8	0.068	0.518	1.123	0.49	≈ 1 MIN	70	DRY AIR	81.7	4.7	86.4	0.865	PROOF Δa = 0.002″
				STOP	0.095	0.375	0.253	143.3	0.647	20.8	0.068	0.529	1.126	0.47				82.3	4.5	86.8	0.869	
				START	0.095	0.375	0.253	108.6	0.490	16.8	0.067	0.529	1.126	0.47	20 CYCLES			61.6	3.6	65.2	0.653	MDOP Δa = 0.001″
				STOP	0.096	0.375	0.256	108.6	0.490	16.8	0.067	0.534	1.128	0.46				61.8	3.5	65.3	0.654	
				START	0.096	0.375	0.256	116.5	0.526	17.7	0.067	0.534	1.128	0.46	30 DAYS			66.5	3.7	70.2	0.703	SUSTAIN NO GROWTH
				STOP	0.096	0.375	0.256	116.5	0.526	17.7	0.067	0.534	1.128	0.46				66.5	3.7	70.2	0.703	
				FAIL	0.112	0.395	0.284	157.1	0.710	22.2	0.076	0.623	1.161	0.31	STATIC		LAB AIR	98.3	3.4	101.7	–	
TW-36	0.181	1.502	IN-SIDE HAZ	START	0.095	0.390	0.244	151.0	0.682	23.3	0.070	0.525	1.131	0.48	≈ 1 MIN	70	DRY AIR	88.4	5.2	93.6	0.937	PROOF Δa = 0.002″
				STOP	0.097	0.390	0.249	151.0	0.682	23.3	0.071	0.537	1.135	0.47				89.1	5.2	94.3	0.944	
				START	0.097	0.390	0.249	114.5	0.517	18.2	0.069	0.537	1.135	0.47	20 CYCLES			66.5	4.0	70.5	0.706	MDOP Δa = 0.002″
				STOP	0.099	0.390	0.254	114.5	0.517	18.2	0.070	0.548	1.138	0.44				67.1	3.8	70.9	0.710	
				START	0.099	0.390	0.254	115.3	0.520	18.4	0.070	0.548	1.138	0.44	30 DAYS		3,000 PSI GOX	67.5	3.8	71.3	0.714	SUSTAIN NO GROWTH
				STOP	0.099	0.390	0.254	115.3	0.520	18.4	0.070	0.548	1.138	0.44				67.5	3.8	71.3	0.714	
				FAIL	0.105	0.397	0.264	156.9	0.708	24.1	0.075	0.581	1.150	0.38	STATIC		LAB AIR	96.2	4.4	100.6	–	

[1] TANK ORIGINALLY HAD A 4-HOUR BAKE AT 375°F IN ARGON, THEN PAINT WAS REMOVED BY SANDBLASTING, TANK WAS REBAKED ADDITIONAL 24 HOURS AT 375°F IN VACUUM, AND IT WAS REPAINTED BY GRUMMAN

[2] FLAWS MECHANICALLY CUT

[3] σ_{ys} = 221.7 ksi

Table 32: PROOF/MDOP/30-DAY SUSTAINED TESTS OF D6 STEEL WELDMENT SPECIMENS FROM LM/ECS DESCENT GOX TANK (S/N 0041) [1] [2]

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED AXIAL STRESS, σ_A (ksi)	σ_A/σ_{ys} [3]	APPLIED BENDING STRESS, σ_B (ksi)	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	BENDING STRESS MAGNIFICATION FACTOR, M_B	TEST DURATION	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY DUE TO BENDING K_{IB} (ksi$\sqrt{in}$)	STRESS INTENSITY DUE TO TENSION K_{IK} (ksi$\sqrt{in}$)	$K_{IK} + K_{IB} = K_I$	K_I/K_{Ic}	REMARKS
SN-41-5	0.177	1.502	IN-SIDE HAZ	START	0.098	0.375	0.261	153.7	0.694	17.0	0.070	0.553	1.136	0.43	≈ 1 MIN	70	DRY AIR	90.1	3.4	93.5	0.936	PROOF Δa = 0.003" Δ2c = 0.005"
				STOP	0.101	0.380	0.266	153.7	0.694	17.0	0.071	0.570	1.143	0.40				91.6	3.2	94.8	0.949	
				START	0.101	0.380	0.266	116.5	0.526	16.4	0.069	0.570	1.143	0.40	20 CYCLES			68.4	3.1	71.5	0.716	MDOP NO GROWTH
				STOP	0.101	0.380	0.266	116.5	0.526	16.4	0.069	0.570	1.143	0.40				68.4	3.1	71.5	0.716	
				START	0.101	0.380	0.266	117.6	0.531	16.5	0.069	0.570	1.143	0.40	30 DAYS			69.0	3.1	72.1	0.722	SUSTAIN NO GROWTH
				STOP	0.101	0.380	0.266	117.6	0.531	16.5	0.069	0.570	1.143	0.40				69.0	3.1	72.1	0.722	
				FAIL	0.103	0.395	0.261	168.4	0.760	17.2	0.075	0.581	1.154	0.40	STATIC		LAB AIR	103.6	3.3	106.9	–	
SN-41-4	0.175	1.501	IN-SIDE HAZ	START	0.104	0.385	0.270	155.7	0.703	14.2	0.073	0.594	1.153	0.38	≈ 1 MIN	70	DRY AIR	94.6	2.6	97.2	0.973	PROOF Δa = 0.003" Δ2c = 0.005"
				STOP	0.107	0.390	0.274	155.7	0.703	14.2	0.074	0.611	1.161	0.34				96.1	2.3	98.4	0.985	
				START	0.107	0.390	0.274	118.0	0.532	11.6	0.072	0.611	1.161	0.34	20 CYCLES			71.8	1.9	73.7	0.738	MDOP Δa = 0.002"
				STOP	0.109	0.390	0.279	118.0	0.532	11.6	0.073	0.623	1.164	0.32				72.2	1.8	74.0	0.741	
				START	0.109	0.390	0.279	119.1	0.538	11.7	0.073	0.623	1.164	0.32	30 DAYS		3,000 PSI GOX	72.9	1.8	74.7	0.748	SUSTAIN NO GROWTH
				STOP	0.109	0.390	0.279	119.1	0.538	11.7	0.073	0.623	1.164	0.32				72.9	1.8	74.7	0.748	
				FAIL	0.111	0.398	0.279	159.1	0.719	14.4	0.077	0.634	1.173	0.31	STATIC		LAB AIR	100.7	2.2	102.9	–	

[1] TANK ORIGINALLY HAD A 4-HOUR BAKE AT 375°F IN ARGON, THEN PAINT WAS REMOVED BY SANDBLASTING, TANK WAS REBAKED ADDITIONAL 24 HOURS AT 375°F IN VACUUM, AND IT WAS REPAINTED BY GRUMMAN

[2] FLAWS MECHANICALLY CUT

[3] σ_{ys} = 221.7 ksi

Table 33: PROOF/MDOP/30-DAY SUSTAINED TESTS OF NICKEL-PLATED, 0.21 THICK LONGITUDINAL GRAIN D6 STEEL PLATE (1) (2)

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi$\sqrt{in.}$)	K_I/K_{Ic}	REMARKS
G-28	0.206	1.803	OUT-SIDE HAZ	START	0.102	0.420	0.243	129.1	198.2	0.652	0.075	0.494	1.112	≈ 1 MIN	70	DRY AIR	76.8	0.800	PROOF Δ a = 0.003"
				STOP	0.105	0.420	0.250	129.1	↑	0.652	0.076	0.509	1.116				77.6	0.809	
				START	0.105	0.420	0.250	97.8		0.493	0.074	0.509	1.116	20 CYCLES			58.0	0.605	MDOP NO GROWTH
				STOP	0.105	0.420	0.250	97.8		0.493	0.074	0.509	1.116				58.0	0.605	
		1.442 (3)		START	0.105	0.420	0.250	97.8		0.493	0.074	0.509	1.116	30 DAYS			58.0	0.605	SUSTAIN NO GROWTH
				STOP	0.105	0.420	0.250	97.8		0.493	0.074	0.509	1.116				58.0	0.605	
				FAIL		(CYCLED THROUGH-THE-THICKNESS)								STATIC		LAB AIR	–	–	
G-29	0.207	1.803	IN-SIDE HAZ	START	0.105	0.425	0.247	120.8		0.610	0.076	0.508	1.117	≈ 1 MIN	70	DRY AIR	72.6	0.756	PROOF Δ a = 0.005" Δ 2c = 0.005"
				STOP	0.110	0.430	0.256	120.8		0.610	0.078	0.533	1.127				74.3	0.774	
				START	0.110	0.430	0.256	91.6		0.462	0.076	0.533	1.127	20 CYCLES			55.7	0.581	MDOP NO GROWTH
				STOP	0.110	0.430	0.256	91.6		0.462	0.076	0.533	1.127				55.7	0.581	
		1.540 (3)		START	0.110	0.430	0.256	91.6		0.462	0.076	0.533	1.127	30 DAYS			55.7	0.581	SUSTAIN NO GROWTH
				STOP	0.110	0.430	0.256	91.6	↓	0.462	0.076	0.533	1.127				55.7	0.581	
				FAIL	0.140	0.460	0.304	111.6	198.2	0.563	0.089	0.678	1.175	STATIC		LAB AIR	76.2	–	

(1) AS RECEIVED (4-HOUR BAKE AT 375°F IN AIR) + 24-HOUR BAKE AT 375°F IN VACUUM AND PAINTED

(2) FLAWS MECHANICALLY CUT

(3) SPECIMEN WIDTH WAS REDUCED SO THAT SPECIMENS COULD BE SUSTAINED LOADED IN A 30-KIP TEST MACHINE

Table 34: PROOF/MDOP/30-DAY SUSTAINED TESTS OF NICKEL-PLATED, 0.21 THICK LONG TRANSVERSE GRAIN D6 STEEL PLATE [1] [2]

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi $\sqrt{in.}$)	K_I/K_{Ic}	REMARKS
GB-24	0.215	1.800	OUT-SIDE	START	0.105	0.450	0.233	160.4	[3]	0.782	0.082	0.489	1.115	≈ 1 MIN	70	DRY AIR	99.6	0.965	PROOF Δ a = 0.005" Δ 2c = 0.010"
				STOP	0.110	0.460	0.239	160.4	↕	0.782	0.084	0.512	1.125				102.2	0.990	
				START	0.110	0.460	0.239	121.6		0.594	0.081	0.512	1.125	20 CYCLES			75.9	0.735	MDOP Δ a = 0.002"
				STOP	0.112	0.460	0.243	121.6		0.594	0.082	0.522	1.128				76.5	0.742	
				START	0.112	0.460	0.243	121.6		0.594	0.082	0.522	1.128	30 DAYS		3,000 PSI GOX	76.5	0.742	SUSTAIN NO GROWTH
				STOP	0.112	0.460	0.243	121.6		0.594	0.082	0.522	1.128				76.5	0.742	
				FAIL	0.165	0.500	0.330	137.1	[3]	0.669	0.101	0.769	1.201	STATIC		LAB AIR	101.9	–	

[1] AS RECEIVED (4-HOUR BAKE AT 375°F IN AIR) + 24-HOUR BAKE AT 400°F IN FLOWING NITROGEN

[2] FLAW MECHANICALLY CUT

[3] ASSUMED σ_{ys} = 205.0 ksi

Table 35: PROOF/MDOP/30-DAY SUSTAINED TESTS OF NICKEL-PLATED, 0.21 THICK D6 STEEL WELDMENT [1] [2]

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi $\sqrt{in.}$)	K_I/K_{Ic}	REMARKS
GW-IP-6	0.202	1.793	IN-SIDE HAZ	START	0.131	0.380	0.345	162.2	208.3	0.778	0.079	0.650	1.119	≈ 1 MIN	70	DRY AIR	99.3	0.886	PROOF Δ a = 0.003" Δ 2c = 0.010"
				STOP	0.134	0.390	0.344	162.2	↕	0.778	0.081	0.665	1.127				101.4	0.905	
				START	0.134	0.390	0.344	123.0		0.590	0.078	0.665	1.127	20 CYCLES			75.6	0.675	MDOP NO GROWTH
				STOP	0.134	0.390	0.344	123.0		0.590	0.078	0.665	1.127				75.6	0.675	
				START	0.134	0.390	0.344	130.1		0.624	0.079	0.665	1.127	30 DAYS		3,000 PSI GOX	80.2	0.716	SUSTAIN NO GROWTH
				STOP	0.134	0.390	0.344	130.1		0.624	0.079	0.665	1.127				80.2	0.716	
				FAIL	0.153	0.410	0.373	167.2	208.3	0.803	0.087	0.759	1.142	STATIC		LAB AIR	109.6	–	

[1] AS RECEIVED (4-HOUR BAKE AT 375°F IN AIR) + 24-HOUR BAKE AT 375°F IN VACUUM

[2] FLAW MECHANICALLY CUT

Table 36: PROOF/MDOP/30-DAY SUSTAINED TESTS OF NICKEL-PLATED, 0.21 THICK D6 STEEL WELDMENT [1] [2]

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi $\sqrt{in.}$)	K_I/K_{Ic}	REMARKS
GW-38	0.223	1.796	OUT-SIDE HAZ	START	0.115	0.400	0.287	152.9	208.3	0.734	0.078	0.517	1.096	≈ 1 MIN	70	DRY AIR	91.4	0.815	PROOF Δa = 0.005″ Δ2c = 0.010″
				STOP	0.120	0.410	0.293	152.9	↑	0.734	0.081	0.539	1.105				93.5	0.835	
				START	0.120	0.410	0.293	115.9		0.556	0.078	0.539	1.105	20 CYCLES			69.8	0.623	MDOP Δa = 0.002″
				STOP	0.122	0.410	0.298	115.9		0.556	0.078	0.548	1.106				70.0	0.625	
				START	0.122	0.410	0.298	117.6		0.564	0.079	0.548	1.106	30 DAYS			71.1	0.635	SUSTAIN NO GROWTH
				STOP	0.122	0.410	0.298	117.6		0.564	0.079	0.548	1.106				71.1	0.635	
				FAIL	0.126	0.420	0.300	168.9		0.810	0.085	0.566	1.113	STATIC		LAB AIR	106.6	–	
GW-47	0.203	1.805	IN-SIDE HAZ	START	0.093	0.390	0.238	166.4		0.799	0.072	0.458	1.097	≈ 1 MIN	70	DRY AIR	95.3	0.851	PROOF Δa = 0.003″
				STOP	0.096	0.390	0.246	166.4		0.799	0.073	0.473	1.100				96.3	0.859	
				START	0.096	0.390	0.246	126.2		0.606	0.070	0.473	1.100	20 CYCLES			71.5	0.638	MDOP Δa = 0.002″
				STOP	0.098	0.390	0.251	126.2		0.606	0.070	0.483	1.101				71.9	0.642	
				START	0.098	0.390	0.251	128.2		0.615	0.070	0.483	1.101	30 DAYS		3,000 PSI GOX	73.1	0.652	SUSTAIN NO GROWTH
				STOP	0.098	0.390	0.251	128.2	↓	0.615	0.070	0.483	1.101				73.1	0.652	
				FAIL	0.114	0.420	0.271	177.4	208.3	0.852	0.083	0.562	1.133	STATIC		LAB AIR	112.7	–	

[1] AS RECEIVED (4-HOUR BAKE AT 375°F IN AIR) + 24-HOUR BAKE AT 375°F IN FLOWING NITROGEN

[2] FLAWS MECHANICALLY CUT

Table 39: CYCLE THROUGH – THE – THICKNESS TEST OF D6 STEEL WELDMENT SPECIMEN FROM LM/ECS DESCENT GOX REQUAL TANK (S/N 0032) [1] [2]

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED AXIAL STRESS, σ_A (ksi)	σ_A/σ_{ys} [5]	APPLIED BENDING STRESS, σ_B (ksi)	STRESS RATIO, R	FLAW SIZE a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	BENDING STRESS MAGNIFICATION FACTOR, M_B	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY DUE TO TENSION K_{IK} (ksi $\sqrt{in.}$)	STRESS INTENSITY DUE TO BENDING K_{IB} (ksi $\sqrt{in.}$)	$K_{IK}+K_{IB}=K_I$	REMARKS
TW-31	0.179	1.498	IN-SIDE HAZ	START	0.086	0.383	0.225	80.0	0.361	[3]	0.1	0.063	0.482	1.116	0.55	70	LAB AIR	43.7	4.9	48.6	2200↔ TO BREAK-THROUGH. HELD AT 80 KSI FOR 20 MIN. AFTER BREAKTHROUGH
				STOP	0.179	0.565	0.316	80.0	0.361	[3]	0.1	0.108	1.0	[4]	–			[4]	–	[4]	
				FAIL				(CYCLED THROUGH – THE – THICKNESS)										–	–	–	

[1] TANK HAD PAINT REMOVED BY SANDBLASTING, THEN IT HAD ADDITIONAL 24 HOUR BAKE AT 375°F IN VACUUM AND IT WAS REPAINTED BY GRUMMAN.

[2] FLAWS WERE EDM'D AFTER LAST BAKE OUT BY BOEING

[3] ESTIMATED BENDING STRESS = 20.0 KSI

[4] $a/t > 0.85$, M_K CURVE NOT APPLICABLE

[5] σ_{ys} = 221.7 KSI

Table 37: CYCLE THROUGH-THE-THICKNESS TESTS OF BOEING-PROCESSED D6 STEEL FORGING SPECIMENS (1) (2)

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION (hours)	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi$\sqrt{in.}$)	GROWTH	REMARKS
DBM -5	0.126	2.004	IN-SIDE	START	0.094	0.530	0.177	130.0	212.4	0.612	0.079	0.746	1.386	71 CYCLES	70	LAB AIR	99.0	YES	R = 0, f = 10 cpm Δa = 0.032" $\Delta 2c$ = 0.010" at breakthrough
				STOP	0.126	0.540	0.233	130.0		0.612	0.094	1.0	(3)				(3)		
				FAIL	0.126	0.575	0.219	130.0		0.612	0.097	1.0	(3)	2 CYCLES			(3)		
DBM -6	0.125	2.006	OUT-SIDE	START	0.061	0.520	0.117	121.0		0.570	0.057	0.488	1.172	330 CYCLES	70	LAB AIR	66.2	YES	R = 0, f = 40 cpm to 302 cycles, then f = 10 cpm Δa = 0.064" $\Delta 2c$ = 0.050"
				STOP	0.125	0.570	0.219	121.0		0.570	0.096	1.0	(3)				(3)		
				FAIL	0.125	0.655	0.191	130.9	212.4	0.616	0.103	1.0	(3)	STATIC			(3)		

(1) HEATH TECNA PLATED; FLAWED AFTER BAKE AT 375°F FOR 4 HOURS IN AIR

(2) FLAWS EDM'D

(3) a/t > 0.85, M_K CURVE NOT APPLICABLE

Table 38: CYCLE THROUGH-THE-THICKNESS TESTS OF NICKEL-PLATED, 0.21 THICK, LONGITUDINAL GRAIN D6 STEEL PLATE (1) (2) (5)

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION (hours)	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi$\sqrt{in.}$)	GROWTH	REMARKS
G-15	0.206	1.800	IN-SIDE	START	0.148	0.495	0.299	95.7	198.2	0.483	0.094	0.718	1.207	400 CYCLES	70	LAB AIR	69.0	YES	R = 0.1, f = 180 cpm Δa = 0.058" $\Delta 2c$ = 0.205"
				STOP	0.206	0.700	0.294	95.7		0.483	0.132	1.0	(3)				(3)		
G-16	0.206	1.802	IN-SIDE	START	0.115	0.460	0.250	86.25		0.435	0.081	0.559	1.148	(4)	70	LAB AIR	54.8	YES	R = 0.1, f = 180 cpm Δa = 0.081" $\Delta 2c$ = 0.215"
				STOP	0.206	0.675	0.305	88.95	198.2	0.449	0.128	1.0	(3)				(3)		

(1) AS RECEIVED (4-HOUR BAKE AT 375°F IN AIR) + BAKED 24 HOURS AT 375°F IN VACUUM AND PAINTED BY BOEING

(2) ALL FLAWS EDM'D AFTER EXTRA BAKE CYCLE AND PAINTING

(3) a/t > 0.85, M_K CURVE NOT APPLICABLE

(4) CYCLED AT 86.25 KSI FOR 1,450 CYCLES AND CYCLED AT 88.95 KSI FOR 150 CYCLES, THEN HELD AT 88.95 KSI FOR 10 MINUTES

(5) SPECIMENS G-15 AND G-16 WERE PREVIOUSLY SUSTAINED LOADED; SEE TABLE A15 FOR SUSTAINED LOADED DATA

Table A-1: FRACTURE TESTS OF NICKEL-PLATED D6 STEEL PLATE AND WELDMENT [5]

MATERIAL	SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST TEMPERATURE (^oK)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi $\sqrt{in.}$)	
BASEMETAL	GBM-1	0.214	1.802	OUT-SIDE	0.101	0.445	0.227	174.0	204.8	0.850	0.081	0.472	1.110	70	LAB AIR	107.2	[1]
	GTB-4	0.386	2.256	OUT-SIDE	0.169	0.550	0.307	149.8	192.5	0.779	0.111	0.438	1.056	70	LAB AIR	102.7	[2]
WELDMENT	GW-17	0.215	1.803	OUT-SIDE HAZ	0.097	0.467	0.208	181.5	208.3	0.871	0.082	0.451	1.109	70	LAB AIR	112.3	[3]
	GW-18	0.215	1.801	OUT-SIDE HAZ	0.086	0.457	0.188	184.8	208.3	0.887	0.076	0.400	1.086	70	LAB AIR	108.2	[3]
	GW-6	0.215	1.801	OUT-SIDE HAZ	0.095	0.445	0.213	164.0	208.3	0.787	0.077	0.442	1.100	70	LAB AIR	97.9	[4]

[1] 0.21 THICK, LONG GRAIN, AS RECEIVED (BAKED 4 HOURS AT 375^{o}F IN AIR)

[2] 0.375 THICK, LONG GRAIN, AS RECEIVED (BAKED 4 HOURS AT 375^{o}F IN AIR)

[3] 0.21 THICK, LONG GRAIN, AS RECEIVED (BAKED 4 HOURS AT 375^{o}F IN AIR)

[4] 0.21 THICK, LONG GRAIN, AS RECEIVED (BAKED 4 HOURS AT 375^{o}F IN AIR) + BAKED 20 HOURS AT 900^{o}F IN AIR

[5] ALL FLAWS EDM'D AFTER ALL BAKING

Table A-2: STATIC FRACTURE TESTS OF BOEING-PROCESSED D6 STEEL SPECIMENS [1] [2]

MATERIAL	SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST TEMPERATURE (°K)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi $\sqrt{in.}$)
FORGING	DBM-8	0.128	2.007	–	0.056	0.493	0.114	186.9	212.4	0.880	0.058	0.439	1.136	70	LAB AIR	99.9
	DBM-9	0.127	1.995	–	0.088	0.497	0.177	167.8	212.4	0.790	0.078	0.696	1.333	70	LAB AIR	121.6
WELDMENT	DWM-3	0.208	1.759	OUT-SIDE ℄	0.081	0.445	0.182	168.0	216.7	0.776	0.070	0.389	1.085	70	LAB AIR	94.4
	DWM-15	0.182	1.890	OUT-SIDE HAZ	0.085	0.496	0.171	171.7	216.7	0.793	0.076	0.467	1.133	70	LAB AIR	104.6

[1] UNPLATED AND UNBAKED

[2] ALL FLAWS EDM'D

Table A-3: STATIC FRACTURE TESTS OF NICKEL-PLATED, 0.21 THICK LONGITUDINAL GRAIN D6 STEEL PLATE [1] [2]

PLATE	G-7	0.207	1.791	IN-SIDE	0.093	0.445	0.209	144.0	198.2	0.727	0.075	0.449	1.107	70	LAB AIR	85.3

[1] AS RECEIVED

[2] FLAW EDM'D

Table A-4: STATIC FRACTURE TESTS OF D6 STEEL SPECIMENS FROM LM/ECS DESCENT GOX TANKS ⑦

SPECIMENS FROM TANK	MATERIAL	SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED AXIAL STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	APPLIED BENDING STRESS, σ_B (ksi)	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	BENDING STRESS MAGNIFICATION FACTOR, M_B	TEST TEMPERATURE (°K)	TEST ENVIRONMENT	STRESS INTENSITY DUE TO TENSION, K_{IK} (ksi $\sqrt{in.}$)	STRESS INTENSITY DUE TO BENDING, K_{IB} (ksi $\sqrt{in.}$)	$K_{IK} + K_{IB} = K_I$	REMARKS (NOTES ARE CHRONOLOGICAL)
S/N 0010	FORGING	TB-5	0.120	0.808	IN-SIDE	0.054	0.202	0.267	177.2	220.5	0.804	-12.6	0.039	0.450	1.079	0.53	70	LAB AIR	73.6	-2.3	71.3	② ③ ④ ⑤
		TB-18	0.111	1.001	IN-SIDE	0.062	0.250	0.248	178.0	220.5	0.808	44.7	0.047	0.561	1.151	0.44	70	LAB AIR	86.5	7.6	94.1	② ③ ④ ⑤
	WELDMENT	TW-3	0.179	1.507	IN-SIDE HAZ	0.090	0.371	0.243	161.6	221.7	0.730	36.6	0.068	0.503	1.116	0.51	70	LAB AIR	91.5	8.6	100.1	①
		TW-10	0.182	1.496	OUT-SIDE HAZ	0.093	0.395	0.235	187.1	221.7	0.845	-41.8	0.073	0.512	1.127	0.51	70	LAB AIR	111.2	-10.2	101.0	② ③ ④ ⑤
S/N 0032 (REQUAL)	WELD-MENT	TW-32	0.180	1.497	IN-SIDE HAZ	0.084	0.383	0.219	162.0	221.7	0.731	⑥ 41.0	0.067	0.467	1.111	0.57	70	LAB AIR	90.5	10.7	101.2	② ③ ④ ⑤
S/N 0041	WELDMENT	SN 41-2	0.181	1.497	IN-SIDE HAZ	0.093	0.395	0.235	160.5	221.7	0.725	29.2	0.071	0.514	1.129	0.51	70	LAB AIR	94.1	7.0	101.1	② ③ ④ ⑤
		SN 41-3	0.181	1.501	IN-SIDE HAZ	0.089	0.400	0.222	157.9	221.7	0.713	24.8	0.070	0.493	1.123	0.55	70	LAB AIR	91.2	6.4	97.6	② ③ ④ ⑤

① AS RECEIVED (4-HOUR BAKE AT 375°F IN ARGON)
② PAINT REMOVED BY SANDBLASTING
③ 24-HOUR ADDITIONAL BAKE AT 375°F IN VACUUM
④ REPAINTED AFTER ADDITIONAL BAKE
⑤ FLAWED AFTER LAST BAKE
⑥ ESTIMATE
⑦ ALL FLAWS EDM'D

Table A-5: LOAD/UNLOAD TESTS OF BOEING PROCESSED D6 STEEL SPECIMENS [1] [2]

MATERIAL	SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi $\sqrt{in.}$)	GROWTH	REMARKS
FORGING	DBM -7	0.127	1.999	—	START	0.050	0.490	0.102	158.9	212.4	0.749	0.051	0.394	1.108	≈ 1 MIN.	70	LAB AIR	77.3	YES	Δ a = 0.002" UNPLATED SPECIMEN
					STOP	0.052	0.490	0.106	158.9	↕	0.749	0.052	0.410	1.116				79.1		
					FAIL.	0.053	0.490	0.108	192.0	↕	0.904	0.056	0.418	1.122	STATIC			99.5		
	DBM -11	0.122	1.995	IN-SIDE	START	0.091	0.504	0.181	125.0	↕	0.588	0.076	0.745	1.380	≈ 1 MIN.	70	LAB AIR	92.7	YES	Δ a = 0.002" PLATED SPECIMEN
					STOP	0.093	0.504	0.185	125.0	↕	0.588	0.077	0.761	1.392				94.1		
					FAIL.	0.112	0.504	0.222	151.9	212.4	0.715	0.088	0.917	[3]	STATIC			[3]		
WELDMENT	DWM -5	0.199	1.900	OUT-SIDE ℄	START	0.086	0.510	0.169	126.0	216.7	0.582	0.073	0.433	1.113	≈ 1 MIN.	70	LAB AIR	74.0	YES	Δ a = 0.005" UNPLATED SPECIMEN
					STOP	0.091	0.510	0.178	126.0	216.7	0.582	0.076	0.458	1.125				76.2		
					FAIL.	0.146	0.530	0.275	129.1	216.7	0.596	0.099	0.735	1.248	STATIC			99.0		

[1] PLATED SPECIMENS WERE DONE BY HEATH TECNA AND FLAWED AFTER BAKE AT 375° FOR 4 HRS IN AIR

[2] ALL FLAWS EDM'D

[3] a/t > 0.85; M_K CURVE NOT APPLICABLE

Table A-6: LOAD/UNLOAD TESTS OF D6 STEEL SPECIMENS FROM LM 2 ECS DESCENT GOX TANK (S/N 0010) [1] [2]

MATERIAL	SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED AXIAL STRESS, σ_A (ksi)	σ_A/σ_{ys} [3]	APPLIED BENDING STRESS, σ_B (ksi)	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	BENDING STRESS MAGNIFICATION FACTOR, M_B	TEST DURATION	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY DUE TO TENSION, K_{IK} (ksi $\sqrt{in.}$)	STRESS INTENSITY DUE TO BENDING, K_{IB} (ksi $\sqrt{in.}$)	$K_{IK} + K_{IB} = K_I$	GROWTH	REMARKS
FORGING	TB-7	0.118	0.808	IN-SIDE	START	0.055	0.200	0.275	143.0	0.649	22.1	0.038	0.465	1.081	0.50	≈ 1 MIN	70	LAB AIR	58.6	3.8	62.4	NO	
					STOP	0.055	0.200	0.275	143.0	0.649	22.1	0.038	0.465	1.081	0.50				58.6	3.8	62.4		
					FAIL	0.085	0.225	0.378	162.1	0.735	25.2	0.047	0.718	1.114	0.12	STATIC			76.5	1.1	77.6		
WELDMENT	TW-11	0.182	1.497	OUT-SIDE HAZ	START	0.095	0.395	0.241	140.6	0.635	-41.3	0.070	0.523	1.131	0.50	≈ 1 MIN	70	LAB AIR	82.2	-9.7	72.5	YES	Δa = 0.002"
					STOP	0.097	0.395	0.246	140.6	0.635	-41.3	0.071	0.534	1.135	0.47				82.9	-9.2	73.7		
					FAIL	0.123	0.397	0.310	169.9	0.767	-45.6	0.080	0.677	1.169	0.22	STATIC			109.5	-5.0	104.5		

[1] SPECIMENS HAD PAINT REMOVED BY SANDBLASTING, THEN THEY HAD ADDITIONAL 24-HOUR BAKE AT 375°F IN VACUUM AND WERE REPAINTED BY BOEING

[2] FLAWS WERE EDM'D AFTER LAST BAKE BY BOEING

[3] σ_{ys} OF FORGING = 220.5 KSI; σ_{ys} OF WELDMENT = 221.7 KSI

Table A-7: SUSTAINED LOAD TESTS OF BOEING-PROCESSED D6 STEEL FORGING SPECIMENS [1] [2]

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION (hours)	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi$\sqrt{in.}$)	GROWTH	REMARKS
DBM -3	0.127	1.999	IN-SIDE	START	0.098	0.509	0.193	125.0	212.4	0.589	0.080	0.772	1.392	5 MIN	70	LAB AIR	95.7	YES	Initially loaded and test machine failed after 5 min, reloaded Δa_{TOTAL} = 0.011"
				START	0.101	0.509	0.198	125.0	↓	0.589	0.081	0.796	1.406	20.0			97.6		
				STOP	0.109	0.509	0.214	125.0	↓	0.589	0.085	0.859	[3]				[3]		
				FAIL	0.111	0.542	0.205	141.9	↓	0.668	0.089	0.875	[3]	STATIC			[3]		
DBM -1	0.120	2.013	IN-SIDE	START	0.051	0.500	0.102	158.9	↓	0.749	0.052	0.424	1.133	20.0	70	3000 PSI GOX	79.6	YES	Δa = 0.002"
				STOP	0.053	0.500	0.106	158.9	↓	0.749	0.053	0.441	1.141				81.7		
				FAIL	0.054	0.500	0.108	187.7	↓	0.884	0.057	0.449	1.146	STATIC		LAB AIR	100.0		
DBM -2	0.125	2.011	IN-SIDE	START	0.052	0.490	0.106	125.0	↓	0.589	0.050	0.416	1.121	20.0	70	3000 PSI GOX	61.1	YES	Δa = 0.001"
				STOP	0.053	0.490	0.108	125.0	↓	0.589	0.051	0.424	1.126				61.9		
				FAIL	0.053	0.490	0.108	193.7	↓	0.912	0.056	0.424	1.127	STATIC		LAB AIR	101.0		
DBM -4	0.127	2.010	IN-SIDE	START	0.090	0.500	0.180	125.0	↓	0.589	0.075	0.708	1.341	20.0	70	3000 PSI GOX	89.6	YES	Δa = 0.005"
				STOP	0.095	0.500	0.190	125.0	↓	0.589	0.078	0.747	1.370				93.0		
				FAIL	0.095	0.500	0.190	162.0	212.4	0.763	0.081	0.747	1.370	STATIC		LAB AIR	123.1		

[1] HEATH TECNA PLATED; FLAWED AFTER BAKE AT 375°F FOR 4 HOURS IN AIR

[2] ALL FLAWS EDM'D

[3] a/t > 0.85; M_K CURVE NOT APPLICABLE

Table A-8: SUSTAINED LOAD TESTS OF BOEING-PROCESSED D6 STEEL WELDMENT SPECIMENS [1] —FLAWS IN ℄ [2]

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION (hours)	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi$\sqrt{in.}$)	GROWTH	REMARKS
DWM -2	0.201	1.998	IN-SIDE ℄	START	0.095	0.500	0.190	126.0	216.7	0.582	0.078	0.473	1.129	68.2	70	3000 PSI GOX	77.2	YES	Δa = 0.026" Δ2c = 0.013"
				STOP	0.121	0.513	0.236	126.0		0.582	0.089	0.603	1.190				87.5		
				FAIL	0.132	0.555	0.238	151.4		0.699	0.100	0.658	1.232	STATIC		LAB AIR	114.8		
DWM -4	0.205	1.992	IN-SIDE ℄	START	0.087	0.498	0.175	126.5		0.583	0.073	0.424	1.105	20.0	70	3000 PSI GOX	73.8	YES	Δa = 0.018"
				STOP	0.105	0.498	0.211	126.5		0.583	0.082	0.512	1.142				80.7		
				FAIL	0.114	0.498	0.229	133.6		0.617	0.086	0.556	1.162	STATIC		LAB AIR	88.9		
DWM -6	0.196	2.005	IN-SIDE ℄	START	0.096	0.510	0.188	100.0		0.462	0.077	0.490	1.140	20.0	70	3000 PSI GOX	61.7	YES	Δa = 0.023"
				STOP	0.119	0.510	0.233	100.0		0.467	0.087	0.607	1.196				68.7		
				FAIL	0.149	0.562	0.265	119.1		0.550	0.103	0.760	1.281	STATIC		LAB AIR	95.4		
DWM -8	0.206	1.997	IN-SIDE ℄	START	0.158	0.500	0.316	75.0		0.346	0.095	0.766	1.217	20.0	70	3000 PSI GOX	54.9	YES	Δa = 0.002"
				STOP	0.160	0.500	0.320	75.0	216.7	0.346	0.096	0.775	1.218				55.1		
				FAIL	(CYCLED THROUGH-THE-THICKNESS)									STATIC		LAB AIR	—		

[1] HEATH TECNA PLATED; FLAWED AFTER BAKE AT 375°F FOR 4 HOURS IN AIR

[2] ALL FLAWS EDM'D

Table A-9: SUSTAINED LOAD TESTS OF BOEING PROCESSED D6 STEEL WELDMENT SPECIMENS [1] — FLAWS IN HAZ [2]

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION (hours)	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi$\sqrt{in.}$)	GROWTH	REMARKS
DWM -7	0.206	2.005	IN-SIDE	START	0.098	0.510	0.192	100.0	216.7	0.462	0.078	0.476	1.130	189.8	70	LAB AIR	61.5	YES	Δa = 0.047" Δ2c = 0.028" PLATED SPECIMEN
				STOP	0.145	0.538	0.270	100.0		0.462	0.098	0.705	1.233				75.2		
			HAZ	FAIL	0.180	0.600	0.300	134.8		0.622	0.116	0.875	[3]	STATIC			[3]		
DWM -18	0.206	2.004	IN-SIDE	START	0.097	0.523	0.185	100.0		0.462	0.078	0.470	1.129	20.0	70	LAB AIR	61.6	YES	Δa = 0.012" Δ2c = 0.009" PLATED SPECIMEN
				STOP	0.109	0.532	0.205	100.0		0.462	0.084	0.528	1.159				65.7		
			HAZ	FAIL.	(CYCLED THROUGH-THE-THICKNESS)									STATIC			—		
DWM -1	0.210	2.005	IN-SIDE	START	0.089	0.508	0.175	74.8		0.346	0.072	0.424	1.105	20.0	70	3000 PSI GOX	43.3	YES	Δa = 0.010" PLATED SPECIMEN
				STOP	0.099	0.508	0.195	74.8		0.346	0.077	0.472	1.126				45.6		
			HAZ	FAIL.	0.126	0.513	0.246	155.3		0.717	0.094	0.601	1.179	STATIC		LAB AIR	109.4		
DWM -11	0.209	2.000	IN-SIDE	START	0.096	0.525	0.183	40.0		0.185	0.075	0.460	1.124	20.0	70	3000 PSI GOX	24.1	YES	Δa = 0.007" PLATED SPECIMEN
				STOP	0.103	0.525	0.196	40.0		0.185	0.079	0.493	1.138				24.9		
			HAZ	FAIL.	0.137	0.543	0.252	128.4		0.592	0.098	0.656	1.216	STATIC		LAB AIR	95.3		
DWM -13	0.203	2.001	IN-SIDE	START	0.087	0.503	0.173	100.0		0.462	0.072	0.429	1.108	20.0	70	3000 PSI GOX	58.0	YES	Δa = 0.013" PLATED SPECIMEN
				STOP	0.100	0.503	0.199	100.0		0.462	0.078	0.493	1.136				62.1		
			HAZ	FAIL.	0.108	0.508	0.213	151.0		0.698	0.086	0.532	1.157	STATIC		LAB AIR	100.0		
DWM -14	0.208	1.985	IN-SIDE	START	0.083	0.500	0.166	126.5		0.584	0.071	0.400	1.092	20.0	70	3000 PSI GOX	71.9	YES	Δa = 0.013" PLATED SPECIMEN
				STOP	0.096	0.500	0.192	126.5		0.584	0.078	0.463	1.121				77.3		
			HAZ	FAIL.	0.117	0.509	0.230	150.0	216.7	0.692	0.090	0.564	1.167	STATIC		LAB AIR	102.3		

Table A-9: SUSTAINED LOAD TESTS OF BOEING PROCESSED D6 STEEL WELDMENT SPECIMENS — FLAWS IN HAZ (CONTINUED)

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION (hours)	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi$\sqrt{in.}$)	GROWTH	REMARKS
DWM -16	0.207	2.007	IN-SIDE	START	0.087	0.490	0.178	100.0	216.7	0.462	0.071	0.421	1.102	20.0	70	3000 PSI GOX	57.4	YES	Δa = 0.001" UNPLATED SPECIMEN
				STOP	0.088	0.490	0.180	100.0	216.7	0.462	0.072	0.425	1.103				57.8		
			HAZ	FAIL.	0.122	0.490	0.249	157.1	216.7	0.725	.0.090	0.590	1.169	STATIC		LAB AIR	107.6		

[1] PLATED SPECIMENS WERE DONE BY HEATH TECNA AND FLAWED AFTER BAKE AT 375°F FOR 4 HOURS IN AIR

[2] ALL FLAWS EDM'D

[3] a/t > 0.85, M_K CURVE NOT APPLICABLE

Table A-10: SUSTAINED LOAD TESTS OF RE-BAKED [1] BOEING PROCESSED D6 STEEL WELDMENT SPECIMEN — FLAW IN HAZ [2]

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION (hours)	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi$\sqrt{in.}$)	GROWTH	REMARKS
DWM -9	0.207	2.001	IN-SIDE	START	0.093	0.513	0.181	100.0	216.7	0.462	0.076	0.449	1.118	20.0	70	3000 PSI GOX	60.0	YES	Δa = 0.001" PLATED SPECIMEN
				STOP	0.094	0.513	0.183	100.0	216.7	0.462	0.076	0.454	1.119				60.2		
			HAZ	FAIL.	0.112	0.519	0.216	142.9	216.7	0.660	0.088	0.541	1.161	STATIC		LAB AIR	96.0		

[1] HEATH TECNA PLATED; FLAWED AFTER EXTRA BAKE AT 375° F FOR 24 HRS IN AIR

[2] FLAW EDM'D

Table A-11: SUSTAINED LOAD TESTS OF D6 STEEL FORGING SPECIMENS FROM LM 2 ECS DESCENT GOX TANK (S/N 0010) (7)

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED AXIAL STRESS, σ_A (ksi)	σ_A/σ_{ys} (5)	APPLIED BENDING STRESS, σ_B (ksi)	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	BENDING STRESS MAGNIFICATION FACTOR, M_B	TEST DURATION (hours)	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY DUE TO TENSION K_{IK} (ksi$\sqrt{in.}$)	STRESS INTENSITY DUE TO BENDING K_{IB} (ksi$\sqrt{in.}$)	$K_{IK} + K_{IB} = K_I$	GROWTH	REMARKS (NOTES ARE CHRONOLOGICAL)
TB-3	0.115	0.816	OUT-SIDE	START	0.058	0.200	0.290	140.0	0.635	-43.0	0.038	0.504	1.088	0.44	20.0	70	DRY AIR	58.2	-6.5	51.7	YES	Δa = 0.001" (1)
				STOP	0.059	0.200	0.295	140.0	0.635	-43.0	0.039	0.513	1.090	0.42				58.5	-6.3	52.2		
				FAIL	0.101	0.212	0.476	163.1	0.740	-46.4	0.045	0.878	(6)	–	STATIC		LAB AIR	(6)	–	(6)		
TB-9	0.111	0.802	OUT-SIDE	START	0.057	0.220	0.259	160.0	0.726	-44.6	0.041	0.514	1.113	0.47	20.0	70	DRY AIR	70.5	-7.5	63.0	YES	Δa = 0.002" (1)
				STOP	0.059	0.220	0.268	160.0	0.726	-44.6	0.042	0.532	1.118	0.44				71.3	-7.1	64.2		
				FAIL	0.102	0.230	0.443	166.3	0.755	-45.3	0.049	0.921	(6)	–	STATIC		LAB AIR	(6)	–	(6)		
TB-2	0.118	0.803	IN-SIDE	START	0.053	0.200	0.265	161.1	0.731	22.1	0.038	0.448	1.079	0.53	20.0	70	3,000 PSI GOX	66.0	4.0	70.0	YES	Δa = 0.008" Δ2c = 0.003" (2) (3) (4)
				STOP	0.061	0.203	0.303	161.1	0.731	22.1	0.040	0.519	1.088	0.41				68.6	3.2	71.8		
				FAIL	0.062	0.212	0.292	173.5	0.787	22.8	0.042	0.524	1.097	0.42	STATIC		LAB AIR	76.2	3.5	79.7		
TB-4	0.112	0.807	IN-SIDE	START	0.054	0.200	0.270	125.0	0.567	23.8	0.037	0.482	1.091	0.49	20.0	70	3,000 PSI GOX	51.1	4.0	55.1	YES	Δa = 0.001" (1)
				STOP	0.055	0.200	0.275	125.0	0.567	23.8	0.037	0.491	1.091	0.47				51.3	3.8	55.1		
				FAIL	0.075	0.225	0.333	163.7	0.742	27.9	0.046	0.670	1.140	0.21	STATIC		LAB AIR	78.0	2.2	80.2		
TB-6	0.118	0.804	IN-SIDE	START	0.057	0.202	0.282	136.6	0.619	37.6	0.038	0.483	1.084	0.47	20.0	70	3,000 PSI GOX	56.5	6.1	62.6	YES	Δa = 0.001" (2) (3) (4)
				STOP	0.058	0.202	0.287	136.6	0.619	37.6	0.039	0.491	1.084	0.46				56.7	6.1	62.8		
				FAIL	0.100	0.290	0.345	137.9	0.625	37.7	0.059	0.847	1.232	0.0	STATIC		LAB AIR	80.2	0.0	80.2		
TB-1	0.117	0.800	IN-SIDE	START	0.053	0.192	0.276	152.1	0.690	28.6	0.037	0.453	1.076	0.52	20.0	70	MIL-H-5606 HYD OIL	61.1	5.1	66.2	YES	Δa = 0.002" (2) (3) (4)
				STOP	0.055	0.192	0.286	152.1	0.690	28.6	0.037	0.470	1.077	0.48				61.5	4.7	66.2		
				FAIL	0.060	0.203	0.296	177.4	0.805	31.2	0.041	0.513	1.089	0.42	STATIC		LAB AIR	76.0	4.7	80.7		

(1) AS RECEIVED (4-HR BAKE AT 375°F IN ARGON)
(2) PAINT REMOVED BY SANDBLASTING
(3) BAKED 24 HRS AT 375°F IN VACUUM AND PAINTED BY BOEING
(4) FLAWED BY BOEING
(5) σ_{ys} = 220.5 KSI
(6) a/t > 0.85, M_K CURVE NOT APPLICABLE
(7) ALL FLAWS EDM'D

Table A-12: SUSTAINED LOAD TESTS OF D6 STEEL WELDMENT SPECIMENS FROM LM 2 ECS DESCENT GOX TANK (S/N 0010) (Continued)

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED AXIAL STRESS, σ_A (ksi)	σ_A/σ_{ys} (5)	APPLIED BENDING STRESS, σ_B (ksi)	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	BENDING STRESS MAGNIFICATION FACTOR, M_B	TEST DURATION (hours)	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY DUE TO TENSION, K_{IK} (ksi $\sqrt{in.}$)	STRESS INTENSITY DUE TO BENDING, K_{IB} (ksi $\sqrt{in.}$)	$K_{IK} + K_{IB} = K_I$	GROWTH	REMARKS (NOTES ARE CHRONOLOGICAL)
TW-5	0.176	1.495	IN-SIDE ℄	START	0.089	0.375	0.237	40.0	0.181	11.6	0.063	0.506	1.121	0.52	20.0	70	3000 PSI GOX	21.9	2.7	24.6	NO	(1)
				STOP	0.089	0.375	0.237	40.0	0.181	11.6	0.063	0.506	1.121	0.52				21.9	2.7	24.6		
				FAIL	0.113	0.393	0.288	142.0	0.641	25.5	0.075	0.642	1.169	0.28	STATIC		LAB AIR	88.9	2.2	91.1		
TW-8	0.179	1.501	IN-SIDE HAZ	START	0.092	0.398	0.231	109.0	0.492	22.7	0.068	0.514	1.131	0.52	20.0	70	3000 PSI GOX	62.6	5.5	68.1	YES	Δa = 0.008" (2) (3B) (4)
				STOP	0.100	0.398	0.251	109.0	0.492	22.7	0.070	0.559	1.147	0.44				64.7	4.7	69.4		
				FAIL	0.110	0.418	0.263	148.9	0.672	26.5	0.078	0.615	1.174	0.36	STATIC		LAB AIR	95.2	4.7	99.9		
TW-9	0.181	1.503	IN-SIDE HAZ	START	0.093	0.403	0.231	112.1	0.506	28.0	0.069	0.514	1.131	0.52	20.0	70	3000 PSI GOX	64.8	6.8	71.6	YES	Δa = 0.006" Δ2c = 0.004" (2) (3B) (4)
				STOP	0.099	0.407	0.243	112.1	0.506	28.0	0.071	0.547	1.145	0.46				66.8	6.1	72.9		
				FAIL	0.109	0.423	0.258	148.5	0.670	33.6	0.078	0.602	1.170	0.39	STATIC		LAB AIR	94.7	6.5	101.2		
TW-12	0.183	1.503	IN-SIDE HAZ	START	0.091	0.390	0.233	105.3	0.475	32.3	0.066	0.496	1.118	0.52	20.0	70	3000 PSI GOX	59.2	7.6	66.8	YES	Δa = 0.008" Δ2c = 0.007" (2) (3A) (4)
				STOP	0.099	0.397	0.249	105.3	0.475	32.3	0.070	0.540	1.137	0.46				61.7	7.0	68.7		
				FAIL	0.155	0.495	0.313	127.7	0.576	35.2	0.097	0.846	1.274	0.0	STATIC		LAB AIR	98.6	0.0	98.6		
TW-16	0.179	1.495	IN-SIDE HAZ	START	0.087	0.408	0.213	88.6	0.400	31.9	0.066	0.485	1.124	0.56	19.5	70	3000 PSI GOX	49.8	8.1	57.9	NO	(2) (3B) (4)
				STOP	0.087	0.408	0.213	88.6	0.400	31.9	0.066	0.485	1.124	0.56				49.8	8.1	57.9		
				FAIL	0.132	0.448	0.295	140.9	0.636	39.3	0.087	0.736	1.225	0.18	STATIC		LAB AIR	99.0	3.7	102.7		
TW-18	0.181	1.505	IN-SIDE HAZ	START	0.092	0.392	0.235	81.1	0.366	22.9	0.066	0.509	1.125	0.52	19.5	70	3000 PSI GOX	45.8	5.4	51.2	YES	Δa = 0.002" (2) (3B) (4)
				STOP	0.094	0.392	0.240	81.1	0.366	22.9	0.067	0.520	1.129	0.50				46.2	5.3	51.5		
				FAIL	0.144	0.473	0.304	131.1	0.592	30.4	0.092	0.796	1.252	0.10	STATIC		LAB AIR	96.9	1.6	98.5		

(1) AS RECEIVED (4-HOUR BAKE AT 375°F IN ARGON)
(2) PAINT REMOVED BY SANDBLASTING
(3A) BAKED 24 HOURS AT 375°F IN VACUUM AND PAINTED BY BOEING
(3B) BAKED 24 HOURS AT 375°F IN VACUUM AND PAINTED BY GRUMMAN
(4) FLAWED BY BOEING
(5) σ_{ys} = 221.7 KSI
(6) a/t > 0.85; M_K CURVE NOT APPLICABLE
(7) ALL FLAWS EDM'D

Table A-12: SUSTAINED LOAD TESTS OF D6 STEEL WELDMENT SPECIMENS FROM LM 2 ECS DESCENT GOX TANK (S/N 0010) [7]

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED AXIAL STRESS, σ_A (ksi)	σ_A/σ_{ys} [5]	APPLIED BENDING STRESS, σ_B (ksi)	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	BENDING STRESS MAGNIFICATION FACTOR, M_B	TEST DURATION (hours)	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY DUE TO TENSION, K_{IK} (ksi $\sqrt{in.}$)	STRESS INTENSITY DUE TO BENDING, K_{IB} (ksi $\sqrt{in.}$)	$K_{IK} + K_{IB} = K_I$	GROWTH	REMARKS (NOTES ARE CHRONOLOGICAL)
TW-1	0.194	1.511	IN-SIDE HAZ	START	0.090	0.375	0.240	90.0	0.406	24.2	0.064	0.463	1.098	0.55	20.0	70	LAB AIR	48.9	6.0	54.9	YES	Δa = 0.012" [1]
				STOP	0.102	0.375	0.272	90.0	0.406	24.2	0.068	0.525	1.111	0.44				50.9	4.9	55.8		
				FAIL	0.131	0.412	0.318	129.6	0.585	31.0	0.081	0.675	1.159	0.22	STATIC			83.3	3.4	86.7		
TW-7	0.178	1.496	OUT-SIDE HAZ	START	0.094	0.400	0.235	130.6	0.589	-20.8	0.070	0.528	1.139	0.50	20.0	70	DRY AIR	76.6	-4.9	71.7	YES	Δa = 0.007" [2] [3B] [4]
				STOP	0.101	0.400	0.252	130.6	0.589	-20.8	0.072	0.567	1.152	0.43				78.8	-4.3	74.5		
				FAIL	0.120	0.415	0.289	163.0	0.736	-24.3	0.081	0.674	1.189	0.24	STATIC		LAB AIR	107.7	-8.4	99.3		
TW-13	0.181	1.506	IN-SIDE HAZ	START	0.090	0.398	0.226	90.0	0.406	29.8	0.066	0.496	1.123	0.54	20.0	70	DRY AIR	50.7	7.3	58.0	YES	Δa = 0.010" [2] [3A] [4]
				STOP	0.100	0.398	0.251	90.0	0.406	29.8	0.070	0.552	1.143	0.44				52.9	6.2	59.1		
				FAIL			(CYCLED TO FAILURE)								STATIC		LAB AIR	–	–	–		
TW-14	0.181	1.504	OUT-SIDE HAZ	START	0.092	0.398	0.231	104.2	0.470	-32.4	0.067	0.509	1.127	0.52	20.0	90	DRY AIR	59.5	-7.7	51.8	YES	Δa = 0.004" [2] [3A] [4]
				STOP	0.096	0.398	0.241	104.2	0.470	-32.4	0.069	0.531	1.136	0.48				60.6	-7.2	53.4		
				FAIL	0.148	0.415	0.357	155.9	0.704	-38.8	0.085	0.818	1.197	0.02	STATIC	70	LAB AIR	106.4	-0.4	106.0		
TW-17	0.180	1.505	OUT-SIDE HAZ	START	0.093	0.395	0.235	107.0	0.483	-28.6	0.068	0.518	1.131	0.51	20.0	70	DRY AIR	61.4	-6.7	54.7	YES	Δa = 0.004" [2] [3B] [4]
				STOP	0.097	0.395	0.246	107.0	0.483	-28.6	0.069	0.540	1.139	0.46				62.5	-6.1	56.4		
				FAIL	0.156	0.420	0.371	153.6	0.693	-32.4	0.087	0.869	[6]	–	STATIC		LAB AIR	[6]	–	[6]		
TW-4	0.179	1.504	IN-SIDE HAZ	START	0.092	0.380	0.242	90.0	0.406	11.8	0.065	0.514	1.124	0.50	20.0	70	3000 PSI GOX	50.4	2.7	53.1	YES	Δa = 0.003" [1]
				STOP	0.095	0.380	0.250	90.0	0.406	11.8	0.066	0.531	1.130	0.47				51.1	2.5	53.6		
				FAIL	0.115	0.410	0.280	142.0	0.641	19.5	0.078	0.642	1.177	0.29	STATIC		LAB AIR	91.0	2.8	93.8		

Table A-13: SUSTAINED LOAD TESTS OF D6 STEEL WELDMENT SPECIMENS FROM LM/ECS DESCENT GOX REQUAL TANK (S/N 0032) [1] [2]

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED AXIAL STRESS, σ_A (ksi)	σ_A/σ_{ys} [3]	APPLIED BENDING STRESS, σ_B (ksi)	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	BENDING STRESS MAGNIFICATION FACTOR, M_B	TEST DURATION (hours)	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY DUE TO TENSION, K_{IK} (ksi $\sqrt{\text{in.}}$)	STRESS INTENSITY DUE TO BENDING, K_{IB} (ksi $\sqrt{\text{in.}}$)	$K_{IK} + K_{IB} = K_I$	GROWTH	REMARKS
TW-34	0.180	1.509	OUT-SIDE HAZ	START	0.112	0.390	0.287	93.9	0.424	-14.6	0.072	0.622	1.156	0.31	504.7	70	DRY AIR	57.0	-2.2	54.8	YES	Δa = 0.017″ $\Delta 2c$ = 0.003″
				STOP	0.129	0.393	0.328	93.9	0.424	-14.6	0.076	0.717	1.172	0.16				59.3	-1.1	58.2		
				START	0.129	0.393	0.328	93.9	0.424	-14.6	0.076	0.717	1.172	0.16	20.0	120		59.3	-1.1	58.2	NO	
				STOP	0.129	0.393	0.328	93.9	0.424	-14.6	0.076	0.717	1.172	0.16				59.3	-1.1	58.2		
				START	0.149	0.425	0.351	93.9	0.424	-14.6	0.084	0.828	1.211	0.02	20.9	70		64.3	-0.2	64.1	NO	
				STOP	0.149	0.425	0.351	93.9	0.424	-14.6	0.084	0.828	1.211	0.02				64.3	-0.2	64.1		
				FAIL			(CYCLED THROUGH THE THICKNESS)								STATIC		LAB AIR	—	—	—		
TW-35	0.180	1.504	OUT-SIDE HAZ	START	0.093	0.397	0.234	93.9	0.424	-13.0	0.067	0.518	1.132	0.51	414.0	70	DRY AIR	53.8	-3.0	50.8	NO	
				STOP	0.093	0.397	0.234	93.9	0.424	-13.0	0.067	0.518	1.132	0.51				53.8	-3.0	50.8		
				FAIL	0.131	0.412	0.318	164.9	0.735	-18.9	0.083	0.730	1.192	0.17	STATIC		LAB AIR	110.6	-1.6	109.0		

[1] TANK HAD PAINT REMOVED BY SANDBLASTING, THEN IT HAD ADDITIONAL 24-HOUR BAKE AT 375°F IN VACUUM AND IT WAS REPAINTED BY GRUMMAN

[2] FLAWS WERE EDM'D BY BOEING AFTER LAST BAKE

[3] σ_{ys} = 221.7 KSI

Table A-14: SUSTAINED LOAD TESTS OF NICKEL-PLATED, 0.21 THICK LONGITUDINAL GRAIN D6 STEEL PLATE [1] [2]

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION (hours)	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi$\sqrt{in.}$)	GROWTH	REMARKS
G-4	0.207	1.804	OUT-SIDE	START	0.092	0.450	0.204	100.0	198.2	0.505	0.072	0.444	1.106	8.7	70	DRY AIR	57.8	YES	Δa = 0.011 to 0.013" Δ2c = 0.005" Test machine failed during test
				STOP	0.103	0.455	0.226	100.0	↕	0.505	0.077	0.498	1.123				60.7		
				FAIL	0.155	0.517	0.300	126.4		0.638	0.101	0.749	1.226	STATIC		LAB AIR	95.8		
G-5	0.207	1.800	OUT-SIDE	START	0.093	0.450	0.207	100.0		0.505	0.072	0.449	1.108	20.0	70	DRY AIR	58.1	YES	Δa = 0.024" Δ2c = 0.020"
				STOP	0.117	0.470	0.249	100.0		0.505	0.083	0.565	1.153				64.8		
				FAIL	0.173	0.540	0.320	103.6		0.523	0.105	0.836	1.258	STATIC		LAB AIR	82.5		
G-6	0.207	1.791	IN-SIDE	START	0.091	0.450	0.202	100.0		0.505	0.071	0.440	1.105	20.0	70	3,000 PSI GOX	57.5	YES	Δa = 0.028 to 0.031" Δ2c = 0.005"
				STOP	0.119	0.455	0.262	100.0	↕	0.505	0.082	0.575	1.149				64.2		
				FAIL	0.169	0.523	0.323	100.9	198.2	0.509	0.102	0.816	1.241	STATIC		LAB AIR	78.0		

[1] AS RECEIVED (4-HOUR BAKE AT 375° IN AIR)

[2] ALL FLAWS EDM'D

Table A-15: SUSTAINED LOAD TESTS OF NICKEL-PLATED, 0.21 THICK LONGITUDINAL GRAIN D6 STEEL PLATE 1▷ 2▷

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION (hours)	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi $\sqrt{in.}$)	GROWTH	REMARKS
G-9	0.207	1.804	OUT-SIDE	START	0.090	0.447	0.201	115.0	198.2	0.580	0.072	0.434	1.102	20.0	70	DRY AIR	66.2	YES	Δa = 0.013" Δ2c = 0.003" 3▷
				STOP	0.103	0.450	0.229	115.0		0.580	0.077	0.497	1.121				69.9		
				FAIL	0.127	0.485	0.262	151.9		0.767	0.092	0.613	1.174	STATIC		LAB AIR	105.5		
G-10	0.207	1.802	OUT-SIDE	START	0.092	0.460	0.200	106.6		0.538	0.073	0.445	1.109	20.0	70	DRY AIR	62.2	YES	Δa = 0.013" Δ2c = 0.0" 3▷
				STOP	0.105	0.460	0.228	106.6		0.538	0.078	0.508	1.129				65.7		
				FAIL	0.140	0.480	0.292	154.4		0.779	0.095	0.678	1.189	STATIC		LAB AIR	110.4		
G-12	0.206	1.801	OUT-SIDE	START	0.094	0.460	0.204	100.0		0.505	0.073	0.456	1.112	24.0	70	DRY AIR	58.8	YES	Δa = 0.012" Δ2c = 0.0" 3▷
				STOP	0.106	0.460	0.230	100.0		0.505	0.078	0.514	1.132				61.7		
				FAIL	0.148	0.497	0.298	149.4		0.754	0.099	0.717	1.208	STATIC		LAB AIR	110.5		
G-13	0.207	1.802	OUT-SIDE	START	0.093	0.457	0.204	121.0		0.611	0.074	0.450	1.110	64.4	70	DRY AIR	71.3	YES	Δa = 0.024" Δ2c = 0.013" 3▷
				STOP	0.117	0.470	0.249	121.0		0.611	0.085	0.566	1.154				79.2		
				FAIL	0.140	0.488	0.287	156.9		0.792	0.096	0.678	1.194	STATIC		LAB AIR	113.5		
G-15	0.206	1.800	IN-SIDE	START	0.092	0.455	0.202	100.0		0.505	0.072	0.446	1.108	19.5	120	DRY AIR	58.1	NO	3▷
				STOP	0.092	0.455	0.202	100.0	198.2	0.505	0.072	0.446	1.108				58.1		
				FAIL		(CYCLED THROUGH THE THICKNESS)								STATIC	70	LAB AIR	–		

Table A-15: SUSTAINED LOAD TESTS OF NICKEL-PLATED, 0.21 THICK LONGITUDINAL GRAIN D6 STEEL PLATE (Continued)

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION (hours)	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi$\sqrt{in.}$)	GROWTH	REMARKS
G-16	0.206	1.802	IN-SIDE	START	0.091	0.460	0.198	100.0	198.2	0.505	0.072	0.442	1.108	19.5	90	DRY AIR	58.0	NO	3
				STOP	0.091	0.460	0.198	100.0		0.505	0.072	0.442	1.108				58.0		
				FAIL		(CYCLED THROUGH THE THICKNESS)								STATIC	70	LAB AIR	–		
G-17	0.208	1.800	OUT-SIDE	START	0.093	0.452	0.206	93.4		0.471	0.072	0.448	1.108	19.5	90	DRY AIR	54.1	YES	Δa = Trace to 0.003″ Δ2c = 0.0″ 4
				STOP	0.094	0.452	0.208	93.4		0.471	0.072	0.453	1.109				54.4		
				FAIL	0.138	0.475	0.291	144.5		0.729	0.093	0.665	1.182	STATIC	70	LAB AIR	101.5		
G-18	0.207	1.800	OUT-SIDE	START	0.095	0.455	0.209	72.6		0.356	0.072	0.459	1.112	64.5		DRY AIR	42.3	YES	Δa = 0.023″ Δ2c = 0.0″ 4
				STOP	0.118	0.455	0.259	72.6		0.356	0.080	0.571	1.148		70		46.1		
				FAIL		(CYCLED THROUGH THE THICKNESS)								STATIC		LAB AIR	–		
G-19	0.206	1.802	OUT-SIDE	START	0.097	0.455	0.213	56.7		0.286	0.072	0.471	1.116	64.5		DRY AIR	33.2	YES	Δa = 0.020″ Δ2c = 0.0″ 4
				STOP	0.117	0.455	0.257	56.7		0.286	0.080	0.568	1.198		70		35.8		
				FAIL		(CYCLED THROUGH THE THICKNESS)								STATIC		LAB AIR	–		
G-11	0.207	1.803	IN-SIDE	START	0.089	0.455	0.196	106.6		0.538	0.071	0.431	1.102	20.0		3000 PSI GOX	61.1	YES	Δa = 0.017″ Δ2c = 0.0″ 3
				STOP	0.106	0.455	0.233	106.6		0.538	0.078	0.513	1.129		70		65.7		
				FAIL	0.148	0.490	0.302	146.9	198.2	0.741	0.097	0.716	1.202	STATIC		LAB AIR	107.5		

1 AS RECEIVED (4-HOUR BAKE AT 375°F IN AIR) + BAKED 24 HOURS AT 375°F IN VACUUM AND PAINTED

2 ALL FLAWS EDM'D AFTER EXTRA BAKE CYCLE AND PAINTING

3 EXTRA BAKE AND PAINTING DONE BY BOEING

4 EXTRA BAKE AND PAINTING DONE BY GRUMMAN

Table A-16: SUSTAINED LOAD TESTS OF BARE, 0.375 THICK LONGITUDINAL GRAIN D6 STEEL PLATE [1] [2]

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION (hours)	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi $\sqrt{in.}$)	GROWTH	REMARKS
GTB -1	0.385	2.257	–	START	0.116	0.552	0.210	126.0	192.5	0.655	0.092	0.302	1.058	20.0	70	DRY AIR	78.9	YES	Δa = 0.015"
				STOP	0.131	0.552	0.237	126.0	↕	0.655	0.098	0.341	1.059				81.5		
				FAIL	0.228	0.640	0.356	128.2	192.5	0.666	0.131	0.593	1.083	STATIC		LAB AIR	98.0		

[1] BAKED 20 HOURS AT 900°F IN VACUUM

[2] FLAW EMD'D AFTER BAKE CYCLE

Table A-17: SUSTAINED LOAD TESTS OF NICKEL-PLATED, 0.21 THICK D6 STEEL WELDMENT [1] [2]

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION (hours)	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi $\sqrt{in.}$)	GROWTH	REMARKS
GW -15	0.214	1.799	OUT-SIDE HAZ	START	0.083	0.445	0.187	137.0	208.3	0.657	0.069	0.387	1.084	20.0	70	DRY AIR	76.2	YES	Δa = 0.001" line
				STOP	0.084	0.445	0.189	137.0	↕	0.657	0.070	0.392	1.084				76.5		
				FAIL	0.137	0.445	0.308	182.5	↕	0.875	0.092	0.639	1.148	STATIC		LAB AIR	123.7		
GW -40	0.215	1.804	IN-SIDE HAZ	START	0.098	0.455	0.215	137.0	↕	0.658	0.077	0.455	1.107	20.0	70	DRY AIR	82.0	YES	Δa = 0.014"
				STOP	0.112	0.455	0.246	137.0	↕	0.658	0.082	0.520	1.126				86.2		
				FAIL	0.125	0.470	0.266	153.9	208.3	0.738	0.089	0.581	1.149	STATIC		LAB AIR	103.0		

[1] AS RECEIVED (4-HOUR BAKE AT 375°F IN AIR)

[2] FLAWS EDM'D

Table A-18: SUSTAINED LOAD TESTS OF NICKEL-PLATED, 0.21 THICK D6 STEEL WELDMENT [1] [2]

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION (hours)	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi$\sqrt{in.}$)	GROWTH	REMARKS
GW -9	0.214	1.801	OUT-SIDE HAZ	START	0.091	0.460	0.198	137.0	208.3	0.658	0.074	0.426	1.098	20.0	70	DRY AIR	79.9	YES	Δa = 0.013" [3]
				STOP	0.104	0.460	0.226	137.0	↑	0.658	0.080	0.486	1.117				84.3		
				FAIL	0.170	0.493	0.345	165.7		0.795	0.103	0.795	1.198	STATIC		LAB AIR	124.0		
GW -10	0.215	1.800	OUT-SIDE HAZ	START	0.090	0.456	0.197	111.3		0.534	0.072	0.419	1.095	20.0	70	DRY AIR	63.6	YES	Δa = 0.008" [3]
				STOP	0.098	0.456	0.215	111.3		0.534	0.075	0.456	1.107				65.9		
				FAIL			(CYCLED THROUGH-THE-THICKNESS)							STATIC		LAB AIR	–		
GW -11	0.222	1.804	OUT-SIDE ℄	START	0.090	0.457	0.197	137.0		0.658	0.074	0.406	1.087	20.0	70	DRY AIR	78.8	YES	Δa = 0.017" [4]
				STOP	0.107	0.457	0.234	137.0		0.658	0.081	0.482	1.111				84.3		
				FAIL	0.108	0.460	0.235	175.0		0.840	0.085	0.487	1.113	STATIC		LAB AIR	110.7		
GW -12	0.218	1.804	OUT-SIDE HAZ	START	0.089	0.462	0.193	111.3		0.534	0.072	0.408	1.090	20.0	70	DRY AIR	63.3	NO	Δa < 0.001" line [4]
				STOP	0.090	0.462	0.195	111.3	↓	0.534	0.072	0.413	1.091				63.6		
				FAIL	0.197	0.564	0.349	136.2	208.3	0.653	0.115	0.903	[5]	STATIC		LAB AIR	[5]		

[1] AS RECEIVED (4-HOUR BAKE AT 375°F IN AIR) + BAKED 20 HOURS AT 900°F IN ATMOSPHERE NOTED

[2] ALL FLAWS EDM'D AFTER ALL BAKING

[3] BAKED IN AIR

[4] BAKED IN VACUUM

[5] a/t > 0.85, M_K CURVE NOT APPLICABLE

Table A-19: SUSTAINED LOAD TESTS OF NICKEL PLATED 0.21 THICK D6 STEEL WELDMENT ▷1

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION (hours)	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi$\sqrt{in.}$)	GROWTH	REMARKS	EXTRA BAKE TIME (hours)
GW-14	0.221	1.803	OUT-	START	0.096	0.450	0.213	137.0	208.3	0.658	0.076	0.434	1.096	20.2	70	DRY	80.6	YES	Δa = 0.018"	24
			SIDE	STOP	0.114	0.468	0.244	137.0		0.658	0.084	0.515	1.124			AIR	87.1		Δ2c = 0.018" ▷2	
			HAZ	FAIL	0.124	0.475	0.261	159.6		0.765	0.090	0.560	1.140	STATIC		LAB AIR	106.6			
GW-16	0.218	1.803	OUT-	START	0.066	0.440	0.150	137.0		0.658	0.059	0.302	1.071	4.9	70	DRY	69.8	YES	Δa = 0.001"	24
			SIDE	START	0.067	0.440	0.152	137.0		0.658	0.060	0.307	1.071			AIR	70.2		▷3 ▷4	
			HAZ	FAIL	0.208	0.655	0.318	119.9		0.575	0.128	0.953	▷5	STATIC		LAB AIR	▷5			
GW-20	0.216	1.800	OUT-	START	0.090	0.450	0.200	137.0		0.658	0.073	0.417	1.092	19.5	70	DRY	78.9	YES	Δa = 0.012"	48
			SIDE	STOP	0.102	0.450	0.227	137.0		0.658	0.078	0.473	1.110			AIR	82.9		▷2	
			HAZ	FAIL	0.157	0.475	0.331	150.1		0.720	0.096	0.728	1.176	STATIC		LAB AIR	106.9			
GW-21	0.216	1.800	OUT-	START	0.129	0.451	0.286	137.0		0.658	0.087	0.598	1.141	19.5	70	DRY	89.7	YES	Δa = 0.003"	48
			SIDE	STOP	0.123	0.451	0.293	137.0		0.658	0.087	0.612	1.144			AIR	90.3		▷3	
			HAZ	FAIL	0.186	0.545	0.341	131.5		0.631	0.110	0.862	▷5	STATIC		LAB AIR	▷5			
GW-23	0.222	1.800		START	0.082	0.405	0.202	137.0		0.658	0.066	0.370	1.075	20.0	70	DRY	73.9	YES	Δa = 0.001" Δ2c = 0.010"	
			OUT-	STOP	0.083	0.415	0.200	137.0		0.658	0.067	0.375	1.077			AIR	74.7		▷3	
			SIDE	START	0.123	0.443	0.278	137.0		0.658	0.084	0.555	1.125	≈1		LAB	87.2	YES	Δa = 0.002"	72
			HAZ	STOP	0.125	0.443	0.282	137.0		0.658	0.085	0.564	1.126	MIN.			87.5			
				FAIL	0.170	0.509	0.334	158.2	208.3	0.759	0.104	0.767	1.196	STATIC		AIR	119.2			

▷1 AS RECEIVED (4-HOUR BAKE AT 375°F IN AIR) + BAKED AT 400°F IN FLOWING NITROGEN FOR TIME INDICATED

▷2 FLAW EDM'D AFTER ALL BAKING

▷3 FLAW SHALLOW EDM'D AFTER ALL BAKING

▷4 TEST ABORTED AT 4.9 HOURS BECAUSE OF MACHINE FAILURE

▷5 a/t > 0.85 M_K CURVE NOT APPLICABLE

Table B-1: SUSTAINED LOAD TESTS OF NICKEL-PLATED, 0.21 THICK D6 STEEL WELDMENT ▷6

SPECIMEN NUMBER	THICKNESS, t (inch)	WIDTH, w (inch)	FLAW LOCATION	TEST CONDITIONS AT	FLAW DEPTH, a (inch)	FLAW LENGTH, 2c (inch)	a/2c	APPLIED STRESS, σ_A (ksi)	YIELD STRENGTH, σ_{ys} (ksi)	σ_A/σ_{ys}	FLAW SIZE, a/Q (inch)	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST DURATION (hours)	TEST TEMPERATURE (°F)	TEST ENVIRONMENT	STRESS INTENSITY, K_I (ksi$\sqrt{in.}$)	K_I/K_{Ic}	REMARKS
GW-32	0.223	1.806	OUT-SIDE ℄	START	0.102	0.450	0.227	140.0	208.3	0.672	0.078	0.458	1.103	20.0	70	DRY AIR	84.3	0.753	Δ a = 0.001" ▷1
				STOP	0.103	0.450	0.229	140.0		0.672	0.079	0.463	1.104				84.6	0.755	
				FAIL	0.139	0.465	0.299	165.0		0.792	0.093	0.625	1.147	STATIC		LAB AIR	112.6	–	
GW-33	0.225	1.802	OUT-SIDE ℄	START	0.104	0.450	0.231	140.0		0.672	0.079	0.463	1.103	20.0	70	DRY AIR	84.7	0.756	Δ a = 0.004" ~ 0.010" ▷2
				STOP	0.108	0.450	0.240	140.0		0.672	0.081	0.481	1.107				85.8	0.766	
				FAIL	0.133	0.490	0.271	164.6		0.791	0.095	0.592	1.151	STATIC		LAB AIR	113.8	–	
GW-34	0.219	1.802	OUT-SIDE ℄	START	0.099	0.450	0.220	140.0		0.672	0.077	0.452	1.103	20.0	70	DRY AIR	83.7	0.747	Δ a = 0.002" ~ 0.007" ▷3
				STOP	0.101	0.450	0.224	140.0		0.672	0.078	0.461	1.105				84.3	0.753	
				FAIL	0.127	0.480	0.265	157.1		0.754	0.091	0.580	1.150	STATIC		LAB AIR	106.4	–	
GW-35	0.223	1.801	OUT-SIDE ℄	START	0.098	0.450	0.218	140.0		0.672	0.077	0.440	1.098	20.0	70	DRY AIR	83.0	0.741	Δ a = 0.017" ▷4
				STOP	0.115	0.450	0.256	140.0		0.672	0.083	0.516	1.117				87.8	0.784	
				FAIL	0.115	0.460	0.250	164.6		0.791	0.086	0.516	1.121	STATIC		LAB AIR	105.6	–	
GW-36	0.228	1.799	OUT-SIDE ℄	START	0.100	0.450	0.222	140.0		0.672	0.078	0.440	1.095	22.0	70	DRY AIR	83.3	0.744	Δ a = 0.003" ▷5
				STOP	0.103	0.450	0.229	140.0		0.672	0.079	0.453	1.099				84.2	0.752	
				FAIL	0.203	0.590	0.344	135.8	208.3	0.652	0.120	0.892	▷7	STATIC		LAB AIR	▷7	–	

▷1 FAST EDM IN KEROSENE, ELERODA D1 MACHINE, SETTINGS: ▼▼▼ 1 = 3 FOR 35 MINUTES + ▼▼▼ 1 = 3, R_c STABILIZED FOR 15 MINUTES

▷2 SLOW EDM IN KEROSENE, ELERODA D1 MACHINE, SETTINGS: ▼▼▼ 2 = 3 FOR 120 MINUTES + ▼▼▼ 2 = 3, R_c STABILIZED FOR 70 MINUTES

▷3 FAST EDM IN KEROSENE, ELERODA D1-S MACHINE, SETTINGS: ▼▼▼ 1 = 3 FOR 30 MINUTES + ▼▼▼ 1 = 3, STABILIZED FOR 15 MINUTES

▷4 SLOW EDM IN KEROSENE, ELERODA D1-S MACHINE, SETTINGS: ▼▼▼ 2 = 3 FOR 135 MINUTES + ▼▼▼ 2 = 3, R_c STABILIZED FOR 50 MINUTES

▷5 SLOW EDM IN HYDRAULIC OIL, ELERODA D4 MACHINE, SETTINGS: C5, I4 FOR 20 MINUTES + C2, I2 FOR 10 MINUTES

▷6 AS RECEIVED (4-HOUR BAKE AT 375°F IN AIR) + 180-HOUR BAKE AT 600°F IN FLOWING NITROGEN

▷7 $a/t > 0.85$, M_K CURVE NOT APPLICABLE

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