s131-PR04-W187f2e

NERVA MATERIALS DEVELOPMENTS
FOURTH QUARTER - CONTRACT YEAR 1970
(JULY, AUGUST, AND SEPTEMBER)

NERVA Program, Contract SNP-1

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NERVA Program

Contract SNP-1

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ABSTRACT

Materials and processes development activities for the fourth quarter of Contract Year 1970 are reported. Materials development topics include: (1) planning material test activities for CY 71 and beyond; (2) development of analysis techniques to adjust heterogeneous data; (3) determination of thermal conductivity for AISI 347 stainless steel and elastic moduli and Poisson's ratio for Inconel 718 and Ti 5Al-2.5Sn (ELI); (4) embrittlement effects of 1400 psi gaseous hydrogen for alloy 718 and Ti 5Al-2.5Sn (ELI); (5) cryogenic radiation damage of Ti 5Al-2.5Sn (ELI); and (6) evaluation of prepreg, impregnation and fabric materials for optimum fibrous graphite properties. Component support topics include: (1) tensile design allowable development of Ti 5Al-2.5Sn (ELI) for turbopump applications; (2) evaluation of fatigue, fracture toughness and stress corrosion properties of AA 7039-T63 for pressure vessel applications; (3) development of AISI 347 sheet tensile and creep properties for nozzle applications; (4) evaluation of orbital weld techniques for aluminum line fabrication; (5) material selection of shield materials; (6) development of high load friction and wear properties of hard chrome/gold plate combinations; (7) revision of Contamination and Corrosion Control Plan; and (8) evaluation of weld processes for NASS duct coolant channel fabrication.

CONTENTS

APPENDIX

<u>TABLES</u>

TABLES (cont.)

FIGURES

FIGURES (cont.)

I. PROGRAM IMPACT

A. Revised material problem areas and test requirements were established for current component designs and their respective engine operational environments.

B. Statistically established "alternatives" were approved to "adjust" data that have been heavily penalized for heterogeneous heat-to-heat variability that made data unsuitable for design.

C. Since alloy 718 and Ti 5Al-2.5Sn (ELI) are embrittled by gaseous hydrogen near room temperature, extensive cyclic and sustained load fracture toughness testing is required to establish use limits. Proof-testing for individual TPA components may be required to "screen" materials with critical flaw sizes from use.

D. Irradiation at 10^{17} nvt > 1 Mev equivalent to a location above the internal shield does not degrade Ti 5Al-2.5Sn (ELI) parent metal.

E. Marginal yield strength of AISI 347 stainless steel in the nozzle-jacket flange area initiated an investigation of higher strength alloy ARMCO 22-13-5.

F. Preliminary formulations were established for the selection of optimizing properties of fibrous graphite material. Properties tests are delayed by higher priority Pewee skirt fabrication.

G. High temperatures caused by a high gamma dose below the external shield may prevent utilization of aluminum alloys for uncooled thrust structure applications.

H. Category "A" data were developed for Ti 5Al-2.5Sn (ELI), alloy 718, and AISI 347 stainless steel. Forging, tensile and fracture toughness properties for alloy 718 have also been developed to "A" basis.

I. Aluminum alloy 7075-T73 is prime backup for 7039-T63 pressure vessel shell material because of stress-corrosion susceptibility of the 7039 alloy. Aluminum alloy 6061-T6 is considered a backup closure material because of the additional requirement of weldability.

II. ACCOMPLISHMENTS

A. PLANNING

A revised Materials Program Plan was published as Data Item S-131-CP090290AF1. Potential material problems of the current engine design were identified and coordinated with the project, design, and support disciplines. Test-plan matrices to establish material-property and specimen-population requirements were prepared and coordinated and approved by reliability. Materials test requirements for CY 1971 were established on the basis of priority for each major component.

B. MECHANICAL PROPERTIES

Three alternative methods were established for adjusting category "A" data that were not suitable for design because of heat-to-heat variance. These methods were coordinated and approved with WANL and SNPO-C. Twenty-five DRMs were issued for physical and mechanical properties of NERVA materials.

C. PHYSICAL PROPERTIES

The thermal conductivity of furnace-brazed AISI 347 stainless steel from liquid-helium temperature to room temperature measured at the National Bureau of Standards showed no adverse effect and agreed with previous nonfurnace-brazed values. Elastic moduli and Poisson's ratio of Inconel 718 and Ti 5Al-2.5Sn (ELI) forging material were measured at room temperature.

D. HYDROGEN COMPATIBILITY

The embrittling effects of gaseous hydrogen were evaluated for notch-tensile and fracture-strength characteristics of TPA materials and released in ANSC Report S-131-MA04-W187-04. Static failure loads and subcritical stress intensity for 10 hr of sustained stress tests of alloy 718 and

Ti 5Al-2.5Sn (ELI) were conducted in 1400-psi cryogenic pure gaseous hydrogen. Ten hr sustained-load results showed deterioration of the threshold stress intensity of about 85% at room temperature and 15% at -160°F when compared to the static critical stress intensity for alloy 718. At -100°F, little improvement was shown over room-temperature degradation, indicating an abrupt transition in fracture-toughness threshold between -100° and -160°F. Alloy Ti 5Al-2.5Sn (ELI) showed a comparable 80 and 30% deterioration at room temperature and -160°F, respectively. Limited tests at -100°F indicated more than 50% deterioration and an apparent linear-degradation relationship. Both alloys are classified brittle for room-temperature service. Alloy 718 appears to be brittle at -100°F. Combined, sustained, and cyclic stress tests indicated a flaw growth in direct relation to the sum of separate effects.

E. RADIATION DAMAGE

Preliminary results from GTR-20C indicate that Ti 5Al-2.5Sn (ELI) irradiated to a level between 2×10^{17} nvt and 6×10^{18} nvt > 1 Mev exhibited a threshold of radiation damage of ductility and toughness at 1×10^{17} nvt. This suggests that the radiation level anticipated above the internal shield is not expected to affect design criteria.

F. FIBROUS GRAPHITE

Evaluation of prepreg resins in the carbonization and graphitization process resulted in selection of a single resin based upon minimum shrinkage. A fiber-resin formulation system was selected to combine high elastic modulus, block-tensile and tensile strength in warp and fill directions, and maximum density. Impregnation formulations were also selected on the basis of low viscosity, high carbon yield, and the ability to graphitize. Indene has been selected as the best solvent for reducing viscosity and improving carbon yield. Techniques have been demonstrated for weaving 3-dimensional tufted fabric. Techniques have been developed for bonding the honeycomb cell to the liner fabric. Completion of property tests on available samples has been delayed, however, because of manpower demands of the Pewee skirt contract.

G. TURBOPUMP MATERIALS

Design-allowable tensile property category "A" was completed for Ti 5Al-2.5Sn (ELI) at 70°, -320° and -423°F. Preliminary analyses of -423°F toughness indicated ductile fracture based upon fracture-toughness criteria. Additional requirements were prepared for the cyclic fracture-toughness evaluation of K_i at SNPO-C request.

H. PRESSURE VESSEL MATERIALS

Fatigue tests of aluminum alloy 7039-T63 at 150°F were completed for the high-cycle rotating beam. Results indicate an endurance limit of 23 ksi at 10^7 complete-reverse cycles. Stress-corrosion evaluations indicate that grit blasting and protective coatings can prolong stress-corrosion life. The flange-seal area was identified as the most susceptible to stress corrosion. Limitiations of protection are identified as nonadhesion of coatings and the occurrence of undetectable residual stress.

Low- and nominal-chemistry-subscale forging fracture-toughness results at room temperature, -100° and -320°F showed acceptable values for both flange and wall-section materials with improved values in the wall material indicating the beneficial effects of the supplemental extrusion process. While high-chemistry forging values were low in the short transverse direction, these were less significant since the short-transverse is not a principal stress direction for pressure-vessel application. In general, 7039-T63 values decreased with decreased temperature whereas 6061-T6 step-forging values increased with decreased temperature. Short transverse values improved with increased forge reduction. Aluminum alloy 6061-T6 values indicate a completely ductile material for all temperatures, directions, and reductions tested. Statistical analyses of the subscale-forging results are in process.

I. NOZZLE MATERIALS

AISI 347 stainless-steel sheet tested at ORNL is currently identified as category "C" data because of heat-to-heat variability. An investigation was initiated to establish the cause of this anomaly. ARMCO 22-13-5 has been posed as a substitute for AISI 347 to improve forging yield allowables required for the flange design. An investigation also was initiated on the new material to determine its brazeability, weldability qualities, the effect of radiation, and embrittling effects at cryogenic temperatures. Creep tests in gaseous hydrogen for 100 hr at 1200°, 1400°, and 1600°F indicated reduced creep resistance by exposure to gaseous hydrogen and degradation by small grain size at 1400° and 1600°F.

J. LINE MATERIALS

Orbital welding of lines for aluminum alloys was continued with improved control being shown of crown and "drop-through" contour.

K. SHIELD MATERIALS

The predicted service temperature of above 500°F suggests the need to employ AISI 347 stainless steel for the shield.

L. FRICTION AND WEAR

Evaluation of hard chromium against electrodeposited gold at high loads to simulate 70,000-psi Hz stress exhibited a wear life of 200 cycles with friction coefficients ranging from 0.07 to 0.09. Samples of ion-deposited and electron-beam-deposited gold were unsatisfactory with a typical wear life of 20 test cycles at 20,000-psi Hz stress being shown.

M. CONTAMINATION AND CORROSION

The scope of the NERVA Contamination and Corrosion Control Plan (Data Item S-021-CP09 290) was expanded to include space, biological and radiation contamination environments, and the planned support of trend-data reliability analysis. The revised data item was republished in July.

N. NASS FACILITY

A simulated weld section of the primary ejector L-channel configuration was prepared to evaluate distortion. Excessive distortion was encountered from the heat of semi-automatic GTAW welding. Evaluation of GMAW welding was initiated.

III. TECHNICAL DEVELOPMENTS

A. PLANNING

During the quarter, emphasis was placed upon programing the materials effort for CY 1971. Problem areas were first identified by consultation with design and reliability disciplines for the resolution of critical design and reliability inadequacies. This was accomplished by updating the Material Problem Identification sheets prepared for CY 1970 program plans (reported in RN-DR-0189), and coordination with and approval by, project, stress analysis, thermal analysis, nuclear analysis, and reliability disciplines. The updated current material problem identification sheets are presented in Appendix A. Significant changes include: (1) use of a higher strength multiphase material as a backup candidate for TPA and PV bolts, as a result of increased hydrogen pressure requirements; (2) use of phosphorous bronze for valve seal elements; (3) use of AISI 9310 for actuator gears; and (4) addition of instrumentation and controls and shield components to problem-identification evaluation.

Material property tests to resolve established problem areas were projected. These are presented in Appendix B as Material Test Plans and include the complete effort projected for CY 1971 and beyond.

In the test plans, specimen populations for design-allowable development were established on the basis of the requirements of TD 69-28. Screening and physical-property development were based upon previous experience of variability. These plans are presently being coordinated with reliability and project disciplines to assess their program significance. From these plans, specific component property items are being selected on the basis of priority and data-maturity requirements. The higher priority items are being selected on the basis of support for the major subassemblies and components: e.g., TPA, nozzle, and pressure vessel.

B. MECHANICAL PROPERTIES

1. Statistical Analysis of Material Test Data

Methods were established for the statistical analyses currently utilized for treatment of material properties test data.

The data are first grouped according to known sources of fixed and random variation (i.e., test temperature, test direction, and lot-to-lot or heat-to-heat) and tested for homogeneity of within-group variances. Box's modification of the Bartlett test for homogeneity of within-group variances is used at the 10% significance level. When screening alloys for use in a specific environment (e.g., gaseous or liquid hydrogen embrittlement and radiation damage), the fixed variables are tested for the difference between means at the 5% significance level.

If the within-group variances are heterogeneous, the data history is studied in detail to find the cause of the anomalies. If no test error or metallurgical cause is uncovered to explain the anomalous values, then a standard statistical test for extreme values may be applied to the data, and, if outliers are found, these values are excluded from the data analysis. The test for homogeneity is again applied to the data, excluding the outliers. If the within-group variances are still heterogeneous, the data are then divided into smaller groups according to the fixed variables. The sequence of testing data groups to eliminate the effects of fixed variables to achieve homogeneity of within-group variances is as follows: (1) each test direction throughout all test temperatures; (2) all test directions within a test temperature; and (3) individual test directions with a test temperature. If the within-group variances of the data groups in (3) are still not homogeneous, then other techniques (e.g., log transformation) are employed to achieve homogeneity. If the within-in group variances are heterogeneous and the only source of variation remaining is random test error, then process variation, design of the experiment, and testing techniques must be assessed and controlled to a greater extent to randomize these sources of error throughout all data groups.

When the within-group variances are homogeneous, analysis of variance technique is applied to test for homogeneity of mean variances at the 10% significance level. If the group means are the same, the minimum design allowable for 99% reliability with 95% confidence is computed using the equation:

$$\text{Minimum design allowable} = \bar{\bar{X}} - ks,$$

where $\bar{\bar{X}}$ is the grand mean, k is the one-sided tolerance factor for N observations, and s is the within-group standard deviation with N-1 degrees of freedom.

When the means are heterogeneous, the degrees of freedom associated with the standard deviation are calculated using the Satterthwaite approximation. The degrees of freedom (with which the mean is estimated) and the degrees of freedom from the Satterthwaite approximation are then used to determine the one-sided tolerance factor, k. Final computation is made using the pooled within- and among-group variances.

In certain situations, the Satterthwaite approximation will lead to results which are not suitable for design: i.e., when the computed degrees of freedom are ≤ 4, and the k tolerance factor is large, providing an unreasonably small design allowable. This problem arises when the within-group variance is small compared with the among-group variance or the among-group variance is unusually large, or both. In these situations, a decision must be made to test more material or to use other methods of computation. If no further testing is to be done, three alternative methods of computation are available.

a. Estimation of the Upper Bound of Among-Group Variance

An estimate is made of the upper bound of the lot-to-lot variance based upon the relevant information that is available. This estimated value is used with the observed within-lot variation and overall mean to compute the minimum design allowable. The sample size used to estimate the lot-to-lot variance is assumed to be infinite. The tolerance factor, k, associated with the within-group variance is computed by use of noncentral t-distribution.

b. Use of the Lowest Group Mean and the Within-Group Variance

The lowest group mean, the within-group variance, and the degrees of freedom associated with each are used to compute the minimum design-allowable. It is assumed that there is sufficient knowledge of the entire population to be assured that the limited samples are not from the high side of population distribution.

c. Interpolation between Adjacent Environmental Conditions

When the data at one temperature cannot be analyzed in the normal manner and do not conform to the trend of the curve of material-property-versus-temperature, this portion of the curve can be interpolated from adjacent test points to achieve a smooth design curve. The interpolated point will be categorized at the same level as adjacent test points. Values obtained by extrapolation beyond actual test values will be classified category "C" data.

C. PHYSICAL PROPERTIES

As previously described in ANSC Report S131-PR3, the AISI 347 stainless-steel thermal-conductivity data at liquid hydrogen temperatures to 2300°R that were obtained from the literature were statistically evaluated by regression analysis and found to agree well with current curves published in the Materials Properties Data Book. Investigation was continued to determine the effect of furnace brazing upon thermal-conductivity properties.

The thermal diffusivity of specimens of AISI 347 stainless steel in the furnace-brazed condition was measured from -320° to 1800°F at the Los Alamos Scientific Laboratory (the diffusivity results also were published in ANSC Report S131-PR3). These results were reduced to thermal-conductivity data with the result that the individual data points deviated by approximately 5% from the regression-analysis curve. The agreement between the LASL and regression-analysis data was good considering the fact that experimental errors inherent in diffusivity measurements are usually about 5% or greater. In addition, a thermal-conductivity specimen of AISI 347 stainless steel in the furnace-brazed condition was sent to the National Bureau of Standards (NBS) for measurement. The thermal conductivity results from NBS have been received and are compared with the results of regression-analysis in Table 1.

Both the LASL and NBS results agreed well with the regression-analysis data, indicating that furnace brazing had no effect upon the thermal-conductivity of AISI 347 stainless steel.

The measurement of Young's modulus, E, shear modulus, G, and Poisson's ratio, μ, of Inconel 718 and Ti 5Al-2.5Sn (ELI) forging specimens was made at room temperature by exciting the specimens into a resonance vibration*. Preliminary results of these measurements are given in Table 2.

*See S. Spinner and W.E. Tefft, ASTM Proc., 61, 1221-38 (1961).

TABLE 1

347 STAINLESS STEEL THERMAL CONDUCTIVITY VERSUS TEMPERATURE

Temp °R	K Btu-ft/hr ft^2-°R Regression Analysis*	K Btu-ft/hr ft^2-°R National Bureau of Standards	3σ Limits Upper*	3σ Limits Lower*
40	1.39	1.43	1.8	1.01
50	1.77	1.83	2.2	1.36
60	2.13	2.22	2.6	1.7
70	2.49	2.59	2.98	2.03
80	2.83	2.94	3.34	2.35
90	3.15	3.27	3.69	2.65
100	3.45	3.57	4.02	2.93
120	4.01	4.10	4.61	3.44
140	4.5	4.54	5.14	3.9
160	4.93	4.91	5.6	4.3
180	5.3	5.23	6.01	4.65
200	5.64	5.50	6.37	4.96
220	5.93	5.74	6.69	5.24
240	6.2	5.96	6.97	5.48
260	6.44	6.15	7.23	5.7
280	6.65	6.34	7.46	5.9
300	6.85	6.49	7.67	6.08
350	7.27	6.90	8.12	6.48
400	7.62	7.26	8.5	6.81
450	7.93	7.64	8.84	7.09
500	8.21	7.91	9.14	7.36

*Reported previously in ANSC Report S131-PR3.

TABLE 2

MEASUREMENT OF E, G, AND μ OF
INCONEL 718 AND Ti 5Al-2.5Sn (ELI)

Material	Heat Number	Measurement Direction	E 10^6 psi	G 10^6 psi	μ
Inconel 718	86582	Radial	29.88	11.70	0.28
Inconel 718	86582	Radial	30.00	11.71	0.28
Inconel 718	86582	Tangential	29.45	11.41	0.29
Inconel 718	86582	Tangential	29.33	11.48	0.28
Ti 5Al-2.5Sn (ELI)	K-1029	Radial	18.16	6.98	0.30
Ti 5Al-2.5Sn (ELI)	K-1029	Radial	18.16	6.98	0.30
Ti 5Al-2.5Sn (ELI)	K-1029	Tangential	18.22	7.08	0.29
Ti 5Al-2.5Sn (ELI)	K-1029	Tangential	18.25	7.08	0.29

There was no significant anisotropy observed in E, G, or μ for either Inconel 718 or Ti 5Al-2.5Sn (ELI). The first measurements of E, G, and μ were made below room temperature on a specimen of Inconel 718 with the result that E increased by 1.4×10^6 psi and G increased by 0.7×10^6 psi as the temperature decreased from room temperature to -320°F. There was, however, no change observed in Poisson's ratio over the same temperature range. In addition, Young's modulus of several fibrous-graphite composite materials with different pitches and resins in varying stages of graphitization was measured at room temperature by using the apparatus described by Spinner and Tefft*. The results of these measurements are reported in Section F of this report.

*ibid

D. HYDROGEN COMPATIBILITY

1. Fracture Toughness Test Results

a. Summary

Initial tests conducted with alloy 718 and Ti 5Al-2.5Sn (ELI) in 1400-psi gaseous hydrogen at room temperature and -160°F were reported in the ANSC Report S131-PR3. The 10-hr sustained-load tests reported earlier indicated that a significant environmental effect might be experienced by both materials at room temperature, with lesser effect at -160°F. Results obtained during this quarter verified a beneficial temperature dependence but, in the case of alloy 718, the low-temperature fracture recovery was observed to take place over a very narrow temperature range. In addition to sustained load stress intensity tests in gaseous hydrogen, both cyclic and combined sustained-cyclic loading tests also were made.

b. Objectives and Test Conditions

The objective of this investigation was to determine the fracture and flaw-growth characteristics of Inconel 718 and Ti 5Al-2.5Sn (ELI) forgings in a high-purity gaseous hydrogen environment. The temperatures investigated were 70°, -100°, and -160°F with the hydrogen gas maintained at a pressure of 1400 psi. The specific test conditions and specimens tested in this program are listed in Table 3.

c. Static-Fracture test Results*

Static-fracture tests of alloy 718 and Ti 5Al-2.5Sn (ELI) forgings were conducted using single-edge-notched-bend specimens (three-point bend) and surface-flawed specimens. The three-point bend specimens were tested

*ANSC Report S131-MA04-W187-04

TABLE 3

PROGRAM TO INVESTIGATE THE EFFECT OF GH_2 ON Ti 5Al-2.5Sn (ELI) AND ALLOY 718 FRACTURE PROPERTIES

	Tests Conducted					
	Alloy 718			Ti 5Al-2.5Sn (ELI)		
Test Condition	Qty	Temp °F	Environment	Qty	Temp °F	Environment
Static Fracture (K_{I_C})	1	70	Air	1	70	Air
	1	[1] 70	GH_2	1	[1] 70	GH_2
	1	-160	GH_2	1	-160	GH_2
End Point Fracture [2]	13	[1] 70	Air	11	[1] 70	Air
	2	70	GH_2	1	70	GH_2
	1	[1] -320	LN_2	1	[1] -320	LN_2
Sustained Load (10 hr)	5	70	GH_2	5	70	GH_2
	1	-100	GH_2	1	[1] -100	GH_2
	4	-160	GH_2	6	-160	GH_2
Load/Unload	1	70	Air	1	70	Air
	1	-160	Air/GN_2	1	[1] -160	Air/GN_2
				1	[1] -160	GH_2
Combined Sustained/ Cyclic (Suslic)	2	70	GH_2	2	70	GH_2
	2	-160	GH_2	3	-160	GH_2
Cyclic	1	-160	Air/GN_2			

1 Specimen market after original test and then retested.

2 Retest of sustained or cyclic test that did not result in failure.

in air at 70°F while the surface-flawed specimens were tested in a gaseous-hydrogen environment at 70° and -160°F. End-point fracture results (i.e., failure of specimens that did not fail during cyclic or sustained loading) were also obtained for both materials in air at 70°F and in liquid nitrogen at -320°F. Results of these tests are presented in Table 4.

Plane-strain fracture toughnesses were not obtained for the majority of material and temperature combinations tested because of limited specimen thickness which suppressed fracture toughnesses. Based upon the results obtained, alloy 718 had a fracture toughness (ksi $\sqrt{in.}$) greater than 125.2, 103.2, and 108.0 at temperatures of 70°, -160°, and -320°F, respectively. The titanium test results at 70° and -160°F indicated toughnesses (ksi $\sqrt{in.}$) greater than 100 and 103, respectively. The single, valid plane-strain fracture toughness value of 85 ksi $\sqrt{in.}$ was obtained at -320°F for titanium. No differences in the results were observed whether the static fracture tests were conducted in gaseous hydrogen or an air-gaseous nitrogen environment.

d. Sustained Load and Growth-On-Loading Fracture Test Results

Sustained-load threshold tests of Inconel 718 and Ti 5Al-2.5Sn (ELI) forging were conducted in an environment of high-purity, high-pressure gaseous hydrogen. The tests were of 10-hr duration or until failure occurred. The primary temperatures investigated were 70° and -160°F with a single sustained test at -100°F for each material. Results of these tests are summarized in Tables 5 and 6.

(1) Alloy 718

Significant flaw growth in alloy 718 was observed at 70°F to the extent of failure only 1.15 hr after being loaded (see Table 5). The threshold indicated by these tests was between 19.8 and 35 ksi $\sqrt{in.}$ No crack growth was observed at the 19.8 ksi $\sqrt{in.}$ value while only 0.001 growth at

TABLE 4

STATIC FRACTURE TESTS OF
ALLOY 718 AND Ti 5Al-2.5Sn (ELI) FORGED MATERIAL

Material	Test Temp °F	Test Environment	Specimen Thickness, In.	Specimen Width In.	Average Crack Length, In.	P_Q Kips	P_{Fail} Kips	K_Q Ksi-In.$^{1/2}$
718 (Bend)	70	Air	1.50	3.00	1.510	36.4	38.0	125.2*
718 PTC	70	Air	0.25	-	-	-	-	103.2**
718 PTC	70	GH_2	0.25	-	-	-	-	93.0***
718 PTC	70	GH_2	0.25	-	-	-	-	105.3***
718 PTC	70	GH_2	0.25	-	-	-	-	108.2***
718 PTC	-160	GH_2	0.25	-	-	-	-	103.2***
718 PTC	-320	LN_2	0.25	-	-	-	-	108.0***
Ti 5Al-2.5Sn (ELI) (Bend)	70	Air	1.52	3.00	1.542	23.5	26.7	82.3*
TI PTC	70	Air	0.38	-	-	-	-	88.9**
TI PTC	70	GH_2	0.38	-	-	-	-	84.9***
TI PTC	70	GH_2	0.38	-	-	-	-	111.3***
TI PTC	-160	GH_2	0.38	-	-	-	-	103.0***
TI PTC	-320	LN_2	0.38	-	-	-	-	85.0

*Suppressed value because of inadequate specimen thickness.
**Average of 12 end-point tests.
***Suppressed value because of $\sigma_{NET}/\sigma_{YS} \geq 1.0$.

TABLE 5

SUSTAINED LOAD TESTS OF
ALLOY 718 FORGING

Test Type	Test Temp °F	Environment	Initial Stress Intensity, K_{Ii} Ksi-In.$^{1/2}$	Amount of Flaw Growth Δa In.
Sustained Load	70	1400 psi GH_2	52.5	0.010
		↓	35.0	0.001
		↓	68.9	0.090 (Failed in 1.15 hr)
		↓	19.8	None
		↓	56.6	0.045
Sustained Load	-100	1400 psi GH_2	63.9	0.010
Sustained Load	-160	1400 psi GH_2	52.0	None
		↓	83.2	0.003
		↓	72.2	0.002
		↓	99.4	0.006 *
Load/Unload	70	Air	82.7	0.001
Load/Unload	-160	Air/GN_2	98.0	0.005 *

*These two test results indicate that 0.006-in. flaw growth in gaseous-hydrogen was load-induced rather than environmental or time dependent.

TABLE 6

SUSTAINED LOAD TESTS OF
Ti 5Al-2.5Sn (ELI)

Test Type	Test Temp °F	Environment	Initial Stress Intensity, K_{Ii} Ksi-In.$^{1/2}$	Amount of Flaw Growth Δa In.
Sustained Load	70	1400 psi GH_2	41.8	0.070
		↓	76.7	0.102 (failed in 6 Min)
		↓	23.6	<0.001
		↓	32.2	0.005
		↓	14.9	None
Sustained Load	-100	1400 psi GH_2	57.5	0.005
Sustained Load	-160	1400 psi GH_2	39.1	None
		↓	89.4	0.015
		↓	67.1	None
		↓	80.2	0.006
		↓	63.5	0.002
		↓	53.3	None
Load/Unload	70	Air	74.9	0.002
Load/Unload	-160	Air/GN_2	85.5	0.003
Load/Unload	-160	GH_2	102.5	0.005

the 35.0 ksi $\sqrt{in.}$ value was noted. Based upon a reported threshold value of 20 ksi $\sqrt{in.}$ for Inconel 718 in a high-purity, high pressure gaseous hydrogen environment*, it was decided to select the lower-bound stress intensity (19.8 ksi $\sqrt{in.}$) as the threshold. Although not of any practical significance in establishing the threshold at 70°F, a single load-unload test was conducted in air at 70°F at a stress intensity exceeding the highest sustained load-stress-intensity tested. The amount of growth was almost negligible (0.001 in. in flaw depth).

Flaw growth was also observed at -160°F, and it became necessary to separate time-dependent, sustained load-flaw growth from growth-on-loading. This was expecially true for the sustained tests at -160°F, where a maximum amount of growth of Δa = 0.006 in. was observed. This test point was duplicated with a specimen of similar flaw depth and loaded to the same stress level and then unloaded immediately. This particular load-unload test was conducted in an air-gaseous nitrogen environment at -160°F. Approximately 0.005 in. of flaw-depth growth was observed. Because of a slightly smaller flaw size, the initial stress intensity for this load-unload specimen was slightly less than the sustained load specimen it duplicated (i.e., 98.0 ksi $\sqrt{in.}$ as opposed to 99.4 ksi $\sqrt{in.}$). This specimen proved that the growth observed on the sustained load specimens tested at -160°F was growth-on-loading and not environmentally induced, time-dependent flaw growth. Because of limiting factors (e.g., flaw size relative to the specimen cross-sectional dimensions and stress levels approaching the yield strength) higher stress intensity levels could not be tested: therefore, the threshold at -160°F can only be defined as being above 99.4 ksi $\sqrt{in.}$ Because of the sharp transition in threshold between 70° and -160°F (K_{TH} = 19.8 ksi $\sqrt{in.}$ at 70°F compared with K_{TH} > 99.4 ksi $\sqrt{in.}$ at -160°F), an intermediate temperature of -100°F was selected for a single, sustained load test. The amount of flaw depth growth

*P.M. Lorenz, Effects of Pressurized Hydrogen Upon Inconel 718 and 2219 Aluminum, (Technical Paper) at -100°F was observed to be 0.010 in. when sustained-loaded for 10 hr at an initial stress intensity of 63.9 ksi $\sqrt{in.}$ Comparing this result with the results obtained at 70°F would indicate a threshold of about 30 ksi $\sqrt{in.}$ at -100°F. This test indicates than an even sharper threshold transition exists between -100°F and -160°F than originally indicated by the 70° and -160°F tests.

(2) Ti 5Al-2.5Sn (ELI)

The sustained load test results for the Ti 5Al-2.5Sn (ELI) forging at 70° and -160°F are shown in Table 6. Flaw growth was observed at both temperatures and it became necessary, as it did with alloy 718, to separate time-dependent, sustained-load flaw growth from growth-on-loading. The sustained tests conducted at -160°F indicated a maximum flaw-depth growth of 0.015 in. To determine how much of this growth was caused by loading, two load-unload specimens were tested at -160°F at bracketing stress-intensity levels. One specimen was tested in gaseous hydrogen while the other was tested in an air-gaseous nitrogen environment. These tests indicated that although part of the growth observed was the result of growth-on-loading, the majority of the growth was probably environmentally induced. A single load-unload test at 70°F is also presented in Table 6.

The effect of high-pressure gaseous hydrogen at 70°F on Ti 5Al-2.5Sn (ELI) is as severe as with the alloy 718. A very low threshold of 21.5 ksi $\sqrt{in.}$ was established for the titanium alloy at 70°F. One failure was observed under sustained load at 70°F. This specimen, loaded to an initial stress intensity 76.7 ksi $\sqrt{in.}$, failed within 6 min after being loaded.

Although the extremely sharp transition in threshold with temperature was not observed with Ti 5Al-2.5Sn (ELI) as with alloy 718, a single specimen was sustained-load tested at -100°F. The result of this test is presented in Table 6 with the data obtained at 70° and -160°F. These results indicated that the threshold probably varies linearly with temperature between -160° and 70°F.

On the basis of the test results and the load-unload results at -160°F, a threshold of 53.3 ksi $\sqrt{in.}$ was established for Ti 5Al-2.5Sn (ELI) at -160°F.

A composite picture of the effects of hydrogen gas upon the titanium alloy, with estimated fracture toughness as functions of temperature, is illustrated in Figure 1. Throughout the temperature range tested, the threshold appears to vary from 50% of K_{IC} at -160°F to about 18% of K_{IC} at 70°F.

e. Combined Sustained-Cyclic (Suslic) Tests: 60-Cycle Target

Tests involving combined sustained-cyclic (suslic) loading were conducted to determine whether such loading below the sustained-load threshold would promote flaw growth exceeding that expected from basic cyclic flaw-growth data. The loading profile utilized is presented in Figure 2. When it became evident that the sustained-load thresholds for alloy 718 and Ti 5Al-2.5Sn (ELI) at 70°F was extremely low (about 20 ksi $\sqrt{in.}$) no attempt was made to conduct suslic tests below the threshold. Instead, tests were made above the threshold to determine combined effects. The suslic test results for alloy 718 and Ti 5Al-2.5Sn (ELI) forging material are presented in Table 7. One alloy 718 suslic test performed both at 70°F and above the threshold indicated significant flaw growth over and above that expected from sustained-load growth. The specimen, loaded to an initial stress intensity of 52.3 ksi $\sqrt{in.}$ at 70°F, failed on the 51st cycle (510 min at load). About 0.135 in. of flaw-depth growth was observed in this specimen compared to only 0.010 in. of growth observed in a 10-hr sustained-load specimen loaded to about the same stress-intensity level. Cyclic flaw-growth-rate data for this forging were not available at 70°F: therefore, no estimate could be made to determine whether the cyclic-load flaw-growth rate added directly to the sustained-load flaw-growth rate and accounted for all growth observed. The only conclusion that can be drawn from the 70°F tests is that suslic loading does promote flaw growth greater than that expected from sustained load growth.

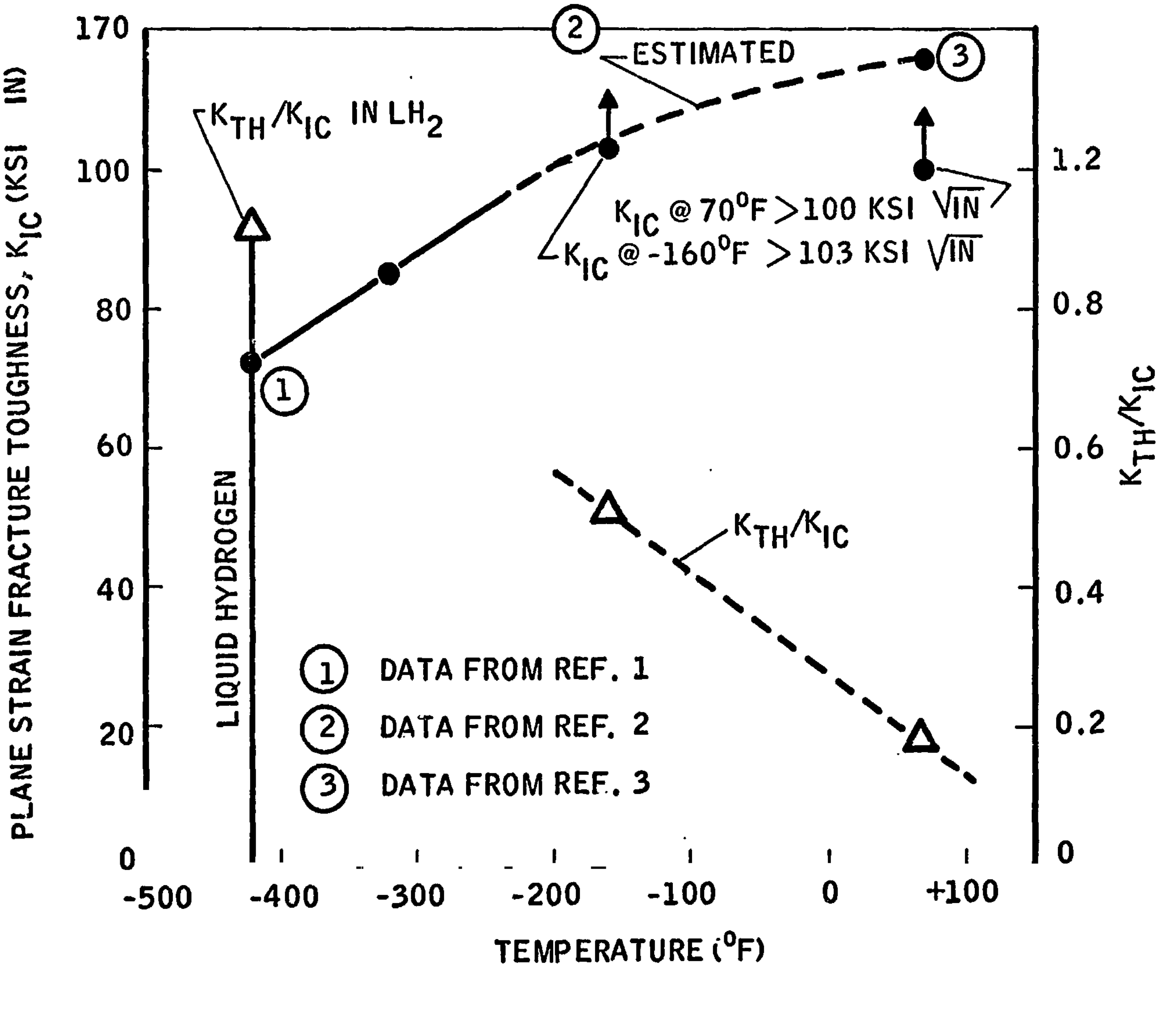


Figure 1 - Effects of Gaseous Hydrogen Upon Titanium Alloy With Estimated Fracture Toughness as a Function of Temperature

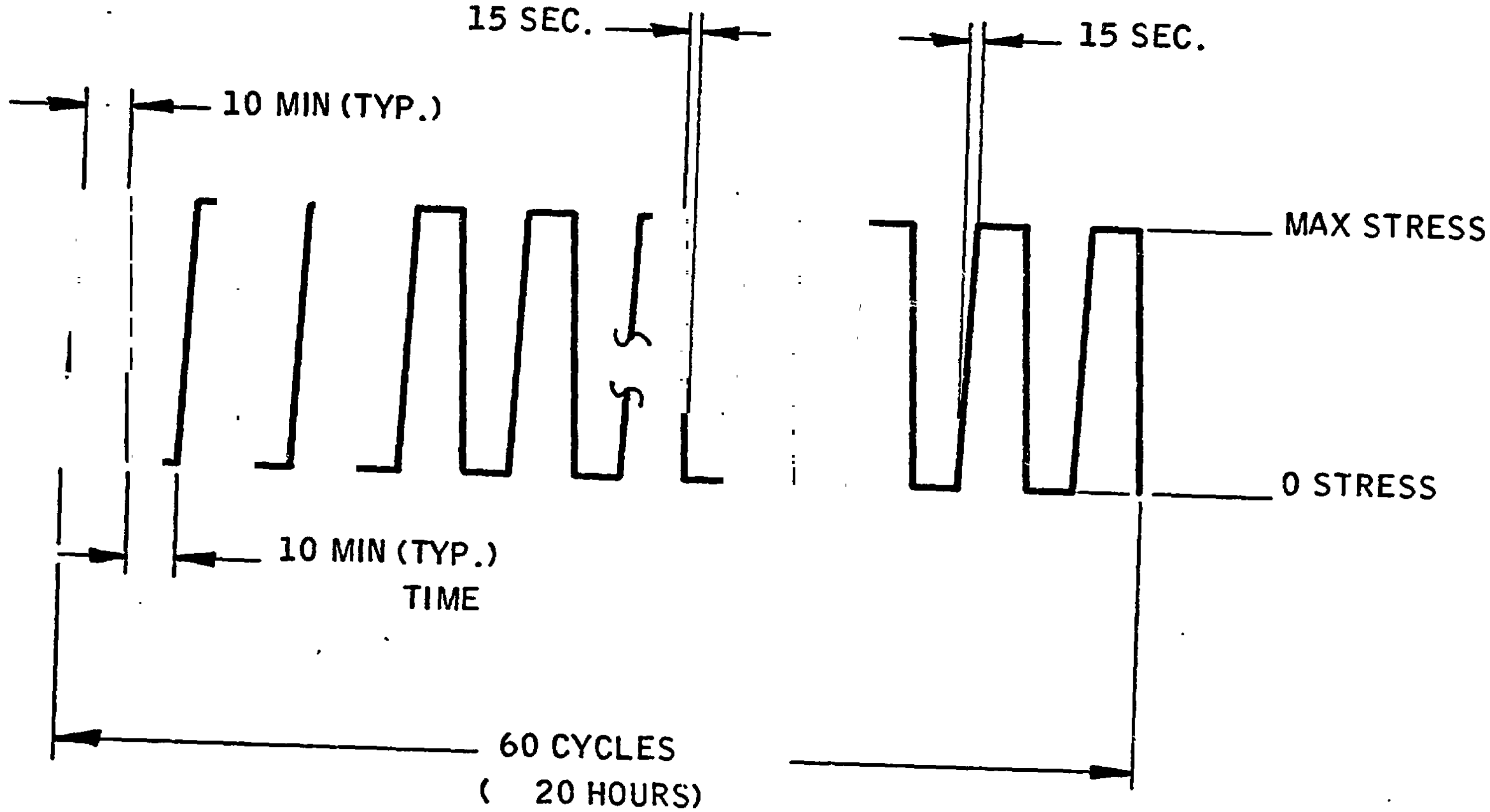


Figure 2 - Trapezoidal Suslic Load Profile

TABLE 7

SUSLIC TESTS OF ALLOY 718 AND Ti 5Al-2.5Sn (ELI) FORGING MATERIAL IN 1400-PSI GASEOUS HYDROGEN

Material	Test Temp °F	Initial Stress Intensity, K_{ii}, Ksi-In.$^{1/2}$	Amount of Flaw Growth Δa, In.
Alloy 718	70	52.3	0.135 Failed on 51st Cycle
	70	40.1	0.004
	-160	51.6	None
	-160	83.2	0.001
Ti 5Al-2.5Sn (ELI)	70	41.3	0.080 x 0.080 (localized growth)
	70	21.5	None
	-160	41.1	None
	-160	71.8	0.025
	-160	52.7	0.002

Alloy 718 suslic specimens tested below the lower-bound threshold defined at -160°F did not indicate more growth than would be expected from growth-on-loading (see Table 6).

The suslic test results for the Ti 5Al-2.5Sn (ELI) forging are also presented in Table 7.

At 70°F, two suslic tests were conducted, one at the threshold (approximately 21 ksi-in.$^{1/2}$) which showed no growth, and one well above the threshold which showed a irregular flaw growth. No attempt was made to determine a cyclic growth rate from this suslic test because of the apparent preferential flaw growth.

Suslic specimens tested at -160°F, at or above the threshold, showed more flaw growth than would have been expected from sustained-load flaw growth alone. No flaw growth was observed on the single suslic specimen tested below the threshold. An attempt was made to determine a cyclic growth rate from one of the suslic specimens that indicated the most flaw growth (0.025 in.). The calculations for this are shown in Table 8. The sustained-load flaw growth was determined by selecting an average sustained-load flaw-growth rate and multiplying it by the time at maximum load. This sustained-load flaw growth was then substracted from the total flaw growth, and the amount that remained was assumed to be the result of 60 cycles. A cyclic flaw-growth rate at 90 ksi was calculated to be 60 micro-in./cycle. The cyclic growth rate calculated from the suslic test agrees favorably with the Masters, et al, although the Masters data are slightly more conservative.*

*Masters, J.N., Haese, W.P., amd Finger, R.W., Investigation of Deep Flaws in Thin-Walled Tanks, NASA CR-72606, December 1969.

TABLE 8

CALCULATION OF CYCLIC GROWTH RATE FROM A SUSLIC TEST FOR Ti 5Al-2.5Sn (ELI)
FORGING IN HIGH PURITY GASEOUS HYDROGEN AT -160°F AND 1400 PSI

Specimen Number	Thickness, t (in.)	Test Condition	Flaw Depth, a (in.)	Flaw Width, 2C (in.)	a/2C	Stress, σ	σ/σ_{ys} [1]	Shape Parameter, Q	Flaw Size, a/Q (in.)	a/t	Magnification Factor, Mk	Stress Intensity, K_I (ksi $\sqrt{in.}$)	(K_I Aver. ksi $\sqrt{in.}$)	$\frac{\Delta a/Q}{\Delta T}$ (Micro-In./Sec)	Sustained Time, ΔT (hr)	$(\Delta a/Q)$ Sust. (In.)	$(\Delta a/Q)_{Total}-(\Delta a/Q)_{Sust.}$ (In.)	Cycles, ΔN	$\frac{(\Delta a/Q)}{\Delta N}$ Cyclic
T-13	0.379	Init.	[2] 0.196	0.637	0.308	90.0	0.621	1.574	0.1245	0.518	1.162	72.0	74.3	0.0050	10.0	0.0002	0.0036	60	[3] 60
		Final	0.220	0.637	0.346	90.0	0.621	1.713	0.1283	0.581	1.218	76.5							

[1] σ_{ys} @ -160°F = 145 ksi

[2] Includes Δa due to growth-on-loading on first cycle

[3] Δa/Q/ΔN = 48.6 micro-in./cycle at 100 ksi; $\left(\frac{\Delta a/Q}{\Delta N}\right)_\sigma = \left(\frac{\Delta a/Q}{\Delta N}\right)_{\sigma=100} \times \left(\frac{100}{\sigma}\right)^2$

f. Cyclic Test Results

A single Inconel 718 specimen was sinusodially cycled at -160°F to determine cyclic flaw-growth rate. This specimen was cycled for 5800 cycles at a maximum stress of 100 ksi and a stress ratio (i.e., minimum to maximum stress) of zero. The result obtained is presented in Table 9.

g. Observations and Conclusions

The following major observations were made from the tests conducted:

TABLE 9

CYCLIC FLAW-GROWTH RATE OF INCONEL 718 FORGING IN AIR/GN_2 AT -160°F AND AMBIENT PRESSURE

Specimen Number	Thickness, t (in.)	Test Condition	Flaw Depth, a (in.)	Flaw Width, 2C (in.)	a/2C	Stress, σ (ksi)	σ/σ_{ys} [1]	Shape Parameter, Q	Flaw Size, a/Q (in.)	a/t	Magnification Factor, Mk	Stress Intensity, K_I (ksi $\sqrt{in.}$)	$\Delta a/Q$ (in.)	Cycles, ΔN	$\frac{(\Delta a/Q)}{\Delta N}$ Aver. (Micro-In./Cycle)	(K_I) Aver. (ksi $\sqrt{in.}$)
I-18	0.252	Init.	0.046	0.245	0.188	100.0	0.544	1.230	0.0374	0.183	1.015	38.2	0.0118	5800	2.04	41.8
		Final	0.075	0.260	0.288	100.0	0.544	1.527	0.0492	0.298	1.043	45.2				

[1] σ_{ys} @ -160°F = 184 ksi

(1) Static Fracture

Material	K_{IC} (ksi $\sqrt{in.}$) 70°F	-160°F	-320°F
Alloy 718	> 125.2	> 103.2	> 108.0
Ti 5Al-2.5Sn (ELI)	> 100.0	> 103.0	> 85.0

Plane-strain fracture was not obtained for the majority of the material-temperature combinations because of limited specimen thickness. No differences were observed whether static fracture testing was performed in gaseous hydrogen or an air-inert environment.

(2) Sustained Load

Material	K_{TH} (ksi $\sqrt{in.}$) IN GH_2 AT 1400 PSI 70°F	-100°F	-160°F
Alloy 718	19.8	≈ 30 [1]	> 99.4
Ti 5Al-2.5Sn (ELI)	21.5	≈ 45 [1]	53.3

Alloy 718 exhibited a very severe threshold transition between -100° and -160°F, whereas Ti 5Al-2.5Sn (ELI) exhibited an essentially linear variation of threshold with temperatures between 70° and -160°F.

[1] Estimate based on single test.

(3) Combined Sustained-Cyclic (Suslic) Load

For both materials investigated, suslic tests conducted below the threshold resulted in flaw growth that could be directly attributed to basic cyclic growth only. Suslic tests conducted above the threshold resulted in flaw growth that appears to be the direct summation of sustained-load flaw growth and cyclic-load flaw growth.

Based primarily on these observations, the following conclusions were reached pertaining to the suitability of the two alloys for use as turbine-rotor materials:

(a) Alloy 718

This material exhibits a very high threshold at -160°F but a very significant reduction in the threshold appears to occur somewhere between -100° and -160°F. The exact point of the transition as a function of temperature is not known, but if the turbine happened to operate at a slightly higher temperature than -160°F, safe operation could not be guaranteed. A proof test of the rotor at 70°F to about the yield strength of the material would probably assure safe operation under normal operating conditions at -160°F. Safe operation of the rotor at -160°F during a malfunction condition (i.e., an overload with one turbine out) is unknown since valid fracture data at cryogenic temperatures could not be obtained from available specimen sizes.

(b) Ti 5Al-2.5Sn (ELI)

Although this material has a relatively low threshold at -160°F, safe operation under normal operating conditions can be guaranteed by a -160°F proof test that approaches the yield strength of the material. To guarantee safe operation under malfunction conditions (i.e., an overload with one turbine out), it appears possible that a proof test at temperatures below -160°F could be designed. For this to be feasible, lower-bound growth rates would have to be obtained.

REFERENCES

1. Dessau, P.P., "Tensile Strength and Fracture Toughness of Ti 5Al-2.5Sn (ELI) Forging", Materials Memo 70-001, Aerojet Nuclear Systems Company, January 1970.

2. Tiffany, C.F., Lorenz, P.M., and Shah, R.C., "Extended Loading of Cryogenic Tanks", NASA-CR-72252, December 1966.

3. Tiffany, C.F., Lorenz, P.M., and Hall, L.R., "Investigation of Plane Strain Flaw Growth in Thick-Walled Tanks", NASA CR-54837, February 1966.

4. Masters, J.N., Haese, W.P., amd Finger, R.W., "Investigation of Deep Flaws in Thin Walled Tanks", NASA CR-72606, December 1969.

E. RADIATION DAMAGE

1. GTR-20C Materials Irradiation Test

The combined WANL-ANSC materials irradiation test GTR-20C was completed 15 June with a total reactor time of 600 hr corresponding to 6000 Mw-hr. The planned fluence objectives summarized in S131-PR3, page 31, were achieved. Fluence range for ANSC specimens was between 2×10^{17} and 6×10^{18} nvt > 1 Mev. All tensile and fracture-toughness specimens were irradiated while immersed in liquid nitrogen at 140°R. The majority of the specimens were tested in liquid nitrogen without an intermediate warmup. Preliminary data are now available for the Ti 5Al-2.5Sn (ELI) forging tensile specimens. Average data and standard deviations are shown in Table 10. Average data are shown graphically in Figures 3, 4 and 5, for elongation, ultimate and yield strengths, respectively. The maximum exposure of 5.2×10^{18} nvt > 1 Mev is the highest fluence to which the alloy has been irradiated at cryogenic temperatures. The low elongation of 3.9% at this level suggests serious embrittlement: however, since reduction-in-area experienced only minor changes, it is possible that fracture toughness may not be degraded as much as elongation. Postirradiation toughness data will provide a better basis for classifying the material as "ductile" or "brittle" at various radiation levels.

TABLE 10

EFFECT OF FAST NEUTRON IRRADIATION
AT 140°R ON THE TENSILE PROPERTIES OF
A LARGE Ti 5Al-2.5Sn (ELI) FORGING AT 140°R

Preliminary Data*

Fluence NVT, E > 1 Mev	0.2% Yield Strength ksi Avg. of 4	0.2% Yield Strength ksi Std. Dev.	Ultimate Strength ksi Avg. of 4	Ultimate Strength ksi Std. Dev.	Elong (Chart) % Avg. of 4	Elong (Chart) % Std. Dev.	Area Reduction % Avg. of 4	Area Reduction % Std. Dev.
Control	174.8	1.5	185.7	2.1	10.3	2.0	30.0	3.2
2.3×10^{17}	183.2	1.8	189.5	1.1	8.8	0.8	30.4	2.6
8.2×10^{17}	188.0	1.5	195.5	1.7	7.4	1.0	29.5	5.0
4.9×10^{18}	199.1	3.3	204.4	3.1	3.9	0.4	25.4	3.4
5.2×10^{18}	Annealed at 540°R for 100 min between irradiation and testing							
	192.8	1.9	200.0	1.0	6.0	0.4	27.0	1.5

*Subject to change if arithmetical or measurement errors are discovered during data review.

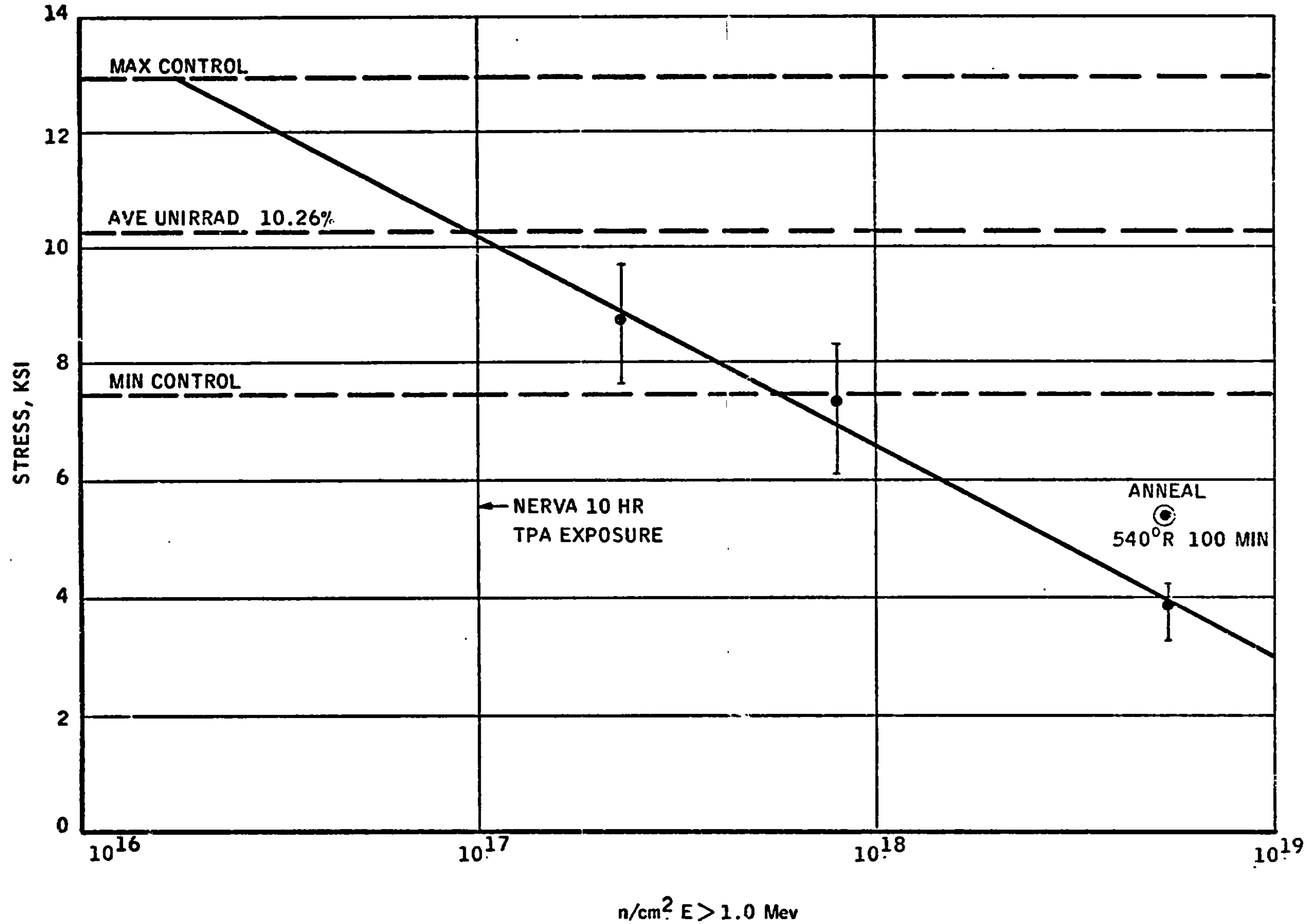


Figure 3 - Ti 5Al-2.5Sn (ELI) Elongation at 140°R, Irradiated at 140°R

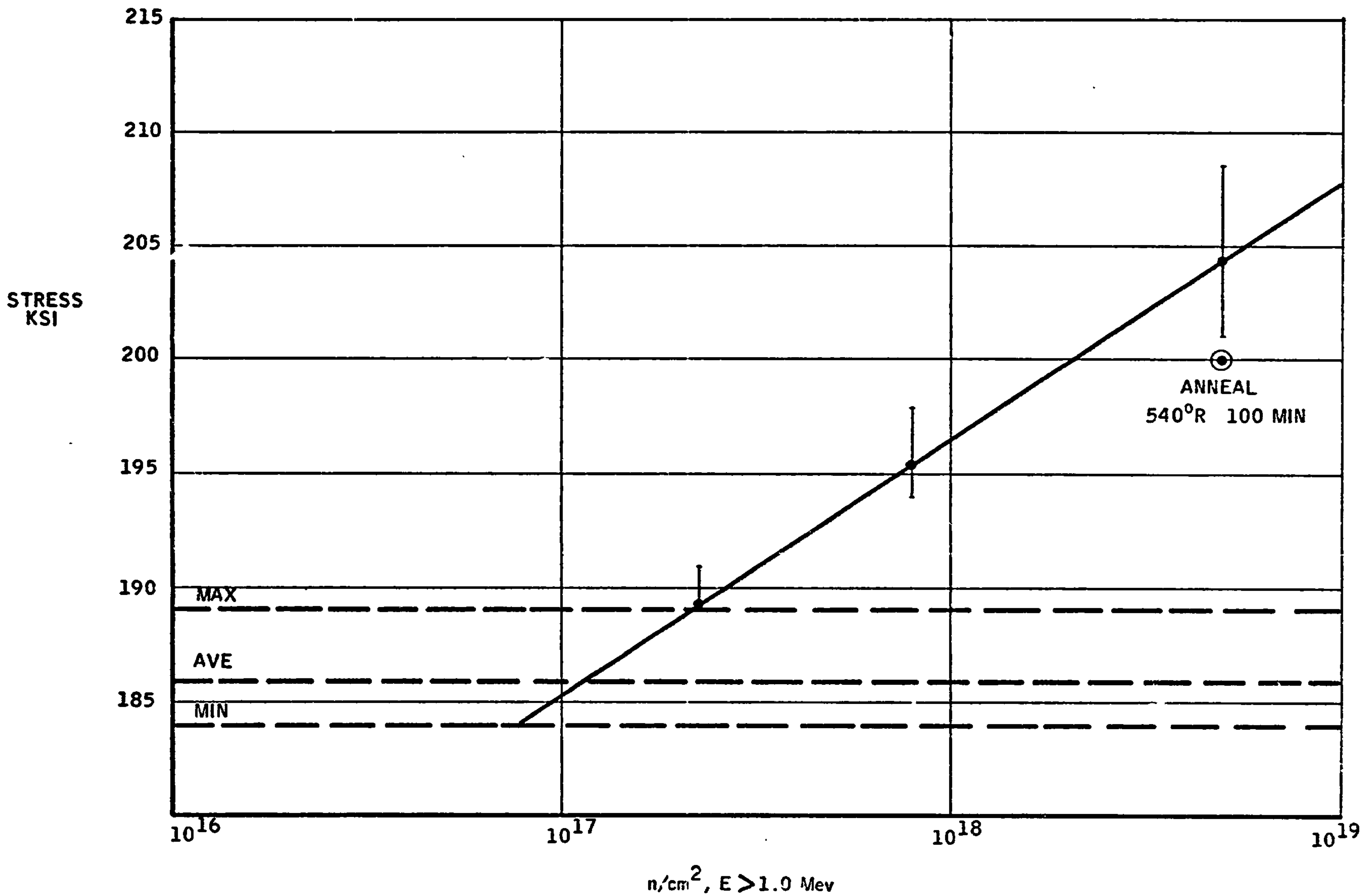


Figure 4 - Ti 5Al-2.5Sn (ELI) Tensile Ultimate Strength at 140°R

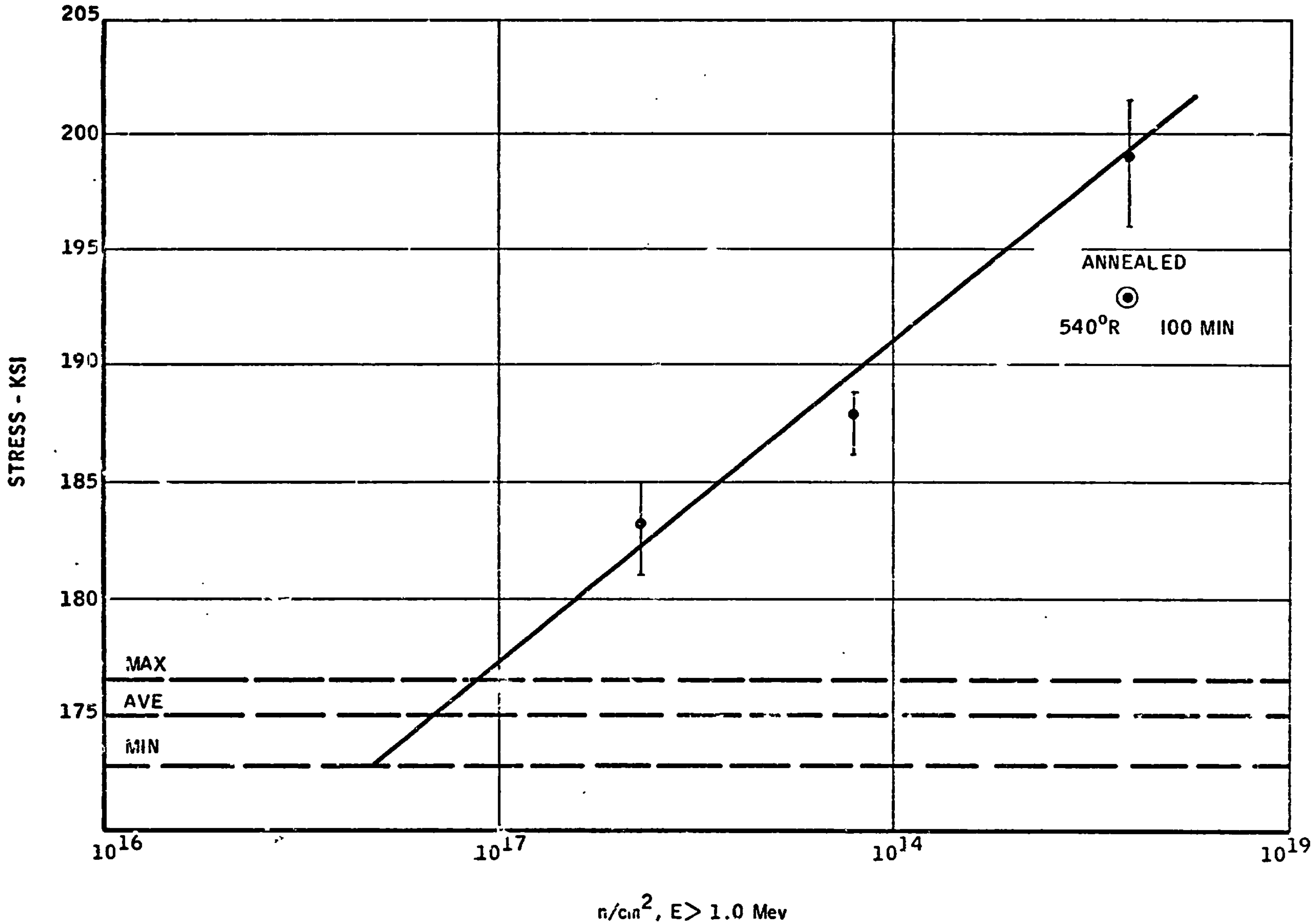


Figure 5 - Ti 5Al-2.5Sn (ELI) Tensile Yield Strength at 140°R, Irradiated at 140°R

F. FIBROUS GRAPHITE

1. Scope of Program

Developmental efforts have been concentrated upon the following three major activities to resolve the selection of materials, processes, and manufacturing methods required for fabricating the nozzle extension:

1. Selection of the optimum resin system for impregnating graphite fabric.

2. Development of high-carbon-yielding impregnants for densifying and strengthening the fibrous matrix.

3. Design and development of special woven graphite fabrics for the honeycomb cells and liner.

2. Prepreg Resin Systems

Nine resin systems are under evaluation for impregnating the cell wall and liner fabrics. These systems, their designation, and process conditions (previously described in ANSC Report S13-PR3) are being evaluated to determine their binder strength, shrinkage characteristics, carbon yield, and effects upon the modulus of elasticity.

a. Physical Properties

Table 11 is a compilation of the process results related to shrinkage, weight loss, and densities after the processing steps of cure, postcure, carbonization, and graphitization.

TABLE 11

PROPERTIES OF CANDIDATE PREPREG RESIN SYSTEMS

Prepreg Panel Designation/ Date Fabricated (10 in. x 14 in.	Panel Segments (5 in. x 14 in.)	Cure RT to 325°F Thickness* (in.)	Cure RT to 325°F Density (g/cm³)	Postcure 325 to 500°F Shrinkage(1) %	Postcure 325 to 500°F Wt Loss (%)	Postcure 325 to 500°F Density (g/cm³)	Carbonization 500°F to 1500°F Shrinkage(1) (%)	Carbonization 500°F to 1500°F Wt Loss (%)	Carbonization 500°F to 1500°F Density (g/cm³)	Graphitization 1500 to 5000°F Shrinkage(1) (%)	Graphitization 1500 to 5000°F Wt Loss (%)	Graphitization 1500 to 5000°F Density (g/cm³)	Total Change From Cured Condition Shrinkage(1) (%)	Total Change From Cured Condition Wt Loss (%)
1. EC260/WCA	Control 1	.330	1.369	-0.3	2.7	1.329	-2.11	11.83	1.197	-2.5	0.94	1.219	-4.2	15.03
3-20-70	Control 2	.335	1.354	-0.5	3.5	1.313	-1.50	11.85	1.172	-4.9	1.04	1.225	-6.7	15.86
2. EC260/WCA	A-1	.248	1.398	-0.4	3.26	1.361	-1.21	10.40	1.236	-3.3	0.87	1.277	-4.8	14.08
3-30-70	A-2	.247	1.407	Panel being held in reserve										
3. EC260/WCA	B-1	.252	1.402	-0.79	3.41	1.363	-1.20	10.33	1.243	-2.83	0.55	1.279	-4.8	13.87
3-30-70	B-2	.251	1.396	-1.59	3.43	1.370	-1.21	9.89	1.248					
4. EC260/WCA	C-1	.240	1.397	0.0	2.90	1.355								
3-30-70	C-2	.238	1.414	+0.84	2.91	1.360	-0.83	10.07	1.215	-2.94	0.83	1.269	-2.9	13.41
5. 4G3008	B-1	.318	1.383	-0.94	3.14	1.351	-1.58	12.21	1.207	-1.9	1.02	1.219	-4.4	15.83
4-30-70	B-2	.319	1.382	-0.63	3.12	1.344	-2.52	12.51	1.205	-1.3	0.99	1.213	-4.4	16.08
6. 4G3008	C-1	.312	1.216	Panel being held in reserve										
4-30-70	C-2	.312	1.215	Panel being held in reserve										
7. CA8207	A-1	.280	1.396	-0.71	3.79	1.351	-2.15	12.74	1.208	-1.47	1.21	1.202	-4.3	17.04
4-6-70	A-2	.280	1.393	-1.07	3.03	1.351								
8. CA8207	B-1	.281	1.391	-1.42	3.99	1.352	-1.80	12.68	1.204	-1.47	1.21	1.202	-4.6	17.18
4-6-70	B-2	.282	1.385	-1.41	4.07	1.342	-1.43	12.65	1.200					
9. CA8207	C-1	.280	1.417	-1.07	5.22	1.349	-2.16	12.78	1.204	-1.11	1.20	1.197	-4.3	18.33
4-6-70	C-2	.281	1.369	Panel being held in reserve										
10. CA8204	A-1	.274	1.380	-2.92	11.85	1.250	0.0	10.53	1.200					
4-9-70	A-2	.270	1.398	-2.22	14.38	1.220	0.0	10.36	1.095	- .38	1.17	1.091	-2.59	24.10
11. CA8204	B-1	.274	1.382	-3.28	11.34	1.263	0.0	10.37	1.134	-1.1	1.05	1.138	-4.4	21.38
4-8-70	B-2	.273	1.386	-2.56	11.60	1.254								
12. CA8204	C-1	.275	1.378	-3.27	11.82	1.254	0.0	10.57	1.123	-1.1	1.13	1.126	-4.4	22.03
4-9-70	C-2	.271	1.390											
13. MXG-248	C-1	.243	1.376	-0.82	4.95	1.318	0.0	9.90	1.189	-0.83	0.91	1.191	-1.6*	15.14
4-16-70	C-2	.243	1.378	-0.82	4.94	1.319								
14. MXG-248	B-1	.279	1.386											
4-17-70	B-2	.279	1.385	-1.43	5.63	1.325	0.0	10.39	1.188	-1.1	0.92	1.193	-2.5	16.22
15. MXG-248	C-3	.277	1.392	-0.036	5.15	1.323	-0.72	10.53	1.194	-1.1	0.92	1.200	-2.2	15.92
4-17-70	C-4	.278	1.389	-0.72	6.20	1.309	0.0	10.90	1.168					
16. 4G3086	A-1	.270	1.389	-1.48	3.19	1.366	-1.50	12.22	1.218	-1.9	0.78	1.237	-4.8	15.69
4-24-70	A-2	.271	1.387	-1.48	3.16	1.364	-1.87	12.10	1.221	-1.1	0.95	1.228	-4.4	15.68

(1) + Increase in thickness.
    _ Decrease in thickness.

*Initial thickness after 325°F cure.

TABLE 11 (cont.)

Prepreg Panel Designation/ Date Fabricated (10 in. x 14 in.)	Panel Segments (5 in. x 14 in.)	Cure RT to 325°F Thickness* (in.)	Cure RT to 325°F Density (g/cm³)	Postcure 325 to 500°F Shrinkage⁽¹⁾ %	Postcure 325 to 500°F Wt Loss (%)	Postcure 325 to 500°F Density (g/cm³)	Carbonization 500°F to 1500°F Shrinkage⁽¹⁾ (%)	Carbonization 500°F to 1500°F Wt Loss (%)	Carbonization 500°F to 1500°F Density (g/cm³)	Graphitization 1500 to 5000°F Shrinkage⁽¹⁾ (%)	Graphitization 1500 to 5000°F Wt Loss (%)	Graphitization 1500 to 5000°F Density (g/cm³)	Total Change From Cured Condition Shrinkage⁽¹⁾ (%)	Total Change From Cured Condition Wt Loss (%)
17. WCA/L8	B-1	.74	1.394	-0.73	2.59	1.368	-1.84	10.96	1.240	-2.2	0.85	1.265	-4.7	14.00
4-24-70	B-2	.274	1.398	-0.36	2.64	1.366	-2.56	11.05	1.247	-1.5	0.88	1.260	-4.4	14.16
18. CA8235	B-1	.280	1.386	-2.86	9.66	1.289	+1.47	12.83	1.110	-1.8	1.09	1.135	-3.2	22.10
4-29-70	B-2	.278	1.387	-1.80	7.62	1.304	+0.37	12.80	1.134					
19. CA8235	B-3	.280	1.385	-2.14	8.03	1.299	+0.36	12.73	1.130	-2.2	1.53	1.142	-3.9	20.99
5-1-70														
20. CA8235	C-1	.281	1.352	-2.49	6.55	1.294								
5-1-70	C-2	.280	1.356	-2.50	9.77	1.255	+1.47	12.94	1.078	-1.1	1.41	1.079	-2.1	22.56
21. CA8235	B-1	.249	1.369	-1.20	8.17	1.274								
5-5-70	B-2	.249	1.366	-1.20	7.92	1.273	+1.63	11.05	1.115	-0.4	1.32	1.108	0.0	19.17
22. CA8235	C-1	.253	1.376	-1.20	8.57	1.279	+1.61	11.66	1.113	-1.19	0.67	1.120	-1.20	19.61
23. FM5228/21435	A-1	.255	1.412	-0.78	4.29	1.361	-0.40	13.85	1.180	+0.40	0.69	1.163	-0.78	18.12
5-14-70	A-2	.255	1.415	-0.78	4.51	1.362	0.0	13.55	1.178	-1.19	1.42	1.176	-1.96	18.62
24. FM5228/21436	A-1	.253	1.420	0.0	4.36	1.357				Graphitized to 4000°F				
5-15-70	A-2	.253	1.416	-0.79	4.57	1.363	0.0	13.09	1.185	-0.40	0.83	1.80	-1.20	17.74
25. FM5228/21436	B-1	.259	1.392	-0.77	4.86	1.335	-0.39	13.23	1.163	-0.78	1.11	1.160	-1.93	18.27
5-15-70	B-2	.260	1.388	-1.15	4.80	1.335	-0.78	13.27	1.169					
26. FM5228/21436	C-1	.252	1.422	-0.40	4.23	1.368	0.0	13.39	1.186	-0.80	1.18	1.184	-1.19	18.02
5-15-70														
27. FM5228	A-1	.263	1.373											
Standard	A-2	.262	1.382	-0.76	4.35	1.332	-0.38	12.77	1.169	-0.39	1.23	1.157	-1.53	17.59
5-19-70														
28. FM5228	B-1	.261	1.364	-1.15	3.82	1.327								
Standard	B-2	.260	1.368	-0.77	4.03	1.322	+0.39	12.49	1.156	-0.77	1.25	1.146	-1.15	17.07
5-19-70														
29. FM5228	C-1	.262	1.376	-1.15	4.37	1.331	0.0	12.60	1.166					
Standard	C-2	.262	1.377	-1.15	4.30	1.333	0.0	12.64	1.167	-0.77	1.23	1.160	-1.91	17.43
5-19-70														
30. FM5228/21436	A-1	.265	1.402	-1.13	7.62	1.310								
5-21-70	A-2	.264	1.401	-1.14	7.25	1.314	+0.77	10.97	1.163	-1.14	1.39	1.162	-1.52	18.58
31. FM5228/21436	B-1	.266	1.392											
5-21-70	B-2	.266	1.394	-1.50	7.78	1.304	+0.76	10.92	1.154	-0.38	1.25	1.147	-1.13	18.89
32. FM5228/21436	C-1	.263	1.393	-1.15	7.39	1.303	+0.38	10.91	1.159	-0.77	1.15	1.158	-1.14	18.44
5-21-70	C-2	.262	1.403	-0.76	7.76	1.303	+0.38	11.08	1.163	-0.39	1.37	1.157	-0.76	19.11
33. EC260/WCA	A-1	.289	1.392	-0.35	2.59	1.361	-2.08	11.30	1.232	-2.48	1.06	1.229	-4.64	14.51
6-5-70	A-2	.287	1.389	-0.70	2.63	1.363	-1.75	11.25	1.231	-3.21	1.06	1.266	-5.57	14.50

(1) + Increase in thickness.
_ Decrease in thickness.

*Initial thickness after 325°F cure.

TABLE 11 (cont.)

Prepreg Panel Designation/ Date Fabricated (10 in. x 14 in.)	Panel Segments (5 in. x 14 in.)	Cure RT to 325°F Thickness* (in.)	Cure RT to 325°F Density (g/cm³)	Postcure 325 to 500°F Shrinkage(1) %	Postcure 325 to 500°F Wt Loss (%)	Postcure 325 to 500°F Density (g/cm³)	Carbonization 500°F to 1500°F Shrinkage(1) %	Carbonization 500°F to 1500°F Wt Loss (%)	Carbonization 500°F to 1500°F Density (g/cm³)	Graphitization 1500 to 5000°F Shrinkage(1) %	Graphitization 1500 to 5000°F Wt Loss (%)	Graphitization 1500 to 5000°F Density (g/cm³)	Total Change From Cured Condition Shrinkage(1) %	Total Change From Cured Condition Wt Loss (%)
34. FM5228/21436	A-1	.262	1.414	-0.92	5.06	1.353	+1.169	12.22	1.171	-1.14	1.01	1.173	-0.38	17.51
6-26-70	A-2	.262	1.418	-0.53	5.05	1.353	+1.30	11.76	1.176	-1.51	1.73	1.175	-0.38	17.68
35. FM5228	C-1	.261	1.370	-0.77	3.45	1.315	+1.16	12.01	1.145	-0.76	1.24	1.137	-0.38	17.14
Standard	C-2	.263	1.362	-1.15	4.43	1.315	+1.54	12.17	1.140	0.0	1.28	1.139	-1.14	17.16
6-26-70														
36. FM5228/21436	A-1	.262	1.414	-0.76	5.21	1.351	+1.54	12.12	1.170	-0.76	1.56	1.161	0.00	18.00
6-29-70	A-2	.260	1.417	-1.35	5.12	1.350	+1.75	12.59	1.171	-1.53	1.02	1.179	-1.15	17.92
37. FM5228	B-1	.263	1.361	-1.15	5.42	1.302	+1.16	11.22	1.143	-0.77	1.38	1.135	-0.77	17.20
Standard	B-2		1.356	-1.15	6.34	1.283								
6-30-70														
38. FM5228	C-1	.260	1.370	-0.77	6.39	1.291	+1.16	11.12	1.136	-1.15	1.01	1.136	-0.77	17.65
Standard	C-2	.261	1.362	-0.54	6.38	1.285	+0.92	10.84	1.137	-1.53	1.43	1.134	-1.15	17.46
6-30-70														
39. CA 8235	B-1	.246	1.363	-0.81	10.70	1.228	+2.87	8.62	1.092					
Batch #2	B-2	.245	.375	-0.82	9.57	1.253	+3.29	8.82	1.107	0.00	1.33	1.095	+2.45	18.65
7-2-70														
40. CA 8235	C-1	.277	1.369	-1.81	15.58	1.178	+1.47	8.63	1.060	-1.09	1.56	1.058	-1.44	24.06
Batch #1	C-2	.279	1.379	-2.15	10.80	1.256	+2.56	11.09	1.089	-1.43	1.49	1.091	-1.08	21.88
7-2-70														

(1) + Increase in thickness.
_ Decrease in thickness.

*Initial thickness after 325°F cure.

One of the prime considerations in the selection of a resin system is a low shrinkage rate which is essential in reducing residual stress distortion and delaminations. One resin system (U.S. Polymeric's Grade USP-39 resin with filler) exhibited the lowest total shrinkage of any system. For this resin, shrinkages ranged from 0.38 to 1.96% with an average of 1.1% for the 12 panels processed. These data represent two manufacturing lots of prepreg fabric which are referred to as FM 5228 (standard) and FM 5228 (21436) in Table 11.

Ferro Grade CA 8235 had a wide variability in shrinkage, ranging from 0.06 to 3.9%. This variability is believed caused by an uneven distribution of filler in the resin.

Fiberite's MXG-248 system had the second lowest overall rate of shrinkage which ranged from 1.6 to 2.2%, with an average of 2.1% for the three panels tested. All of the other resin systems had shrinkage rates in the 4 to 6% range. This rate of shrinkage is considered too excessive for producing structurally sound composites.

All resin systems, with the exception of Ferro Grade CA 8204, had the highest weight loss during the carbonizing cycle. In several tests, Ferro Grade 8235 had higher weight loss during the postcure cycle. No correlation was found, however, between total weight loss and shrinkage.

b. Mechanical Properties

(1) Young's Modulus

The results of modulus measurements on material produced from each of the nine prepreg resins are presented in Table 12. Measurements were made on each material after the carbonization and graphitization cycles to determine the effects of thermal treatment. Measurements

TABLE 12

YOUNG'S MODULUS MEASUREMENTS

	Material Ident	Carbonized (1550°F) E, 10^6 psi	Density g/cm^3	Graphitized (5000°F) E, 10^6 psi	Density g/cm^3
1.	MXG-248	1.45	1.17	1.35	1.19
2.	CA 8207	1.92	1.20	1.45	1.20
3.	CA 8204	1.84	1.20	0.74	1.09
4.	WCA/EC260	1.95	1.25	1.54	1.25
5.	4G3086	0.82*	1.20	1.40	1.19
6.	WCA/L-8	1.49	1.24	0.80	1.15
7.	4G3008	0.83	1.21	0.61	1.22
8.	CA 8235 (B-1)	1.18	1.11	0.96	1.14
9.	CA 8235 (C-1)			1.20	1.12
10.	FM 5228 (21436) B-1 A-2	1.83	1.17	1.51	1.17
11.	FM 5228 (Standard)	1.94	1.17		

*Specimen measured in fill direction.

were made at room temperature by exciting each specimen into flexural resonance. The modulus for all of the specimens (with the exception of specimen G-463086) was measured in the warp-fiber direction.

As can be noted from the data, the modulus values decreased from a carbonized to a graphitized state, the result of ordered crystal development within the resin binder that is characteristic of graphite products. Two of the resin systems (CA 8204 and WCA/L-8) underwent large decreases in modulus after graphitization that corresponded to significant decreases in density which, in turn, apparently accounts for decreases in moduli. The WCA/EC260 resin system exhibited the highest modulus and density after carbonization and graphitization. This is believed to be the result of a high carbon yield after pyrolysis. The degree of graphitization of each of these resins will be further evaluated by examining X-ray diffraction patterns and equating these data to the modulus data.

The moduli for these composites will increase somewhat after pitch impregnation and regraphitization: however, it is anticipated that their values will be lower than those determined for AGCarb-101 because of the use of a lower modulus pitch system as compared with the higher modulus Code 88 treatment used by Carbon Products, a Division of Union Carbide Corporation.

(2) Block Tensile

The weakest property of laminated fibrous-graphite composites is the block tensile property: i.e., tensile strength across the layers of fabric. This property is basically a measure of carbon-binder strength between the layers of fabric which is derived from the pyrolysis of the prepreg resin. The results of these property measurements are presented in Table 13. The EC260 resin system (a 4,4' dihydroxy biphenyl formaldehyde) revealed high average strengths of 257 and 272 psi in the carbonized and

TABLE 13

BLOCK TENSILE STRENGTHS OF LAMINATES
AFTER CARBONIZATION AND GRAPHITIZATION

Material Identification	Specimen No.	Block Tensile Strength (psi)
A. After Carbonizations (to 1550°F)		
WCA/EC260-B2	1	277
Hexcel 800138	2	294
4-1-70	3	200
	Avg	257
WCA/L8-B1	1	221
Hexcel L800138	2	196
3-9-70	3	214
	Avg	210
4G3008-C1	1	219
Hexcel L800138	2	211
3-12-70	3	201
	Avg	210
CA8207-B2	1	179
Ferro L800137	2	240
4-6-70	3	146
	Avg	188
FM5228/21436-B1	1	134
Polymeric N900020	2	185
5-14-70	3	156
	Avg	158
FM5228-C1	1	136
Polymeric N900019	2	172
5-19-70	3	-
	Avg	154
4G3086-C2	1	136
Hexcel L800138	2	67
	3	113
	Avg	105
CA8235-B1	1	102
Ferro L800137	2	89
5-1-70	3	101
	Avg	97
MXG248 [illegible]4	1	43
Fiber[illegible] L800136	2	77
4-17-70	3	92
	Avg	71
CA8204-A1	1	34
Ferro L800137	2	76
4-9-70	3	25
	Avg	45

TABLE 13 (cont.)

Material Identification	Specimen No.	Block Tensile Strength (psi)
B. After Graphitization (to 5000°F)		
CA8207-A1	1	251
Ferro L800137	2	316
4-6-70	3	311
	Avg	293
WCA/E260-B-1	1	317
Hexcel L800138	2	226
4-1-70	3	273
	Avg	272
FM5228/21436	1	201
Polymeric N900030(2)	2	216
5-15-70	3	211
	Avg	209
4G3008-C1	1	185
Hexcel L800138	2	222
3-17-70	3	49(1)
	Avg	204
4G3086-A1	1	189
Hexcel L800138	2	201
4-24-70	3	193
	Avg	194
WCA/L8-B1	1	146
Hexcel L800138	2	96
4-24-70	3	153
	Avg	132
MXG248-B2	1	145
Fiberite L800136	2	111
4-17-70	3	121
	Avg	126
CA8235-B1	1	74
Ferro L800137	2	78
4-29-70	3	89
	Avg	80
CA8235-C1	1	79
Ferro L800137	2	82
5-5-70	3	83
	Avg	81
CA8204-A2	1	86
Ferro L800137	2	70
4-9-70	3	91
	Avg	82

(1) Peel failure, valve not included in average
(2) Graphitized at 4000°F.

graphitized states, respectively. For nearly all resins, strength values increased in proceeding from a carbonized to a graphitized state. These strengths should significantly increase after multiple pitch impregnations and regraphitizations.

(3) Tensile Strength

The results of tensile-strength measurements in the warp and fill directions after carbonization and graphitization cycles are presented in Table 14. After carbonization, the highest strength was obtained with the EC260 resin system which had an average strength of 10,462 psi. The strengths for the other resin systems in the warp direction ranged from 8,486 to 9,353 psi. Two of the resin systems (4G-3086 and 4G-3008) were measured in the fill direction since material of sufficient length to measure warp direction properties was not available. The tensile strength decreased after graphitization for all resins except Fiberite Grade MXG-248.

The tensile strengths for all systems without pitch impregnation are relatively high in comparison to the typical value of 11,140 psi for AGCarb-101 which had been subjected to a series of pitch impregnation and regraphitizations.

(4) Interlaminar Shear Strength

The interlaminar shear strengths of the nine resin systems after carbonization and graphitization are shown in Table 15. Grade EC260 resin showed the highest interlaminar shear strengths of 787 and 737 psi. The other systems showed significant decreases in strength down to a range of 27- to 301 psi for Grades CA8204 and CA8235.

TABLE 14

ULTIMATE TENSILE STRENGTH AND MODULUS OF ELASTICITY OF CARBONIZED AND GRAPHITIZED LAMINATES (Tested in the Warp and Direction Fill)

Material Identification	Specimen No.	Ultimate Tensile Strength (psi)	Tensile Modulus(2) (psi x 10^{-6})
A. After Carbonization			
WCA/EC260-B2	1	10,661	1.58
Hexcel L800138	2	10,127	1.65
4-1-70	3	10,597	1.48
	Avg	10,462	1.57
CA8207-B2	1	9,609	3.22
Ferro L800137	2	8,826	1.74
4-6-70	3	9,714	1.46
	Avg	9,383	2.14
FM5228-B1	1	8,652	1.29
Polymeric N900020	2	9,477	1.88
5-1-70	3	9,169	1.37
	Avg	9,099	1.51
CA8235-B1	1	8,904	1.23
Ferro L800137	2	9,592	1.07
5-1-70	3	8,192	0.71
	Avg	8,896	1.01
MXG248-C4	1	8,314	1.14
Fiberite L800136	2	9,449	1.19
4-17-70	3	8,841	1.57
	Avg	8,868	1.30
CA8204-A1	1	9,750	1.18
Ferro L800137	2	8,706	1.40
4-9-70	3	8,000	0.69
	Avg	8,819	1.09
WCA/L8-B1	1	9,242	1.38
Hexcel L800138	2	8,667	1.21
3-9-70	3	8,515	1.30
	Avg	8,808	1.32
FM5228-C1	1	8,215	1.12
Polymeric N900019	2	8,879	1.58
5-19-70	3	8,364	1.44
	Avg	8,486	1.38

(1) Tested in fill direction.
(2) Modulus of elasticity values are calculated per FTMS 406 from initial portion of stress/strain curve.

TABLE 14 (cont.)

Material Identification	Specimen No.	Ultimate Tensile Strength (psi)	Tensile Modulus(2) (psi x 10^{-6})
4G3008-C1	1	4,568	0.65
Hexcel L800138	2	4,513	0.53
3-12-70	3	4,444	0.57
	Avg	4,508(1)	0.58
4G3086-C2	1	4,597	0.48
Hexcel L800138	2	4,113	0.52
3-9-70	3	4,705	0.47
	Avg	4,472(1)	0.49

Material Identification	Specimen No.	Ultimate Tensile Strength (psi)	Ultimate Elongation (%)	Tensile Modulus (psi x 10^{-6})
B. After Graphitization				
4G3086-A1	1	10,573	2.29	1.24
Hexcel L800138	2	10,567	2.30	1.31
4-24-70	3	11,367	2.42	1.34
	Avg	10,836	2.34	1.34
MXG248-B2	1	9,014	3.00	1.14
Fiberite L800136	2	9,304	2.57	1.29
4-17-70	3	9,739	2.42	1.42
	Avg	9,353	2.66	1.28
WCA/EC260-B1	1	9,017	0.85	1.25
Hexcel L800138	2	8,770	0.95	1.59
4-17-70	3	8,656	1.30	1.51
	Avg	8,814	1.03	1.45
CA8235-C1	1	9,698	3.20	0.94
Ferro L800137	[illegible]	7,730	3.05	0.55
5-5-70	3	8,016	2.50	0.81
	Avg	8,481	2.92	0.76
FM5228-A2	1	8,516	1.90	1.29
Polymeric N900020	2	8,438	2.20	1.11
5-15-70	3	7,719	1.70	1.56
	Avg	8,224	1.93	1.32
CA8235-B1	1	7,384	3.20	0.73
Ferro L800137	2	8,694	2.60	1.32
4-29-70	3	8,514	2.55	0.73
	Avg	8,197	2.78	0.93

TABLE 14 (cont.)

Material Identification	Specimen No.	Ultimate Tensile Strength (psi)	Ultimate Elongation (%)	Tensile Modulus (psi x 10^{-6})
CA8207-A1	1	8,162	1.65	1.35
Ferro L800137	2	8,088	1.75	1.43
4-6-70	3	7,912	1.35	1.43
	Avg	8,054	1.58	1.40
CA8204-A2	1	6,493	2.30	1.01
Ferro L800137	2	6,866	2.35	0.81
4-9-70	3	6,735	2.60	0.57
	Avg	6,698	2.42	0.80
WCA/L8-D1	1	4,603	6.60	0.40
Hexcel L800138	2	4,613	5.88	0.56
4-24-70	3	5,032	6.20	0.90
	Avg	4,749(1)	6.23	0.62
4G3008-C1	1	3,893	5.90	0.31
Hexcel L800138	2	4,093	5.88	0.39
3-17-70	3	3,974	5.80	0.32
	Avg	3,987(1)	5.86	0.34

(1) Tested in fill direction.

TABLE 15

INTERLAMINAR SHEAR STRENGTH OF CARBONIZED AND GRAPHITIZED LAMINATES[1]

Material Identification	Specimen No.	Shear Strength PSI
A. After Carbonization (1550°F)		
WCA/EC260	1	767
L-800138	2	800
B-2	3	797
4-1-70	Avg	787
CA8207	1	764
L800137	2	673
B-2	3	604
	Avg	680
WCA/L8	1	556
L800138	2	632
B-1	3	516
3-9-70	Avg	568
MXG248	1	558
L800136	2	403
C-4	3	628
4-17-70	Avg	530
FM5228	1	500
N900020	2	484
(21436)	3	508
5-16-7	Avg	497
4G3086	1	465
L800136	2	512
C-2	3	459
3-9-70	Avg	479
4G3008	1	486
L800138	2	476
C-1	3	467
3-12-70	Avg	476
CA8204	1	471
L800137	2	237
A-1	3	195
4-9-70	Avg	301

(1) Test Conditions - (a) .05"/min load rate, Room Temp. (b) 0.250 overlap 1" wide specimen with support, (c) Drawing No. 1138105-1-notch 0.140 ± .005

TABLE 15 (cont.)

Material Identification	Specimen No.	Shear Strength PSI
CA8235	1	198
L800137	2	312
B-1	3	367
5-1-70	Avg	292
FM5228	1	
N90020	2	150 (2)
C-1	3	556
5-19-70	Avg	Not meaningful
B. After Graphitization (5000°F)		
WCA/EC260	1	653
L800138	2	737
B-1	3	823
4-1-70	Avg	737
CA8207	1	592
L800137	2	731
A-1	3	678
4-6-70	Avg	667
WCA/L8	1	562
L800138	2	578
B-1	3	525
4-24-70	Avg	555
FM5228	1	484
N900020	2	500
(21436)	3	506
A-2	Avg	497
5-15-70		
MXG248	1	480
L800136	2	428
B-2	3	512
4-17-70	Avg	473
4G3086	1	Specimen broken
L800138	2	456
A-1	3	455
4-24-70	Avg	456

(2) Specimen precracked prior to test.

TABLE 15 (cont.)

Material Identification	Specimen No.	Shear Strength PSI
4G3008	1	464
L800138	2	406
C-1	3	455
3-17-70	Avg	441
CA8235	1	311
L800137	2	201
B-1	3	321
4-29-70	Avg	278
CA8204	1	Specimen broken
L800137	2	Specimen broken
A-2	3	277
4-9-70	Avg	
CA8235	1	All specimens
L800137	2	broken during
C-1	3	machining and/or
5-5-70		handling

(5) Hardness and Specific Gravity

The results of hardness and specific-gravity measurements on specimens taken from each plate of fabricated material are presented in Table 16. It is apparent from the data that hardness values do differentiate between the various resin systems after both carbonization and graphitization. Therefore, hardness measurements may be useful as a quality-control procedure for in-process inspection. This would require the establishment of the upper and lower limits for each phase of processing on a statistical basis from a large lot of samples. Hardness tests will also be required on pitch-impregnated and regraphitized material in order to provide a complete hardness characterization for quality control purposes.

3. <u>Impregnation Resins</u>

The evaluation of pitch and resin-binder systems was narrowed to Allied Chemical Grade 15V and Ashland Oil and Refining Company Grade 170. Grade 15V is produced from coal tar and is used widely in the graphite industry for impregnation purposes. Grade 170 is a somewhat newer pitch that is a byproduct of petroleum refining. Indications are that this pitch is ideal for impregnation purposes because of its low viscosity at moderate temperatures, high carbon yield, and ability to graphitize at low temperature to produce a "soft" carbon structure. Grade 15V pitch, on the other hand, produces a "hard carbon".

Two furfuryl alcohol systems (Quaker Oats Fapreg P-3 and Varcum 8251) are still being evaluated as an additive to the pitch to impart thermosetting properties and to reduce the viscosity for increased impregnation efficiency.

Indene has been selected as the best solvent for reducing the high viscosity of the pitch.

TABLE 16

HARDNESS AND SPECIFIC GRAVITY OF CARBONIZED AND GRAPHITIZED TEST LAMINATES

Material Identification	Specimen No.	Specific Gravity	Rockwell "L" Hardness Smooth(1)	Rough(2)
A. After Carbonization(1550°F)				
WCA/EC260-B-2	1	1.235	82	77
Hexcel L800138	2	1.238	78	76
4-1-70	3	1.244	84	79
	Avg	1.239	81	77
WCA/L8-B1	1	1.238	16	23
Hexcel L800138	2	1.253	11	17
3-9-70	3	1.245	11	13
	Avg	1.245	13	18
4G3008-C1	1	1.212	46	47
Hexcel L800138	2	1.222	41	56
3-12-70	3	1.209	52	54
	Avg	1.214	46	52
4G3086-C2	1	1.210	63	52
Hexcel L800138	2	1.207	50	50
3-9-70	3	1.211	51	54
	Avg	1.209	55	52
CA8204-A1	1	1.073	8	8
Ferro L800137	2	1.161	17	22
4-9-70	3	1.080	5	9
	Avg	1.105	10	13
CA8235-B1	1	1.110	12	7
Ferro L800137	2	1.133	7	9
5-1-70	3	1.071	5	5
	Avg	1.105	8	7
CA8207-B2	1	1.196	49	43
Ferro L800137	2	1.182	40	44
4-6-70	3	1.199	45	46
	Avg	1.192	45	44
FM5228-B1	1	1.160	19	21
Polymeric N900020	2	1.158	19	17
5-14-70	3	1.163	20	26
	Avg	1.160	19	21

(1) Surface cured against mold.
(2) Surface cured against bag.

TABLE 16 (cont.)

Material Identification	Specimen No.	Specific Gravity	Rockwell "L" Hardness Smooth (1)	Rockwell "L" Hardness Rough (2)
FM5228-C1	1	1.172	19	40
Polymeric N900019	2	1.162	31	36
5-19-70	3	1.168	25	33
	Avg.	1.167	36	36
MXG248-C4	1	1.159	26	28
Fiberite L800136	2	1.173	40	39
4-17-70	3	1.165	29	28
	Avg	1.166	32	32
B. After Graphitization (5000°F)				
4G3008-C1	1	1.205	5	5
Hexcel L800138	2	1.209	9	7
3-17-70	3	1.213	5	5
	Avg	1.209	6	6
4G3086-A1	1	1.206	9	7
Hexcel L800138	2	1.205	14	14
4-24-70	3	1.215	13	9
	Avg	1.209	12	10
WCA/L8-B1	1	1.232	57	46
Hexcel L800138	2	1.229	59	55
4-24-70	3	1.230	59	59
	Avg	1.230	58	53
WCA/EC260	1	1.284	9	12
Hexcel L800138	2	1.271	18	8
4-1-70	3	1.279	14	12
	Avg	1.278	14	11
CA8207-A1	1	1.202	4	5
Ferro L800137	2	1.168	3	4
4-6-70	3	1.165	4	4
	Avg	1.178	4	4
CA8204-A2	1	1.091	-3	-4
Ferro L800137	2	1.070	-6	-5
4-9-70	3	1.084	-1	-4
	Avg	1.082	-3	-4
CA8235-B1	1	1.069	-13	-7
Ferro L800137	2	1.128	-5	-4
4-29-70	3	1.119	-5	-5
	Avg	1.105	-8	-5

(1) Surface cured against mold.
(2) Surface cured against bag.

TABLE 16 (cont.)

Material Identification	Specimen No.	Specific Gravity	Rockwell "L" Hardness Smooth(1)	Rough(2)
CA8235-C1	1	1.071	-6	-5
Ferro L800157	2	1.136	-3	-6
5-5-70	3	1.134	-6	-2
	Avg	1.114	-5	-4
MXG248-B2	1	1.134	7	7
Fiberite L800136	2	1.178	10	10
4-17-70	3	1.149	7	8
	Avg	1.154	8	8
FM5228-A2	1	1.145	14	11
Polymeric N900020	2	1.143	15	17
5-15-70	3	1.129	14	17
	Avg	1.139	14	15

(1) Surface cured against mold.
(2) Surface cured against bag.

Table 17 is a compilation of the various impregnation tests that have been in process to evaluate the influence of variations in solvent-to-pitch ratios and temperatures upon impregnation efficiency. The major portion of the studies have been performed on graphitized panels produced from FM 5228 prepreg which is Grade WCA graphite fabric impregnated with USP-39 resin and filler. This resin system has shown the lowest shrinkage characteristics of the nine resin systems evaluated.

Solvent-to-pitch ratios of 20:80, 25:75, and 15:85 were used for the three studies since these ratios are in the optimum range for reducing the viscosity of the pitch while still yielding a high carbon yield. For the FM 5228 system, typical densities after the first graphitization ranged from 1.14 to 1.18 g/cm^3. After one pitch-impregnation and regraphitization cycle, densities in the 1.34-1.35 range were typical for 20 Indene/80 15V pitch compositions. A ratio of 25 Indene/75 15V pitch resulted in the highest density for this series of tests (1.37 g/cm^3). Lowering the Indene to a 15/85 ratio resulted in a lower density in the 1.32 range after graphitization. Changing the process temperature of the pitch from 225° to 275°F did not result in noticeable density differences. The use of Fapreg P-3 or Varcum in lieu of Indene did not show any significant improvement in the final density.

The target density for the composite is a minimum of 1.40 g/cm^3. It would be desirable to achieve this density by using only two pitch-impregnation cycles to minimize processing time and production costs. The next set of impregnation studies will involve two impregnations and two graphitization cycles to determine the density limits that can be achieved.

4. Fabric Development

Developmental efforts have been completed at Woven Structures, Huntington Park, California, on the three-dimensional tufted fabric which is designed to have radial yarns running through multilayers of fabric. This

TABLE 17

PITCH IMPREGNATION STUDIES

	Material ID	Run No.	Solvent/Pitch Ratio %	Target Temp °F	Actual Temp °F	Viscosity CPS	Evacuation Time Min.	Pressure psi	Pressure Hold Time Hrs.	Temp After Impreg °F	Viscosity After Impreg CPS	Temp Immed. Upon Opening Lid °F	Specific Gravity Prior to Impreg	Specific Gravity After Impreg	Specific Gravity After Cure	Specific Gravity After Carbon.	Specific Gravity After Graphit.
1.	WCA/EC260	A	20 P3 80 15V	250	250	-	60	215	2	-	-	260	1.19	1.51	1.45	1.36	1.34
													1.19	1.48	1.43	1.35	1.34
													1.20	1.50	1.45	1.37	-
												Avg	1.193	1.496	1.443	1.360	1.340
2.	WCA/EC260	B	20 P3 80 15V	250	250	65	60	215	4	230	80	230	1.22	1.55	1.50	1.41	1.40
													1.23	1.57	1.50	1.40	1.39
													1.23	1.57	1.53	1.41	-
												Avg	1.227	1.563	1.510	1.407	1.395
3.	WCA/EC260	C	20 P3 80 15V	250	235	69	60	215	6	-	-	240	1.20	1.50	1.42	1.35	1.34
													1.21	1.49	1.42	1.39	1.36
													1.15	1.52	1.45	1.37	-
												Avg	1.187	1.503	1.430	1.370	1.350
4.	FM5228	D	20 P3 80 15V	250	265	-	60	215	2	175	-	175	1.16	1.48	-	-	-
													1.14	1.47	-	-	-
													1.17	1.48	-	-	-
												Avg	1.157	1.477			
5.	FM5228	E	20 Varcum 8251 (2 Oxalic) 80 15V	275	280	-	60	215	2	-	-	280	1.15	1.39	-	-	-
													1.17	1.43	-	-	-
													1.15	1.41	-	-	-
												Avg	1.157	1.410			
6.	FM5228	F	40 Varcum, 2% Oxalic 60 15V	250	235	-	60	220	4	-	-	195	1.17	1.42	1.40	1.33	1.32
													1.16	1.42	1.40	1.32	1.31
													1.15	1.40	1.38	1.32	1.29
												Avg	1.16	1.413	1.393	1.323	1.307
7.	FM5228 WCA/EC260	G	20 P3 80 15V	250	240	54	10	215	4	-	-	245	1.16	1.50	1.4[illegible]	1.33	1.32
													1.21	1.50	1.45	1.37	1.36
8.	FM5228 WCA/EC260	H	20 P3 80 15V	250	265	67	5	210	6	-	-	250	1.14	1.45	1.41	1.32	1.31
													1.16	1.42	1.38	1.30	1.29
9.	FM5228	I	20 Indene 80 15V	250	255	-	5	215	2	-	-	245	1.18	1.49	1.42	1.35	1.34
													1.21	1.47	1.40	1.34	1.33
												Avg	1.20	1.48	1.41	1.35	1.34
10.	FM5228	J	20 Indene 80 15V	250	240	52-54	6	215	4	-	-	245	1.15	1.48	1.41	1.35	1.34
													1.16	1.48	1.42	1.36	1.35
												Avg	1.16	1.48	1.42	1.36	1.35
11.	FM5228	K	20 Indene 80 15V	250	240	52.54	5	215	6	-	-	245	1.14	1.48	1.42	1.31	1.31
													1.12	1.43	1.39	1.33	1.32
												Avg	1.13	1.46	1.41	1.32	1.32
12.	FM5228	L	40 Varcum 2 Oxalic 60 15V	-	-	-	5	225	2	-	-	260	1.16	1.42	1.39	1.31	1.31

TABLE 17 (cont.)

Material ID	Run No.	Solvent/Pitch Ratio %	Target Temp °F	Actual Temp °F	Visco-sity CPS	Evacu-ation Time Min.	Pres-sure psi	Pres-sure Hold Time Hrs.	Temp After Impreg °F	Visco-sity After Impreg CPS	Temp Immed. Upon Opening Lid °F	Specific Gravity Prior to Impreg	Specific Gravity After Impreg	Specific Gravity After Cure	Specific Gravity After Carbon.	Specific Gravity After Graphit.
13. FM5228	M	20 P3 80 15V	250	245	65	5	210	2	-	-	252 Avg	1.04 1.14 1.090	1.45 1.50 1.475	- -	- -	- -
14. EC260 Cortrol #1	N	20 Indene 80 15V	250	240	52	5	215	4	240	54	245	1.17	1.53	1.49	1.37	1.36
15. WCA/EC260 Nylon Scrim B-1	O	20 Indene 80 15V	250	240	54	5	225	4	245	52	245	1.17	1.42	1.39	1.32	1.31
16. FM5228 5-14-70 21436	P	20 Indene 80 15V	250	246	50-52	5	220	2	244	53	240 Avg	1.18 1.17 1.177	1.49 1.49 1.49	1.44 1.44 1.443	1.38 1.38 1.38	1.35 1.35
17. FM5228 5-14-70 21436	Q	25 Indene 75 15V	250	250	[illegible]-32	5	215	2	190	180	190 Avg	1.16 1.17 1.18 1.17	1.50 1.52 1.53 1.516		1.38 1.40 1.40 1.393	1.34 1.37 1.37
18. FM5228 5-14-70 21436	R	15 Indene 85 15V	250	245	80	5	220	2	-	-	200 Avg	1.14 1.14 1.14 1.14	1.46 1.46 1.46 1.46		1.35 1.35 1.35 1.35	1.32 1.33 1.32
19. FM5228 5-14-70 21436	S	20 P3 80 15V	250	250	33	5	205	2	205	130	220 Avg	1.17 1.17 1.17 1.17	1.50 1.53 1.54 1.523	1.43 1.46 1.47 1.453	1.35 1.36 1.37 1.36	1.34 1.36 1.36
20. FM5228 5-14-70 21436	T	25 P3 75 15V	250	260	50	5	220	2	250	65	- Avg	1.15 1.14 1.15 1.146	1.48 1.47 1.50 1.483	1.39 1.38 1.40 1.39	1.32 1.31 1.33 1.32	1.31 1.30 1.32
21. FM5228 5-14-70 21436	U	20 P3 80 15V	250	245	42-45	5	200	2	209	60	- Avg	1.14 1.13 1.14 1.136	1.47 1.46 1.54 1.49	1.42 1.41 1.47 1.433	1.33 1.33 1.31 1.323	1.33 1.32 1.31
22. FM5228 5-14-70 21436	V	15 P3 85 15V	250	250	155	5	215	2	210	355	210 Avg	1.17 1.17 1.17 1.17	1.50 1.49 1.50 1.496	1.46 1.45 1.47 1.46	1.35 1.35 1.35 1.35	1.34 1.34 1.34
23. FM5228	W	20 Indene 80 15V	225	223	75	5	220	2	202	100	202	1.16 1.15 1.15	1.50 1.49 1.48	1.45 1.43 1.43	1.35 1.31 1.31	1.32 1.30 1.30
24. FM5228	X	20 Indene 80 15V	275	280	17	5	230	2	231	63	234	1.18 1.18 1.17	1.45 1.47 1.46	1.31 1.33 1.31	1.27 1.29 1.27	1.27 1.28 1.27

TABLE 17 (cont.)

Material ID	Run No.	Solvent/Pitch Ratio %	Target Temp °F	Actual Temp °F	Viscosity CPS	Evacuation Time Min.	Pressure psi	Pressure Hold Time Hrs.	Temp After Impreg °F	Viscosity After Impreg CPS	Temp Immed. Upon Opening Lid °F	Specific Gravity Prior to Impreg	Specific Gravity After Impreg	Specific Gravity After Cure	Specific Gravity After Carbon.	Specific Gravity After Graphit.
25. FM5228	Y	20 P3	225	223	80	5	215	2	220	100	220	1.17	1.52	1.46	1.35	1.34
		80 15V										1.18	1.52	1.46	1.37	1.36
												1.18	1.52	1.46	1.36	1.35'
											Avg		1.520	1.460	1.360	1.350
26. FM5228	Z	20 P3	275	275	70	5	215	2	245	200	245	1.17	1.53	1.44	1.38	1.37
		80 15V										1.17	1.55	1.44	1.38	1.38
												1.18	1.54	1.44	1.39	1.38
											Avg		1.54	1.44		
27. FM5228	AA	20 Indene	250	245	50	5	150	2	253	50	-	1.11	1.48	1.39	1.32	1.30
(21436)		80 15V										1.11	1.47	1.40	1.31	1.30
C-2 5-21-70												1.11	1.47	1.40	1.32	1.30
28. FM5228	BB	20 Indene	250	-	-	5	50	2	253	50	-	1.10	1.44	1.37	1.32	1.31
(21436)		80 15V										1.12	1.45	1.39	1.34	1.33
C-2 5-21-70												1.13	1.46	1.40	1.34	1.33
29. FM5228	CC	20 P3	250	250	90				250	70		1.12	1.48	1.43	1.32	1.32
(21436)		80 15V											1.48	1.42	1.31	1.30
C-2 5-21-70											Avg		1.48			
30. FM5228	DD	20 P3	250	250	90				250	70		1.11	1.49	1.43	1.32	
(21436)		80 15V										1.11	1.48	1.42	1.32	1.31
C-2 5-21-70												1.12	1.49	1.43	1.32	1.31

fabric is to be used for the liner construction of the nozzle extension. Woven Structures has developed techniques for weaving eight layers of fabric with simultaneous incorporation of the tufting so the weaving is completely automated. Earlier tufting work was accomplished as a hand operation. The feasibility of this weaving technique has been demonstrated by the weaving of a panel 12-in. wide by 25-ft long, using triple end yarn for the tufts, 1/8-in. spacings between the tufts, and a tuft height of 0.25 in. This fabric is presently at U.S. Polymeric Corporation, Santa Ana, California, where techniques are being developed for impregnating it with USP-39 resin.

The second, specially woven graphite fabric that has been developed is to be used for fabricating the honeycomb cells. This fabric has been designed to provide a cell-wall thickness of 0.050 in. after graphitization. In addition, white Refrasil fibers severed with fine copper wire have been incorporated into the root fibers for ease of visual identification. The bonding of the cell-wall fabric to the liner fabric is dependent upon the removal of the Refrasil fibers in order to expose fill fibers which interlock with fibers extending from the tufted three-dimensional liner material.

Thirty ft of this fabric design has been woven with three parallel roots spaced 3 in. apart along the length of the fabric. This material has been impregnated with USP-39 resin at U.S. Polymeric Corporation.

G. TURBOPUMP MATERIALS

1. Ti 5Al-2.5Sn (ELI)

Additional cryogenic tensile and fracture toughness tests were performed. Compact tension fracture-toughness tests were made in liquid hydrogen using chevron-notched precracked specimens removed from two 14-in. diameter, 6-in. thick pancake forgings produced by the Carlton Forge Works. Tensile and compact tension (WOL) specimens were removed from locations and orientations shown in Figure 6. The location and orientation of liquid hydrogen flexure fatigue specimens currently in test at General Dynamics/ Convair are also shown.

Results of tensile tests are presented in Table 18. The room temperature, liquid nitrogen and valid liquid hydrogen tensile results were statistically combined with the tensile results of a previously tested, larger titanium forging (17-in. in diameter and 10-in. high produced by the Wyman-Gordon Company). These earlier tensile data were reported in ANSC Report, S131-PR2. However, because of three invalid test results of Carlton Heat 294245 and the inability to determine yield strength in a fourth test, this heat was not used in the analyses. The remaining data were analyzed and conformed to the most recent criteria for category "A" data. A summary of the tensile design-allowables, as published in DRM M-4B, Supplement 1, is presented in Table 19.

Compact tension fracture-toughness tests were made using chevron-notched, precracked specimens removed from each of the two Carlton forgings as shown in Figure 6. Precrack flaw growth was predominantly radial and driven by tangential loading.

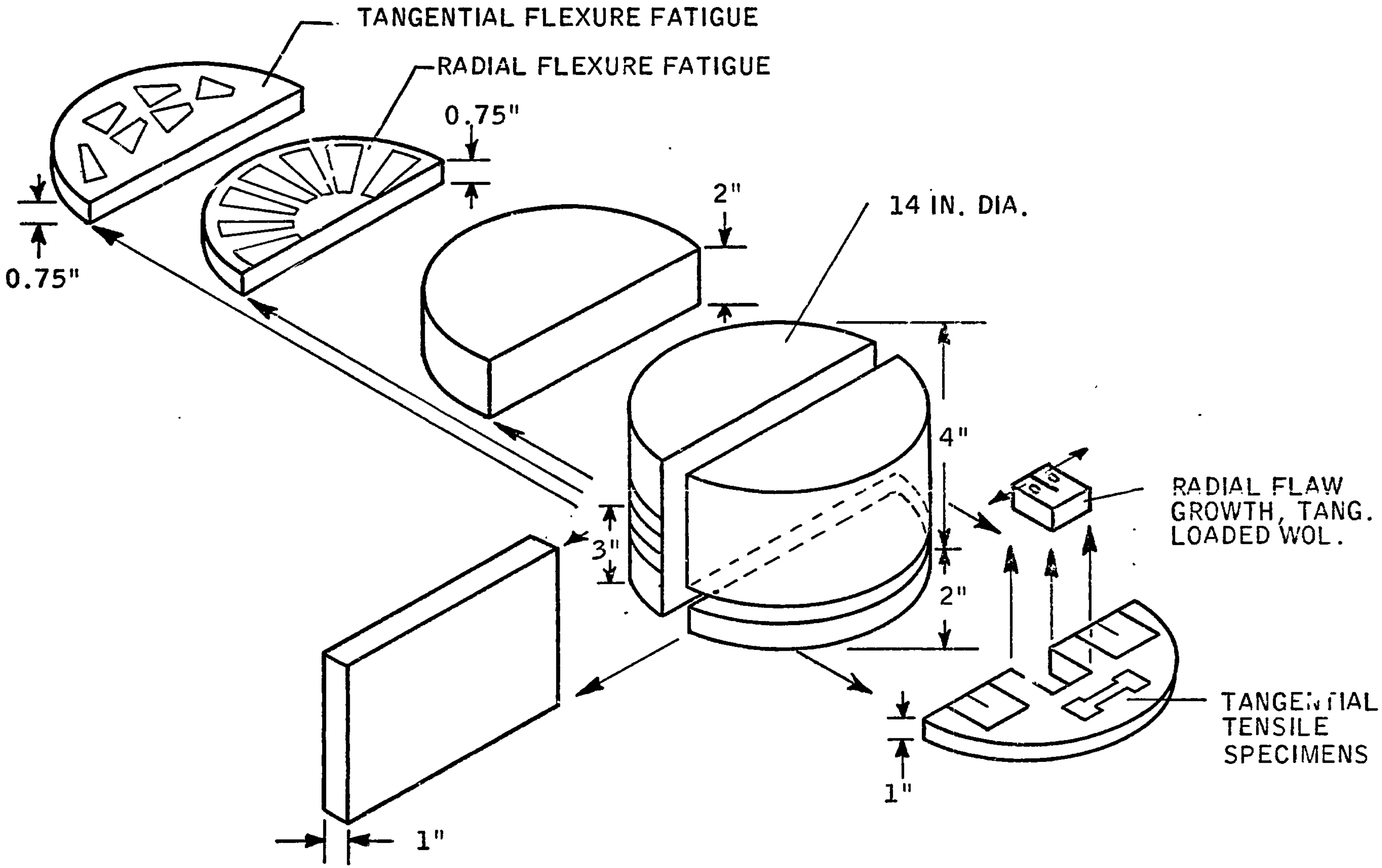


Figure 6 - Specimen Location and Orientation, Ti 5Al-2.5Sn (ELI) Forgings 14-in. Diameter, 6-in. Thick, Carlton Forge Works

TABLE 18

RT AND CRYOGENIC TENSILE STRENGTH OF
Ti 5Al-2.5Sn (ELI) CARLTON FORGINGS

Test Temperature

Heat	RT				LN_2 (-320)					LH_2 (-423)				
	UTS	TYS	% EL	% RA	UTS	TYS	% EL	% RA	E	UTS	TYS	% EL	% RA	E
Carlton Forge	117	109	18	36	192	182	12	29	20.6	213	187	11	16	19.7
14-in. dia x	117	110	19	35	191	178	12	24	16.5	212	196	9*	11	19.1
6-in. High	114	106	17	31	192	179	13	24	18.9	211	184	16	19	18.8
Heat 293722	116(R)	106	14	32	187	172	13	24	17.3	208	182	14	15	19.3
	117(R)	112	16	31										
	117(R)	108	16	31										
Carlton Forge	121	113	15	29	188	174	9	22	19.6	205	184	5*	11	20.2
14-in. dia x	118	112	18	33	187	174	9	22	19.1	218	-	15	17	-
6 in. High	121	114	14	31	189	174	8	26	21.8	208	194	7*	10	19.7
Heat 294245	117(R)	108	14	26	184	171	11	28	18.9	211	187	15	18	20.8
	117(R)	110	16	25						210	180	13*	11	21.3
	117(R)	110	12	25										

NOTE: All strengths are in ksi; elongation is in 1 in. (4D). All testing in tangential direction except where noted.

*Test invalid: failure occurred in gage length punch mark.

TABLE 19

CATEGORY "A" TENSILE DESIGN ALLOWABLES FOR
Ti 5Al-2.5Sn (ELI) PANCAKE FORGING MATERIAL

(Source: DRM M-4B, Supp. 1, dated 7-28-70)

	RT Radial	RT Tangential	-320°F Tangential	-423°F Tangential
F_{tu}, ksi	108	108	178	202
F_{ty}, ksi	98	98	163	179
% Elong	10.5	10.5	4.2	8.1

Results of fracture-toughness tests in liquid hydrogen are presented in Table 20. The data met the criteria contained in ASTM Standard E399. Although no pronounced anisotropy was noted, there appeared to be a toughness gradient in the axial direction, as indicated by the higher toughnesses of specimens 6 and 7 of forging C2A Ti (Heat 293722), located directly below specimens 2 and 3 in the forging. Slightly-coarser-appearing fracture surfaces of specimens 6 and 7 may have been caused by overheating during sectioning of the forging and specimen machining.

A preliminary statistical analysis of current Carlton data and the previously reported (S131-PR2) liquid hydrogen Ti 5Al-2.5Sn (ELI) fracture-toughness data was made. Statistical heterogeneity was found between the means of the old and present data. Therefore, only the present Carlton data (shown in Table 18) was used to calculate an interim statistical fracture-toughness value. The Wyman-Gordon forging fracture-toughness values, averaging only 53.3 ksi-in.$^{1/2}$, were eliminated because of the larger (17 x 10) size of the forging, compared to what will ultimately be procured for impeller forgings. The remaining Carlton forging data were analyzed and resulted in the following values that were applicable to thicknesses of $\leq$ 2:

$$\bar{X}_{K_{IC}} = 68.3 \text{ ksi-in.}^{1/2},$$

$$S_{K_{IC}} = 3.2 \text{ ksi-in.}^{1/2};$$

for N = 10, $$K_{IC\ 99/95} = 55.7 \text{ ksi-in.}^{1/2},$$

and $$\sigma_{nc} = 214{,}000 \text{ psi.}$$

TABLE 20

LIQUID HYDROGEN (-423°F) PLANE STRAIN FRACTURE TOUGHNESS TEST RESULTS IN Ti 5Al-2.5Sn (ELI) FORGED MATERIAL

Forging Source	Spec No.	Predominant Flaw Growth Direction	Load Rate ksi-in.$^{1/2}$/min	a/W	K_Q ksi-in.$^{1/2}$	K_{IC} ksi-in.$^{1/2}$
Carlton Heat 294245	C1ATiR-1	Tangential		Lost Curve - No Data		
	-2	Tangential	44.6	0.531	66.6	66.6
	-3	Radial	41.4	0.507	66.3	66.3
	-4	Tangential	43.3	0.522	61.1	61.1
	-5	Tangential			70.8	70.8
	-6	Tangential			69.8	69.8
	-7	Radial			69.8	69.8
	-8	Tangential			70.0	70.0
Carlton Heat 293722	C2ATiR-1	Tangential	41.5	0.508	67.0	67.0
	-2	Tangential	41.2	0.505	82.7	-
	-3	Radial	43.6	0.524	76.7	-
	-4	Tangential	41.3	0.506	71.6	-
	-5	Tangential			71.2	71.2
	-6	Tangential			90.6	-
	-7	Radial			105.2	-
	-8	Tangential			70.0	70.0
		$\overline{X}$			-	68.3
		S				3.2
		$\overline{X}$ - KS				55.7

Since the net critical stress exceeds the liquid hydrogen yield-strength-allowable of 179,000 psi, the material would be classified as ductile for liquid hydrogen applications. Further data are needed, however, to achieve category "A" data.

H. PRESSURE VESSEL MATERIALS

1. Fatigue Tests

Rotating-beam fatigue tests at 150°F were conducted on material from 7039-T63 subscale pressure-vessel forging Heat AA. The specimens were sectioned from the cylindrical subscale forgings in an axial orientation.

Fatigue specimens were fabricated in accordance with ANSC Drawing 1137588. The specimens had a minor diameter of 0.300 in., a zero-gage-length reduced section radius of 9.875, and an overall length of 5.31 in. Testing was accomplished on a Krause pure-bending-type rotating-beam fatigue machine. The specimens were tested at a test frequency of 8000 cycles/min.

Eleven specimen levels were investigated in the range of 22.0 to 42.5 ksi. Fifty specimens were tested for all stress levels. Remote specimens (i.e., specimens which were tested to 10^7 cycles without failure) were retested to failure at stress levels of 35, 40, and 42.5 ksi.

The results of these fatigue tests are tabulated in Table 21 and presented graphically in Figure 7. These experimental data indicate the fatigue limit for 7039-T63 at 10^7 cycles is 23.0 ksi. Alcoa properties data for 7000-series aluminum alloys indicate a 5 x 10^8 cycle fatigue limit of 22 ksi which is in close agreement with the experimental data.

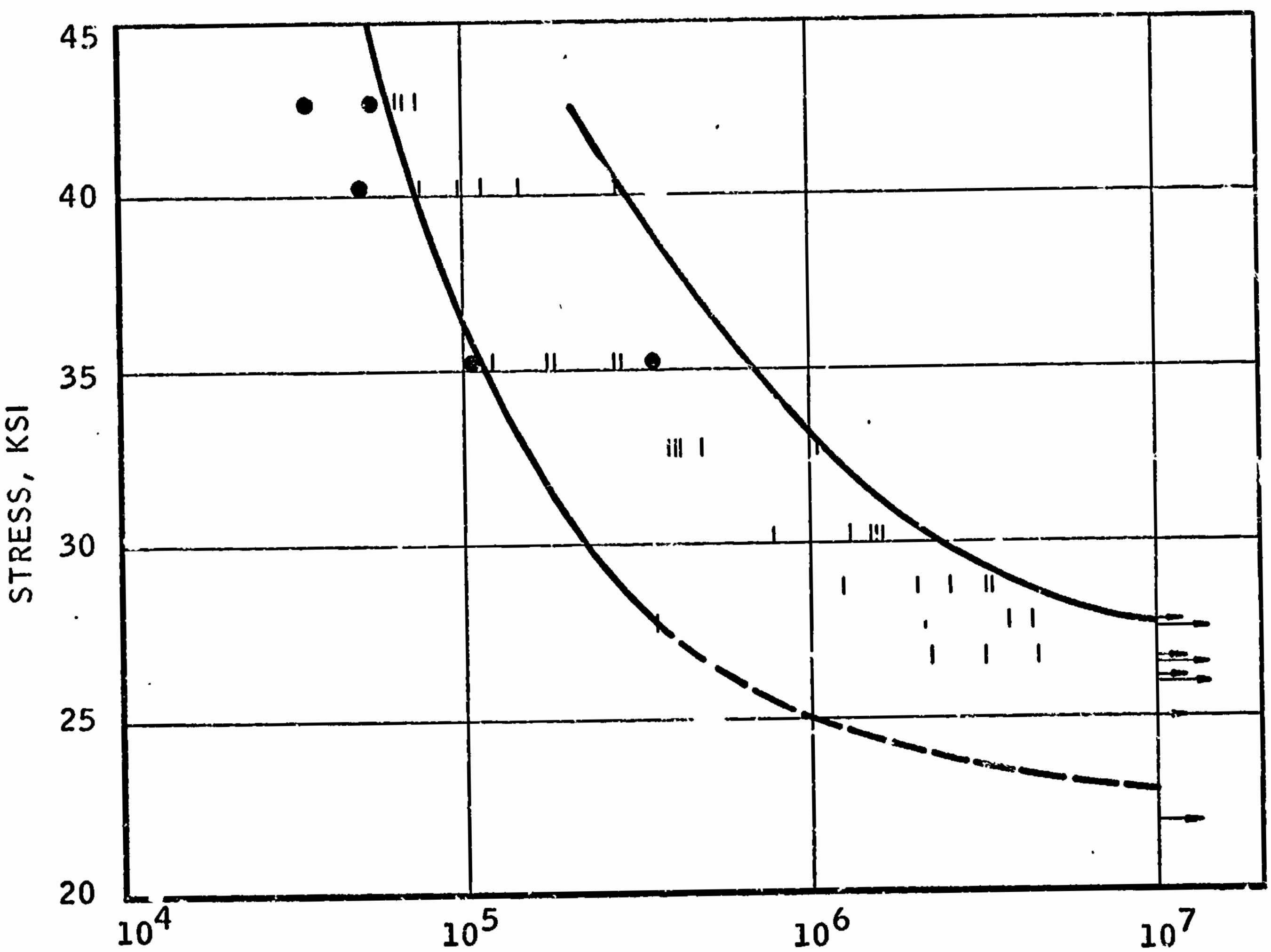
2. Stress Corrosion

Field and laboratory stress corrosion testing of pressure vessel candidate materials in CY 1970 demonstrated: (1) absence of stress-corrosion susceptibility in aluminum alloy 6061 at the 35-ksi stress level; (2) the superiority of the T63 heat treatment over the T6 heat treatment for stress-corrosion resistance of aluminum alloy 7039; (3) benefit of shot-peening

TABLE 21

ROTATING BEAM FATIGUE TESTS OF AA 7039-T63, HEAT AA, AXIAL ORIENTATION TEST TEMPERATURE 150°F

Stress Level	Cycles 1	2	3	4	5	6	Retests 7	8
42.5	62,900	75,500	63,900	63,100			54,600	36,300
40.0	113,000	144,100	280,000	78,900	99,800		50,600	-
35.0	279,800	120,600	184,300	284,000	174,000		108,900	366,100
32.5	400,700	1,021,800	411,200	407,100	484,000			
30.0	795,600	1,594,900	1,548,800	1,310,000	1,550,000			
28.75	1,550,000	3,380,000	3,400,000	2,590,000	1,250,000			
27.5	10^7	4,370,000	3,760,000	10^7	360,000	2,160,000		
26.5	10^7	4,650,000	10^7	2,280,000	3,250,000			
26.0	10^7	10^7	4.4×10^7					
25.0	10^7							
22.0	10^7							



LEGEND:

I — SINGLE TEST

● — TESTED TO 10^7 CYCLES AT LOWER STRESS LEVEL AND RETESTED AT INDICATED STRESS

Figure 7 - Rotating Beam Fatigue Test, AA7039-T63, Heat AA, Axial Orientation, Test Temperature of 150°F

and coating protection in lengthening time-to-failure of aluminum alloy 7039 in stress-corrosion exposure; and (4) an apparent safe operating stress of 15 ksi for 6 months exposure of aluminum alloy 7039-T63. These observations were reported in previous CY 1970 materials quarterly reports. In this quarter, laboratory results indicated that thermal-control candidate coatings can significantly reduce stress-corrosion sensitivity of 7039-T63. A corrosion-control plan* for a 7039-T63 pressure vessel was prepared detailing the methodology required to prevent stress-corrosion cracking.

a. Field Tests

Aluminum alloy 7039 stress-corrosion specimens placed in the Kennedy Space Center (KSC) ocean-beach test rack were examined weekly for the period 1 June through 1 September. Failures during this period (tabulated in Table 22) included: (1) at the 20 ksi level, one 7039-T6 flange specimen, two 7039-T63 flange specimens, and one 7039-T63 wall specimen; (2) one shot-peened 7039-T63 flange specimen at the 45-ksi level; (3) one A612-metallized 7039-T63 specimen at the 25-ksi level; and (4) one A612-metallized and epoxy-polyamide-painted specimen at the 45-ksi level.

A summary of the ocean-beach exposures of uncoated 7039-T63 specimens is given in Figure 9. Exposure times for these specimens range from 380 to 674 days. It should be noted from the figure that only one of 18 specimens failed at the 20-ksi level during 6-months exposure while there were no failures of 15 specimens during 12 months at the 10-ksi level. This type of behavior strengthens the previously stated estimate of 15 ksi being a safe stress limit for six-month ocean-beach exposure (see ANSC Report S131-PR3).

Fifty-three additional stress-corrosion specimens were placed on the ocean beach rack 5 August. These specimens were exposed to determine: (1) the heat-to-heat variability of stress-corrosion behavior of 7039-T63 in the 10-25 ksi stress range; and (2) effect of thermal-control coatings on the stress-corrosion behavior of 7039-T63.

* Memo No. 70-328, A. L. Armitage from: M. L. Murchison, Corrosion Control for 7039-T63 pressure vessel dated 31 August 1970.

TABLE 22

FAILED SPECIMENS AT KENNEDY SPACE CENTER
FOR PERIOD 1 JUNE THROUGH 1 SEPTEMBER 1970

Material	Location	Date in Exposure	Type Specimen	Stress ksi	Time to Fail (Days)	Failure Ratio
7039-T6	PV Forged Flange	10/16/68	Tensile	20	674	4/5
7039-T63	PV Forged Flange	10/16/68	Tensile	25	660	1/2
7039-T63 (Shot Peened)	PV Forged Flange	5/1/69	Tensile	45	361	2/5
7039-T63	PV Forged Flange	5/1/69	Tensile	20	399	1/3
7039-T63	Forged Wall	8/6/69	Tune Fork	20	364	2/5
7039-T63 (Metallized)	PV Forged Flange	8/6/69	Tensile	25	338	5/5
7039-T63 (Metallized and Painted)	PV Forged Flange	8/6/69	Tensile	45	370	2/5

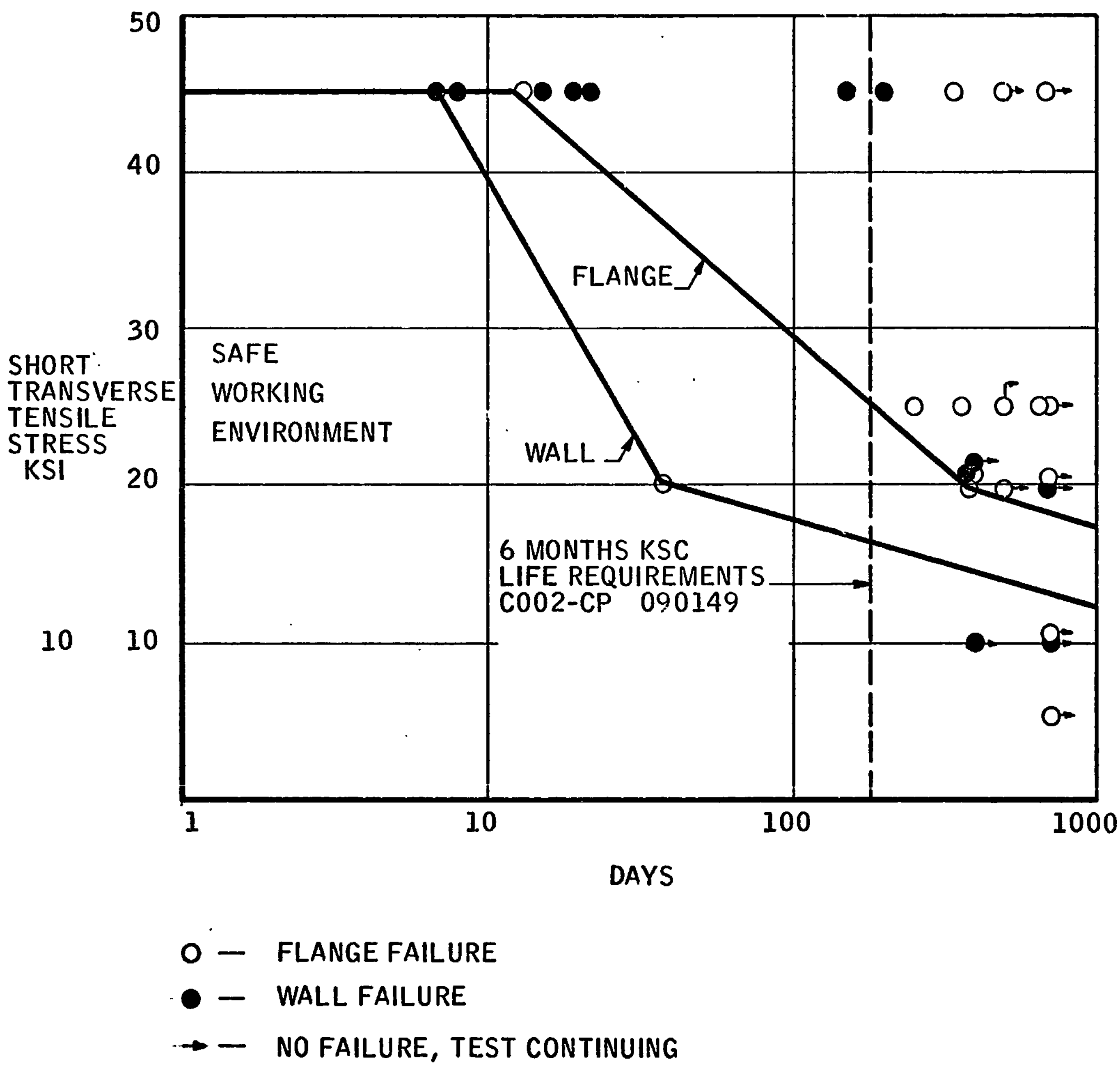


Figure 8 - Results of Stress Corrosion, Exposure of AA7039-T63 On the Beach at the Kennedy Space Center

The exposure conditions of all specimens are tabulated in Table . All are tuning-fork specimens cut from the short-transverse direction of 7039-T63 wall forgings. Specimens from Heats AA and BB were added to the program to more closely define the behavior of 7039-T63 in the low stress range.

Twenty tuning-fork specimens from Heat AA were coated with thermal-control candidates and placed at KSC. Ten specimens were plasma coated with alumina (Al_2O_3) after a grit-blast surface preparation. Ten specimens were coated with Z-93, a proprietary coating of the Illinois Institute of Technology (Z-93 is composed of zinc oxide with a potassium-silicate binder). A more detailed description of these coatings is contained in ANSC Report S131-PR3.

b. Laboratory Tests

Fifty-eight 7039-T63 tuning-fork specimens were placed in exposure at the Sacramento facility. Forty-nine specimens were exposed in a 5% salt-fog cabinet and nine specimens placed in indoor atmosphere exposures. Results of these exposures to 1 September are given in Table 24. Significance of the laboratory results is illustrated in Figures 9 and 10. Figure 9 depicts the stress-corrosion behavior of 7039-T63 as a function of stress and illustrates the importance of reducing residual stresses in a 7039-T63 pressure vessel: i.e., below 20 ksi, a small decrease in stress means a very large increase in the stress-corrosion life of the material. Figure 10 compares the specimen life of 7039-T63 as functions of atmosphere and surface treatments. This comparison illustrates two other aspects of stress-corrosion control of 7039: (1) limiting exposure to innocuous atmospheres; and (2) stress-corrosion-prevention qualities of the thermal-control system which is required for the pressure vessel. Al_2O_3 is a candidate coating for thermal control of the pressure vessel. Grit blasting is the preferred surface treatment of the basis metal for Al_2O_3 application.

TABLE 23

AA 7039-T63 STRESS-CORROSION SPECIMENS
PLACED IN TEST AT KSC, 5 AUGUST 1970

Condition	Stress, ksi	No. Specimens
AA 7039-T63	25	4
Uncoated, Heat AA	20	5
	15	5
	10	5
AA 7039-T63	25	5
Uncoated, Heat BB	20	5
	15	5
AA 7039-T63	45	5
Plasma Sprayed	25	5
Al_2O_3 Surface, Heat AA		
AA 7039-T63	45	5
Surface Coated with	25	5
Z-93, Heat AA		

Test Conditions:

1. All specimens are tuning-fork specimens from short-transverse orientation of forged wall.
2. Specimens placed in rack, 300 ft from high-tide mark.

TABLE 24

RESULTS OF 5% NEUTRAL SALT EXPOSURE OF AA 7039-T63 SPECIMENS

Material and Condition	Stress ksi	Time to Failure Hours	Failure Ratio	Exposure Time for Unfailed Specimens, Hours
7039-T63, Heat AA Bare	45	72, 72, 72, 72	4/4	-
	25	196, 216, 336, 384	4/4	-
	20	568, 952, 952, 1296, 1744	5/5	-
	15	1288, 1936, 2356	3/5	2572
7039-T63, Heat AA, Grit Blasted with Al_2O_3, 80 lb Pressure	45	640, 736, 1376, 1600	4/4	-
	25	1744, 1744, 1800	3/5	1920
7039-T63, Heat AA Grit Blasted and Plasma Sprayed with Al_2O_3	45	568, 640	2/5	2328
	25	NF	0/5	2328
7039-T63, Heat AA, Al_2O_3 Coated, Scratched	45	NF	0/4	1328
7039-T63, Heat AA, Al_2O_3 Coated, Scratched, Coated with Textilana #2	45	NF	0/3	1328
7039-T63, Heat AA, Al_2O_3 Coated, Scratched, Coated with Textilana #4	45	NF	0/3	1328
7039-T63, Heat AA, Grit Blasted and MgO Sprayed	45	NF	0/2	2280
7309-T63, Heat AA*, Exposed to Shop Atmosphere, Bldg. 2004	45	NF	0/3	2424
7039-T63, Heat AA*, Exposed to Office Atmosphere, Bldg. 2019	45	NF	0/2	2280
	25	NF	0/2	2280
	15	NF	0/2	2280

*Indoor Atmosphere Exposures.

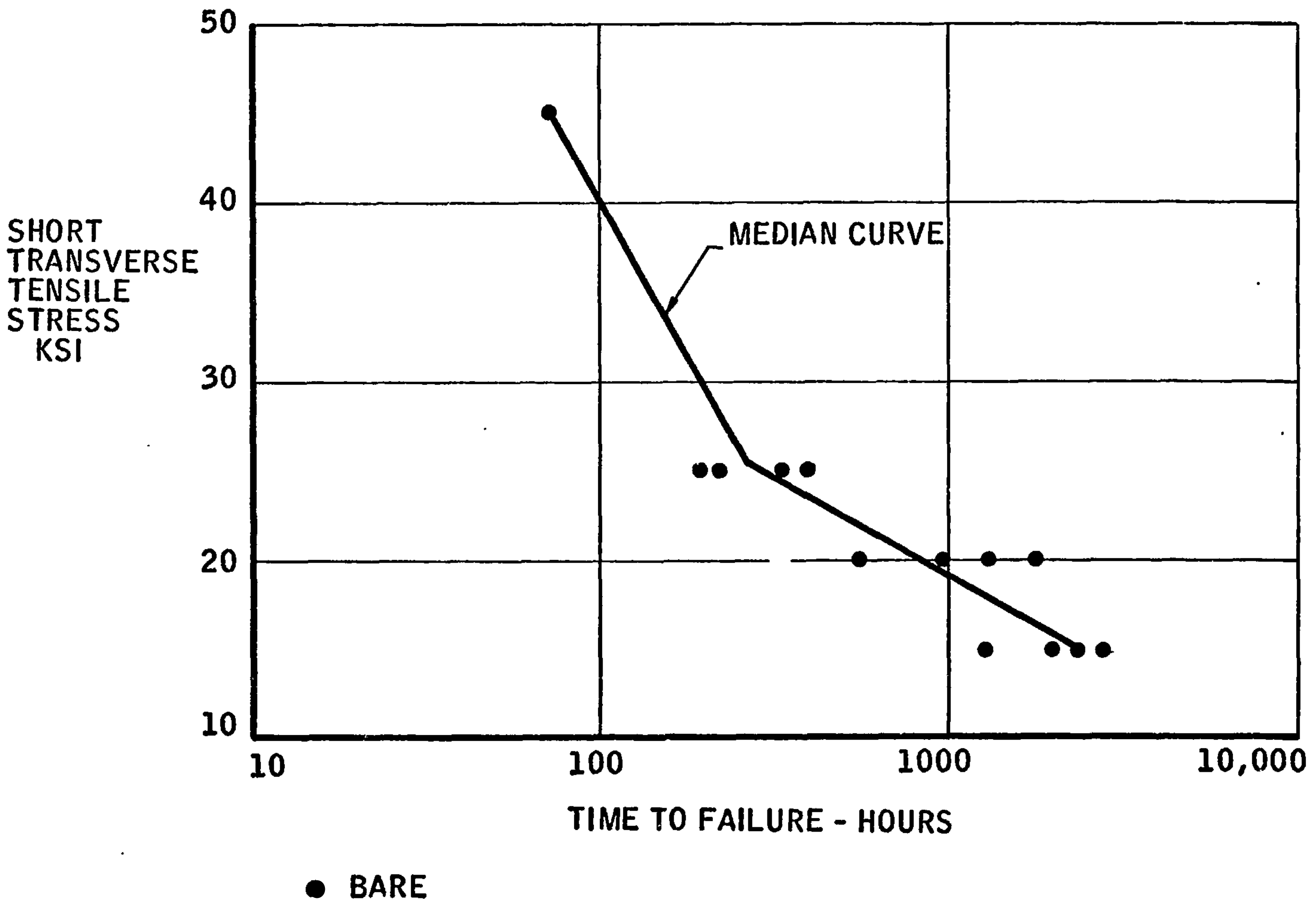


Figure 9 - Salt Cabinet Exposure of AA7039-T63, Heat AA, Specimens to 5% Salt Spray

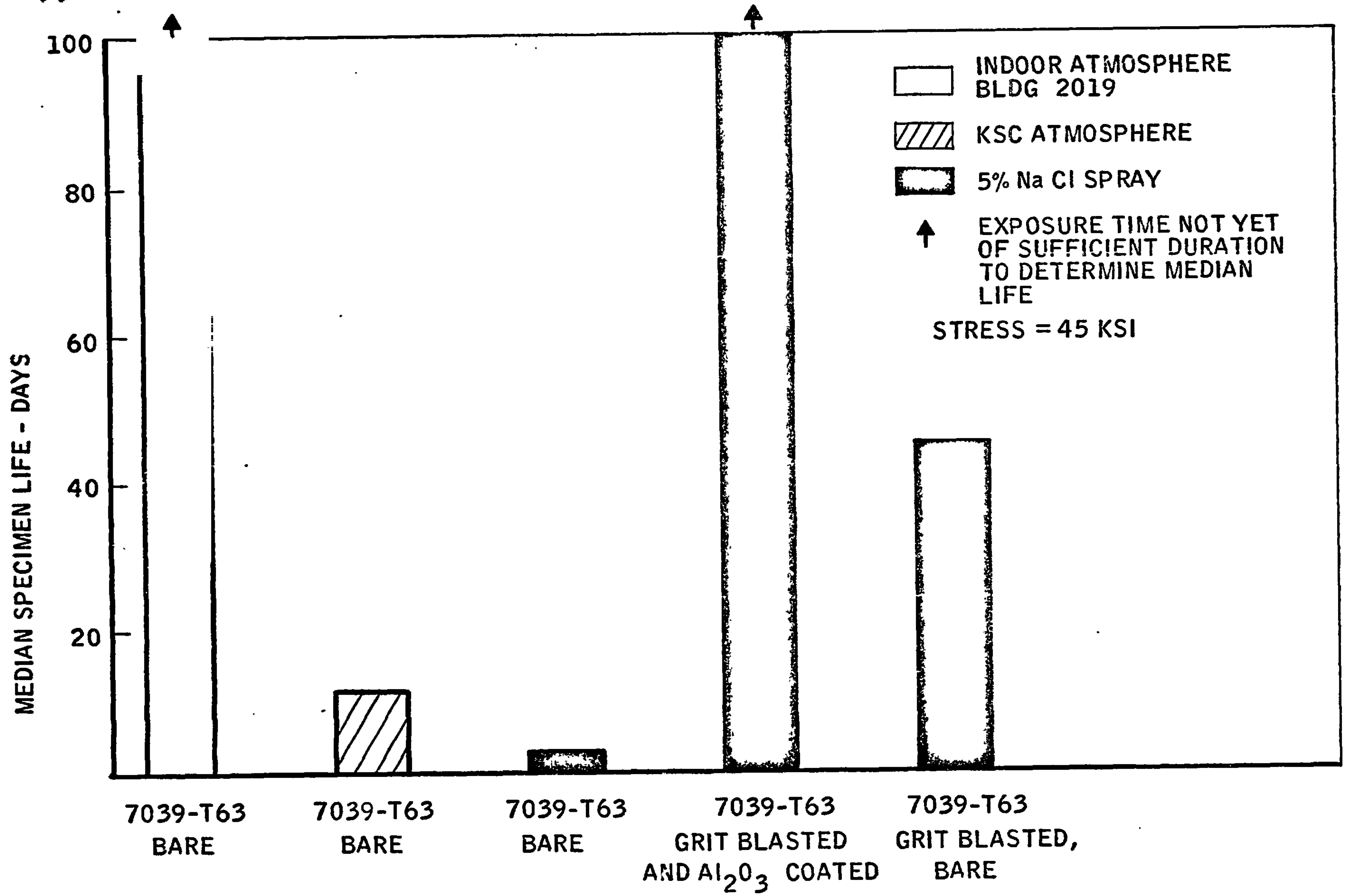


Figure 10 - Significance of Laboratory Stress-Corrosion Tests

c. Corrosion Control for Aluminum Alloy 7039-T63 Pressure Vessel

Detailed corrosion control measures for a 7039-T63 pressure vessel were prepared and are summarized as follows:

Test results show that 7039-T63 is susceptible to stress-corrosion cracking in the short-transverse direction with a threshold of 15-ksi sustained tensile surface stress projected for a six-month exposure period. Residual-stress measurements indicate a maximum radial tensile stress in the flange of 20 ksi, indicating a potential failure area. Exposure of short-transverse (i.e., end-grain) material by intersecting forging grain flow line, machining bolt holes, and seal glands (accompanied by tensile residual stresses generated from heat-treat quench, assembly, and seal welds) could cause stress-corrosion cracking.

Prevention can be implemented by: (1) designing to minimize end-grain exposure; (2) minimizing and controlling residual stress in the critical area; and (3) applying protective coatings. End-grain exposure will be minimized by forming the vessel configuration to forge-flow capability. Minimizing section thickness by rough machining the final configuration prior to heat treating would be implemented to minimize residual stress. Thermal coatings can be utilized for protection of all surfaces except seal flange surfaces which are not compatible with these coatings. These surfaces are identified as the most critical areas and may require cold planishing for generation of surface compressive stresses for residual stress control, followed by strict environmental control during fabrication and assembly. Prevention limitations are attributed to coating nonadherence and the presence of high, undetectable residual stresses.

3. Fracture Toughness

a. Introduction and Objectives

Previous fracture toughness testing of 7039-T63 material (Heat AA) to establish minimum specimen thickness for valid K_{IC} values at room temperature and -320°F was reported in ANSC Report S131-PR2. The objective of further investigation was to determine effects of:

1. NERVA operating temperature regime.
2. Anisotropy of ring-forged and extrusion-forging processes.
3. Major alloy chemistry variations.
4. 3/1, 6/1, and 12/1 forge-reduction ratios (7039-T63 and 6061-T6 step-hand forgings).

Critical crack size upon cryogenic temperature.

b. Summary of Results

Three heats of 7039-T63 subscale pressure-vessel forgings, a 6061-T6 hand-step forging, and a 7039-T63 hand-step forging were evaluated for plane-strain fracture toughness (K_{IC}) values utilizing compact tension specimens and testing over the NERVA operating range (-320°F, -100°F, room temperature) in accordance with ASTM-recommended procedures. Chemistry, temperature, and forging anisotropy effects were studied for subscale flange (ring-roll-forged), chamber wall (ring forged and extruded), and 3/1, 6/1, and 12/1 hand-forged reduction ratios.

Flange material results showed low critical stress intensity (K_{IC}) values of 10 ksi$\sqrt{in.}$ in the axial direction for the high-chemistry heat. The other directions were above 15 ksi$\sqrt{in.}$ with the low-chemistry heat showing superior (i.e., higher) values over the nominal chemistry heat. The cylinder-wall material showed values above 24 ksi$\sqrt{in.}$ mean except for the short-transverse direction where values decreased to as low as 12 ksi$\sqrt{in.}$ at -320°F. The axial orientation exhibited a 50% higher increase in K_{IC} value or K_Q over that of the flange section material, indicating beneficial effects from the supplemental extrusion process. The circumferential orientation values were about equivalent for both flange and cylinder-wall material, indicating equivalent ring-forging effects in each section. For all 7039-T63 material tested, room temperature values were decreased by the low temperature exposure.

The 7039-T63 step forgings results at -320°F indicated that the long-transverse-oriented specimens had the highest mean K_{IC} (above 24 ksi$\sqrt{in.}$). Longitudinal oriented specimens had values above 20 ksi$\sqrt{in.}$, except the 12/1 reduction which was lower (17 ksi$\sqrt{in.}$). Short transverse specimens were lowest with values as low as 15 ksi$\sqrt{in.}$ The increase of forge reduction had little effect upon the magnitude of trend of long-transverse or longitudinal fracture-toughness data. However, the longitudinal values of the 12/1 reduced material were some 6 to 8 ksi in. lower than corresponding 6/1 and 6/1 values. The short-transverse values showed improvement with higher reduction increasing from 14 ksi$\sqrt{in.}$ at a 3/1 reduction to 17 ksi$\sqrt{in.}$ at 12/1 reduction. All values decreased as a result of low temperature exposure which was consistent with other 7039-T63 material tested.

The 6061-T6 step-forging results showed an opposite trend with increased K_{IC} occurring at -320°F compared with corresponding room temperature values. The long-transverse values were highest for all reductions tested. All values were above 26 ksi$\sqrt{in.}$ at room temperature and above 35 ksi$\sqrt{in.}$ at -320°F, indicating a completely ductile material. No apparent benefit was realized from the increased forge reduction.

Critical-flaw-size calculations for subscale forgings indicated a minimum flaw size of a = 0.027 in. and 2C = 0.14 for a part-through crack and 2a = 0.065 and 2C = 0.16 for an internal flaw in two principal directions (circumferential and axial) for both low- and nominal chemistry heats. The high-chemistry heat material tolerated a much shorter flaw size, indicating inadequate cryogenic toughness. Short-transverse values were also low, but were less significant because the short transverse is not a principal stress direction for pressure-vessel application.

c. Material and Specimen Orientation

Subscale pressure-vessel forgings of three different major alloy chemistries (low BB heat; normal AA heat; high CC heat) as previously described were investigated to determine temperature, chemistry, and anisotropy effects. The forgings were of the same configuration with the flange being ring-roll-forged with a portion of the flange extruded to form the wall section. The flaw-stress orientations investigated for the flange and wall section, shown in Figures 11 and 12, respectively, were:

1. Flange

Nomenclature

RC - Radial-orientated flaw driven by circumferential stress.

RA - Radial-orientated flaw drive by axial stress.

CR - Circumferential-orientated flaw driven by radial (short-transverse) stress.

2. Wall Section

Nomenclature

CA - Circumferential-orientated flaw driven by axial stress.

RC - Radial- (short-transverse) orientated flaw driven by circumferential stress.

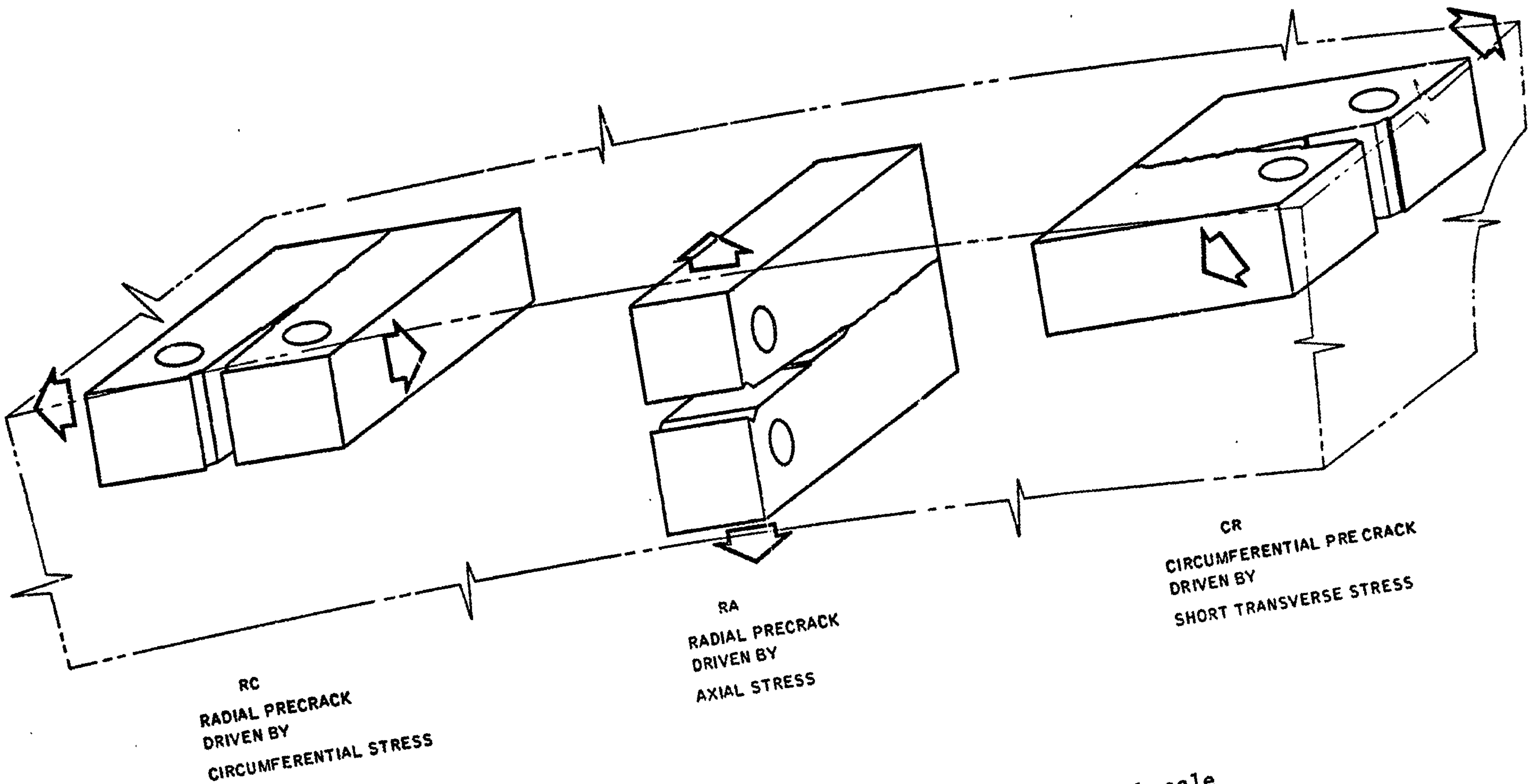


Figure 11 - Specimen Orientation for AA7039-T63 Subscale Pressure Vessel Forging Flange Section

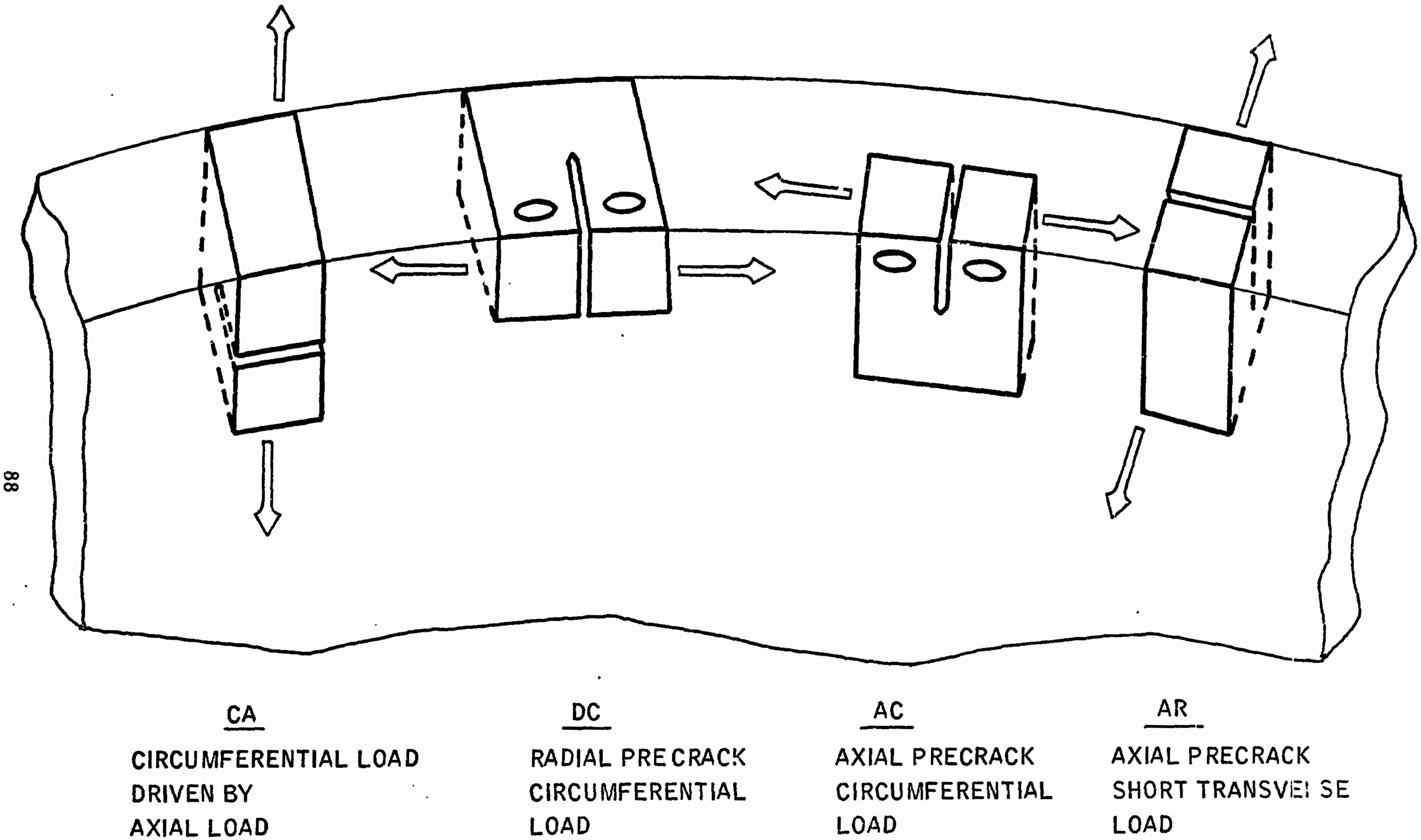


Figure 12 - Specimen Orientation For AA7039-T63 Subscale Ring Forging Chamber Section

AC - Axial-orientated flaw driven by circumferential stress.

AR - Axial-orientated flaw driven by radial (short-transverse) stress.

AC orientation is equivalent to axial flow with hoop stress that is most critical for pressure-vessel application.

Step-hand forgings of 7039-T63 and 6061-T6 were investigated for forge-reduction effects and were fabricated by identical forging practice to obtain ratios of 3/1, 6/1, and 12/1 as previously described in ANSC Report S131-PR2. Flaw-stress orientations investigated, shown in Figure 13, include: (1) LT-L, long-transverse-orientated flaw driven by longitudinal stress; (2) L-LT, longitudinal-orientated flaw driven by long-transverse stress; and (3) SL-LT short-transverse-orientated flaw driven by long-transverse stress.

d. Test Methods and Deviations

Compact tension specimens were used for determining the plane-strain critical stress intensity (K_{IC}). The specimens were designed and tested in accordance with the recommendations of the ASTM E-24 Fracture Toughness Committee*. The following deviations to the recommended test-method criteria for fatigue precracking were utilized to reduce occurrence of tunneling (i.e., irregular crack length through a section) and reduce fatigue time:

1. Precrack length was required to be greater than 0.05 length from the tensile load line to the precrack tip (i.e., instead of longer specimen edge-to-precrack tip length).

2. Precrack stress-intensity limit was increased from 0.5 K_{IC} to 0.6 K_{IC}.

* "Proposed Method of Test for Plane-Strain Fracture Toughness of Metallic Materials," ASTM Std. No. 399, May 1969.

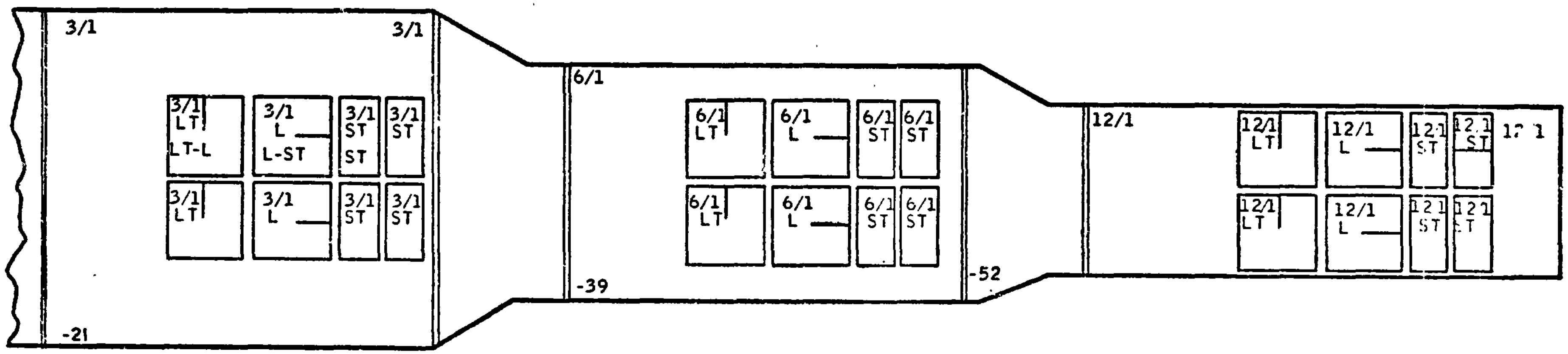


Figure 13 - Specimen Orientation (Tension) For AA7039-T63 and AA6061-T6 Hand-Step Forgings

The following code was applied to denote significance of critical stress-intensity values at fracture:

1. K_{IC}: Test values conforming to all ASTM - recommended criteria including precrack deviations listed above.

2. K_{IC}*: Test values conforming to all ASTM - recommended criteria as in (1) above with the exception that the theoretical specimen thickness as defined by $B < 2.5 (K_{IC}/\sigma_{YS})^2$ was not met. This applied to specimens of insufficient material thickness such as the short-transverse loaded wall specimens.

3. K_Q: Test values not conforming to one or more ASTM test criteria, other than those noted above.

K_{IC}* values are considered valid for a 7039-T63 thickness of ≥ 0.5 at -320°F and >0.62 at room temperature (as reported in ANSC Report S131-PR2) where it was determined that $K_{IC}* < K_{IC}$ for $B < 2.5 (K_{IC}/\sigma_{YS})^2$.

K_{IC} was substituted for K_Q where it was found that the K_Q value was the same as a valid K_{IC} plane-strain stress-intensity value under the same test conditions. The most conservative classification always will be used for combining data to perform statistical analysis.

e. Test Results

(1) Subscale Forgings

(a) Flange Section

Test results are listed in Tables 25 and 26 and plotted in Figure 14 to show the effect of anisotropy and the effects of chemical composition as a result of test temperature. Because

TABLE 25

ROOM-TEMPERATURE FRACTURE-TOUGHNESS RESULTS OF 7039-T63 ALUMINUM SUBSCALE RING FORGING (FLANGE SECTION)

Specimen No.	Thickness (B) in.	Fatigue Crack Parameters: $K_{initial}$ (a) ksi-in.$^{1/2}$	Fatigue Crack Parameters: K_{final} (b) ksi-in.$^{1/2}$	Deviation from ASTM Recommended Practice, Fatigue Crack Length (c)	(d)	(e)	(f)	Load Rates ksi-in.$^{1/2}$	a/W	Stress Intensity K_q ksi-in.$^{1/2}$	Yield Strength σ_{ys} ksi	2.5 $(K_{Ic}/\sigma_{ys})^2$ in.
AA-RA #1	0.499	8.0	7.2	OK	0.007	(0.86)	25°	40.2	0.516	22.6	55.2	0.418
#2	0.500	8.0	7.1	+0.006	-0.005	(0.88)	30°	39.4	0.510	22.3	55.2	0.408
#3	0.500	7.0	6.2	OK	OK	OK	30°	34.6	0.463	24.6	55.2	0.498
#4	0.500	7.1	6.3	OK	OK	OK	30°	34.9	0.467	24.0	55.2	0.472
BB-RA #1	1.001	17.4	17.4	OK	OK	OK	12°	41.9	0.516	26.7	54.4	0.602
#2	1.000	14.2	11.5	OK	OK	OK	15°	37.8	0.479	27.1	54.4	0.620
CC-RA #1	1.000	Failed during fatigue cracking										
#2	1.001	12.5	9.8	OK	OK	OK	12°	38.6	0.487	20.0	56.8	0.310
AA-RC #1	0.499	18.6	18.6	OK	OK	(0.86)	OK	41.4	0.525	30.0(g)	59.0	0.645
#2	0.499	12.0	15.2	OK	OK	OK	OK	49.8	0.573	29.1(g)	59.0	0.608
#3	0.498	13.1	12.2	OK	OK	(0.88)	OK	44.5	0.546	29.4(g)	59.0	0.620
#4	0.500	9.6	8.5	OK	OK	OK	OK	37.6	0.493	33.5(g)	59.0	0.806
BB-RC #1	1.000	14.0	11.3	OK	OK	OK	OK	37.1	0.472	41.3(g)	56.9	1.318
#2	1.002	14.0	11.5	+0.005	OK	OK	OK	37.7	0.480	40.9(g)	56.9	1.292
#3	1.000	14.0	11.6	+0.012	OK	OK	OK	37.9	0.481	42.8(g)	56.9	1.415
#4	1.000	14.5	12.0	OK	OK	OK	OK	38.4	0.485	42.3(g)	56.9	1.380
CC-RC #1	1.001	13.9	12.7	OK	OK	OK	OK	37.6	0.478	30.6(g)	60.0	0.650
#2	1.001	14.5	13.1	OK	OK	OK	OK	38.8	0.489	30.1(g)	60.0	0.630
#3	1.002	14.1	12.8	OK	OK	OK	OK	37.8	0.481	30.2(g)	60.0	0.632
#4	1.002	17.6	17.6	+0.005	OK	(0.87)	OK	42.5	0.521	30.1(g)	60.0	0.630
AA-CR #1	0.499	7.8	6.6	OK	-0.033	(0.86)	OK	36.6	0.484	24.9	58.4	0.452
#2	0.499	7.7	6.6	OK	-0.038	(0.86)	OK	36.4	0.481	26.7	58.4	0.522
#3	0.500	7.3	6.7	OK	-0.022	(0.87)	OK	37.1	0.488	21.7	58.4	0.345
#4	0.500	7.1	6.4	+0.006	-0.020	OK	OK	35.7	0.474	21.9	58.4	0.352
BB-CR #1	1.001	15.3	11.6	OK	OK	OK	OK	37.9	0.481	34.9(g)	53.8	1.052
#2	1.001	14.4	11.2	OK	OK	OK	OK	36.6	0.468	33.9(g)	53.8	0.992
CC-CR #1	1.001	16.2	16.2	+0.025	OK	(0.88)	OK	41.5	0.513	24.4(g)	57.2	0.455
#2	1.001	13.4	10.0	OK	OK	OK	OK	39.2	0.493	23.5(g)	57.2	0.422

NOTES

(a) The initial stress intensity factor ($K_{initial}$) to be less than 0.6 K_{Ic} or 0.6 K_q.

(b) The final stress intensity factor (K_{final}) to be less than 12.5 ksi-in.$^{1/2}$.

(c) The difference between the three crack measurements at 1/4, 1/2 and 3/4 B to be less than 0.05 Ao.

(d) All parts of the fatigue crack front to be greater than 0.050 or 0.050 Ao in., whichever was greater, in front of machined notch front.

(e) The fatigue crack length at free surface of the specimen to be greater than 0.9 Ao.

(f) The plane of the fatigue crack deviates from the plane of the machined notch by less than 10°.

(g) These values were considered to be K_{IC} results.

TABLE 26

FRACTURE-TOUGHNESS RESULTS OF 7039-T63 ALUMINUM SUBSCALE RING FORGING (FLANGE REGION)

Tested at -100 and -320°F

Specimen No.	Test Temp. (°F)	Thick (B) in.	Fatigue Crack Parameters: $K_{initial}$ (a) ksi-in.$^{1/2}$	Fatigue Crack Parameters: K_{final} (b) ksi-in.$^{1/2}$	Deviation from ASTM Recommended Practice Fatigue Crack Length (c)	(d)	(e)	(f)	Load Rate ksi-in.$^{1/2}$	a/W	Stress Intensity K_q ksi-in.$^{1/2}$	Yield Strength σ_{ys}	$2.5(K_{Ic}/\sigma_{ys})^2$ in.
AA-RC #5	-100	0.499	7.7	7.1	OK	OK	(0.89)	OK	39.4	0.509	27.8(g)	64.6	0.462
#6	-100	0.500	8.0	7.2	OK	OK	(0.88)	OK	39.8	0.513	31.0(g)	64.6	0.575
BB-RC #5	-100	1.000	12.7	11.8	OK	OK	OK	OK	38.7	0.488	35.8(g)	62.0	0.832
#6	-100	1.001	12.7	11.7	OK	OK	OK	OK	38.2	0.484	38.9(g)	62.0	0.982
CC-RC #5	-100	1.002	13.5	12.9	OK	OK	OK	OK	38.0	0.482	27.8(g)	65.8	0.445
#6	-100	1.002	12.3	11.3	OK	OK	OK	OK	37.0	0.473	27.6(g)	65.8	0.440
AA-RA #5	-320	0.500	7.7	6.8	+0.012	-0.025	(0.87)	30°	37.7	0.495	16.2	66.8	0.148
#6	-320	0.499	8.0	6.9	OK	-0.028	(0.84)	30°	38.2	0.498	[illegible]	66.8	0.165
#7	-320	0.501	8.8	7.7	OK	OK	OK	25°	34.9	0.467	[illegible]	66.8	0.155
#8	-320	0.500	8.6	7.6	+0.005	-0.009	OK	25°	34.7	0.464	17.3	66.8	0.168
BB-RA #3	-320	1.001	13.9	14.2	OK	OK	OK	14°	41.8	0.515	15.5	65.2	0.142
#4	-320	1.002	12.4	11.7	OK	OK	OK	15°	38.5	0.487	14.6	65.2	0.125
CC-RA #3	-320	0.998	7.7	7.7	OK	OK	OK	18°	37.5	0.475	10.5	68.0	0.060
#4	-320	0.999	7.3	7.3	OK	OK	OK	20°	35.7	0.459	11.3	68.0	0.070
AA-RC #7	-320	0.499	8.6	7.7	OK	-0.012	OK	OK	38.3	[illegible]	25.3(g)	72.0	0.308
#8	-320	0.498	8.5	7.7	OK	OK	OK	OK	39.6	[illegible]	26.4(g)	72.0	0.338
BB-RC #7	-320	1.000	13.5	13.1	OK	OK	OK	OK	38.8	0.489	38.5(g)	68.7	0.785
#8	-320	1.000	13.5	13.2	OK	OK	OK	OK	39.0	0.490	33.8(g)	68.7	0.605
CC-RC #7	-320	1.000	13.2	12.7	OK	OK	OK	OK	37.5	0.477	29.9(g)	73.3	0.460
#8	-320	1.001	14.4	14.1	+0.022	OK	(0.87)	OK	41.7	0.514	29.9(g)	73.3	0.460
AA-CR #5	-320	0.500	7.1	6.3	OK	-0.020	OK	OK	34.0	0.467	15.0(g)	69.4	0.115
#6	-320	0.499	7.8	6.9	OK	-0.025	(0.85)	OK	38.4	0.499	17.2(g)	69.4	0.155
#7	-320	0.500	10.1	9.0	OK	OK	(0.86)	OK	41.0	0.522	16.4(g)	69.4	0.140
#8	-320	0.498	9.3	8.5	OK	OK	OK	OK	38.6	0.500	17.3(g)	69.4	0.155
BB-CR #3	-320	1.000	12.8	9.6	+0.013	-0.020	OK	OK	37.8	0.480	25.9(g)	63.0	0.422
#4	-320	1.000	13.2	9.7	OK	OK	OK	OK	38.0	0.482	24.6(g)	63.0	0.380
CC-CR #3	-320	1.001	12.6	9.5	+0.005	OK	OK	OK	39.5	0.496	19.4(g)	68.2	0.202
#4	-3[illegible]0	1.000	10.9	9.7	OK	OK	OK	OK	38.3	0.465	18.2(g)	68.2	0.178

Notes

(a) The initial stress intensity factor $K_{initial}$ to be less than 0.6 K_{Ic} or 0.6 K_q.

(b) The final stress intensity factor K_{final} to be less than 12 ksi-in.$^{1/2}$.

(c) The difference between the three crack measurements at 1/4, 1/2 and 3/4B to be less than 0.05 Ao.

(d) All parts of the fatigue crack front to be greater than 0.050 or 0.050 Ao in., whatever was greater, in front of machined notch front.

(e) The fatigue crack length at free surface of the specimen to be greater than 0.9 Ao.

(f) The plane of the fatigue crack deviates from the plane of the machined notch by less than 10°.

(g) These values were considered to be K_{IC} results.

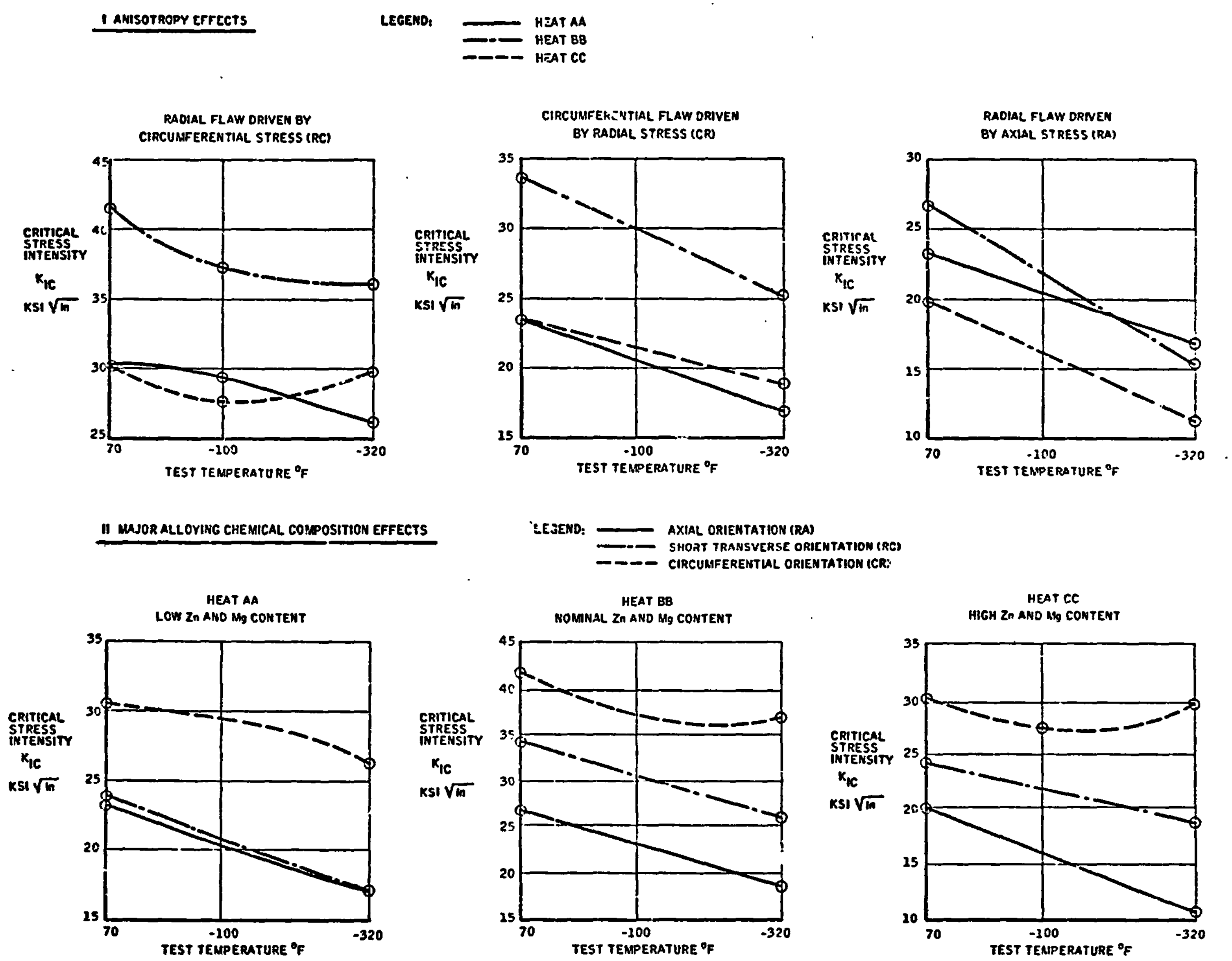


Figure 14 - Effects of Anisotropy and Chemical Composition Upon AA7039-T6 Subscale Forging Flange Section

of prior residual-stress measurement tests on Heat AA, 0.50-in. specimen thickness was the maximum size available from a Heat AA forging. One-inch-thick specimens were fabricated for heats BB and CC forgings.

The RA (i.e., axial stress) results were the lowest values of any direction tested at room temperature with Heat BB having the highest mean value (26.9 ksi$\sqrt{\text{in.}}$), followed by Heat AA (23.4 ksi$\sqrt{\text{in.}}$) and Heat CC (20.0 ksi$\sqrt{\text{in.}}$) at room temperature (see Figure 14). At -320°F, Heat AA had the highest mean value (16.8 ksi$\sqrt{\text{in.}}$), followed closely by Heat BB (16.5 ksi$\sqrt{\text{in.}}$), with Heat CC lower (10.9 ksi$\sqrt{\text{in.}}$). All results were designated K_Q because fatigue precrack deviated from notch plane by more than allowed 10°. The -320°F Heat AA values are probably fictitiously high because of the fatigue precrack deviating 30° from notch plane, whereas values from Heats AA and BB deviated only 15° and lower.

The RC (i.e., circumferential stress) results contained the highest values of any direction tested with Heat BB having the highest mean value (41.8 ksi$\sqrt{\text{in.}}$) at 70°F. Other mean values at 70°F were much lower with Heat AA heat at 30.4 ksi$\sqrt{\text{in.}}$ and Heat CC at 30 ksi$\sqrt{\text{in.}}$ At -320°F, Heat BB also had the highest mean value (36 ksi), followed by Heat CC (30 ksi$\sqrt{\text{in.}}$), and Heat AA (25.8 ksi$\sqrt{\text{in.}}$). All values were designated K_{IC} or K_{IC}*.

The AR (i.e., short-transverse stress) results were at intermediate levels at room temperature with Heat BB having the highest mean value (34.2 ksi$\sqrt{\text{in.}}$), followed by both Heats AA and CC values (approximately 24 ksi$\sqrt{\text{in.}}$). At -320°F, Heat BB was also highest (25 ksi $\sqrt{\text{in.}}$), followed by Heat CC (19 ksi$\sqrt{\text{in.}}$), and Heat AA (17 ksi$\sqrt{\text{in.}}$). All results were K_{IC} values except Heat AA results at room temperature where initial crack lengths were shorter than specified and thus designated K_Q.

(b) Chamber-Wall Section

Test results are listed in Tables 27 and 28. They are plotted in Figure 15 to show the effect of chemical composition and the effect of anisotropy as a result of test temperature. The maximum thickness available for Heat AA was 0.50 in. The same thickness was used for Heat BB to eliminate size effects. Heat CC was not tested because previous tensile data indicated low cryogenic ductility in the short-transverse direction that eliminated the high chemistry (Heat CC) from further consideration.

The CA (i.e., axial stress) results showed the highest values of any direction tested with Heat BB (40.5 ksi$\sqrt{in.}$) being higher than the Heat AA mean value (35.8 ksi$\sqrt{in.}$). At -320°F, the mean values were degraded to 26.8 ksi$\sqrt{in.}$ and 24 ksi$\sqrt{in.}$ values, respectively. All room temperature values were K_{IC}*, while -320°F values were K_{IC}.

The RC (i.e., circumferential stress) results were somewhat lower with Heat BB (38.7 ksi$\sqrt{in.}$) being higher than the Heat AA (36.0 ksi$\sqrt{in.}$) mean value at room temperature. At -100°F, the mean values were degraded to 33.2 ksi$\sqrt{in.}$ and 31.5 ksi$\sqrt{in.}$, respectively. The -320°F results were reversed with Heat AA (25.0 ksi$\sqrt{in.}$) being higher than the Heat BB (22.5 ksi$\sqrt{in.}$) mean value. All values at room temperature and -100°F were K_{IC}*, while -320°F results were K_{IC}.

The AC (i.e., circumferential stress) results were about the same as RC results at room temperature with higher corresponding results present at -100° and -320°F. At room temperature, Heat BB (37 ksi $\sqrt{in.}$) was higher than the Heat AA (33 ksi$\sqrt{in.}$) mean valve. Heat BB mean values at -100° and -320°F were higher (30.8 and 32 ksi$\sqrt{in.}$, respectively). Heat AA at -100° and -320°F were not tested because of lack of material. All room temperature and -320°F results were designated K_Q because the precrack length was shorter than allowed. Results at -100°F were designated K_{IC}*.

TABLE 27

ROOM-TEMPERATURE FRACTURE-TOUGHNESS DATA FOR 7039-T63 ALUMINUM ALLOY SUBSCALE RING FORGING

Orientation Specimen No.	B (in.)	Fatigue Crack Parameters ksi-in.$^{(a)}$	Deviation from ASTM Recommended Practices Fatigue Crack Length (b)	(c)	(d)	(e)	Load Rate ksi-in.$^{1/2}$/min	a/W	Stress Intensity K_q ksi-in.$^{1/2}$	Yield Strength σ_{ys} ksi	2.5 $(K_{1c}/\sigma_{ys})^2$ in.
AA-CA #4	0.506	8.7	OK	-0.005	OK	OK	38.7	0.514	36.8	57.7	1.018
#5	0.506	9.0	OK	-0.013	OK	OK	39.9	0.513	41.1	57.7	1.268
#6	0.506	9.4	OK	OK	OK	OK	41.6	0.527	34.6	57.7	0.900
AA-RC #7	0.506	9.2	OK	OK	OK	OK	40.8	0.520	35.8	60.2	0.882
#8	0.508	10.1	OK	OK	OK	OK	45.0	0.550	36.5	60.2	0.918
#9	0.508	9.6	OK	OK	OK	OK	42.7	0.535	35.1	60.2	0.850
AA-AR #5	0.503	7.1	OK	-0.007	OK	OK	35.2	0.470	21.5	62.0	0.300
#6	0.505	6.7	OK	-0.006 -0.011	OK	OK	38.4	0.450	20.6	62.0	0.275
#7	0.506	7.1	OK	-0.007	OK	OK	35.3	0.470	21.5	62.0	0.300
#8	0.506	7.0	OK	-0.017	OK	OK	35.0	0.455	21.4	62.0	0.294
AA-AC #1	0.502	12.3	+0.015	-0.015	0.88	OK	37.8	0.496	31.7	60.2	0.692
#2	0.502	12.3	OK	-0.010	OK	OK	37.8	0.496	35.4	60.2	0.865
#3	0.502	13.7	OK	OK	0.88	OK	41.6	0.528	31.7	60.2	0.692
BB-CA #4	0.502	8.8	OK	-0.015	OK	OK	39.1	0.506	41.8	55.8	1.402
#5	0.502	9.1	OK	OK	OK	OK	40.3	0.516	41.3	55.8	1.370
#6	0.501	6.6	OK	-0.012	OK	OK	38.0	0.496	39.0	55.8	1.222
BB-RC #7	0.505	8.8	OK	OK	OK	OK	39.0	0.505	39.3	59.8	1.080
#8	0.505	8.4	OK	-0.006 -0.016	OK	OK	37.4	0.491	36.9	59.8	0.952
#9	0.505	8.7	OK	-0.008	OK	OK	38.6	0.502	39.9	59.8	1.112
BB-AR #5	0.506	6.4	OK	-0.018 -0.007	OK	OK	32.1	0.443	28.1	58	0.595
#6	0.506	6.7	+0.011	-0.019	OK	OK	33.4	0.457	26.6	58	0.528
#7	0.506	6.6	OK	-0.015 -0.008	OK	OK	33.1	0.454	27.8	58	0.572
#8	0.506	6.6	OK	-0.016 -0.009	OK	OK	32.9	0.452	28.5	58	0.608
BB-AC #7	0.504	7.4	OK	-0.005 -0.022	OK	OK	33.0	0.446	37.1	57.8	0.960
#8	0.502	7.6	OK	-0.005 -0.014	OK	OK	34.0	0.456	37.5	59.8	0.982
#9	0.503	7.8	OK	-0.005	OK	OK	34.6	0.463	36.2	59.8	0.915

Notes

(a) The stress intensity factor for fatigue cracking to be less than 0.6 K_q or 12.5 ksi-in.$^{1/2}$, whichever is smaller.

(b) The difference between the three crack length measurements at 1/4, 1/2, and 3/4 B, to be less than 0.05 Ao.

(c) All parts of the fatigue crack to be greater than 0.050 in. in front of machined notch root.

(d) Fatigue crack length at free surface of specimen to be greater than 0.9 Ao.

(e) Plane of the fatigue crack deviates from the plane of the machined notch by less than 10°.

TABLE 28

FRACTURE-TOUGHNESS RESULTS OF 7039-T63 ALUMINUM ALLOY SUBSCALE RING FORGING (CYLINDER SECTION)

Tested at -100 and -320°F

Orientation Specimen No.	Test Temp. (°F)	Thickness B (In.)	Fatigue Crack Parameters(a) ksi-in.$^{1/2}$	Deviation from ASTM Recommended Practices Fatigue Crack Length (b)	(c)	(d)	(e)	Load Rates ksi-in.$^{1/2}$/min.	a/W	Stress Intensity K_q ksi-in.$^{1/2}$	Yield Strength σ_{ys} ksi	$1/\sigma_{ys}$) in.
AA-RC #4	-100	0.507	9.3	OK	OK	OK	OK	41.2	0.524	31.9	64.7	0.608
#5	-100	0.508	9.0	OK	OK	OK	OK	40.0	0.514	30.2	64.7	0.545
#6	-100	0.508	9.3	OK	-0.005	OK	OK	41.2	0.524	32.4	64.7	0.628
BB-RC #4	-100	0.505	8.0	OK	-0.008 -0.017	OK	OK	35.7	0.474	35.6	62.9	0.800
#5	-100	0.505	8.3	OK	OK	OK	OK	36.9	0.486	33.9	62.9	0.728
#6	-100	0.506	8.4	OK	-0.012	OK	OK	37.4	0.491	30.0	62.9	0.570
BB-AC #4	-100	0.501	7.[illegible]	OK	OK	OK	OK	35.2	0.468	31.2	62.9	0.615
#5	-100	0.501	8.0	OK	OK	OK	OK	35.6	0.475	29.8	62.9	0.562
#6	-100	0.502	7.[illegible]	OK	-0.010 -0.010	OK	OK	34.3	0.450	31.1	62.9	0.610
AA-CA #1	-320	0.507	9.6	OK	OK	OK	OK	42.5	0.539	23.8	73.1	0.265
#2	-320	0.507	8.9	OK	OK	OK	OK	39.4	0.509	23.1	73.1	0.250
#3	-320	0.508	8.8	OK	OK	OK	OK	39.3	0.514	25.5	73.1	0.305
AA-RC #1	-320	0.508	9.5	OK	-0.004	OK	OK	37.9	0.502	25.4	70.3	0.325
#2	-320	0.506	9.1	OK	OK	OK	OK	40.4	0.517	22.9	70.3	0.335
#3	-320	0.506	9.0	OK	OK	OK	OK	40.1	0.516	26.3	70.3	0.350
AA-AR #1	-320	0.507	6.8	+0.014	-0.045 -0.008	OK	OK	30.0	0.416	11.9	66.8	0.080
#2	-320	0.502	7.1	OK	-0.022	OK	OK	31.8	0.431	11.2	66.8	0.070
#3	-320	0.504	7.1	OK	-0.018	OK	OK	31.8	0.431	13.6	66.8	0.105
#4	-320	0.502	7.0	OK	OK	OK	OK	31.2	0.423	12.3	66.8	0.085
BB-CA #1	-320	0.500	8.7	OK	-0.025	OK	OK	38.5	0.501	27.0	67	0.405
#2	-320	0.503	8.7	OK	-0.020	OK	OK	38.5	0.501	26.2	67	0.382
#3	-320	0.502	8.9	OK	OK	OK	OK	39.7	0.511	26.9	67	0.402
BB-RC #1	-320	0.505	7.4	OK	-0.023	OK	OK	37.0	0.489	23.2	74.5	0.242
#2	-320	0.505	8.4	OK	OK	OK	OK	37.4	0.490	21.5	74.5	0.210
#3	-320	0.506	8.0	OK	-0.005 -0.015	OK	OK	35.7	0.474	23.4	74.5	0.248
BB-AR #2	-320	0.506	6.3	OK	-0.020	OK	OK	3[illegible].6	0.437	11.9	63.7	0.088
#3	-320	0.504	6.7	OK	-0.010	OK	OK	33.6	0.452	12.1	63.7	0.090
#4	-320	0.50[illegible]	7.0	OK	OK	OK	OK	35.0	0.467	12.0	63.7	0.088
BB-AC #1	-320	0.503	7.5	OK	-0.028 -0.006	OK	OK	33.2	0.4[illegible]8	30.8	74.5	0.428
#2	-320	0.502	7.3	+0.028	-0.043	OK	OK	32.2	0.433	30.3	74.5	0.415
#3	-320	0.502	8.1	OK	-0.010	OK	OK	36.1	0.478	34.5	74.5	0.535

Notes

(a) The stress intensity factor for fatigue cracking to be less than 0.6 K_q or 12.0 ksi-in.$^{1/2}$, whichever is smaller.

(b) The difference between the three crack length measurements at 1/4, 1/2, and 3/4 to be less than 0.005 Ao.

(c) All parts of the fatigue crack to be greater than 0.050 in. in front of machined notch root.

(d) Fatigue crack length of free surface of specimen to be greater than 0.9 Ao.

(e) Plane of the fatigue crack deviates from the pl[illegible] of the machined notch by less than 10°.

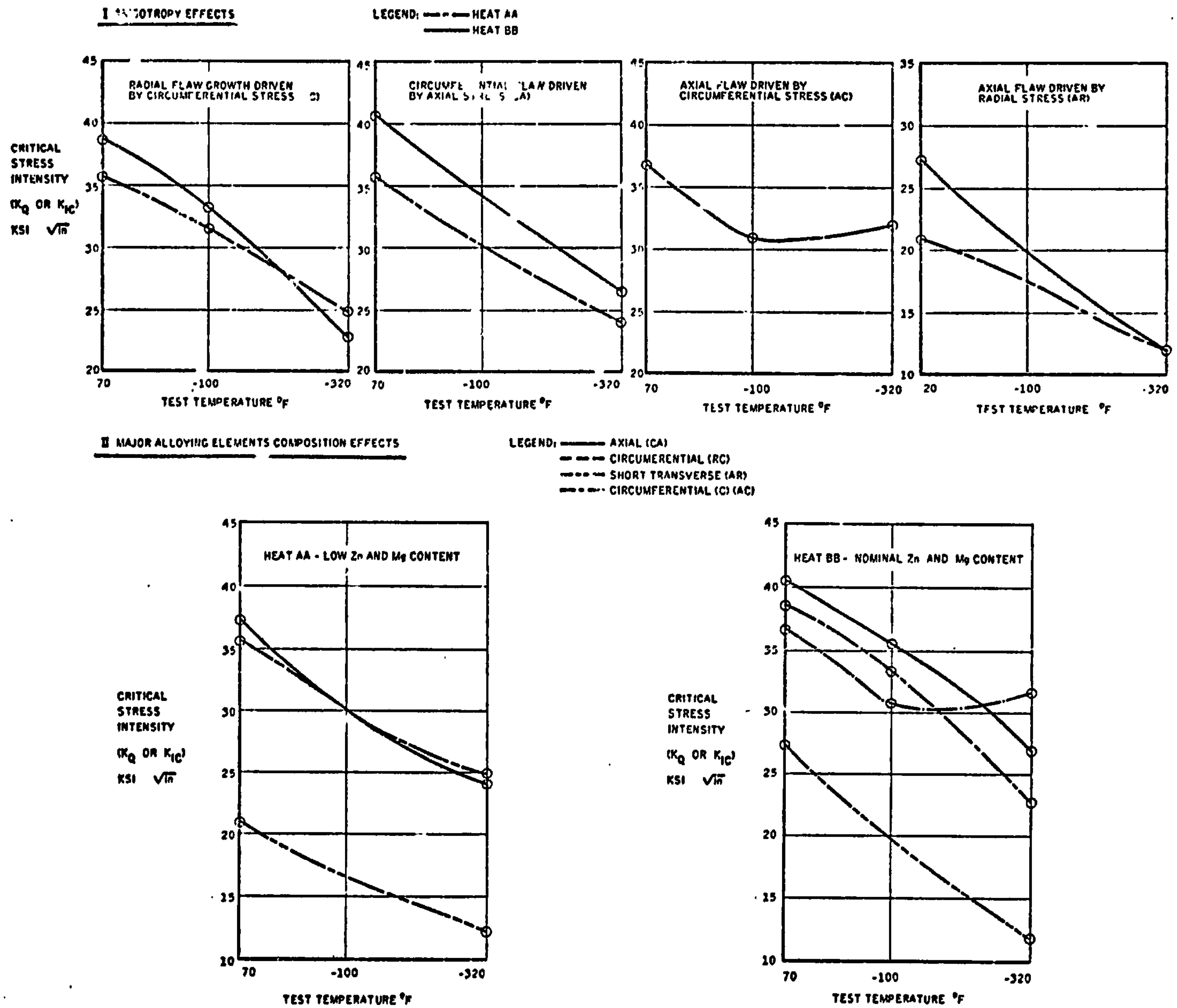


Figure 15 - Effects of Anisotropy and Chemical Composition Upon AA7039-T63 Subscale Forging Chamber Wall Section

The AR (i.e., short-transverse stress) results were the lowest of any direction tested with Heat BB (28 ksi$\sqrt{\text{in.}}$) being higher than the Heat AA (21 ksi$\sqrt{\text{in.}}$) mean values. At -320°F, the mean values were both degraded to a common mean value of 12 ksi$\sqrt{\text{in.}}$ The results at room temperature were designated K_Q because the precrack length was shorter than required. Results at -320°F were designated K_{IC}.

(2) Hand-Step Forgings

(a) Aluminum Alloy 7039-T63

Test results are listed in Table 29. These are plotted in Figure 16 to show the effects of reduction and orientation as a result of test temperature.

The LT-L (i.e., longitudinal stress) results at room temperature were highest at the 3/1 reduction (26.8 ksi$\sqrt{\text{in.}}$) with lower values recorded at 6/1 (25.4 ksi$\sqrt{\text{in.}}$) and 12/1 reductions (25.0 ksi $\sqrt{\text{in.}}$). At -320°F, the values were degraded to values of 22, 20, and 17.4 psi $\sqrt{\text{in.}}$, respectively. The room temperature, 3/1 reduction values were designated K_Q because of insufficient thickness to meet criteria and higher-than-allowed stress intensity during fatigue precracking. All other results were K_{IC}.

The L-LT (i.e., long-transverse stress) results were generally the highest obtained at room temperature with the 12/1 reduction being highest (38.0 ksi$\sqrt{\text{in.}}$), followed by the 6/1 (34.0 ksi$\sqrt{\text{in.}}$) and 3/1 reductions (32 ksi$\sqrt{\text{in.}}$). At -320°F, degradation was evident to converge the values between 25 and 26 ksi$\sqrt{\text{in.}}$ All results were designated K_{IC} at room temperature except the 12/1 reduction was designated K_{IC}* because of insufficient thickness to meet criteria. The 6/1 and 12/1 reduction values at -320°F were designated K_Q because of higher-than-allowed stress intensity during fatigue precracking. The 3/1 reduction values were designated K_{IC}.

TABLE 29

FRACTURE-TOUGHNESS RESULTS OF 7039-T63 ALUMINUM ALLOY HAND-STEP FORGING USING COMPACT TENSION SPECIMENS

Orientation Specimen No.	Thickness B in.	Test Temp °F	Fatigue Crack Parameters: $K_{initial}$ (a) ksi-in.$^{1/2}$	Fatigue Crack Parameters: K_{final} (b) ksi-in.$^{1/2}$	Deviation from ASTM Recommended Practices, Fatigue Crack Length (c)	(d)	(e)	(f)	Load Rate ksi-in.$^{1/2}$/min	a/W	Stress Intensity K_{1c} ksi-in.$^{1/2}$	Strength σ_{ys},ksi	$2.5(K_{1c}/\sigma_{ys})^2$
L3-1, L-LT #1	1.006	70	17.7	17.7	OK	OK	OK	OK	42.7	0.523	26.2(g)	53.6	0.598
#2	1.005	70	16.2	16.2	+0.005	OK	OK	OK	39.1	0.493	26.9(g)	53.6	0.630
#3	1.004	-320	13.5	10.9	OK	OK	OK	OK	37.9	0.482	23.0	64.1	0.322
#4	1.005	-320	13.3	10.9	OK	OK	OK	OK	37.8	0.481	21.5	64.1	0.280
L6-1, L-LT #1	1.003	70	29.2	29.2	+0.004	OK	OK	OK	74.9	0.629	31.1(g)	53.7	0.838
#2	1.005	70	12.9	11.3	OK	OK	OK	OK	36.9	0.472	25.3	53.7	0.555
#3	1.005	-320	13.1	10.8	OK	OK	OK	OK	37.4	0.477	21.2	64.8	0.268
#4	1.006	-320	13.5	10.9	OK	OK	OK	OK	37.9	0.482	19.4	64.8	0.222
L12-1, L-LT #1	0.999	70	14.5	13.1	OK	OK	OK	OK	43.0	0.523	24.9(h)	55.4	0.505
#2	1.005	70	12.2	11.1	OK	-0.004	OK	OK	36.3	0.467	25.2	55.4	0.518
#3	1.006	-320	12.2	10.6	OK	OK	OK	OK	36.6	0.470	17.1	62	0.192
#4	1.005	-320	12.2	10.3	OK	OK	OK	OK	35.9	0.462	17.8	62	0.205
LT3-1, LT-L #1	1.005	70	13.3	10.8	OK	OK	OK	OK	37.6	0.479	31.9	53.2	0.900
#2	1.007	70	12.9	10.9	OK	OK	OK	OK	38.0	0.483	31.7	53.2	0.888
#3	1.006	-320	14.9	13.3	OK	OK	OK	OK	46.3	0.547	25.3(h)	66.8	0.360
#4	1.000	-320	13.4	10.[illegible]	OK	OK	OK	OK	36.9	0.470	25.5	66.8	0.365
T6-1, LT-L #1	1.005	70	12.7	10.5	OK	OK	OK	OK	36.3	0.466	33.6	53.9	0.970
#2	1.004	70	12.7	10.4	OK	OK	OK	OK	36.2	0.465	34.0	53.9	0.995
#3	1.005	-320	16.5	16.5	OK	OK	OK	OK	44.2	0.534	25.4(g)	63.3	0.402
#4	1.005	-320	12.7	10.1	OK	-0.013	OK	OK	36.3	0.466	26.8(g)	63.3	0.448
LT12-1, LT-L #1	1.005	70	12.9	11.3	OK	OK	OK	OK	37.0	0.473	38.5	57.3	1.130
#2	1.004	70	15.4	15.4	OK	OK	OK	OK	41.3	0.511	37.3(h)	57.3	1.060
#3	1.007	-320	13.7	13.7	OK	OK	OK	OK	49.1	0.562	25.1(g)	64	0.385
#4	1.005	-320	9.9	9.9	OK	-0.031	OK	OK	35.3	0.457	25.0(g)	64	0. 82
ST3-1, ST-LT #1	1.005	70	18.5	18.5	OK	OK	OK	OK	49.6	0.564	20.3(g)	51.8	0.385
#2	0.999	70	14.1	14.1	OK	OK	OK	OK	41.5	0.511	20.6(g)	51.8	0.395
#3		-320	Failed during fatigue cracking										
#4	1.005	-320	9.1	9.1	OK	-0.018	OK	OK	35.8	0.461	14.5(g)	61.9	0.138
ST6-1, ST-LT #1	1.006	70	12.8	11.7	OK	OK	OK	OK	37.7	0.507	20.8	52.6	0.390
#2	1.008	70	12.2	10.7	OK	OK	OK	OK	38.4	0.489	20.2	52.6	0.368
#3	1.007	-320	9.2	9.2	OK	OK	OK	OK	36.3	0.467	15.0	61.6	0.150
#4	1.005	-320	9.4	9.4	OK	OK	OK	OK	37.1	0.474	13.8	61.6	0.125
ST12-1, ST-LT #1	1.006	70	11.4	9.9	OK	OK	OK	OK	35.6	0.459	22.8	53.4	0.455
#2	1.00[illegible]	70	12.1	10.8	OK	OK	OK	OK	37.6	0.479	23.9	53.4	0.502
#3	1.004	-320	9.2	9.2	OK	OK	OK	OK	36.0	0.464	16.3	64.3	0.160
#4	1.005	-320	9.2	9.2	+0.009	-0.021	OK	OK	36.2	0.465	17.2(h)	64.3	0.178

NOTES

(a) The initial stress intensity factor ($K_{initial}$) to be less than 0.6 K_q.

(b) The final stress intensity factor (K_{final}) to be less than 12.5 ksi-in.$^{1/2}$ for 70°F tests and 12.0 ksi-in.$^{1/2}$ for -320°F tests.

(c) The difference between the three crack measurements at 1/4, 1/2, and 3/4B to be less than 0.05 Ao.

(d) All parts of the fatigue crack front to be greater than 0.050 or 0.05 Ao in., whichever was greater, in front of machined notch root.

(e) The fatigue crack length at free surface of the specimen to be greater than 0.9 Ao.

(f) The plane of the fatigue crack deviates from the plane of the machined notch be less than 10°.

(g) Invalid tests, the result was denoted as K_q.

(h) Even though the result was invalid, it was acceptable as K_{IC} because of agreement with a valid duplicate specimen.

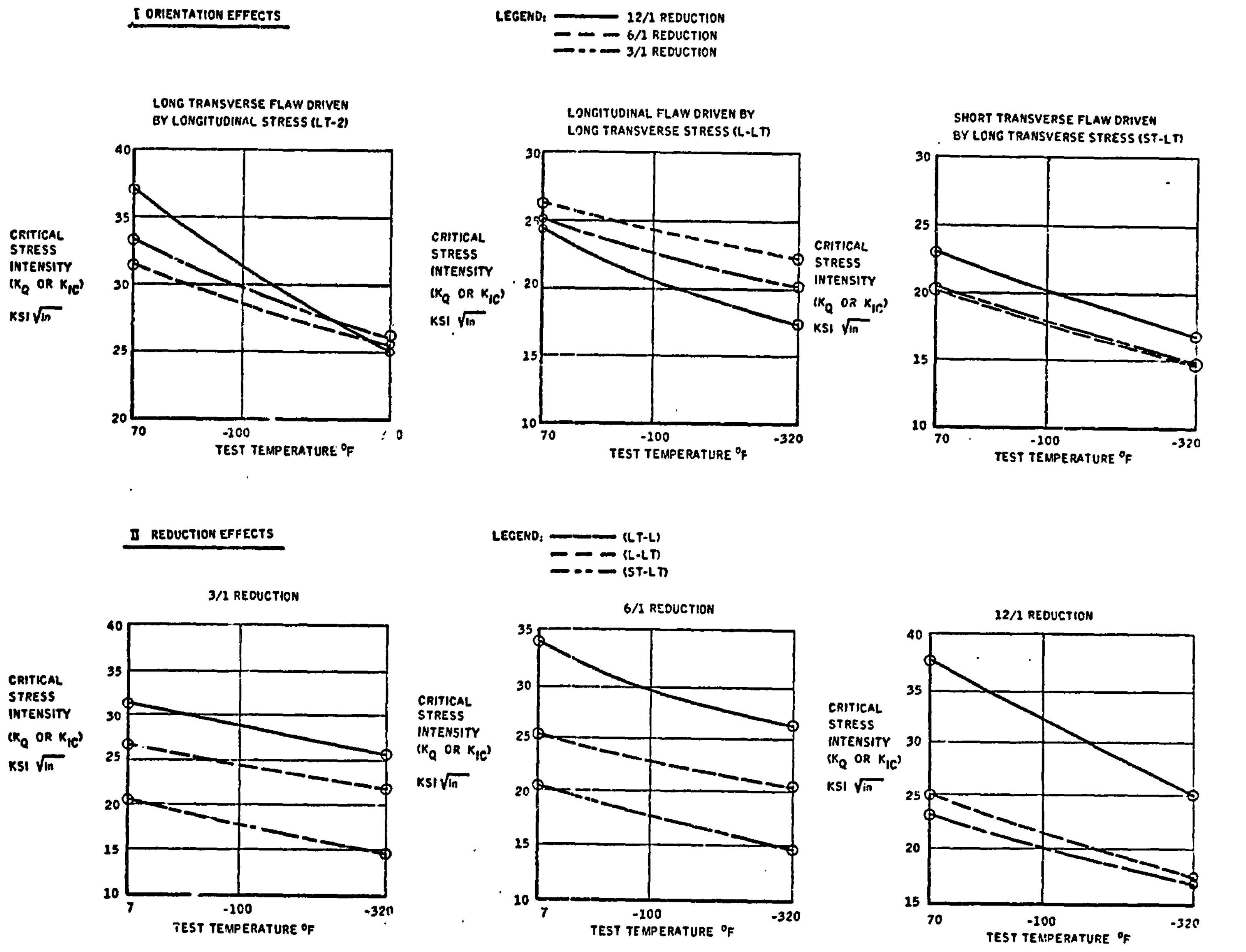


Figure 16 - Effects of Orientation and Reduction Upon AA7039-T63 Step Forging

The ST-LT (i.e., long-transverse stress) results were lower than other directions with the 12/1 reduction being higher (23.1 ksi $\sqrt{in.}$) than the 6/1 and 12/1 reductions (20.6 ksi$\sqrt{in.}$) at room temperature. At -320°F, uniform degradation was evident to reduce values .to 17 and 14.5 ksi$\sqrt{in.}$, respectively. The room temperature 3/1 reduction values were designated K_Q because of higher-than-allowed stress intensity during fatigue precracking. All other values were designated K_{IC}.

(b) Aluminum Alloy 6061-T6

Test results are listed in Tables 30 and 31. These are plotted in Figure 17 to show the effects of reduction and orientation as a result of test temperature.

The LT-L (i.e., longitudinal stress) results showed typical mean values with the 3/1 reduction being highest (31 ksi$\sqrt{in.}$), followed closely by 12/1 (30.5 ksi$\sqrt{in.}$) and 6/1 reductions (28.3 ksi$\sqrt{in.}$). At -320°F, all values increased to within a narrow range value of about 39 ksi $\sqrt{in.}$ All room temperature results were K_Q as a result of excessive precrack tunneling (i.e., irregular crack-propagation front). Remaining specimens were machined with a modified chevron-notch that minimized deviations to provide K_Q values close to valid K_{IC}. These were designated K_{IC}.

The L-LT (long-transverse stress) results were similar to LT-L results with the room temperature results grouped closely between 32 and 33 ksi$\sqrt{in.}$ At -320°F, all values increased with the 6/1 reduction being highest (43.8 ksi$\sqrt{in.}$), followed closely by the 3/1 reduction (143 ksi$\sqrt{in.}$). The 12/1 reduction was much lower (38.6 ksi$\sqrt{in.}$). All results were designated K_{IC}* because of insufficient theoretical specimen thickness.

The ST-LT (i.e., long-transverse stress) results were lowest with the 12/1 reduction being highest (31.8 ksi$\sqrt{in.}$) of the three:

TABLE 30

FRACTURE-TOUGHNESS RESULTS OF 6061-T6 ALUMINUM ALLOY HAND-STEP FORGING USING COMPACT-TENSION SPECIMENS AT 70°F

Specimen No.	B (in.)	Fatigue Crack Parameters (a)	Fatigue Crack Parameters (b)	Deviation From ASTM Recommended Practices, Fatigue Crack Length (c)	(d)	(e)	(f)	Load Rate ksi-in.$^{1/2}$/min.	a/W	K_q ksi-in.$^{1/2}$	σ_{ys} ksi	$2.5\,(K_q/\sigma_{ys})^2$ in.
61-3:1-LT-L #2	1.000	12.5	12.5	OK	OK	OK	OK	47.5	0.552	33.5(h)	43.0	1.518
#3	1.000	11.3	11.3	OK	-0.023	OK	OK	43.1	0.526	32.4(h)	43.0	1.418
61-6:1-LT-L #2	0.999	11.5	11.5	OK	OK	OK	OK	42.4	0.518	32.7(h)	43.2	1.432
#4	0.999	11.7	11.7	+0.016	-0.033	0.89	OK	43.2	0.524	31.5(h)	43.2	1.328
61-1:2-LT-L #2	1.000	12.1	12.1	OK	-0.005	0.88	OK	46.1	0.546	31.9(h)	42.6	1.402
#3	1.000	11.4	11.4	OK	OK	OK	OK	43.4	0.526	33.9(h)	42.6	1.585
61-3:1-ST-LT #2	1.000	10.7	10.7	OK	-0.040	OK	OK	40.7	0.504	27.1	45.3	0.895
#3	1.000	10.7	10.7	+0.029	-0.046	OK	OK	40.6	0.506	26.2	45.3	0.835
61:6:1-ST-LT #2	1.000	12.8	12.8	OK	OK	0.87	OK	48.6	0.558	28.8	45.4	1.005
#3	1.000	11.4	11.4	OK	-0.015	OK	OK	43.5	0.529	27.2	45.4	0.898
61-12:1-SI-LT #2	0.999	11.5	11.5	+0.011	-0.043	0.86	OK	44.0	0.530	31.7	45.0	1.240
#4	1.000	11.1	11.1	OK	-0.047	0.89	OK	42.2	0.519	31.2	45.0	1.200
61-3:1-L-LT #1(g)	1.002	19.1	13.8	+0.067	-0.022	0.81	OK	45.3	0.541	30.0	41.6	1.300
#2(g)	1.002	19.7	13.4	+0.054	OK	0.85	OK	44.0	0.532	31.7	41.6	1.452
61-6:1 L-LT #1(g)	1.003	19.7	13.6	OK	-0.010	0.83	OK	44.5	0.536	28.5	41.8	1.162
#2(g)	1.001	19.6	13.8	+0.027	-0.008	0.85	OK	45.1	0.540	28.5	41.8	1.162
61-12:1-L-LT #1(g)	1.002	14.8	11.5	+0.044	-0.031	0.87	OK	39.8	0.499	28.1	40.6	1.198
#2(g)	1.003	15.7	11.4	OK	-0.018	0.89	OK	39.5	0.497	33.0	40.6	1.652

(a) The initial stress intensity factor ($K_{initial}$) to be less than 0.6 K_q.

(b) The final stress intensity factor (K_{final}) to be less than 12.0 ksi-in.$^{1/2}$ or 0.6 K_q, whichever is smaller.

(c) Difference between the three crack length measurements, at 1/4, 1/2, and 3/4B to be less than 0.05 Ao.

(d) All points of fatigue crack are to be greater than 0.050 or 0.05 Ao, whichever is greater, in. in front of machined notch root.

(e) Fatigue crack length at free surface to be greater than 0.9 Ao.

(f) The plane of the fatigue crack deviates from the plane of the machined notch by less than 10°.

(g) Initial specimens tested before modifying fatigue crack starter notch.

(h) Designated as K_{IC} values.

TABLE 31

FRACTURE-TOUGHNESS RESULTS OF 6061-T6 ALUMINUM ALLOY HAND-STEP FORGING USING COMPACT TENSION SPECIMENS AT -320°F

Specimen No.	B (in.)	Fatigue Crack Parameters (a) $ksi\text{-}in.^{1/2}$	Fatigue Crack Parameters (b) $ksi\text{-}in.^{1/2}$	Deviation From ASTM Recommended Practices, Fatigue Crack Length (c)	(d)	(e)	(f)	Load Rate $ksi\text{-}in.^{1/2}/min.$	a/W	K_q $ksi\text{-}in.^{1/2}$	σ_{ys} ksi	$2.5\ (K_q/\sigma_{ys})^2$
61-3:1-LT-L #1(g)	1.002	14.8	14.8	OK	OK	OK	OK	48.5	0.559	43.2(h)	51.8	1.740
#4	1.000	10.8	10.8	+0.010	-0.030	OK	OK	39.9	0.498	42.2(h)	51.8	1.660
61-6:1-LT-L #1(g)	1.001	14.2	11.8	OK	OK	OK	OK	46.4	0.546	41.5(h)	52.6	1.558
#3	1.000	11.6	11.6	OK	-0.012	OK	OK	44.1	0.531	45.6(h)	52.6	1.880
61-12:1-LT-L #1(g)	1.007	14.6	12.2	OK	OK	OK	14°	47.8	0.555	38.4(h)	52.8	1.322
#4	1.000	10.2	10.2	OK	-0.043	OK	OK	38.7	0.489	42.6	52.8	1.628
Transition #10	2.003	20.6	17.3	OK	OK	0.88	25°	51.1	0.633	51.5	52.8	2.378
Area (LT)-L #11	2.006	20.2	17.3	OK	OK	0.88	OK	51.2	0.629	45.8(h)	52.8	1.972
61-3:1-ST-LT #1(g)	1.003	14.6	14.6	OK	OK	0.86	OK	57.3	0.604	36.2	61.3	0.872
#4	0.998	10.1	10.1	OK	-0.030	OK	OK	38.5	0.485	34.5	61.3	0.792
61-6:1-ST-LT #1(g)	1.002	17.2	17.2	OK	OK	0.88	OK	67.7	0.642	37.8(h)	61.6	0.942
#2	0.999	12.9	12.9	OK	OK	OK	OK	49.0	0.56	36.6(h)	61.6	0.882
61-12:1-ST-LT #1(g)	1.001	12.4	12.4	OK	OK	OK	OK	48.9	0.561	38.2(h)	60.3	1.002
#3	1.002	11.3	11.3	OK	-0.047	0.87	OK	43.0	0.525	34.6	60.3	0.822
61-3:1-L-LT #3	0.999	11.6	11.6	OK	-0.045	0.87	OK	44.2	0.534	40.3	47.4	1.805
#4	1.000	10.1	10.1	+0.016	-0.044	OK	OK	38.3	0.485	37.6	47.4	1.572
61-6:1-L-LT #3	1.001	11.7	11.7	OK	-0.034	OK	OK	44.5	0.536	39.9	50.5	1.560
#4	0.998	11.5	11.5	+0.017	-0.023	0.89	OK	43.7	0.528	39.6	50.5	1.538
61-12:1-L-LT #3	0.997	11.8	11.8	OK	-0.005	0.84	OK	46.3	0.545	40.5	48.6	1.735
#4	0.999	11.2	11.2	OK	-0.012	OK	OK	42.5	0.521	39.2	48.6	1.628

(a) The initial stress intensity factor ($K_{initial}$) to be less than 0.6 K_q.

(b) The final stress intensity factor (K_{final}) to be less than 13.4 $ksi\text{-}in.^{1/2}$ or 0.6 K_q, whichever is smaller.

(c) Difference between the three crack length measurements at 1/4, 1/2 and 3/4B, to be less than 0.05 Ao.

(d) All points of fatigue crack are to be greater than 0.050 or 0.05 Ao in., whichever is greater, in front of machined notch root.

(e) Fatigue crack length at free surface to be greater than 0.9 Ao.

(f) The plane of the fatigue crack deviates from the plane of the machined notch by less than 10°.

(g) Initial specimens tested after modifying fatigue crack starter notch.

(h) Designated as K_{IC} value.

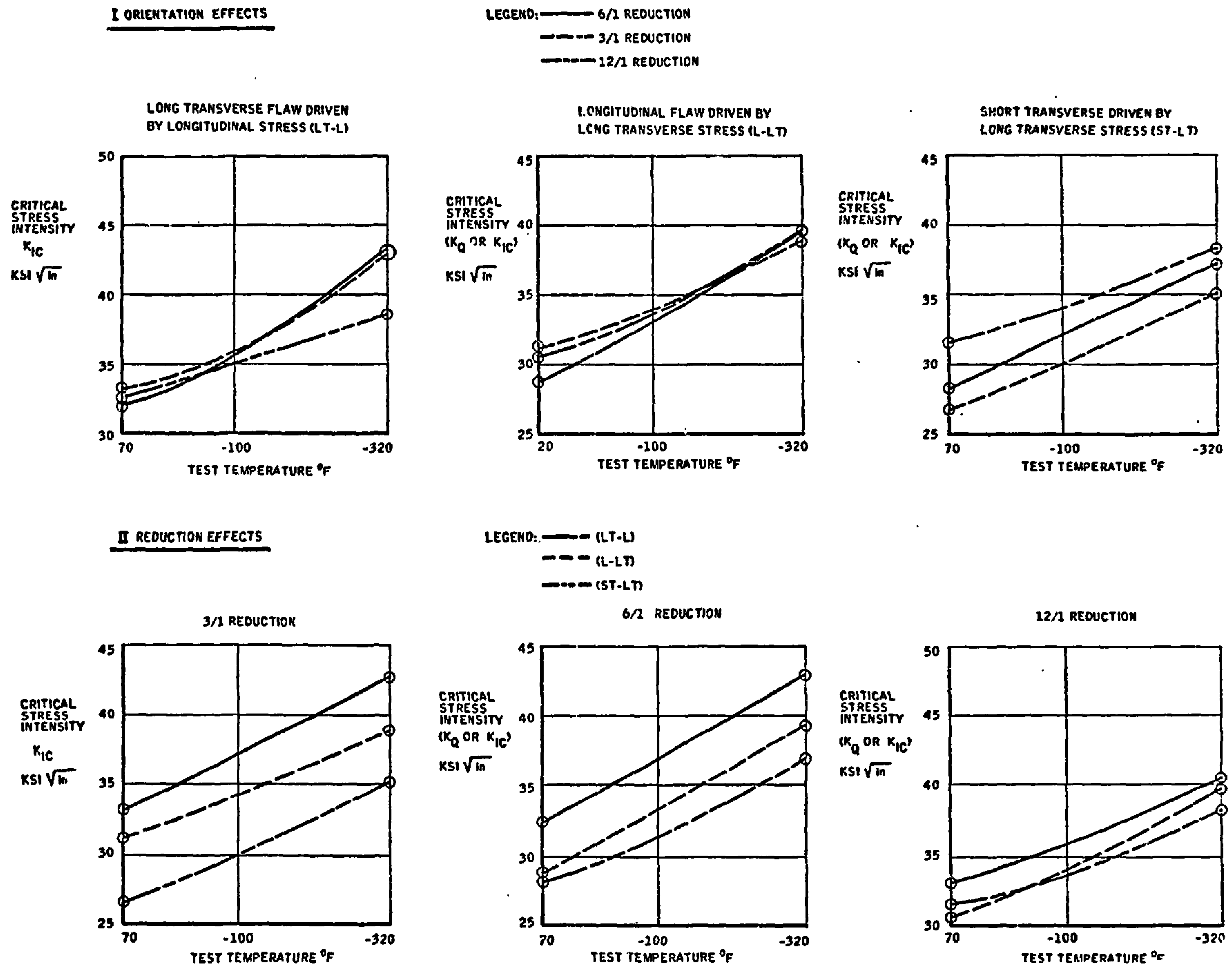


Figure 17 - Effects of Orientation and Reduction Upon AA6061-T6 Step Forging

the 6/1 reduction was 28 ksi $\sqrt{in.}$, the 3/1 reduction was 26.6 ksi $\sqrt{in.}$ At -320°F, all results increased to mean values of 38, 37, and 35.5 ksi $\sqrt{in.}$, respectively. The 3/1 and 12/1 reduction values at room temperature and the 3/1 reduction at -320°F were designated K_Q because of higher-than-allowed stress intensity during fatigue precracking. All other results were designated K_{IC}.

Specimens of LT-L orientation were used to investigate the influence of thickness. The results for one specimen were invalid because of the deviation of the crack plane. The second specimen conformed to the ASTM criteria except for: (1) high stress-intensity for final fatigue-crack-growth; (2) the fatigue-crack length of 0.88 Ao (instead of 0.90 Ao minimum); and (3) the A/W ratio. An ASTM E-24 committee representative was contacted to ascertain the validity of these results. It was the concensus that: (1) the high stress-intensity for final fatigue-crack growth would give a fictitiously high value for K_{IC}; (2) the fatigue-crack length of 0.88 Ao would have only a slight effect upon K_{IC}; and (3) values obtained by the recommended ASTM method and those obtained for A/W > 0.55 are in good agreement. The K_{IC} value for specimen 11 was about 10% higher (45.8 ksi $\sqrt{in.}$) than the average K_Q value for 1-in. thick specimens: this value, however, is within the normal scatter band obtained for the three sets of 1-in. specimens of similar orientation. Based upon this one test, it was assumed that the K_{IC} values will be 1.0 to 1.1 times the K_Q values of specimens meeting the thickness requirement. Thus, the use of K_{IC}* for the K_Q values obtained from specimens that conformed to all ASTM standards but thickness will result in a slightly conservative value.

f. Discussion of Results

(1) Effect of Temperature

With one exception, the K_Q, K_{IC}, or K_{IC}* of 7039-T63 decreased with decreasing temperature regardless of specimen orientation. This decrease in fracture toughness reduces the maximum, permissible critical flaw size. To offset decreased fracture-toughness, the operating stress at lower temperatures should be reduced. If the maximum stress level at the lower temperature is the same as at room temperature, the effect of the lower toughness is partially offset by the higher yield strength at that temperature.

In contrast to the behavior of 7039-T63, aluminum alloy 6061-T6 exhibits an increasing fracture toughness with decreasing temperature. This is a desirable characteristic for cryogenic temperature operation, and proof testing at room temperature is more critical than a similar test at cryogenic temperature.

Of particular interest was the anomalous behavior evident on the longitudinal and long-transverse orientations of the 6061-T6 step forging. The percentage of fracture shear-lip decreased as temperature decreased with corresponding toughness increasing. This disagrees with previous observations that the amount of shear lip decreases with corresponding decrease in fracture toughness.

(2) Effect of Chemistry Variations

The variations in chemical composition within specification limits showed small but significant differences. Heats low in magnesium and zinc showed superior fracture toughness in practically every orientation. However, the nominal and high-chemistry materials (i.e., Heats and CC) possessed acceptable fracture toughness values in all orientations except short transverse. Hence, it would be beneficial to decrease the existing chemistry limits to obtain improved crack-propagation characteristics.

The principal difference noted in fracture behavior was the delamination tendency in Heats BB and CC. There was an increased in the extent of delamination parallel to the direction of flaw growth as toughness values decreased. No differences in microstructure were noted, indicating that the difference in fracture toughness was principally a result of chemical composition.

(3) Effect of Forging Processes

(a) Subscale Pressure Vessel

A distinct difference in fracture toughness should be afforded by different forging processes and anisotropy differences. The flange is ring-rolled and the cylinder or wall section is extruded from the portion of the flange. The axially oriented specimens from the cylinder had approximately a 50% higher K_Q or K_{IC} value than specimens of similar orientation taken from the flange. The differences obtained for the circumferentially oriented specimens were not as great. From these results, it is apparent that the extrusion process improves fracture toughness for axial orientation without marked degradation of this property in the circumferential direction.

(b) Step Forging

An analysis of results for the step forging (especially for the 7039 alloy) is difficult because of the large number of invalid tests. The most striking difference is observed for the ST-LT orientation as a function of reduction and as a function of alloy. As the reduction is increased from 3/1 to 12/1, there is a gradual increase in toughness. The values of 6061-T6 in this orientation are almost double that for 7039 in a similar orientation.

The net effect of increased reduction for the step-forging is small and within the limits studied: there does not appear to be an optimum reduction to obtain maximum fracture-toughness. However, no detrimental reduction effects were evident for forge reductions greater than the 7/1 reduction currently used on the subscale forged and extruded wall section.

That the method of working influences toughness may be seen by comparing the cylinder wall with the step forging. The amount of reduction obtained during extrusion of the wall is 7/1 and is accompanied by higher toughness in the wall than in the step forging. The difference in magnitude of toughness because of orientation is small in the cylinder as compared to the step forging. The lowest values were obtained in the AR (i.e., axial precrack-radial load) or CR in the flange. This is comparable to the short-transverse direction in the step forging where the values are about half that of the chamber.

(4) Maximum Critical Crack Size

One of the primary uses of fracture-toughness results is to calculate the critical flaw size to determine whether available inspection techniques can detect flaws equal to or greater than the critical flaw size. If there is no subcritical flaw growth caused by the environment and/or fatigue, then the detection of all flaws equal to or greater than the critical flaw size will eliminate premature failure. For calculating critical flaw sizes, all assumptions were made so that conservative values would be obtained for both part-through-crack and internal flaws. Calculated critical flaw sizes assumed that the gross stress was equal to the yield strength, the best estimation of K_{IC}, and a/2C = 0.20 and 0.50. The two a/2C values were chosen to illustrate the effect of flaw configuration upon critical crack size.

(a) Part-Through-Crack

The part-through-crack is analogous to a thumbnail-configuration flaw occurring at the metal surface. The critical flaw size is calculated using the equation:

$$K_1 = 1.1\ \sigma_g \sqrt{\pi a/Q}, \qquad (1)$$

where:

K_1 = K_{IC} (plane-strain critical stress intensity),
σ_g = σ_{ys} (yield strength of material at 0.2% offset),
a = critical flaw depth,
$2C$ = critical flaw length,
Q = 1.11 for σ_g/σ_{ys} = 1.0 and $a/2C$ = 0.20,
Q = 2.25 for σ_g/σ_{ys} = 1.0 and $a/2C$ = 0.50.

By substitution and simplication, Equation 1 becomes:

$$a = \frac{Q}{\pi}\left(\frac{K_{IC}}{1.1\ \sigma_{ys}}\right)^2 = 0.35\left(\frac{K_{IC}}{1.1\ \sigma_{ys}}\right)^2 = 0.72\left(\frac{K_{IC}}{1.1\ \sigma_{ys}}\right).$$

(b) Internal Flaw

The internal or embedded flaw is completely contained inside the structure. The critical flaw size is calculated using the equation:

$$K_1 = \sigma_g \sqrt{\pi a/Q}\ , \qquad (2)$$

where:

K_1 = K_{IC} plane-strain critical stress intensity,
σ_g = σ_{ys} (yield strength of material at 0.2% offset),
a = one-half minor axis of embedded flaw,
$2C$ = major axis of embedded flaw,
Q = 1.11 for σ_g/σ_{ys} = 1.0 and $a/2C$ = 0.20,
Q = 2.25 for σ_g/σ_{ys} = 1.0 and $a/2C$ = 0.50.

By substitution and simplification, Equation 2 becomes:

$$a = \frac{Q}{\pi} \left(\frac{K_{IC}}{\sigma}\right)^2 = 0.35 \left(\frac{K_{IC}}{\sigma}\right)^2 \text{ or } 0.72 \left(\frac{K_{IC}}{\sigma_{ys}}\right)^2 .$$

The data collected for the flange and cylinder section of the subscale pressure vessel in this investigation were used to calculate critical flaw size. The average stress-intensity values designated as K_{IC}* (or K_Q where it was less than or equal to K_{IC}) were considered useful data. Where the K_Q designation was used because of short fatigue-crack length, the critical flaw size must be considered an approximation. The critical flaw sizes are listed in Table 32.

Crack growth through the thickness would be the limiting factor: therefore, the critical flaw sizes of interest would be those in the axial or circumferential orientation. Since the pressure-vessel operating temperature may be as low as -320°F, calculated critical flaw sizes at -320°F would be necessary for defining inspection requirements.

For both the axial and circumferential orientations, the use of either the Heats BB or AA chemistry would result in a minimum critical crack size at least as large as the above reported values. In the pressure vessel, the maximum stresses occur in the hoop direction; therefore, the minimum critical crack size for the axial designated specimens would be of primary importance.

(5) Anisotropy Effects

The preferential grain orientation produced by deformation (e.g., forging) can be directly related to the magnitude of fracture toughness. By selecting a forging process and schedule, it is possible to orient the direction of maximum fracture-toughness with the direction of principal stress and to minimize anisotropy.

TABLE 32

SUMMARY OF FRACTURE TOUGHNESS DATA AND CRITICAL FLAW SIZE FROM FLANGE AND CYLINDRICAL SECTIONS OF 7039-T63 ALUMINUM FORGING SUBSCALE PRESSURE VESSEL

Orientation	Chemistry I.D.	Section	Average Critical Stress K_{IC} ksi-in.$^{1/2}$	Yield Strength σ_{ys} ksi	Critical Flaw Size, For a/2c = .20, Part-Through-Crack a in.	For a/2c = .20, Part-Through-Crack 2c in.	For a/2c = .20, Internal 2a in.	For a/2c = .20, Flaw 2c in.	For a/2c = .50, Part-Through-Crack a in.	For a/2c = .50, Part-Through-Crack 2c in.	For a/2c = .50, Internal 2a in.	For a/2c = .50, Flaw 2c in.
Tests Conducted at 70°F												
Axial	AA	Flange	23.4(1)	55.2	0.052	.26	.126	.32	.107	.21	.259	.26
	AA	Cylinder	36.0(2)	57.7	0.112	.56	.271	.68	.231	.46	.559	.56
	BB	Flange	26.9(1)	54.4	0.071	.36	.172	.43	.146	.29	.354	.35
	BB	Cylinder	40.7(2)	55.8	0.154	.77	.373	.93	.317	.63	.768	.77
	CC	Flange	20.0(1)	56.8	0.036	.18	.087	.22	.074	.15	.180	.18
Circumferential B	AA	Flange	30.5	59.0	0.077	.38	.186	.46	.159	.32	.384	.38
	AA	Cylinder	35.7(2)	60.2	0.102	.51	.247	.62	.210	.42	.509	.51
	BB	Flange	4.18	56.9	0.156	.78	.378	.94	.321	.64	.778	.78
	BB	Cylinder	38.7(2)	59.8	0.121	.60	.293	.73	.249	.50	.604	.60
	CC	Flange	30.2	60.0	0.074	.37	.179	.45	.152	.30	.369	.37
Circumferential C	AA	Cylinder	32.9(3)	60.2	0.086	.43	.208	.52	.177	.35	.429	.43
	BB	Cylinder	36.9(3)	59.8	0.110	.55	.266	.66	.227	.45	.549	.55
Short Transverse	AA	Flange	23.8(3)	58.4	0.048	.24	.116	.29	.099	.20	.240	.24
	AA	Cylinder	21.2(3)	62.0	0.034	.17	.082	.20	.070	.14	.170	.17
	BB	Flange	34.4	53.8	0.118	.59	.286	.72	.243	.49	.589	.59
	BB	Cylinder	27.8(3)	58.0	0.066	.33	.160	.40	.136	.27	.329	.33
	CC	Flange	24.0	57.2	0.051	.26	.123	.31	.105	.21	.254	.25
Tests Conducted at -100°F												
Circumferential B	AA	Flange	29.4	64.6	0.060	.30	.145	.36	.124	.25	.299	.30
	AA	Cylinder	31.5	64.7	0.068	.34	.165	.41	.140	.28	.339	.34
	BB	Flange	37.4	62.0	0.105	.52	.254	.64	.216	.43	.524	.52
	BB	Cylinder	33.2	62.9	0.080	.40	.194	.48	.165	.33	.399	.40
	CC	Flange	27.7	65.8	0.051	.26	.123	.31	.105	.21	.254	.25

(1) Designated as K_Q value as fatigue crack deviated by more than 10° from the plane of the machined notch.

(2) Designated as K_{IC} values because the thickness was less than $2.5\ (K_{Ic}/\sigma_{ys})^2$.

(3) Designated as K_Q because the fatigue crack length was too short.

TABLE 32 (cont.)

Orientation	Chemistry I.D.	Section	Average Critical Stress K_{IC} ksi-in.$^{1/2}$	Yield Strength σ_{ys} ksi	Critical Flaw Size: For a/2c = .20, Part-Through-Crack a in.	For a/2c = .20, Part-Through-Crack 2c in.	For a/2c = .20, Internal 2a in.	For a/2c = .20, Flaw 2c in.	For a/2c = .50, Part-Through-Crack a in.	For a/2c = .50, Part-Through-Crack 2c in.	For a/2c = .50, Internal 2a in.	For a/2c = .50, Flaw 2c in.
Circumferential C	BB	Cylinder	30.7(2)	62.9	0.069	.34	.167	.42	.142	.28	.344	.34
Tests Conducted at -320°F												
Axial	AA	Flange	16.8(1)	66.8	0.018	.09	.044	.11	.037	.07	.090	.09
	AA	Cylinder	24.1	73.1	0.032	.16	.077	.19	.066	.13	.160	.16
	BB	Flange	15.0(1)	65.2	0.015	.08	.036	.09	.031	.06	.075	.08
	BB	Cylinder	26.7	67.0	0.046	.23	.111	.28	.095	.19	.230	.23
	CC	Flange	10.9(1)	68.0	0.007	.04	.017	.42	.014	.03	.035	.04
Circumferential B	AA	Flange	25.8	72.0	0.037	.18	.090	.22	.076	.15	.185	.18
	AA	Cylinder	24.9	70.3	0.036	.18	.087	.22	.074	.15	.180	.18
	BB	Flange	36.2	68.7	0.080	.40	.194	.48	.165	.33	.399	.40
	BB	Cylinder	22.6	74.5	0.027	.14	.065	.16	.056	.11	.135	.13
	CC	Flange	29.9	73.3	0.048	.24	.116	.29	.099	.20	.240	.24
Circumferential C	BB	Cylinder	31.9	74.5	0.053	.26	.128	.32	.109	.22	.264	.26
Short Transverse	AA	Flange	16.8	69.4	0.017	.08	.041	.10	.035	.07	.085	.08
	AA	Cylinder	12.2	66.8	0.010	.05	.024	.06	.021	.04	.050	.05
	BB	Flange	25.2	63.0	0.046	.23	.111	.28	.095	.19	.230	.23
	BB	Cylinder	12.0	63.7	0.010	.05	.024	.06	.021	.04	.050	.05
	CC	Flange	18.8	68.2	0.022	.11	.053	.13	.045	.09	.110	.11

(1) Designated as K_Q value as fatigue crack deviated by more than 10° from the plane of the machined notch.
(2) Designated as K_{IC} values because the thickness was less than 2.5 $(K_{Ic}/\sigma_{ys})^2$.
(3) Designated as K_Q because the fatigue crack length was too short.

The flange area of the pressure vessel has a more complex stress pattern than the chamber wall and good fracture-toughness in all directions is desirable. A review of the results of fracture toughness of the flange (with only Heat BB considered) shows a good balance in magnitude of fracture toughness although a degree of anisotropy does exist. Of particular interest are the high values obtained in the short-transverse direction which minimizes the dangers of end effects.

In the chamber wall, the highest values of fracture toughness are obtained in the axial orientation although the principal stresses in service are in the circumferential direction. Comparing the results of Heat BB in the circumferential and axial directions, it is noted that the difference because of orientation is small. The high axial values were not obtained to the detriment (to any large degree) of the circumferential values.

The largest degree of anisotropy of fracture toughness was found in the step forgings of the 7039-T63 alloy. The very low values in the short-transverse direction at -320°F indicate that the use of this type of forging process for this alloy is unsuitable for cryogenic applications. The behavior of 6061-T6 is greatly dissimilar. The fracture-toughness values are greater than those for 7039 in all directions. In the short-transverse direction, the toughness of 6061 is greatly superior to the 7039 alloy, and the use of 6061 would greatly enhance the reliability of components made by the hand-forging process.

g. Conclusions

1. The highest average K_{IC} in the ring forgings was obtained from Heat BB which had magnesium and zinc contents near the minimum specification limits.

2. The fracture-toughness behavior of the two alloys studied are dissimilar. The magnitude of toughness decreased with decreasing

temperature for 7039-T63, whereas toughness increased with decreasing temperature for 6061-T6.

3. No optimum reduction was found for the step forging to obtain a marked increase in toughness.

4. The cylinder wall had good toughness in all orientations.

5. The short-transverse orientation in the hand forging had the lowest toughness.

6. Critical crack sizes calculated from toughness values are within the detection limits of nondestructive testing techniques.

h. Recommendations

1. Based upon plane-strain fracture-toughness tests only, is is recommended that 6061-T6 be used in place of 7039-T63.

2. For maximum plane-strain fracture toughness in the 7039-T63, it is recommended that a chemistry comparable to that of the Heat BB forging be used: i.e., a chemistry where both the magnesium and zinc contents were at the minimum allowable. Because of anisotropy, it is suggested that the direction of maximum stress be compatible with the K_{IC} value for that direction.

I. NOZZLE MATERIAL

1. AISI 347 Sheet

The AISI 347 sheet specimens were tensile tested at the Oak Ridge National Laboratories. The specimens were from three heats (28241-2, 42449, and 42656) and the specimens were tested at temperatures of -320°, -100°, -52°, 75°, 800°, 1600°, and 2000°F. Mechanical property data made available were for yield strength, ultimate strength, uniform elongation, total elongation, and total gage elongation. In addition, two grain directions (i.e., parallel with rolling and transverse to rolling) were presented for each of the heat-temperature-property combinations.

The purpose of the analysis was to derive 99/95 design allowable data for the yield-strength results and mean-value results for other mechanical properties.

The average 0.2% offset yield strengths reported are shown in Table 33. The comparatively high cryogenic and room-temperature results obtained for Heat 42656 resulted in an excessively high heat-to-heat variation that prevents combining yield-strength data. Individual results for each heat (considering only within-heat variations) were analyzed and $\bar{X}$- KS results were obtained for each heat. ORNL has shipped all test specimens and a final report to ANSC. After receipt, the test specimens will be subjected to metallographic examination to determine why Heat 42656 material differs from material from Heats 28241-2 and 42449.

TABLE 33

AISI 347 0.2% OFFSET YIELD STRENGTH, KSI

Test Temp °F	28241-2 Direction of Rolling		42449 Direction of Rolling		42656 Direction of Rolling	
	P*	T**	P	T	P	T
-320	50.8	51.8	52.7	50.2	59.9	57.1
-100	49.6	49.6				
- 52			42.5	44.3	48.9	50.5
75	36.6	36.7	35.8	36.9	39.5	41
800	27.8	25.5	28.1	28.6	24.3	25.3
1600	9.2	9.7	10.1	10.1	8.9	9.1
2000	2.0	1.9	2.1	1.8	2.2	2.2

*P = Parallel

**T = Transverse

2. ARMCO 22-13-5 Alloy

A program and schedule have been developed for the preliminary evaluation of ARMCO 22-13-5 alloy. While the results obtained from this program using 1-in.- and 3-in.-thick bar will not develop nozzle design-allowables, they will indicate potential problem areas that may require further investigations and will verify the properties of the alloy.

Both the change in the alloy's mechanical properties after it is subjected to thermal annealing cycles (using retort cooling rather than a water quench) and the effects of furnace-brazing cycles on its mechanical properties will be determined. The technology braze cycles that will be simulated are described in AGC Specification 90006. In summary, they consist of three cycles: the first at 1850°F; the second at 1825°F; and the third at 1750°F. The simulated braze cycles that will be used will duplicate the heating and cooling rates obtained for technology nozzle SN-27. The proposed NERVA braze cycles will use a 1950°F braze temperature for the first braze cycle. The rates of heating and cooling and the braze temperatures for the second and third cycles will be the same as for the simulated technology braze cycles. Ultimate tensile strength, 0.2% offset yield strength, percentage of elongation, reduction in area, and a stress-strain curve to yield strength will be obtained for the test conditions shown in Table 34.

In addition to tensile testing, a preliminary investigation into determinations of magnetic permeability, hydrogen embrittlement, effects of radiation, stress-corrosion cracking resistance, brazeability, weldability, and thermal conductivity are being accomplished.

An adequate amount of ARMCO 22-13-5 material to accomplish the above program has been received. This material was supplied with certified chemical analysis. Preliminary metallographic examination has determined the structure to be normal, possessing a uniform ASTM Number 8 grain

TABLE 34

PROPOSED MECHANICAL PROPERTIES TESTS ON BAR
ARMCO 22-13-5

Test Temp	Condition	Number	Serial No.
-320°F	As received (mill annealed)	5 ea	C1-C5
Room		5 ea	C6-C10
600°F		5 ea	C11-C15
-320°F	As received + 2050°F anneal	5 ea	A16-A20
Room	+ retort cooling	5 ea	A21-A25
600°F		5 ea	A26-A30
-320°F	As received + 2050°F anneal	5 ea	D31-D35
Room	+ retort cooling + technology	5 ea	D36-D40
600°F	furnace braze cycles	5 ea	D41-D45
-320°F	As received + 2050°F anneal	5 ea	B46-B50
-100°F	+ retort cooling + NERVA	5 ea	B51-B55
Room	braze cycles	5 ea	B56-B60
600°F		5 ea	B61-B65

size. Fabrication of all specimens (excluding the weldability specimen) and normal tensile testing (excluding radiation effects, hydrogen embrittlement, stress-corrosion test, and weldability tests) will be accomplished on an accelerated basis.

3. Creep Testing of AISI 347 Sheet

Battelle Memorial Institute completed 24 preliminary creep tests on AISI 347 sheet (0.016 in.) at 1200°, 1400°, and 1600°F in high-purity hydrogen (-75°F dew point). This was the first portion of a program to statistically define the creep resistance of this material in terms of 1.0% total deformation curves on a category "A" basis (99/95). The primary objective was the determination of stress for 1.0% deformation in 100 hr. A second objective was to take sufficient measurements at 1-min intervals to define the early portion of the creep curve for use in stress analysis.

Three heats of 0.016-in.-thick material were procured from Ulbrich Inc., each rolled from 0.125-in. stock from three different mills.

Stress-versus-time curves for 1.0% deformation are shown in Figure 18 and supporting data in Table 35. At 1200°F, all heats (A, B, and C) show equivalent creep resistance. However, at both 1400°F and 1600°F, heats B and C demonstrated significantly higher creep resistance than heat A. For example, the extrapolated stress for 1.0% creep in 100 hr for heats B and C is 57.0% higher at 1400°F and 144.0% higher at 1600°F than the actual values for heat A. It was by chance that the most conservative heat A was selected for the majority of preliminary testing and hence will be incorporated into the stress calculations for thermal buckling by North American Rockwell, Columbus.

The metallurgical reasons for this difference are being investigated as the second series of tests are continued at General Electric, Cincinnati.

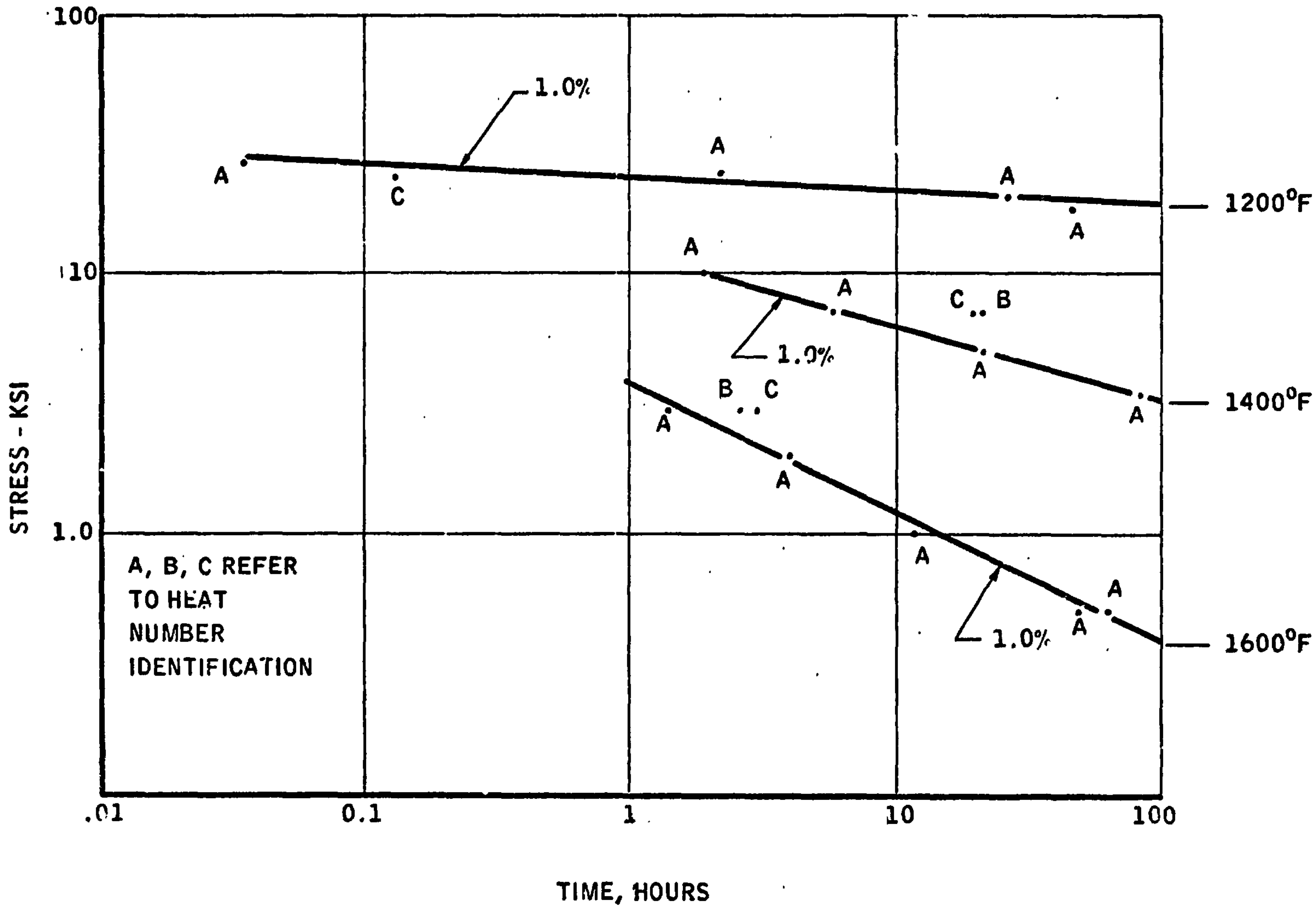


Figure 18 - Creep of 0.016-in. AISI 347 Sheet in Gaseous Hydrogen, Triple-Braze Heat-Treated

TABLE 35

CREEP-TEST DATA ON AISI 347 SHEET (01016-in.)
(TRIPLE-BRAZE, HEAT-TREATED)

Temp (°F)	Stress ksi	Heat ID	Time (hours) to Total Deformation of 0.5%	1.0%	3.0%	Rupture	Remarks
1200	27	A	On Loading	0.035	1.6	34.9	Failed
	24	A	0.75	2.2	40	-	Discontinued at 42.5 hr
	24	B	On Loading	On Loading	53	-	Discontinued at 59.5 hr
	24	C	On Loading	0.13	55.1	-	Discontinued at 55.1 hr
	20	A	2.9	26.5	-	-	Discontinued at 110.3 hr
	18	A	12.5	46.5	-	-	Discontinued at 110.5 hr
	16	A	-	-	-	-	0.407% in 115.2 hr
	14	A	-	-	-	-	0.206% in 117.3 hr
1400	10	A	0.95	1.9	5.7	23.5	Failed
	7	A	2.9	5.8	17.5	-	Discontinued at 22.6 hr
	7	B	11.5	21.0	51.0	-	Discontinued at 54.0 hr
	7	C	12.0	20.0	39.5	-	Discontinued at 50.3 hr
	5	A	10.7	21.5	60.7	-	Discontinued at 60.7 hr
	3.4	A	40.0	82.0	-	-	Discontinued at 110.0 hr
	3.1	A	23	50	-	-	0.982% in 114 hr
	2.5	A	56	-	-	-	Discontined at 114 hr
1600	3	A	0.67	1.4	5.6	-	Discontinued at 5.6 hr
	3	B	1.2	2.6	10.5	-	Discontinued at 10.5 hr
	3	C	0.85	3.0	9.0	-	Discontinued at 9.0 hr
	2	A	2.0	3.9	12.1	-	Discontinued at 12.1 hr
	1	A	6.6	11.7	32.0	-	Discontinued at hr
	1	C				-	Discontinued at hr
	0.5	A	13.0	61.0	-	-	1.65% in 141 hr
	0.5	A	28.5	48.5	-	-	2.5% in 117 hr
	0.5	C	139.0	-	-	-	Discontinued at hr

J. LINES, ORBITAL-WELD PROGRAM

As reported in ANSC Report S131-PR3, a demonstration welding program was completed to evaluate the Liquid Carbonic and Astro-Arc orbital TIG tube welders for NERVA line use. The Astro-Arc system was tentatively selected as offering the best potential. The objective of the line-welding program is to develop compact orbital weld heads and process techniques to accomplish line welding without filler-wire additions. An additional goal is to develop joint configurations and compact orbital tube-cutting devices to establish criteria for welded semi-permanent joint technology, wherein sections of the line assembly may be removed, replaced, and rewelded at least five times without reducing structural strength or introducing contamination to the interior of the lines.

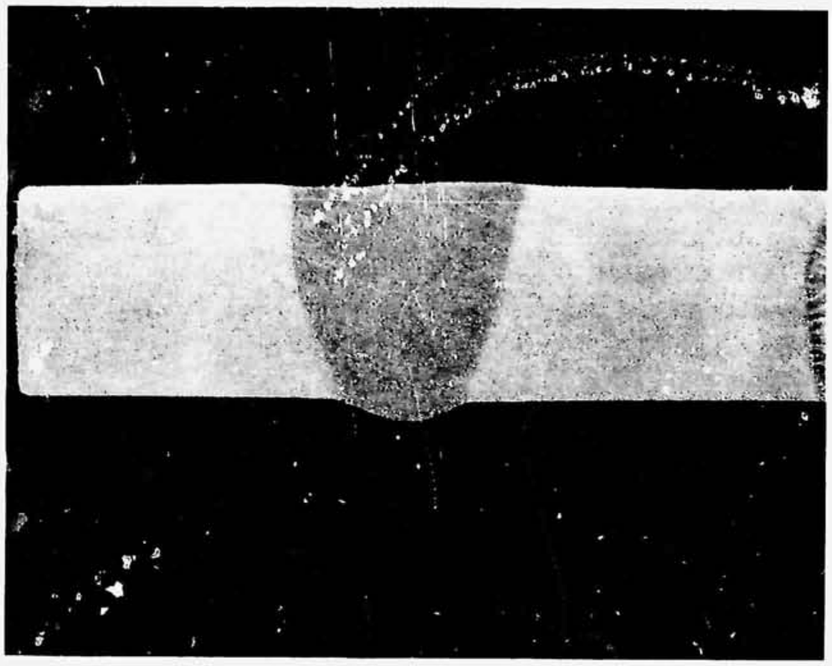
New developments in orbital-weld and tube-cutting equipment and techniques are being investigated. A program is being formulated to determine the effect of the cut and reweld technique upon tube properties.

Figure 19 illustrates the capability of an orbital-type TIG welder to make a full-joint-thickness weld, with no filler added, in a square butt joint of a 0.250-in.-thick wall and 5.5-in.-diameter aluminum tube utilizing the high-frequency current pulsation mode.

Figure 20 shows one of the Inconel 718 tube weldments made by the orbital-weld process during the demonstration program.

Figure 21 shows a photomacrograph and a photomicrograph of one of the Inconel 718 tube welds. The full-joint-thickness weld in the 0.050-in.-thick and 6-in.-diameter 718 tube (without filler) should be noted. Table 36 records the tensile properties of transverse-welded specimens removed from the tube.

Welding also was completed on ten aluminum alloy 6061 test plates for welded, flexural-fatigue-specimen testing.



MAT'L:	ALUM-5086-H32 WELDED TUBE
JOINT:	SQUARE BUTT WALL THICKNESS 0.250, OD DIA 5.5 IN
CURRENT MODE:	HIGH FREQUENCY CURRENT PULSATION DC
	MAGNIFICATION 4X

NOTE FULL JOINT THICKNESS OF WELD
WITH NO FILLER ADDED

Figure 19 - Orbital TIG Weld in Aluminum Tube

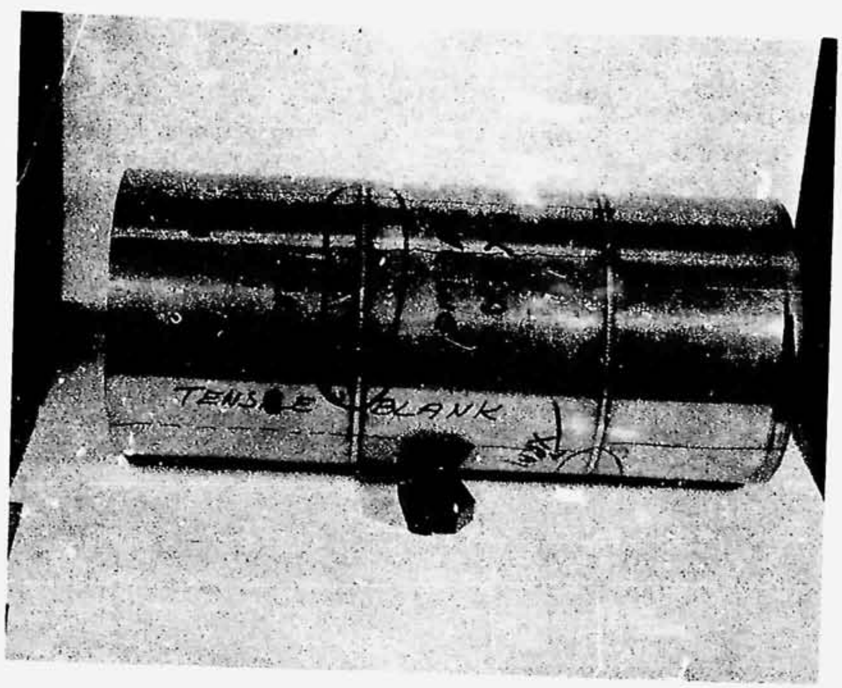
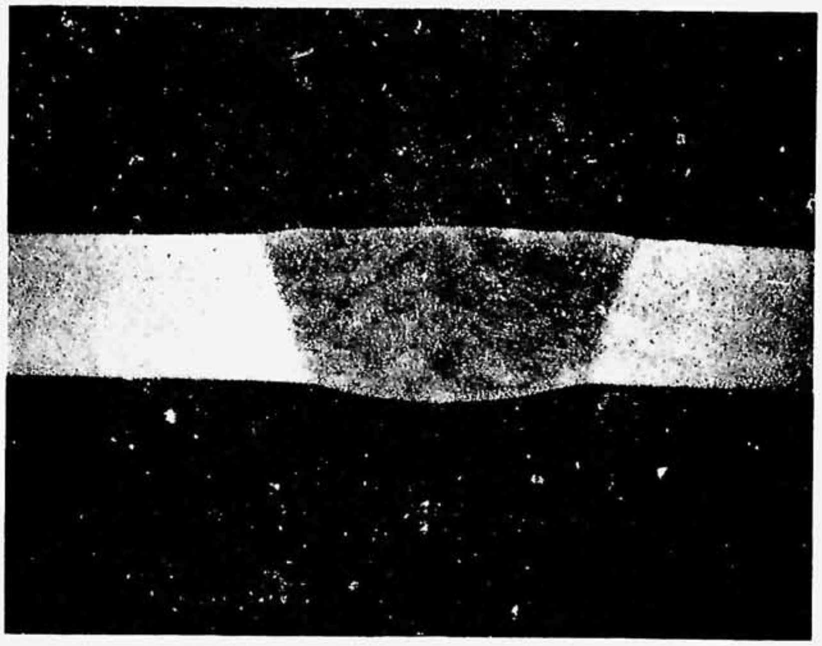


Figure 20 - Typical Orbital TIG Weld in Inconel 718 Tube, 0.05-in. Wall and 6-in. Diameter, No Filler Added



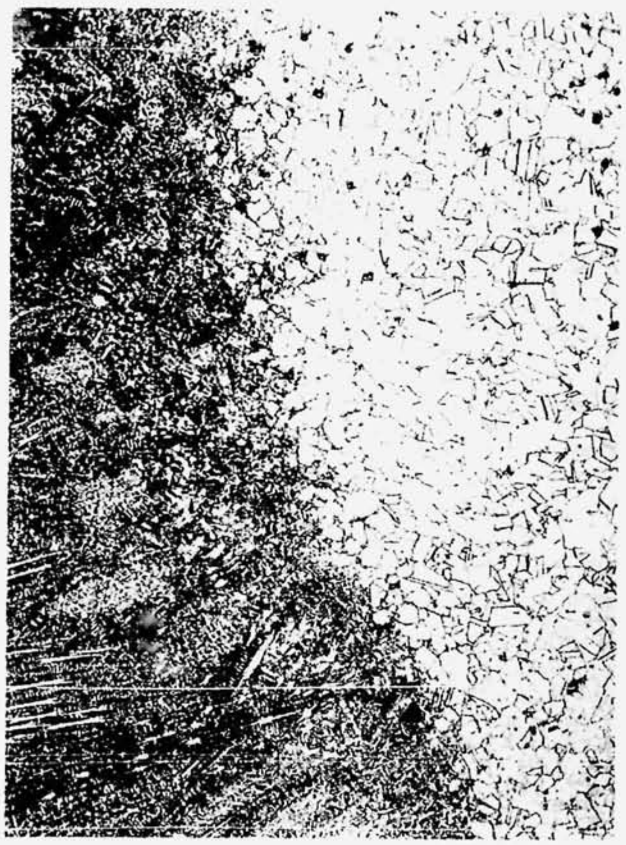


Figure 21 - Inconel 718 Tube Welds Showing TIG Weld In Square Butt, 0.05-in. Wall, 6-in. Diameter, (Above, Photomacrograph, 15X) and Weld at Heat-Affected Zone (Below, Photomicrograph, 100X)

TABLE 36

TENSILE PROPERTIES OF INCONEL 718 WELDED SHEET

Specimen Ident	UTS ksi	YS ksi	EL in 2 in. %	Location of Failure
1	177.0	161.2	10	HAZ
2	182.0	163.4	12	PM
3	176.1	157.1	9	HAZ

Material: Inconel 718 - 0.050 wall x 6-in. dia tube

Joint: Square butt, no filler added

Postweld HT Treatment: Solution heat treat at 1950°F, 60 min cool in air

Age at 1350°F - 8-10 hr. Furnace cool to 1200°F. Hold at 1200°F until total aging time of 20 hr has elapsed. Air cool to RT.

K. VALVE AND ACTUATOR MATERIALS

High-Speed Tensile Testing of Ti 5Al-2.5Sn (ELI)

A program was initiated to study the effect of high-speed actuation combined with cryogenic temperatures on Ti 5Al-2.5Sn (ELI). A purchase order was issued to the Denver Research Institute of the University of Denver for this work. Tensile specimens, from the tangential direction of a titanium forging, will be tensile tested at a speed of 1200 ft/min at temperatures of ambient, -100°, and -320°F. Specimen configuration, test setup, and testing will be under cognizance of materials and processes personnel.

L. SHIELD MATERIALS

The structural material for the external shield was generally assumed to be AISI 347 stainless steel. Although aluminum provides a substantial reduction of secondary radiation, the anticipated temperatures above 500°F are excessive for aluminum alloys.

The use of a commercial grade stainless-clad aluminum plate was found to be a potential compromise with satisfactory high-temperature properties of stainless steel to significantly reduce the shield temperature caused by gamma radiation. While sufficient data were not available at the higher temperature to forecast design properties, the aluminum alloy 3004 clad with type 304 stainless steel is reported to be useful to temperatures above 750°F for short periods of time. The LiH containers, as well as upper-surface structure, could be fabricated from the clad aluminum plate.

The only materials with significantly lower contributions to the radiation levels above the shield would be beryllium (which is too brittle), beryllium-aluminum "Lockalloy," and zirconium alloys which would add to fabrication cost and development time. The top cover plate of the shield which is assembled with bolts could be fabricated from Lockalloy to save weight and reduce the radiation source strength above the shield.

The use of composite materials (e.g., graphite fiber-aluminum or boron-aluminum) was not suggested because of limited experience, substantial development time, and cost.

M. FRICTION AND WEAR

An evaluation of friction and wear of materials for gimbal-line applications was conducted by simulated load-surface speed with "stop-start" motion cycles on machineability lathe with test method, apparatus and specimens previously described.** The objective of the tests was to determine the friction and wear-life characteristics imposed by the higher loading of this application.

Hard-chromium-coated Inconel 718 was tested in contact with electrodeposited (dalic) gold of 0.0005-in. thickness. The specimen was loaded to 900 lb/in. and cycled for two rotations of the mandrel before it was stopped and restarted. Minimum surface speed was 25 ft/min. Hertz contact stress was calculated by formula for a cylinder against flat plate ($S = 3190 \sqrt{P/D}$)* and was about 68,000 psi. The specimens were enclosed in a pure helium environment and tested at ambient temperature.

The results of three test runs are plotted in Figure 22 and show the characteristic drop in dynamic friction coefficient from about 0.12 to 0.08 before an escalation of friction 11 to a point of wearing out. Wearing through of the gold plate occurred after approximately 200 test cycles. Static friction values were equivalent to dynamic friction, indicating there was no increase of friction at the start of test cycle. Also shown is the variability that can be expected from test to test. The results were quite consistent with all friction coefficients within the range of 0.09 to 0.07. Also, wear-life results were consistent with some variation being the result of interpretation of the friction-climb section of the curve. The 0.15 value of friction was selected for wear-life determination and provided a wear life of above 200 test cycles. A source of test variation was identified as load variation

*Formulas for Stress and Strain, R. J. Rourk, 4th Ed., Table XIV, Case 4.
**AGC Report RN-S-0311

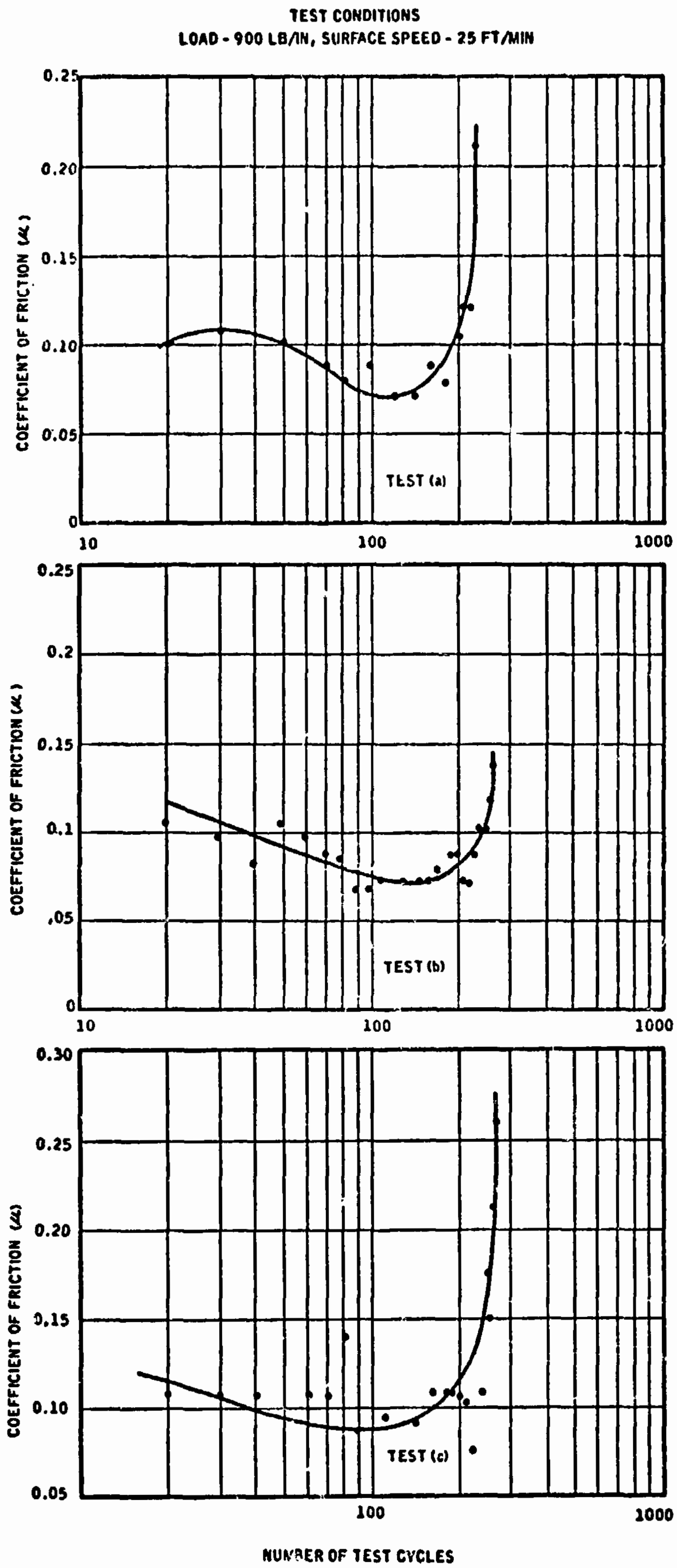


Figure 22 - Friction and Wear of Hard-Chromium-Coated Inconel 718 vs Gold-Plated Inconel 718

caused by mandrel eccentricity. This is maintained within a 0.0001 total indicator reading to prevent any effect or test results.

Ion-deposited-gold on 301 stainless steel has also been friction and wear tested. Electron-beam, as well as ion-plated gold by BMI, was evaluated in 5 and 10 micron-deposited thicknesses. All tests were conducted at lower loads of 120 lb/in.

Literature indicated that a much longer wear life and a somewhat lower friction value should be evident as a result of superior substrate cleanliness and bonding with pure, softer gold deposition. However, all tests indicated far less wear life with ion-deposited gold than with dalic-deposited gold. Tests sustained, at most, 10-20 cycles before wearing through of the gold occurred. Appearance of the "wear-through" area showed oxidation and nonadherence, indicating the presence of substrate oxidation and, thus, the cause of coating unbonding. Further investigation is being conducted to determine whether better processing can be applied to provide bond improvement.

N. THERMAL PROTECTION COATINGS

Two thermal-protection-coating candidates (plasma-deposited Al_2O_3 and paint-applied Z-93) are being evaluated to determine their worth as stress-corrosion-protection coatings. The predicted radiative properties of both materials were reported in ANSC Report S131-PR3.

Al_2O_3 and Z-93 were applied to tune-fork stress-corrosion specimens of aluminum alloy 7039-T63 for evaluation both in a salt cabinet (5% neutral NaCl) and sea-coast environment at KSC. The Al_2O_3 was plasma-deposited upon a grit-blasted surface. A low-temperature spray process was used to deposit on a chemically prepared surface. The Z-93 was cured at ambient temperature although it may be cured at an elevated temperature for a harder finish. However, the curing temperature is relatively close to the aging temperature of the aluminum alloy 7039-T63 to which it was applied.* Only the plasma-deposited Al_2O_3 specimens have been exposed. The results show that this coating system, which includes grit-blast surface preparation, can significantly increase specimen life in stress-corrosion conditions.

Specimens coated with both Al_2O_3 and Z-93 have been placed on the beach at KSC, not only to determine stress-corrosion-protection qualities in a marine atmosphere, but also to determine the weathering effects of a marine atmosphere upon the radiative and adhesion properties of these coatings.

Four experimental inhibitors are being evaluated in conjunction with the thermal-protection coatings to offset the possible porosity of these inorganic coatings. These compounds are miscellaneous amine salts of carboxylic or alkyl phosphoric acids and have been applied to scratched specimens of the plasma-deposited Al_2O_3. The specimens are currently being evaluated in salt-spray environments.

*Results to date from salt-spray exposure were reported in Section H.

O. CONTAMINATION AND CORROSION CONTROL

The NERVA Contamination and Corrosion Control Plan (Data Item S-021-CP090290) was revised to include material requested by SNPO-C as a result of review of the preliminary draft. Provisions were made in the outline of the plan for a major expansion of scope and content in CY 1971. Contamination and corrosion control will now include space usage, biological and radiation contamination control, and the nuclear subsystem.

An analysis is planned in CY 1971 for determining the feasibility of using a spare engine for contamination and corrosion studies in support of trend-data analysis.

Major revisions to the plan included expansion of the following areas:

1. Identification of disciplines involved in analysis to establish allowable levels of contamination.

2. Consideration of upstream contaminants from the propellant feed tank.

3. Responsibilities of quality assurance in contamination control.

4. Precision cleaning and control of special processes.

5. Identification of disciplines involved in recognition and control of corrosion mechanisms.

6. Clarification of the definition of galvanic corrosion.

7. Corrosion-control treatment of hardware fabricated from aluminum forgings, bar, or plate.

8. Revision of the training outline to include additional emphasis upon the origin of contamination, mechanism of contamination migration, and retention and criteria for microbial contamination.

P. NASS FACILITY

1. Low-Cycle Fatigue

Cyclic strain behavior of AISI 347 stainless steel is necessary to enable design of the NASS primary ejector for a life of 1000-to-2000-cycles at operational temperatures near 1500°R. General Electric Company fatigue data which plotted strain-range versus cycles-to-failure for test temperatures of room temperature, 392°, 662°, 932°, and 1112°F were located. SNPO-C direction permitted the use of these curves using 50% of the strain-range values. This scale is shown in the figure with an 80% scale used for design allowables in the absence of statistically computed data.

2. NASS-EDS Drawing Package and Specification Review

NASS duct drawings and fabrication and installation specifications were reviewed by materials and processes personnel for correct application of materials and fabrication processes. Suggested corrections and recommended changes to satisfy PDK requirements were indicated. The curved TIG-welded coolant channel was presented and possible causes of distortion (e.g., high process heat, improper hold-down) were discussed.

Also present were the weld specimen chronology and primary-ejector coolant status, which defined the problems of fabrication, residual stresses, and cyclic life that must be considered in the resolution of the coolant channel fabrication problem. ANSC was directed to redefine the minimum required weld and to proceed with the MIG-weld sample. However, direction was received that no other sample effort was to be undertaken without prior customer concurrence. It was emphasized that the requirement for coolant channel acceptance criteria that would also determine repairability of the welded structure should also be defined.

This development work established that the "L"-channel fillet welds could be held to closer tolerances than those required by the applicable drawing. It was also established that the closure welds, which require fillet welds in an access space of 1/2-in. wide by 1-in. deep, can be accomplished by the manual tungsten-arc process.

3. NASS Primary-Ejector Weld-Sample Fabrication

A weld test plan and procedure were prepared for the fabrication of the NASS primary-ejector demonstration sample. These documents cover the procedure to evaluate weld size and the tolerance criteria involved in the design and fabrication of the "L"-channel duct configuration. The procedures suggested the evaluation of two welding processes: inert gas non-consumable (GTAW); and (2) inert gas consumable (GMAW).

A primary ejector "L"-channel weld sample was initiated and completed, investigating both semi-automatic GTAW and manual GTAW weld processes. The sample (0.050-in. by 18-in. by 36-in.) was curved to simulate the cylindrical configuration of the primary ejector. Nine channels were manually tack welded and TIG welded to the curved inner sheet as shown in Figure 23. The sheet material from which the channels and inner sheet was fabricated was AISI 347 stainless steel per MIL-S-6721 (Heat 42730). Type 349 filler wire (per MIL-R-5031, Cl.6) was utilized for wall welding. Welding parameters were difficult to control because of the excessive distortion encountered during TIG welding. Distortions associated with the welding are shown in Figures 24 and 25.

The sample was presented 6 August at a NASS Program Review Meeting at Las Vegas, Nevada.

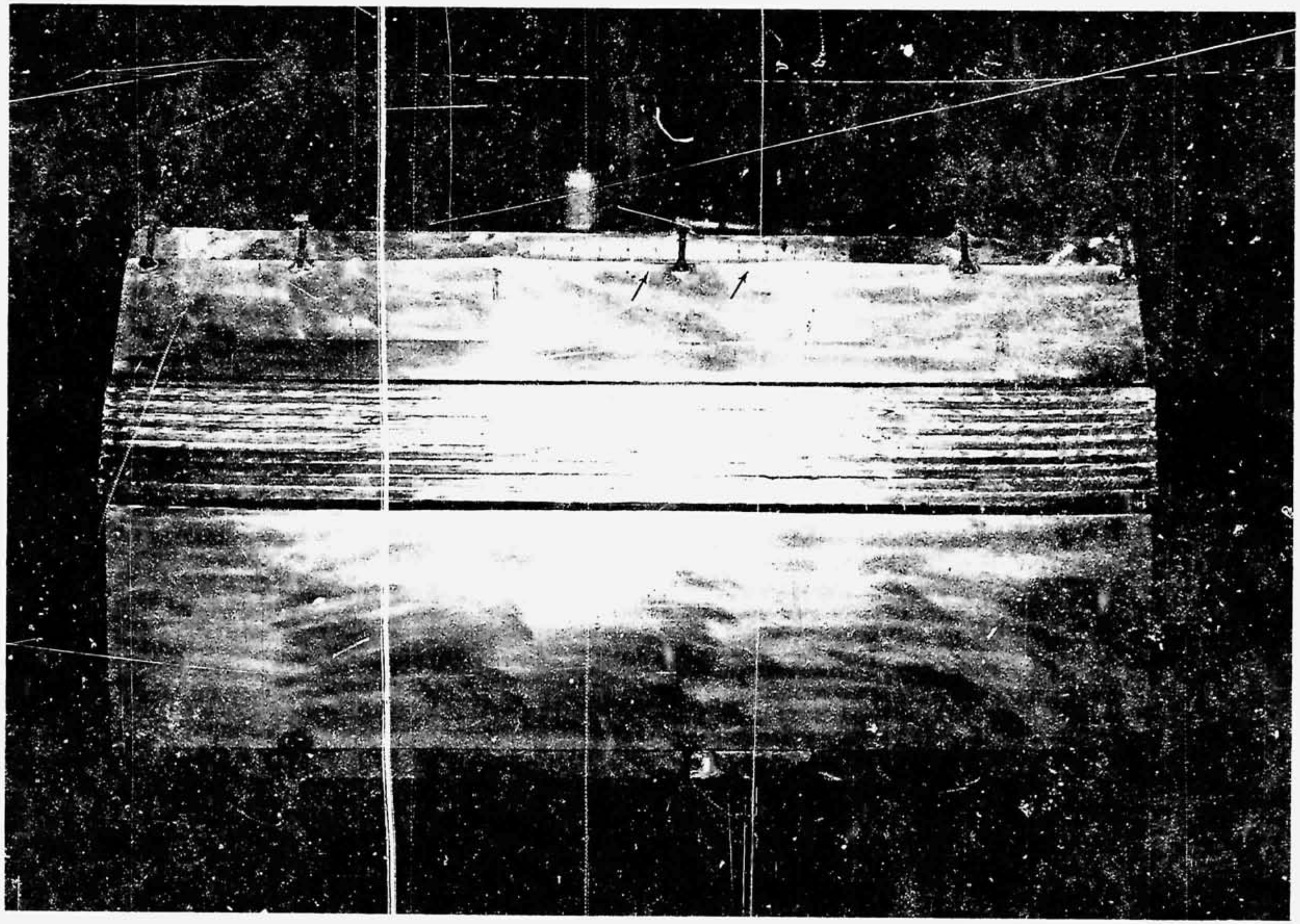


Figure 23 - Distortion Effects Associated with Nine-Channel Welds

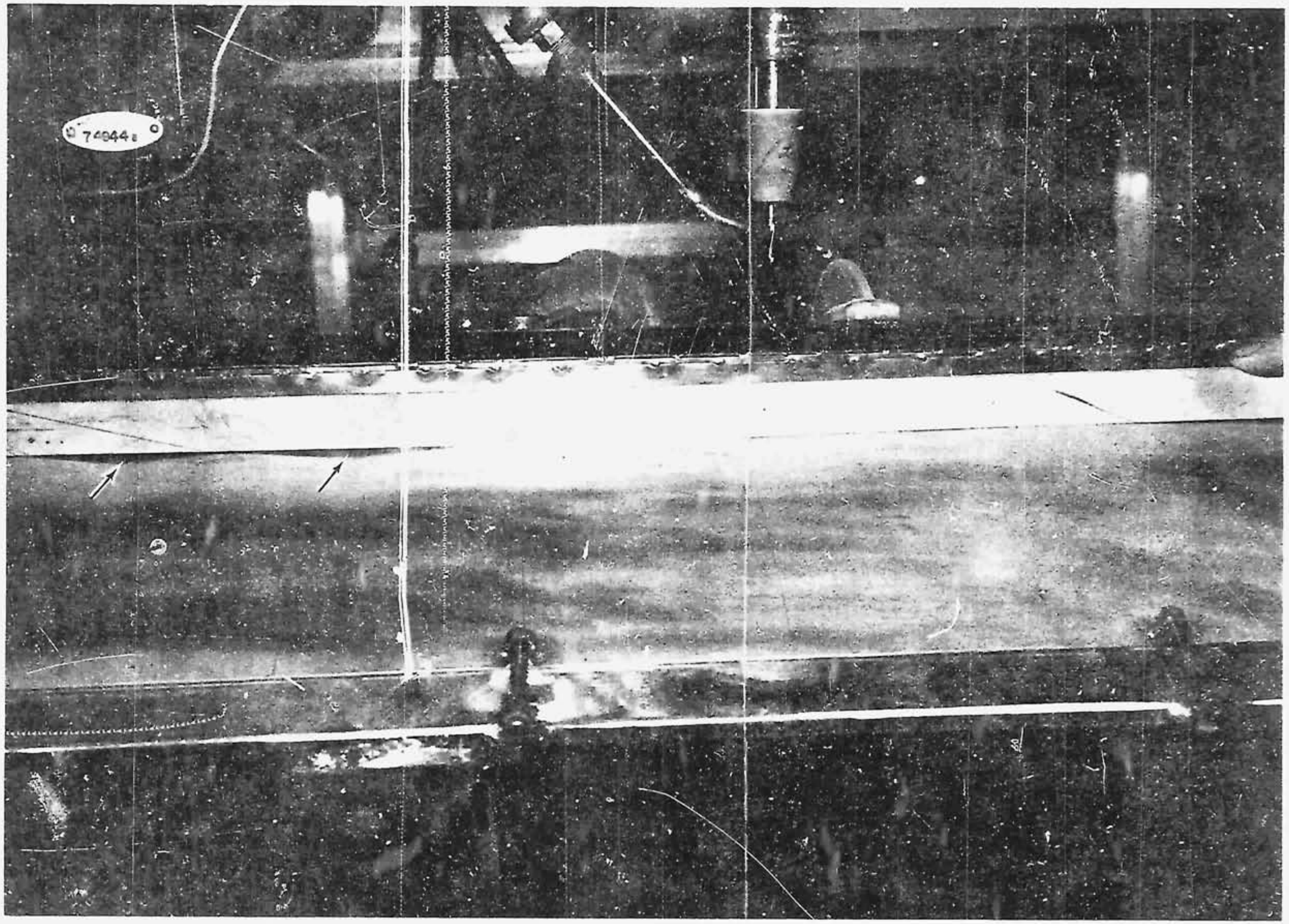


Figure 24 - Distortion Effects Associated with Welding AISI 347

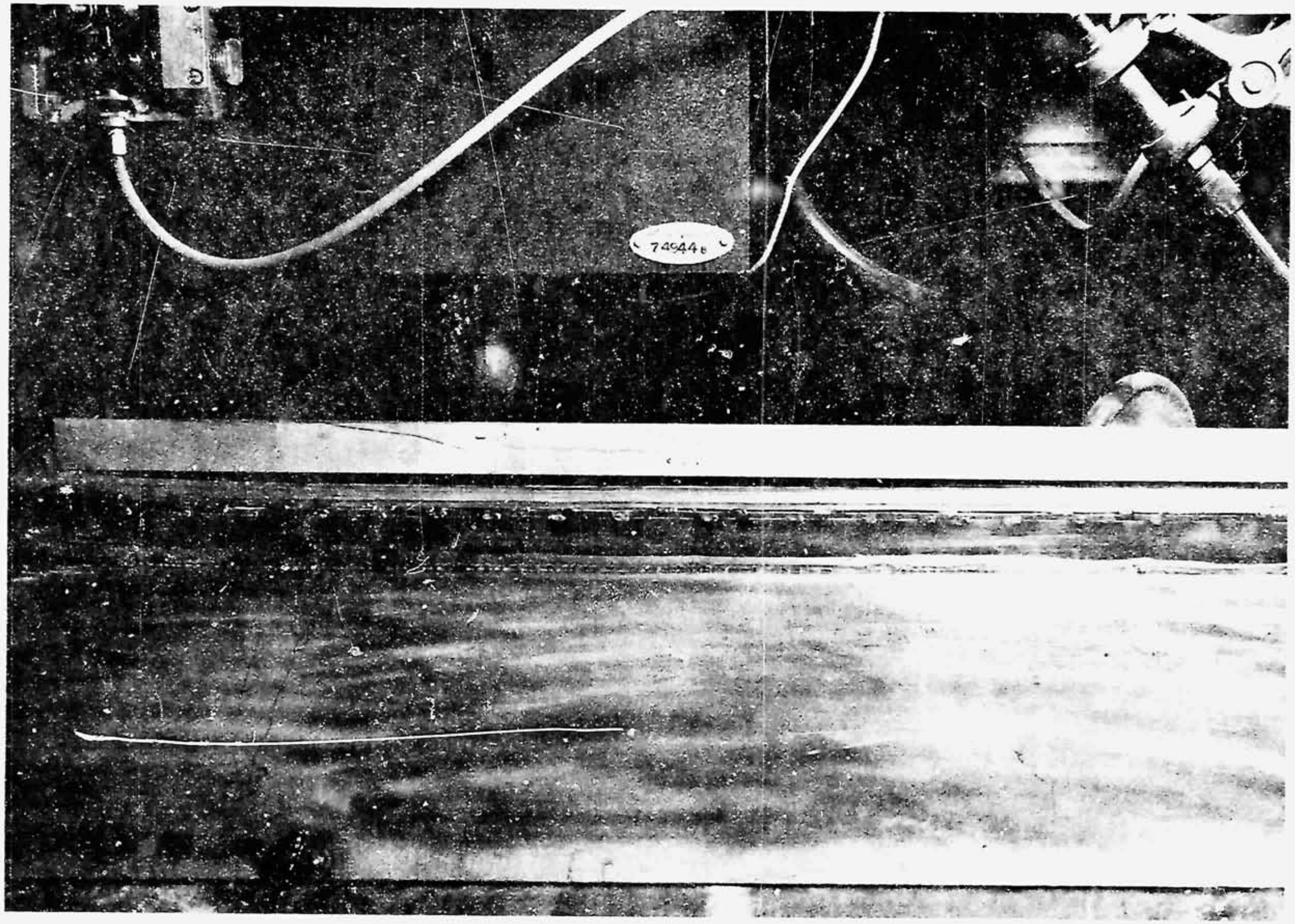


Figure 25 - Distortion Effects Encountered with TIG Welding of AISI 347

APPENDIX A

MATERIALS DATA RELEASE MEMORANDA

APPENDIX A

MATERIALS DATA RELEASE MEMORANDA

ANSC MATERIAL AND PROCESSES STAFF
(Released During Second Quarter)

Index of Active ANSC Materials Data Release Memo (DRM)

Material	Condition	Form	Load Direction	Properties	Test Condition	Data Category	DRM No.	Issue Date
AGCARB	Graphitized	Composite	Warp, Fill, Perpendicular, Parallel	TYS, TUS, CYS, Modulus, Interlaminar Shear Strength, Fatigue, Fracture, Troughness, Flexural Strength, Thermal Conductivity, Coefficient of Linear Thermal Expansion	RT, 2000°F, 3000°F	C	M-6 BØ	1-14-70
AA 6061	T-6	Sheet/Plate	L, LT	TYS, TUS, Elong Mod	-423°F, -320°F, RT	B	M-7 ACØ	1-15-70
AA 6061	T-6	Forging		TYS, TUS, Mod, Elong	-423°F, -320°F, RT	B	M-7 BØ	1-15-70
718	(B)	Sheet	L	TYS	RT	C	M-1 AØ	1-15-70
301 SS	1/4 Hard	Sheet	L	TYS, TUS, Elong, Mod, Thermal Conductivity	-423°F, -320°F,	C	M-10 AØ	1-15-70
Ti 6Al-4V	Annealed	Sheet	L, T	TYS, TUS, Elong, Mod,	-320°F, -100°F	B	M-9 AØ	1-15-70
718	(B)	Forging	T	TUS, TYS, Mod	-423°F, RT	C	M-1 BØ	1-19-70
AA 5083	H323	Sheet	L, T	TYS, TUS, Elon, Mod	-423°F, -320°F,	C	M-20 AØ	1-23-70
AA 7075	T-73	Forging	L, LT, ST	TYS, TUS, Mod, Poisson's Thermal Conductivity	-320°F, RT,	C	M-21 BØ	1-23-70
AA 6061	T-6	Forging Plate/Bar	L, LT, ST,	Fatigue	-320°F, -110°F, RT	C	M-7 BCDØ	2-2-70
AA 7039	T-63	Forging	L, T	TYS, TUS, Mod	200°F, 300°F	C	M-3 BØ	2-3-70
A-286	ST & Aged	Forging	R, T	TYS, TUS, Mod, Elong, Thermal Conductivity	-320°F, -100°F, RT	C	M-5 BØ	2-19-70
718	(B)	Sheet/Plate	Across Weld	TYS, TUS, Elong	RT	C	M-1 AG	2-19-70

FORM IDENTIFICATION

A - Sheet
B - Forging
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E - Tube
F - Weld and Heat Treat
G - As Welded

H - Composite
I - Triple Brazed
J - Coatings

ANSC MATERIAL AND PROCESSES STAFF
(Released During Third Quarter)

Index of Active ANSC Materials Data Release Memo (DRM)

Material	Condition	Form	Load Direction	Properties	Test Condition	Data Category	DRM No.	Issue Date
A-286	CW & Aged	B	L	TYS, TUS, Elong	-423°F, -320°F, RT	C	M-5 DØ	3-10-70
347	Triple Brazed	Forging	A & C	TYS	-100°F, RT, 600°F, 1200°F	B	M-2 BIØ	3-16-70
AGCarb	Graphitized	Composite		Solar Absorptance Total Hemispherical Emittance	1150°F, 2150°F, 2950°F, 4000°F, RT	D	M-6 HØ	3-25-70
18 Maraging	GR 250		All	Solar Absorptance Total Hemispherical Emittance Specific Heat Thermal Conductivity Coefficient of Thermal Exp.	-200°F, RT, 400°F -200°F, 40°F, 400°F -200°F, -100°F, RT, 200°F, 400°F -200°F, -100°F, RT, 200°F, 400°F RT to -200°F, RT to 400°F	D	M-16 Ø	3-25-70
AA 2024	All Conditions	All	All	Solar Absorptance Total Hemispherical Emittance	40°F 40°F, 60°F, 140°F	D	M-8 Ø	3-23-70
Alum Oxide	Rokide A	Coating		Solar Absorptance Emittance	Flame Sprayed -60°F, 40°F, 140°F	D	M-24 JØ	3-31-70
Aluminum	Elemental	Coating		Emittance Solar Absorptance	-230°F, -100°F, 70°F, 300°F, 40°F	D	M-25 JØ	4-1-70
718	55% Ni		All	Solar Absorptance Emittance	Miscl. Test Conditions, -60°F, 40°F, 140°F	D	M-1 Ø	4-2-70
6061	T-6	Sheet/Plate	LT, L	TYS, TUS, Elong	-423°F, -320°F, 70°F	B	M-7 AC1	4-2-70
AA 6061	T-6	Forging		TYS, TUS, Elong	-423°F, -320°F, 70°F	B	M-7 B1	4-2-70

FORM IDENTIFICATION

A - Sheet
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D - Bar
E - Tube
F - Weld and Heat Treat
G - As Welded
H - Composite
I - Triple Brazed
J - Coatings

ANSC MATERIAL AND PROCESSES STAFF
(Released During Third Quarter)

Index of Active ANSC Materials Data Release Memo (DRM)

Material	Condition	Form	Load Direction	Properties	Test Condition	Data Category	DRM No.	Issue Date
AA 6061	T-6	Sheet/Plate/ Forging		Modulus of Elasticity, Mod of (R), Creep Strength, Rupture Strength, Impact Strength, Fatigue, K, A, Specific Heat, Thermal Diffus, Density, Resistivity, Emittance, Solar Absorp	-423°F, -320°F, -100°F, 70°F, 200°F, 300°F NOTE: See DRM's for specific data.	C	M-7 ABC	4-2-70
718	ST & Aged	Sheet	Flex Rev Bending	Fatigue	-423°F, -320°F, 70°F	C	M-1 A1	4-15-70
718	ST & Aged	Bar	Rot Beam Fatigue	Fatigue	-320°F, 70°F	C	M-1 DØ	4-15-70
AA 7039	T-63	Forging	L & C	TUS, Elong	-320°F, -100°F, 70°F, 200°F, 300°F	B	M-3 B1	4-23-70
347	Triple Brazed	Forging	A & C	TUS, Elong	-100°F, 70°F, 600°F, 1200°F	C	M-2 B11	4-27-70
Lead (Pb)	High Purity		N/A	K, A, Density, Specific Heat	-415 to + 440°F	B	M-27 Ø	5-25-70
Miscel-laneous	Miscellaneous		N/A	Friction	40°R, 65°R, 280°R, 620°R	D	M-11 Ø	5-25-70

FORM IDENTIFICATION

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G - As Welded
H - Composite
I - Triple Brazed
J - Coatings

ANSC MATERIAL AND PROCESSES STAFF
(Released During Fourth Quarter)

Index of Active ANSC Matericls Data Release Memo (DRM)

Material	Condition	Form	Load Direction	Properties	Test Condition	Data Category	DRM No.	Issue Date
Misc.	Misc.	All	All	Vap/Press/Contam. SP./HT.,K, Density	Space (UHV)	D	M-26-0	5-27-70
GR/37B	ATJ	All	All	SP./HT.,K,Density	See DRM's for specific test conditions	D	M-28-0	6-03-70
AA 7039	All	All	All	SP./HT.,K, A, D,		D	M-3 0	6-10-70
310SS	WRGT	All	All	Emitt. Absorp. TY, TU,	See DRM's for specific test conditions	C	M-29 0	6-19-70
GR/37B	ATJ NI/BAS	All All	All	SP./HT.,K and Density Den., SP/HT,K,A,E, E of (R.N,Resist. Emiss.	See DRM's for specific test conditions	D	M-28 1 M-1 1	6-22-70 6-18-70
AA 7039	T-63	Forging	Long., Circ.	TYS, TUS, Elong.	-320,-100,RT, 200, 300F	B	M-3B 2	6-24-70
718	(B)	Forging	Tang.	TYS,TUS,Elong.	-423,-320,RT.	A	M-1B 1	6-25-70
2024 BRONZ	All Brng	All		Absorp., Emitt. Coef/Frct, Misc. Properties	RT -330F	C	M-8 1 M-32 0	6-[illegible]5-70 7-13-70
718	(B)	Forging	Circ., Axial	KIC	-423F	A	M-1B 1	7-16-70
7039	T-63	Forging	Circ., Axial	KIC	RT., -320F	C	Sup #1 M-3B 2	7-16-70
Ti 5Al-2.5Sn	ANN	Forging	Circ., Radial	TYS,TUS,Elong	RT, -320F	A	M-4B 0	7-17-70
347	All	All		Den,SP/HT, K, Absorp, Emitt, Rad Energy Ratio	See DRM's for Temp's	D	M-2 0	7-20-70
LiH	Pure			SP/HT, K, Den.	See DRM's	C	M-33 0	7-27-70

FORM IDENTIFICATION

A - Sheet
B - Forging
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D - Bar
E - Tube
F - Weld and Heat Treat
G - As Welded

H - Composite
I - Triple Brazed
J - Coatings

ANSC MATERIAL AND PROCESSES STAFF
(Released During Fourth Quarter)

Index of Active ANSC Materials Data Release Memo (DRM)

Material	Condition	Form	Load Direction	Properties	Test Condition	Data Category	DRM No.	Issue Date
Ti 5Al-2.5Sn		PNCK		TYS, TUS, Elong	-423,-320,RT See DRM's for specific Temp's.	A	M-4B 0 Sup #1	7-27-70
347 SS	Brazed	Sheet	T,L	TYS	See DRM's for specific Temp's.	C	M-2AI0	7-30-70
302 SS		All	All	K, SP HT	See DRM's for specific Temp's.	C	M-10 0	8-06-70
22-13-5SS	Annealed	Bar	All	TYS, TUS, Elong			M-38 0	8-07-70
347 SS	Triple	Forging	A&C	TUS, Elong	-100,RT,600,1200F	A	M-2BI 2	8-07-70
718		All	All	C T E	See DRM's for specific Temp's.		M-1 2	8-07-70
21-6-9 SS	Triple Braze	Forging	C&R	TUS,TYS,Elong	-423,-320,-110,RT,600F	C	M-36B 0	8-10-7C
21-6-9 SS	Triple Braze	Sheet	L&T	TUS,TYS, Elong	-423,-320,-110,RT,800, 1200,1600F	C	M-36A 0	8-10-70
Ti 5Al-2.5Sn	Annealed	Forging	C&R	TUS,TYS,Elong	RT and -320F	A	M-4B 1	9-03-70
AGCarb	Graphitized	Composite		K,SP HT, Density	Misc. Temp. See DRM's	C	M-6H Supp #1	9-09-70
AA 6061	T-6	Forging	L,ST,T	TYS,TUS, Elong	-423, -320, R.T., 300F	B	M-7B 2	9-10-70

FORM IDENTIFICATION

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J - Coating

DRM TYPE:	DATA RELEASE MEMORANDUM NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 6	DRM NO. M-26 REV. NO. 0

SUBJECT: METALLIC MATERIAL VAPOR PRESSURE AND MATERIAL CONTAMINANT LIMITS **DATE:** 5-21-70

1. SCOPE:

Literature data were gathered and studied to determine a material vapor pressure limit and to set material contaminant limits for metallic materials used on the NERVA engine.

2. DATA ANALYSIS:

Data from several sources were studied, along with the experimental techniques, to evaluate their credibility and their usefulness to this application. To evaluate whether or not loss of material by direct evaporation or sublimation is significant, the rate of evaporation is calculated using the Langmuir equation

$$W = \frac{P}{17.14}\sqrt{M/T}$$

$W \frac{gm}{cm^2\text{-sec}}$ = rate of evaporation or sublimation

P torr = vapor pressure of the material

$M \frac{gms}{mol}$ = molecular weight in gas phase

T °K = temperature

The Langmuir equation predicts the maximum sublimation rates of unalloyed elements. Calculations made on the basis of .040 and .010 in. maximum sublimation in a year's exposure provide a maximum exposure temperature for several commonly used elements in space (UHV) vacuum as tabulated in Table 1.

The observed rate is always lower. Loss of one volatile component from an alloy is more difficult to predict. For solid solutions, Raoult's Law may be used for an approximation. For other alloy systems, such as eutectics, the vapor pressure of the alloy can be higher than that of its components. When the low vapor pressure element is present in high concentration, sublimation will proceed from grain boundaries and surfaces until the volatile element is depleted at the surface. Thereafter, the sublimation rate will be diffusion controlled, and diffusion generally does not take place at the temperatures in question.

APPROVED BY DATE	PREPARED FOR: DATE:	COMPONENT/ ASSEMBLY IDENT
PREPARED BY	AUTHORIZED CLASSIFIER DATE 23 May	

The evaporated atoms, in space atmosphere, will travel in straight lines and deposit only on surfaces which are cooler than the source and in an optical line of sight with the source.

Loss of material by direct evaporation in the low-pressure environment of space is insignificant for Al, Fe, Be, Ti, and the refractory metals and their alloys, at all temperatures up to their melting points. However, Zn, Cd, Mg, Hg, As, and yellow brass (Zn present) will sublime at a significant rate in space environment at 400°F (greater than .040 in./yr) and should not be used. Most ceramics and refractory compounds have very low vapor pressures at ordinary temperatures.

A vapor pressure limit of 10^{-7} torr at 400°F (860°R) has been specified by ANSC Specifications EC-90177 and EC-90179 for metallics used in the wiring harness and the engine instrumentation. These specifications also limit the inclusion in materials of the elements lithium, boron, and cobalt to 0.1 weight percent maximum.

The following data sheets also list the vapor pressure of less known metallic elements which may sublime at an appreciable rate within the specification limits of temperature and pressure in the space environment.

APPROVED BY	DATE	PREPARED FOR: DATE:		COMPONENT/ ASSEMBLY IDENT
PREPARED BY		AUTHORIZED CLASSIFIER	DATE	

TABLE 1

TEMPERATURE AT WHICH SOME COMMON STRUCTURAL MATERIALS WILL LOSE 0.040 IN./YR IN ULTRA-HIGH SPACE VACUUM (2×10^{-14} torr or lower)

MATERIAL	TEMPERATURE °F	TEMPERATURE °R
Cd	248	708
Zn	324	784
Mg	464	924
Sn	1472	1932
Al	1490	1950
Be	1544	2004
Fe	1922	2382
Ti	2282	2742

TEMPERATURE AT WHICH SOME COMMON STRUCTURAL MATERIALS WILL LOSE 0.010 IN./YR IN ULTRA-HIGH SPACE VACUUM (2×10^{-14} torr or lower)

MATERIAL	TEMPERATURE °F	TEMPERATURE °R
Cd	207	667
Zn	291	751
Mg	397	857
Al	1341	1801
Be	1540	2000

REFERENCE: Space Materials Handbook, National Aeronautics and Space Administration, Third Edition, 1969.

AEROJET NUCLEAR SYSTEMS COMPANY

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-26 PAGE NO. 4 DATE 5-21-70 MATERIAL Several with vapo: pressures of 10^{-7} torr or lower.

CONDITION — TEST DIRECTION — —

SPEC. NOS. — FORM — —

DATA BASIS — COMMENT — —

PROPERTY Vapor Pressure of Metals

TEMP °R	°K	Zn	Cd	Hg	Mg	As	~~As~~$_2$	~~As~~$_4$
		VAPOR PRESSURE (TORR) ELEMENT						
585	325							1.31×10^{-7}
675	375		1.98×10^{-7}					
720	400						2.8×10^{-12}	1.48×10^{-5}
810	450	8.13×10^{-7}			6.32×10^{-9}	6.1×10^{-24}		
855	475	4.90×10^{-6}	3.68×10^{-4}	20.4				
900	500				3.17×10^{-7}			

TEMP °R	°K	Se_2	Se_4	ΣSe	Te_2	ΣTe
		VAPOR PRESSURE (TORR) ELEMENT				
720	400	3.53×10^{-7}	1.42×10^{-6}	1.77×10^{-1}		
810	450	3.41×10^{-5}	1.81×10^{-4}	2.15×10^{-4}	1.64×10^{-8}	1.64×10^{-8}
900	500				1.65×10^{-6}	1.65×10^{-6}

REFERENCE: An. N. Nesmeyanov, "Vapor Pressure of the Elements," Academic Press, New York, 1961

AEROJET NUCLEAR SYSTEMS COMPANY

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-26 PAGE NO. 5 DATE 5-21-70 MATERIAL Several with Vapor Pressures 10^{-7} torr or lower

CONDITION ______ TEST DIRECTION ______

SPEC. NOS. ______ FORM ______

DATA BASIS ______ COMMENT ______

PROPERTY Vapor Pressure of Metals

TEMP °R	°K	VAPOR PRESSURE (TORR) ELEMENT Na	Na_2	K	K_2	P_4 (White)	P_4 (Red)
583	325			1.9×10^{-7}			
675	375	1.54×10^{-7}				3.63	2.46×10^{-7}
855	475	1.77×10^{-4}	4.695×10^{-7}	6.840×10^{-3}	6.03×10^{-6}		

TEMP °R	°K	VAPOR PRESSURE (TORR) ELEMENT S_2	S_4	S_6	S_8
810	450	1.59×10^{-4}	7.23×10^{-5}	1.96×10^{-1}	5.8×10^{-1}

REFERENCE: An. N. Nesmeyanov, "Vapor Pressure of the Elements," Academic Press, New York, 1961

AEROJET NUCLEAR SYSTEMS COMPANY

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. DRM M-26 PAGE NO. 6 DATE 5-21-70 MATERIAL

CONDITION TEST DIRECTION

SPEC. NOS. FORM

DATA BASIS COMMENT

PROPERTY Vapor Pressure of Metals

TEMP °R	°K	Rb	Rb_2	Cs	Cs_2	Fr	Po	Po_2
		VAPOR PRESSURE TORR — ELEMENT						
450	250					1.24×10^{-7}		
495	275			1.068×10^{-7}				
540	300	3.307×10^{-7}						
675	375				1.56×10^{-7}			
720	400		4.767×10^{-7}					
810	450						7.65×10^{-7}	7.65×10^{-7}
855	475	3.905×10^{-2}	8.112×10^{-5}	1.07×10^{-1}	8.23×10^{-6}	6.92×10^{-2}	2.65×10^{-5}	3.30×10^{-5}

REFERENCE: An. N. Nesmeyanov, "Vapor Pressure of the Elements," Academic Press, New York, 1961.

DATA RELEASE MEMORANDUM

DRM TYPE:	NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 5	DRM NO. M-28 REV. NO. 0

SUBJECT: DESIGN ALLOWABLES FOR GRAPHITE -3% BORON COMPOSITE

DATE: 6-1-70

1. **SCOPE:**

The following properties for graphite-3% boron composite are attached:

Specific Heat
Thermal Conductivity
Density

2. TEST MATERIAL:

No data on this composition graphite exist. All data are estimated or calculated based upon ATJ graphite data which is considered to be the base material.

3. DATA ANALYSIS:

The specific heat data were calculated on the basis of 97% of values for manufactured graphites. The values are estimated to be ± 15% of the true values.

Thermal conductivity of this composition was calculated in the perpendicular and parallel directions using the data for ATJ graphite of 1.73 gm/cc density. Because of the lack of experimental data, the conductivity was calculated on the basis of 80% of the conductivity of ATJ.

A density of .061 lb/in.^{3} at room temperature was assumed based on using ATJ process schedule. Density for other temperatures was not calculated because of the lack of thermal expansion data.

4. CONCLUSIONS:

The data are considered category "D", a conservative engineering estimate of the properties listed based on the ATJ process schedule.

APPROVED BY DATE	PREPARED FOR: L Sheeley DATE:	COMPONENT/ ASSEMBLY IDENT	Shield
[signature] 6/3/70			
PREPARED BY [signature]	AUTHORIZED CLASSIFIER DATE [signature] 4 Jun 70		

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-28 PAGE NO. 2 DATE 6-1-70 MATERIAL 3% Boron-Graphite

CONDITION ____ TEST DIRECTION All

SPEC. NOS. ____ FORM ____

DATA BASIS No Category Required COMMENT .061 lbs/in.^{3} density minimum

PROPERTY Specific Heat

TEMP °F		C_p BTU/LB/°F		TEMP °F		C_p BUT/LB/°F	COMPUTED VALUE
0		0					
-379	(a)	.00844					
-370	(b)	.00980					
-280	(b)	.0325					
-190	(b)	.0624					
-100	(b)	.0965					
- 10	(b)	.132					
80	(b)	.167					
260	(b)	.238					
350	(b)	.268					
440	(b)	.294					
530	(b)	.313					
620	(b)	.330					
710	(b)	.345					
800	(b)	.359					
890	(b)	.371					
980	(b)	.381					
1070	(b)	.390					

(a) Table 5B.05.01, Specific Heat of Manufactured Graphite, The Industrial Graphite Engineering Handbook, Union Carbide Corp., April 1964.

(b) Kelly, B. T. and Walker, Jr., P. L., "Theory of Thermal Expansion of a Graphite Crystal in the Semi-Continuum Model," Carbon, March 1970.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRL NO. M-28 PAGE NO. 3 DATE 6-1-70 MATERIAL .3% Boron-Graphite

CONDITION - TEST DIRECTION Perpendicular to molding pressure with grain direction.

SPEC. NOS. - FORM Molded

DATA BASIS Category "D" COMMENT Density .061 lb/in.^{3} mininum

PROPERTY Thermal Conductivity

TEMP °F		BTU/HR/FT/°F					
-459.7		0					
-441.7		.226					
-423.7		1.2					
-405.7		2.8					
-369.7		7.9					
-351.7		11.5					
-333.7		14.8					
-315.7		19.0					
-297.7		22.6					
-189.7		43.4					
- 99.7		55.4					
- 9.7		60.6					
32		61.0					
170.3		57.8					
260.3		55.0					
440.3		49.4					
620.3		44.4					
800.3		40.2					
980.3		36.5					

COMMENTS: Touloukian, Y. S., Thermophysical Properties Research Center Data Book

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRN NO. M-28 PAGE NO. 4 DATE 6-1-/70 MATERIAL 3% Boron-Graphite

CONDITION ________ TEST DIRECTION Parallel to molding pressure across grain

SPEC. NOS. ________ FORM Molded

DATA BASIS Category "D" COMMENT Density 1.70 gm/cc minimum

PROPERTY Thermal Conductivity

TEMP °F		BTU/HR/FT/°F					
-459.7		0					
-441.7		.185					
-423.7		.9					
-405.7		2.8					
-369.7		6.0					
-351.7		8.3					
-333.7		13.0					
-315.7		13.8					
-297.7		16.6					
-189.7		31.0					
- 99.7		39.8					
- 9.7		44.8					
32		45.3					
80.3		45.3					
170.3		43.9					
260.3		42.1					
440.3		37.9					
620.3		34.2					
800.3		31.0					
980.3		28.2					

COMMENTS:

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DMH NO. M-28 PAGE NO. 5 DATE 6-1-70 MATERIAL 3% Boron-Graphite

CONDITION - TEST DIRECTION All

SPEC. NOS. - FORM Molded

DATA BASIS Category "D" COMMENT

PROPERTY Density

TEMP °F		LBS/IN.^{3}					
80		.061					

COMMENTS: Calculated value based on ATJ process schedule.

DRM TYPE:	DATA RELEASE MEMORANDUM NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 9	DRM NO. M-3 REV. NO. 0

SUBJECT: THERMOPHYSICAL PROPERTIES OF 7039 ALUMINUM ALLOY   DATE: 6-10-70

1. SCOPE:

The following thermophysical properties are attached:

Specific Heat
Thermal Conductivity
Linear Coefficient of Thermal Expansion
Density
Total Hemispherical Emittance
Solar Absorptance

2. TEST MATERIAL:

The data are applicable to the heat treat conditions specified.

3. DATA ANALYSIS:

The specific heat data were calculated using the Neumann-Kopp rule and the best fit curves for the specific heats of the principal alloying elements. Maximum variability is estimated to be within ± 10% of the calculated values for 7039 alloy.

Maximum variability of thermal conductivity data is estimated to be ± 5% at moderate temperatures and ± 15% at low temperatures (<-300°F) for the heat treat conditions specified based on measurement accuracy of ± 1% for the 0 data and ± 3% for the T6 condition. Data below -100°F for the T61 condition were suspect, and, therefore, not included in this memorandum. The difference in conductivity produced by the T61 and T63 conditions is expected to be very small and within the heat-to-heat variation due to compositional effects. On this basis the T61 data are estimated to cover the T63 condition and be within the estimated maximum variability limits listed above.

Maximum variability of coefficients of thermal expansion are estimated to be within ± 5% of the values presented.

Density values were calculated using thermal expansion data. Maximum variability is estimated to be within ± 10% of the calculated values.

APPROVED BY DATE	PREPARED FOR: DATE:	COMPONENT/ ASSEMBLY IDENT
PREPARED BY 6/15/70	AUTHORIZED CLASSIFIER DATE 18 Jun 70	

SUBJECT: THERMOPHYSICAL PROPERTIES OF 7039 ALUMINUM ALLOY

DATE: 6-10-70

Emittance and absorptance values are based on data for 6061 aluminum forging material. These properties show greater variation attributable to surface conditions than that which can be traced to chemical composition. The range of values represents those obtained by various chemical polishing and cleaning methods. Data for aluminum alloy 7039 T63 are expected to be within this range if processed in a similar manner. Maximum variability of all values is estimated to be ±10%. Only minor degradation of surface properties can be expected in space environment, and this degradation value is estimated to be within the range of values listed.

4. CONCLUSIONS:

Thermal conductivity and expansion data are classified as category "B" based on evaluation of experimental data; solar absorptance and total emittance data are classified categroy "D" because data are conservative engineering judgement based on experimental results of similar alloys; density, coefficient of thermal expansion, and specific heat data are not categorized; however, the range of uncertainties is included.

5. REFERENCES:

References are listed in the individual data sheets.

APPROVED BY DATE	PREPARED FOR: DATE:	COMPONENT/ ASSEMBLY IDENT
PREPARED BY	AUTHORIZED CLASSIFIER DATE	

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-3 PAGE NO. 3 DATE 6-10-70 MATERIAL 7039

CONDITION All TEST DIRECTION All

SPEC. NOS. FORM All

DATA BASIS No Category Required COMMENT Maximum Variability Estimated to be + 10%

PROPERTY Specific Heat

TEMP °F	C, BTU/LB/°F						
-424	.0197						
-370	.0362						
-280	.1137						
-100	.1904						
80	.2141						
260	.2250						
440	.2350						

COMMENTS: The above values were calculated using the Neumann-Kopp rule, the weighted fraction of elements in the alloy and the specific heat of the elements using the best fit curves for that element appearing in the Thermophysical Properties Research Center Data Book.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-3 PAGE NO. 4 DATE 6-10-70 MATERIAL 7039

CONDITION 0 TEST DIRECTION All

SPEC. NOS. FORM All

DATA BASIS No Category Assigned COMMENT Max. Variability Estimated to be ± 5% Down to -300°F and ± 15% Below

PROPERTY Thermal Conductivity

TEMP °F		THERMAL CONDUCTIVITY BTU/HR-FT-°F					
-449		4.97					
-442		8.38					
-424		16.87					
-406		24.91					
-388		31.96					
-370		37.79					
-352		40.53					
-334		46.41					
-316		49.70					
-298		52.53					
-280		55.02					
-190		65.88					
-100		75.70					
- 28		83.22					
44		88.90					

COMMENTS: Hust, J., et al, Thermal Conductivity, Electrical Resistivity and Thermopower of Aerospace Alloys From 4 to 300°K, NBS Report 9732, Natl Bureau of Standards, Boulder, Colorado, June 1969.

Dillon, J. J., and Wallace, L. A., Cryogenic and Elevated Temperature Properties of 7039 Aluminum Plate and Weldments, ACF Report 412-462, ACF Industries, Los Alamos Division, October 1965.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-3 PAGE NO. 5 DATE 6-10-70 MATERIAL 7039

CONDITION T61-63 TEST DIRECTION All

SPEC. NOS. FORM -

DATA BASIS Category "B" COMMENT Maximum Variability Estimated to be ± 5%.

PROPERTY Thermal Conductivity

TEMP °F		BTU/HR/FT/°F					
-100		73					
70		86					
200		93					
300		96					

COMMENTS: Dillon, J. J., and Wallace, L. A., Cryogenic and Elevated Temperature Properties of 7039 Aluminum Plate and Weldments, ACF Report 412-462, ACF Industries, Los Alamos Division, October 1965.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-3 PAGE NO. 6 DATE 6-10-70 MATERIAL 7039

CONDITION 0 TEST DIRECTION All

SPEC. NOS. FORM

DATA BASIS Category "B" COMMENT Maximum Variability Estimated to be ± 5%

PROPERTY Coefficient of Linear Thermal Expansion

TEMP °F	IN./IN. X 10^{-6}						
-424	8.5						
-351	9.75						
-297	10.48						
- 99	12.13						
- 8	12.79						
212	13.0						

COMMENTS: 27th Progress Report, NBS Report 9291, National Bureau of Standards, Boulder Laboratories, 30 September 1967.
Aluminum Alloy 7039, Kaiser Aluminum and Chemical Company, June 1965.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-3 PAGE NO. 7 DATE 6-10-70 MATERIAL 7039

CONDITION All TEST DIRECTION All

SPEC. NOS. FORM All

DATA BASIS No Category Required COMMENT Maximum Variability Estimated to be + 10%

PROPERTY Density

TEMP °F		DENSITY (ρ) LBS/IN^3		TEMP °F		DENSITY (ρ) LBS/IN^3	
212		.0983		-424		.1001	
80		.0988		-442		.1001	
44		.0989		-460		.1001	
32		.0990					
8		.0991					
- 28		.0992					
- 64		.0993					
-100		.0994					
-136		.0996					
-172		.0997					
-208		.0998					
-244		.0999					
-280		.09995					
-298		.1000					
-316		.1000					
-344		.1000					
-352		.1001					
-370		.1001					
-388		.1001					
-405		.1001					

COMMENTS: Calculated based on coefficient of linear thermal expansion data.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-3 PAGE NO. 8 DATE 6-10-70 MATERIAL 7039

CONDITION T63 TEST DIRECTION All

SPEC. NOS. FORM Forging

DATA BASIS Category "D" COMMENT

PROPERTY Solar Absorptance (α_S)

TEMP °F		MIN.		MAX.			
40		.18		.44			

COMMENTS: Gaumer, R. E., and McKellar, L. A., Thermal Radiative Control Surfaces for Spacecraft, LMSD Report No. 704014, March 1961

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-3 PAGE NO. 9 DATE 6-10-70 MATERIAL 7039

CONDITION T-63 TEST DIRECTION All

SPEC. NOS. FORM Forging

DATA BASIS Category "D" COMMENT

PROPERTY Total Hemispherical Emittance

TEMP °F		MIN.		MAX.			
- 60		.03		.11			
40		.03		.12			
140		.04		.12			

COMMENTS: Gaumer, R. E., and McKellar, L. A., Thermal Radiative Control Surfaces for Spacecraft, LMSD Report No. 704014, March 1961

DRM TYPE:	DATA RELEASE MEMORANDUM NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 7	DRM NO. M-29 REV. NO. 0

SUBJECT: TENSILE DESIGN ALLOWABLES FOR 310 STAINLESS STEEL WROUGHT PRODUCTS, ANNEALED   DATE: 6-11-70

1. SCOPE:

Literature data were analyzed to estimate a design allowable for stainless steel alloy 310 wrought products.

2. TEST MATERIAL:

Unspecified wrought products annealed at 2150°F, 0.750-in. diameter bar, and annealed .062-in. sheet tensile test results are reported in References 1 through 3.

3. DATA ANALYSIS:

The test data were analyzed to obtain conservative design allowables for 310 stainless steel sheet and bar. The quantity of raw tensile data available for 310 stainless steel was small; however, estimates of the means and among- and within-lot variances were made from the available data. Since the sheet data came from only one heat, the lot-to-lot variance of the bar data was combined with the within-lot variance of the sheet data to estimate the combined within- and among-group standard deviation.

4. CONCLUSION:

Data are classified as category "C" since engineering judgement was used to estimate the design allowables for sheet and the degrees of freedom associated with the estimate of the random variance was less than 15.

5. REFERENCES:

(1) "Report on the Elevated Temperature Properties of Stainless Steel," ASTM Report STP 124, January 1952.

(2) K. A. Warren and R. P. Reed, "Tensile and Impact Properties of Selected Materials from 20° to 300°K," NBS Monography 63, June 1963.

(3) A. S. Rabensteine, "Mechanical Properties of 310, 316 and 316L Stainless Steel Sheet Alloys at Elevated Temperatures," Contract AF 33(657)-8706, Project 281, The Marquardt Corp., Van Nuys, Calif., dated 1 Dec. 1962.

APPROVED BY / DATE	PREPARED FOR: E. S... DATE:	COMPONENT/ ASSEMBLY IDENT
PREPARED BY	AUTHORIZED CLASSIFIER / DATE	

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AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-29 PAGE NO. 2 DATE 6-11-70 MATERIAL SS 310

CONDITION Annealed TEST DIRECTION

SPEC. NOS. FORM 0.750-in. diameter bar

DATA BASIS Category "C" COMMENT

PROPERTY Tensile Ultimate Strength

TEMP °F	LOTS/ HEATS	N	df	$\bar{X}$	K	S	COMPUTED VALUE
RT	2	6	8	85	4.143	3.94	68.7
-320	1	3	8	156	4.143	3.9	140.0
-423	1	4	8	182	4.143	5.0	161

COMMENTS: References (1) and (2).

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-29 PAGE NO. 4 DATE 6-11-70 MATERIAL SS 310

CONDITION Annealed TEST DIRECTION

SPEC. NOS. FORM 0.750-in. diameter bar

DATA BASIS Category "C" COMMENT

PROPERTY Tensile Elongation

TEMP °F	LOTS/ HEATS	N	df	$\bar{X}$	K	S	COMPUTED VALUE
RT	2	7	11	53.4	3.852	5	34.4
-320	1	3	11	67.0	3.852	4	51.6
-423	1	4	11	47.7	3.852	4.1	31.9

COMMENTS: References (1) and (2).

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-29 PAGE NO. 5 DATE 6-11-70 MATERIAL SS 310

CONDITION Annealed TEST DIRECTION

SPEC. NOS. FORM 0.062-in. sheet

DATA BASIS Category "C" COMMENT

PROPERTY Tensile Ultimate Strength

TEMP °F	LOTS/ HEATS	N	df	$\overline{X}$	K	S	COMPUTED VALUE
RT	1	7	6	84.8	4.642	2.98	71.0

COMMENTS: References (1) and (3).

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-29 PAGE NO. 6 DATE 6-11-70 MATERIAL SS 310

CONDITION Annealed TEST DIRECTION

SPEC. NOS. FORM 0.062-in. sheet

DATA BASIS Category "C" COMMENT

PROPERTY Tensile Yield Strength

TEMP °F	LOTS/ HEATS	N	df	$\overline{X}$	K	S	COMPUTED VALUE
RT	1	7	6	40.3	4.642	1.56	33.1

COMMENTS: References (1) and (3).

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-29 PAGE NO. 7 DATE 6-11-70 MATERIAL SS 310

CONDITION Annealed TEST DIRECTION

SPEC. NOS. FORM 0.062-in. sheet

DATA BASIS COMMENT

PROPERTY Tensile Elongation

TEMP °F	LOTS/ HEATS	N	df	$\overline{X}$	K	S	COMPUTED VALUE
RT	1	7	6	47.7	4.642	4.1	28.7

COMMENTS: References (1) and (3).

DATA RELEASE MEMORANDUM

NRO MATERIALS AND PROCESSES STAFF

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

SHEET 1 OF 5

DRM TYPE:		DRM NO. M-28
		REV. NO. 1

SUBJECT: DESIGN ALLOWABLES FOR GRAPHITE - 3% BORON COMPOSITE

DATE: 6-17-70

1. SCOPE:

The following properties for graphite-3% boron composite are attached:

Specific Heat
Thermal Conductivity
Density

2. TEST MATERIAL:

Data for this composition graphite do not exist. All data are estimated or calculated based upon ATJ graphite data which is considered to be the base material.

3. DATA ANALYSIS:

The specific heat data were calculated on the basis of 97% of values for manufactured graphites. The values are estimated to be ± 15% of the true values.

Thermal conductivity of this composition was calculated in the perpendicular and parallel directions using the data for ATJ graphite of 1.73 gm/cc density. Because of the lack of experimental data, the conductivity was calculated on the basis of 80% of the conductivity of ATJ. Because the processing parameters for this alloy have not been established, it is estimated that the values listed will be within ± 25% at temperatures below -300°F and ± 20% at temperatures above -300°F of the projected true values of thermal conductivity of this composite.

A density of .061 $lb/in.^3$ at room temperature was assumed based on using ATJ process schedule. Density for other temperatures was not calculated because of the lack of thermal expansion data. The density listed is estimated to be within ± 10% of the projected true density.

4. CONCLUSIONS:

The data are considered category "D", a conservative engineering estimate of the properties listed based on the ATJ process schedule. This revision issued to include uncertainty range.

APPROVED BY DATE	PREPARED FOR: L. Shirley DATE:	COMPONENT/ ASSEMBLY IDENT
[signature] 6/22/70		Shield
PREPARED BY [signature] 6/18/70	AUTHORIZED CLASSIFIER DATE [signature] 22 June	

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-28 PAGE NO. 2 DATE 6-17-70 MATERIAL 3% Boron-Graphite

CONDITION ______ TEST DIRECTION All

SPEC. NOS. ______ FORM .061 lbs/in.^{3} density minimum.

DATA BASIS No Category Required COMMENT Uncertainty, ± 15%

PROPERTY Specific Heat

TEMP °F		C_p BTU/LB/°F					
0		0					
-379	(a)	.00844					
-370	(b)	.00980					
-280	(b)	.0325					
-190	(b)	.0624					
-100	(b)	.0965					
- 10	(b)	.132					
80	(b)	.167					
260	(b)	.238					
350	(b)	.268					
440	(b)	.294					
530	(b)	.313					
620	(b)	.330					
710	(b)	.345					
800	(b)	.359					
890	(b)	.371					
980	(b)	.381					
1070	(b)	.390					

(a) Table 5B.05.01, Specific Heat of Manufactured Graphite, The Industrial Graphite Engineering Handbook, Union Carbide Corp., April 1964.

(b) Kelly, B. T., and Walker, Jr., P. L., "Theory of Thermal Expansion of a Graphite Crystal in the Semi-Continuum Model," Carbon, March 1970.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-28 PAGE NO. 3 DATE 6-17-70 MATERIAL 3% Boron-Graphite

CONDITION - TEST DIRECTION With Grain Direction

SPEC. NOS. - FORM Molded

DATA BASIS Category "D" COMMENT Uncertainty, ± 25% at temperatures below -300°F, ± 20% at temps above -300°F

PROPERTY Thermal Conductivity

TEMP °F		BTU/ HR/FT/ °F					
-459.7		0					
-441.7		.226					
-423.7		1.2					
-405.7		2.8					
-369.7		7.9					
-351.7		11.5					
-333.7		14.8					
-315.7		19.0					
-297.7		22.6					
-189.7		43.4					
- 99.7		55.4					
- 9.7		60.6					
32		61.0					
80.3		60.1					
170.3		57.8					
260.3		55.0					
440.3		49.4					
620.3		44.4					
800.3		40.2					
980.3		36.5					

Touloukian, Y. S., Thermophysical Properties Research Center Data Book

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-28 PAGE NO. 4 DATE 6-17-70 MATERIAL 3% Boron-Graphite

CONDITION ______ TEST DIRECTION Across Grain Direction

SPEC. NOS. ______ FORM Molded

DATA BASIS Category "D" COMMENT Uncertainty, ± 25% at temps below -300°F; ± 20% at temps above -300°F.

PROPERTY Thermal Conductivity

TEMP °F		BTU/HR/FT/°F					
-459.7		0					
-441.7		.184					
-423.7		.9					
-405.7		2.8					
-369.7		6.0					
-351.7		8.3					
-333.7		13.0					
-315.7		13.8					
-297.7		16.6					
-189.7		31.0					
- 99.7		39.8					
- 9.7		44.8					
32		45.3					
80.3		45.3					
170.3		43.9					
260.3		42.1					
440.3		37.9					
620.3		34.2					
800.3		31.0					
980.3		28.2					

Touloukian, Y. S., Thermophysical Properties Research Center Data Book

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-28 PAGE NO. 5 DATE 6-17-70 MATERIAL 3% Boron-Graphite

CONDITION - TEST DIRECTION All

SPEC. NOS. - FORM Molded

DATA BASIS Category "D" COMMENT Uncertainty ± 10%

PROPERTY Density

TEMP °F		LBS/IN.^{3}					
80		.061					

Calculated value based on ATJ process schedule.

DATA RELEASE MEMORANDUM

NRO MATERIALS AND PROCESSES STAFF

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

DRM TYPE:	SHEET 1 OF 17	DRM NO. M-1 REV. NO. 1

SUBJECT: THERMOPHYSICAL PROPERTIES OF 718 NICKEL BASE ALLOY

DATE: 6-12-70

1. SCOPE:

The design allowables for the following thermal and physical properties of nickel-base alloy 718 are attached:

- Density
- Specific Heat
- Thermal Conductivity
- Thermal Diffusivity
- Coefficient of Linear Thermal Expansion
- Modulus of Elasticity
- Modulus of Rigidity
- Poisson's Ratio
- Electrical Resistivity
- Total Normal Emissivity

2. TEST MATERIAL:

Material conformed to chemical composition requirements for alloy 718 heat treat as indicated on the respective data sheets.

3. ANALYSIS OF DATA:

Density: This property was calculated using a computerized program which included thermal expansion data. The density values reflect the uncertainty range of the thermal expansion data which is ± 5%. This range should encompass all variations due to chemical composition. The data are applicable to both heat treat A and B.

Specific Heat: The specific heat data were calculated using the formula of Lucke, Deim and Weiss. These data should be in agreement within ± 10% of the true value of specific heat for the 718 alloy and its limited compositional variation. The formula cannot be used for calculations of this property below RT because of the magnetic transformation temperature (-170°F) and its effect on specific heat. The data are applicable to heat treat A and B modifications.

APPROVED BY / DATE	PREPARED FOR: L. Johnson, E. Buir / DATE:	COMPONENT/ ASSEMBLY IDENT
[signature] 6/12/70		
PREPARED BY: [signature] 6/18/70	AUTHORIZED CLASSIFIER: W Funk / DATE: 18 Jun 70	

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DRM TYPE:	DATA RELEASE MEMORANDUM NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA	DRM NO. M-1 REV. NO. 1

SUBJECT: THERMOPHYSICAL PROPERTIES OF 718 NICKEL BASE ALLOY   DATE: 6-12-70

Thermal Conductivity: The thermal conductivity data were obtained from two sources. The values for RT and above were calculated from electrical resistivity data. For temperatures less than -420°F, the estimated variability is ± 15%, for temperatures above -420°F, the variability is estimated to be ± 10%. These variability limits will encompass any changes in this property attributable to chemical composition. The data are applicable to heat treat A; data can be extended to heat treat B providing the variability limits at -420°F and below are increased to ± 20%. At other temperatures, the variability limits noted will encompass changes due to heat treatment.

Thermal Diffusivity: The values were calculated using calculated values of density, specific heat, and thermal conductivity. The lack of experimental data increases the estimated variability to ± 15%. The data are applicable to heat treat A condition and can be extended to the heat treat B condition providing the variability is increased to ± 20%.

Coefficient of Linear Thermal Expansion: The data were calculated using thermal expansion experimental data. The difference in the calculated expansion coefficients for heat treat A and B may be due to experimental error, chemical composition, and/or heat treatment. These data do not reflect measurements made at one source using one technique and one heat of material with heat treatment the only variable. The estimated variability is ± 5% for the heat treat A data and ± 10% in the heat treat B data.

Modulus of Elasticity: Data for dynamic modulus will differ from static tensile moduli value, especially at elevated temperatures, where time dependent reactions are apt to occur. The data listed here are estimated to be within ± 5% of the true dynamic moduli values, and this range will encompass any changes attributable to variations in chemical composition.

Modulus of Rigidity: The estimated range of variability of the dynamic modulus of rigidity is ± 5%, and this range should encompass any variations attributable to chemical composition.

Poisson's Ratio: Poisson's ratio was calculated using dynamically determined values. The values are estimated to be within ± 5% of the time values, and this range will encompass any variation attributable to chemical composition.

APPROVED BY DATE	PREPARED FOR: DATE:	COMPONENT/ ASSEMBLY IDENT
PREPARED BY	AUTHORIZED CLASSIFIER DATE	

SUBJECT: THERMOPHYSICAL PROPERTIES OF 718 NICKEL BASE ALLOY

DATE: 6-12-70

Electrical Resistivity: Electrical resistivity data were experimentally determined by two sources. The variation at RT and below is estimated to be ± 5% (NBS data) and for RT and above (International Nickel Co. data) the variation is estimated to be ± 10%. The estimated variation in values due to chemical composition is ± 5% of those listed.

Total Normal Emittance: The values listed are one time tests, applicable to the condition or the surface and material tested. Because this property is sensitive to surface condition and degree of cleanliness, degree of oxidation, the values may range to ~~± 50%~~ +5, -50% of the values listed.

4. CONCLUSIONS:

This supplements data contained in Revision 0, DRM M-1.

APPROVED BY	DATE	PREPARED FOR: DATE:	COMPONENT/ ASSEMBLY IDENT
PREPARED BY		AUTHORIZED CLASSIFIER DATE	

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-1 PAGE NO. 4 DATE 6-12-70 MATERIAL 718

CONDITION Heat Treat A TEST DIRECTION All

SPEC. NOS. FORM All

DATA BASIS No Category Required COMMENT Estimated uncertainty range ± 5%

PROPERTY Density

TEMP °F		ρ LBS/IN³					
80		.297					
200		.296					
400		.295					
600		.293					
800		.292					
1000		.290					
1200		.289					
1400		.287					
1600		.284					
1800		.282					
2000		.281					

Calculated using linear coefficient of thermal expansion listed in this data release and on the basis of room temperature density and unit volume change.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-1 PAGE NO. 5 DATE 6-12-70 MATERIAL 718

CONDITION Heat Treat B TEST DIRECTION All

SPEC. NOS. FORM All

DATA BASIS No Category Required COMMENT Estimated Uncertainty Range ± 5%

PROPERTY Density

TEMP °F		ρ LBS/IN³					
70		.297					
-100		.298					
-200		.299					
-300		.299					
-423		.299					

Calculated from instantaneous linear coefficient expansion data as contained in this data release.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-1 PAGE NO. 6 DATE 6-12-70 MATERIAL 718

CONDITION All TEST DIRECTION All

SPEC. NOS. FORM All

DATA BASIS No Category Required COMMENT Estimated Uncertainty Range ± 10%

PROPERTY Specific Heat

TEMP °F		BTU/ LB/°F					
0		.0995					
70		.1019					
200		.1063					
400		.1129					
600		.1197					
800		.1264					
1000		.1331					
1200		.1398					
1400		.1465					
1600		.1532					
1800		.1599					
2000		.1666					

Calculated using formula by Lucks, Deim and Weiss - Private Communication, Huntington Alloy Products Div., International Nickel Co., June 1970.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-1 PAGE NO. 7 DATE 6-12-70 MATERIAL 718

CONDITION Heat Treat A TEST DIRECTION All

SPEC. NOS. FORM

DATA BASIS No Category Required COMMENT Estimated Maximum Variability Range + 10%

PROPERTY Thermal Conductivity

TEMP °F							
-448		.389*		1200		12.3	
-423		1.39		1400		13.4	
-387		2.51		1600		14.4	
-351		3.25		1800		15.5	
-315		3.75		2000		16.6	
-279		4.10					
-243		4.38					
-171		4.87					
-135		5.12					
- 99		5.37					
- 63		5.63					
- 27		5.87					
9		6.08					
45		6.27					
70		6.6					
200		7.2					
400		8.3					
600		9.3					
800		10.3					
1000		11.3					

*Variability at this temperature, + 15%.

70° to 2000° Table 5, Inco 718 data Sheet, Huntington Alloy Product Division, International Nickel Co., February 1968.

-448° to RT - Hust, J. G., et. al., Thermal Conductivity, Electrical Resistivity and Thermopower of Aerospace Alloys from 4 to 300°K, NBS Report 9732, June 1969.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-1 PAGE NO. 8 DATE 6-12-70 MATERIAL 718

CONDITION Heat Treat A TEST DIRECTION All

SPEC. NOS. FORM

DATA BASIS No Category Required COMMENT Estimated Maximum Variability Range ± 15%

PROPERTY Thermal Diffusivity

TEMP °F		α FT^2/HR						
70		.1262						
200		.1324						
400		.1442						
600		.1535						
800		.1615						
1000		.1694						
1200		.1762						
1400		.1844						
1600		.1915						
1800		.1989						
2000		.2052						

Calculated using specific heat density and thermal conductivity as listed in their respective data sheets using equation $\alpha = K/\rho C_p$.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-1 PAGE NO. 9 DATE 6-12-70 MATERIAL 718

CONDITION Heat Treat A TEST DIRECTION All

SPEC. NOS. FORM All

DATA BASIS No Category Required COMMENT Estimated Maximum Variability ± 5%

PROPERTY Coefficient of Linear Thermal Expansion

TEMP °F		α IN/IN/°F X 10^{-6}						
-424		4.84						
-351		5.53						
-297		5.94						
-207		6.43						
- 99		6.81						
8		7.07						
200		7.2						
400		7.8						
600		8.0						
800		8.1						
1000		8.2						
1200		8.6						
1400		9.1						
1600		9.5						
1800		9.8						
2000		10.0						

(All values from 70°F to temperature indicated.)

RT to -460°F - Report 9291, NBS, Boulder Division, Sept. 67.
RT to 2000°F - Table 5, page 2, Inconel Alloy 718, Huntington Alloy Products Div., International Nickel Co., Feb. 68.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-1 PAGE NO. 10 DATE 6-12-70 MATERIAL 718

CONDITION Heat Treat B TEST DIRECTION All

SPEC. NOS. FORM All

DATA BASIS No Category Required COMMENT Estimated Maximum Variability Range ± 10%

PROPERTY Coefficient of Linear Thermal Expansion

TEMP °F		α IN/IN/°F *					
0		6.57					
-100		6.24					
-200		6.15					
-320		5.46					
-420		4.82					

*From room temperature to temperature indicated.

Aerojet LRP Report DVR 65-146, Thermal Expansion of TPA Materials, March 1965.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-1 PAGE NO. 11 DATE 6-12-70 MATERIAL 718

CONDITION Heat Treat A TEST DIRECTION All

SPEC. NOS. FORM All

DATA BASIS No Category Required COMMENT Estimated Maximum Variability Range ± 5%

PROPERTY Modulus of Elasticity (Dynamic)

TEMP °F		E psi $\times 10^6$		TEMP °F		E psi $\times 10^6$	
70		29.0		1700		18.8	
100		28.8		1800		17.4	
200		28.4		1900		15.9	
300		28.0		2000		14.3	
400		27.6					
500		27.1					
600		26.7					
700		26.2					
800		25.8					
900		25.3					
10000		24.8					
1100		24.2					
1200		23.7					
1300		23.0					
1400		22.3					
1500		21.3					
1600		20.2					

Table 4, page 2, Data Sheet, Inconel 718, Huntington Alloy Products Div., International Nickel Co., Feb. 68.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-1 PAGE NO. 12 DATE 6-12-70 MATERIAL 718

CONDITION Heat Treat A TEST DIRECTION All

SPEC. NOS. FORM All

DATA BASIS No Category Required COMMENT Estimated Maximum Variability Range ± 5%

PROPERTY Modulus of Rigidity (Dynamic)

TEMP °F		E psi X 10^6					
70		11.2					
100		11.2					
200		11.0					
300		10.9					
400		10.8					
500		10.6					
600		10.5					
700		10.3					
800		10.1					
900		9.9					
1000		9.7					
1100		9.5					
1200		9.2					
1300		8.9					
1400		8.5					
1500		8.1					
1600		7.6					
1700		7.1					
1800		6.5					
1900		5.8					
2000		5.1					

Table 4, page 2, Data Sheet, Inconel 718, Huntington Alloy Products Div., International Nickel Co., Feb. 68.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-1 PAGE NO. 13 DATE 6-12-70 MATERIAL 718

CONDITION Heat Treat A TEST DIRECTION All

SPEC. NOS. FORM All

DATA BASIS No Category Required COMMENT Estimated maximum Variability Range ± 10%

PROPERTY Poisson's Ratio[(a)]

TEMP °F								
70		.294						
100		.291						
200		.288						
300		.280						
400		.280						
500		.275						
600		.272						
700		.273						
800		.271						
900		.272						
1000		.271						
1100		.276						
1200		.283						
1300		.292						
1400		.306						
1500		.321						
1600		.331						
1700		.334						
1800		.341						
1900		.366						
2000		.402						

(a) Calculated from E and G data as listed.

Table 4, page 2, Data Sheet, Inconel 718, Huntington Alloy Products Div., International Nickel Co., Feb. 68.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-1 PAGE NO. 14 DATE 6-12-70 MATERIAL 718

CONDITION Heat Treat A TEST DIRECTION All

SPEC. NOS. FORM All

DATA BASIS No Category Required COMMENT Estimated Maximum Variability Range ± 5%

PROPERTY Electrical Resistivity (micro ohms-ft)

TEMP °F	MICRO-OHM FT						
-423	42.39						
-360	42.47						
-324	42.65						
-261	43.05						
-207	43.41						
- 99	44.14						
45	45.05						

Hust, J. G., et. al., Thermal Conductivity, Electrical Resistivity, and Thermopower of Aerospace Alloys from 4 to 300°K, NBS Report 9732, June 1969.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-1 PAGE NO. 15 DATE 6-12-70 MATERIAL 718

CONDITION Heat Treat A TEST DIRECTION All

SPEC. NOS. FORM All

DATA BASIS No Category Required COMMENT Estimated Maximum Variability ± 10%

PROPERTY Electrical Resistivity Micro ohm-ft.

TEMP °F		ρ MICRO OHM-FT.					
70		47.45					
200		47.97					
400		48.41					
600		50.27					
800		50.72					
1000		51.57					
1200		51.97					
1400		52.16					
1600		52.10					
1800		52.36					
2000		52.10					

Inconel Alloy 718, Data Sheet, Huntington Alloy Products Div., International Nickel Co., Feb. 1968.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-1 PAGE NO. 16 DATE 6-12-70 MATERIAL 718

CONDITION All TEST DIRECTION All

SPEC. NOS. FORM All

DATA BASIS No Category Required COMMENT Estimated Maximum Variability Range ~~± 50%~~ +5, -50%

PROPERTY Total Normal Emissivity (a)

TEMP °F		ε					
975		.852					
1079		.881					
1199		.852					
1240		.942					
1300		.947					
1350		.950					
1368		.960					
1518		.949					
1661		.921					
1680		.930					
1725		.942					

(a) Oxidized Surface

Private Communication, Huntington Alloy Products Div., International Nickel Co., June 1970.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-1 PAGE NO. 17 DATE 6-12-70 MATERIAL 718

CONDITION Heat Treat B TEST DIRECTION All

SPEC. NOS. FORM All

DATA BASIS No Category Required COMMENT Estimated Maximum Variability Range ± 5%

PROPERTY Poisson's Ratio (a)

TEMP °F							
70		.300					

(a) Calculated from E and G data.

NERVA Materials Staff unpublished report.

DRM TYPE:	DATA RELEASE MEMORANDUM NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 8	DRM NO. M-3B REV. NO. 2

SUBJECT: 7039-T63 Forgings DATE: 6-22-70

1. SCOPE:

Tensile data from ANSC pressure vessel materials test program were analyzed to develop minimum design allowable values for the following mechanical properties:

Tensile Ultimate
Tensile Yield
Tensile Elongation

This supercedes DRM-3B, Rev. 1, dated 4-20-70, and DRM 3B, Rev. 0, dated 8-29-69.

2. TEST MATERIAL:

Subscale pressure vessel forgings were fabricated and test specimens taken from the cylindrical shell section of the forging. Three heats, representing low, nominal, and high alloy limits, were tested, but the data analysis includes only the low and nominal alloy heats identified as Heats BB and AA, respectively. The high alloy Heat CC was not included in the analysis because the data were not homogeneous with Heats AA and BB. Chemistry limits of material specification will be adjusted to prevent high alloy material from being used on the program.

3. DATA ANALYSIS:

Test data from specimens exposed 1/2 hour and 100 hour, respectively, to the test temperature were analyzed.

The within-group variances of tensile ultimate strength, tensile yield strength and elongation data were homogeneous over all temperatures, directions and heats for both sets of data with one exception. Elongation data for 100-hour exposure to the 300 and 200 degree test temperatures were not homogeneous with regard to the within-group variance. However, the data within each direction were homogeneous and allowables were calculated for each direction.

APPROVED BY DATE	PREPARED FOR: L. Shurley DATE:	COMPONENT/ ASSEMBLY IDENT PV.
[signature] 6/24/70		
PREPARED BY V. E. Kahle	AUTHORIZED CLASSIFIER DATE [signature] 24 June 70	

most of the data points for the 1/2-hour exposure were homogeneous with regard to the means. Since the heat-to-heat variances were negligible, the allowables were calculated using the within-group variance and the degrees of freedom associated with it. The 200°F Tys strength means were not homogeneous, and the degrees of freedom, as calculated using the Satterthwaite's approximation, were very small (df = 2). Therefore, the allowable was calculated using the lowest group mean and the combined within- and among-group variance. The degrees of freedom associated with the overall within-group variance were used to choose the one-sided tolerance factor, k.

The lot means for the 100-hour exposure data were homogeneous except for the 200°F circumferential elongation data, all the tensile yield data, and the 300°F. The allowables for these points were computed using the lowest mean and the combined within- and among-group variance.

4. CONCLUSIONS:

The design values which were obtained by using the lowest means and the combined variances are classified category "B"; however, since these points are associated with and supported by data points obtained by rigorous statistical methods, the curve of tensile properties versus temperature will be classified category "A".

5. REFERENCES:

(1) NRO Materials Memo 69-232, F. J. Flens to A. D. Cornell, Subject: Preliminary Pressure Vessel Materials Tensile Properties Data, dated 6 January 1970.

(2) NRO Materials Memo 70-155, F. J. Flens to C. W. Funk/L. A. Shurley, Subject: Tensile Properties of 7039-T63.

APPROVED BY DATE	PREPARED FOR: DATE:	COMPONENT/ ASSEMBLY IDENT
PREPARED BY	AUTHORIZED CLASSIFIER DATE	

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-3B PAGE NO. 3 DATE 6-22-70 MATERIAL 7039

CONDITION T63 TEST DIRECTION Longitudinal & Circumferential

SPEC. NOS. FORM Midshell Forging

DATA BASIS Category "A" COMMENT 1/2-Hr Soak at Test Temperature

PROPERTY Tensile Ultimate Strength

TEMP °F	LOTS/ HEATS	N	df	$\overline{X}$ ksi	K	S	COMPUTED VALUE ksi
300	2	85	65	53.8	2.781	1.44	49.8
200	2	85	65	60.6	2.781	2.74	53.0
RT	2	85	65	65.3	2.781	2.16	59.3
-100	2	85	65	75.6	2.781	1.40	71.7
-320	2	85	65	90.8	2.781	1.40	86.9

COMMENTS: Reference (1).

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-3B PAGE NO. 4 DATE 6-22-70 MATERIAL 7039

CONDITION T63 TEST DIRECTION Longitudinal & Circumferential

SPEC. NOS. FORM Ring Forgings

DATA BASIS Category "A" COMMENT 1/2-Hr Soak at Test Temperature

PROPERTY Tensile Yield Strength

TEMP °F	LOTS/ HEATS	N	df k	$\overline{X}$ ksi	K	S	COMPUTED VALUE ksi
300	2	83	63	49.8	2.789	1.40	45.9
200	2	83	63	54.1	2.789	2.55	47.0
RT	2	83	63	58.4	2.789	1.40	54.5
-100	2	83	63	65.9	2.789	1.40	61.0
-320	2	83	63	74.1	2.789	1.40	70.2

COMMENTS: Reference (1).

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-3B PAGE NO. 5 DATE 6-22-70 MATERIAL 7039

CONDITION T63 TEST DIRECTION Longitudinal & Circumferential

SPEC. NOS. FORM Midshell Forging

DATA BASIS Category "A" COMMENT 1/2-Hr Soak at Test Temperature

PROPERTY Tensile Elongation

TEMP °F	LOTS/ HEATS	N	df %	$\overline{X}$ % e	K	S	COMPUTED VALUE % e
300	2	86	66	21.3	2.777	1.965	15.9
200	2	86	66	14.0	2.777	1.05	11.1
RT	2	86	66	14.0	2.777	1.26	10.6
-100	2	86	66	13.1	2.777	1.45	9.1
-320	2	86	66	13.9	2.777	1.26	10.4

COMMENTS: Reference (1).

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-3B PAGE NO. 6 DATE 6-22-70 MATERIAL 7039

CONDITION T63 TEST DIRECTION Longitudinal & Circumferential

SPEC. NOS. FORM Midshell Forging

DATA BASIS Category "A" COMMENT 100-Hr Soak at Test Temperature

PROPERTY Tensile Ultimate Strength

TEMP °F	LOTS/ HEATS	N	df	$\bar{X}$ ksi	K	S	COMPUTED VALUE ksi
300	2	64	56	43.4	2.822	1.4	39.4
200	2	64	31	59.8	3.034	2.18	53.2

COMMENTS: Reference (2).

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-3B PAGE NO. 7 DATE 6-22-70 MATERIAL 7039

CONDITION T63 TEST DIRECTION Longitudinal & Circumferential

SPEC. NOS. FORM Midshell Forging

DATA BASIS Category "A" COMMENT 100-Hr Soak at Test Temperature

PROPERTY Tensile Yield Strength

TEMP °F	LOTS/ HEATS	N	df	$\bar{X}$ ksi	K	S	COMPUTED VALUE ksi
300	2	63	55	38.7	2.827	1.58	34.2
200	2	63	55	53.6	2.827	2.27	48.5

COMMENTS: Reference (2).

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-3B PAGE NO. 8 DATE 6-22-70 MATERIAL 7039

CONDITION T63 TEST DIRECTION Longitudinal & Circumferential

SPEC. NOS. FORM Midshell Forging

DATA BASIS Category "A" COMMENT 100-Hr Soak at Test Temperature

PROPERTY Tensile Elongation

TEMP °F	LOTS/ HEATS	DIREC-TION	N	df	$\bar{X}$ % e	K	S	COMPUTED VALUE % e
300	2	Long	16	15	25.3	3.464	3.13	14.5
300	2	Circ.	16	15	25.6	3.464	3.02	15.1
200	2	Long	16	15	17.4	3.464	1.17	13.3
200	2	Circ.	16	15	16.8	3.464	1.20	11.0

COMMENTS: Reference (2).

DRM TYPE:	DATA RELEASE MEMORANDUM NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 5	DRM NO. M-1B REV. NO. 1

SUBJECT: DESIGN ALLOWABLES FOR INCONEL 718 HEAT TREAT B **DATE:** 6-25-70

1. SCOPE:

The design allowables for the following tensile properties for Inconel 718 alloy forging, heat treat B, are attached:

Tensile Ultimate Strength
Tensile Yield Strength
Elongation

2. TEST MATERIAL:

Three heats of material conforming to AGC Specification 90093A were forged by Coulter Steel and Forge Company to produce an 8-inch diameter by 2-1/2-in. thick pancake. After forging, the pancakes were sandblasted and heat treated in accordance with AGC Specification 46604, which consisted of solution annealing at 1950°F and double aging.

3. DATA ANALYSIS:

Data analysis was limited to one group of pancakes from one forging source. Each pancake was forged from a different heat of material and initially three heats were used. The chemical analysis of the three heats was similar with reasonably similar Ti-Al ratios. The primary difference among the heats was the grain size of one pancake. Whereas one heat had a grain size of five and finer (HT 90301), the remaining two heats had grain sizes of four and coarser. The fine grain size was reflected in higher strengths and ductility. The heat with the fine grain size represented a heat with unusual processing which would tend to bias the allowables upward. To simplify the analysis and eliminate the bias, this heat was not included in the analysis.

The between-lot means for tensile and yield strengths at all temperatures were homogeneous for the two heats analyzed. The within-lots variance for all temperatures (RT, -320, and -423°F) was homogeneous, and this variance was used to calculate the allowables because the greater number of degrees of freedom permitted the use of a smaller one-sided tolerance k factor.

APPROVED BY DATE	PREPARED FOR: E Bair/L. Johnson DATE:	COMPONENT/ ASSEMBLY IDENT
R.J. [signature] 6/25/70		
PREPARED BY R. [signature] 6/25/70	AUTHORIZED CLASSIFIER DATE [signature] 25 Jun 70	

TPA Values

DRM TYPE:	DATA RELEASE MEMORANDUM NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 2 OF 5	DRM NO. M-1B REV. NO. 1

SUBJECT: DESIGN ALLOWABLES FOR INCONEL 718 HEAT TREAT B   DATE: 6-25-70

4. CONCLUSIONS:

The data are classified category "A" in accordance with TD 69-27. This DRM supersedes DRM 1B, Rev. 0, dated 2-4-70.

5. REFERENCES:

(1) Metallurgical Report for AGC P.O. No. G106220, Coulter Steel and Forge Company, Emeryville, California, 27 May 1969.

(2) 1970 Third Quarter Report, NERVA Materials Developments

APPROVED BY DATE	PREPARED FOR: DATE:	COMPONENT/ ASSEMBLY IDENT
PREPARED BY	AUTHORIZED CLASSIFIER DATE	

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-18 PAGE NO. 3 DATE 6-25-70 MATERIAL 718

CONDITION Heat Treat B TEST DIRECTION

SPEC. NOS. FORM Pancake Forging

DATA BASIS Category "A" COMMENT ≤ 2.5 in. thickness

PROPERTY Tensile Ultimate Strength, F_{tu}

TEMP °F	LOTS/ HEATS	N	df	$\bar{X}$	K	S	COMPUTED VALUE ksi
-423	2	10	18	255	3.33	2.71	246
-320	2	10	18	236	3.33	1.95	229
RT	2	4	18	182	3.33	1.95	175

COMMENTS: References (1) and (2).

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-1B PAGE NO. 4 DATE 6-25-70 MATERIAL 718

CONDITION Heat Treat B TEST DIRECTION Tangential

SPEC. NOS. FORM Pancake Forging

DATA BASIS Category "A" COMMENT ≤ 2.5 in. thickness

PROPERTY Tensile Yield Strength, F_{ty}

TEMP °F	LOTS/ HEATS	N	df	$\bar{X}$	K	S	COMPUTED VALUE ksi
-423	2	10	18	188	3.33	2.25	180
-320	2	10	18	181	3.33	2.25	173
RT	2	4	18	157	3.33	2.25	149

COMMENTS: References (1) and (2)

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-1B PAGE NO. 5 DATE 6-25-70 MATERIAL 718

CONDITION Heat Treat B TEST DIRECTION Tangential

SPEC. NOS. FORM Pancake Forging

DATA BASIS Category "A" COMMENT $\leq$ 2.5 in. thickness

PROPERTY Elongation, % (e)

TEMP °F	LOTS/ HEATS	N	df	$\overline{X}$	K	S	COMPUTED VALUE %
-423	2	4	18	29	3.33	1.74	23
-320	2	10	18	28	3.33	1.74	22
RT	2	10	18	22	3.33	1.74	16

COMMENTS: References (1) and (2).

DRM TYPE:	NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 4	DRM NO. M-8 REV. NO. 1

SUBJECT: RADIATIVE PROPERTIES OF ALUMINUM ALLOY 2024 **DATE:** 6-16-70

1. SCOPE:

The following radiative properties for 2024 aluminum alloy are attached:

Solar Absorptance
Total Hemispherical Emittance

2. TEST MATERIAL:

Surface conditions for the data are as indicated on the attached data sheets. Values represent base material only.

3. DATA ANALYSIS:

The radiative properties of metals are extremely sensitive to surface condition. The values for ε and α_S can range considerably depending on the degree of cleanliness and smoothness of the surface. The range for each property is primarily the uncertainty associated with the efficiency of the cleaning process and variability of the blasting process to roughen the surface. Thermal radiant energy ratios are based on maximum and minimum combinations for transfer of radiant energy.

4. CONCLUSIONS:

The range of values listed for each property encompasses the uncertainties associated with the factors influencing their absolute value. Since the surface conditions are for base material, no further degradation is expected from exposure to vac or radiation.

APPROVED BY / DATE	PREPARED FOR: L. Shurley DATE:	COMPONENT/ ASSEMBLY IDENT
[signature] 6/25/70		Thrust Structure
PREPARED BY	AUTHORIZED CLASSIFIER / DATE	
Ralph J. [signature]	[signature] 25 Jun 70	

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-8 PAGE NO. 2 DATE 6-16-70 MATERIAL 2024

CONDITION Base Material TEST DIRECTION -

SPEC. NOS. FORM Wrought

DATA BASIS No Category Required COMMENT

PROPERTY Solar Absorptance, α_s

TEMP °F	SURFACE CONDITION	MIN.	MAX.
	As Received	.18	.30
	Cleaned	.18	.44
	Mechanically Polished and Degreased	.18	.40
	Sandblasted (1 F mesh SiC at 18 inches)	.50	.70
	Values represent worse conditions with no further conservatism required for degradation in space.		

Thermal Radiative Control Surfaces for Spacecraft, R. E. Gaumer and L. A. McKellar, LMSD-704104, March 1961.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-8 PAGE NO. 3 DATE 6-16-70 MATERIAL 2024

CONDITION Base Material TEST DIRECTION -

SPEC. NOS. FORM Wrought

DATA BASIS No Category Required COMMENT

PROPERTY Total Hemispherical Emittance, ε

TEMP °F	SURFACE CONDITION	MIN.	MAX.
	As Received		
-60		.02	.06
40		.02	.06
140		.02	.06
	Cleaned		
-60		.03	.11
40		.03	.12
140		.03	.12
	Mechanically Polished and Degreased		
-60		.03	.11
40		.03	.12
140		.03	.12
	Sandblasted with 1F mesh SiC at 18 inches		
-60		.20	.40
40		.20	.41
140		.20	.41

Values represent worse conditions with no further conservatism required for degradation in space.

Thermal Radiative Control Surfaces for Spacecraft, R. E. Gaumer and L. A. McKellar, LMSD 704104, 1961.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-8 PAGE NO. 4 DATE 6-16-70 MATERIAL 2024

CONDITION Base Material TEST DIRECTION -

SPEC. NOS. FORM Wrought

DATA BASIS No Category Required COMMENT

PROPERTY Thermal Radiant Energy Ratio, α_s/ε

TEMP °F	SURFACE CONDITION	MIN.	MAX.
	As Received	3	15
	Cleaned	1.5	15
	Mechanically Polished and Degreased	1.5	13
	Sandblasted with 1F mesh SiC at 18 inches	1.2	3.5

Values represent worse conditions with no further conservatism required for degradation in space.

DATA RELEASE MEMORANDUM

NRO MATERIALS AND PROCESSES STAFF

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

DRM TYPE:	SHEET 1 OF 9	DRM NO. M-32
		REV. NO. 0

SUBJECT: Design Allowables For Bronze Bearing Alloys DATE: 7-15-70

1. SCOPE:

The design allowable for three grades of a bearing metal of the nominal composition 70% Cu-tin-lead are attached

2. TEST MATERIAL

Test data for this material were obtained from the literature.

3. DATA ANALYSIS

Technical data for bearings of this composition were reviewed and conservative estimate of allowable property limits were established. The tensile properties were set at 80% of average; coefficient of friction was increased approximately 50% to allow for environmental effects (atmosphere and temperature); variability limits were set for the reported thermal and physical properties.

4. CONCLUSIONS

The data are rated category "C", a conservative estimate of design allowables.

APPROVED BY	DATE	PREPARED FOR: DATE:	COMPONENT/ ASSEMBLY IDENT
PREPARED BY		AUTHORIZED CLASSIFIER DATE 17 July 70	

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-32 PAGE NO. 2 DATE 7-15-70 MATERIAL Bearings

CONDITION Cast TEST DIRECTION -

SPEC. NOS. - FORM -

DATA BASIS Category C COMMENT Grade B-4 - 70% Cu - 4% Sn - 26% Pb
Grade B-8 - 70% Cu - 8% Sn - 22% Pb
Grade B-10 - 70% Cu - 10% Sn - 20% Pb

PROPERTY Coefficient of Friction, μ

TEMP °F	GRADE	N	N_e	$\bar{X}$	K	S	COMPUTED VALUE
RT	B-4						.20
	B-8						.22
	B-10						.25

COMMENTS: Data Sheet, "Mechanical Properties of Bearium Metal," Bearium Metals Corporation, Rochester, New York, undated.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-5 PAGE NO. 3 DATE 7-15-70 MATERIAL Bearings

CONDITION Cast TEST DIRECTION -

GRADE: B-4 - 70% Cu - 4% Sn - 26% Pb
B-8 - 70% Cu - 8% Sn - 22% Pb
B-10 - 70% Cu - 10% Sn - 20% Pb

SPEC. NOS. -

DATA BASIS Category C COMMENT -

PROPERTY Tensile Ultimate Strength, F_{tu}

TEMP °F	GRADE	N	N_e	$\overline{X}$	K	S	COMPUTED VALUE ksi
RT	B-4						17
	B-8						19
	B-10						21

COMMENTS: Data Sheet, "Mechanical Properties of Bearium Metal," Bearium Metals Corporation, Rochester, New York. undated.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-32 PAGE NO. 4 DATE 7-15-70 MATERIAL Bearings

CONDITION Cast TEST DIRECTION -

GRADE: B-4 - 70% Cu - 4% Sn - 26% Pb
B-8 - 70% Cu - 8% Sn - 22% Pb
B-10 - 70% Cu - 10% Sn - 20% Pb

SPEC. NOS. -

DATA BASIS Category C COMMENT -

PROPERTY Tensile Yield Strength, F_{ty}

TEMP °F	GRADE	N	N_e	$\overline{X}$	K	S	COMPUTED VALUE ksi
RT	B-4						8
	B-8						10
	B-10						13

COMMENTS: Data Sheet, "Mechanical Properties of Bearium Metal," Bearium Metals Corporation, Rochester, New York, undated.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-32 PAGE NO. 5 DATE 7-15-70 MATERIAL Bearings

CONDITION Cast TEST DIRECTION -

GRADE: B-4 - 70% Cu - 4% Sn - 26% Pb
B-8 - 70% Cu - 8% Sn - 22% Pb
B-10 - 70% Cu - 10% Sn - 20% Pb

SPEC. NOS.

DATA BASIS Category C COMMENT -

PROPERTY Elongation,%

TEMP °F	GRADE	N	N_e	$\overline{X}$	K	S	COMPUTED VALUE %
RT	B-4						12
	B-8						8
	B-10						6

COMMENTS: Data Sheet, "Mechanical Properties of Bearium Metal," Bearium Metals Corporation, Rochester, New York, undated.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-32 PAGE NO. 6 DATE 7-15-70 MATERIAL Bearings

CONDITION Cast TEST DIRECTION -

GRADE: B-4 - 70% Cu - 4% Sn - 26% Pb
B-8 - 70% Cu - 8% Sn - 22% Pb
B-10 - 70% Cu - 10% Sn - 20% Pb

SPEC. NOS. -

DATA BASIS Category C COMMENT Uncertainty, -5% +20%

PROPERTY Modulus of Elasticity, E

TEMP °F	GRADE	N	N_e	$\overline{X}$	K	S	COMPUTED VALUE psi x 10^6
RT	B-4						10
	B-8						10
	B-10						10

COMMENTS: Data Sheet, "Mechanical Properties of Bearium Metal," Bearium Metals Corporation, Rochester, New York, undated.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-32 PAGE NO. 7 DATE 7-15-70 MATERIAL Bearings

CONDITION Cast TEST DIRECTION -

GRADE: B-4 - 70% Cu - 4% Sn - 26% Pb
B-8 - 70% Cu - 8% Sn - 22% Pb
B-10 - 70% Cu - 10% Sn - 20% Pb

SPEC. NOS. -

DATA BASIS Category C COMMENT Uncertainty ± 10%

PROPERTY Modulus of Rigidity, G

TEMP °F	GRADE	N	N_e	$\bar{X}$	K	S	COMPUTED VALUE psi x 10^6
RT	B-4						3.0
	B-8						3.3
	B-10						3.7

COMMENTS: Data Sheet, "Mechanical Properties of Bearium Metal," Bearium Metals Corporation, Rochester, New York, undated.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-32 PAGE NO. 8 DATE 7-15-70 MATERIAL Bearings

CONDITION ______ TEST DIRECTION -

GRADE: B-4 - 70% Cu - 4% Sn - 26% Pb
B-8 - 70% Cu - 8% Sn - 22% Pb
B-10 - 70% Cu - 10% Sn - 20% Pb

SPEC. NOS. -

DATA BASIS Category C COMMENT Uncertainty ± 5%

PROPERTY Density

TEMP °F	GRADE	N	N_e	$\overline{X}$	K	S	COMPUTED VALUE lbs/in^3
RT	B-4						.334
	B-8						.324
	B-10						.320

COMMENTS: Data Sheet, "Mechanical Properties of Bearium Metal," Bearium Metals Corporation, Rochester, New York, undated.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-32 PAGE NO. 9 DATE 7-15-70 MATERIAL Bearings

CONDITION Cast TEST DIRECTION -

GRADE: B-4 - 70% Cu - 4% Sn - 26% Pb
B-8 - 70% Cu - 8% Sn - 22% Pb
B-10 - 70% Cu - 10% Sn - 20% Pb

SPEC. NOS. -

DATA BASIS Category C COMMENT Uncertainty ± 15%

PROPERTY Coefficient of Linear Thermal Expansion

TEMP °F		N	N_e	$\overline{X}$	K	S	COMPUTED VALUE in/in/°F x 10^{-6}
-115*							11.0
-330							8.7

*From RT to temperature indicated.

COMMENTS: Data Sheet, "Mechanical Properties of Bearium Metal," Bearium Metals Corporation, Rochester, New York, undated.

DRM TYPE:	NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 4	DRM NO. M-1B SUPPLEMENT #1 REV. NO. 1

SUBJECT: FRACTURE TOUGHNESS OF ALLOY 718 FORGING DATE: 7-15-70

1. SCOPE:

Cryogenic (LH_2) fracture toughness data for alloy 718 were analyzed to develop minimum design allowable values for 95% confidence with 99% reliability. This revision supplements DRM M-1B, dated 1-19-70.

2. TEST MATERIAL:

Alloy 718 material (1950°F/1350°F and 1200°F) from a 14-in. diameter by 6-in. high pancake forging produced by Viking Metallurgical Corporation and a second heat from a 13-in. diameter by 3-in. high pancake forging produced by West Coast Forge, Division of Whittaker Corporation, were tested. Wedge opening loaded (WOL) type specimens 1-in. thick were stressed in the circumferential direction, and the cracks were oriented in the radial direction.

3. DATA ANALYSIS:

For a valid fracture toughness test, the requirement exists that the thickness be equal to or greater than 2.5 $(K_Q/\text{yield strength})^2$, where K_Q is a provisional value of K_{Ic}. The specimens tested were fabricated 1-in. thick because the extremely good fracture toughness of the alloy was underestimated. To obtain valid K_{Ic} values, specimen thickness should have been approximately 1.5 in. thick. Although the test values did not meet the thickness requirement, flat fractures were obtained indicative of plane-strain conditions.

Test data were statistically analyzed to obtain minimum design allowable for 99% reliability with 95% confidence. Box's modification of the Bartlett's test and the one-way analysis of variance were used to evaluate homogeneity of data and establish the heat-to-heat and within-heat variability.

The within-lot variability from the two heats was heterogeneous at the 90% significance level, and the means were homogeneous at the 86% level. Since the heat-to-heat variability was high, two values were calculated. One value was computed using the overall mean and N-1 degrees of freedom; the second and smaller value was computed using the combined within-lot and among-lot variances and computing the degrees of freedom using Satterthwaite's approximation. The lower value is a more conservative evaluation of the fracture toughness characteristics of this alloy.

APPROVED BY DATE	PREPARED FOR: DATE:	COMPONENT/ ASSEMBLY IDENT
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PREPARED BY [signature] 7/15/70	AUTHORIZED CLASSIFIER DATE [signature] 16 July 70	

DRM TYPE:

DRM NO. M-1B

SUPPLEMENT #1

REV. NO. 1

SUBJECT: FRACTURE TOUGHNESS OF ALLOY 718 FORGING DATE: 7-15-70

Using the minimum allowable fracture toughness and yield strength values at -423°F, critical crack sizes were calculated using the following formulas:

For internal flaws $$\left(\frac{a}{Q}\right)_{cr} = .318 \frac{K_{IC}^2}{\sigma^2}$$

For surface flaws $$\left(\frac{a}{Q}\right)_{cr} = .263 \frac{K_{IC}^2}{\sigma^2}$$

K_Q values were used in lieu of K_{Ic} values. Flaw shape parameter (Q) - a/2c ratio relationship as developed by Tiffany were used. For these calculations, the σ/σ_{ys} ratio was assumed to be 1, the most severe condition. In all instances, the critical crack size exceeded the defect size that can be detected by NDT inspection techniques.

The material is classified ductile at temperatures as low as -423°F.

4. CONCLUSIONS:

Although the fracture toughness values (K_Q) did not meet the rigorous ASTM standards, the data can be utilized in establishing the crack propagation characteristics of this alloy at LH_2 temperatures. K_Q values are lower than K_{Ic}, and determination of valid K_{Ic} values will not affect the conclusions reached by these data. The data are classified category "A" though only K_Q values were determined.

5. REFERENCE:

Materials Memo 70-161, P. P. Dessau to W. E. Campbell, Subject: LH_2 Fracture Toughness of Alloy 718, dated 27 April 1970.

APPROVED BY DATE	PREPARED FOR: DATE:	COMPONENT/ ASSEMBLY IDENT
PREPARED BY	AUTHORIZED CLASSIFIER DATE	

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-1B PAGE NO. 3 DATE 7-15-70 MATERIAL Alloy 718

CONDITION 1950°F Solution Treated Double Aged 1350°F/1200°F TEST DIRECTION C-R

SPEC. NOS. AGC 90172-2 FORM Forging

DATA BASIS Category "A" COMMENT -

PROPERTY Fracture Toughness, K_Q

TEMP °F	LOTS/ HEATS	N	df	N_e	$\bar{X}$	K	S	K_Q COMPUTED VALUE psi $\sqrt{in.}$
-423	2	13	12		157.3	3.659	6.75	132
-423	2	13		7	157.3	4.354	7.07	127

1-in. thick specimen.

COMMENTS:

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-1B PAGE NO. 4 DATE 7-15-70 MATERIAL Alloy 718

CONDITION Heat Treat B TEST DIRECTION C-R

SPEC. NOS. FORM

DATA BASIS Category "A" COMMENT

PROPERTY Critical Crack Size

TEMP °F	FLAW SHAPE PARAM. Q	SURFACE CRACKS a in.	SURFACE CRACKS 2c, in.		INTERNAL CRACKS 2a, in.	INTERNAL CRACKS 2c, in.	
-423	.9	.111	1.11		.266	1.33	
	1.41	.173	.576		.418	.696	
	2.2	.271	.542		.652	.652	

DRM TYPE:	DATA RELEASE MEMORANDUM NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 5	DRM NO. M-3B SUPPLEMENT #1 REV. NO. 2

SUBJECT: FRACTURE TOUGHNESS OF ALUMINUM ALLOY 7039-T63 FORGING — DATE: 7-16-70

1. SCOPE:

Fracture toughness and critical flaw sizes allowed for aluminum alloy 7039-T63 forging are attached. This supplements DRM M-3B, Rev. 2, dated 6-24-70.

2. TEST MATERIAL:

One subscale (Heat AA) external ring forging was tested to determine its fracture toughness. The material was tested in four specimen groups at room temperature and two specimen groups at -320°F. Grouping of specimens was made on the basis of thickness. The specimen used was the WOL type with thickness varying from .40 to 1.12 inches. Specimen orientation was arranged that the load axis was in the circumferential direction, while the crack was orientated in the axial direction of the forging to simulate the hoop stress direction of the pressure vessel application.

3. DATA ANALYSIS:

Data from one group of specimens tested at RT (.40-.50 thick) were invalid because the thickness was not sufficient to meet the required criterion of

$$B = 2.5 \left(\frac{K_Q}{YS}\right)^2$$

where B = Thickness, in.
K_Q = Provisional value of fracture toughness
YS = Yield strength

Data from this group were not included in the analysis. The remaining three groups covered the thickness range from .62 to 1.12 and fulfilled the ASTM criteria for acceptable fracture toughness data. These groups, although from one heat, were found to be heterogeneous in means but homogeneous in variance within groups. Satterthwaite's approximation yielded an N_e of 3, which was considered too small for use in calculating realistic fracture toughness allowables. This required the method developed by Layard [Reference (c)] to determine the 99/95 allowables at room temperature. The variance among groups (6σ) was estimated to be 8 ksi in.$^{1/2}$ which was approximately 2 ksi $\sqrt{in.}$ above and below the highest and lowest mean calculated from the test data.

APPROVED BY DATE	PREPARED FOR: DATE:	COMPONENT/ ASSEMBLY IDENT
PREPARED BY 7/16/70	AUTHORIZED CLASSIFIER DATE 14 July 70	

SUBJECT: FRACTURE TOUGHNESS OF ALUMINUM ALLOY 7039-T63 FORGING

DATE: 7-16-70

The same variances as calculated for room temperature were used to establish the allowable at -320°F.

Using the minimum allowable fracture toughness values and yield strengths at room temperature and -320°F, critical crack sizes were calculated, using the following formulas:

For Internal Flaws $$\left(\frac{a}{Q}\right)_{cr} = .318 \frac{K_{Ic}^2}{\sigma^2}$$

For Surface Flaws $$\left(\frac{a}{Q}\right)_{cr} = .263 \frac{K_{Ic}^2}{\sigma^2}$$

Flaw shape parameter -a/2c ratio relationships, as developed by Tiffany, were used. For these calculations, the σ/σ_{YS} ratio was assumed to be 1, the most severe condition. In all instances, the area of the crack that can be tolerated exceeded the defect size that can be detected by NDT techniques (ultrasonic for internal defects, dye penetrant for surface defects). Aluminum alloys are required to meet the quality level of AGC Standard 9014-11. Class 11 internal defects are those equivalent to a 5/64-in. diameter flat-bottom hole; the area of this allowable defect is .005 square in. The most critical are the surface critical crack sizes (calculated on the basis of -320°F data) whose areas are only slightly greater than the defects allowed by AGC Standard 9014-11. Although the critical crack sizes listed exceed the detectable defects, no allowance is made for crack growth by fatigue or stress corrosion.

4. CONCLUSIONS:

Because only one heat was tested and among-group variance was estimated, the data are classified category "C" in accordance with SNPO-C directives. The critical flaw sizes are greater than the minimum allowable detectable defects, and the material is considered ductile when stressed circumferentially with flaw orientated in the axial direction.

APPROVED BY	DATE	PREPARED ...: DATE:	COMPONENT/ ASSEMBLY IDENT
PREPARED BY		AUTHORIZED CLASSIFIER DATE	

DRM TYPE:	DATA RELEASE MEMORANDUM NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 3 OF 5	DRM NO. M-3B SUPPLEMENT #1 REV. NO. 2

SUBJECT: FRACTURE TOUGHNESS OF ALUMINUM ALLOY 7039-T63 FORGING   DATE: 7-16-70

5. REFERENCES:

(a) Third Quarterly Report, Contract Year 1970, NERVA Materials Developments, S131-PR3.

(b) Memorandum 7732:ML 70-219, G. F. Mader to L. C. Corrington, Subject: "Interpretation of Technical Directive SNPO-C 69-28," dated 7 July 1970.

(c) Memorandum, M. W. Layard to C. W. Funk, "Adjusted Design Allowable Values," dated 1 July 1970.

(d) Campbell, J. E., Plane Strain Fracture Toughness for Selected Metals and Alloys, DMIC Report S-28, June 1969.

APPROVED BY	DATE	PREPARED FOR: DATE:		COMPONENT/ ASSEMBLY IDENT
PREPARED BY		AUTHORIZED CLASSIFIER	DATE	

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-3B PAGE NO. 4 DATE 7-16-70 MATERIAL 7039

CONDITION T63 TEST DIRECTION C-A

SPEC. NOS. - FORM Ring Forging

DATA BASIS Category "C" COMMENT -

PROPERTY Fracture Toughness

TEMP °F	LOTS/ HEATS	N	$\overline{X}$	K B	K W	S B	S W		COMPUTED VALUE ksi $\sqrt{in.}$
RT	1	13	36.5	2.336	1.33	3.48	1.01		29.9
-320	1	8	30.1	2.336	1.33	3.48	1.01		23.5

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-3B PAGE NO. 5 DATE 7-16-70 MATERIAL 7039

CONDITION T63 TEST DIRECTION C-A

SPEC. NOS. - FORM Ring Forging

DATA BASIS Category "C" COMMENT

PROPERTY Critical Crack Size

TEMP °F	FLAW SHAPE PARAM. Q	SURFACE a, in.	CRACKS 2c, in.		INTERNAL 2a, in.	CRACKS 2c, in.	
RT	.9	.071	.713		.172	.860	
	1.41	.112	.374		.270	.450	
	2.2	.174	.174		.422	.422	
-320	.9	.0266	.266		.064	.32	
	1.41	.0416	.1386		.100	.168	
	2.2	.065	.065		.156	.156	

DRM TYPE:	DATA RELEASE MEMORANDUM NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 5	DRM NO. M-4B REV. NO. 0

SUBJECT: TENSILE DESIGN ALLOWABLES FOR TI 5AL-2.5SN ELI RING FORGINGS — DATE: 7-17-70

1. SCOPE:

Data furnished by WANL and from an Aerojet test program were analyzed to develop minimum design allowable values for the following mechanical properties:

Tensile Ultimate Strength
Tensile Yield Strength
Tensile Elongation

2. TEST MATERIALS:

Ring Forgings, annealed, 40-in. diameter x 3-in. thick x 5-in. long. Purchased to WANL PDS 30028-1. Data from 23 heats were reported for tensile ultimate strength, 22 heats for yield strength, and 24 heats for tensile elongation.

3. DATA ANALYSIS:

Test data were statistically analyzed to obtain minimum design allowables for 99% reliability with 95% confidence. Box's modification of the Bartlett's test and the one-way analysis of variance were used to evaluate homogeneity of data and establish the heat-to-heat and within-heat variability.

Tensile ultimate strength data from 23 heats tested at RT and -320°F were used to estimate the within-lot variance and to test for homogeneity. The within-group variances were homogeneous, but the means were heterogeneous. The degrees of freedom were computed using the N effective method.

Tensile yield strength data from 22 heats tested at RT and -320°F were used to estimate the within lot variance and to test for homogeneity. The within-group variances were homogeneous, but the means were heterogeneous. The degrees of freedom were computed using the N effective method.

Tensile elongation data from 24 heats tested at RT and -320°F were used to estimate the within-lot variance and to test for homogeneity. The within-group variances were homogeneous, but the means were heterogeneous, except for the radial-direction data at -320°F. The degrees of freedom for the circumferential data at -320°F and the circumferential and radial data at RT were computed using the N_e calculation method.

APPROVED BY / DATE	PREPARED FOR: / DATE:	COMPONENT/ ASSEMBLY IDENT
[signature] 7/17/70	W. Campbell L. Johnson	TPA Valves
PREPARED BY	AUTHORIZED CLASSIFIER / DATE	
[signature]	[signature] 20 July	

DRM TYPE:

DRM NO. M-4B

REV. NO. 0

SUBJECT: TENSILE DESIGN ALLOWABLES FOR TI 5AL-2.5SN ELI RING FORGINGS

DATE: 7-17-70

4. CONCLUSIONS:

The design allowable values are category "A" data, since the requirements of TD 69-28 of 15 degrees of freedom to estimate the random variance and homogeneity of the within-group variance at the 90% significance level were satisfied.

5. REFERENCES:

WANL Quality Control Data on Ring Forgings and Test Data Requisition No. 51281, transmitted to Aerojet by R. Shollenberg.

APPROVED BY	DATE	PREPARED FOR: DATE:	COMPONENT/ ASSEMBLY IDENT
PREPARED BY		AUTHORIZED CLASSIFIER DATE	

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRW NO. M-4B PAGE NO. 3 DATE 7-17-70 MATERIAL Ti 5Al-2.5Sn (ELI)

CONDITION Annealed TEST DIRECTION C & R

SPEC. NOS. FORM Ring Forgings

DATA BASIS Category "A" COMMENT Data from all 23 lots or heats at RT and -320°F were used to estimate the within-lot variance.

PROPERTY Tensile Ultimate Strength

TEMP °F	LOTS/ HEATS	N	df N_e*	DIRECTION	$\overline{X}$ ksi	K	S ksi	COMPUTED VALUE ksi
RT	8	34	30.3	C**	120	3.034	3.68	109
RT	7	20	36	R**	117	2.972	3.09	108
-320	4	16	37	C	190	2.961	2.95	181
-320	4	8	27	R	185	3.098	4.77	170
	See Comments							

COMMENTS: *N_e = Effective N
**C = Circumferential; R = Radial

REFERENCE 1.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-4B PAGE NO. 4 DATE 7-17-70 MATERIAL Ti 5Al-2.5Sn (ELI)

CONDITION Annealed TEST DIRECTION C & R

SPEC. NOS. FORM Ring Forgings

DATA BASIS Category "A" COMMENT Data from all 22 lots or heats were analyzed to estimate the within-lot variance

PROPERTY Tensile Yield Strength

TEMP °F	LOTS/ HEATS	N	df* N_e	DIRECTION	$\bar{X}$ ksi	K	S ksi	COMPUTED VALUE ksi
RT	7	34	27	C**	111	3.098	4.35	97.5
RT	7	22	27	R	107	3.098	4.34	93.6
-320	4	7	24	C	175	3.158	5.87	157
-320	4	8	23	R	170	3.181	7.35	147
	See Comments							

COMMENTS: *Degrees of freedom, N_e calculation
**C = Circumferential, R = Radial

REFERENCE 1.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRL NO. M-4B PAGE NO. 5 DATE 7-17-70 MATERIAL Ti 5Al-2.5Sn (ELI)

CONDITION Annealed TEST DIRECTION C & R

SPEC. NOS. FORM Ring Forgings

DATA BASIS Category "A" COMMENT Data from all 24 heats or lots were used to estimate the within-lot variance.

PROPERTY Elongation

TEMP °F	LOTS/ HEATS	N	df*	DIRECTION	$\bar{X}$ %	K	S %	COMPUTED VALUE %
	See Comments							
RT	8	34	58	C**	16.6	2.812	1.835	11.5
RT	8	24	33	R	13.5	2.812	1.735	8.6
-320	4	16	37***	C	14.4	2.961	2.94	5.7
-320	4	8	58	R	10.5	2.812	1.735	6.7

COMMENTS: *df = Degrees of freedom
**C = Circumferential, R = Radial
***N_e Calculation
REFERENCE 1.

DRM TYPE:	DATA RELEASE MEMORANDUM NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 7	DRM NO. M-2 REV. NO. 0

SUBJECT:	THERMOPHYSICAL PROPERTIES OF AISI 347 STAINLESS STEEL	DATE: 6-22-70

1. SCOPE:

The following thermophysical properties of AISI 347 stainless steel are attached:

Density
Specific Heat
Thermal Conductivity
Solar Absorptance
Total Emittance
Radiant Energy Ratio

2. TEST MATERIAL:

Material conforms to chemical composition of AISI 347.

3. DATA ANALYSIS:

Density was calculated using thermal expansion data. The uncertainty range of the values is ± 5%.

Specific heat at low temperatures was calculated using Neumann-Kopp's law and determined experimentally at elevated temperatures. The uncertainty in values is ± 10% at temperature of -423°F and below and ± 5% at other temperatures.

The uncertainty in values for thermal conductivity is ± 15% from -420°F to -320°F, ± 10% from -320°F to 540°F, and ± 5% at temperatures above 540°F.

The solar absoprtance and total emittance data are extremely sensitive to surface cleanliness and condition. Because methods of cleaning or polishing cannot be standardized, the values for emittance and absorptance vary according to the efficiency of these operations. Minimum-maximum values are presented for these properties. Radiant energy ratios are calculated using minimum and maximum values of solar absorptance and minimum values of emittance.

4. CONCLUSIONS:

No category classification for these data is required.

APPROVED BY / DATE	PREPARED FOR: / DATE:	COMPONENT/ ASSEMBLY IDENT
[signature] 7/20/70	L. Shurley, L. Johnson, W. Campbell.	
PREPARED BY	AUTHORIZED CLASSIFIER / DATE	
[signature]	[signature]	

Nozzle Values TPA

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-2 PAGE NO. 2 DATE 6-22-70 MATERIAL 347

CONDITION Wrought TEST DIRECTION All

SPEC. NOS. FORM All

DATA BASIS COMMENT Uncertainty ± 5%

PROPERTY Density

TEMP °F.		ρ LBS/IN³					
-459		.289					
-279		.288					
- 99.4		.287					
80.6		.285					
261		.284					
441		.283					
621		.281					
801		.280					
981		.278					
1161		.277					
1341		.275					
1521		.273					
1701		.271					
1881		.269					
2061		.267					
2241		.265					

T. S. Touloukian, Recommended Values of the Thermophysical Properties of Eight Alloys, Major Constituents and Their Oxides, Thermophysical Properties Research Center, February 1966.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-2 PAGE NO. 3 DATE 6-22-70 MATERIAL 347

CONDITION ______ TEST DIRECTION All

SPEC. NOS. ______ FORM ______

DATA BASIS No Category Required COMMENT Uncertainty <423°F ± 10%; >422°F ± 5%

PROPERTY Specific Heat

TEMP °F	C_p BTU/LB/°F		TEMP °F	C_p BTU/LB/°F			
-450	.0001		1161	.145			
-441	.0003		1341	.149			
-432	.0006		1521	.152			
-423	.0010		1701	.156			
-405	.005		1881	.160			
-387	.007		2061	.164			
-369	.013		2241	.168			
-351	.026						
-333	.036						
-315	.045						
-297	.054						
-279	.063						
-189	.087						
- 99	.097						
80	.108						
261	.117						
441	.123						
621	.130						
801	.135						
981	.140						

Touloukian, T. S., Recommended Values of the Thermophysical Properties of Eight Alloys, Major Constituents and Their Oxides, Thermophysical Properties Research Center, February 1966.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-2 PAGE NO. 4 DATE 6-22-70 MATERIAL 347

CONDITION ______ TEST DIRECTION All

SPEC. NOS. ______ FORM ______

DATA BASIS No Category Required COMMENT Uncertainty ± 15% from -420°F to -320°F; > -320°F and < 540°F, ± 10%; > 540°F, ± 5%

PROPERTY Thermal Conductivity

TEMP °F		BTU/HR-FT-°F					
-420		1.39					
-410		1.77					
-360		3.50					
-320		4.5					
-260		5.64					
-200		6.44					
-160		6.85					
- 60		7.62					
- 10		7.93					
40		8.21					
140		8.73					
540		10.78					
1040		12.82					
1540		14.93					
1840		16.11					

Materials Memorandum 7732:MM 70-199, A. J. Giannuzzi to K. Sato, Thermal Conductivity of AISI 347 Including Recommended Curves, dated 22 May 1970.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-2 PAGE NO. 5 DATE 6-22-70 MATERIAL 347

CONDITION - TEST DIRECTION -

SPEC. NOS. - FORM -

DATA BASIS No Category Required COMMENT

PROPERTY Solar Absorptance

TEMP °F	SURFACE CONDITION		MIN.	MAX. α_S
	(a) Vapor degreased in trichloroethylene sandblasted with 100 mesh grit Al_2O_3 with nozzle 12 in. from surface.	40°F	.57	.69
	(b) Mechanically polished	40°F	.32	.44

Thermal Radiative Control Surfaces for Spacecraft, R. E. Gaumer and L. A. McKellar, LMSD-704104, 1961.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-2 PAGE NO. 6 DATE 6-22-70 MATERIAL 347

CONDITION - TEST DIRECTION -

SPEC. NOS. - FORM -

DATA BASIS No Category Required COMMENT

PROPERTY Total Emittance, ε

TEMP °F	SURFACE CONDITION	MIN.	MAX.
(a)	Vapor degreased in trichloroethylene, sandblasted with 100 mesh Al_2O_3 with nozzle 12 in. from surface.		
- 60		.40	.52
40		.40	.52
140		.41	.53
(b)	Mechanically polished		
- 60		.11	.23
40		.13	.25
140		.14	.26

Thermal Radiative Control Surfaces for Spacecraft, R. E. Gaumer and L. A. McKellar, LMSD-704104, 1961.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-2 PAGE NO. 7 DATE 6-22-70 MATERIAL 347

CONDITION Wrought TEST DIRECTION All

SPEC. NOS. FORM

DATA BASIS No Category Required COMMENT

PROPERTY Thermal Radiant Energy Ratio, α_S/ε

TEMP °F	SURFACE CONDITION	MIN. α_S/ε	MAX. α_S/ε
40	Vapor degreased in trichloroethylene, sandblasted with 100 mesh Al_2O_3 with nozzle 12 in. from surface.	1.4	1.7
40	Mechanically polished	2.5	3.4

Calculated using min. and max. α_S and min. ε at 40°F using values from individual data sheets.

DRM TYPE:	NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 4	DRM NO. M-33 REV. NO. 0

SUBJECT: DESIGN ALLOWABLES FOR THE THERMAL AND PHYSICAL PROPERTIES OF LiH — DATE: 7-17-70

1. SCOPE:

The design allowables for the following properties of LiH are attached:

Specific Heat
Thermal Conductivity
Density

2. TEST MATERIAL:

The data were obtained using material of 99.8% purity.

3. DATA ANALYSIS:

The uncertainty in values for specific heat is ± 10% at temperatures below -320°F and ± 5% at temperature above -320°F. Because specific heat is based on Btu/lb, there is no difference in absolute values which may be attributed to the method of fabrication agglomeration (cast or compact).

The uncertainties of thermal conductivity are ± 20% to 302°F and ± 15% above 302°F. This uncertainty is attributed to conflicting data appearing in the literature. The thermal conductivity will vary in proportion to density and composition of entrapped gases, if any.

The uncertainty in density measurement is ± 10%. Density will vary according to method of agglomeration of powders or, if by casting, by the amount of void formation during freezing. The values of other temperatures are based on room temperature density and thermal expansion.

4. CONCLUSIONS:

The uncertainties for LiH are generally higher than for metals. The data are classified category "C".

APPROVED BY / DATE	PREPARED FOR: L. Shirley DATE:	COMPONENT/ ASSEMBLY IDENT: Shield
[signature] 7/27/70		
PREPARED BY: [signature] 7/27/70	AUTHORIZED CLASSIFIER: [signature] DATE: 27 Jul 70	

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-33 PAGE NO. 2 DATE 7-17-70 MATERIAL LiH

CONDITION - TEST DIRECTION -

SPEC. NOS. - FORM 99.8 LiH

DATA BASIS Category "C" COMMENT Uncertainty ± 10% at temperatures less than -320°F; ± 5% above -320°F.

PROPERTY Specific Heat, C_p

TEMP °F		C_p BTU/LB °F					
-420		0					
-320		.1					
-160		.47					
-100		.57					
0		.72					
70		.82					
300		1.08					
560		1.28					
810		1.48					

REFERENCE: Touloukian, Y. S., Thermophysical Properties of High Temperature Solid Materials, Macmillan Co., New York, 1967.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-33 PAGE NO. 3 DATE 7-17-70 MATERIAL LiH

CONDITION - TEST DIRECTION -

SPEC. NOS. - FORM Compacted 99.2% Dense

DATA BASIS Category "C" COMMENT Uncertainty ± 20% to 302°F; ± 15% above 302°F.

PROPERTY Thermal Conductivity, K

TEMP °F		K BTU/ FT-HR-°F					
122		4.0					
212		3.8					
302		3.5					
392		3.3					
482		3.1					
572		2.98					

REFERENCE: Technical Data Sheet, Lithium Hydride, Foote Mineral Co.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-33 PAGE NO. 4 DATE 7-17-70 MATERIAL LiH

CONDITION - TEST DIRECTION -

SPEC. NOS. - FORM 100% Dense

DATA BASIS Category "C" COMMENT Uncertainty, ± 5%

PROPERTY Density

TEMP °F		ρ LBS/IN.^{3}					
-360		.0284					
-260		.0283					
-160		.0283					
- 60		.0282					
80		.028					
140		.0279					
240		.0277					
340		.0275					
440		.027					
540		.0271					
740		.0265					

Density will vary according to efficiency of compaction. This property will vary in direct proportion to its room temperature density. In addition, uncertainties in the thermal expansion measurements with densities at temperatures other than RT are calculated, will add to the uncertainty in density values.

DRM TYPE:	NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 5	DRM NO. M-4B REV. NO. 0 SUPP. NO. 1

SUBJECT: TENSILE DESIGN ALLOWABLES FOR TI 5AL-2.5SN ELI PANCAKE FORGINGS **DATE:** 7-28-70

1. SCOPE:

Design allowables for the following properties of Ti 5Al-2.5Sn (ELI) alloy are attached:

Tensile Ultimate Strength
Tensile Yield Strength
Elongation

This DRM supplements M-4B, Rev. 0, dated 17 July 1970.

2. TEST MATERIALS:

Three heats of billet stock from two producers (Titanium Metals Corp. and Reactive Metals Co.) meeting requirements for chemical composition to AGC Specification 90163 were tested. The raw stock was forged by two forgers (Wyman Gordon Co. and Carleton Forge Co.) with each forger using material from one producer. The billets were forged into pancakes 17-in. diameter x 10-in. high and 14-in. diameter x 6-in. high, respectively, using accepted practice for this material. Tensile tests were conducted by the forger at room temperature and by AGC at -320 and -423°F.

3. DATA ANALYSIS:

The data results were grouped by heat, temperature and direction and then combined to determine the homogeneity with respect to the means and to the variances. All variances were homogeneous at the 90% level with respect to temperature, heat and direction, and this permitted the use of overall within-lot variance to calculate the allowables.

The room temperature tensile ultimate strengths and the elongation at -320 and -423°F were heterogeneous with respect to the means and N_e calculations were made. The design allowables are shown on the individual data sheets attached.

The minimum allowable elongation at -320°F is 4%; this low value is due primarily to the low test values obtained from Reactive Metals Heat No. 294245.

APPROVED BY / DATE	PREPARED FOR: / DATE:	COMPONENT/ ASSEMBLY IDENT
[signature]	W. Campbell	TPA Valves.
PREPARED BY: [signature] 7/27/70	AUTHORIZED CLASSIFIER: [signature] / DATE: 28 July 70	

DRM TYPE:	NRO MATERIALS AND PROCESSES STAFF / AEROJET-GENERAL CORPORATION / SACRAMENTO, CALIFORNIA / SHEET 2 OF 5	DRM NO. M-4B / REV. NO. 0 / SUPP. NO. 1

SUBJECT: TENSILE DESIGN ALLOWABLES FOR TI 5AL-2.5SN ELI PANCAKE FORGINGS   DATE: 7-28-70

Three heats were tested at -423°F. Fracture occured at the gauge punch marks in three of the five specimens of Heat No. 294245, and these values were deleted. In addition, a yield point was not obtained for one of the remaining specimens. Because of these anomalies, all results of this heat were not used in the analyses.

4. CONCLUSIONS:

The data are classified category "A" according to the intent of SNPO TD 69-37.

5. REFERENCES:

(a) NRO Materials Memorandum 69-131, P. P. Dessau to W. E. Campbell, Subject: Evaluation of Large Ti 5Al-2.5Sn ELI and Alloy 718 Forgings, dated 18 September 1969

(b) NRO Materials Memorandum 70-001, P. P. Dessau to W. E. Campbell, Subject: Tensile Strength and Fracture Toughness of Ti 5Al-2.5 Sn ELI Forging, dated 5 January 1970

(c) NRO Materials Memorandum 70-088, P. P. Dessau to W. E. Campbell, Subject: Additional LH_2 Tensile Test Results of Ti 5Al-2.5Sn ELI Forging, dated 27 February 1970.

APPROVED BY DATE	PREPARED FOR: DATE:	COMPONENT/ ASSEMBLY IDENT
PREPARED BY	AUTHORIZED CLASSIFIER DATE	

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-4B PAGE NO. 3 DATE 7-28-70 MATERIAL Ti-5Al-2.5Sn ELI

CONDITION Annealed TEST DIRECTION Rad and Circum.

SPEC. NOS. FORM Forging

DATA BASIS Category "A" COMMENT

PROPERTY Tensile Ultimate Strength, F_{tu}

TEMP °F	LOTS/ HEATS	N	N_e	$\overline{X}$	K	S	COMPUTED VALUE
RT (R)	3	10	37	118	2.961	3.4	108
RT (C)	3	10	32	119	3.206	3.5	108
-320 (C)	3	11	48	188	2.869	3.4	178
-423	2	28	48	210	2.864	2.77	202

COMMENTS: References (a), (b) and (c).

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-4B PAGE NO. 4 DATE 7-28-70 MATERIAL Ti-5Al-2.5Sn ELI

CONDITION Annealed TEST DIRECTION Rad & Circum

SPEC. NOS. FORM Pancake Forging

DATA BASIS Category "A" COMMENT

PROPERTY Tensile Yield Strength

TEMP °F	LOTS/ HEATS	N	N_e	$\overline{X}$	K	S	COMPUTED VALUE
RT (C & R)	3	20	47	109	2.876	3.67	98
-320 (C)	3	11	47	175	2.876	4.18	163
-423 (C)	2	27	47	191	2.876	4.15	179

COMMENTS:

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-4B PAGE NO. 5 DATE 7-28-70 MATERIAL Ti-5Al-2.5Sn ELI

CONDITION Annealed TEST DIRECTION Circumferential and Radial

SPEC. NOS. FORM Pancake Forging

DATA BASIS Category "A" COMMENT

PROPERTY Elongation, e

TEMP °F	LOTS/ HEATS	N	N_e	$\bar{X}$	K	S	COMPUTED VALUE %
RT (C&R)	3	20	20	15.8	2.862	1.86	10.5
-320	3	11	28	11.0	3.080	2.22	4.2
-423	2	29	22	15.8	3.206	2.4	8.1

COMMENTS:

DRM TYPE:	DATA RELEASE MEMORANDUM NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 3	DRM NO. M-2AI REV. NO. 0

SUBJECT: TENSILE YIELD DESIGN ALLOWABLES FOR AISI 347 TRIPLE BRAZE SHEET

DATE: 7-30-70

1. SCOPE:

The tensile yield strength design allowable for AISI 347 simulated braze cycled sheet are attached.

2. TEST MATERIAL:

Sheet stock .012-in. thick, Heat No. 42449, 28241-2, 42656, tensile tested at Oak Ridge National Laboratory.

3. DATA ANALYSIS:

Test data were statistically analyzed to obtain minimum design allowables for 99% reliability with 95% confidence. A one-way analysis of variance was used to establish the heat-to-heat variability at room temperature. The heat-to-heat variances for the other six temperatures were estimated from the room temperature value. To obtain this estimate, the yield strength at each temperature was divided by the room temperature yield strength, then the product of this ratio and the room temperature heat-to-heat variance was used as an estimate of the among-group variance at the temperature of interest.

4. CONCLUSIONS:

The data are classified category "C" since the heat-to-heat variances at other than room temperature were estimated.

5. DATA REFERENCE:

Department 7850Memo A0701, A. J. Mihanovich to J. L. Watkins, Subject: Statistical Analysis of CRES 347 Sheet Material Property Data, dated 7 July 1970.

APPROVED BY DATE	PREPARED FOR: DATE:	COMPONENT/ ASSEMBLY IDENT
[signature] 7/30/70	L S Kinley	Nozzle
PREPARED BY	AUTHORIZED CLASSIFIER DATE	
V. E. Kalb	[signature] 30 July	

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-2AI PAGE NO. 2 DATE 7-30-70 MATERIAL AISI 347

CONDITION Simulated Braze Cycle TEST DIRECTION Transverse and Longitudinal to Rolling Direction

SPEC. NOS. - FORM Sheet

DATA BASIS Category "C" COMMENT -

PROPERTY Tensile Yield Strength

TEMP °F	HEATS	DIRECTION	N	$\bar{X}$ KSI	TOLERANCE FACTOR	SW KSI	SH-H KSI	MINIMUM DESIGN VALUES (KSI)
-302	3	L*	33	54.5	2.097 2.326	2.17	2.63	43.8
-320	3	T*	36	53.0	2.232 2.326	1.74	2.63	43.0
-100	2	T	14	49.5	3.128 2.326	1.57	2.51	38.8
- 52	2	L	23	45.7	3.995 2.326	0.827	2.41	36.8
- 52	2	T	18	47.4	3.961 2.326	0.86	2.41	38.4
75	3	L	36	37.3	3.009 2.326	0.829	2.16	29.8
75	3	T	36	38.2	2.978 2.326	0.841	2.16	30.7

+6

-3

L* = Parallel to rolling direction.
T* = Transverse to rolling direction..

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-2AI PAGE NO. 3 DATE 7-30-70 MATERIAL AISI 347

CONDITION Simulated Braze Cycle TEST DIRECTION Transverse and Parallel to rolling direction

SPEC. NOS. - FORM Sheet

DATA BASIS Category "C" COMMENT -

PROPERTY Tensile Yield Strength

TEMP °F	HEATS	DIRECTION	N	$\overline{X}$ KSI	TOLERANCE FACTOR	SW KSI	SH-H KSI	MINIMUM DESIGN VALUE (KSI)
800	3	L	33	25.7	2.952 2.326	0.715	1.80	19.4
800	3	T	35	26.5	3.181 2.326	0.642	1.80	20.3
1600	3	L	33	9.4	2.467 2.326	0.582	1.09	5.437
1600	3	T	35	9.6	2.565 2.326	0.538	1.09	5.69
2000	3	L	32	2.1	2.257 2.326	0.457	0.173	0.665
2000	3	T	35	1.98	2.245 2.326	0.472	0.173	0.517

DATA RELEASE MEMORANDUM

DRM TYPE:	NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 3	DRM NO. M-10 REV. NO. 0

SUBJECT: THERMOPHYSICAL PROPERTIES OF AISI 302 DATE: 8-3-70

1. SCOPE:

The design allowables for the following thermal properties of AISI 302 are attached:

Thermal Conductivity
Specific Heat

2. TEST MATERIAL:

Thermal conductivity data for material which conforms to the chemical composition requirements for AISI 302 were gathered from two literature sources. Data from AISI 303 were used at cryogenic temperature as a close approximation to the thermal conductivity of AISI 302 material.

The specific heat of alloy AISI 301 is reported as a close approximation to the specific heat of AISI 302.

3. ANALYSIS OF DATA:

The thermal conductivity data for AISI 302 were compiled from three literature sources, and uncertainty factors were estimated to be ± 20% from 37°R (-423°F), ± 15% to points from 37°R to 140°R (-320°F), ± 10% from -320°F to RT, ± 5% at RT and higher.

4. CONCLUSIONS:

These data are categorized "C", a conservative engineering estimate of the properties with uncertainty ranges.

5. CONCLUSIONS:

(1) Cryogenic Materials Data Handbook, AFML-TDR-64-280, Supplement 4, Vol. I.

(2) Thermophysical Properties of High Temperature Solid Materials, Thermophysical Properties Research Center, Purdue University, Purdue, Indiana, Y. S. Touloukian, Editor.

(3) Aerospace Structural Metals Handbook, Syracuse University Institute, AFSC Project 7381, Contract AF33(615)-1184.

APPROVED BY DATE	PREPARED FOR: L. D. Johnson DATE:	COMPONENT/ ASSEMBLY IDENT: Valves & Actuator
PREPARED BY V. E. Kohl	AUTHORIZED CLASSIFIER DATE 7 Aug 70	

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-10 PAGE NO. 2 DATE 8-3-70 MATERIAL AISI 302

CONDITION ______ TEST DIRECTION ______

SPEC. NOS. ______ FORM ______

DATA BASIS Category "C" COMMENT Data is from Alloy AISI 301 data

PROPERTY Specific Heat

TEMP °F		C_P BTU/LB °F		UNCERTAINTY FACTOR %			
-300		0.0775		± 15			
-200		0.09		± 10			
-100		0.095		± 10			
0		0.104		± 5			
200		0.115		± 5			
400		0.126		± 5			

REFERENCE (2)

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-10 PAGE NO. 3 DATE 8-3-70 MATERIAL AISI 302

CONDITION ______ TEST DIRECTION ______

SPEC. NOS. ______ FORM ______

DATA BASIS Category "C" COMMENT Data from 37°R to 137°R is from AISI 303 material.

PROPERTY Thermal Conductivity

TEMP °F		k BTU-FT/ HR FT^2 °F		UNCERTAINTY FACTOR %			
-420		1.39		± 20			
-410		1.77		± 20			
-360		3.50		± 20			
-320		4.5		± 15			
-260		5.64		± 5			
-200		6.44		± 5			
-160		6.85		± 5			
- 60		7.62		± 5			
- 10		7.93		± 5			

REFERENCES (1), (2), AND (3).

DRM TYPE:	DATA RELEASE MEMORANDUM NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 4	DRM NO. M-38 REV. NO. 0

SUBJECT: DESIGN ALLOWABLES FOR ALLOY 22-13-5 STAINLESS STEEL BAR **DATE:** 8-7-70

1. SCOPE:

The design allowable values for the following properties of alloy 22-13-5 stainless steel are attached:

Ultimate Tensile Strength
Tensile Yield Strength
Elongation

2. TEST MATERIAL:

The test data were taken from 1-in. diameter annealed bar conforming to the chemical requirements of alloy 22-13-5 stainless steel alloy.

3. DATA ANALYSIS:

The referenced product data sheet values were reduced by 20% to provide a conservative estimate for design allowable values.

4. CONCLUSIONS:

The data are classified category "C" according to interpretation of TD 69-37, a conservative engineering estimate of the design allowables.

5. REFERENCE:

(1) Armco Product Data Sheet S-45, Armco Steel Corp., Advanced Materials Division, Baltimore, Maryland.

APPROVED BY DATE	PREPARED FOR: K. A. Shurley DATE:	COMPONENT/ ASSEMBLY IDENT — Nozzle
[signature] 8/7/70		
PREPARED BY [signature]	AUTHORIZED CLASSIFIER DATE [signature] 7 Aug 70	

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-38 PAGE NO. 2 DATE 8-7-70 MATERIAL Alloy 22-13-5 Stainless Steel

CONDITION Annealed TEST DIRECTION

SPEC. NOS. FORM 1-In. Diameter Bar

DATA BASIS Category "C" COMMENT Typical values reduced by 20%

PROPERTY Tensile Ultimate Strength

TEMP °F		DESIGN VALUE ksi					
-320		181					
-100		117					
75		97					
600		84					
800		78					
1000		74					
1200		66					
1350		56					
1500		42					

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-38 PAGE NO. 3 DATE 8-7-70 MATERIAL Alloy 22-13-5 Stainless Steel

CONDITION Annealed TEST DIRECTION

SPEC. NOS. FORM In. Diameter Bar

DATA BASIS Category "C" COMMENT Typical values reduced by 20%

PROPERTY TENSILE YIELD STRENGTH

TEMP °F		DESIGN VALUE ksi					
-320		102					
-100		68					
75		52					
600		37					
800		36					
1000		33					
1200		33					
1350		32					
1500		27					

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-38 PAGE NO. 4 DATE 8-7-70 MATERIAL Alloy 22-13-5 Stainless Steel

CONDITION Annealed TEST DIRECTION

SPEC. NOS. FORM 1-In. Diameter Bar

DATA BASIS Category "C" COMMENT Typical values reduced by 20%

PROPERTY Elongation

TEMP °F		DESIGN VALUE % IN 2 IN.				
-320		33.0				
-100		39.6				
75		37.2				
600		30.0				
800		24.0				
1000		31.6				
1200		28.4				
1350		31.2				
1500		34.4				

DRM TYPE:	NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 4	DRM NO. M-2B1 REV. NO. 2

SUBJECT: AISI 347 TRIPLE BRAZED FORGINGS **DATE:** 8-7-70

1. SCOPE:

Tensile data from the two triple-brazed nozzle forgings were analyzed to develop minimum design allowable values for the following properties:

Tensile Ultimate Strength
Elongation

This revision supercedes DRM M-2BI, Rev. 1, dated 4-24-70.

2. TEST MATERIAL.

Large triple-brazed nozzle forgings, S/N 27 and S/N 33, fabricated by the Ladish Company.

3. DATA ANALYSIS:

Test data were statistically analyzed to obtain minimum design allowables for 99% reliability with 95% confidence. Box's modification to the Bartlett's test and the one-way analysis of variance were used to evaluate homogeneity of data and establish the heat-to-heat and within-heat variability. Only test data dated 30 September 1969 were used in the computation. The -320°F data were not analyzed.

All sources of variation (test temperatures, test directions and the two heats) were tested for homogeneity using Box's modification of the Bartlett's test. Since this test showed that the groups of data were not homogeneous, a design allowable was computed for each direction at each temperature. A one-way analysis of variance analysis was used to compute the component of variance contributed by the lot-to-lot variability.

When the within-lot variances were homogeneous and the means were not, the Satterthwaite's approximation was used to compute the degrees of freedom associated with the combined within- and among-lot variance. When this calculation resulted in an unrealistically small number of degrees of freedom, the method developed by Layard [Reference (2)] was used.

APPROVED BY / DATE	PREPARED FOR: L. A. Schurley DATE:	COMPONENT/ Nozzle ASSEMBLY IDENT
[signature] 8/7/70		
PREPARED BY [signature]	AUTHORIZED CLASSIFIER / DATE [signature] 7 Aug 70	

DRM TYPE:	DATA RELEASE MEMORANDUM NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 2 OF 4	DRM NO. M-2BI REV. NO. 2

SUBJECT: AISI 347 TRIPLE BRAZED FORGINGS DATE: 8-7-70

4. CONCLUSIONS.

Although some data points were not homogeneous with regard to the within variance, these estimated design values are supported by adjacent category "A" data points, therefore, the entire curve or group of points are categorized "A" data.

5. REFERENCES.

(1) Materials Memo 70-104, W. F. Emmons to D. J. Lamvermeyer, Subject: Raw Tensile Data for AISI 347 Nozzle Forgings, S/N 21, 27 and 33, dated 9 March 1970.

(2) Dept. 7850 Memo M0698, M. W. Layard to C. W. Funk, Subject: Adjusted Design Allowable Values, dated 1 July 1970.

APPROVED BY DATE	PREPARED FOR: DATE:	COMPONENT/ ASSEMBLY IDENT
PREPARED BY	AUTHORIZED CLASSIFIER DATE	

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-2BI PAGE NO. 3 DATE 8-7-70 MATERIAL AISI 347

CONDITION Triple Brazed TEST DIRECTION Axial and Circumferential

SPEC. NOS. ______ FORM Forging

DATA BASIS Category "A" COMMENT ______

PROPERTY Tensile Ultimate Strength

TEMP °F	LOTS/ HEATS	N	df*	Direction	$\bar{X}$ ksi	K	S ksi	COMPUTED VALUE ksi
-100	2	23	8**	Axial	118	4.143	3.34	104
RT	2	18	16	Axial	81.0	2.326 5.854	1.45 0.342	75.6
600	2	24	22	Axial	56.3	2.326 3.506	0.54 1.33	51.3
1200	2	22	4	Axial	43.6	5.741	0.61	40.0
-100	2	24	21**	Circ	121	3.233	4.26	107
RT	2	36	34	Circ	81	2.326 3.966	1.70 0.607	74.7
600	2	19	18	Circ	55.4	4.354	1.6	49.2
1200	2	18	4**	Circ	44.4	5.741	0.721	40.3

COMMENTS: *df = degrees of freedom
**N_e calculation

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-2BI PAGE NO. 4 DATE 8-7-70 MATERIAL AISI 347

CONDITION Triple Brazed TEST DIRECTION Axial and Circumferential

SPEC. NOS. FORM Forging

DATA BASIS Category "A" COMMENT

PROPERTY Tensile Elongation

TEMP °F	LOTS/ HEATS	N	df*	Direction	$\overline{X}$ %	K	S %	COMPUTED VALUE %
-100	2	23	5**	Axial	54.0	5.062	1.30	47.4
RT	2	18	17	Axial	63.5	3.37	1.504	58.4
600	2	16	14	Axial	35.8	2.326 4.012	1.34 0.537	30.5
1200	2	24	22	Axial	39.0	2.326 2.698	2.86 1.40	28.0
-100	2	25	23	Circ	54.9	2.326 2.698	2.26 1.39	45.9
RT	2	36	34	Circ	63.1	3.181	1.15	59.4
600	2	29	28	Circ	36.8	3.080	1.903	30.9
1200	2	19	16**	Circ	38.5	3.414	1.263	34.2

COMMENTS: *df = degrees of freedom
**N_e calculation.

DRM TYPE:	DATA RELEASE MEMORANDUM NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 2	DRM NO. M-1 REV. NO. 2

SUBJECT: DESIGN ALLOWABLES FOR THERMOPHYSICAL PROPERTIES OF ALLOY 718 **DATE:** 8-7-70

1. SCOPE:

The design allowables for linear thermal expansion of alloy 718 are attached.

2. TEST MATERIAL:

Material conformed to chemical composition requirements for alloy 718 Heat Treat B.

3. DATA ANALYSIS:

Thermal expansion experimental data from two sources were compared and linear thermal expansion coefficients calculated. The estimated variability is ± 10% for all temperatures.

4. CONCLUSIONS:

This supercedes the linear thermal expansion data contained in Rev. 1, DRM M-1, dated 6-12-70.

5. REFERENCES:

(1) Clark, A. F., "Low Temperature Thermal Expansion of Some Metallic Alloys," Proceedings of the Second International Cryogenic Engineering Conference (ICEC2), Brighton, U.K., 1968, Cryogenics, Oct. 1968.

(2) Aerojet LRP Report DVR 65-146, Thermal Expansion of TPA Materials, March 1965.

APPROVED BY	DATE	PREPARED FOR: W. E. Campbell DATE:	COMPONENT/ ASSEMBLY IDENT /
[signature]	8/7/70		
PREPARED BY [signature]		AUTHORIZED CLASSIFIER [signature] DATE 10 Aug 70	

TPA

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-1 PAGE NO. 2 DATE 8-7-70 MATERIAL Alloy 718

CONDITION Heat Treat B TEST DIRECTION All

SPEC. NOS. FORM All

DATA BASIS No Category Required COMMENT Estimated Maximum Variability Range ± 10%

PROPERTY Coefficient of Linear Thermal Expansion

TEMP °F		α IN/IN/°F X 10^{-6} *					
0		6.4					
-100		6.17					
-200		6.04					
-320		5.47					
-423		4.78					

*From room temperature to temperature indicated.

Aerojet LRP Report DVR 65-146, Thermal Expansion of TPA Materials, March 1965.

DRM TYPE:	DATA RELEASE MEMORANDUM NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 4	DRM NO. M-36B REV. NO. 0

SUBJECT: TENSILE DESIGN ALLOWABLES FOR 21-6-9 STAINLESS STEEL FORGINGS

DATE: 8-7-70

1. SCOPE:

The following design allowables for the Fe-21 Cr-6 Ni-9 Mn stainless steel alloy forgings are attached:

Tensile Ultimate Strength
Tensile Yield Strength
Elongation

2. TEST MATERIAL:

The basic data were obtained from supplier technical literature.

3. DATA ANALYSIS:

The tensile ultimate and tensile yield values at room and subzero temperatures were based on typical values obtained on a 4-3/4 in. thick slab. The values were adjusted to compensate for the thermal effects of the simulated brazing cycle(1) and differences in room temperature properties. These values were then decreased by 20% to obtain a conservative estimate of the statistical allowable values.

The 600°F values were obtained using the same procedure as for subzero properties except that sheet typical values were used as the base.

4. CONCLUSIONS:

The data are classified category "C", a conservative estimate of the statistical allowables, according to directive SNPO TD 69-37.

5. REFERENCES:

(1) DRM M-36A, Tensile Design Allowables for the 21-6-9 Stainless Steel Alloy Sheet, dated 8-7-70.

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PREPARED BY [signature]	AUTHORIZED CLASSIFIER [signature] DATE 13 Aug 70	

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-36B PAGE NO. 2 DATE 8-7-70 MATERIAL Fe-21 Cr-6 Ni-9 Mn

CONDITION Triple Brazed TEST DIRECTION Circumferential and Radial

SPEC. NOS. - FORM Forging

DATA BASIS Category "C" COMMENT

PROPERTY Tensile Ultimate Strength, F_{tu}

TEMP °F	LOTS/ HEATS	N	N_e	$\overline{X}$	K	S	COMPUTED VALUE ksi
-423							186
-320							154
-110							102
RT							78
600							61

COMMENTS: Adjusted values of data contained in Armco Technical Data Bulletin S-26, Armco Steel Corp., Middletown, Ohio, 3/66.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-36B PAGE NO. 3 DATE 8-7-70 MATERIAL Fe-21 Cr-6 Ni-9 Mn

CONDITION Triple Brazed TEST DIRECTION Circumferential and Radial

SPEC. NOS. - FORM Forging

DATA BASIS Category "C" COMMENT

PROPERTY Tensile Yield Strength, F_{ty}

TEMP °F	LOTS/ HEATS	N	N_e	$\overline{X}$	K	S	COMPUTED VALUE ksi
-423							141
-320							108
-110							62
RT							42
600							24

COMMENTS: Adjusted values of data contained in Armco Tehcnical Data Bulletin S-26, Armco Steel Corp., Middletown, Ohio, 3/66.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-36B PAGE NO. 4 DATE 8-7-70 MATERIAL Fe-21 Cr-6 Ni-9 Mn

CONDITION Triple Brazed TEST DIRECTION Circumferential and Radial

SPEC. NOS. - FORM Forging

DATA BASIS Category "C" COMMENT

PROPERTY Elongation, e

TEMP °F	LOTS/ HEATS	N	N_e	$\overline{X}$	K	S	COMPUTED VALUE %
-423							12
-320							20
-110							45
RT							40
600							33

COMMENTS: Adjusted values of data contained in Armco Technical Data Bulletin S-26, Armco Steel Corp., Middletown, Ohio, 3/66.

DRM TYPE:	NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 5	DRM NO. M-36A REV. NO. 0

SUBJECT: TENSILE DESIGN ALLOWABLES FOR THE 21-6-9 STAINLESS STEEL ALLOY SHEET **DATE:** 8-7-70

1. SCOPE:

The following design allowables for the Fe-21% Cr-6% Ni-9% Mn alloy sheet are attached:

Tensile Ultimate Strength
Tensile Yield Strength
Elongation

2. TEST MATERIAL:

All data were obtained from supplier technical literature.

3. DATA ANALYSIS:

To establish room temperature properties after exposure to the simulated brazing cycle, the effect of annealing data for the 21-6-9 alloy was reviewed. A gradual decrease (total 10 ksi) of TUS and TYS is noted when annealing temperature is increased from 1800 to 1950°F. It was estimated that strengths would further decrease 5 ksi by thermal exposure to temperatures above 2000°F.

Values below room temperature (RT to -423°F) were available at the same room temperature tensile ultimate strength level as that selected for the TUS of the brazed material, and, therefore, there was no need to adjust room temperature tensile strength to determine subzero TUS properties. However, it was necessary to adjust TYS room temperature properties to determine subzero TYS properties.

Elevated temperature properties were available; however, these had to be adjusted to account for difference in room temperature baseline properties. Values for the 1600°F temperature were extrapolated on the basis of AISI 347 behavior.

All adjusted TUS and TYS values were discounted by 20% as a conservative statistical estimate of design allowables.

Elongation values were decreased by 20% of published values. The typical elongation at 1600°F was estimated from the elongation curves at lower temperatures.

APPROVED BY DATE	PREPARED FOR: L. A. Shurley DATE:	COMPONENT/ASSEMBLY IDENT Nozzle
PREPARED BY	AUTHORIZED CLASSIFIER DATE 13 Aug 70	

DRM TYPE:	DATA RELEASE MEMORANDUM NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 2 OF 5	DRM NO. M-36A REV. NO. 0

SUBJECT:	TENSILE DESIGN ALLOWABLES FOR THE 21-6-9 STAINLESS STEEL ALLOY SHEET	DATE:	8-7-70

4. CONCLUSIONS:

The data are rated category "C", a conservative estimate of the statistical allowable, according to directive SNPO 69-37.

5. REFERENCES:

(1) Technical Bulletin S-26, Armco 21-6-9 Stainless Steel, Armco Steel Co., Middletown, Ohio, 3/66.

APPROVED BY	DATE	PREPARED FOR: DATE:		COMPONENT/ ASSEMBLY IDENT
PREPARED BY		AUTHORIZED CLASSIFIER	DATE	

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-36A PAGE NO. 3 DATE 8-7-70 MATERIAL Fe-21 Cr-6 Ni-9 Mn

CONDITION Triple Brazed TEST DIRECTION L & T

SPEC. NOS. - FORM Sheet

DATA BASIS Category "C" COMMENT

PROPERTY Tensile Ultimate Strength, F_{tu}

TEMP °F	LOTS/ HEATS	N	N_e	$\overline{X}$	K	S	COMPUTED VALUE ksi
-423							196
-320							162
-110							107
RT							82
800							57
1200							45
1600							16

COMMENTS:

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-36A PAGE NO. 4 DATE 8-7-70 MATERIAL Fe-21 Cr-6 Ni-9 Mn

CONDITION Brazed TEST DIRECTION L & T

SPEC. NOS. - FORM Sheet

DATA BASIS Category "C" COMMENT

PROPERTY Tensile Yield Strength, F_{ty}

TEMP °F	LOTS/ HEATS	N	N_e	$\overline{X}$	K	S	COMPUTED VALUE ksi
-423							151
-320							116
-110							67
RT							45
800							20
1200							18
1600							12

COMMENTS:

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-36A PAGE NO. 5 DATE 8-7-70 MATERIAL Fe-21 Cr-6 Ni-9 Mn

CONDITION Brazed TEST DIRECTION L & T

SPEC. NOS. FORM Sheet

DATA BASIS Category "C" COMMENT

PROPERTY Elongation, e

TEMP °F	LOTS/ HEATS	N	N_e	$\overline{X}$	K	S	COMPUTED VALUE %
-423							12
-320							24
-110							37
RT							34
800							33
1200							21
1600							14

COMMENTS:

DRM TYPE:	DATA RELEASE MEMORANDUM NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 5	DRM NO. M-4B REV. NO. 1

SUBJECT: TENSILE DESIGN ALLOWABLES FOR TI 5AL-2.5SN ELI RING FORGINGS   DATE: 9-1-70

1. SCOPE:

Data furnished by WANL were analyzed to develop minimum design allowable values for the following mechanical properties:

Tensile Ultimate Strength
Tensile Yield Strength
Tensile Elongation

This DRM supercedes DRM M-4B, Rev. 0, dated 7-17-70, to clarify numbers of heats and lots from which the data originated.

2. TEST MATERIALS:

Ring Forgings, annealed, 40-in. diameter x 3-in. thick x 5-in. long. Purchased to WANL PDS 30028-1. Data from 12 different lots were reported. Room temperature and -320°F tensile data were reported for 4 lots in the radial direction (Nos. 39409, 24916, 19284, 19283), and 4 different lots in the circumferential direction (Nos. 30949, 47428, TME 1860, 51281). In addition, RT data in both radial and circumferential directions were reported for 4 additional lots (Nos. 24918, 52782, 46784, 19285). Although the lots were not identified as separate heats, since the forgings were large, it is assumed each lot constituted a different heat.

3. DATA ANALYSIS:

Test data were statistically analyzed to obtain minimum design allowables for 99% reliability with 95% confidence. Box's modification of the Bartlett's test and the one-way analysis of variance were used to evaluate homogeneity of data and establish the heat-to-heat and within-heat variability.

Tensile ultimate strength data from material tested at RT and -320°F were used to estimate the within-lot variance and to test for homogeneity. The within-group variances were homogeneous, but the means were heterogeneous. The degrees of freedom were computed using the Satterthwaite approximation.

Tensile yield strength data from material tested at RT and -320°F were used to estimate the within-lot variance and to test for homogeneity. The within-group variances were homogeneous, but the means were heterogeneous. The degrees of freedom were computed using the Satterthwaite approximation.

APPROVED BY / DATE	PREPARED FOR: N. A. Edlebeck DATE: L. D. Johnson	COMPONENT/ ASSEMBLY IDENT: TPA VALVES
[signature] 5 Sept 70		
PREPARED BY: V. E. Kahle	AUTHORIZED CLASSIFIER: Uncl. [signature] DATE: 9-3-70	

Tensile elongation data from material tested at RT and -320°F were used to estimate the within-lot variance and to test for homogeneity. The within-group variances were homogeneous, but the means were heterogeneous, except for the radial-direction data at -320°F. The degrees of freedom for the circumferential data at -320°F and the circumferential and radial data at RT were computed using the Satterthwaite approximation.

4. CONCLUCIONS.

The design allowable values are category "A" data, since the requirements of TD 69-28 of 15 degrees of freedom to estimate the random variance and homogeneity of the within-group variance at the 90% significance level were satisfied.

5. REFERENCES:

WANL Quality Control Data on Ring Forgings and Test Data Requisition No. 51281, transmitted to Aerojet to R. Shollenberger.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-4B PAGE NO. 3 DATE 9-1-70 MATERIAL Ti 5Al-2.5Sn (ELI)

CONDITION Annealed TEST DIRECTION C & R

SPEC. NOS. FORM Ring Forgings

DATA BASIS Category "A" COMMENT Data from all 23 data groups at RT and -320°F were used to estimate the within-lot variance.

PROPERTY Tensile Ultimate Strength

TEMP °F	LOTS/ HEATS	N	df N_e*	DIRECTION	$\overline{X}$ ksi	K	S ksi	COMPUTED VALUE ksi
RT	8	34	30.3	C**	120	3.034	3.68	109
RT	7	20	36	R**	117	2.972	3.09	108
-320	4	16	37	C	190	2.961	2.95	181
-320	4	8	27	R	185	3.098	4.77	170

See Comments

*N_e = Satterthwaite's approximation

**C = Circumferential; R = Radial.

REFERENCE 1.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-4B PAGE NO. 4 DATE 9-1-70 MATERIAL Ti 5Al-2.5Sn (ELI)

CONDITION Annealed TEST DIRECTION C & R

SPEC. NOS. FORM Ring Forgings

DATA BASIS Category "A" COMMENT Data from all 24 data groups were analyzed to estimate the within-lot variance

PROPERTY Tensile Yield Strength

TEMP °F	LOTS/ HEATS	N	df* N_e	DIRECTION	$\overline{X}$ ksi	K	S ksi	COMPUTED VALUE ksi
RT	8	34	27	C**	111	3.098	4.35	97.5
RT	8	22	27	R	107	3.098	4.34	93.6
-320	4	7	24	C	175	3.158	5.87	157
-320	4	8	23	R	170	3.181	7.35	147
	See	Comments						

*Degrees of freedom, Satterthwaite's approximation.
**C = Circumferential; R = Radial

REFERENCE 1.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-4B PAGE NO. 5 DATE 9-1-70 MATERIAL Ti 5Al-2.5Sn (ELI)

CONDITION Annealed TEST DIRECTION C & R

SPEC. NOS. FORM Ring Forgings

DATA BASIS Category "A" COMMENT Data from all 24 data groups were used to estimate the within-lot variance.

PROPERTY Elongation

TEMP °F	LOTS/ HEATS	N	df*	DIRECTION	$\overline{X}$ %	K	S %	COMPUTED VALUE %
	See Comments							
RT	8	34	58	C**	16.6	2.812	1.835	11.5
RT	8	24	33	R	13.5	2.812	1.735	8.6
-320	4	16	37***	C	14.4	2.961	2.94	5.7
-320	4	8	58	R	10.5	2.812	1.735	6.7

*df - Degrees of freedom
**C = Circumferential; R = Radial
***Satterthwaite's Approximation

REFERENCE 1.

DRM TYPE:	DATA RELEASE MEMORANDUM NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 5	DRM NO. M-6H REV. NO. 0 SUPP. 1

SUBJECT: PHYSICAL PROPERTIES OF FIBROUS GRAPHITE COMPOSITE **DATE:** 9-9-70

1. SCOPE:

The following physical properties of fibrous graphite composite are attached and include estimates of variability:

Bulk Density
Thermal Conductivity
Specific Heat

2. TEST MATERIAL:

Fibrous graphite composite specimens from 1/4-in. and 1-in. thick plates were taken from one lot of material for bulk density and thermal conductivity data. The specific heat data are taken from manufactured graphite.

3. DATA ANALYSIS:

The bulk densities of specimens taken from 1/4-in. and 1-in. thick plates were measured at room temperature. The dimensions of the rectangular specimens were measured to within 0.0001 in. and the volume calculated. The specimen was weighed on an analytical balance capable of weighing to 0.1 Mg. The RT density was then calculated.

The minimum and maximum densities at temperatures other than RT were computed from thermal expansion data and the RT minimum-maximum values. The uncertainty range of the data is estimated to be $\pm$ .05.

The thermal conductivity of fibrous graphite is estimated for 5 temperatures, RT to 3000°F from thermal diffusivity measurements. The uncertainty range of the data is estimated to be $\pm$ .20.

The specific heat data are for manufactured graphite with an estimated uncertainty range of $\pm$ .10 and is considered to be a good estimate of the specific heat of fibrous graphite.

4. CONCLUSIONS:

The data are classified as category "C" data since the values and uncertainty ranges were estimated.

APPROVED BY DATE	PREPARED FOR: L. A. Shurley DATE: 9-9-70	COMPONENT/ ASSEMBLY IDENT	Skirt Extensio
[signature] 9/9/70			
PREPARED BY	AUTHORIZED CLASSIFIER DATE		
[signature]	[signature] 9 Sept 70		

DRM TYPE:	DATA RELEASE MEMORANDUM NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 2 OF 5	DRM NO. M-6H REV. NO. 0 SUPP. 1

SUBJECT: PHYSICAL PROPERTIES OF FIBROUS GRAPHITE COMPOSITE

DATE: 9-9-70

5. REFERENCES:

(1) Davis, H. O., Kotfila, R. J., and Schleicher, W. J., "The Fabrication and Properties of the Fibrous Reinforced Graphite Composite, AGCarb-101," Aerojet Nuclear Systems Company, RN-S-0549, March 1970.

(2) The Industrial Graphite Engineering Handbook, Union Carbide Corp., Carbon Products Division, 270 Park Avenue, New York, New York.

APPROVED BY DATE	PREPARED FOR: DATE:	COMPONENT/ ASSEMBLY IDENT
PREPARED BY	AUTHORIZED CLASSIFIER DATE	

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-6H PAGE NO. 3 DATE 9-9-70 MATERIAL Fibrous Graphite Composite

CONDITION ______ TEST DIRECTION ______

SPEC. NOS. ______ FORM 1-In. and 1/4-In. Thick Block

DATA BASIS Category "C" COMMENT Uncertainty Range of ± 5%

PROPERTY Bulk Density

TEMP °F		DENSITY (LBS/IN.^{3}) MAXIMUM	MINIMUM				
75		.0560	.0506				
250		.0559	.0505				
500		.0559	.0505				
1000		.0557	.0503				
2000		.0554	.0500				
3000		.0550	.0497				

REFERENCE (1).

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-6H PAGE NO. 4 DATE 9-9-70 MATERIAL Manufactured Graphite

CONDITION TEST DIRECTION

SPEC. NOS. FOR.

DATA BASIS Category "C" COMMENT Uncertainty Range ± 10%

PROPERTY Specific Heat

TEMP °F		SPECIFIC HEAT C_p (BTU/LB °F) MAXIMUM	MINIMUM				
-100		.090	.109				
80		.155	.190				
170		.230	.188				
350		.304	.248				
530		.355	.291				

REFERENCE (2).

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-6H PAGE NO. 5 DATE 9-9-70 MATERIAL Fibrous Graphite Composite

CONDITION ________ TEST DIRECTION Perpendicular and Parallel to Plies

SPEC. NOS. ________ FORM ________

DATA BASIS Category "C" COMMENT Uncertainty Range is ± 20%

PROPERTY Thermal Conductivity, BUT/Hr/Ft^2/°F/Ft

TEMP °F		PERPENDICULAR TO PLIES			PARALLEL TO PLIES		
		MINIMUM	MAXIMUM		MINIMUM	MAXIMUM	
80		14.0	21.0		26.4	39.6	
500		10.4	15.6		20.0	30.0	
1000		[illegible].8	13.2		15.3	22.9	
2000		8.0	12.0		12.0	18.0	
3000		8.0	12.0		13.2	16.8	

REFERENCE (1).

DRM TYPE:	DATA RELEASE MEMORANDUM NRO MATERIALS AND PROCESSES STAFF AEROJET-GENERAL CORPORATION SACRAMENTO, CALIFORNIA SHEET 1 OF 10	DRM NO. M-7B REV. NO. 2

SUBJECT: DESIGN ALLOWABLES FOR 6061-T6 ALUMINUM ALLOY FORGINGS **DATE:** 9-3-70

1. SCOPE:

The design allowable values for the following properties of 6061-T6 aluminum alloy forgings are attached:

Ultimate Tensile Strength
Tensile Yield Strength
Elongation

This DRM supercedes the tensile data published in DRM M-7B, Rev. 1, dated 3-18-70 and adds detailed mean and standard deviation values for the computed values.

2. TEST MATERIAL:

The data are applicable to hand forgings or equivalent less than 4.00 inches thick and not exceeding 256 sq. in. cross-sectional area.

3. DATA ANALYSIS:

"A" basis Mil-Handbook-5 data were obtained which meet NERVA requirements of 99% reliability with 95% confidence level. The means and the standard deviations for room temperature and each direction were provided by R. Koffman of Alcoa. However, the number of specimens was not included. The one-sided tolerance factor (k) for room temperature was calculated and assumed to be the same for all temperatures. The standard deviations and means at temperatures other than room were calculated from the Mil-Hdbk-5 values and the assumed one-sided tolerance factor, k. The number of actual test values, N, may be inferred from the k factor.

4. CONCLUSIONS:

The data are classified category "B" according to interpretation of TD 69-37 which permits the use of handbook data providing the proper degree of statistics were used to meet the intent of TD 28.

5. DATA REFERENCE:

MIL-HDBK-5 insert, dated 8 February 1966, and 1 December 1968.

Private Communication from R. Koffman, Alcoa, dated 26 May 1970.

APPROVED BY / DATE	PREPARED FOR: / DATE: L. D. Johnson/ L. A. Shurley	COMPONENT/ ASSEMBLY IDENT	Valves, Pressure Vessel
[signature] 10 Sept 70			
PREPARED BY	AUTHORIZED CLASSIFIER / DATE		
V. E. Kahl 10 Sept 70	[signature] 10 Sept 70		

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-7B PAGE NO. 2 DATE 9-3-70 MATERIAL 6061

CONDITION T6 TEST DIRECTION Longitudinal

SPEC. NOS. MIL-A-22771 FORM Hand Forging

DATA BASIS Category "B" TD 69-28 COMMENT ≤ 4.0 in. Thick

PROPERTY Ultimate Tensile Strength, F_{tu}

TEMP °F	LOTS/ HEATS	N	N_e	$\overline{X}$ ksi	K	S ksi	COMPUTED VALUE ksi
-423				68.9	3.05	3.4	58.5
-320				57.5	3.05	2.8	49.0
70				44.7	3.05	2.2	38.0
300				35.9	3.05	1.8	30.4

COMMENTS: Mil Handbook 5 - Basis "A", dated 8 February 1966. Room temperature data obtained from Table 3.2.6.0(d), page 324; multiplication factors for other temperatures obtained from Figure 3.2.6.2.1(a), 100 hour exposure, page 325 of reference.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-7B PAGE NO. 3 DATE 9-3-70 MATERIAL 6061

CONDITION T6 TEST DIRECTION Transverse

SPEC. NOS. Mil-A-22771 FORM Hand Forging

DATA BASIS Category "B" TD 69-28 COMMENT ≤ 4.0 in. Thick

PROPERTY Ultimate Tensile Strength, F_{tu}

TEMP °F	LOTS/ HEATS	N	N_e	$\bar{X}$ ksi	K	S ksi	COMPUTED VALUE ksi
-423				69.5	3.94	2.8	58.5
-320				58.0	3.94	2.3	49.0
70				45.1	3.94	1.8	38.0
300				34.7	3.94	1.44	30.4

COMMENTS: Mil Handbook 5 - Basis "A", dated 8 February 1966. Room temperature data obtained from Table 3.2.6.0(d), page [illegible]4; multiplication factors for other temperatures obtained from Figure 3.2.6.2.1(a), 100 hour exposure, page 325, of said reference.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-7B PAGE NO. 4 DATE 9-3-70 MATERIAL 6061

CONDITION T6 TEST DIRECTION Short Transverse

SPEC. NOS. Mil-A-22771 FORM Hand Forging

DATA BASIS Category "B" TD 69-28 COMMENT ≤ 4.0 in. Thick

PROPERTY Ultimate Tensile Strength, F_{tu}

TEMP °F	LOTS/ HEATS	N	N_e	$\overline{X}$ ksi	K ksi	S ksi	COMPUTED VALUE ksi
-423				71.0	4.79	2.9	57.0
-320				59.4	4.79	2.45	47.7
70				46.1	4.79	1.9	37.0
300				36.9	4.79	1.52	29.6

COMMENTS: Mil Handbook 5 - Basis "A", dated 8 February 1966. Room temperature data obtained from Table 3.2.6.0(d), page 324; multiplication factor for other temperatures obtained from Figure 3.2.6.2.1(a), 100 hour exposure, page 325, of said reference.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-7B PAGE NO. 5 DATE 9-3-70 MATERIAL 6061

CONDITION T6 TEST DIRECTION Longitudinal

SPEC. NOS. Mil-A-22771 FORM Hand Forging

DATA BASIS Category "B" TD 69-28 COMMENT ≤ 4.0 in. Thick

PROPERTY Tensile Yield Strength, F_{ty}

TEMP °F	LOTS/ HEATS	N	N_e	$\bar{X}$ ksi	K	S ksi	COMPUTED VALUE ksi
-423				55.9	2.89	2.62	48.3
-320				47.8	2.89	2.24	41.3
70				40.5	2.89	1.9	35.0
300				33.6	2.89	1.6	29.0

COMMENTS: Mil Handbook 5 - Basis "A", dated 8 February 1966. Room temperature data obtained from Table 3.2.6.0(d), page 324; multiplication factors for other temperatures obtained from Figure 3.2.6.2.1(b), 100 hour exposure, page 326, of said reference.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-7B PAGE NO. 6 DATE 9-3-70 MATERIAL 6061

CONDITION T6 TEST DIRECTION Transverse

SPEC. NOS. Mil-A-22771 FORM Hand Forging

DATA BASIS Category "B" TD 69-28 COMMENT ≤ 4.0 in. Thick

PROPERTY Tensile Yield Strength, F_{ty}

TEMP °F	LOTS/ HEATS	N	N_e	$\bar{X}$ ksi	K	S ksi	COMPUTED VALUE ksi
-423				55.9	2.75	2.76	48.3
-320				47.8	2.75	2.36	41.3
70				40.7	2.75	2.0	35.0
300				33.6	2.75	1.66	29.0

COMMENTS: Mil Handbook 5 - Basis "A", dated 8 February 1966. Room temperature data obtained from Table 3.2.6.0(d), page 324; multiplication factors for other temperatures obtained from Figure 3.2.6.2.1(b), 100 hour exposure, page 326, of said reference.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-7B PAGE NO. 7 DATE 9-3-70 MATERIAL 5051

CONDITION T6 TEST DIRECTION Short Transverse

SPEC. NOS. Mil-A-22771 FORM Hand Forging

DATA BASIS Category "B" TD 69-28 COMMENT ≤ 4.0 in. Thick

PROPERTY Tensile Yield Strength, F_{ty}

TEMP °F	LOTS/ HEATS	N	N_e	$\bar{X}$ ksi	K	S ksi	COMPUTED VALUE ksi
-423				55.4	3.8	2.6	45.5
-320				47.4	3.8	2.24	38.9
70				40.3	3.8	1.9	33.0
300				33.5	3.8	1.6	27.4

COMMENTS: Mil Handbook 5 - Basis "A", dated 8 February 1966. Room temperature data obtained from Table 3.2.6.0(d), page 324; multiplication factors for other temperatures obtained from Figure 3.2.6.2.1(b), 100 hour exposure, page 326, of said reference.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-7B PAGE NO. 8 DATE 9-3-70 MATERIAL 6061

CONDITION T6 TEST DIRECTION Longitudinal

SPEC. NOS. Mil-A-22771 FORM Hand Forging

DATA BASIS Category "B" TD 69-28 COMMENT ≤ 4.0 in. Thick

PROPERTY Elongation, e

TEMP °F	LOTS/ HEATS	N	N_e	$\bar{X}$ %	K	S %	COMPUTED VALUE %
-423				29.0	4.33	3.0	16.6
-320				25.0	4.33	2.5	14.0
70				17.8	4.33	1.8	10.0
200				13.7	4.33	1.7	9.4

COMMENTS: Data obtained from Table 3.2.6.0(d), page 324, Mil Handbook 5, basis "A", dated 8 February 1966. Data for -320 and 200°F are to be acquired by test or from literature.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-7B PAGE NO. 9 DATE 9-3-70 MATERIAL 6061

CONDITION T6 TEST DIRECTION Transverse

SPEC. NOS. Mil-A-22771 FORM Hand Forging

DATA BASIS Category "B" TD 69-28 COMMENT ≤ 4.0 In. Thick

PROPERTY Elongation, e

TEMP °F	LOTS/ HEATS	N	N_e	$\overline{X}$	K	S	COMPUTED VALUE
-320							-
70				14.3	2.86	2.2	8%
300							-

COMMENTS: Data obtained from Table 3.2.6.0(d), page 324, Mil Handbook 5, dated 8 February 1966. Data for -320 and 300°F are to be acquired by test or from literature.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-7B PAGE NO. 10 DATE 9-3-70 MATERIAL 6061

CONDITION T6 TEST DIRECTION Short Transverse

SPEC. NOS. Mil-A-22771 FORM Hand Forging

DATA BASIS Category "B" TD 69-28 COMMENT ≤ 4.0 in. Thick

PROPERTY Elongation, e

TEMP °F	LOTS/ HEATS	N	N_e	$\bar{X}$	K	S	COMPUTED VALUE
-320							-
70				12.7	3.66	2.1	5%
300							-

COMMENTS: Data obtained from Table 3.2.6.0(d), page 324, Mil Handbook 5, dated 8 February 1966.

APPENDIX B

MATERIAL PROBLEM IDENTIFICATION SHEETS

PROJECT: [illegible]
STRESS: [illegible]
THERMAL: [redacted]
MATERIALS: [illegible]
RELIABILITY: [illegible]
NUCLEAR: [illegible]

PROBLEM SHEET NO. 1
9 JUNE 1970[redacted]
SHEET 1 OF [illegible]
INVESTIGATOR: P. P. DESSAU

IDENTIFICATION OF MATERIALS PROBLEMS

TURBOPUMP ASSEMBLY

SUBASSEMBLY	PREDICTED ENVIRONMENT			SELECTED MATERIAL AND CONDITION		PROBLEM	TEST PLAN IDENTITY	
	°F	ATMOS	RADIATION NVT 10 HRS	PRIME	BACKUP		PRIME	BACKUP
TURBINE ROTOR	RT to -423	GH_2 LH_2	10^{16} to 10^{17} (F)	Ti-5Al-2.5Sn ELI Forging Annealed	718 Forging HT (B)	Mechanical Properties Physical Properties Fracture Toughness Anisotropy Radiation Damage Fatigue Resistance Hydrogen Embrittlement Joint Properties - EB	M-4	M-1
MANIFOLD	RT to -160	GH_2	10^{16} to 10^{17} (F)	310 Sheet & Forging Annealed	718 Sheet & Forging HT (B)	Mechanical Properties Physical Properties Fracture Toughness Anisotropy Radiation Damage Hydrogen Embrittlement Joint Properties - EB & TIG Fatigue Resistance	M-29	M-1
HOUSING	RT to -423	LH_2	10^{16} to 10^{17} (F)	310 Sheet & Forging Annealed	718 Sheet & Forging HT (B)	Mechanical Properties Physical Properties Fracture Toughness Anisotropy Radiation Damage Hydrogen Embrittlement Joint Properties - EB & TIG	M-29	M-1
IMPELLER AND INDUCER	RT to -423	LH_2	10^{16} to 10^{17} (F)	Ti-5Al-2.5Sn ELI Forging Annealed	718 Forging HT (B)	Mechanical Properties Physical Properties Fracture Toughness Anisotropy Radiation Damage Hydrogen Embrittlement Fatigue Resistance	M-4	M-1
BOLTS	RT to -423	GH_2 LH_2	10^{16} to 10^{17} (F)	A286 CW Bar Aged	Multiphase	Mechanical Properties Physical Properties Fracture Toughness Radiation Damage Corrosion Resistance Fatigue Resistance	M-5	M-3u
ROTOR TIE BOLTS	RT to -423	GH_2 LH_2	10^{16} to 10^{17} (F)	718 CW Bar Aged	Multiphase	Mechanical Properties Physical Properties Fracture Toughness Radiation Damage Corrosion Resistance Fatigue Resistance	M-1	M-30

IDENTIFICATION OF MATERIALS PROBLEMS

TURBOPUMP ASSEMBLY

SUBASSEMBLY	PREDICTED ENVIRONMENT			SELECTED MATERIAL AND CONDITION		PROBLEM	TEST PLAN IDENTITY	
	°F	ATMOS	RADIATION NVT 10 HRS	PRIME	BACKUP		PRIME	BACKUP
BEARING, RACES AND ROLLING ELEMENTS	RT to -423	GH_2 LH_2	10^{16} to 10^{17} (F)	440C Forging HT	-	Fatigue Properties Grain Flow Control	M-13	
RETAINER	RT to -423	GH_2 LH_2	γ-10^9 to 10^{10} erg/gm	PBI-Glass Laminate	PBI-Graphite Laminate	Control and Reproducibility of Laminate Properties	M-11	

(F) signifies fast neutrons with energies in excess of 1 Mev.

PROJECT[redacted]
STRESS:
THERMAL:
MATERIALS:
RELIABILITY:
NUCLEAR:

PROBLEM S[redacted]T NO. 2
25 MAY 1970
SHEET 1 OF 1
INVESTIGATOR: D.LAHVERMEYER

IDENTIFICATION OF MATERIAL PROBLEMS

PRESSURE VESSEL ASSEMBLY

SUBASSEMBLY	PREDICTED ENVIRONMENT			SELECTED MATERIAL AND CONDITION		PROBLEM	TEST PLAN IDENTITY	
	°F	ATMOS	RADIATION NVT 10 HRS.	PRIME	BACKUP		PRIME	BACKUP
CYLINDER AND CLOSURE	300 to -320	Air/Space GH_2	10^{17} to 10^{18} (F) (1 HR) 10^{18} to 10^{19} (F) (10 HRS)	7039 Al T-63 Forging	6061 Al T6 Forging	Cryogenic Fracture Toughness Fatigue Resistance Thermal Control Coating Stability Radiation Damage Stress Corrosion Resistance Anisotropy of Forging Weld Properties Mechanical Properties Physical Properties	M-3	M-7
BOLTS FOR CYLINDER AND CLOSURE	TBD TBD	Air/Space GH_2	10^{17} to 10^{18} (F) (1 HR) 10^{18} to 10^{19} (F) (10 HRS)	A-286	Multiphase 260 ksi Bolts	Hydrogen Embrittlement Radiation Damage Cryogenic Fracture Toughness Stress Corrosion Resistance Fatigue Mechanical Properties Physical Properties	M-5	M-30
THREADED INSERTS	300 to -320	Air/Space GH_2	10^{17} to 10^{18} (F) (1 HR) 10^{18} to 10^{19} (F) (10 HRS)	347 CRES Bar	TBD	Fatigue Strength Disassembly Galling Mechanical Properties Physical Properties	M-2	-

(F) signifies fast neutrons with energies in excess of 1 Mev.

PROJECT: [illegible]
STRESS: [illegible]
THERMAL: [illegible]
MATERIALS: [illegible]
RELIABILITY: [illegible]
NUCLEAR: [illegible]

PROBLEM SHEET NO. 3
25 MAY 1970
SHEET 1 OF 1
INVESTIGATOR: W. F. EMMONS

IDENTIFICATION OF MATERIALS PROBLEMS

NOZZLE ASSEMBLY

SUBASSEMBLY	PREDICTED ENVIRONMENT °F	ATMOS	RADIATION NVT 10 HRS	SELECTED MATERIAL AND CONDITION PRIME	BACKUP	PROBLEM	TEST PLAN IDENTITY PRIME	BACKUP
JACKET	1240	GH_2	10^{14} to 10^{17} (T) (1 HR)	347	Hastelloy X	Mechanical Properties	M-2	M-12
	to		10^{15} to 10^{18} (T) (10 HRS)	Forging	Forging	Radiation Damage		
	-423	LH_2	10^{16} to 10^{18} (F) (1 HR)	Furnace Brazed	Furnace Brazed	Anisotropy		
			10^{17} to 10^{19} (F) (10 HRS)			Physical Properties		
						Martensite Transformation		
TUBES	2000	GH_2	10^{14} to 10^{17} (T) (1 HR)	347	Hastelloy X	Creep		
	to		10^{15} to 10^{18} (T) (10 HRS)	Sheet	Sheet	Resistance to Buckling		
	-423	LH_2	10^{16} to 10^{18} (F) (1 HR)	Furnace Brazed	Furnace Brazed	Thermal Fatigue		
			10^{17} to 10^{19} (F) (10 HRS)			Mechanical Properties	M-2	M-12
						Martensite Transformation		
NOZZLE EXTENSION	3000	GH_2	10^{12} to 10^{17} (T) (1 HR)	Graphite	AISI 347	Fabrication Development		
	to		10^{13} to 10^{18} (T) (10 HRS)	Composite	Sheet	Mechanical Properties (Flange Joint, Liner, Cell Wall)	M-6	M-2
	-100		10^{13} to 10^{17} (F) (1 HR)	Fiber		Anisotropy		
			10^{14} to 10^{18} (F) (10 HRS)			Physical Properties		
						Fatigue Resistance		
						Corrosion (High Temperature GH_2)		
						Radiation Damage		
						Fracture Toughness		

(T) designates thermal neutron with energies below 0.4 ev.

(F) signifies fast neutrons with energies in excess of 1 Mev.

PROJECT:
STRESS:
THERMAL:
MATERIALS.
RELIABILITY:
NUCLEAR:

PROBLEM SHEET NO. 4
25 MAY 19[illegible]
SHEET 1 OF 1
INVESTIGATOR: W. F. EMMONS

IDENTIFICATION OF MATERIALS PROBLEMS

LINE ASSEMBLIES

SUBASSEMBLY	PREDICTED ENVIRONMENT °F	PREDICTED ENVIRONMENT ATMOS	PREDICTED ENVIRONMENT RADIATION "NVT" 10 HRS.	SELECTED MATERIAL AND CONDITION PRIME	SELECTED MATERIAL AND CONDITION BACKUP	PROBLEM	TEST PLAN IDENTIFY PRIME	TEST PLAN IDENTIFY BACKUP
UPPER LINES (PDL, TIL, TDL, SSCL, TBL, CSL)	RT to -423	GH_2 LH_2	10^{16} to 10^{17} (F)	718 Tube HT (B)	Ti 5Al-2.5Sn (ELI) Tube Annealed	Joint Properties Mechanical Properties Fatigue Resistance Fracture Toughness Radiation Damage Hydrogen Embrittlement	M-1	M-4
LOWER LINES (PDL, TIL, TDL)	RT to -423	GH_2 LH_2	10^{17} to 10^{19}(F) 10^{17} to 10^{19}(F)	6061 Tube T-6	5086-H32	Weld Properties Mechanical Properties Fatigue Resistance Fracture Toughness Radiation Damage	M-7	M-20
LOW PRESSURE LINES (PIL)	RT to -423	GH_2 LH_2	10^{16} to 10^{17} (F)	347 SS Tube Anneal	718 Tube HT (B)	Mechanical Properties Fatigue Resistance Fracture Toughness Radiation Damage	M-2	M-1
CRYOGENIC BELLOWS BEARING	RT to -423	GH_2 LH_2	10^{16} to 10^{17} (F)	718 CW Bar with Several Coatings	Waspaloy with Several Coatings	Friction and Wear Space Vacuum Adhesion	M-1	M-17
BELLOWS CONVOLUTES (CRYOGENIC)	RT to -423	GH_2 LH	10^{16} to 10^{17} (F)	718 Sheet HT (B)	347 SS Sheet Annealed	Joint Properties Mechanical Properties Fatigue Resistance Fracture Toughness Radiation Damage	M-1	M-2
BELLOWS RESTRAINT JOINT	RT to -423	GH_2 LH_2	10^{16} to 10^{17} (F)	718 Bar Forging HT (B)	-	Joint Properties Mechanical Properties Fatigue Resistance Fracture Toughness Radiation Damage	M-1	
BELLOWS RESTRAINT WIRE BRAID	RT to -423	GH_2 LH_2	10^{16} to 10^{17} (F)	321 Wire		Joint Properties Mechanical Properties Fatigue Resistance Fracture Toughness Radiation Damage Space Vacuum Adhesion	-	-
TRANSITION JOINTS	RT to -423	GH_2 LH_2	10^{16} to 10^{17} (F)	718 718 347 347	6061 Aluminum 5086 Aluminum 6061 Aluminum 5086 Aluminum	Joint Properties Mechanical Properties Fatigue Resistance Fracture Toughness Radiation Damage	M-1 M-2	M-7 M-20

PROJECT: [handwritten initials] 7/1/70
STRESS: [redacted]
THERMAL: [handwritten initials]
MATERIALS: [handwritten initials]
RELIABILITY: [handwritten initials]
NUCLEAR: JCC

PROBLEM SHEET NO. 5
2 JUNE 1[redacted]
SHEET 1 [redacted]
INVESTIGATOR: D. J. LAMVERMEYER

IDENTIFICATION OF MATERIALS PROBLEMS

ACTUATORS AND VALVE ASSEMBLIES INCLUDING PURGE AND STAGE PRESSURANT LINE SYSTEMS

SUBASSEMBLY	PREDICTED ENVIRONMENT				SELECTED MATERIAL AND CONDITION		PROBLEM	TEST PLAN IDENTITY	
	°F	ATMOS	PRESSURE PSIG	RADIATION NVT 10 HRS	PRIME	BACKUP		PRIME	BACKUP
VALVE AND ACTUATOR SEAL	RT to -423	GH_2 LH_2	1300	10^{15} to 10^{16}(F) (1 HR) 10^{16} to 10^{17}(F) (10 HR) γ-10^{7} to 10^{10} ergs/gm (1 HR) γ-10^{8} to 10^{11} ergs/gm (10 HR)	301 SS Sheet 1/4 Hard	Vespel "SP-1" Polyimide	Radiation Damage Fatigue Resistance CREEP	M-10	M-14
SEAL AND ACTUATOR INTERFACES	RT to -423	Vac, GH_2 LH_2	1000	10^{16} to 10^{17}(F) (10 HR)	Hard Cr Versus Au, MoS_2, etc.	TBD Versus Ag, $MoSe_2$, etc.	Friction and Wear Coating Adhesion Coating Process Control	M-11	
BEARING, BALL & ROLLER	RT to -423	GH_2 LH_2	1300	10^{16} to 10^{17}(F) (10 HR)	440C	TBD	Friction and Wear Thermal Shock Impact Strength	M-19 M-11	
VALVE SHAFTS AND GEARS	RT to -423	GH_2 LH_2	1300	10^{16} to 10^{17}(F) (10 HR)	718 Bar HT (B)	A286 CW Bar Aged	Fracture Toughness Radiation Damage Hydrogen Embrittlement Fatigue Resistance	M-1	M-5
CLOSURE ELEMENTS	RT to -423	GH_2 LH_2	1300	10^{16} to 10^{17} (F)	718 Forging HT (B)	A286 Forging Solu Treat and Aged	Hydrogen Embrittlement	M-1	M-5
HOUSINGS (VALVE)	RT to -423	GH_2 LH_2	1300	10^{16} to 10^{17} (F)	718 Forged Welded HT (B)	6061 Forged Welded T-6	Thermal Distortion Joint Properties Hydrogen Embrittlement (718 Only) Radiation Damage Fracture Toughness	M-7	M-1
HOUSINGS (ACTUATOR), SOME VALVES & CLOSURES	RT to -423	GH_2 LH_2	1100	10^{16} to 10^{17} (F)	Ti 5Al-2.5Sn ELI	Ti 6Al-4V	Thermal Distortion Joint Properties Hydrogen Embrittlement Radiation Damage Fracture Toughness Impact Strength (RT to -200°F)	M-4	M-9
BELLVILLE SPRINGS	RT to -423	GH_2 LH_2	1000 to 1300	10^{16} to 10^{17} (F)	Full Hard 301	BeCu	Mechanical Properties Elastic Modulus	M-10	

SUBASSEMBLY	PREDICTED ENVIRONMENT °F	ATMOS	PRESSURE PSIG	RADIATION "NVT" 10 HRS.	SELECTED MATERIAL AND CONDITION PRIME	BACKUP	PROBLEM	TEST PLAN IDENTITY PRIME	BACKUP
ACTUATOR BEARING GEAR LUBRICANT INTERFACES	RT to -423	GH_2	1300	10^{16} to 10^{17} (F)	Carburized 9310 with Bonded MoS_2	Case Harden A286 with Bonded MoS_2	Friction and Wear Including Space Vac High Pressure Gaseous H_2 (9310) Embrittlement Cryogenic Fracture Toughness (9310) C' ogenic Impact (9310) Radiation Damage (9310)	M-31 M-11	M-5
ACTUATOR SPRINGS	RT to -423	GH_2 LH_2	1300	10^{16} to 10^{17} (F)	718 Rod HT (B)	Udimet 630 Rod	Fracture Toughness Radiation Damage Fatigue Resistance Torsional Modulus	M-1	M-15
CONTROL VALVE BEARING AND SEAL INTERFACES	RT to -423	Vac, GH_2 LH_2	1300	10^{16} to 10^{17} (F)	Hard Cr Versus Hard Cr with MoS_2	TBD	Fretting Friction and Wear	M-11	
VALVE SHUTOFF SEAL ELEMENTS					Phosphor Bronze Versus Hard Cr (Electrolize)	CRES Gold Plated Versus Hard Cr	Mechanical Properties Radiation Damage Friction and Wear Including Space Vac Coating Adhesion Thermal Distortion	M-11	
ACTUATOR SLIP BRAKE	RT to -423	GH_2	1300	10^{16} to 10^{17} (F)	Phosphor Bronze	TBD	Stable Friction above .1 μ Wear Rate	M-11	
BEARING, SLIDING CONTACT	RT to -423	GH_2 LH_2	1300	10^{16} to 10^{17} (F)	Phosphor Bronze Vs Hrd Cr 718	Vespel SP-3 Vs Hd Cr 718	Friction and Wear Including Space Vacuum		
VALVE ROLLER CAM TRACKS & SHUTOFF SEAL ELEMENTS	RT to -423	GH_2 LH_2	1300	10^{16} to 10^{17} (F)	Colmonoy Hard Facing on 718 Vs 440C Rollers & Phosphor Bronze Sliding	Case Harden Vs 440C Rollers and Phospher Bronze Sliding	Radiation Damge Coating Adhesion Friction and Wear Including Space Vacuum Thermal Effects Coating Process Control		
ROLLER ELEMENTS BEARING CAGE	RT to -423	GH_2 LH_2	1300	10^{16} to 10^{17} (F)	FEURALON AW	TBD	RADIATION DAMAGE		

(F) DESIGNATES FAST NEUTRON FLUENCE GREATER THAN 1 MEV OVER 10 HOURS.

PROJECT: 2001 per H.L.H.
STRESS:
THERMAL: [redacted]
MATERIALS. CWZ
RELIABILITY:
NUCLEAR: FRC

PROBLEM SHEET NO. 6
30 JUNE 1970
SHEET 1 OF 2
(INVESTIGATOR: W[redacted]. EMMONS)

IDENTIFICATION OF MATERIAL PROBLEMS

THRUST STRUCTURES

SUBASSEMBLY	PREDICTED ENVIRONMENT			SELECTED MATERIAL AND CONDITION		PROBLEM	TEST PLAN IDENTITY	
	°F	ATMOS	RADIATION NVT 10 HRS	PRIME	BACKUP		PRIME	BACKUP
UPPER THRUST STRUCTURE	200 to -145	Air and Vacuum	10^{16} to 10^{17} (F)	2024-T6 Forging & 2024-T6 Sheet/Plate & Extruded	6061-T6 Sheet, Forging, & Extruded Molding with & without Welding	Mechanical Properties Joint Properties Fatigue Resistance Fracture Toughness Stress Corrosion Corrosion Fabrication Development	M-8	M-7
LOWER THRUST STRUCTURE	400 to -145	Air and Vacuum	10^{17} to 10^{19}(F) 10 Hrs	7039-T61 Sheet and Forgings	Ti-6Al-4V	Mechanical Properties Joint Properties Fatigue Resistance Fracture Toughness Fabrication Development	M-3	M-9
LOWER THRUST STRUCTURE	700 to -200	Air and Vacuum	10^{17} to 10^{19}(F) 10 Hrs	Ti-6Al-4V Sheet and Forgings	Ti-5Al-2.5Sn Sheet and Forgings	Mechanical Properties Joint Properties Fatigue Resistance Fracture Toughness Fabrication Development	M-9	M-4
SHIELD	700 to -100	Air and Vacuum	10^{16} to 10^{18} (F)	TBD	TBD	Fabrication Development	-	-
THRUST VECTOR CONTROL TRUNNION FLEXURAL JOINTS	250 to -100	Vacuum	10^{16} to 10^{17} (F)	18 Ni Maraging Steel	TBD	Flexural Fatigue Fastener Joint Properties	M-16	-
GIMBAL PIVOT ASSEMBLY	250 to -100	Vacuum	10^{16} to 10^{17} (F)	18 Ni Maraging Steel	TBD	Mechanical Properties Corrosion Stress Corrosion Fatigue Fracture Toughness Joint Properties (EB)		
LUBRICANT	250 to -100	Vacuum	10^{16} to 10^{17} (F)	MoS_2	$MoSe_2$	Friction and Wear	M-11	-
BEARING SLEEVE	250 to -100	Vacuum	10^{16} to 10^{17} (F)	Al Bronze	TBD	Friction and Wear Bearing Strength	M-11	-

SUBASSEMBLY	PREDICTED ENVIRONMENT			SELECTED MATERIAL AND CONDITION		PROBLEM	TEST PLAN IDENTITY	
	°F	ATMOS	RADIATION NVT	PRIME	BACKUP		PRIME	BACKUP
TVC ACTUATOR	250 to -100	Vacuum	10^{16} to 10^{17} (F)					
BALL SCREW				18 Nickel Maraging Steel	TBD	Mechanical Properties Friction and Wear	M-16 M-11	
BALLS				440C				
BALL SCREW NUT				18 Nickel Maraging Steel			M-16	
SEAL	250 to -100	Vacuum	10^{16} to 10^{17} (F)	301 SS	TBD	Flexure and Fatigue	M-10	
LUBRICANT				MoS_2	$MoSe_2$	Friction and Wear	M-11	

PROJECT. [illegible]
STRESS: [illegible]
THERM[redacted] [illegible]
MATERIALS: [illegible]
RELIABILITY: [illegible]
NUCLEAR: [illegible]

PROBLEM SHEET NO. 7
25 JUNE 1970
SHEET 1 OF 1
INVESTIGATOR: W. [redacted] EMMONS

IDENTIFICATION OF MATERIALS PROBLEMS

TEST FACILITIES OPERATIONS

ASSEMBLY: NASS

SUBASSEMBLY	PREDICTED ENVIRONMENT			SELECTED MATERIAL AND CONDITION		PROBLEM	TEST PLAN IDENTITY	
	°F	ATMOS	RADIATION "NVT" 10 HRS.	PRIME	BACKUP		PRIME	BACKUP
NASS DUCT PRIMARY SECTION	RT to 3925	GN_2, GH_2	NOT SIGNIFICANT	347 SS Annealed Sheet, Plate & Tubing As Welded	NONE	Fabrication, NDT Joint Properties Thermal Fatigue Water Scaling	M-2	
NASS DUCT PLENUM SECTION	RT to 540	GN_2, GH_2 Steam	NOT SIGNIFICANT	347 SS Annealed Sheet, Plate As Welded	NONE	Fabrication, NDT Joint Properties Thermal Fatigue	M-2	
NASS DUCT SECONDARY STEAM EJECTOR	RT to 540	GN_2, GH_2 Steam	NOT SIGNIFICANT	347 SS Annealed Sheet & Plate As Welded	NONE	Joint Properties, NDT Thermal Fatigue	M-2	
NASS DUCT UNCOOLED COLLAR	4000 to -300	GN_2, GH_2	NOT SIGNIFICANT	Graphite Composite	NONE	Mechanical Properties, Fabrication Dev Corrosion/Erosion Physical Properties	M-6	
NASS TRUNNIONS	RT to 150 (Vault)	H_2O, GN_2 Ambient (Vault)	NOT SIGNIFICANT	718 with Graphite Bronze Bearing Blocks	NONE	Mechanical Properties	M-1	
NASS PIPING	RT to 150	H_2O 240 psia	NOT SIGNIFICANT	304L Annealed Pipe & Tube As Welded	NONE	Mechanical Properties	M-18	
NASS PIPING SUPPORT STRUCTURE	Ambient (Vault)	Ambient (Vault)	NOT SIGNIFICANT	304L SS Annealed Pipe As Welded	NONE	Mechanical Properties	M-18	

MATERIALS: *[handwritten initials]*

PROBLEM SHEET NO. 8
27 JULY 1970
SHEET 1 OF 2

PRELIMINARY IDENTIFICATION OF CORROSION PROBLEMS

MECHANISM	ASSEMBLY-SUBASSEMBLY	MATERIAL	ACTION
Stress Corrosion	PV - Shell and Head	Al 7039-T63	Seacoast Test; Develop Protective Finish, Limit Residual Stress
	PV - Bolt	A-286, Multiphase	Seacoast Test; Limit Torque; Limit Misalignment
	Thrust Structure - Upper and Lower Thrust Structure	2024-T6	Develop Protective Finish, Test
		7039-T61	Develop Protective Finish
	Pneumatic System	Ti 6Al-4V	Limit Cl Prior to HT by Process STD
	TPA - Impeller, Rotor	Ti 5Al-2.5Sn ELI	Limit Cl Prior to HT by Process STD
	Thrust Vector Control	18% Maraging Steel	Develop Protective Finish
Galvanic Corrosion	PV - Shell and Head	Al 7039-T63	Seacoast Testing; Develop Insulation
	PV - Shell and Head	Al 6061-T6	Seacoast Testing; Develop Insulation
	Thrust Structure	Al 2024-T6	Seacoast Testing; Develop Insulation
	Actuators and Valves	Graphite Containing Solid Film Lubricants	Seacoast Testing; Develop Insulation
Pitting Corrosion	TCA - Tubes	347 SS	Seacoast Test; Control Halide Contamination, Periodic Rinses
	TCA - Bleed Port	347 SS	Seacoast Test; Control Halide Contamination, Periodic Rinses
Integranular Corrosion	Thrust Structure - Skin Panels	Al 2024-T6	Clad Plus Protective Finish at Edges
Crevice Corrosion	Cryo Valve - Housing	Al 6061-T6	Minimize by Design, Eliminate Crevices
	PV - Bolts	A-286, Multiphase	Develop Inhibitor
Cavitation	TPA - Impeller	Inconel 718	Monitor Component Testing
	TPA - Impeller	Ti 5Al-2.5Sn ELI	Monitor Component Testing
Moisture Absorption	Skirt Extension - Lines	Graphite Composite	Investigate
	Instrumentation	Electrical Materials	Investigate
Fungus	Instrumentation	Electrical Materials	Qualify per Method 508, MIL-STD-810A Moisture Control in Storage
Oxidation, Chemical Firings	TCA - Tubes	347 SS	Monitor Chemical Test Firings
General Corrosion	PV - Head and Shell	Al 7039-T63	Develop Protective Finish
	Cryo Valve - Housing	Al 6061-T6	Develop Protective Finish
	Facilities - Pressure Vessel	AOS 1146 Steel	Maintain Exterior Protective Finish

PRELIMINARY IDENTIFICATION OF CONTAMINATION PROBLEMS

MECHANISM	ASSEMBLY-SUBASSEMBLY	MATERIAL	ACTION
Reaction with Solvents	PV - Shell and Head	Al 7039-T63	Specify Nonreactive Solvents
	Thrust Structure - Upper and Lower Thrust Structures	Ti 6Al-4V	Specify Nonreactive Solvents
	Thrust Structures - Skin Panels	Al 2024-T6	Specify Nonreactive Solvents
	TPA - Impeller	Ti 5Al-2.5Sn ELI	Specify Nonreactive Solvents
Cleaning - Soil Removal	All Components	All Materials	Monitor Cleaning of Components; Develop Procedures as Required
Drying	All Components	All Materials	Monitor Drying of Components; Develop Procedures as Required
Entrapment of Particles or Frozen Fluids	Lines - Bellows Convolutes	718, 6061, 347	Design for Flushing, Draining, Helium Purge
	TPA	Inconel 718, AISI 310	Design for Flushing, Draining, Helium Purge
	Valve Assemblies	Al 6061-T6	Design for Flushing, Draining, Helium Purge
	Filter Elements	300 Stainless	
Dry Storage. Transportation	All Components	All Materials	Develop Packaging Procedures and Specifications
Contamination Criteria	All Components	All Materials	To Be Determined; Component Specifications
Monitoring Corrosion in Storage	All Components	All Materials	Method to be Determined
Assembly Environment	All Components	All Materials	To Be Determined
Corrosion Generation of Particles	PV - Shell and Head	Al 7039-T63	Protective Finish Interior Surfaces; Inert Atmosphere in Storage
	Cryo Valve - Housing	Al 6061-T6	Protective Finish Interior Surfaces; Inert Atmosphere in Storage
Mechanical Generation of Particles	TPA - Impeller	Ti 5Al-2.5Sn ELI	Design Clearances; Monitor Wear
	TPA - Housing	AISI 310	Design Clearances; Monitor Wear
	Cryo Bellows Bearing	718, Coated	Coating Quality Assurance
	Actuator Interfaces	Cr, Au, MoS_2	Wear Testing, Coating Quality Assurance
	Valve Roller Cam Tracks	Colmonoy Hard Facing	Wear Testing, Coating Quality Assurance

PROJECT: SK YODER
STRESS: [illegible]
THERMAL: [illegible]
MATERIALS: [illegible]
RELIABILITY: [illegible]
NUCLEAR: [illegible]

PROBLEM SHEET NO. 10
25 MAY 19[illegible]
SHEET 1 O[illegible]
INVESTIGATOR: C. E. DIXON

IDENTIFICATION OF MATERIAL PROBLEMS

INSTRUMENTATION AND CONTROLS

SUBASSEMBLY	PREDICTED ENVIRONMENT				SELECTED MATERIAL AND CONDITION		PROBLEM	TEST PLAN IDENTITY
	°F	ATMOS	RADIATION "NVT" 10 HRS.	10 HR RADS	PRIME	BACKUP		
THRUST CHAMBER PROBE (TEMP.)	-320 to 4100	Vac/GH_2	10^{17} to 10^{19} (F)	10^8 to 10^{10}	Tungsten-25 Re	None	Thermal Cycling 4100 to -300°F Effect of Grain Growth on Physical Properties and Low Temperature Ductility Cryogenic Properties before and after Operation.	
WIRING HARNESS INSUL.	-350 to 450 (560 at OD of Shield)	Air/Vac (Space)	10^{15} to 10^{18} (F)	10^7 to 10^9 Below Disk Shield	Polyimide Ins. Copper Wire	Sheathed Ceramic Insulated Wire Ekonol High Temp Polyester.	High Temperature Degradation in Space Vacuum. Outgassing Problems.	Ref. 7820:M950: HAF
CONNECTORS	-350 to 400	Air/Vac	10^{15} to 10^{18} (F)	10^7 to 10^9	Reinforced Polymer Insul.	Ceramic Insul.	Brittleness of Electrical Insulation Surface Contamination.	Ref. 7820:M910: RML
POTTING MATERIAL	-300 to 400	Air/Vac	10^{13} to 10^{18} (F)	10^7 to 10^9	To Be Selected	To Be Selected	Material Selection to Provide Adequate Properties at High & Low Temperatures in Space. Must Not Outgas or Spall.	" "
TRANSDUCERS								
PRESSURE	-320 to 400	Air/Vac	10^{15} to 10^{18} (F)	10^6 to 10^9	410 Stainless Base Material	To Be Selected	Cryogenic Brittleness	

(F) - Designates fast neutron fluence greater than 1 Mev over 10 hours.

PROJECT: *[handwritten initials]*
STRESS: [redacted]
THERMAL: *[handwritten initials]*
MATERIALS: *[handwritten initials]*
RELIABILITY: *[handwritten initials]*
NUCLEAR: *[handwritten initials]*

PROBLEM SHEET NO. 11
25 MAY 19[redacted]
SHEET 1 OF 1
INVESTIGATOR: C. E. DIXON

IDENTIFICATION OF MATERIAL PROBLEMS

DISK SHIELD ASSEMBLY

SUBASSEMBLY	PREDICTED ENVIRONMENT °F	ATMOS	RADIATION - 10 HR NVT	SELECTED MATERIAL AND CONDITION PRIME	BACKUP	PROBLEM	TEST PLAN IDENTITY PRIME	BACKUP
GRAPHITE 3% BORON	-100 to 600	Air/Space (Outside Housing)	10^{14} to 10^{17} (F) 10^{15} to 10^{18} (T)	UCC "CS" + B	UCC ATJ + B	Mechanical Properties Physical Properties Porosity Homogeneity Commercial Product Utilization		
LEAD SLABS	-100 to 600	Air/Space (Outside Housing)	10^{13} to 10^{17} (F) 10^{14} to 10^{18} (T)	St. Joe "DS Lead"	Ca Lead	Dimensional Stability Close Dimensional Tolerance Control Differential Thermal Expansion with Canning Material Thermal Cycling and Distortion Dispersion Harden Mech. Properties		
	-100 to 600	Air/Space (Outside Housing)	10^{13} to 10^{17} (F) 10^{15} to 10^{18} (T)	347 CRES Can or Housing				
LITHIUM HYDRIDE SHIELD CANS	-100 to 600	GH_2 Internal Outside Space	10^{12} to 10^{16} (F) 10^{11} to 10^{17} (T)	LiH	None	GH_2 Generation at High Service Temp. Powder Compaction Parameters Mechanical Properties Physical Properties		
				347 CRES	Boron Stainless	Weld Development Dimensional Stability Assembly Fit Up Mechanical Properties Physical Properties		
HOUSING	-100 to 600	Air (Salt Contamination) Space Vac	5×10^{17}	347 CRES Outside Coated with Al_2O_3	Alternate Coatings	Thermal Coating Reliability and Properties Coating Application Integrity Stability in Space Environment		

(T) - Designates total neutron fluence over 10 hours.

(F) - Designates fast neutron fluence greater than 1 Mev over 10 hours.

APPENDIX C

PRELIMINARY TEST PLAN MATRICES

TEST PLAN: M-1 718

COMPONENTS: TPA, VALVES, LINES

DATE: 23 JULY 1970
REVISION: 1

CONDITION/FORM	TEST TYPE PROPERTY	RAD LEVEL*** 10 PWR	HEATS	TEST TEMPERATURE, °F				TOTAL SPECS	TEST MATRIX BASIS
				-423	-320	-160	RT		
HT B/F	TENSILE		1	8			8	16	DESIGN*
HT B/S TO F EB WELD	TENSILE		2	8		8	8	24	DESIGN
HT B/S TO F EB WELD	TOUGHNESS		2	8		8	8	24	DESIGN
HT B/F/EB	IRRAD TENSILE	0,17,18	1	12				12	SCREEN
HT B/F/EB	IRRAD TOUGH	0,17,18	1	12				12	SCREEN
HT B/F	FATIGUE		2	60		60		120	DESIGN
HT B/F	HI FREQ FATIGUE		1	30		30		60	SCREEN
HT B/SW	TENSILE		2	8		8	8	24	DESIGN
HT B/T	TENSILE		2	8	8		8	24	DESIGN
HT B/T W	TENSILE		2	8	8		8	24	DESIGN
HT B/T	FATIGUE		2				60	60	DESIGN
HT B/T W	FATIGUE		2	60				60	DESIGN
HT B/T	TOUGHNESS		2	10	10			20	DESIGN
HT B/T W	TOUGHNESS		2	10	10			20	DESIGN
T tj** 718/6061	TENSILE		1	8			8	16	SCREEN
T tj 718/6061	FATIGUE		1	8			8	16	SCREEN
HT B/F CW & AGE	TENSILE		2	8	8		8	24	DESIGN

*One Heat Already Tested in CY 70.
**Transition Joint.
***Fast Neutron Fluence 10^{17} to 10^{18} Energy Greater than 1 Mev.

TEST PLAN: M-2 AISI 347

COMPONENTS: NOZZLE, LINES

DATE: 23 JU[illegible]970
REVISION: 1

CONDITION/FORM	PROPERTY	RAD LEVEL*** 10 PWR	HEATS	TEST TEMPERATURE, °F -423	-320	-100	RT	800	1200	1400	1600	TOTAL SPECS	TEST MATRIX BASIS
FB/F	IRRAD TENSILE	0,18,19	1	12								12	SCREEN
ANN/S	CREEP		3						72	72	72	216	DESIGN
ANN/B(S)	FATIGUE, LOW CYCLE		3					48	288		48	384	DESIGN
FB/FW	IRRAD TENSILE	0,18,19	1		12							12	SCREEN
FB/FW	TENSILE		2	8	8	8	8		8		8	48	DESIGN
FB/F	MARTENSITIC TRANS EFFECTS		1		6							6	SCREEN
ANN/T	DYNAMIC MOD & POISSON'S RATIO		2		2		2					4	(DESIGN)
	TENSILE		2	8	3		8					24	DESIGN
ANN/TW	TENSILE		2	8	8		8					24	DESIGN
ANN/T	FATIGUE		2				60					60	DESIGN
ANN/TW	FATIGUE		2	60								60	DESIGN
ANN/SW	TENSILE 3 PROCESSES		1				48		24			72	SCREEN
ANN/T tj* 347/6061	TENSILE		1	8			8					16	SCREEN
ANN/T tj 347/6061	FATIGUE		1	8			8					16	SCREEN
ANN/T tj 347/5086	TENSILE		1	8			8					16	SCREEN
ANN/T tj 347/5086	FATIGUE		1	8			8					16	SCREEN

FB - Furnace Braze Condition

*Transition Joint.

(   ) Low variability indicated by experience and/or literature. TD 69-28 STATISTICAL RULES NOT REQUIRED.

***Fast Neutron Fluence   Energy Greater than 1 Mev.

TEST PLAN: M-3 7039-T63

COMPONENT: PRESSURE VESSEL

DATE: 23 JULY 1970
REVISION: 1

CONDITION/FORM	PROPERTY	RAD LEVEL*** 10 PWR	HEATS	TEST TEMPERATURE, °F / TEST DIRECTION -320 L	-320 T	-320 ST	-100 L	-100 T	-100 ST	70 L	70 T	70 ST	200 L	200 T	200 ST	300 L	300 T	300 ST	TOTAL SPECS	TEST MATRIX BASIS
T63/WALL/F	LOW CYCLE FLAW GROWTH		2	4	4		4	4		4	4								24	DESIGN
T63/WELD/F	TOUGHNESS		2	4	4		4	4		4	4								24	DESIGN
T63/WELD/F	TENSILE		2	4	4		4	4		4	4		4	4		4	4		40	DESIGN
T63/WELD/F	IRRAD TENSILE	0,17,18,19	1	16															16	SCREEN
T63/WELD/F	IRRAD TOUGHNESS	0,17,18,19	1	16															16	SCREEN
T63/WALL/F	FATIGUE		1										30 (150°F)						30	DESIGN*
T63/FLANGE/F + WALL/F	STRESS CORROSION		2									100							100	SCREEN
T63/FLANGE/F + WALL/F	STRESS CORROSION PROTECT COAT		(2) COATINGS									150							150	SCREEN
T63/WELD DEPOSIT & NAT AGE	TENSILE		2	4	4		4	4		4	4		4	4		4	4		40	DESIGN
T63/WELD DEPOSIT & NAT AGE	IRRAD TENSILE	0,17,18,19	1	16															16	SCREEN
T63/WELD DEPOSIT & NAT AGE	IRRAD TOUGHNESS	0,17,18,19	1	16															16	SCREEN
WALL	DYNAMIC MODULUS AND POISSON'S RATIO		2	2			2			2			2			2			8	(DESIGN)

(   ) Low variability indicated by experience and/or literature.   TD 69-28 STATISTICAL RULES NOT REQUIRED.

*One Heat Already Tested in CY 70.

***Fast Neutron Fluence, Energy Greater than 1 Mev.

TEST PLAN: M-3 7039-T61

COMPONENT: LOWER THRUST STRUCTURE

DATE: 23 JULY 1970
REVISION: 1

CONDITION/FORM	PROPERTY	RAD LEVEL*** 10 PWR	HEATS	TEST TEMPERATURE, °F / TEST DIRECTION -320 L	-320 T	-100 L	-100 T	70 L	70 T	200 L	200 T	300 L	300 T	TOTAL SPECS	TEST MATRIX BASIS
T61/S	TENSILE		2			4	4	4	4	4	4	4	4	32	DESIGN
T61/SW	TENSILE		2			4	4	4	4	4	4	4	4	32	DESIGN
T61/SW	FATIGUE		2			60								60	DESIGN
T61/SW	TOUGHNESS		2			6	6	6	6					24	DESIGN
T61/SW	IRRAD TENSILE	0,17,18,19	1	16										16	SCREEN
T61/SW	IRRAD TOUGHNESS	0,17,18,19	1	16										16	SCREEN
T61/S	DYNAMIC MODULUS		1					1	1					2	SCREEN

***Fast Neutron Fluence, Energy Greater than 1 Mev.

TEST PLAN: M-4 TI 5AL-2.5SN ELI

COMPONENTS: TPA, LINES, VALVES & LOWER THRUST STRUCTURE

DATE: 23 JULY 1970
REVISION: 1

CONDITION/FORM	PROPERTY	RAD LEVEL*** 10 PWR	HEATS	TEST TEMPERATURE, °F / TEST DIRECTION -423 L	-423 T	-320 L	-320 T	-150 L	-150 T	RT L	RT T	500 L	500 T	700 L	700 T	TOTAL SPECS	TEST MATRIX BASIS
ANN/EB W/F	TENSILE		2	8		8				8						24	DESIGN
ANN/F	TOUGHNESS		2	10		10										20	DESIGN
ANN/EB W/F	TOUGHNESS		2	8		8				8						24	DESIGN
ANN/F	FATIGUE		2		60											60	DESIGN
ANN/F	HIGH FREQ FATIGUE		1		30				30							60	DESIGN
ANN/F	IMPACT TENSILE		1			8		8		8						24	SCREEN
ANN/F	IRRAD TENSILE	0,17,18,19	1	16												16	SCREEN
ANN/F	IRRAD TOUGHNESS	0,17,18,19	1	16												16	SCREEN
ANN/T	TENSILE		2	4	4	4	4			4	4					24	DESIGN
ANN/TW	TENSILE		2	4	4	4	4			4	4					24	DESIGN
ANN/T	TOUGHNESS		2	4	4	4	4			4	4					24	DESIGN
ANN/TW	TOUGHNESS		2	4	4	4	4			4	4					24	DESIGN
T	FATIGUE		2							60						60	DESIGN
TW	FATIGUE		2	60												60	DESIGN
S	TENSILE		2					4	4	4	4	4	4	4	4	32	DESIGN
SW	TENSILE		2					4	4	4	4	4	4	4	4	32	DESIGN
S	FATIGUE		2											60		60	DESIGN
SW	FATIGUE		2					60								60	DESIGN
SW	DYNAMIC MODULUS & POISSON'S RATIO		2					4	4							8	SCREEN

***Fast Neutron Fluence, Energy Greater than 1 Mev.

TEST PLAN: M-5 A-286

COMPONENTS: TPA, VALVES

DATE: 23 JULY 1970
REVISION: 1

CONDITION/FORM	PROPERTY	RAD LEVEL 10 PWR	HEATS	TEST TEMPERATURE, °F			TOTAL SPECS	TEST MATRIX BASIS
				-423	-160	RT		
SOL & AGE/F	FATIGUE		2	60	60		120	DESIGN
SOL & AGE/F	TENSILE*		3	8	8	8	24	DESIGN
					70 TO -423			
SOL & AGE/F	THERMAL EXPANSION		1		1		1	(DESIGN)
SOL & AGE/F	THERMAL CONDUCTIVITY		1		1		1	SCREEN
SOL & AGE/F	DYNAMIC MODULUS & POISSON'S RATIO		2		4		4	(DESIGN)
SOL & AGE/F	DAMPING CAPACITY		1		2		2	SCREEN
SOL & AGE/F	HI FREQUENCY FATIGUE		1	30	30		60	SCREEN
SOL & AGE/F AND NITRIDED	HARDNESS PROFILE AND CASE DEPTH		1			12	12	SCREEN

*TEST AND REPORT ONLY; MATERIAL HAS BEEN BOUGHT AND SPECIMENS FABRICATED IN 1970.

(   ) LOW VARIABILITY INDICATED BY EXPERIENCE AND/OR LITERATURE.   TD 69-28 STATISTICAL RULES NOT REQUIRED.

TEST MATERIALS	TENSILE BLOCK	TENSILE TEE BAR*	COMPRESSIVE EDGEWISE	TENSILE WARP	TENSILE FILL	MODULUS OF ELASTICITY WARP	MODULUS OF ELASTICITY FILL	INTERLAMINAR SHEAR	WEIGHT CHANGE	LINEAR SHRINKAGE	PORE SPECTRA	MICRO EXAM	IRRAD TENSILE	IRRAD FLEXURE	DENSITY	PREPREG RESIN ANALYSIS	PREPREG ANALYSIS	THERMAL EXPANSION	THERMAL CONDUCTIVITY	SCOPE OF TESTS
PHASE I																				
TASK A GRAPHITE FABRIC DEVEL																				
SUBTASK 1 - CELL WALL FABRIC				12	12	4	4								24					EVALUATE 2 FABRICS AT 2 MOLDING PRESSURES WITH ONE RESIN SYSTEM. (SCREEN)
SUBTASK 2 - LINER FABRICS	24		24	24	6	8**	4	24	14	14	8	8			14			4	4	EVALUATE 6 TYPES OF FABRIC, 1 RESIN SYSTEM, PROCESSED UNDER IDENTICAL CONDITIONS. (SCREEN)
TASK B RESIN DEVELOPMENT																				
SUBTASK 1 - PREPREG RESINS	72		72	72		20		72	24	24	10	10			24	270	150			PROPERTIES MEASURED ON 10 RESIN SYSTEMS WITH 1 GRADE OF FABRIC, PROCESSING CONDITIONS CONSTANT. (SCREEN)
SUBTASK 2 - IMPREGNATION RESIN	12		12	12		4		12	8	8		4			8					PROPERTIES MEASURED ON 4 BINDER SYSTEMS. (SCREEN)
TASK C STRUCTURAL DEVELOPMENT																				
SUBTASK 1 - LINER CONCEPTS	4		4	27				24	27	27	6	6			24					COMBINE OPTIMUM RESULTS OF TASKS A&B TO PRODUCE 4 LINER CONCEPTS. (SCREEN)
SUBTASK 2 - CELL WALL/ LINER INTEGRATION		96							96	96		10	24***	24***						EVALUATE BONDING HONEYCOMB CELLS TO 8 LINER CONCEPTS. (SCREEN)
TOTAL	112	96	112	147	18	36	8	132	169	169	24	38	24	24	94	270	150	4	4	

*CELL WALL TO LINER BOND STRENGTH.
**ONLY TO BE CONDUCTED ON FINAL CANDIDATE MATERIAL.
***5×10^{18} NVT - FAST NEUTRON FLUENCE, ENERGY GREATER THAN 1 MEV. TEST CONTROLS.

CONDITION/FORM	PROPERTY	RAD LEVEL 10 PWR	HEATS	TEST TEMPERATURE, °F	TOTAL SPECS	TEST MATRIX BASIS
GRAPHITIZED CURVED PLATE	TENSILE - BLOCK		4	RT	150	SCREEN
	TENSILE- WARP		4	RT	150	SCREEN
	TENSILE - FILL		4	RT	150	SCREEN
	TENSILE - T-BAR*		4	RT	84	SCREEN
	COMP - WARP		4	RT	150	SCREEN
	COMP - FILL		4	RT	42	SCREEN
	COMP - BLOCK		4	RT	42	SCREEN
	INTERLAMINAR SHEAR		4	RT	150	SCREEN
	WEIGHT CHANGE		4	RT	60	SCREEN
	SHRINKAGE		4	RT	40	SCREEN
	POROSITY		4	RT	40	SCREEN
	DENSITY		4	RT	40	SCREEN
	MICROSTRUCTURE		4	RT	60	SCREEN
	MOD OF ELASTICITY		4	RT	27	SCREEN
	THERMAL CONDUCTIVITY		4	RT TO 4000	8	SCREEN
	THERMAL EXPANSION		4	RT TO 4000	8	SCREEN

CONDITION/FORM	PROPERTY	LOTS	TEST TEMPERATURE, °F RT	1500	3000	TOTAL SPECS	TEST MATRIX BASIS
PHASE III							
DEMONSTRATION SEGMENTED CONFIGURATIONS	FLEXURE (FLATWISE)	4	32			32	SCREEN
	TENSILE (BLOCK)	4	32			32	SCREEN
TASK A - FOUR LINER CONCEPTS	TENSILE (WARP)	4	32			32	SCREEN
	TENSILE (FILL)	4	32			32	SCREEN
	INTERLAMINAR SHEAR	4	32			32	SCREEN
	COMPRESSIVE (EDGE)	4	32			32	SCREEN
	THERMAL EXPANSION	4	8*		8	8	SCREEN
	THERMAL DIFFUSIVITY	4	8*		8	8	SCREEN
	MODULUS OF ELASTICITY (3 DIRECTIONS)	4	30			30	SCREEN
	POROSITY	4	24			24	SCREEN
	FATIGUE	4	8			8	SCREEN
	FRACTURE TOUGHNESS	4	4			4	SCREEN
TASK B - HONEYCOMB CELLS	TENSILE (TEE BAR)	4	32			32	SCREEN
	TENSILE (WARP)	1	8			8	SCREEN
	TENSILE (FILL)	1	8			8	SCREEN
	MODULUS OF ELASTICITY (3 DIRECTIONS)	1	30			30	SCREEN

*SAME SPECIMENS WILL BE USED FOR ENTIRE TEMPERATURE RANGE.

TEST PLAN: M-6 GRAPHITE COMPOSITE

COMPONENT: NOZZLE EXTENSION

CONDITION/FORM	PROPERTY	LOTS	TEST TEMPERATURE, °F				TOTAL SPECS	TEST MATRIX BASIS
			RT	1500	3000	3500		
PHASE IV								
FULL SCALE NOZZLE EXTENSION PROPERTY DESIGN ALLOWABLE DEVELOPMENT	**TENSILE	2	24		16		40	DESIGN
	COMPRESSIVE	2	16		16		32	DESIGN
	**FLEXURE	2	16		16		32	DESIGN
	SHEAR	2	16		8		24	DESIGN
	FATIGUE	2	60				60	DESIGN
	PHYSICAL	2	18				18	DESIGN
	POROSITY	2	18				18	DESIGN
	MODULUS OF ELASTICITY	2	16*		16*		16	(DESIGN)
	THERMAL DIFFUSIVITY	2	16*		16*		16	(DESIGN)
	THERMAL EXPANSION	2	6*		6*		6	(DESIGN)
	RAD DAMAGE, BLOCK TENSILE	2	16		16		32	SCREEN
	RAD DAMAGE, FLEXURE	2	16			16	32	SCREEN
	CREEP	2		16		16	32	DESIGN
	FRACTURE TOUGHNESS	2	16		16		32	DESIGN
	DAMPING CAPACITY	2	2				2	SCREEN

*SAME SPECIMEN WILL BE USED FOR ENTIRE TEMPERATURE RANGE.

**INCLUDE BOTH UNIAXIAL AND BIAXIAL STRENGTH DETERMINATIONS.

( ) LOW VARIABILITY INDICATED BY EXPERIENCE AND/OR LITERATURE. TD 69-28 STATISTICAL RULES NOT REQUIRED.

TEST PLAN: M-7 6061-T6

COMPONENTS: PRESSURE VESSEL, VALVES, LINES, THRUST STRUCTURE

DATE: 23 [illegible]Y 1970
REVISION: 1

CONDITION/FORM	PROPERTY	RAD LEVEL*** 10 PWR	HEATS	TEST TEMPERATURE, °F / TEST DIRECTION -423 L	-423 T	-423 ST	-320 L	-320 T	-320 ST	-100 L	-100 T	-100 ST	70 L	70 T	70 ST	200 L	200 T	200 ST	300 L	300 T	300 ST	TOTAL SPECS	TEST MATRIX BASIS
T6/F	LOW CYCLE FLAW GROWTH		1				4	4		4	4											16	SCREEN
T6/WF	FRACTURE TOUGHNESS		1	4	4		4	4	4													20	SCREEN
T6/F	IRRAD TOUGHNESS	17,18,19	1				16															16	SCREEN
T6/WF	IRRAD TOUGHNESS	17,18,19	1				16															16	SCREEN
T6/F	FATIGUE		2																60 (275°F)			60	DESIGN
T6/S	IRRAD TENSILE	0.16,17,18	1	16																		16	SCREEN
T6/S	IRRAD TOUGHNESS	0,16,17,18.	1	16																		16	SCREEN
T6/S	FATIGUE		(1)										30									30	DESIGN*
T6/WS	FATIGUE		1	30																		30	DESIGN*
T6/T	TENSILE		(2)	4	4		4	4		4	4		4	4		4	4		4	4		48	DESIGN
T6/WT	TENSILE		(2)	4	4		4	4		4	4		4	4		4	4		4	4		48	DESIGN
												RT TO -423											
T6/F	α, K, μ, E		1									4										4	(DESIGN)

( ) LOW VARIABILITY INDICATED BY EXPERIENCE AND/OR LITERATURE. TD 69-28 STATISTICAL RULES NOT REQUIRED.

*ONE HEAT ALREADY TESTED IN CY 70.

***Fast Neutron Fluence, Energy Greater than [illegible] Mev.

TEST PLAN: M-8 2024 SHEET/PLATE; 2014 FORGING/EXTRUSION

DATE: 23 JULY 1970
REVISON: 1

COMPONENT: UPPER THRUST STRUCTURE

CONDITION/FORM	PROPERTY	RAD LEVEL 10 PWR	HEATS	TEST TEMPERATURE, °F TEST DIRECTION -200 L	-200 T	-200 ST	RT L	RT T	RT ST	TOTAL SPECS	TEST MATRIX BASIS
T6/S	TENSILE		2	6	6		6	6		24	DESIGN
T6/SW			2	6	6		6	6		24	DESIGN
T6/SR			2	6	6		6	6		24	DESIGN
T6/S	FATIGUE		2				60			60	DESIGN
T6/SW			2	60						60	DESIGN
T6/SR			2	60						60	DESIGN
T6/S	STRESS CORROSION		1						15	15	SCREEN
T6/SW			1						15	15	SCREEN
T6/SR			1						15	15	SCREEN
T6/F	TENSILE		2	6	6		6	6		24	DESIGN
T6/FW			2	6	6		6	6		24	DESIGN
T6/E			2	10			10			20	DESIGN
T6/EW			2	10			10			20	DESIGN
T6/F	FATIGUE		2				30			30	SCREEN
T6/FW			2	30						30	SCREEN
T6/E			2				60			60	DESIGN
T6/EW			2	60						60	DESIGN
T6/F	STRESS CORROSION		1						15	15	SCREEN
T6/FW			1						15	15	SCREEN
T6/E			1						15	15	SCREEN
T6/EW			1						15	15	SCREEN
				-200 TO RT							
T6/S	K, α, μ, E		1	4						4	(DESIGN)
T6/F	K, α, μ, E		1	4						4	(DESIGN)

( ) LOW VARIABILITY INDICATED BY EXPERIENCE AND/OR LITERATURE. TD 69-28 STATISTICAL RULES NOT REQUIRED.

TEST PLAN: M-9 TI 6AL-4V

COMPONENT: LOWER THRUST STRUCTURE

DATE: 23 JULY 1970
REVISION: 1

CONDITION/FORM	PROPERTY	RAD LEVEL*** 10 PWR	HEATS	TEST TEMPERATURE, °F / TEST DIRECTION										TOTAL SPECS	TEST MATRIX BASIS
				-320		-150		RT		500		700			
				L	T	L	T	L	T	L	T	L	T		
ANN/S	TENSILE		2			4	4	4	4	4	4	4		32	DESIGN
ANN/SW*	TENSILE		2			8		8		8		8		32	DESIGN
ANN/SR**	TENSILE		2			8		8		8		8		32	DESIGN
ANN/S	FATIGUE		2									60		60	DESIGN
ANN/SW	FATIGUE		2			60								60	DESIGN
ANN/SR	FATIGUE		2			60								60	DESIGN
ANN/S	FRACTURE TOUGHNESS		2			6	6	6	6					24	DESIGN
ANN/SW	FRACTURE TOUGHNESS		2			10		10						20	DESIGN
ANN/S	IRRAD TENSILE	0,17,18	1	12										12	SCREEN
	DYNAMIC MOD & POISSON'S RATIO		2					8						16	(DESIGN)

*SPOT WELDED

**RIVETED

***FAST NEUTRON FLUENCE, ENERGY GREATER THAN 1 MEV.

( ) LOW VARIABILITY INDICATED BY EXPERIENCE AND/OR LITERATURE. TD 69-28 STATISTICAL RULES NOT REQUIRED.

TEST PLAN: M-10 AISI 301

COMPONENTS: ACTUATORS, VALVES

DATE: 16 SEPTEMBER 1970
REVISION: 1

CONDITION/FORM	PROPERTY	RAD LEVEL 10 PWR	HEATS	TEST TEMPERATURE, °F / TEST DIRECTION -423 L	-423 T	-320 L	-320 T	RT L	RT T	TOTAL SPECS	TEST MATRIX BASIS
1/4 HARD/SHEET	TENSILE		2	3	3	3	3	3	3	36	DESIGN
1/4 HARD/SHEET	ELASTIC MODULUS & POISSON'S RATIO		1				-423 TO RT: T			1	(DESIGN)
1/4 HARD/SHEET	FLEXURAL FATIGUE		2					60		60	DESIGN
FULL HARD	ELASTIC MODULUS & POISSON'S RATIO		1				1			1	(DESIGN)

( ) LOW VARIABILITY INDICATED BY EXPERIENCE AND/OR LITERATURE   TD 69-28 STATISTICAL RULES NOT REQUIRED.

FRICTION & WEAR - SPACE VACUUM TEST PLAN

M-II

ASSEMBLY	COMPONENT	ENVIRONMENT: LOAD	SPEED	°F	ATMOS	SCREEN TEST FOR MATERIAL SELECTION: SHAFT SUB-STRATE	SHAFT COATING		FLAT SUB-STRATE	FLAT COATING	ATM	TEMP	NO. TESTS	QUALIFICATION	TESTS REQUIREMENTS: ATMOS	°F	NO. TESTS	PROPERTY
LINES	BELLOWS BEARINGS	HIGH	SLOW OSC SLIDE	160° -423°	CH_2 VAC LH_2	718 718 718 718 718 718	HARD Cr HARD Cr HARD Cr HARD Cr HARD Cr HARD Cr	VS	440C 440C CW 718 CW 718 18 Ni MARAGING 18 Ni MARAGING	Ag MoS_2 Ag MoS_2 Ag MoS_2	He	R.T.	8 8 8 8 8 8 48	BEST MATERIAL SELECTION COMBINATION	N_2O/CH_4 CH_2/LH_2 10^{-10} TORR	R.T. R.T. -200 -423	4 4 4 12	COEFFICIENT OF FRICTION AND WEAR LIFE
						4 REP (3 COMBO x 2 COAT x 2 PROCESS x 1 ENV) = 48									4 REP (1 COMBO x 3 ENV)			
VALVES	SEALS & ACTUATOR	HIGH	MED OSC SLIDE	160° -423°	CH_2 He LH_2	718	HARD Cr HARD Cr HARD Cr HARD Cr HARD Cr	VS VS VS VS VS	301 SS 301 SS PHOS. BRONZE PHOS. BRONZE PHOS. BRONZE	Ag MoS_2 NONE Ag MoS_2	He	R.T.	8 8 4 8 8 36	BEST MATERIAL SELECTION COMBINATION	CH_2/LH_2 10^{-10} TORR	R.T. -200 -423	4 4 4 12	COEFFICIENT OF FRICTION AND WEAR LIFE
						4 REP (2 COMBO x 2 COAT x 2 PROCESS x 1 ENV) (4 NO COAT)												
	JOURNAL BEARINGS	HIGH	MED OSC SLIDE	160° -423°	CH_2 VAC LH_2	718	HARD Cr HARD Cr HARD Cr	VS	718 VESPEL SP-1	Ag MoS_2 NONE	He He	R.T. R.T.	8 8 4 20	BEST MATERIAL SELECTION COMBINATION	10^{-10} TORR VAC W/INTERMEDIATE DWELL TIME CH_2/LH_2	R.T. -200 -423	4 4 4 12	COEFFICIENT OF FRICTION AND WEAR LIFE
						4 REP (1 COMBO x 2 COAT x 2 PROCESS) + (4 NO COAT)									4 REP (1 COMBO x 3 ENV)			
TVC ACTUATOR	BALL SCREW BALL BALL SCREW	HIGH	ROLLING LOW	250° -100°	VAC	18 Ni MARAGING 440C 18 Ni MARAGING	MoS_2 $MoSe_2$	VS	18 Ni MARAGING	$MoSe_2$		250	NONE	BEST MATERIAL SELECTION COMBINATION	10^{-10} TORR VAC W/INTERMEDIATE DWELL TIME	250	4 4 8	COMPONENT TESTS TO EVALUATE WEAR LIFE OF 2 LUBRICANTS IN ULTRA HIGH VAC
															4 REP (1 COMBO x 2 COAT x 1 ENV)			
	GIMBAL BEARING	HIGH	SLOW OSC SLIDE	250° -100°	VAC	18 Ni MARAGING	BONDED MoS_2	VS	ALUMINUM BRONZE	BONDED MoS_2	He	250	8 8	BEST MATERIAL SELECTION COMBINATION	10^{-10} TORR VAC W/INTERMEDIATE DWELL TIME	250	4 4	COEFFICIENT OF FRICTION AND WEAR LIFE
						4 REP (1 COMBO x 1 COAT x 2 PROCESS x 1 ENV)									4 REP (1 COMBO x 1 ENV)			
	SEAL	HIGH	MED	250° -100°	VAC	18 Ni MARAGING		VS	301 SS	Ag MoS_2	He		8 8 16	BEST MATERIAL SELECTION COMBINATION	10^{-10} TORR VAC W/INTERMEDIATE DWELL TIME	250	4 4	COEFFICIENT OF FRICTION AND WEAR LIFE
						4 REP (1 COMBO x 2 COAT x 2 PROCESS x 1 ENV)									4 REP (1 COMBO x 1 ENV)			
	ELECTRICAL CONTACTS	MED	SLIDING	250° -100°	VAC	Ag-GRAPHITE		VS	Co, Ag BOEING (PROPRIETARY)	$MoSe_2$	He	R.T.	8 8 8 24	BEST MATERIAL SELECTION COMBINATION	10^{-10} TORR VAC W/INTERMEDIATE DWELL TIME	R.T.	4 4	COEFFICIENT OF FRICTION AND WEAR LIFE
						4 REP (3 COMBO x 1 COAT x 2 PROCESS x 1 ENV)									4 REP (1 COMBO x 1 ENV)			
VALVE ACTUATORS	ROLLER ELEMENTS & BEARINGS	HIGH	MED ROLLING	160° -423°	VAC	440C	MoS_2 RETAINER: POLYIMIDE, FEURALON						NONE	BEST MATERIAL SELECTION COMBINATION	10^{-10} TORR VAC CH_2/LH_2	R.T. -200 -423	8 8 8 24	COMPONENT TESTS TO EVALUATE WEAR LIFE
															4 REP (2 COMBO x 1 COAT x 3 ENV)			
	GEARS	MED HIGH	LOW	160° -423°	VAC	CARBURIZED 9310	MoS_2 OR $MoSe_2$	VS	CARBURIZED 9310		He	R.T.	8 8 16	EVALUATION FOR GEAR APPLICATION	10^{-10} TORR VAC W/INTERMEDIATE DWELL TIME CH_2/LH_2	R.T. -200 -423	4 4 4 12	COMPONENT TESTS TO EVALUATE WEAR LIFE
						4 REP (1 COMBO x 2 COAT x 2 PROCESS x 1 ENV)									4 REP (1 COMBO x 3 ENV)			
TURBINE	TURBINE BEARINGS ROLLING ELEMENTS	HIGH	ROLLING HIGH	160° -423°	CH_2 He	440C PBI/GRAPHITE OR PI/GLASS	MoS_2 MoS_2	VS	440C				NONE	BEST MATERIAL SELECTION COMBINATION	10^{-10} TORR VAC	R.T.	4 4	COMPONENT TO EVALUATE START UP FRICTION AND WEAR LIFE
															4 REP (1 COMBO x 3 ENV)			

LH_2 FRICTION AND WEAR SPACE VACUUM TEST PLAN

M-11

DATE: 16 SE[illegible]BER 1970

SHEET 2 OF 2

ASSEMBLY	COMPONENT	FORM	PROPERTY	TEST CONDITIONS °F	ATMOS	MATERIAL	FACILITY	LOTS	TOTAL SPECS	TEST MATRIX BASIS
TPA	THRUST BALANCER & HYDROSTATIC BEARING	ROD	FRICTION & WEAR	-423	LH_2	BOEING	A	1	10	SCREEN
		ROD	FRICTION & WEAR	-423	LH_2	GRAPHITE	A	1	4	SCREEN
		ROD	FRICTION & WEAR	-423	LH_2	$Ni-MoS_2$	A	1	6	SCREEN
		ROD	FRICTION & WEAR	-423	LH_2	BEARIUM-B10 COORS AD-999	A	1	15	SCREEN
		ROD	FRICTION & WEAR	-423	LH_2	PBI/MODMOR I	A	3	15	SCREEN
		ROD	FRICTION & WEAR	-423	LH_2	EKONOL(1)	A	1	5	SCREEN
		ROD	FRICTION & WEAR	-423	LH_2	PQ/MODMOR I(2)	A	1	10	SCREEN
		60 MM CAGES	FRICTION & WEAR	-423	LH_2	PQ/MODMOR I	A	2	6	SCREEN
		60 MM CAGES	FRICTION & WEAR	-423	LH_2	PBI/MODMOR I	A	2	6	SCREEN

(1) REFERENCE: MEMO 70-202, SOURCE CARBORUNDUM CO.

(2) REFERENCE: ANSC QUOTE NO. (AQR) L-0135.

TEST PLAN: M-12 HASTELLOY X (LOW AL)

DATE: 23 JULY 1970
REVISION: 1

COMPONENT: NOZZLE

CONDITION/FORM	PROPERTY	RAD LEVEL 10 PWR	HEATS	TEST TEMPERATURE, °F								TOTAL SPECS	TEST MATRIX BASIS
				-423	-320	RT	1000	1200	1400	1600	2000		
BAR	FATIGUE, LOW CYCLE		2				48		48	48		144	DESIGN
SHEET	CREEP		2					72	72	72		216	DESIGN
SHEET	TENSILE		2	16	16	16		16	16	16		96	DESIGN
FORGING (NOZZLE)	TENSILE		2	16	16	16		16	16	16		96	DESIGN
FORGING WELDED (NOZZLE)	TENSILE		2	16	16	16		16	16	16		96	DESIGN

TEST PLAN: M-14 POLYIMIDES

COMPONENTS: VALVES

DATE: 23 JULY 1970
REVISION: 1

CONDITION/FORM	PROPERTY	RAD LEVEL 10 PWR	HEATS	TEST TEMPERATURE, °F -423	-320	RT	200	TOTAL SPECS	TEST MATRIX BASIS
PLATE (VESPEL)	TENSILE		2	8	8	8	8	32	DESIGN
PLATE (VESPEL)	TOUGHNESS		2	8	8	8		24	DESIGN
PLATE (VESPEL)	FATIGUE		2	60			60	120	DESIGN
PLATE (VESPEL)	COMP CREEP		1			5		5	SCREEN
PLATE (VESPEL)	COATING ADHESION		1		5		5	10	SCREEN
PLATE (VESPEL)	THERMAL EXPANSION		2		RT TO -423			2	(DESIGN)
PLATE (FELRALON AW)	IRRAD TENSILE	10, 11* γ	1	16				16	SCREEN

(   ) LOW VARIABILITY INDICATED BY EXPERIENCE AND/OR LITERATURE. - TD 69-28 STATISTICAL RULES NOT REQUIRED.

*GAMMA DOSE EXPRESSED IN ERGS/GM.

TEST PLAN: M-16 18 NI MARAGING STEEL

COMPONENT: FLEXURES

DATE: 23 JULY 1970
REVISION: 1

CONDITION/FORM	PROPERTY	RAD LEVEL*** 10 PWR	HEATS	TEST TEMPERATURE, °F / TEST DIRECTION: -320 L	-320 T	RT L	RT T	300 L	300 T	TOTAL SPECS	TEST MATRIX BASIS
SOL & AGE/B	IRRAD TOUGHNESS	0,16,17,18	1	16						16	SCREEN
SOL & AGE/B	IRRAD TENSILE	0,16,17,18	1	16						16	SCREEN
SOL & AGE/B	TENSILE	•	2	4	4	4	4	4	4	24	DESIGN
SOL & AGE/B	FLEX FATIGUE		2					60		60	DESIGN
SOL & AGE W/B	FLEX FATIGUE		2	60						60	DESIGN
SOL & AGE W/B	TENSILE		2	4	4	4	4	4	4	24	DESIGN
SOL & AGE/B	FRACTURE TOUGHNESS		1	4	4		4			12	SCREEN
SOL & AGE/B	STRESS CORROSION PROTECTIVE COATING		13 COATINGS			90				90	SCREEN
	CORROSION FATIGUE PROTECTIVE COATING		13 COATINGS			48				48	SCREEN
	DYNAMIC MODULUS & POISSON'S RATIO					2	2			4	SCREEN

***FAST NEUTRON FLUENCE, ENERGY GREATER THAN 1 MEV.

TEST PLAN: M-19 440C STAINLESS STEEL

COMPONENTS: VALVES, ACTUATORS, TPA

DATE: 23 JULY 1970
REVISION: 1

CONDITION/FORM	PROPERTY	RAD LEVEL 10 PWR	HEATS	TEST TEMPERATURE, °F		TOTAL SPECS	TEST MATRIX BASIS
				-423	RT		
BAR	HARDNESS		2		18	18	DESIGN
BAR	MODULUS OF ELASTICITY		2		4	4	(DESIGN)
BAR	POISSON'S RATIO		2		4	4	(DESIGN)
BAR	COMPRESSIVE YIELD		2	16	16	32	DESIGN
BAR	THERMAL EXPANSION		2	1	1	2	(DESIGN)

( ) LOW VARIABILITY INDICATED BY EXPERIENCE AND/OR LITERATURE. TD 69-28 STATISTICAL RULES NOT REQUIRED

TEST PLAN: M-20 AA 5086

COMPONENTS: LINES

DATE: 23 JULY 1970
REVISION: 1

CONDITION/FORM	PROPERTY	RAD LEVEL*** 10 PWR	HEATS	TEST TEMPERATURE, °F -423	-320	RT	TOTAL SPECS	TEST MATRIX BASIS
H32/T	TENSILE		2	8	8	8	24	DESIGN
H32/TW*	TENSILE		2	8	8	8	24	DESIGN
H32/T	FATIGUE		2			60	60	DESIGN
H32/TW*	FATIGUE		2	60			60	DESIGN
H32/T	FRACTURE TOUGHNESS		2	8	8	8	24	DESIGN
H32/TW*	FRACTURE TOUGHNESS		2	8	8	8	24	DESIGN
5086/718 T/tj	TENSILE		1	5	5	5	15	SCREEN
5086/718	FATIGUE		1	5	5	5	15	SCREEN
H32/TW	IRRAD TENSILE	0,17,18,19	1	16			16	SCREEN
H32/W	IRRAD TENSILE	0,17,18,19	1	16			16	SCREEN

*As-Welded

T/tj - Transition Joint.

***FAST NEUTRON FLUENCE, ENERGY GREATER THAN 1 MEV.

TEST SUMMARY SHEET

7075-T73 ALUMINUM ALLOY FORGING, EXTRUDED

CONDITION	TEST TYPE	RAD LEVEL*** 10 PWR	HEATS	TEST TEMPERATURE, °F 300 C	300 A	300 ST	200 C	200 A	200 ST	70 C	70 A	70 ST	-100 C	-100 A	-100 ST	-320 C	-320 A	-320 ST	TOTAL	TEST MATRIX BASIS
T73/WALL/F	LOW CYCLE FLAW GROWTH		2	6	6		6	6											24	DESIGN
T73/WALL/F	TENSILE		2	4	4		4	4		4	4	4	4	4		4	4	4	48	DESIGN
T73/WALL/F IRRAD	IRRAD TENSILE	0,17,18,19	1														16		16	SCREEN
T73/WALL/F	IRRAD TOUGHNESS	0,17,18,19	1														16		16	SCREEN
										-320 TO RT										
T73/WALL/F	THERMAL EXPANSION		1								1								1	(DESIGN)
T73/WALL/F	THERMAL CONDUCTIVITY		1								1								1	(DESIGN)
T73/WALL/F	FRACTURE TOUGHNESS		2							4	4	4	4	4		4	4	4	32	DESIGN
T73/FLANGE/F	FRACTURE TOUGHNESS		2							4	4	4	4	4		4	4	4	32	DESIGN
T73/WALL + FLANGE/F	STRESS CORROSION		2								100								100	SCREEN
T73/WALL/F	FATIGUE		2								60 (150°F)								60	DESIGN
T73/WALL/F	FLAME SPRAY DEGRADATION		1							10	10								20	SCREEN

( ) LOW VARIABILITY INDICATED BY EXPERIENCE AND/OR LITERATURE. TD 69-28 STATISTICAL RULES NOT REQUIRED.

***FAST NEUTRON FLUENCE ENERGY GREATER THAN 1 MEV.

TEST PLAN: M-22 HIGH PRESSURE GH_2 EMBRITTLEMENT

COMPONENTS: TPA, ACTUATOR, NOZZLE

DATE: 23[illegible]Y 1970
REVISION: 1

CONDITION/FORM	PROPERTY	RAD LEVEL 10 PWR	HEATS	TEST TEMPERATURE, °F			TOTAL SPECS	TEST MATRIX BASIS
				-320	-160	RT		
ANN/TI 5AL-2.5SN ELI	10 HR SUSTAIN STRESS TOUGHNESS (K_{TH})							
	1400 PSIG		2	8	8	8	24	DESIGN
	500 PSIG		2	10		10	20	DESIGN
	100 HR SUSTAIN STRESS TOUGHNESS (K_{TH})							
	500 PSIG		2	10		10	20	DESIGN
	1400 PSIG		2	10		10	20	DESIGN
	CYCLIC/STRESS (10 HR) TOUGHNESS (K_{Ii})							
	500 PSIG		2	8	8	8	24	DESIGN
	1400 PSIG		2	8	8	8	24	DESIGN
	CYCLIC/STRESS (100 HR) TOUGHNESS (K_{Ii})							
	500 PSIG		2	10		10	20	DESIGN
	1400 PSIG		2	10		10	20	DESIGN
SOL & AGE/A286/F	10 HR SUSTAIN STRESS TOUGHNESS (K_{TH})							
	1400 PSIG		1		4	4	8	SCREEN
	500 PSIG		1	4	4	4	12	SCREEN
QUENCH & TEMP/ 9310/B	NOTCH-TENSILE							
	1400 PSIG		1	6		6	12	SCREEN
	SUSTAIN STRESS (10 HR) TOUGHNESS (K_{TH})							
	1000 PSIG		1	6		6	12	SCREEN
ANN/310/F	SUSTAIN STRESS (10 HR) TOUGHNESS (K_{TH})							
	1400 PSIG		1	6		6	12	SCREEN

CONDITION/FORM	PROPERTY	RAD LEVEL 10 PWR	HEATS	TEST TEMPERATURE, °F -320	-160	RT	TOTAL SPECS	TEST MATRIX BASIS
ANN/310/SW	1400 PSIG		1	6		6	12	SCREEN
FB*/347/F	NOTCH TENSILE		1	6		6	12	SCREEN
	SUSTAIN STRESS (10 HR) (K_{TH})							
	1400 PSIG		1	6		6	12	SCREEN
ANN/21-6-9/F	NOTCH TENSILE							
	1400 PSIG		1	6		6	12	SCREEN
FB/HASTELLOY X/F	NOTCH TENSILE 1400 PSIG		1	6		6	12	SCREEN
	SUSTAIN STRESS (10 HR) (K_{TH})							
	1400 PSIG		1	6		6	12	SCREEN

*FB - Furnace Braze

TEST PLAN: M-23 GH_2, STRESS AND RADIATION SYNERGISTIC EFFECTS

DATE: 23 [illegible] 1970
REVISION: 1

COMPONENTS: ALL

PHASE	MATERIAL FORM	TEST CONDITIONS: SUSTAINED STRESS ATMOS.	SUSTAINED STRESS STRESS (KSI)	RADIATION NVT †	RADIATION PSI ATM.	RADIATION °F TEMP	RADIATION KSI STRESS	POSTRADIATION DYNAMIC NOTCH TEST ATMOS. ATMOS.	POSTRADIATION °F TEMP	NO. OF SPECS	TOTAL SPECS	TEST MATRIX BASIS
2	INCONEL 718 A286 CW & AGE 301 CW			10^{20}	500 GH_2	200	0	500 GH_2	80	3	9	SCREEN
				10^{20}	1000 GH_2	200	0	1500 GH_2	80	3	9	SCREEN
				10^{20}	1000 GH_2	200	0	1500 GHe	80	2	6/24	SCREEN
3	INCONEL 718	1-1500 PSI	250	**				1-1500	80	2	2	SCREEN
			200						80	2	2	SCREEN
			150						80	2	2	SCREEN
		GH_2	125						80	2	2/8	SCREEN
3	INCONEL 718 301 CW A286	***		10^{20}	1000	200	Max	1500 GHe	80	2	6	SCREEN
				10^{20}	1000	200	Max	1500 GH_2	80	2	6	SCREEN
				10^{20}	500	200	Max	500 GH_2	80	2	6/18	SCREEN
4				10^{19}	1000	200	Max	1500 GHe	80	2	6	SCREEN
				10^{19}	1000	200	Max	1500 GH_2	80	2	6	SCREEN
				10^{19}	500	200	Max	500 GH_2	80	2	6/18	SCREEN
5		IRRADIATION TEMPERATURE DEPENDENT		10^{19}	1000	-200	Max	1500 GHe	80	2	6	SCREEN
				10^{19}	1000	-200	Max	1500 GH_2	80	2	6	SCREEN
				10^{19}	500	-200	Max	500 GH_2	80	2	6/18	SCREEN

**CONTROL TESTS TO ESTABLISH IF GH_2 + STRESS WILL FRACTURE SPECIMENS WITHOUT MACRO-DEFORMATION, IF FRACTURE DOES NOT OCCUR AT 1500 PSI, SUSTAINED STRESS WILL BE MAINTAINED FOR 10^2 HOURS.

***FLUENCE AND TEST PRESSURE DEPENDENCE.

† FAST NEUTRON FLUENCE, ENERGY GREATER THAN 1 MEV.

26 IRRAD EACH OF 3 MATERIALS.
81 UNIRRADIATED 718 ONLY.

TEST PLAN: M-27 LEAD

COMPONENT: SHIELD

DATE: 23 JULY 1970
REVISION: 1

CONDITION/FORM	PROPERTY	RAD LEVEL 10 PWR	HEATS	TEST TEMPERATURE, °F / TEST DIRECTION / 100°F: L	T	ST	TOTAL SPECS	TEST MATRIX BASIS
CAST	CREEP		2	10	10		20	DESIGN
CAST	THERMAL EXPANSION		2	1 MEASUREMENT (-100 TO 600°F)			2	(DESIGN)
CAST	DYNAMIC YOUNG'S MODULUS		2	1	1 (AT ROOM TEMP)		2	(DESIGN)

( ) LOW VARIABILITY INDICATED BY EXPERIENCE AND/OR LITERATURE. TD 69-28 STATISTICAL RULES NOT REQUIRED.

TEST PLAN: M-28 GRAPHITE 3% BORON

COMPONENT: SHIELD

DATE: 23 JULY 1970
REVISION: 1

CONDITION/FORM	PROPERTY	RAD LEVEL 10 PWR	HEATS	TEST TEMPERATURE, °F / TEST DIRECTION -600 WITH GRAIN	-600 AGAINST GRAIN	+100 WITH GRAIN	+100 AGAINST GRAIN	TOTAL SPECS	TEST MATRIX BASIS
BLOCK	FLEXURAL ULT STRENGTH		2	6	6	6	6	24	DESIGN
BLOCK	COMPRESSIVE ULT STRENGTH		2	6	6	6	6	24	DESIGN
BLOCK	YOUNG'S MODULUS (DYNAMIC)		2			2	2 (AT ROOM TEMP)	4	SCREEN
BLOCK	SPECIFIC HEAT		2			2 MEASUREMENTS (-100 TO 600)		2	SCREEN
BLOCK	THERMAL CONDUCTIVITY		2			2 MEASUREMENTS (-100 TO 600)		2	SCREEN
BLOCK	X-RAY RADIOGRAPHY		2				2	2	SCREEN
BLOCK	DENSITY		2					2	SCREEN

TEST PLAN: M-29 310 SS

COMPONENTS: TPA MANIFOLD AND HOUSING

DATE: 23 JULY 1970
REVISION: 1

CONDITION/FORM	PROPERTY	RAD LEVEL 10 PWR	HEATS	TEST TEMPERATURE, °F TEST DIRECTION -423 L	-423 T	-160 L	-160 T	RT L	RT T	TOTAL SPECS	TEST MATRIX BASIS
ANN/S	TENSILE		2	4	4	4	4	4	4	24	DESIGN
ANN/SW_1	TENSILE		2	4	4	4	4	4	4	24	DESIGN
ANN/S-F/W_1*	TENSILE		2	4	4	4	4	4	4	24	DESIGN
ANN/S-F/W_2**	TENSILE		2	4	4	4	4	4	4	24	DESIGN
ANN/S	FATIGUE		2					60		60	DESIGN
ANN/SW_1	FATIGUE		2	60						60	DESIGN
ANN/S	FRACTURE TOUGHNESS		2	4	4	4	4	4	4	24	DESIGN
ANN/SW_1	FRACTURE TOUGHNESS		2	4	4	4	4	4	4	24	DESIGN
ANN/S-F/W_1*	FRACTURE TOUGHNESS		2	4	4	4	4	4	4	24	DESIGN
ANN/S-F/W_2**	FRACTURE TOUGHNESS		2	4	4	4	4	4	4	24	DESIGN
ANN/F (RING)	TENSILE		2	4	4	4	4	4	4	24	DESIGN
ANN/F (RING)	FRACTURE TOUGHNESS		2	10	10					20	DESIGN
	THERMAL EXPANSION		1	1 MEASUREMENT (RT TO -160)						1	(DESIGN)
	THERMAL CONDUCTIVITY		1	1 MEASUREMENT (RT TO -160)						1	(DESIGN)

*W_1 = TIG WELDING

**W_2 = ELECTRON BEAM WELDING

( ) LOW VARIABILITY INDICATED BY EXPERIENCE AND/OR LITERATURE. TD 69-28 STATISTICAL RULES NOT REQUIRED.

TEST PLAN: M-30 BOLT MATERIAL

DATE: 23 JUL 1970
REVISION:]

COMPONENTS: TPA, PRESSURE VESSEL, VALVES, LINES

CONDITION/FORM	PROPERTY	RAD LEVEL*** 10 PWR	HEATS	TEST TEMPERATURE, °F -423	-320	-160	RT	TOTAL SPECS	TEST MATRIX BASIS
CW & AGE/A286	FATIGUE		2	60			60	120	DESIGN
	STRESS CORROSION		1				20	20	SCREEN
	TENSILE		2	8	8		8	24	DESIGN
	IRRAD TENSILE	0,17,18,19	1	16				16	SCREEN
CW & AGE/ MULTIPHASE	NOTCH TENSILE IN GH_2 1400 PSI		1			4	4	8	SCREEN
	NOTCH TENSILE IN GHe 1400 PSI		1			2	2	4	SCREEN
	TENSILE		2	8	8	8	8	32	DESIGN
	TENSILE IRRAD	0,18,19	1	12		12		24	SCREEN
	TOUGHNESS		2	8	8	8	8	32	DESIGN
	IRRAD TOUGHNESS	0,18,19	1	12		12		24	SCREEN
	FATIGUE		2		60			60	DESIGN
	STRESS CORROSION		1				20	20	SCREEN
	DYNAMIC MODULUS		2					2	(DESIGN)
	THERMAL EXPANSION		2					2	(DESIGN)
SOL & DOUBLE AGE/ 718 TPA TIE BOLTS	TENSILE		2	8		8	8	24	DESIGN
	TOUGHNESS		2	8		8	8	24	DESIGN
	FATIGUE		2	60				60	DESIGN

( ) LOW VARIABILITY INDICATED BY EXPERIENCE AND/OR LITERATURE. TD 69-28 STATISTICAL RULES NOT REQUIRED.

***FAST NEUTRON FLUENCE, ENERGY GREATER THAN 1 MEV.

TEST PLAN: M-31 AISI 9310 CARBURIZED

DATE: 23 JULY 1970
REVISION: 1

COMPONENT: ACTUATOR

CONDITION/FORM	PROPERTY	RAD LEVEL*** 10 PWR	HEATS	TEST TEMPERATURE, °F / TEST DIRECTION: -423 L	-423 T	-423 ST	-320 L	-320 T	-320 ST	-100 L	-100 T	-100 ST	RT L	RT T	RT ST	200 L	200 T	200 ST	300 L	300 T	300 ST	TOTAL SPECS	TEST MATRIX BASIS
Q + T/BAR	IRRAD TOUGHNESS	0,16,17,18	1	16																		16	SCREEN
Q + T/BAR	IRRAD TENSILE	0,16,17,18	1	16																		16	SCREEN
Q + T/BAR	CHARPY IMPACT STRENGTH		1				4	4		4	4											16	SCREEN
Q + T/CARBURIZED BAR	CHARPY IMPACT STRENGTH		1				4	4		4	4											16	SCREEN
Q + T/BAR	TENSILE		2	4	4		4	4		4	4		4	4		4	4		4	4		48	DESIGN
Q + T/CARBURIZED BAR (GEAR)	HARDNESS PROFILE & CASE DEPTH		1										12									12	SCREEN
Q + T/BAR	THERMAL EXPANSION		1									RT TO -423: 1										1	SCREEN
Q + T/BAR	THERMAL CONDUCTIVITY		1									1										1	SCREEN
Q + T/BAR	FRACTURE TOUGHNESS		2	4	4		4	4		4	4		4	4								32	DESIGN

***FAST NEUTRON FLUENCE, ENERGY GREATER THAN 1 MEV.

TEST PLAN: M-33 LITHIUM HYDRIDE

DATE: 23 JULY 1970
REVISION: 1

COMPONENT: SHIELD

CONDITION/FORM	PROPERTY	RAD LEVEL TO PWR	HEATS	TEST TEMPERATURE, °F -100	RT	600	TOTAL SPECS	TEST MATRIX BASIS
COMPOSITE	DENSITY VS PROCESSING		3	6	6	6	18	SCREEN
COMPOSITE	SPECIFIC HEAT		1	2 MEASUREMENTS FROM -100 TO 600°F			2	(DESIGN)
COMPOSITE	THERMAL CONDUCTIVITY		1	2 MEASUREMENTS FROM -100 TO 600°F			2	(DESIGN)
COMPOSITE	COMPRESSIVE STRENGTH		2	8	8	8	24	DESIGN
COMPOSITE	FLEXURAL STRENGTH		2	8	8	8	24	DESIGN
COMPOSITE	GH_2 RATE GENERATION AT HIGH TEMP (600°F) (MEASUREMENT OF OUTGASSING OF GH_2 IN VACUUM)		1		TBD		2	SCREEN

( ) LOW VARIABILITY INDICATED BY EXPERIENCE AND/OR LITERATURE. TD 69-28 STATISTICAL RULES NOT REQUIRED.

TEST PLAN M-34 INSTRUMENTATION AND CONTROLS

DATE: 23 JULY 1970
REVISION: 1

SUBASSEMBLY	MATERIAL	PROPERTY	RAD LEVEL, 10 PWR	HEATS	TEST TEMPERATURE, °F -320	TOTAL SPECS	TEST MATRIX BASIS
THRUST CHAMBER PROBE	TUNGSTEN 25 Re	HIGH STRAIN RATE TENSILE TEST FOLLOWING THERMAL CYCLE FROM 4100°F TO -320°F		1	2	2	SCREEN
THRUST CHAMBER PROBE	TUNGSTEN 25 Re	LOW STRAIN RATE TENSILE TEST FOLLOWING THERMAL CYCLE FROM 4100°F TO -320°F		1	2	2	SCREEN
THRUST CHAMBER PROBE	TUNGSTEN 25 Re	HIGH STRAIN RATE TENSILE TEST PRIOR TO THERMAL CYCLE		1	2	2	SCREEN
THRUST CHAMBER PROBE	TUNGSTEN 25 Re	LOW STRAIN RATE TENSILE TEST PRIOR TO THERMAL CYCLE		1	2	2	SCREEN
WIRING HARNESS INSULATION	TBD	TBD	TBD	TBD	TBD	TBD	TBD
CONNECTORS	TBD	TBD	TBD	TBD	TBD	TBD	TBD
POTTING MATERIALS	TBD	TBD	TBD	TBD	TBD	TBD	TBD
TRANSDUCER PRESSURE	Be-Ni & 410	HIGH STRAIN RATE TENSILE TEST		1	4	4	SCREEN
TRANDUCER PRESSURE	Be-Ni & 410	LOW STRAIN RATE TENSILE TEST		1	4	4	SCREEN
TRANSDUCER PRESSURE	Be-Ni & 410	IMPACT TEST		1	4	4	SCREEN

TEST PLAN: M-35 THERMAL CONTROL COATINGS

COMPONENTS: SHIELD, PRESSURE VESSEL

DATE: 23 JULY 1970
REVISION: 1

SUBSTRATE/COATING	PROPERTY	RAD LEVEL*** 10 PWR	HEATS	TEST TEMPERATURE, °F RT	TOTAL SPECS	TEST MATRIX BASIS
347 SS/AL_2O_3 (PLASMA)	THERMAL CYCLING		1	2 (RT TO -320)	2	SCREEN
347SS/AL_2O_3 (PLASMA)	COATING ADHESION		1	4	4	SCREEN
347 SS/AL_2O_3 (PLASMA)	ABSORPTIVITY/α_S/ϵ IN-SPACE VAC EMISSIVITY RATIO		1	2	2	SCREEN
7039/AL_2O_3 (PLASMA)	THERMAL CYCLING		1	2 (RT TO -320)	2	SCREEN
7039/AL_2O_3 (PLASMA)	ADHESION		1	4	4	SCREEN
7039/AL_2O_3 (PLASMA)	ABSORPTIVITY/EMISSIVITY α_S/ϵ IN-SPACE VAC	19	1	4	4	SCREEN
7039/ZN93	THERMAL CYCLING		1	2 (RT TO -320)	2	SCREEN
7039/ZN93	ADHESION		1	4	4	SCREEN
7039/ZN93	ABSORPTIVITY/EMISSIVITY α_S/ϵ IN-SPACE VAC	19	1	4	4	SCREEN

***FAST NEUTRON FLUENCE, ENERGY GREATER THAN 1 MEV.

TEST PLAN: M-37 PHOS BRONZE

COMPONENT: VALVES

DATE: 23 JULY 1970
REVISION: 1

CONDITION/FORM	PROPERTY	RAD LEVEL*** 10 PWR	HEATS	TEST TEMPERATURE, °F / TEST DIRECTION												TOTAL SPECS	TEST MATRIX BASIS
				-423			-320			-100			RT				
				L	T	ST	L	T	ST	L	T	ST	L	T	ST		
ANN/B	TENSILE		2	4	4		4	4		4	4		4	4		32	DESIGN
ANN/B	IRRAD TENSILE	0,16,17,18	1	16												16	SCREEN
ANN/B	IRRAD TOUGHNESS	0,16,17,18	1	16												16	SCREEN
ANN/B	GH_2 EMBRITTLEMENT		1										6			6	SCREEN
ANN/B	FRACTURE TOUGHNESS		1	4	4		4	4								16	SCREEN
	THERMAL EXPANSION		1				1 MEAS. -423 TO RT									2	(DESIGN)
	THERMAL CONDUCTIVITY		1				1 MEAS. -423 TO RT									2	(DESIGN)
	DYNAMIC MODULUS		1											2		2	SCREEN

( ) LOW VARIABILITY INDICATED BY EXPERIENCE AND/OR LITERATURE. TD 69-28 STATISTICAL RULES NOT REQUIRED.

*** FAST NEUTRON FLUENCE, ENERGY GREATER THAN 1 MEV.

TEST PLAN: M-38 STAINLESS STEEL 22-13-5

COMPONENT: NOZZLE

DATE: 11 AUGUST 1970
REVISION: 1

CONDITION/FORM	PROPERTY	RAD LEVEL 10 PWR	HEATS	TEST TEMPERATURE, °F -423	-320	-100	RT	600	1200	TOTAL SPECS	TEST MATRIX BASIS
F	TENSILE		2		16	16	16	16	16	80	DESIGN
F	IRRAD TENSILE	0,17,18,19	1		12					12	SCREEN
FW	TENSILE		2		16	16	16	16	16	80	DESIGN
F	BRAZING TO 347 TUBES		1				12			12	SCREEN
F	GH_2 NOTCH TENSILE		1				12			12	SCREEN

TEST PLAN: M-39 BeCu

COMPONENTS: ACTUATORS, VALVES

DATE: 16 SEPTEMBER 1970
REVISION: 1

CONDITION/FORM	PROPERTY	RAD LEVEL 10 PWR	HEATS	TEST TEMPERATURE, °F / TEST DIRECTION: -423 L	-423 T	-320 L	-320 T	RT L	RT T	TOTAL SPECS	TEST MATRIX BASIS
STA/SHEET	TENSILE		2	3	3	3	3	3	3	36	DESIGN
STA/SHEET	ELASTIC MODULUS		1			-423 TO RT: 1				1	(DESIGN)
STA/SHEET	FLEXURAL FATIGUE		2					60		60	DESIGN

) LOW VARIABILITY INDICATED BY EXPERIENCE AND/OR LITERATURE. TD 69-28 STATISTICAL RULES NOT REQUIRED.