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

NERVA Program, Contract SNP-1

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Scientific Staff Department
Aerojet Nuclear Systems Company

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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 turbo-pump 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.
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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 an
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 $2 \times 10^{17}$ nvt and $6 \times 10^{18}$ nvt > 1 Mev exhibited a threshold of radiation damage of ductility and toughness at $1 \times 10^{17}$ nvt. This suggests that the radiation level anticipated above the internal shield is not expected to affect design criteria.

F. FIBROUS GRAPHITE

Evaluation of prep.ea 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 $K_t$ 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. Limitations 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-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:

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

where $\bar{X}$ 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 $\leq 4$, 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.

### TABLE 1

**347 STAINLESS STEEL THERMAL CONDUCTIVITY VERSUS TEMPERATURE**

<table>
<thead>
<tr>
<th>Temp °R</th>
<th>Regression Analysis*</th>
<th>National Bureau of Standards</th>
<th>3σ Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>K Btu-ft/hr ft² °R</td>
<td></td>
<td>Upper*</td>
</tr>
<tr>
<td>40</td>
<td>1.39</td>
<td>1.43</td>
<td>1.8</td>
</tr>
<tr>
<td>50</td>
<td>1.77</td>
<td>1.83</td>
<td>2.2</td>
</tr>
<tr>
<td>60</td>
<td>2.13</td>
<td>2.22</td>
<td>2.6</td>
</tr>
<tr>
<td>70</td>
<td>2.49</td>
<td>2.59</td>
<td>2.98</td>
</tr>
<tr>
<td>80</td>
<td>2.83</td>
<td>2.94</td>
<td>3.34</td>
</tr>
<tr>
<td>90</td>
<td>3.15</td>
<td>3.27</td>
<td>3.69</td>
</tr>
<tr>
<td>100</td>
<td>3.45</td>
<td>3.57</td>
<td>4.02</td>
</tr>
<tr>
<td>120</td>
<td>4.01</td>
<td>4.10</td>
<td>4.61</td>
</tr>
<tr>
<td>140</td>
<td>4.5</td>
<td>4.54</td>
<td>5.14</td>
</tr>
<tr>
<td>160</td>
<td>4.93</td>
<td>4.91</td>
<td>5.6</td>
</tr>
<tr>
<td>180</td>
<td>5.3</td>
<td>5.23</td>
<td>6.01</td>
</tr>
<tr>
<td>200</td>
<td>5.64</td>
<td>5.50</td>
<td>6.37</td>
</tr>
<tr>
<td>220</td>
<td>5.93</td>
<td>5.74</td>
<td>6.69</td>
</tr>
<tr>
<td>240</td>
<td>6.2</td>
<td>5.96</td>
<td>6.97</td>
</tr>
<tr>
<td>260</td>
<td>6.44</td>
<td>6.15</td>
<td>7.23</td>
</tr>
<tr>
<td>280</td>
<td>6.65</td>
<td>6.34</td>
<td>7.46</td>
</tr>
<tr>
<td>300</td>
<td>6.85</td>
<td>6.49</td>
<td>7.67</td>
</tr>
<tr>
<td>350</td>
<td>7.27</td>
<td>6.90</td>
<td>8.12</td>
</tr>
<tr>
<td>400</td>
<td>7.62</td>
<td>7.26</td>
<td>8.5</td>
</tr>
<tr>
<td>450</td>
<td>7.93</td>
<td>7.64</td>
<td>8.84</td>
</tr>
<tr>
<td>500</td>
<td>8.21</td>
<td>7.91</td>
<td>9.14</td>
</tr>
</tbody>
</table>

*Reported previously in ANSC Report S131-PR3.
<table>
<thead>
<tr>
<th>Material</th>
<th>Heat Number</th>
<th>Measurement Direction</th>
<th>E  (10^6 \text{ psi} )</th>
<th>G  (10^6 \text{ psi} )</th>
<th>( \mu )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inconel 718</td>
<td>86582</td>
<td>Radial</td>
<td>29.88</td>
<td>11.70</td>
<td>0.28</td>
</tr>
<tr>
<td>Inconel 718</td>
<td>86582</td>
<td>Radial</td>
<td>30.00</td>
<td>11.71</td>
<td>0.28</td>
</tr>
<tr>
<td>Inconel 718</td>
<td>86582</td>
<td>Tangential</td>
<td>29.45</td>
<td>11.41</td>
<td>0.29</td>
</tr>
<tr>
<td>Inconel 718</td>
<td>86582</td>
<td>Tangential</td>
<td>29.33</td>
<td>11.48</td>
<td>0.28</td>
</tr>
<tr>
<td>Ti 5Al-2.5Sn (ELI)</td>
<td>K-1029</td>
<td>Radial</td>
<td>18.16</td>
<td>6.98</td>
<td>0.30</td>
</tr>
<tr>
<td>Ti 5Al-2.5Sn (ELI)</td>
<td>K-1029</td>
<td>Radial</td>
<td>18.16</td>
<td>6.98</td>
<td>0.30</td>
</tr>
<tr>
<td>Ti 5Al-2.5Sn (ELI)</td>
<td>K-1029</td>
<td>Tangential</td>
<td>18.22</td>
<td>7.08</td>
<td>0.29</td>
</tr>
<tr>
<td>Ti 5Al-2.5Sn (ELI)</td>
<td>K-1029</td>
<td>Tangential</td>
<td>18.25</td>
<td>7.08</td>
<td>0.29</td>
</tr>
</tbody>
</table>
There was no significant anisotropy observed in $E$, $G$, or $\mu$ for either Inconel 718 or Ti 5Al-2.5Sn (ELI). The first measurements of $E$, $G$, and $\mu$ were made below room temperature on a specimen of Inconel 718 with the result that $E$ increased by $1.4 \times 10^6$ psi and $G$ increased by $0.7 \times 10^6$ psi as the temperature decreased from room temperature to $-220^\circ F$. 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 Zefft*. 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 GH₂ ON Ti 5Al-2.5Sn (ELI) AND ALLOY 718 FRACTURE PROPERTIES

<table>
<thead>
<tr>
<th>Test Condition</th>
<th>Alloy 718</th>
<th>Ti 5Al-2.5Sn (ELI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Qty</td>
<td>°F</td>
</tr>
<tr>
<td>Static Fracture (K₁c)</td>
<td>1</td>
<td>70</td>
</tr>
<tr>
<td>End Point Fracture</td>
<td>13</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>-320</td>
</tr>
<tr>
<td>Sustained Load (10 hr)</td>
<td>5</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>-100</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>-160</td>
</tr>
<tr>
<td>Load/Unload</td>
<td>1</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>-160</td>
</tr>
<tr>
<td>Combined Sustained/</td>
<td>2</td>
<td>70</td>
</tr>
<tr>
<td>Cyclic (Suslic)</td>
<td>2</td>
<td>-160</td>
</tr>
<tr>
<td>Cyclic</td>
<td>1</td>
<td>-160</td>
</tr>
</tbody>
</table>

1 Specimen marked 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 √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 √in.) greater than 100 and 103, respectively. The single, valid plane-strain fracture toughness value of 85 ksi √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 √in. No crack growth was observed at the 19.8 ksi √in. value while only 0.001 growth at
<table>
<thead>
<tr>
<th>Material</th>
<th>Test Temp °F</th>
<th>Test Environment</th>
<th>Specimen Thickness, In.</th>
<th>Specimen Width, In.</th>
<th>Average Crack Length, In.</th>
<th>P_Q Kips</th>
<th>P_Fail Kips</th>
<th>K_Q Ksi-In. 1/2</th>
</tr>
</thead>
<tbody>
<tr>
<td>718 (Bend)</td>
<td>70</td>
<td>Air</td>
<td>1.50</td>
<td>3.00</td>
<td>1.510</td>
<td>36.4</td>
<td>38.0</td>
<td>125.2*</td>
</tr>
<tr>
<td>718 PTC</td>
<td>70</td>
<td>Air</td>
<td>0.25</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>103.2**</td>
</tr>
<tr>
<td>718 PTC</td>
<td>70</td>
<td>GH₂</td>
<td>0.25</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>93.0***</td>
</tr>
<tr>
<td>718 PTC</td>
<td>70</td>
<td>GH₂</td>
<td>0.25</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>105.3***</td>
</tr>
<tr>
<td>718 PTC</td>
<td>70</td>
<td>GH₂</td>
<td>0.25</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>108.2***</td>
</tr>
<tr>
<td>718 PTC</td>
<td>-160</td>
<td>GH₂</td>
<td>0.25</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>103.2***</td>
</tr>
<tr>
<td>718 PTC</td>
<td>-320</td>
<td>LN₂</td>
<td>0.25</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>108.0***</td>
</tr>
<tr>
<td>Ti 5Al-2.5Sn (ELI) (Bend)</td>
<td>70</td>
<td>Air</td>
<td>1.52</td>
<td>3.00</td>
<td>1.542</td>
<td>23.5</td>
<td>26.7</td>
<td>82.3*</td>
</tr>
<tr>
<td>Ti PTC</td>
<td>70</td>
<td>Air</td>
<td>0.38</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>88.9**</td>
</tr>
<tr>
<td>Ti PTC</td>
<td>70</td>
<td>GH₂</td>
<td>0.38</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>84.9***</td>
</tr>
<tr>
<td>Ti PTC</td>
<td>70</td>
<td>GH₂</td>
<td>0.38</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>111.3***</td>
</tr>
<tr>
<td>Ti PTC</td>
<td>-160</td>
<td>GH₂</td>
<td>0.38</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>103.0***</td>
</tr>
<tr>
<td>Ti PTC</td>
<td>-320</td>
<td>LN₂</td>
<td>0.38</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>85.0</td>
</tr>
</tbody>
</table>

*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>
<thead>
<tr>
<th>Test Type</th>
<th>Test Temp °F</th>
<th>Environment</th>
<th>Initial Stress Intensity, $K_{II}$ ksi-in.(^{1/2})</th>
<th>Amount of Flaw Growth Δa in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sustained Load</td>
<td>70</td>
<td>1400 psi GH(_2)</td>
<td>52.5</td>
<td>0.010</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>35.0</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>68.9</td>
<td>0.090 (Failed in 1.15 hr)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>19.8</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>56.6</td>
<td>0.045</td>
</tr>
<tr>
<td>Sustained Load</td>
<td>-100</td>
<td>1400 psi GH(_2)</td>
<td>63.9</td>
<td>0.010</td>
</tr>
<tr>
<td>Sustained Load</td>
<td>-160</td>
<td>1400 psi GH(_2)</td>
<td>52.0</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>83.2</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>72.2</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>99.4</td>
<td>0.006</td>
</tr>
<tr>
<td>Load/Unload</td>
<td>70</td>
<td>air</td>
<td>82.7</td>
<td>0.001</td>
</tr>
<tr>
<td>Load/Unload</td>
<td>-160</td>
<td>Air/GN(_2)</td>
<td>98.0</td>
<td>0.005</td>
</tr>
</tbody>
</table>

*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)

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Temp °F</th>
<th>Environment</th>
<th>Initial Stress Intensity, $K_{II}$ Ksi-In.</th>
<th>Amount of Flaw Growth Δa In.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sustained Load</td>
<td>70</td>
<td>1400 psi GH₂</td>
<td>41.8</td>
<td>0.070</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>76.7</td>
<td>0.102 (failed in 6 Min)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>23.6</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>32.2</td>
<td>0.005</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>14.9</td>
<td>None</td>
</tr>
<tr>
<td>Sustained Load</td>
<td>-100</td>
<td>1400 psi GH₂</td>
<td>57.5</td>
<td>0.005</td>
</tr>
<tr>
<td>Sustained Load</td>
<td>-160</td>
<td>1400 psi GH₂</td>
<td>39.1</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>89.4</td>
<td>0.015</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>67.1</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>80.2</td>
<td>0.006</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>63.5</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>53.3</td>
<td>None</td>
</tr>
<tr>
<td>Load/Unload</td>
<td>70</td>
<td>Air</td>
<td>74.9</td>
<td>0.002</td>
</tr>
<tr>
<td>Load/Unload</td>
<td>-160</td>
<td>Air/GN₂</td>
<td>85.5</td>
<td>0.003</td>
</tr>
<tr>
<td>Load/Unload</td>
<td>-160</td>
<td>GH₂</td>
<td>102.5</td>
<td>0.005</td>
</tr>
</tbody>
</table>
the 35.0 ksi $\sqrt{\text{in.}}$ value was noted. Based upon a reported threshold value of 20 ksi $\sqrt{\text{in.}}$ 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 $\sqrt{\text{in.}}$) 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 especially true for the sustained tests at -160°F, where a maximum amount of growth of $\Delta a = 0.006$ 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 $\sqrt{\text{in.}}$ as opposed to 99.4 ksi $\sqrt{\text{in.}}$). 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 $\sqrt{\text{in.}}$. Because of the sharp transition in threshold between 70° and -160°F ($K_{TH} = 19.8$ ksi $\sqrt{\text{in.}}$ at 70°F compared with $K_{TH} > 99.4$ ksi $\sqrt{\text{in.}}$ 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 $\sqrt{\text{in}}$. Comparing this result with the results obtained at 70°F would indicate a threshold of about 30 ksi $\sqrt{\text{in}}$ 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 $\sqrt{\text{in}}$ 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 $\sqrt{\text{in}}$, 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 $\sqrt{\text{in.}}$ 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 $\sqrt{\text{in.}}$) 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 $\sqrt{\text{in.}}$ 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 Susic Load Profile
### TABLE 7

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

<table>
<thead>
<tr>
<th>Material</th>
<th>Test Temp °F</th>
<th>Initial Stress Intensity, ksi-in. (\frac{1}{\sqrt{2}})</th>
<th>Amount of Flaw Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alloy 718</td>
<td>70</td>
<td>52.3</td>
<td>0.135 Failed on 51st Cycle</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>40.1</td>
<td>0.004</td>
</tr>
<tr>
<td></td>
<td>-160</td>
<td>51.6</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>-160</td>
<td>83.2</td>
<td>0.001</td>
</tr>
<tr>
<td>Ti 5Al-2.5Sn (ELI)</td>
<td>70</td>
<td>41.3</td>
<td>0.080 x 0.080 (localized growth)</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>21.5</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>-160</td>
<td>41.1</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>-160</td>
<td>71.8</td>
<td>0.025</td>
</tr>
<tr>
<td></td>
<td>-160</td>
<td>52.7</td>
<td>0.002</td>
</tr>
</tbody>
</table>
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 an 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 subtracted 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.*

<table>
<thead>
<tr>
<th>Specimen Number</th>
<th>Thickness, t (in.)</th>
<th>Test Condition</th>
<th>Flaw Depth, a (in.)</th>
<th>Flaw Wrap, 2C (in.)</th>
<th>a/2C</th>
<th>Stress, σ (ksi)</th>
<th>o/σys</th>
<th>Shape Parameter, Q</th>
<th>Δa/Q Δr</th>
<th>Magnification Factor, μK</th>
<th>Stress Intensity Factor, K (ksi/√in.)</th>
<th>Δa/ΔN</th>
<th>Δa/ΔN Δt (h)</th>
<th>Δa/ΔN ΔS (in.)</th>
<th>(Δa/ΔN) Total Δa/ΔN ΔS (in.)</th>
<th>Cycles, ΔN</th>
<th>ΔN Cyclic</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-13</td>
<td>0.379</td>
<td>Initial</td>
<td>0.196</td>
<td>0.637</td>
<td>0.308</td>
<td>90.0</td>
<td>0.621</td>
<td>1.574</td>
<td>0.1245</td>
<td>0.518</td>
<td>1.162</td>
<td>72.0</td>
<td>0.0050</td>
<td>10.0</td>
<td>0.0002</td>
<td>0.0036</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Final</td>
<td>0.229</td>
<td>0.637</td>
<td>0.346</td>
<td>90.0</td>
<td>0.621</td>
<td>1.713</td>
<td>0.1283</td>
<td>0.581</td>
<td>1.218</td>
<td>76.5</td>
<td>0.0050</td>
<td>10.0</td>
<td>0.0002</td>
<td>0.0036</td>
<td>60</td>
</tr>
</tbody>
</table>

- \( c_{ys} @ -160^\circ F = 145 \text{ ksi} \)
- Includes \( \Delta a \) due to growth-on-loading on first cycle
- \( \Delta a / \Delta N = 48.6 \text{ micro-in.}/\text{cycle at 100 ksi}; \left( \frac{\Delta a}{\Delta N} \right)_\sigma = \left( \frac{\Delta a}{\Delta N} \right)_v = 100 \times \left( \frac{100}{\sigma} \right)^2 \)
f. Cyclic Test Results

A single Inconel 718 specimen was sinusoidally 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>
<thead>
<tr>
<th>Thickness, t (in.)</th>
<th>1-1/8</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Avg.)((\bar{h}))</td>
<td>0.252</td>
</tr>
<tr>
<td>(spec)</td>
<td>(\bar{h})</td>
</tr>
<tr>
<td>(Test)</td>
<td>0.252</td>
</tr>
<tr>
<td>(Spec)</td>
<td>0.252</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Material Properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\bar{h}) ((K_{I}))</td>
<td>41.8</td>
</tr>
<tr>
<td>(\bar{h}) ((K_{II}))</td>
<td>2.04</td>
</tr>
<tr>
<td>Stress Intensity, (K_I)</td>
<td>5800</td>
</tr>
<tr>
<td>Shape Parameter, (q)</td>
<td>0.0118</td>
</tr>
<tr>
<td>Flaw Size, (a)</td>
<td>0.099</td>
</tr>
<tr>
<td>Flaw Width, (b)</td>
<td>0.099</td>
</tr>
<tr>
<td>Flaw Depth, (d)</td>
<td>0.099</td>
</tr>
<tr>
<td>Stress, (\sigma)</td>
<td>0.099</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Condition</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flaw Depth, (d)</td>
<td>0.099</td>
</tr>
<tr>
<td>Flaw Width, (b)</td>
<td>0.099</td>
</tr>
<tr>
<td>Flaw Size, (a)</td>
<td>0.099</td>
</tr>
</tbody>
</table>

\(\sigma_{y_{\text{g}}} = 160^\circ \text{F} = 184\, \text{ksi}\)
(1) Static Fracture

<table>
<thead>
<tr>
<th>Material</th>
<th>$K_{IC}$ (ksi $\sqrt{\text{in.}}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>70°F</td>
</tr>
<tr>
<td>Alloy 718</td>
<td>&gt; 125.2</td>
</tr>
<tr>
<td>Ti 5Al-2.5Sn (ELI)</td>
<td>&gt; 100.0</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Material</th>
<th>$K_{TH}$ (ksi $\sqrt{\text{in.}}$) IN GH$_2$ AT 1400 PSI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>70°F</td>
</tr>
<tr>
<td>Alloy 718</td>
<td>19.8</td>
</tr>
<tr>
<td>Ti 5Al-2.5Sn (ELI)</td>
<td>21.5</td>
</tr>
</tbody>
</table>

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

 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 \(-160^\circ F\) but a very significant reduction in the threshold appears to occur somewhere between \(-100^\circ F\) and \(-160^\circ F\). 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 \(-160^\circ F\), safe operation could not be guaranteed. A proof test of the rotor at \(70^\circ F\) to about the yield strength of the material would probably assure safe operation under normal operating conditions at \(-160^\circ F\). Safe operation of the rotor at \(-160^\circ F\) 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 \(-160^\circ F\), safe operation under normal operating conditions can be guaranteed by a \(-160^\circ F\) 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 \(-160^\circ F\) could be designed. For this to be feasible, lower-bound growth rates would have to be obtained.
REFERENCES


E. RADIATION DAMAGE

1. GTR-2OC Materials Irradiation Test

The combined WANL-ANSC materials irradiation test GTR-2OC 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 $2 \times 10^{17}$ and $6 \times 10^{18}$ nvt $> 1$ Mev. All tensile and fracture-toughness specimens were irradiated while immersed in liquid nitrogen at $140^\circ$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 (EL1) 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 $5.2 \times 10^{18}$ 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*

<table>
<thead>
<tr>
<th>Fluence NVT, E &gt; 1 Mev</th>
<th>0.2% Yield Strength ksi</th>
<th>Ultimate Strength ksi</th>
<th>Elong (Chart) %</th>
<th>Area Reduction %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>Avg. 174.8 Std. 1.5</td>
<td>Avg. 185.7 Std. 2.1</td>
<td>Avg. 10.3 Std. 2.0</td>
<td>Avg. 30.0 Std. 3.2</td>
</tr>
<tr>
<td>2.3 x 10^{17}</td>
<td>183.2 1.8</td>
<td>189.5 1.1</td>
<td>8.8 0.8</td>
<td>30.4 2.6</td>
</tr>
<tr>
<td>8.2 x 10^{17}</td>
<td>188.0 1.5</td>
<td>195.5 1.7</td>
<td>7.4 1.0</td>
<td>29.5 5.0</td>
</tr>
<tr>
<td>4.9 x 10^{18}</td>
<td>199.1 3.3</td>
<td>204.4 3.1</td>
<td>3.9 0.4</td>
<td>25.4 3.4</td>
</tr>
<tr>
<td>5.2 x 10^{18}</td>
<td>192.8 1.9</td>
<td>200.0 1.0</td>
<td>6.0 0.4</td>
<td>27.0 1.5</td>
</tr>
</tbody>
</table>

Annealed at 540°R for 100 min between irradiation and testing

*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
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>
<thead>
<tr>
<th>Prepreg Panel</th>
<th>Designation/ Date</th>
<th>Postcure</th>
<th>Carbonization</th>
<th>Graphitization</th>
<th>Total Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fabricated (10 in. x 16 in.)</td>
<td>325 to 500°F</td>
<td>500°F to 1500°F</td>
<td>1500 to 2500°F</td>
<td>From Cured Condition</td>
</tr>
<tr>
<td></td>
<td>Panel Segments (5 in. x 16 in.)</td>
<td>Wt Shrinkage</td>
<td>Wt Loss</td>
<td>Density (1)</td>
<td>Wt Shrinkage</td>
</tr>
<tr>
<td></td>
<td>Thickness</td>
<td>Density (g/cm²)</td>
<td>Wt Shrinkage</td>
<td>Wt Loss</td>
<td>Density (1)</td>
</tr>
<tr>
<td>1. E2160/VCA</td>
<td>Control 1</td>
<td>0.350</td>
<td>1.349</td>
<td>-0.3</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>Control 2</td>
<td>0.355</td>
<td>1.354</td>
<td>-0.5</td>
<td>3.5</td>
</tr>
<tr>
<td>2. E2160/VCA</td>
<td>A-1</td>
<td>0.248</td>
<td>1.398</td>
<td>-0.4</td>
<td>3.26</td>
</tr>
<tr>
<td></td>
<td>A-2</td>
<td>0.267</td>
<td>1.407</td>
<td>Panel being held in reserve</td>
<td></td>
</tr>
<tr>
<td>3. E2160/VCA</td>
<td>B-1</td>
<td>0.252</td>
<td>1.402</td>
<td>-0.79</td>
<td>3.41</td>
</tr>
<tr>
<td></td>
<td>B-2</td>
<td>0.251</td>
<td>1.396</td>
<td>-1.59</td>
<td>3.43</td>
</tr>
<tr>
<td>4. E2160/VCA</td>
<td>C-1</td>
<td>0.240</td>
<td>1.397</td>
<td>0.0</td>
<td>2.90</td>
</tr>
<tr>
<td></td>
<td>C-2</td>
<td>0.238</td>
<td>1.414</td>
<td>Panel being held in reserve</td>
<td></td>
</tr>
<tr>
<td>5. G21008</td>
<td>B-1</td>
<td>0.218</td>
<td>1.383</td>
<td>-0.94</td>
<td>3.14</td>
</tr>
<tr>
<td></td>
<td>B-2</td>
<td>0.219</td>
<td>1.382</td>
<td>-0.63</td>
<td>3.12</td>
</tr>
<tr>
<td>6. G21008</td>
<td>C-1</td>
<td>0.212</td>
<td>1.216</td>
<td>Panel being held in reserve</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C-2</td>
<td>0.212</td>
<td>1.215</td>
<td>Panel being held in reserve</td>
<td></td>
</tr>
<tr>
<td>7. C21007</td>
<td>A-1</td>
<td>0.280</td>
<td>1.395</td>
<td>-0.71</td>
<td>3.97</td>
</tr>
<tr>
<td></td>
<td>A-2</td>
<td>0.280</td>
<td>1.393</td>
<td>-1.07</td>
<td>3.03</td>
</tr>
<tr>
<td>8. C21007</td>
<td>B-1</td>
<td>0.281</td>
<td>1.391</td>
<td>-1.62</td>
<td>3.99</td>
</tr>
<tr>
<td></td>
<td>B-2</td>
<td>0.282</td>
<td>1.345</td>
<td>Panel being held in reserve</td>
<td></td>
</tr>
<tr>
<td>9. C21007</td>
<td>C-1</td>
<td>0.280</td>
<td>1.417</td>
<td>-1.07</td>
<td>5.22</td>
</tr>
<tr>
<td></td>
<td>C-2</td>
<td>0.281</td>
<td>1.369</td>
<td>Panel being held in reserve</td>
<td></td>
</tr>
<tr>
<td>10. C21004</td>
<td>A-1</td>
<td>0.274</td>
<td>1.380</td>
<td>-2.92</td>
<td>11.85</td>
</tr>
<tr>
<td></td>
<td>A-2</td>
<td>0.270</td>
<td>1.398</td>
<td>-2.22</td>
<td>14.38</td>
</tr>
<tr>
<td>11. C21004</td>
<td>B-1</td>
<td>0.274</td>
<td>1.382</td>
<td>-3.27</td>
<td>21.24</td>
</tr>
<tr>
<td></td>
<td>B-2</td>
<td>0.273</td>
<td>1.386</td>
<td>-2.56</td>
<td>11.60</td>
</tr>
<tr>
<td>12. C21004</td>
<td>C-1</td>
<td>0.275</td>
<td>1.378</td>
<td>-3.27</td>
<td>11.82</td>
</tr>
<tr>
<td></td>
<td>C-2</td>
<td>0.271</td>
<td>1.390</td>
<td>Panel being held in reserve</td>
<td></td>
</tr>
<tr>
<td>13. M21268</td>
<td>C-1</td>
<td>0.243</td>
<td>1.376</td>
<td>-0.82</td>
<td>4.95</td>
</tr>
<tr>
<td></td>
<td>C-2</td>
<td>0.243</td>
<td>1.378</td>
<td>-0.82</td>
<td>4.94</td>
</tr>
<tr>
<td>14. M21268</td>
<td>B-1</td>
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1. + Increase in thickness.
2. - Decrease in thickness.
3. Initial thickness after 325°F cure.
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<th>Prepreg Panel Designation/ Date Fabricated/ Segments (10 in. x 15 in. x 14 in.)</th>
<th>Panel</th>
<th>Cure RT to 325°F</th>
<th>Postcure 325 to 500°F</th>
<th>Carbonization 500°F to 1500°F</th>
<th>Graphitization 1500 to 5000°F</th>
<th>Total Change From Cured Condition</th>
<th>Prepreg Panel Deaigrution/ Date Fabricated (5 in. x 15 in. x 14 in.)</th>
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<td>1.363</td>
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1. Increase in thickness.  
2. Decrease in thickness.  
3. Initial thickness after 325°F cure.
<table>
<thead>
<tr>
<th>Prepreg Panel Designation/ Date Fabricated</th>
<th>Panel Segments</th>
<th>Cure</th>
<th>Postcure</th>
<th>Carbocation</th>
<th>Graphitization</th>
<th>Total Change</th>
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<tr>
<td></td>
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<td></td>
<td></td>
<td>325°F to 500°F</td>
<td>500°F to 1500°F</td>
<td>1500°F to 5000°F</td>
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<td></td>
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<td>Shrinkage (1)</td>
<td>Loss (%)</td>
<td>Density (g/cm³)</td>
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<td>-0.77</td>
<td>6.39</td>
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<td>40. CA 8235 C-1</td>
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</tbody>
</table>

(1) + Increase in thickness.  
(2) 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>
<thead>
<tr>
<th>Material Ident</th>
<th>Carbonized (1550°F) E, 10^6 psi</th>
<th>Density g/cm³</th>
<th>Graphitized (5000°F) E, 10^6 psi</th>
<th>Density g/cm³</th>
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</thead>
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<td>1.17</td>
<td>1.35</td>
<td>1.19</td>
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<td>2. CA 8207</td>
<td>1.92</td>
<td>1.20</td>
<td>1.45</td>
<td>1.20</td>
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<td>3. CA 8204</td>
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<td>1.20</td>
<td>0.74</td>
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<tr>
<td>4. WCA/EC260</td>
<td>1.95</td>
<td>1.25</td>
<td>1.54</td>
<td>1.25</td>
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<tr>
<td>5. 4G3086</td>
<td>0.82*</td>
<td>1.20</td>
<td>1.40</td>
<td>1.19</td>
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<td>6. WCA/L-8</td>
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<td>1.24</td>
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<td>0.61</td>
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<td>8. CA 8235 (B-1)</td>
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<td>1.11</td>
<td>0.96</td>
<td>1.14</td>
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<td>9. CA 8235 (C-1)</td>
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<td>1.12</td>
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<td>10. FM 5228 (21436) B-1 A-2</td>
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<td>1.17</td>
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<td>1.17</td>
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<td>11. FM 5228 (Standard)</td>
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<td>1.17</td>
<td></td>
<td></td>
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</tbody>
</table>

*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**

<table>
<thead>
<tr>
<th>Material Identification</th>
<th>Specimen No.</th>
<th>Block Tensile Strength (psi)</th>
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</thead>
<tbody>
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</tr>
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<td><strong>Avg</strong></td>
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</table>

*(1)* Peel failure, value 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 277 to 301 psi for Grades CA8204 and CA8235.
### Table 14

**Ultimate Tensile Strength and Modulus of Elasticity of Carbonized and Graphitized Laminates**

(Testing in the Warp and Direction Fill)

<table>
<thead>
<tr>
<th>Material Identification</th>
<th>Specimen</th>
<th>Ultimate Tensile Strength (psi)</th>
<th>Tensile Modulus (psi x 10^-6)</th>
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<tbody>
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<td>A. After Carbonization</td>
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<td>1.58</td>
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<td>1.65</td>
</tr>
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<td>3</td>
<td>10,597</td>
<td>1.48</td>
</tr>
<tr>
<td>Avg</td>
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<td>10,209</td>
<td>1.57</td>
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(1) Tested in fill direction.
(2) Modulus of elasticity values are calculated per FTMS 406 from initial portion of stress/strain curve.
<table>
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<th>Material Identification</th>
<th>Specimen No.</th>
<th>Ultimate Tensile Strength (psi)</th>
<th>Tensile Modulus (psi x 10^-6)</th>
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**B. After Graphitization**

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<td>Tensile Modulus (psi x 10^-6)</td>
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<td>3-17-70</td>
<td>3</td>
<td>3,974</td>
<td>5.80</td>
<td>0.32</td>
</tr>
<tr>
<td>Avg</td>
<td></td>
<td>3,987(1)</td>
<td>5.86</td>
<td>0.34</td>
</tr>
</tbody>
</table>

(1) Tested in fill direction.
### TABLE 15
INTERLAMINAR SHEAR STRENGTH OF CARBONIZED AND GRAPHITIZED LAMINATES (1)

<table>
<thead>
<tr>
<th>Material Identification</th>
<th>Specimen No.</th>
<th>Shear Strength PSI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. After Carbonization (1550°F)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WCA/EC260</td>
<td>1</td>
<td>767</td>
</tr>
<tr>
<td>L-800138</td>
<td>2</td>
<td>800</td>
</tr>
<tr>
<td>B-2</td>
<td>3</td>
<td>797</td>
</tr>
<tr>
<td>4-1-70</td>
<td>Avg</td>
<td>787</td>
</tr>
<tr>
<td>CA8207</td>
<td>1</td>
<td>764</td>
</tr>
<tr>
<td>L800137</td>
<td>2</td>
<td>673</td>
</tr>
<tr>
<td>B-2</td>
<td>3</td>
<td>604</td>
</tr>
<tr>
<td></td>
<td>Avg</td>
<td>680</td>
</tr>
<tr>
<td>WCA/1.8</td>
<td>1</td>
<td>556</td>
</tr>
<tr>
<td>L800138</td>
<td>2</td>
<td>632</td>
</tr>
<tr>
<td>B-1</td>
<td>3</td>
<td>516</td>
</tr>
<tr>
<td>3-9-70</td>
<td>Avg</td>
<td>568</td>
</tr>
<tr>
<td>MXG248</td>
<td>1</td>
<td>558</td>
</tr>
<tr>
<td>L800136</td>
<td>2</td>
<td>403</td>
</tr>
<tr>
<td>C-4</td>
<td>3</td>
<td>628</td>
</tr>
<tr>
<td>4-17-70</td>
<td>Avg</td>
<td>530</td>
</tr>
<tr>
<td>FM5228</td>
<td>1</td>
<td>500</td>
</tr>
<tr>
<td>N900020</td>
<td>2</td>
<td>484</td>
</tr>
<tr>
<td>(21436)</td>
<td>3</td>
<td>508</td>
</tr>
<tr>
<td>5-16-7</td>
<td>Avg</td>
<td>497</td>
</tr>
<tr>
<td>4G3086</td>
<td>1</td>
<td>465</td>
</tr>
<tr>
<td>L800136</td>
<td>2</td>
<td>512</td>
</tr>
<tr>
<td>C-2</td>
<td>3</td>
<td>459</td>
</tr>
<tr>
<td>3-9-70</td>
<td>Avg</td>
<td>479</td>
</tr>
<tr>
<td>4G3008</td>
<td>1</td>
<td>486</td>
</tr>
<tr>
<td>L800138</td>
<td>2</td>
<td>476</td>
</tr>
<tr>
<td>C-1</td>
<td>3</td>
<td>467</td>
</tr>
<tr>
<td>3-12-70</td>
<td>Avg</td>
<td>476</td>
</tr>
<tr>
<td>CA8204</td>
<td>1</td>
<td>471</td>
</tr>
<tr>
<td>L800137</td>
<td>2</td>
<td>237</td>
</tr>
<tr>
<td>A-1</td>
<td>3</td>
<td>195</td>
</tr>
<tr>
<td>4-9-γ</td>
<td>Avg</td>
<td>301</td>
</tr>
</tbody>
</table>

(1) Test Conditions - (a) 0.05"/min load rate, Room Temp. (b) 0.250 overlap 1" wide specimen with support, (c) Drawing No. 1138105-1-notch 0.140 ± 0.005
### TABLE 15 (cont.)

<table>
<thead>
<tr>
<th>Material Identification</th>
<th>Specimen No.</th>
<th>Shear Strength (PSI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA8235</td>
<td>1</td>
<td>198</td>
</tr>
<tr>
<td>L800137</td>
<td>2</td>
<td>312</td>
</tr>
<tr>
<td>B-1</td>
<td>3</td>
<td>367</td>
</tr>
<tr>
<td>5-1-70</td>
<td>Avg</td>
<td>292</td>
</tr>
<tr>
<td>FM5228</td>
<td>1</td>
<td>150</td>
</tr>
<tr>
<td>N90020</td>
<td>2</td>
<td>556</td>
</tr>
<tr>
<td>C-1</td>
<td>3</td>
<td>Not meaningful</td>
</tr>
<tr>
<td>5-19-70</td>
<td>Avg</td>
<td></td>
</tr>
</tbody>
</table>

**B. After Graphitization (5000°F)**

<table>
<thead>
<tr>
<th>Material Identification</th>
<th>Specimen No.</th>
<th>Shear Strength (PSI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WCA/EC260</td>
<td>1</td>
<td>653</td>
</tr>
<tr>
<td>L800138</td>
<td>2</td>
<td>737</td>
</tr>
<tr>
<td>B-1</td>
<td>3</td>
<td>823</td>
</tr>
<tr>
<td>4-1-70</td>
<td>Avg</td>
<td>737</td>
</tr>
<tr>
<td>CA8207</td>
<td>1</td>
<td>592</td>
</tr>
<tr>
<td>L800137</td>
<td>2</td>
<td>731</td>
</tr>
<tr>
<td>A-1</td>
<td>3</td>
<td>678</td>
</tr>
<tr>
<td>4-6-70</td>
<td>Avg</td>
<td>667</td>
</tr>
<tr>
<td>WCA/L8</td>
<td>1</td>
<td>562</td>
</tr>
<tr>
<td>L800138</td>
<td>2</td>
<td>578</td>
</tr>
<tr>
<td>B-1</td>
<td>3</td>
<td>525</td>
</tr>
<tr>
<td>4-24-70</td>
<td>Avg</td>
<td>555</td>
</tr>
<tr>
<td>FM5228</td>
<td>1</td>
<td>484</td>
</tr>
<tr>
<td>N900020</td>
<td>2</td>
<td>500</td>
</tr>
<tr>
<td>(21436)</td>
<td>3</td>
<td>506</td>
</tr>
<tr>
<td>A-2</td>
<td>Avg</td>
<td>497</td>
</tr>
<tr>
<td>5-15-70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MKG248</td>
<td>1</td>
<td>480</td>
</tr>
<tr>
<td>L800136</td>
<td>2</td>
<td>423</td>
</tr>
<tr>
<td>B-2</td>
<td>3</td>
<td>512</td>
</tr>
<tr>
<td>4-17-70</td>
<td>Avg</td>
<td>473</td>
</tr>
<tr>
<td>4G3086</td>
<td>1</td>
<td>Specimen broken</td>
</tr>
<tr>
<td>L800138</td>
<td>2</td>
<td>456</td>
</tr>
<tr>
<td>A-1</td>
<td>3</td>
<td>455</td>
</tr>
<tr>
<td>4-24-70</td>
<td>Avg</td>
<td>456</td>
</tr>
</tbody>
</table>

(2) Specimen precracked prior to test.
<table>
<thead>
<tr>
<th>Material Identification</th>
<th>Specimen No.</th>
<th>Shear Strength - PSI</th>
</tr>
</thead>
<tbody>
<tr>
<td>4G3008</td>
<td>1</td>
<td>464</td>
</tr>
<tr>
<td>L800138</td>
<td>2</td>
<td>406</td>
</tr>
<tr>
<td>C-1</td>
<td>3</td>
<td>455</td>
</tr>
<tr>
<td>3-17-70</td>
<td>Avg</td>
<td>441</td>
</tr>
<tr>
<td>CA8235</td>
<td>1</td>
<td>311</td>
</tr>
<tr>
<td>L800137</td>
<td>2</td>
<td>201</td>
</tr>
<tr>
<td>B-1</td>
<td>3</td>
<td>321</td>
</tr>
<tr>
<td>4-29-70</td>
<td>Avg</td>
<td>278</td>
</tr>
<tr>
<td>CA8204</td>
<td>1</td>
<td>Specimen broken</td>
</tr>
<tr>
<td>L800137</td>
<td>2</td>
<td>Specimen broken</td>
</tr>
<tr>
<td>A-2</td>
<td>3</td>
<td>277</td>
</tr>
<tr>
<td>4-9-70</td>
<td>Avg</td>
<td></td>
</tr>
<tr>
<td>CA8235</td>
<td>1</td>
<td>All specimens</td>
</tr>
<tr>
<td>L800137</td>
<td>2</td>
<td>broken during</td>
</tr>
<tr>
<td>C-1</td>
<td>3</td>
<td>machining and/or</td>
</tr>
<tr>
<td>5-5-70</td>
<td></td>
<td>handling</td>
</tr>
</tbody>
</table>
(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. Impregnation Resins

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

<table>
<thead>
<tr>
<th>Material Identification</th>
<th>Specimen No.</th>
<th>Specific Gravity</th>
<th>Rockwell &quot;L&quot; Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Smooth (1)</td>
<td>Rough (2)</td>
</tr>
<tr>
<td>A. After Carbonization(1550°F)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WCA/EC260-B-2</td>
<td>1</td>
<td>1.235</td>
<td>82</td>
</tr>
<tr>
<td>Hexcel L800138</td>
<td>2</td>
<td>1.238</td>
<td>78</td>
</tr>
<tr>
<td>4-1-70</td>
<td>3</td>
<td>1.244</td>
<td>84</td>
</tr>
<tr>
<td>Avg</td>
<td></td>
<td>1.239</td>
<td>81</td>
</tr>
<tr>
<td>WCA/L8-B1</td>
<td>1</td>
<td>1.238</td>
<td>16</td>
</tr>
<tr>
<td>Hexcel L800138</td>
<td>2</td>
<td>1.253</td>
<td>11</td>
</tr>
<tr>
<td>3-9-70</td>
<td>3</td>
<td>1.245</td>
<td>11</td>
</tr>
<tr>
<td>Avg</td>
<td></td>
<td>1.245</td>
<td>13</td>
</tr>
<tr>
<td>4G3008-C1</td>
<td>1</td>
<td>1.212</td>
<td>46</td>
</tr>
<tr>
<td>Hexcel L800138</td>
<td>2</td>
<td>1.222</td>
<td>41</td>
</tr>
<tr>
<td>3-12-70</td>
<td>3</td>
<td>1.209</td>
<td>52</td>
</tr>
<tr>
<td>Avg</td>
<td></td>
<td>1.214</td>
<td>46</td>
</tr>
<tr>
<td>4G3086-C2</td>
<td>1</td>
<td>1.210</td>
<td>63</td>
</tr>
<tr>
<td>Hexcel L800138</td>
<td>2</td>
<td>1.207</td>
<td>50</td>
</tr>
<tr>
<td>3-9-70</td>
<td>3</td>
<td>1.211</td>
<td>51</td>
</tr>
<tr>
<td>Avg</td>
<td></td>
<td>1.209</td>
<td>55</td>
</tr>
<tr>
<td>CA8204-A1</td>
<td>1</td>
<td>1.073</td>
<td>8</td>
</tr>
<tr>
<td>Ferro L800137</td>
<td>2</td>
<td>1.161</td>
<td>17</td>
</tr>
<tr>
<td>4-9-70</td>
<td>3</td>
<td>1.080</td>
<td>5</td>
</tr>
<tr>
<td>Avg</td>
<td></td>
<td>1.105</td>
<td>10</td>
</tr>
<tr>
<td>CA8235-B1</td>
<td>1</td>
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<tr>
<td>Ferro L800137</td>
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<td>1.133</td>
<td>7</td>
</tr>
<tr>
<td>5-1-70</td>
<td>3</td>
<td>1.071</td>
<td>5</td>
</tr>
<tr>
<td>Avg</td>
<td></td>
<td>1.105</td>
<td>8</td>
</tr>
<tr>
<td>CA8207-B2</td>
<td>1</td>
<td>1.196</td>
<td>49</td>
</tr>
<tr>
<td>Ferro L800137</td>
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<td>1.182</td>
<td>40</td>
</tr>
<tr>
<td>4-6-70</td>
<td>3</td>
<td>1.199</td>
<td>45</td>
</tr>
<tr>
<td>Avg</td>
<td></td>
<td>1.192</td>
<td>45</td>
</tr>
<tr>
<td>FM5228-B1</td>
<td>1</td>
<td>1.160</td>
<td>19</td>
</tr>
<tr>
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<td>2</td>
<td>1.158</td>
<td>19</td>
</tr>
<tr>
<td>5-14-70</td>
<td>3</td>
<td>1.163</td>
<td>20</td>
</tr>
<tr>
<td>Avg</td>
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<td>1.160</td>
<td>19</td>
</tr>
</tbody>
</table>

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

(177x691)
<table>
<thead>
<tr>
<th>Material Identification</th>
<th>Specimen No.</th>
<th>Specific Gravity</th>
<th>Rockwell &quot;L&quot; Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Smooth (1)</td>
</tr>
<tr>
<td>FMS228-C1</td>
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</tr>
<tr>
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<td>1.162</td>
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</tr>
<tr>
<td>5-19-70</td>
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</tr>
<tr>
<td>Avg</td>
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<td>36</td>
</tr>
<tr>
<td>MXG248-C4</td>
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<td>1.159</td>
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</tr>
<tr>
<td>Fiberite L800136</td>
<td>2</td>
<td>1.173</td>
<td>40</td>
</tr>
<tr>
<td>4-17-70</td>
<td>3</td>
<td>1.165</td>
<td>29</td>
</tr>
<tr>
<td>Avg</td>
<td></td>
<td>1.166</td>
<td>32</td>
</tr>
<tr>
<td>B. After Graphitization (5000°F)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>4G3008-C1</td>
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</tr>
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<td>Hexcel L800138</td>
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<td>1.209</td>
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</tr>
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<td>3-17-70</td>
<td>3</td>
<td>1.213</td>
<td>5</td>
</tr>
<tr>
<td>Avg</td>
<td></td>
<td>1.209</td>
<td>6</td>
</tr>
<tr>
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<td>1.206</td>
<td>9</td>
</tr>
<tr>
<td>Hexcel L800138</td>
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<td>1.205</td>
<td>13</td>
</tr>
<tr>
<td>4-24-70</td>
<td>3</td>
<td>1.215</td>
<td>13</td>
</tr>
<tr>
<td>Avg</td>
<td></td>
<td>1.209</td>
<td>12</td>
</tr>
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<td>WCA/L8-B1</td>
<td>1</td>
<td>1.232</td>
<td>57</td>
</tr>
<tr>
<td>Hexcel L800138</td>
<td>2</td>
<td>1.229</td>
<td>59</td>
</tr>
<tr>
<td>4-24-70</td>
<td>3</td>
<td>1.230</td>
<td>58</td>
</tr>
<tr>
<td>Avg</td>
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<td>58</td>
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<tr>
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<td>1.284</td>
<td>9</td>
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<td>1.271</td>
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<td>4-1-70</td>
<td>3</td>
<td>1.279</td>
<td>14</td>
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<tr>
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<td>14</td>
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<td>1.202</td>
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<td>2</td>
<td>1.168</td>
<td>3</td>
</tr>
<tr>
<td>4-6-70</td>
<td>3</td>
<td>1.165</td>
<td>4</td>
</tr>
<tr>
<td>Avg</td>
<td></td>
<td>1.178</td>
<td>4</td>
</tr>
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<td>CA8204-A2</td>
<td>1</td>
<td>1.091</td>
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<tr>
<td>Ferro L800137</td>
<td>2</td>
<td>1.070</td>
<td>-6</td>
</tr>
<tr>
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<td>3</td>
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<td></td>
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</tr>
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<td>-13</td>
</tr>
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<td>Ferro L800137</td>
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<td>-5</td>
</tr>
<tr>
<td>4-29-70</td>
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<td>-5</td>
</tr>
<tr>
<td>Avg</td>
<td></td>
<td>1.105</td>
<td>-8</td>
</tr>
</tbody>
</table>

(1) Surface cured against mold.
(2) Surface cured against bag.
<table>
<thead>
<tr>
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(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 F-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
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</tbody>
</table>
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 (E111) Forgings 14-in. Diameter, 6-in. Thick, Carlton Forge Works
<table>
<thead>
<tr>
<th>Heat</th>
<th>RT</th>
<th>LN₂ (-320)</th>
<th>LN₂ (-423)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>UTS</td>
<td>TYS</td>
<td>% EL</td>
</tr>
<tr>
<td>Carlton Forge</td>
<td>117</td>
<td>109</td>
<td>18</td>
</tr>
<tr>
<td>14-in. dia x</td>
<td>117</td>
<td>110</td>
<td>19</td>
</tr>
<tr>
<td>6-in. High</td>
<td>114</td>
<td>106</td>
<td>17</td>
</tr>
<tr>
<td>Heat 293722</td>
<td>116(R)</td>
<td>106</td>
<td>14</td>
</tr>
<tr>
<td>117(R)</td>
<td>112</td>
<td>16</td>
<td>31</td>
</tr>
<tr>
<td>117(R)</td>
<td>108</td>
<td>16</td>
<td>31</td>
</tr>
<tr>
<td>Carlton Forge</td>
<td>121</td>
<td>113</td>
<td>15</td>
</tr>
<tr>
<td>14-in. dia x</td>
<td>118</td>
<td>112</td>
<td>18</td>
</tr>
<tr>
<td>6 in. High</td>
<td>121</td>
<td>114</td>
<td>14</td>
</tr>
<tr>
<td>Heat 294245</td>
<td>117(R)</td>
<td>108</td>
<td>14</td>
</tr>
<tr>
<td>117(R)</td>
<td>110</td>
<td>16</td>
<td>25</td>
</tr>
<tr>
<td>117(R)</td>
<td>110</td>
<td>12</td>
<td>25</td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th></th>
<th>RT Radial</th>
<th>RT Tangential</th>
<th>-320°F Tangential</th>
<th>-423°F Tangential</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_{tu}$ ksi</td>
<td>108</td>
<td>108</td>
<td>176</td>
<td>202</td>
</tr>
<tr>
<td>$F_{ty}$ ksi</td>
<td>98</td>
<td>98</td>
<td>163</td>
<td>179</td>
</tr>
<tr>
<td>% Elong</td>
<td>10.5</td>
<td>10.5</td>
<td>4.2</td>
<td>8.1</td>
</tr>
</tbody>
</table>
Results of fracture-toughness tests in liquid hydrogen are presented in Table 20. The data met the criteria contained in ASME 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 < 2:

\[
\bar{X}_{KIC} = 68.3 \text{ ksi-in.}^{1/2},
\]

\[
S_{KIC} = 3.2 \text{ ksi-in.}^{1/2};
\]

for \(N = 10\),

\[
K_{IC \ 99/95} = 55.7 \text{ ksi-in.}^{1/2},
\]

and \(\sigma_{nc} = 214,000 \text{ psi.}\)
<table>
<thead>
<tr>
<th>Forging Source</th>
<th>Spec No.</th>
<th>Predominant Flaw Growth Direction</th>
<th>Load Rate (ksi-in. 1/2/min)</th>
<th>a/W</th>
<th>K_Q (ksi-in. 1/2)</th>
<th>K_IC (ksi-in. 1/2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carlton Heat 294245</td>
<td>C1ATiR-1 -2</td>
<td>Tangential</td>
<td>44.6</td>
<td>Lost Curve - No Data</td>
<td>66.6</td>
<td>66.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tangential</td>
<td>41.4</td>
<td>0.507</td>
<td>66.3</td>
<td>66.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Radial</td>
<td>43.3</td>
<td>0.522</td>
<td>61.1</td>
<td>61.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tangential</td>
<td>70.8</td>
<td></td>
<td>70.8</td>
<td>70.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tangential</td>
<td>69.8</td>
<td></td>
<td>69.8</td>
<td>69.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Radial</td>
<td>69.8</td>
<td></td>
<td>69.8</td>
<td>69.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tangential</td>
<td>70.0</td>
<td></td>
<td>70.0</td>
<td>70.0</td>
</tr>
<tr>
<td>Carlton Heat 293722</td>
<td>C2ATiR-1 -2</td>
<td>Tangential</td>
<td>41.5</td>
<td>0.508</td>
<td>67.0</td>
<td>67.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tangential</td>
<td>41.2</td>
<td>0.505</td>
<td>82.7</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Radial</td>
<td>43.6</td>
<td>0.524</td>
<td>76.7</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tangential</td>
<td>41.3</td>
<td>0.506</td>
<td>71.6</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tangential</td>
<td>71.2</td>
<td></td>
<td>71.2</td>
<td>71.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tangential</td>
<td>90.6</td>
<td></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Radial</td>
<td>105.2</td>
<td></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tangential</td>
<td>70.0</td>
<td></td>
<td>70.0</td>
<td>70.0</td>
</tr>
</tbody>
</table>

\[ \bar{X} = 68.3 \]

\[ S = 3.2 \]

\[ \bar{X} - KS = 55.7 \]
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 $5 \times 10^8$ 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**

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

<table>
<thead>
<tr>
<th>Material</th>
<th>Location</th>
<th>Date in Exposure</th>
<th>Type</th>
<th>Stress (ksi)</th>
<th>Time to Fail (Days)</th>
<th>Failure Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>7039-T6</td>
<td>PV Forged Flange</td>
<td>10/16/68</td>
<td>Tensile</td>
<td>20</td>
<td>674</td>
<td>4/5</td>
</tr>
<tr>
<td>7039-T63</td>
<td>PV Forged Flange</td>
<td>10/16/68</td>
<td>Tensile</td>
<td>25</td>
<td>660</td>
<td>1/2</td>
</tr>
<tr>
<td>7039-T63 (Shot Peened)</td>
<td>PV Forged Flange</td>
<td>5/1/69</td>
<td>Tensile</td>
<td>45</td>
<td>361</td>
<td>2/5</td>
</tr>
<tr>
<td>7039-T63</td>
<td>PV Forged Flange</td>
<td>5/1/69</td>
<td>Tensile</td>
<td>20</td>
<td>399</td>
<td>1/3</td>
</tr>
<tr>
<td>7039-T63</td>
<td>Forged Wall</td>
<td>8/6/69</td>
<td>Tensile</td>
<td>20</td>
<td>364</td>
<td>2/5</td>
</tr>
<tr>
<td>7039-T63 (Metallized)</td>
<td>PV Forged Flange</td>
<td>8/6/69</td>
<td>Tensile</td>
<td>25</td>
<td>338</td>
<td>5/5</td>
</tr>
<tr>
<td>7039-T63 (Metallized and Painted)</td>
<td>PV Forged Flange</td>
<td>8/6/69</td>
<td>Tensile</td>
<td>45</td>
<td>370</td>
<td>2/5</td>
</tr>
</tbody>
</table>
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 1. 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 (Al₂O₃) 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. Al₂O₃ is a candidate coating for thermal control of the pressure vessel. Grit blasting is the preferred surface treatment of the basis metal for Al₂O₃ application.
## TABLE 23

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

<table>
<thead>
<tr>
<th>Condition</th>
<th>Stress, ksi</th>
<th>No. Specimens</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA 7039-T63</td>
<td>25</td>
<td>4</td>
</tr>
<tr>
<td>Uncoated, Heat AA</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>AA 7039-T63</td>
<td>25</td>
<td>5</td>
</tr>
<tr>
<td>Uncoated, Heat BB</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>AA 7039-T63</td>
<td>45</td>
<td>5</td>
</tr>
<tr>
<td>Plasma Sprayed</td>
<td>25</td>
<td>5</td>
</tr>
<tr>
<td>Al₂O₃ Surface, Heat AA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AA 7039-T63</td>
<td>45</td>
<td>5</td>
</tr>
<tr>
<td>Surface Coated with</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z-93, Heat AA</td>
<td>25</td>
<td>5</td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>Material and Condition</th>
<th>Stress ksi</th>
<th>Time to Failure Hours</th>
<th>Failure Ratio</th>
<th>Exposure Time for Unfailed Specimens, Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>7039-T63, Heat AA Bare</td>
<td>45</td>
<td>72, 72, 72, 72</td>
<td>4/4</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>196, 216, 336, 384</td>
<td>4/4</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>568, 952, 952, 1296, 1744</td>
<td>5/5</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>1288, 1936, 2356</td>
<td>3/5</td>
<td>2572</td>
</tr>
<tr>
<td>7039-T63, Heat AA, Grit Blasted with Al₂O₃, 80 lb Pressure</td>
<td>45</td>
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<td>3/5</td>
<td>1920</td>
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<td>NF</td>
<td>0/4</td>
<td>1328</td>
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*Indoor Atmosphere Exposures.
Figure 9 - Salt Cabinet Exposure of AA7039-T63, Heat AA, Specimens to 5% Salt Spray

• BARE
Figure 10 - Significance of Laboratory Stress-Corrosion Tests
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 $-320^\circ F$ was reported in ANSC Report SI31-PR2. The objective of further investigation was to determine effects of:

1. NERVA operating temperature regime.
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 ($-320^\circ F$, $-100^\circ F$, 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$\sqrt{\text{in.}}$ in the axial direction for the high-chemistry heat. The other directions were above 15 ksi$\sqrt{\text{in.}}$ 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√\text{in.} mean except for the short-transverse direction where values decreased to as low as 12 ksi√\text{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√\text{in.}). Longitudinal oriented specimens had values above 20 ksi√\text{in.}, except the 12/1 reduction which was lower (17 ksi√\text{in.}). Short transverse specimens were lowest with values as low as 15 ksi√\text{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√\text{in.} at a 3/1 reduction to 17 ksi√\text{in.} at 12/1 reduction. All values decreased as a result of low temperature exposure which was consistent with all 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√\text{in.} at room temperature and above 35 ksi√\text{in.} at -320°F, indicating a completely ductile material. No apparent benefit was realized from the increased forge reduction.

Critical-flaw-size calculations for sub-scale 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 driven 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 (KIC). 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 KIC to 0.6 KIC.*

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 $B < 2.5 \left( \frac{K_{IC}}{\sigma_{YS}} \right)^2$ 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 $\geq 0.5$ at $-320^\circ F$ and $>0.62$ at room temperature (as reported in ANSC Report S131-PR2) where it was determined that $K_{IC}^* < K_{IC}$ for $B < 2.5 \left( \frac{K_{IC}}{\sigma_{YS}} \right)^2$.

$K_{IC}$ 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

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Thickness (in)</th>
<th>Fatigue Crack Parameters</th>
<th>Deviation from ASTM</th>
<th>Load Rates</th>
<th>Stress Intensity</th>
<th>Yield Strength</th>
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<td></td>
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<td>Final (b)</td>
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<td>1/2</td>
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<td>0.005 (0.88)</td>
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<td>6.2</td>
<td>OK</td>
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</table>

**Notes:**

(a) The initial stress intensity factor \( K_{\text{initial}} \) to be less than 0.6 \( K_{\text{IC}} \) or 0.6 \( K_{\text{IC}} \).

(b) The final stress intensity factor \( K_{\text{final}} \) to be less than 12.5 kip-in. 1/2.

(c) The difference between the three crack measurements at 1/4, 1/2 and 3/4 in. 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 \( K_{\text{IC}} \) results.
<table>
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<th>Specimen</th>
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<th>Temp.</th>
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<th>K&lt;sub&gt;final&lt;/sub&gt;</th>
<th>Deviation from ASM</th>
<th>Recommended Practice</th>
<th>Load</th>
<th>Stress</th>
<th>Yield</th>
<th>2.5(K&lt;sub&gt;IC&lt;/sub&gt;/E&lt;sub&gt;u&lt;/sub&gt;)&lt;sup&gt;2&lt;/sup&gt;</th>
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<td>18.2(g)</td>
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(a) The initial stress intensity factor <i>K</i><sub>initial</sub> to be less than 0.6 <i>K</i><sub>c</sub> or 0.6 <i>K</i><sub>c</sub>.  
(b) The final stress intensity factor <i>K</i><sub>final</sub> to be less than 12 ksi-in. 1/2.  
(c) The difference between the three crack measurements at 1/4, 1/2 and 3/4 to be less than 0.05 in.  
(d) All parts of the fatigue crack front to be greater than 0.050 or 0.050 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 in.  
(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 <i>K</i><sub>IC</sub> 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√in.), followed by Heat AA (23.4 ksi√in.) and Heat CC (20.0 ksi√in.) at room temperature (see Figure 14). At -320°F, Heat AA had the highest mean value (16.8 ksi√in.), followed closely by Heat BB (16.5 ksi√in.), with Heat CC lower (10.9 ksi√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√in.) at 70°F. Other mean values at 70°F were much lower with Heat AA heat at 30.4 ksi√in. and Heat CC at 30 ksi√in. At -320°F, Heat BB also had the highest mean value (36 ksi), followed by Heat CC (30 ksi√in.), and Heat AA (25.8 ksi√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√in.), followed by both Heats AA and CC values (approximately 24 ksi√in.). At -320°F, Heat BB was also highest (25 ksi√in.), followed by Heat CC (19 ksi√in.), and Heat AA (17 ksi√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 $K_Q$. 

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(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√in.) being higher than the Heat AA mean value (35.8 ksi√in.). At -320°F, the mean values were degraded to 26.8 ksi√in. and 24 ksi√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√in.) being higher than the Heat AA (36.0 ksi√in.) mean value at room temperature. At -100°F, the mean values were degraded to 33.2 ksi√in. and 31.5 ksi√in., respectively. The -320°F results were reversed with Heat AA (25.0 ksi√in.) being higher than the Heat BB (22.5 ksi√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√in.) was higher than the Heat AA (33 ksi√in.) mean value. Heat BB mean values at -100° and -320°F were higher (30.8 and 32 ksi√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 $K_{IC}^*$. 

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<table>
<thead>
<tr>
<th>Fatigue Crack Length (a)</th>
<th>B</th>
<th>Critical Crack Length (Q)</th>
<th>Yield Strength (ksi)</th>
<th>Stress Intensity Factor (psi^0.5)</th>
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<td>6.0</td>
<td>0.000</td>
</tr>
<tr>
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<td>0.000</td>
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<td>0.508</td>
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Notes:
(a) The exact intensity factor for fatigue cracking to be less than 0.48 ksi, or 12.5 ksi-0.5/2, whichever is smaller.
(b) The difference between the lower and upper measurements at 1.0, 1.25, and 2 ksi, to be less than 0.005 in.
(c) All parts of the fatigue crack to be greater than 0.005 in., to be less than 0.9 in.
(d) Plane of the fatigue crack to be less than 0.9 in.
(e) Plane of the fatigue crack to be greater than 0.05 in.
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<th>Orientation Specimen No.</th>
<th>Test Temperature (°F)</th>
<th>Test Thickness (In.)</th>
<th>Fatigue Crack Parameters, kcal-in. 1/2 (a)</th>
<th>Deviation from ASTM Recommended Practices</th>
<th>Load Rates 1/8-in.</th>
<th>Stress Intensity Factor K (psi-in. 1/2)</th>
<th>Yield Strength (ksi)</th>
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</table>

Notes:
(a) The stress intensity factor for fatigue cracking to be less than 0.6 K, or 12.0 kcal-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 As.
(c) All parts of the fatigue cracks 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 9.9 As.
(e) Plane of the fatigue crack deviates from the pl. 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√in.) being higher than the Heat AA (21 ksi√in.) mean values. At -320°F, the mean values were both degraded to a common mean value of 12 ksi√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√in.) with lower values recorded at 6/1 (25.4 ksi√in.) and 12/1 reductions (25.0 ksi√in.). At -320°F, the values were degraded to values of 22, 20, and 17.4 psi√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√in.), followed by the 6/1 (34.0 ksi√in.) and 3/1 reductions (32 ksi√in.). At -320°F, degradation was evident to converge the values between 25 and 26 ksi√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 $K_{IC}$. 

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## Table 29
FRACTURE-TOUGHNESS RESULTS OF 7039-T63 ALUMINUM ALLOY HARD-STEP FORGING USING COMPACT TENSION SPECIMENS

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<thead>
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<th>Thickness (in)</th>
<th>Test Temp °F</th>
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<th>Deviation from ASTM E264-74 (Recommended Practice)</th>
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**Notes:**

(a) The initial stress intensity factor (K<sub>1</sub> initial) to be less than 0.6 Kc.
(b) The final stress intensity factor (K<sub>1</sub> final) to be less than 12.5 ksi-in. 1/2 for 70°F tests and 12.0 ksi-in. 1/2 for -30°F tests.
(c) The difference between the three crack measurements at 1/4, 1/2, and 3/4h to be less than 0.05 A0.
(d) All parts of the fatigue crack front to be greater than 0.050 or 0.05 A0 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 A0.
(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<sub>1</sub>.
(h) Even though the result was invalid, it was acceptable as K<sub>1</sub> 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**

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>B (in.)</th>
<th>Fatigue Crack Parameters</th>
<th>Fatigue Crack Length</th>
<th>Deviation From ASTM Recommended Practices</th>
<th>Load Rate ksf-in./min.</th>
<th>$K_q$ (ksi-in. 1/2)</th>
<th>$o_y$ (in.)</th>
<th>$2.5 (K_o / o_y)^2$</th>
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<td>OK OK</td>
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<td>0.526</td>
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<td>43.0</td>
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(a) The initial stress intensity factor ($K_{\text{initial}}$) to be less than $0.6 K_q$.
(b) The final stress intensity factor ($K_{\text{final}}$) to be less than $12.0 \text{ ksi-in.}^{1/2}$ or $0.6 K_q$, whichever is smaller.
(c) Difference between the three crack length measurements, at 1/4, 1/2, and 3/48 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 specimen tested before modifying fatigue crack starter notch.
(h) Designated as $K_{IC}$ values.
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<tr>
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<tr>
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<td>OK</td>
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<td>-0.047</td>
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<td>11.3</td>
<td>OK</td>
<td>-0.047</td>
<td>0.87</td>
<td>OK</td>
</tr>
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<td>11.6</td>
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<td>-0.045</td>
<td>0.87</td>
<td>OK</td>
</tr>
<tr>
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<td>10.1</td>
<td>+0.016</td>
<td>-0.044</td>
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</tr>
<tr>
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<td>11.5</td>
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<tr>
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<td>-0.012</td>
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</table>

(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-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 3/48, to be less than 0.05 A0.
(d) All points of fatigue crack are to be greater than 0.050 or 0.05 A0 in., whichever is greater, in front of machined notch root.
(e) Fatigue crack length at free surface to be greater than 0.9 A0.
(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 $\sqrt{\text{in.}}$, the 3/1 reduction was 26.6 ksi $\sqrt{\text{in.}}$. At 
$-320^\circ\text{F}$, all results increased to mean values of 38, 37, and 35.5 ksi $\sqrt{\text{in.}}$, respectively. The 3/1 and 12/1 reduction values at room temperature and the 
3/1 reduction at $-320^\circ\text{F}$ 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 $A_o$ (instead 
of 0.90 $A_o$ minimum); and (3) the $A/W$ ratio. An ASTM E-24 committee repre-
sentative was contacted to ascertain the validity of these results. It was 
the consensus 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 $A_o$ 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 $\sqrt{\text{in.}}$) 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 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:
where:

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

By substitution and simplification, Equation 1 becomes:

\[
\begin{align*}
a &= \frac{Q}{\pi} \left( \frac{K_{IC}}{1.1 \sigma_{ys}} \right)^2 \quad = 0.35 \left( \frac{K_{IC}}{1.1 \sigma_{ys}} \right)^2 \quad = 0.72 \left( \frac{K_{IC}}{1.1 \sigma_{ys}} \right). \\
\end{align*}
\]

(b) Internal Flaw

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

\[
\begin{align*}
K_1 = \sigma_g \sqrt{\frac{a}{Q}},
\end{align*}
\]

where:

\( K_1 = K_{IC} \) plane-strain critical stress intensity,
\( \sigma_g = \sigma_{ys} \) (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 \( \frac{\sigma_g}{\sigma_{ys}} = 1.0 \) and \( a/2C = 0.20 \),
\( Q = 2.25 \) for \( \frac{\sigma_g}{\sigma_{ys}} = 1.0 \) 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 \(-320^\circ F\), calculated critical flaw sizes at \(-320^\circ F\) 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

<table>
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<tr>
<th>Tests Conducted at 70°F</th>
<th>Chemistry</th>
<th>Orientation</th>
<th>Section</th>
<th>Average Critical Stress</th>
<th>Critical Flaw Size</th>
<th>Part-Through-Crack Internal Flow</th>
<th>Part-Through-Crack Internal Flow</th>
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<td></td>
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<td>Kc 56.9</td>
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<tr>
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<td>Kc 59.8</td>
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<td>Kc 57.2</td>
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<td>Flange</td>
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<td>Kc 62.0</td>
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<tr>
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<td>Kc 65.8</td>
<td>0.051</td>
<td>.26 .123 .31 .105 .21 .254 .25</td>
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</table>

(1) Designated as $K_{ic}$ 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 ($K_{ic}/a$)^2.

(3) Designated as $K_{ic}$ because the fatigue crack length was too short.
<table>
<thead>
<tr>
<th>Orientation</th>
<th>Chemistry</th>
<th>Section</th>
<th>Average Critical Stress $K_{IC}$ (1/2) ksi-in.</th>
<th>Yield Strength $\sigma_y$ ksi</th>
<th>Critical Flaw Size for $\alpha/2c = .20$</th>
<th>Critical Flaw Size for $\alpha/2c = .50$</th>
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<td></td>
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<td>Critical Stress $K_{IC}$ (1/2) ksi-in.</td>
<td></td>
<td>Part-Through-Crack Internal Flaw $a$ in.</td>
<td>Part-Through-Crack Internal Flaw $a$ in.</td>
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<td>.09</td>
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<td>.11</td>
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</table>

(1) Designated as $K_{IC}$ values 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 ($K_{IC}/\sigma_y^2$).
(3) Designated as $K_{IC}$ 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, it 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>
<thead>
<tr>
<th>Test Temp °F</th>
<th>28241-2 Direction of Rolling P*</th>
<th>42449 Direction of Rolling P</th>
<th>42656 Direction of Rolling P</th>
</tr>
</thead>
<tbody>
<tr>
<td>-320</td>
<td>50.8</td>
<td>52.7</td>
<td>59.9</td>
</tr>
<tr>
<td>-100</td>
<td>49.6</td>
<td>50.2</td>
<td>57.1</td>
</tr>
<tr>
<td>-52</td>
<td></td>
<td>42.5</td>
<td>48.9</td>
</tr>
<tr>
<td>75</td>
<td>36.6</td>
<td>44.3</td>
<td>50.5</td>
</tr>
<tr>
<td>800</td>
<td>27.8</td>
<td>36.9</td>
<td>41</td>
</tr>
<tr>
<td>1600</td>
<td>9.2</td>
<td>39.5</td>
<td>25.3</td>
</tr>
<tr>
<td>2000</td>
<td>2.0</td>
<td>24.3</td>
<td>9.1</td>
</tr>
</tbody>
</table>

*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>
<thead>
<tr>
<th>Test Temp</th>
<th>Condition</th>
<th>Number</th>
<th>Serial No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>-320°F</td>
<td>As received (mill annealed)</td>
<td>5 ea</td>
<td>C1-C5</td>
</tr>
<tr>
<td>Room</td>
<td></td>
<td>5 ea</td>
<td>C6-C10</td>
</tr>
<tr>
<td>600°F</td>
<td></td>
<td>5 ea</td>
<td>C11-C15</td>
</tr>
<tr>
<td>-320°F</td>
<td>As received + 2050°F anneal</td>
<td>5 ea</td>
<td>A16-A20</td>
</tr>
<tr>
<td>Room</td>
<td>+ retort cooling</td>
<td>5 ea</td>
<td>A21-A25</td>
</tr>
<tr>
<td>600°F</td>
<td></td>
<td>5 ea</td>
<td>A26-A30</td>
</tr>
<tr>
<td>-320°F</td>
<td>As received + 2050°F anneal</td>
<td>5 ea</td>
<td>D31-D35</td>
</tr>
<tr>
<td>Room</td>
<td>+ retort cooling + technology</td>
<td>5 ea</td>
<td>D36-D40</td>
</tr>
<tr>
<td>600°F</td>
<td>furnace braze cycles</td>
<td>5 ea</td>
<td>D41-D45</td>
</tr>
<tr>
<td>-320°F</td>
<td>As received + 2050°F anneal</td>
<td>5 ea</td>
<td>B46-B50</td>
</tr>
<tr>
<td>-100°F</td>
<td>+ retort cooling + NERVA</td>
<td>5 ea</td>
<td>B51-B55</td>
</tr>
<tr>
<td>Room</td>
<td>braze cycles</td>
<td>5 ea</td>
<td>B56-B60</td>
</tr>
<tr>
<td>600°F</td>
<td></td>
<td>5 ea</td>
<td>B61-B65</td>
</tr>
</tbody>
</table>
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°F, 1400°F, 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>
<thead>
<tr>
<th>Temp (°F)</th>
<th>Stress ksi</th>
<th>Heat ID</th>
<th>Time (hours) to Total Deformation</th>
<th>Rupture</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.5%</td>
<td>1.0%</td>
<td>3.0%</td>
</tr>
<tr>
<td>1200</td>
<td>27 A</td>
<td>On Loading</td>
<td>0.035</td>
<td>1.6</td>
<td>34.9</td>
</tr>
<tr>
<td>24</td>
<td>A 0.75</td>
<td>On Loading</td>
<td>2.2</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>B On Loading On Loading</td>
<td>53</td>
<td>-</td>
<td>Discontinued at 59.5 hr</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>C On Loading</td>
<td>0.13</td>
<td>55.1</td>
<td>-</td>
<td>Discontinued at 55.1 hr</td>
</tr>
<tr>
<td>20</td>
<td>A 2.9</td>
<td></td>
<td>26.5</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>A 12.5</td>
<td></td>
<td>46.5</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>A</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.407% in 115.2 hr</td>
</tr>
<tr>
<td>14</td>
<td>A</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.206% in 117.3 hr</td>
</tr>
<tr>
<td>1400</td>
<td>10 A</td>
<td></td>
<td>0.95</td>
<td>1.9</td>
<td>5.7</td>
</tr>
<tr>
<td>7</td>
<td>A 2.9</td>
<td></td>
<td>5.8</td>
<td>17.5</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>B 11.5</td>
<td></td>
<td>21.0</td>
<td>51.0</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>C 12.0</td>
<td></td>
<td>20.0</td>
<td>39.5</td>
<td>-</td>
</tr>
<tr>
<td>3.4</td>
<td>A 10.7</td>
<td></td>
<td>21.5</td>
<td>60.7</td>
<td>-</td>
</tr>
<tr>
<td>3.1</td>
<td>A 40.0</td>
<td></td>
<td>82.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2.5</td>
<td>A 23</td>
<td></td>
<td>50</td>
<td>-</td>
<td>- 0.982% in 114 hr</td>
</tr>
<tr>
<td></td>
<td>A 56</td>
<td></td>
<td>-</td>
<td>-</td>
<td>Discontinued at 114 hr</td>
</tr>
<tr>
<td>1600</td>
<td>3 A 0.67</td>
<td></td>
<td>1.4</td>
<td>5.6</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>B 1.2</td>
<td></td>
<td>2.6</td>
<td>10.5</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>C 0.85</td>
<td></td>
<td>3.0</td>
<td>9.0</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>A 2.0</td>
<td></td>
<td>3.9</td>
<td>12.1</td>
<td>-</td>
</tr>
<tr>
<td>1</td>
<td>A 6.6</td>
<td></td>
<td>11.7</td>
<td>32.0</td>
<td>-</td>
</tr>
<tr>
<td>1</td>
<td>C</td>
<td></td>
<td>-</td>
<td>-</td>
<td>Discontinued at hr</td>
</tr>
<tr>
<td>0.5</td>
<td>A 13.0</td>
<td></td>
<td>61.0</td>
<td>-</td>
<td>1.65% in 141 hr</td>
</tr>
<tr>
<td>0.5</td>
<td>A 28.5</td>
<td></td>
<td>48.5</td>
<td>-</td>
<td>2.5% in 117 hr</td>
</tr>
<tr>
<td>0.5</td>
<td>C 139.0</td>
<td></td>
<td>-</td>
<td>-</td>
<td>Discontinued at hr</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Specimen Ident</th>
<th>UTS ksi</th>
<th>YS ksi</th>
<th>EL in 2 in. %</th>
<th>Location of Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>177.0</td>
<td>161.2</td>
<td>10</td>
<td>HAZ</td>
</tr>
<tr>
<td>2</td>
<td>182.0</td>
<td>163.4</td>
<td>12</td>
<td>PM</td>
</tr>
<tr>
<td>3</td>
<td>176.1</td>
<td>157.1</td>
<td>9</td>
<td>HAZ</td>
</tr>
</tbody>
</table>

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 a 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 \( (S = 3190 \sqrt{F/D}) \) 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.

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*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 $\text{Al}_2\text{O}_3$ 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.

$\text{Al}_2\text{O}_3$ 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 $\text{Al}_2\text{O}_3$ 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 $\text{Al}_2\text{O}_3$ 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 $\text{Al}_2\text{O}_3$ 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 $\text{Al}_2\text{O}_3$. The specimens are currently being evaluated in salt-spray environments.

*Results to date from salt-spray exposure were reported in Section H.
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°F. 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.
APPENDIX A

MATERIALS DATA RELEASE MEMORANDA
APPENDIX A

MATERIALS DATA RELEASE MEMORANDA
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**Form Identification**

- A - Sheet
- B - Forging
- C - Plate
- D - Bar
- E - Tube
- F - Weld and Heat Treat
- G - As Welded
- H - Composite
- I - Triple Brazed
- J - Coatings
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**FORM IDENTIFICATION**

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

ANSC MATERIAL AND PROCESSES STAFF  
(Released During Third Quarter)
## ANS C MATERIAL AND PROCESSES STAFF
(Released During Third Quarter)

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### FORM IDENTIFICATION

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

- H - Composite
- J - Coatings
- K - Triple Brazed

**NOTE:** See DRM's for specific data.

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**Form Identification**

- A - Sheet
- B - Forging
- C - Plate
- D - Bar
- E - Tube
- F - Weld and Heat Treat
- G - As Welded
- H - Composite
- I - Triple Brazed
- J - Coatings
- K - Coatings
- L - Coatings
### ANSC MATERIAL AND PROCESSES STAFF
(Released During Fourth Quarter)

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<td>L, ST, T</td>
<td>TYS, TUS, Elong</td>
<td>-423, -320, R.T., 300F</td>
<td>B</td>
<td>M-7B 2</td>
<td>9-10-70</td>
</tr>
</tbody>
</table>

**Form Identification**

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

\[ \frac{W}{17.14} \sqrt{\frac{T}{N}} = \text{rate of evaporation or sublimation} \]

\[ \frac{W \cdot \text{gm}}{\text{cm}^2 \cdot \text{sec}} \]

\[ I \text{ torr} = \text{vapor pressure of the material} \]

\[ M \frac{\text{gm}}{\text{mol}} = \text{molecular weight in gas phase} \]

\[ T \text{ °K} = \text{temperature} \]

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.
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°K) has been specified by NASA 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.
### TABLE 1

**TEMPERATURE AT WHICH SOME COMMON STRUCTURAL MATERIALS WILL LOSE 0.040 IN./YR IN ULTRA-HIGH SPACE VACUUM**

(2 x 10^-14 torr or lower)

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>°F</th>
<th>°R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cd</td>
<td>248</td>
<td>708</td>
</tr>
<tr>
<td>Zn</td>
<td>324</td>
<td>784</td>
</tr>
<tr>
<td>Mg</td>
<td>464</td>
<td>924</td>
</tr>
<tr>
<td>Sn</td>
<td>1472</td>
<td>1932</td>
</tr>
<tr>
<td>Al</td>
<td>1490</td>
<td>1950</td>
</tr>
<tr>
<td>Be</td>
<td>1544</td>
<td>2004</td>
</tr>
<tr>
<td>Fe</td>
<td>1922</td>
<td>2382</td>
</tr>
<tr>
<td>Ti</td>
<td>2282</td>
<td>2742</td>
</tr>
</tbody>
</table>

**TEMPERATURE AT WHICH SOME COMMON STRUCTURAL MATERIALS WILL LOSE 0.010 IN./YR IN ULTRA-HIGH SPACE VACUUM**

(2 x 10^-14 torr or lower)

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>°F</th>
<th>°R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cd</td>
<td>207</td>
<td>667</td>
</tr>
<tr>
<td>Zn</td>
<td>291</td>
<td>751</td>
</tr>
<tr>
<td>Mg</td>
<td>397</td>
<td>857</td>
</tr>
<tr>
<td>Al</td>
<td>1341</td>
<td>1801</td>
</tr>
<tr>
<td>Be</td>
<td>1540</td>
<td>2000</td>
</tr>
</tbody>
</table>

### Vapor Pressure of Metals

<table>
<thead>
<tr>
<th>TEMP °R</th>
<th>°K</th>
<th>Zn</th>
<th>Cd</th>
<th>Hg</th>
<th>Mg</th>
<th>As</th>
<th>As$_2$</th>
<th>As$_4$</th>
<th>VAPOR PRESSURE (TORR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>585</td>
<td>325</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.31 x 10$^{-7}$</td>
</tr>
<tr>
<td>675</td>
<td>375</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.98 x 10$^{-7}$</td>
</tr>
<tr>
<td>720</td>
<td>400</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.8 x 10$^{-12}$</td>
</tr>
<tr>
<td>810</td>
<td>450</td>
<td>8.13 x 10$^{-7}$</td>
<td>6.32 x 10$^{-9}$</td>
<td>6.1 x 10$^{-24}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>855</td>
<td>475</td>
<td>4.90 x 10$^{-6}$</td>
<td>3.68 x 10$^{-4}$</td>
<td></td>
<td>20.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>900</td>
<td>500</td>
<td>1.98 x 10$^{-7}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Vapor Pressure (TORR)

<table>
<thead>
<tr>
<th>TEMP °R</th>
<th>°K</th>
<th>Se$_2$</th>
<th>Se$_4$</th>
<th>ΣSe</th>
<th>Te$_2$</th>
<th>ΣTe</th>
</tr>
</thead>
<tbody>
<tr>
<td>720</td>
<td>400</td>
<td>3.53 x 10$^{-7}$</td>
<td>1.42 x 10$^{-6}$</td>
<td>1.77 x 10$^{-1}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>810</td>
<td>450</td>
<td>3.41 x 10$^{-5}$</td>
<td>1.81 x 10$^{-4}$</td>
<td>2.15 x 10$^{-4}$</td>
<td>1.64 x 10$^{-8}$</td>
<td>1.64 x 10$^{-8}$</td>
</tr>
<tr>
<td>900</td>
<td>500</td>
<td>1.65 x 10$^{-6}$</td>
<td>1.65 x 10$^{-6}$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**AERONET NUCLEAR SYSTEMS COMPANY**

**MATERIALS AND PROCESSES SECTION**

**DATA RELEASE**

<table>
<thead>
<tr>
<th>DRM NO.</th>
<th>PAGE NO.</th>
<th>DATE</th>
<th>MATERIAL Several with Vapor Pressures $10^{-7}$ torr or lower</th>
</tr>
</thead>
<tbody>
<tr>
<td>M-26</td>
<td>5</td>
<td>5-21-70</td>
<td></td>
</tr>
</tbody>
</table>

**CONDITION**

**TEST DIRECTION**

**SPEC. NOS.**

**FORM**

**DATA BASIS**

**COMMENT**

**PROPERTY** Vapor Pressure of Metals

### Vapor Pressure (torr)

<table>
<thead>
<tr>
<th>Temp °C</th>
<th>Na</th>
<th>Na₂</th>
<th>K</th>
<th>K₂</th>
<th>P₄ (White)</th>
<th>P₄ (Red)</th>
</tr>
</thead>
<tbody>
<tr>
<td>583</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.9 x 10⁻⁷</td>
<td></td>
</tr>
<tr>
<td>675</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.63</td>
<td>2.46 x 10⁻⁷</td>
</tr>
<tr>
<td>855</td>
<td></td>
<td>1.54 x 10⁻⁷</td>
<td>4.695 x 10⁻⁷</td>
<td>6.840 x 10⁻³</td>
<td>6.03 x 10⁻⁶</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Temp °C</th>
<th>S₂</th>
<th>S₄</th>
<th>S₆</th>
<th>S₈</th>
</tr>
</thead>
<tbody>
<tr>
<td>810</td>
<td>1.59 x 10⁻⁴</td>
<td>7.23 x 10⁻⁵</td>
<td>1.96 x 10⁻¹</td>
<td>5.8 x 10⁻¹</td>
</tr>
</tbody>
</table>

## Vapor Pressure of Metals

<table>
<thead>
<tr>
<th>Element</th>
<th>Vapor Pressure Torr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rb</td>
<td>$1.24 \times 10^{-7}$</td>
</tr>
<tr>
<td>Rb$_2$</td>
<td>$1.068 \times 10^{-7}$</td>
</tr>
<tr>
<td>Cs</td>
<td>$1.56 \times 10^{-7}$</td>
</tr>
<tr>
<td>Cs$_2$</td>
<td>$4.767 \times 10^{-7}$</td>
</tr>
<tr>
<td>Fr</td>
<td></td>
</tr>
<tr>
<td>Po</td>
<td></td>
</tr>
<tr>
<td>Po$_2$</td>
<td></td>
</tr>
</tbody>
</table>

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.
### TABLE 5.8.05.01

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

(a) Table 5.8.05.01, Specific Heat of Manufactured Graphite, *The Industrial Graphite Engineering Handbook*, Union Carbide Corp., April 1964.

**Thermal Conductivity**

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>BTU/HR/FT/°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>-459.7</td>
<td>0</td>
</tr>
<tr>
<td>-441.7</td>
<td>0.226</td>
</tr>
<tr>
<td>-423.7</td>
<td>1.2</td>
</tr>
<tr>
<td>-405.7</td>
<td>2.8</td>
</tr>
<tr>
<td>-369.7</td>
<td>7.9</td>
</tr>
<tr>
<td>-351.7</td>
<td>11.5</td>
</tr>
<tr>
<td>-333.7</td>
<td>14.8</td>
</tr>
<tr>
<td>-315.7</td>
<td>19.0</td>
</tr>
<tr>
<td>-297.7</td>
<td>22.6</td>
</tr>
<tr>
<td>-189.7</td>
<td>43.4</td>
</tr>
<tr>
<td>-99.7</td>
<td>55.4</td>
</tr>
<tr>
<td>-9.7</td>
<td>60.6</td>
</tr>
<tr>
<td>32</td>
<td>61.0</td>
</tr>
<tr>
<td>170.3</td>
<td>57.8</td>
</tr>
<tr>
<td>260.3</td>
<td>55.0</td>
</tr>
<tr>
<td>440.3</td>
<td>49.4</td>
</tr>
<tr>
<td>620.3</td>
<td>44.4</td>
</tr>
<tr>
<td>800.3</td>
<td>40.2</td>
</tr>
<tr>
<td>980.3</td>
<td>36.5</td>
</tr>
</tbody>
</table>

**COMMENT**
- Density .061 lb/in.³ minimum

**REFERENCE**
- Touloukian, Y. S., Thermophysical Properties Research Center Data Book
**DATA RELEASE**

**MATERIAL** 3% Boron-Graphite

**CONDITION** Parallel to molding pressure

**TEST DIRECTION** across grain

**SPEC. NOS.**

**FORM** Molded

**DATA BASIS** Category "D"

**COMMENT** Density 1.70 gm/cc minimum

**PROPERTY** Thermal Conductivity

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>BTU/HR/ FT/°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>99.7</td>
<td>39.8</td>
</tr>
<tr>
<td>9.7</td>
<td>44.8</td>
</tr>
<tr>
<td>32</td>
<td>45.3</td>
</tr>
<tr>
<td>80.3</td>
<td>45.3</td>
</tr>
<tr>
<td>170.3</td>
<td>43.9</td>
</tr>
<tr>
<td>260.3</td>
<td>42.1</td>
</tr>
<tr>
<td>440.3</td>
<td>37.9</td>
</tr>
<tr>
<td>620.3</td>
<td>34.2</td>
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<tr>
<td>800.3</td>
<td>31.0</td>
</tr>
<tr>
<td>980.3</td>
<td>28.2</td>
</tr>
</tbody>
</table>

**CONTACT:**
**DATA RELEASE**

**DATA BASIS** Category "D"

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>LBS/IN.³</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>0.061</td>
</tr>
</tbody>
</table>

**COMMENT**: Calculated value based on ATJ process schedule.
DATA RELEASE MEMORANDUM

NRO MATERIALS AND PROCESSES STAFF

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

DRM TYPE:

DRM NO.

REV. NO.

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 DATE AUTHORIZED CLASSIFIER DATE

6-5-70 PLETHUM 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 category "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.
<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>C. BTU/LB/°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>-424</td>
<td>0.0197</td>
</tr>
<tr>
<td>-370</td>
<td>0.0362</td>
</tr>
<tr>
<td>-280</td>
<td>0.1137</td>
</tr>
<tr>
<td>-100</td>
<td>0.1904</td>
</tr>
<tr>
<td>80</td>
<td>0.2141</td>
</tr>
<tr>
<td>260</td>
<td>0.2250</td>
</tr>
<tr>
<td>440</td>
<td>0.2350</td>
</tr>
</tbody>
</table>

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.
## Thermal Conductivity

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>THERMAL CONDUCTIVITY BTU/HR-FT-°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>-449</td>
<td>4.97</td>
</tr>
<tr>
<td>-442</td>
<td>8.38</td>
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<tr>
<td>-424</td>
<td>16.87</td>
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<tr>
<td>-406</td>
<td>24.91</td>
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<td>-388</td>
<td>31.96</td>
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<td>37.79</td>
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<td>-352</td>
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<td>55.02</td>
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</tr>
<tr>
<td>-28</td>
<td>83.22</td>
</tr>
<tr>
<td>44</td>
<td>88.90</td>
</tr>
</tbody>
</table>

Max. Variability Estimated to be +5% Down to -300°F and +15% Below

**COMMENT:**


<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>BTU/HR/ FT/°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>-100</td>
<td>73</td>
</tr>
<tr>
<td>70</td>
<td>86</td>
</tr>
<tr>
<td>200</td>
<td>93</td>
</tr>
<tr>
<td>300</td>
<td>96</td>
</tr>
</tbody>
</table>

**PROPERTY** Thermal Conductivity

**DATA BASIS** Category "B"

**COMMENT** Maximum Variability Estimated to be ± 5%.

### Condition

**Condition:** 0  

**Test Direction:** All

### Specific Numbers

- **Specific Numbers:** 

### Data Basis

- **Category:** "B"  

### Comment

- **Comment:** Maximum Variability Estimated to be ± 5%

### Property

- **Property:** Coefficient of Linear Thermal Expansion

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>IN./IN. X 10^-6</th>
</tr>
</thead>
<tbody>
<tr>
<td>-424</td>
<td>8.5</td>
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<td>-351</td>
<td>9.75</td>
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<td>-297</td>
<td>10.48</td>
</tr>
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<td>-99</td>
<td>12.13</td>
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<tr>
<td>-8</td>
<td>12.79</td>
</tr>
<tr>
<td>212</td>
<td>13.0</td>
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**AEROCJET-GENERAL NUCLEAR ROCKET OPERATIONS**

**MATERIALS AND PROCESSES SECTION**

**DATA RELEASE**

<table>
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<th>DRM NO.</th>
<th>M-3</th>
<th>PAGE NO.</th>
<th>7</th>
<th>DATE</th>
<th>6-10-70</th>
<th>MATERIAL</th>
<th>7039</th>
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<table>
<thead>
<tr>
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<th>All</th>
<th>TEST DIRECTION</th>
<th>All</th>
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<tr>
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<th>No Category Required</th>
<th>COMMENT</th>
<th>Maximum Variability Estimated to be +/- 10%</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>Density</th>
</tr>
</thead>
</table>

| TEMP °F | DENSITY \((\rho)\) LBS/IN\(^3\) | TEMP °F | DENSITY \((\rho)\) 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.
AEROSPACE GENERAL NUCLEAR ROCKET OPERATIONS  
MATERIALS AND PROCESSES SECTION  
DATA RELEASE

<table>
<thead>
<tr>
<th>CONDITION</th>
<th>TEST DIRECTION</th>
<th>SPEC. NOS.</th>
<th>FORM</th>
<th>DATA BASIS</th>
<th>PROPERTY</th>
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<tbody>
<tr>
<td>T63</td>
<td>All</td>
<td></td>
<td>Forging</td>
<td>Category &quot;D&quot;</td>
<td>Solar Absorptance (αₚ)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>MIN.</th>
<th>MAX.</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>.18</td>
<td>.44</td>
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**AEROGET-GENERAL NUCLEAR ROCKET OPERATIONS**

**MATERIALS AND PROCESSES SECTION**

**DATA RELEASE**

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<th>PAGE NO.</th>
<th>DATE</th>
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<tbody>
<tr>
<td>M-3</td>
<td>9</td>
<td>6-10-70</td>
<td>7039</td>
</tr>
</tbody>
</table>

**CONDITION** T-63 **TEST DIRECTION** All

**SPEC. NOS.** Forging

**DATA BASIS** Category "D"

**PROPERTY** Total Hemispherical Emittance

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>MIN.</th>
<th>MAX.</th>
</tr>
</thead>
<tbody>
<tr>
<td>-60</td>
<td>.03</td>
<td>.11</td>
</tr>
<tr>
<td>40</td>
<td>.03</td>
<td>.12</td>
</tr>
<tr>
<td>140</td>
<td>.04</td>
<td>.12</td>
</tr>
</tbody>
</table>

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:


**AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS**

**MATERIALS AND PROCESSES SECTION**

**DATA RELEASE**

<table>
<thead>
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<th>PAGE NO.</th>
<th>DATE</th>
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<tbody>
<tr>
<td>M-29</td>
<td>2</td>
<td>6-11-70</td>
<td>SS 310</td>
</tr>
</tbody>
</table>

**CONDITION** Annealed  
**TEST DIRECTION**

**SPEC. NOS.** FORM 0.750-in. diameter bar

**DATA BASIS** Category "C"  
**COMMENT**

**PROPERTY** Tensile Ultimate Strength

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>LOTS/ HEATS</th>
<th>N</th>
<th>df</th>
<th>( \bar{X} )</th>
<th>K</th>
<th>S</th>
<th>COMPUTED VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT</td>
<td>2</td>
<td>6</td>
<td>8</td>
<td>85</td>
<td></td>
<td></td>
<td>68.7</td>
</tr>
<tr>
<td>-320</td>
<td>1</td>
<td>3</td>
<td>8</td>
<td>156</td>
<td>4.143</td>
<td>3.9</td>
<td>140.0</td>
</tr>
<tr>
<td>-423</td>
<td>1</td>
<td>4</td>
<td>8</td>
<td>182</td>
<td>4.143</td>
<td>5.0</td>
<td>161</td>
</tr>
</tbody>
</table>

**REFERENCES:** (1) and (2)

---

*COMMENT:* References (1) and (2).
## AEROSPACE NUCLEAR ROCKET OPERATIONS

### MATERIALS AND PROCESSES SECTION

#### DATA RELEASE

<table>
<thead>
<tr>
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<th>PAGE NO.</th>
<th>DATE</th>
<th>MATERIAL</th>
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<tbody>
<tr>
<td>M-29</td>
<td>4</td>
<td>6-11-70</td>
<td>SS 310</td>
</tr>
</tbody>
</table>

**CONDITION**: Annealed  
**TEST DIRECTION**:  
**SPEC. NOS.**:  
**FORM**: 0.750-in. diameter bar  
**DATA BASIS**: Category "C"  
**PROPERTY**: Tensile Elongation

### PROPERTY: Tensile Elongation

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>LOTS/HEATS</th>
<th>N</th>
<th>df</th>
<th>( \bar{X} )</th>
<th>K</th>
<th>S</th>
<th>COMPUTED VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT</td>
<td>2</td>
<td>7</td>
<td>11</td>
<td>53.4</td>
<td>3.852</td>
<td>5</td>
<td>34.4</td>
</tr>
<tr>
<td>-320</td>
<td>1</td>
<td>3</td>
<td>11</td>
<td>67.0</td>
<td>3.852</td>
<td>4</td>
<td>51.6</td>
</tr>
<tr>
<td>-423</td>
<td>1</td>
<td>4</td>
<td>11</td>
<td>47.7</td>
<td>3.852</td>
<td>4.1</td>
<td>31.5</td>
</tr>
</tbody>
</table>

**COMMENTS**: References (1) and (2).
**AERوجET-GENERAL NUCLEAR ROCKET OPERATIONS**

**MATERIALS AND PROCESSES SECTION**

**DATA RELEASE**

<table>
<thead>
<tr>
<th>DRM NO.</th>
<th>M-29</th>
<th>PAGE NO.</th>
<th>5</th>
<th>DATE</th>
<th>6-11-70</th>
<th>MATERIAL</th>
<th>SS 310</th>
</tr>
</thead>
</table>

**CONDITION**

Annealed

**TEST DIRECTION**

0.062-in. sheet

**SPEC. NOS.**

Category "C"

**DATA BASIS**

COMMENT

**PROPERTY**

Tensile Ultimate Strength

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>LOTS/HEATS</th>
<th>N</th>
<th>df</th>
<th>X</th>
<th>K</th>
<th>S</th>
<th>COMPUTED VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT</td>
<td>1</td>
<td>7</td>
<td>6</td>
<td>84.8</td>
<td>4.642</td>
<td>2.98</td>
<td>71.0</td>
</tr>
</tbody>
</table>

**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

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>LOTS/HEATS</th>
<th>N</th>
<th>df</th>
<th>X</th>
<th>K</th>
<th>S</th>
<th>COMPUTED VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT</td>
<td>1</td>
<td>7</td>
<td>6</td>
<td>40.3</td>
<td>4.642</td>
<td>1.56</td>
<td>33.1</td>
</tr>
</tbody>
</table>

REFERENCES: References (1) and (3).
AEROGYET-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

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>LOTS/ HEATS</th>
<th>N</th>
<th>df</th>
<th>$\bar{X}$</th>
<th>K</th>
<th>S</th>
<th>COMPUTED VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT</td>
<td>1</td>
<td>7</td>
<td>6</td>
<td>47.7</td>
<td>4.642</td>
<td>4.1</td>
<td>28.7</td>
</tr>
</tbody>
</table>

COMMENT: References (1) and (3).
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.
AERONET-General Nuclear Rocket Operations

MATERIALS AND PROCESSES SECTION

DATA RELEASE

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

Graphite

CONDITION TEST DIRECTION All

.SPEC. NOS. .061 lbs/in.³ density FORM minimum.

DATA BASIS No Category Required COMMENT Uncertainty, ±15%

PROPERTY Specific Heat

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>C_p BTU/LB/°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-379</td>
<td>(a) 0.00844</td>
</tr>
<tr>
<td>-370</td>
<td>(b) 0.00980</td>
</tr>
<tr>
<td>-280</td>
<td>(b) 0.0325</td>
</tr>
<tr>
<td>-190</td>
<td>(b) 0.0624</td>
</tr>
<tr>
<td>-100</td>
<td>(b) 0.0965</td>
</tr>
<tr>
<td>-10</td>
<td>(b) 0.132</td>
</tr>
<tr>
<td>80</td>
<td>(b) 0.167</td>
</tr>
<tr>
<td>260</td>
<td>(b) 0.238</td>
</tr>
<tr>
<td>350</td>
<td>(b) 0.268</td>
</tr>
<tr>
<td>440</td>
<td>(b) 0.294</td>
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<td>530</td>
<td>(b) 0.313</td>
</tr>
<tr>
<td>620</td>
<td>(b) 0.330</td>
</tr>
<tr>
<td>710</td>
<td>(b) 0.345</td>
</tr>
<tr>
<td>800</td>
<td>(b) 0.359</td>
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<tr>
<td>980</td>
<td>(b) 0.381</td>
</tr>
<tr>
<td>1070</td>
<td>(b) 0.390</td>
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</table>

(a) Table 58.05.01, Specific Heat of Manufactured Graphite, The Industrial Graphite Engineering Handbook, Union Carbide Corp., April 1964.

DATA RELEASE

MATERIAL: 3% Boron-Graphite

CONDITION

TEST DIRECTION: With Grain Direction

SPEC. NOS.

FORM: Molded

DATA BASIS: Category "D"

PROPERTY: Thermal Conductivity

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>BTU/HR/FT/°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>-459.7</td>
<td>0</td>
</tr>
<tr>
<td>-441.7</td>
<td>0.226</td>
</tr>
<tr>
<td>-423.7</td>
<td>1.2</td>
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<tr>
<td>-405.7</td>
<td>2.8</td>
</tr>
<tr>
<td>-369.7</td>
<td>7.9</td>
</tr>
<tr>
<td>-351.7</td>
<td>11.5</td>
</tr>
<tr>
<td>-333.7</td>
<td>14.8</td>
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<td>-315.7</td>
<td>19.0</td>
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<td>22.6</td>
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<td>-189.7</td>
<td>43.4</td>
</tr>
<tr>
<td>-99.7</td>
<td>55.4</td>
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<tr>
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<td>60.6</td>
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<td>32</td>
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<td>80.3</td>
<td>60.1</td>
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<td>57.5</td>
</tr>
<tr>
<td>260.3</td>
<td>55.0</td>
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<tr>
<td>800.3</td>
<td>40.2</td>
</tr>
<tr>
<td>980.3</td>
<td>36.5</td>
</tr>
</tbody>
</table>

Uncertainty: ± 25% at temperatures below -300°F, + 20% at temps above -300°F

Touloukian, Y. S., Thermophysical Properties Research Center Data Book
AERONET-GENERAL NUCLEAR ROCKET OPERATIONS
MATERIALS AND PROCESSES SECTION

DATA RELEASE

DISN NO. M-28 PAGE NO. 4 DATE 6-17-70 MATERIAL 3% Boron-D63

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

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>BTU/HR/ FT/°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>-459.7</td>
<td>0</td>
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<tr>
<td>-441.7</td>
<td>0.184</td>
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<tr>
<td>-423.7</td>
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<td>-405.7</td>
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<td>-369.7</td>
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<td>980.3</td>
<td>28.2</td>
</tr>
</tbody>
</table>

Touloukian, Y. S., Thermophysical Properties Research Center Data Book
**DATA RELEASE**

**DIM NO.** M-28  **PAGE NO.** 5  **DATE** 6-17-70  **MATERIAL** Graphite

**CONDITION** —  **TEST DIRECTION** All

**SPEC. NO.** —  **FORM** Molded

**DATA BASIS** Category "D"  **COMMENT** Uncertainty + 10%

**PROPERTY** Density

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>LBS/IN.³</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>.061</td>
</tr>
</tbody>
</table>

Calculated value based on ATJ process schedule.
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 7T 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.
Thermal Conductivity: The thermal conductivity data were obtained from two sources. The values for AT 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.
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 of 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% of the values listed.

4. CONCLUSIONS:

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

<table>
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<th>TEMP °F</th>
<th>( p ) LBS/IN(^3)</th>
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Calculated using linear coefficient of thermal expansion listed in this data release and on the basis of room temperature density and unit volume change.

Comment: Estimated uncertainty range ± 5%.
**AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS**

**MATERIALS AND PROCESSES SECTION**

**DATA RELEASE**

<table>
<thead>
<tr>
<th>DRN NO.</th>
<th>M-1</th>
<th>PAGE NO.</th>
<th>5</th>
<th>DATE</th>
<th>6-12-70</th>
<th>MATERIAL</th>
<th>718</th>
</tr>
</thead>
</table>

**CONDITION** | Heat Treat B  
**TEST DIRECTION** | All

**SPEC. NOS.** |  
**FORM** | All

**DATA BASIS** | Nc Category Required  
**COMMENT** | Estimated Uncertainty Range ± 5%

**PROPERTY** | Density

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<th>$\rho$ LBS/IN$^3$</th>
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*Calculated from instantaneous linear coefficient expansion data as contained in this data release.*
### PROPERTY

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### Thermal Conductivity

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*Variability at this temperature, ± 15%.


**Thermal Diffusivity**

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<th>TEMP °F</th>
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</table>

Calculated using specific heat density and thermal conductivity as listed in their respective data sheets using equation \( \alpha = \frac{K}{\rho C_p} \).
### Data Release

**Basis:**
- Heat Treat A
- All

**Form:**
- All

**Data Basis:**
- No Category Required

**Comment:**
- Estimated Maximum Variability
  - + 5%

**Property:**
- Coefficient of Linear Thermal Expansion

<table>
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<th>TEMP 'F</th>
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(All values from 70°F to temperature indicated.)

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS
MATERIALS AND PROCESSES SECTION
DATA RELEASE

<table>
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<tr>
<th>TEMP °F</th>
<th>α IN/IN/°F *</th>
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*From room temperature to temperature indicated.

Heat Treat A, COS IIU.

All TEST MATERIAL SPEC. NOS.

FORM All

DATA BASIS No Category Required

COMMENT Estimated Maximum Variability Range ± 5%

PROPERTY Modulus of Elasticity (Dynamic)

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>E ( \times 10^6 )</th>
<th>TEMP °F</th>
<th>E ( \times 10^6 )</th>
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Table 4, page 2, Data Sheet, Inconel 718, Huntington Alloy Products Div., International Nickel Co., Feb. 68.
<table>
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Table 4, page 2, Data Sheet, Inconel 718, Huntington Alloy Products Div., International Nickel Co., Feb. 68.
**DATA RELEASE**

<table>
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<th>13</th>
<th>DATE</th>
<th>6-12-70</th>
<th>MATERIAL</th>
<th>718</th>
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**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)

|---------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|

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

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

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**Estimated Maximum Variability**

No Category Required.

**DATA BASIS**

Colba Range +50%, -56%

**PROPERTY**

Total Normal Emissivity (a)

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</tr>
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<td>.930</td>
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<td>.942</td>
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(a) Oxidized Surface

**AEROSPACE CHASSIS NUCLEAR ROCKET OPERATIONS**  
**MATERIALS AND PROCESSES SECTION**  
**DATA RELEASE**

<table>
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<th>Poisson's Ratio (a)</th>
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(a) Calculated from E and G data.

NERVA Material Staff unpublished report.
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.
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:


## Materials and Processes Section

### Data Release

**DRM No.** M-38  **Page No.** 3  **Date** 6-22-70  **Material** 7039

**Condition** T63  **Test Direction** Longitudinal & Circumferential

**Spec. Nos.** FCRM  **Midshell Forging**

**Data Basis** Category "A"  **Comment** 1/2-Hr Soak at Test Temperature

**Property** Tensile Ultimate Strength

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>LOTS/HEATS</th>
<th>N</th>
<th>df</th>
<th>( \bar{X} ) ksi</th>
<th>K</th>
<th>S</th>
<th>COMPUTED VALUE ksi</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>2</td>
<td>85</td>
<td>65</td>
<td>53.8</td>
<td>2.781</td>
<td>1.44</td>
<td>49.8</td>
</tr>
<tr>
<td>200</td>
<td>2</td>
<td>85</td>
<td>65</td>
<td>60.6</td>
<td>2.781</td>
<td>2.74</td>
<td>53.0</td>
</tr>
<tr>
<td>RT</td>
<td>2</td>
<td>85</td>
<td>65</td>
<td>65.3</td>
<td>2.781</td>
<td>2.16</td>
<td>59.3</td>
</tr>
<tr>
<td>-100</td>
<td>2</td>
<td>85</td>
<td>65</td>
<td>75.6</td>
<td>2.781</td>
<td>1.40</td>
<td>71.7</td>
</tr>
<tr>
<td>-320</td>
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<td>65</td>
<td>90.8</td>
<td>2.781</td>
<td>1.40</td>
<td>86.9</td>
</tr>
</tbody>
</table>

**Comments:** Reference (1).
<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>LOTS/HEATS</th>
<th>N</th>
<th>df</th>
<th>$\bar{X}$ ksi</th>
<th>K</th>
<th>S</th>
<th>COMPUTED VALUE ksi</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>2</td>
<td>83</td>
<td>63</td>
<td>49.8</td>
<td>2.789</td>
<td>1.40</td>
<td>45.9</td>
</tr>
<tr>
<td>200</td>
<td>2</td>
<td>83</td>
<td>63</td>
<td>54.1</td>
<td>2.789</td>
<td>2.55</td>
<td>47.0</td>
</tr>
<tr>
<td>RT</td>
<td>2</td>
<td>83</td>
<td>63</td>
<td>58.4</td>
<td>2.789</td>
<td>1.40</td>
<td>54.5</td>
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<tr>
<td>-100</td>
<td>2</td>
<td>83</td>
<td>63</td>
<td>65.9</td>
<td>2.789</td>
<td>1.40</td>
<td>61.0</td>
</tr>
<tr>
<td>-320</td>
<td>2</td>
<td>83</td>
<td>63</td>
<td>74.1</td>
<td>2.789</td>
<td>1.40</td>
<td>70.2</td>
</tr>
</tbody>
</table>

**Comments:** Reference (1).
## DATA RELEASE

**DATE:** 6-22-70  **MATERIAL:** 7039

**CONDITION:** T63  **TEST DIRECTION:** Longitudinal & Circumferential

**SPEC. NO.S.**  **FORM:** Midshell Forging

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

**PROPERTY:** Tensile Elongation

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>LOTS/HEATS</th>
<th>N</th>
<th>(d_f)</th>
<th>(\bar{X}) % e</th>
<th>K</th>
<th>S</th>
<th>COMPUTED VALUE % e</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>2</td>
<td>86</td>
<td>66</td>
<td>21.3</td>
<td>2.777</td>
<td>1.965</td>
<td>15.9</td>
</tr>
<tr>
<td>200</td>
<td>2</td>
<td>86</td>
<td>66</td>
<td>14.0</td>
<td>2.777</td>
<td>1.05</td>
<td>11.1</td>
</tr>
<tr>
<td>RT</td>
<td>2</td>
<td>86</td>
<td>66</td>
<td>14.0</td>
<td>2.777</td>
<td>1.26</td>
<td>10.6</td>
</tr>
<tr>
<td>-100</td>
<td>2</td>
<td>86</td>
<td>66</td>
<td>13.1</td>
<td>2.777</td>
<td>1.45</td>
<td>9.1</td>
</tr>
<tr>
<td>-320</td>
<td>2</td>
<td>86</td>
<td>66</td>
<td>13.9</td>
<td>2.777</td>
<td>1.26</td>
<td>10.4</td>
</tr>
</tbody>
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**COMMENTS:** Reference (1).
### DATA RELEASE

**DEK NO.** M-38  |  **PAGE NO.** 6  |  **DATE** 6-22-70  |  **MATERIAL** 7039

**CONDITION:** T63  |  **TEST DIRECTION** Longitudinal & Circumferential

**SPEC. NO.**  |  **FORM** Midshell Forging

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

**PROPERTY** Tensile Ultimate Strength

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>LOIS/HEATS</th>
<th>N</th>
<th>df</th>
<th>$\bar{X}$ ksi</th>
<th>K</th>
<th>S</th>
<th>COMPUTED VALUE ksi</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>2</td>
<td>64</td>
<td>56</td>
<td>43.4</td>
<td>2.822</td>
<td>1.4</td>
<td>39.4</td>
</tr>
<tr>
<td>200</td>
<td>2</td>
<td>64</td>
<td>31</td>
<td>59.8</td>
<td>3.034</td>
<td>2.18</td>
<td>53.2</td>
</tr>
</tbody>
</table>

**COMMENTS:** Reference (2),

A-55
**Data Release**

**Material:** 7039  
**Condition:** T63  
**Test Direction:** Longitudinal & Circumferential  
**Spec. No.:**  
**Form:** Midshell Forging  
**Data Basis:** Category "A"  
**Comment:** 100-Hr Soak at Test Temperature

**Property:** Tensile Yield Strength

<table>
<thead>
<tr>
<th>Temp °F</th>
<th>Lots/Heats</th>
<th>N</th>
<th>df</th>
<th>( \overline{X} ) ksi</th>
<th>K</th>
<th>S</th>
<th>Computed Value ksi</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>2</td>
<td>63</td>
<td>55</td>
<td>38.7</td>
<td>2.827</td>
<td>1.58</td>
<td>34.2</td>
</tr>
<tr>
<td>200</td>
<td>2</td>
<td>63</td>
<td>55</td>
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<td>2.827</td>
<td>2.27</td>
<td>48.5</td>
</tr>
</tbody>
</table>

**Comments:** Reference (2).
### ALIQUOT GENERAL NUCLEAR ROCKET OPERATIONS

**MATERIALS AND PROCESSES SECTION**

**DATA RELEASE**

**DATE:** 6-22-70  
**MATERIAL:** 7039

**CONDITION:** T63  
**TEST DIRECTION:** Longitudinal & Circumferential

**SPEC. NO:**  
**FORM:** Midshell Forging

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

**PROPERTY:** Tensile Elongation

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>LOTS/HEATS</th>
<th>DIRECTION</th>
<th>N</th>
<th>df</th>
<th>% e</th>
<th>K</th>
<th>S</th>
<th>COMPUTED VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>2</td>
<td>Long</td>
<td>16</td>
<td>15</td>
<td>25.3</td>
<td>3.464</td>
<td>3.13</td>
<td>14.5</td>
</tr>
<tr>
<td>300</td>
<td>2</td>
<td>Circ.</td>
<td>16</td>
<td>15</td>
<td>25.6</td>
<td>3.464</td>
<td>3.02</td>
<td>15.1</td>
</tr>
<tr>
<td>200</td>
<td>2</td>
<td>Long</td>
<td>16</td>
<td>15</td>
<td>17.4</td>
<td>3.464</td>
<td>1.17</td>
<td>13.3</td>
</tr>
<tr>
<td>200</td>
<td>2</td>
<td>Circ.</td>
<td>16</td>
<td>15</td>
<td>16.8</td>
<td>3.464</td>
<td>1.20</td>
<td>11.0</td>
</tr>
</tbody>
</table>

**COMMENTS:** Reference (2).
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.
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:


(2) 1970 Third Quarter Report, NERVA Materials Developments
### 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** \( \leq 2.5 \text{ in. thickness} \)

**PROPERTY** Tensile Ultimate Strength, \( F_{tu} \)

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>LOTS/ HEATS</th>
<th>N</th>
<th>df</th>
<th>( \bar{X} )</th>
<th>K</th>
<th>S</th>
<th>COMPUTED VALUE ksi</th>
</tr>
</thead>
<tbody>
<tr>
<td>(-423)</td>
<td>2</td>
<td>10</td>
<td>18</td>
<td>255</td>
<td>3.33</td>
<td>2.71</td>
<td>246</td>
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<tr>
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<td>10</td>
<td>18</td>
<td>236</td>
<td>3.33</td>
<td>1.95</td>
<td>229</td>
</tr>
<tr>
<td>RT</td>
<td>2</td>
<td>4</td>
<td>18</td>
<td>182</td>
<td>3.33</td>
<td>1.95</td>
<td>175</td>
</tr>
</tbody>
</table>

**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, \( F_{\text{ty}} \)

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>LOTS/ HEATS</th>
<th>N</th>
<th>df</th>
<th>( \bar{X} )</th>
<th>K</th>
<th>S</th>
<th>COMPUTED VALUE ksi</th>
</tr>
</thead>
<tbody>
<tr>
<td>-423</td>
<td>2</td>
<td>10</td>
<td>18</td>
<td>188</td>
<td>3.33</td>
<td>2.25</td>
<td>180</td>
</tr>
<tr>
<td>-320</td>
<td>2</td>
<td>10</td>
<td>18</td>
<td>181</td>
<td>3.33</td>
<td>2.25</td>
<td>173</td>
</tr>
<tr>
<td>RT</td>
<td>2</td>
<td>4</td>
<td>18</td>
<td>157</td>
<td>3.33</td>
<td>2.25</td>
<td>149</td>
</tr>
</tbody>
</table>

COMMENTS: References (1) and (2)
AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS
MATERIALS AND PROCESSES SECTION
DATA RELEASE

DRM NO. M-18  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 < 2.5 in. thickness

PROPERTY Elongation, % (e)

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>LOTS/HEATS</th>
<th>N</th>
<th>df</th>
<th>$\bar{X}$</th>
<th>K</th>
<th>S</th>
<th>COMPUTED VALUE %</th>
</tr>
</thead>
<tbody>
<tr>
<td>-423</td>
<td>2</td>
<td>4</td>
<td>18</td>
<td>29</td>
<td>3.33</td>
<td>1.74</td>
<td>23</td>
</tr>
<tr>
<td>-320</td>
<td>2</td>
<td>10</td>
<td>18</td>
<td>28</td>
<td>3.33</td>
<td>1.74</td>
<td>22</td>
</tr>
<tr>
<td>RT</td>
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<td>10</td>
<td>18</td>
<td>22</td>
<td>3.33</td>
<td>1.74</td>
<td>16</td>
</tr>
</tbody>
</table>

COMMENTS: References (1) and (2).
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 $\epsilon$ and $\alpha_S$ 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.
**Solar Absorptance, \( \alpha_s \)**

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>SURFACE</th>
<th>CONDITION</th>
<th>MIN.</th>
<th>MAX.</th>
</tr>
</thead>
<tbody>
<tr>
<td>As Received</td>
<td></td>
<td></td>
<td>.18</td>
<td>.30</td>
</tr>
<tr>
<td>Cleaned</td>
<td></td>
<td></td>
<td>.18</td>
<td>.44</td>
</tr>
<tr>
<td>Mechanically Polished and Degreased</td>
<td></td>
<td></td>
<td>.18</td>
<td>.40</td>
</tr>
<tr>
<td>Sandblasted (1 F mesh SiC at 18 inches)</td>
<td></td>
<td></td>
<td>.50</td>
<td>.70</td>
</tr>
</tbody>
</table>

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

---

### Property: Total Hemispherical Emittance, \( \varepsilon \)

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>SURFACE CONDITION</th>
<th>MIN.</th>
<th>MAX.</th>
</tr>
</thead>
<tbody>
<tr>
<td>-60</td>
<td>As Received</td>
<td>.02</td>
<td>.06</td>
</tr>
<tr>
<td>40</td>
<td></td>
<td>.02</td>
<td>.06</td>
</tr>
<tr>
<td>140</td>
<td></td>
<td>.02</td>
<td>.06</td>
</tr>
<tr>
<td>-60</td>
<td>Cleaned</td>
<td>.03</td>
<td>.11</td>
</tr>
<tr>
<td>40</td>
<td></td>
<td>.03</td>
<td>.12</td>
</tr>
<tr>
<td>140</td>
<td></td>
<td>.03</td>
<td>.12</td>
</tr>
<tr>
<td>-60</td>
<td>Mechanically Polished and Degreased</td>
<td>.03</td>
<td>.11</td>
</tr>
<tr>
<td>40</td>
<td></td>
<td>.03</td>
<td>.12</td>
</tr>
<tr>
<td>140</td>
<td></td>
<td>.03</td>
<td>.12</td>
</tr>
<tr>
<td>-60</td>
<td>Sandblasted with 1F mesh SiC at 18 inches</td>
<td>.20</td>
<td>.40</td>
</tr>
<tr>
<td>40</td>
<td></td>
<td>.20</td>
<td>.41</td>
</tr>
<tr>
<td>140</td>
<td></td>
<td>.20</td>
<td>.41</td>
</tr>
</tbody>
</table>

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

---

**PROPERTY**  
Thermal Radiant Energy Ratio, \( \alpha_{S} / e \)

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>SURFACE CONDITION</th>
<th>MIN.</th>
<th>MAX.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>As Received</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Cleaned</td>
<td>1.5</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Mechanically Polished and Degreased</td>
<td>1.5</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Sandblasted with 1F mesh SiC at 18 inches</td>
<td>1.2</td>
<td>3.5</td>
</tr>
</tbody>
</table>

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

SPEC. NOS. FORM

DATA BASIS Category C

PROPERTY Coefficient of Friction, $\mu$

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>GRADE</th>
<th>N</th>
<th>N_e</th>
<th>$\bar{X}$</th>
<th>X</th>
<th>S</th>
<th>COMPUTED VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT</td>
<td>B-4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.20</td>
</tr>
<tr>
<td></td>
<td>B-8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.22</td>
</tr>
<tr>
<td></td>
<td>B-10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.25</td>
</tr>
</tbody>
</table>

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-3 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, $F_{tu}$

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>GRADE</th>
<th>N</th>
<th>$N_e$</th>
<th>$\bar{X}$</th>
<th>K</th>
<th>S</th>
<th>COMPUTED VALUE ksi</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT</td>
<td>B-4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>17</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B-8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>19</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B-10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>21</td>
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</tr>
</tbody>
</table>

### DATA RELEASE

**MATERIALS AND PROCESSES SECTION**

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

<table>
<thead>
<tr>
<th>CONDITION</th>
<th>TEST DIRECTION</th>
<th>GRADE</th>
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<tbody>
<tr>
<td>Cast</td>
<td></td>
<td>B-4 - 70% Cu - 4% Sn - 26% Pb</td>
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<tr>
<td></td>
<td></td>
<td>B-8 - 70% Cu - 8% Sn - 22% Pb</td>
</tr>
<tr>
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<td></td>
<td>B-10 - 70% Cu - 10% Sn - 20% Pb</td>
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**SPEC. NOS.**

**DATA BASIS** Category C

**PROPERTY** Tensile Yield Strength, $F_y$

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<th>TEMP °F</th>
<th>GRADE</th>
<th>K</th>
<th>Ne</th>
<th>$\bar{X}$</th>
<th>K</th>
<th>S</th>
<th>COMPUTED VALUE ksi</th>
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<tr>
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**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

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<th>N</th>
<th>N_e</th>
<th>X</th>
<th>K</th>
<th>S</th>
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**COMMENTS:** Data Sheet, "Mechanical Properties of Barium Metal," Bearium Metals Corporation, Rochester, New York, undated.

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### Data Release

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

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<td>Cast</td>
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<td></td>
<td>B-8 - 70% Cu - 8% Sn - 22% Pb</td>
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<td>B-10 - 70% Cu - 10% Sn - 20% Pb</td>
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<table>
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<th>COMputed VALUE (psi x 10^6)</th>
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<th>$N_e$</th>
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<th>K</th>
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<td>B-8</td>
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<td></td>
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**COMMENTS:**  
Data Sheet, "Mechanical Properties of Beryllium Metal,"  
### AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

**MATERIALS AND PROCESSES SECTION**

**DATA RELEASE**

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<th>7</th>
<th>DATE</th>
<th>7-15-70</th>
<th>MATERIAL</th>
<th>Bearings</th>
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**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

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<th>N</th>
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<th>X</th>
<th>K</th>
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**COMMENTS:** Data Sheet, "Mechanical Properties of Bearium Metal," Bearium Metals Corporation, Rochester, New York, undated.
### DATA RELEASE

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

**CONDITION**

**TEST DIRECTION**

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<th>B-10</th>
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**SPEC. NOS.**

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<th>B-10</th>
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<tr>
<td>GRADE</td>
<td>70% Cu - 4% Sn - 26% Pb</td>
<td>70% Cu - 8% Sn - 22% Pb</td>
<td>70% Cu - 10% Sn - 20% Pb</td>
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**DATA BASIS** Category C  
**COMMENT** Uncertainty ± 5%

**PROPERTY** Density

<table>
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<tr>
<th>TEMP °F</th>
<th>GRADE</th>
<th>N</th>
<th>Ne</th>
<th>X</th>
<th>K</th>
<th>S</th>
<th>COMPUTED VALUE 3 lbs/in</th>
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**COMMENTS:** Data Sheet, "Mechanical Properties of Bearium Metal," Bearium Metals Corporation, Rochester, New York, undated.
## AERJOET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

### DATA RELEASE

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<th>DATE</th>
<th>7-15-70</th>
<th>MATERIAL</th>
<th>Bearings</th>
</tr>
</thead>
</table>

### 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

<table>
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<tr>
<th>TEMP °F</th>
<th>N</th>
<th>Nₑ</th>
<th>X</th>
<th>K</th>
<th>S</th>
<th>COMPUTED VALUE in/in/°F x 10⁻⁶</th>
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<td>-115*</td>
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<td></td>
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<td>-330</td>
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<td>8.7</td>
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*From R to temperature indicated.

### COMMENTS

Cryogenic (LH₂) 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 (K₀/yield strength)², where K₀ is a provisional value of KIC. The specimens tested were fabricated 1-in. thick because the extremely good fracture toughness of the alloy was underestimated. To obtain valid KIC 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.
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
\[ \left( \frac{a}{Q_{cr}} \right) = 0.318 \frac{K_{IC}}{\sigma^2} \]

For surface flaws
\[ \left( \frac{a}{Q_{cr}} \right) = 0.263 \frac{K_{IC}}{\sigma^2} \]

\( K_Q \) 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 \( \sigma/\sigma_{YS} \) 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 LH2 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:

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS  
MATERIALS AND PROCESSES SECTION  
DATA RELEASE

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<td>3</td>
<td>7-15-70</td>
<td>Alloy 718</td>
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**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"

**PROPERTY**
- Fracture Toughness, $K_Q$

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<th>N</th>
<th>df</th>
<th>$N_e$</th>
<th>$\bar{X}$</th>
<th>K</th>
<th>S</th>
<th>$K_Q$ COMPUTED VALUE psi/√in.</th>
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<td>~423</td>
<td>2</td>
<td>13</td>
<td>12</td>
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<td>7</td>
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<td>157.3</td>
<td>4.354</td>
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1-in. thick specimen.

**COMMENTS:**
## DATA RELEASE

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

**CONDITION** Heat Treat B  
**TEST DIRECTION** C-R

**SPEC. Nos.**

**DATA BASIS** Category "A"  
**CONSENT**

**PROPERTY** Critical Crack Size

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<th>SURFACE CRACKS</th>
<th>INTERNAL CRACKS</th>
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<td>2c, in.</td>
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<td>.271</td>
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*Note: There is no indication of the document being of the A-79 series in the visible content.*
DATA RELEASE MEMORANDUM
NRO MATERIALS AND PROCESSES STAFF
TYPE: NRO MATERIALS AND PROCESSES STAFF
AEROGENT-GENERAL CORPORATION
SACRAMENTO, CALIFORNIA

SUPPLEMENT #1
REV. NO.

SUBJECT: FRACTURE TOUGHNESS OF ALUMINUM ALLOY 7039-T63 FORGING

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 so that the load axis was in the circumferential direction, while the crack was oriented 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

\[ B = 2.5 \left( \frac{K_*}{Y_S} \right)^2 \]

where

- \( B \) = Thickness, in.
- \( K_* \) = Provisional value of fracture toughness
- \( Y_S \) = 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 \( N_G \) 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 (60) was estimated to be 8 ksi in.\( ^1/2 \) which was approximately 2 ksi in. above and below the highest and lowest mean calculated from the test data.

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<th>DATE:</th>
<th>COMPONENT/ ASSEMBLY IDENT</th>
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<tr>
<td></td>
<td>CMF</td>
<td>14 Jul 70</td>
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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  \[ \left( \frac{a}{Q} \right)_{cr} = 0.318 \frac{K_{IC}^2}{\sigma^2} \]

For Surface Flaws  \[ \left( \frac{a}{Q} \right)_{cr} = 0.263 \frac{K_{IC}^2}{\sigma^2} \]

Flaw shape parameter \(-a/2c\) ratio relationships, as developed by Tiffany, were used. For these calculations, the \(\sigma/\gamma_{YS}\) 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 II 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 SNSPO-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.
5. REFERENCES:


## Fracture Toughness

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<thead>
<tr>
<th>TEMP °F</th>
<th>LOTS/HEATS</th>
<th>N</th>
<th>( \bar{X} )</th>
<th>B'</th>
<th>W</th>
<th>B'</th>
<th>W</th>
<th>COMPUTED VALUE ksi/(\text{in.})</th>
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**DATA RELEASE**

**DRY 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

<table>
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<tr>
<th>TEMP °F</th>
<th>FLAW SHAPE PARAM.</th>
<th>SURFACE</th>
<th>CRACKS</th>
<th>INTERNAL</th>
<th>CRACKS</th>
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<tr>
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<td>2c, in.</td>
<td>2a, in.</td>
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<td>2.2</td>
<td>.065</td>
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<td>.156</td>
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</tbody>
</table>
DATA RELEASE MEMORANDUM

NRO MATERIALS AND PROCESSES STAFF
AEROSPACE CORPORATION
SACRAMENTO, CALIFORNIA

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 allows 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 calculation method.
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.
**DATA RELEASE**

**MATERIAL**

<table>
<thead>
<tr>
<th>DRAW NO.</th>
<th>PAGE NO.</th>
<th>DATE</th>
<th>MATERIAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>M-4B</td>
<td>3</td>
<td>7-17-70</td>
<td>Ti 5Al-2.5Sn</td>
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</table>

**CONDITION**

<table>
<thead>
<tr>
<th>SPEC. NO.</th>
<th>FORM</th>
<th>DATA BASIS</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ring Forgings</td>
<td>Category &quot;A&quot;</td>
<td>Data from all 23 lots or heats at RT and -320°F were used to estimate the within-lot variance.</td>
</tr>
</tbody>
</table>

**PROPERTY**

<table>
<thead>
<tr>
<th>TEMPERATURE °F</th>
<th>LOTS/ HEATS</th>
<th>df</th>
<th>DIRECTION</th>
<th>Χ ksi</th>
<th>K</th>
<th>S ksi</th>
<th>COMPUTED VALUE ksi</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT</td>
<td>8</td>
<td>34</td>
<td>30.3</td>
<td>C**</td>
<td>120</td>
<td>3.034</td>
<td>3.68</td>
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<td>7</td>
<td>20</td>
<td>36</td>
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<td>117</td>
<td>2.972</td>
<td>3.09</td>
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<td>-320</td>
<td>4</td>
<td>16</td>
<td>37</td>
<td>C</td>
<td>190</td>
<td>2.961</td>
<td>2.95</td>
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<tr>
<td>-320</td>
<td>4</td>
<td>8</td>
<td>27</td>
<td>R</td>
<td>185</td>
<td>3.098</td>
<td>4.77</td>
</tr>
</tbody>
</table>

See Comments

**CONVERSIONS:**

*Ne = Effective N

**C = Circumferential; R = Radial

REFERENCE 1.
Ti 5Al-2.5Sn (ELI)

**DATA RELEASE**

**CONDITION:** Annealed

**TEST DIRECTION:** C & R

**SPEC. Nos.**

| Ring Forgings |
| Data from all 22 lots or heats were analyzed to estimate the within-lot variance |

**DATA BASIS**

Category "A"

**PROPERTY**

Tensile Yield Strength

<table>
<thead>
<tr>
<th>TEMP &quot;F</th>
<th>HOIDS/HEATS</th>
<th>df* N</th>
<th>N_e</th>
<th>DIRECTION</th>
<th>( \bar{Y} ) ksi</th>
<th>S ksi</th>
<th>COMPUTED VALU. ksi</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT</td>
<td>7</td>
<td>34</td>
<td>27</td>
<td>C**</td>
<td>111</td>
<td>3.098</td>
<td>4.35</td>
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<tr>
<td>RT</td>
<td>7</td>
<td>22</td>
<td>27</td>
<td>R</td>
<td>107</td>
<td>3.098</td>
<td>4.34</td>
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<td>-320</td>
<td>4</td>
<td>7</td>
<td>24</td>
<td>C</td>
<td>175</td>
<td>3.158</td>
<td>5.87</td>
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<td>-320</td>
<td>4</td>
<td>8</td>
<td>23</td>
<td>R</td>
<td>170</td>
<td>3.181</td>
<td>7.35</td>
</tr>
</tbody>
</table>

See Comments

*Degrees of freedom, \( N_e \) calculation

**NOTES:**

**C** = Circumferential, **R** = Radial

**REFERENCE 1.**
<table>
<thead>
<tr>
<th>TEST °Y</th>
<th>LOAD/HEATS</th>
<th>N</th>
<th>df*</th>
<th>DIRECTION</th>
<th>$\bar{X}$</th>
<th>K</th>
<th>S</th>
<th>COMPUTED VALUE</th>
</tr>
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<tbody>
<tr>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>See Comments</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
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<td>8</td>
<td>34</td>
<td>58</td>
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<td>8</td>
<td>24</td>
<td>33</td>
<td>R</td>
<td>13.5</td>
<td>2.812</td>
<td>1.735</td>
<td>8.6</td>
</tr>
<tr>
<td>-320</td>
<td>4</td>
<td>16</td>
<td>37**</td>
<td>C</td>
<td>14.4</td>
<td>2.961</td>
<td>2.94</td>
<td>5.7</td>
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<td>-320</td>
<td>4</td>
<td>8</td>
<td>58</td>
<td>R</td>
<td>10.5</td>
<td>2.812</td>
<td>1.735</td>
<td>6.7</td>
</tr>
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</table>

*df = Degrees of freedom

**C = Circumferential, R = Radial

***N₁ Calculation

REFERENCE 1.
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 absorptance 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.
**DATA RELEASE**

**CONDITION** Wrought  
**TEST DIRECTION** All  
**SPEC. NO.**  
**FORM** All  
**DATA BASIS**  
**PROPERTY** Density

<table>
<thead>
<tr>
<th>TEMP °F.</th>
<th>$\rho$ LBS/IN$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>-459</td>
<td>0.289</td>
</tr>
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<td>-279</td>
<td>0.288</td>
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<td>-99.4</td>
<td>0.287</td>
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<td>80.6</td>
<td>0.285</td>
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<td>261</td>
<td>0.284</td>
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<td>621</td>
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<td>801</td>
<td>0.280</td>
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<td>981</td>
<td>0.278</td>
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<td>1161</td>
<td>0.277</td>
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<td>1341</td>
<td>0.275</td>
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<tr>
<td>1521</td>
<td>0.273</td>
</tr>
<tr>
<td>1701</td>
<td>0.271</td>
</tr>
<tr>
<td>1881</td>
<td>0.269</td>
</tr>
<tr>
<td>2061</td>
<td>0.267</td>
</tr>
<tr>
<td>2241</td>
<td>0.265</td>
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</table>

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>( C_p ) BTU/LB/°F</th>
<th>TEMP °F</th>
<th>( C_p ) BTU/LB/°F</th>
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<tbody>
<tr>
<td>1161</td>
<td>0.145</td>
<td>1341</td>
<td>0.149</td>
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<td>1521</td>
<td>0.152</td>
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<tr>
<td>2241</td>
<td>0.168</td>
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</table>

### Uncertainty

- Uncertainty ± 15% from -420°F to -320°F; > -320°F and < 540°F.
- No Category Required
- Comment: + 10%; > 540°F, ± 5%

### Materials


### Table: Thermal Conductivity

<table>
<thead>
<tr>
<th>Temp °F</th>
<th>BTU/HR-FT-°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>-420</td>
<td>1.39</td>
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<tr>
<td>-410</td>
<td>1.77</td>
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<tr>
<td>-360</td>
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<td>-320</td>
<td>4.5</td>
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<td>5.84</td>
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<tr>
<td>-200</td>
<td>6.44</td>
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<tr>
<td>-160</td>
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<td>-100</td>
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<tr>
<td>0</td>
<td>8.21</td>
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<tr>
<td>200</td>
<td>8.73</td>
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<td>540</td>
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<td>1040</td>
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<td>1540</td>
<td>14.93</td>
</tr>
<tr>
<td>1840</td>
<td>16.11</td>
</tr>
<tr>
<td>TEMP °F</td>
<td>SURFACE CONDITION</td>
</tr>
<tr>
<td>-------</td>
<td>------------------</td>
</tr>
<tr>
<td></td>
<td>(a) Vapor degreased in trichloroethylene sandblasted with 100 mesh grit Al₂O₃, with nozzle 12 in. from surface.</td>
</tr>
<tr>
<td></td>
<td>(b) Mechanically polished</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>SURFACE CONDITION</th>
<th>MIN.</th>
<th>MAX.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>Vapor degreased in trichloroethylene, sandblasted with 100 mesh Al₂O₃ with nozzle 12 in. from surface.</td>
<td>.40</td>
<td>.52</td>
</tr>
<tr>
<td></td>
<td>- 60</td>
<td>.40</td>
<td>.52</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>.41</td>
<td>.53</td>
</tr>
<tr>
<td></td>
<td>140</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(b)</td>
<td>Mechanically polished</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 60</td>
<td></td>
<td>.11</td>
<td>.23</td>
</tr>
<tr>
<td>40</td>
<td></td>
<td>.13</td>
<td>.25</td>
</tr>
<tr>
<td>140</td>
<td></td>
<td>.14</td>
<td>.26</td>
</tr>
</tbody>
</table>

### DATA RELEASE

**CONDITION**  Wrought  **TEST DIRECTION**  All

**SPEC. NO.**  **FORM**

**DATA BASIS**  No Category Required  **COMMENT**

**PROPERTY**  Thermal Radiant Energy Ratio, \( \alpha_s/\varepsilon \)

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>SURFACE CONDITION</th>
<th>MIN. ( \alpha_s/\varepsilon )</th>
<th>MAX. ( \alpha_s/\varepsilon )</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>Vapor degreased in trichloroethylene, sandblasted with 100 mesh Al(_2)O(_3) with nozzle 12 in. from surface.</td>
<td>1.4</td>
<td>1.7</td>
</tr>
<tr>
<td>40</td>
<td>Mechanically polished</td>
<td>2.5</td>
<td>3.4</td>
</tr>
</tbody>
</table>

Calculated using min. and max. \( \alpha_s \) and min. \( \varepsilon \) at 40°F using values from individual data sheets.
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 temperatures 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".
### AEROFLEX GENERAL NUCLEAR ROCKET OPERATIONS

**MATERIALS AND PROCESSES SECTION**

**DATA RELEASE**

<table>
<thead>
<tr>
<th>DRM NO.</th>
<th>M-33</th>
<th>PAGE NO.</th>
<th>2</th>
<th>DATE 7-17-70</th>
<th>MATERIAL</th>
<th>Lih</th>
</tr>
</thead>
</table>

**CONDITION**

**TEST DIRECTION**

- **SPEC. NO.**
- **FORM** 99.8 Lih
- **DATA BASIS** Category "C"
- **COMMENT** Uncertainty ± 10% at temperatures less than -320°F; + 3% above -320°F.

### PROPERTY

**Specific Heat, C_p**

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>C_p BTU/LB °F</th>
</tr>
</thead>
<tbody>
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<td>-420</td>
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</tr>
<tr>
<td>-320</td>
<td>0.1</td>
</tr>
<tr>
<td>-160</td>
<td>0.47</td>
</tr>
<tr>
<td>-100</td>
<td>0.57</td>
</tr>
<tr>
<td>0</td>
<td>0.72</td>
</tr>
<tr>
<td>70</td>
<td>0.82</td>
</tr>
<tr>
<td>300</td>
<td>1.08</td>
</tr>
<tr>
<td>560</td>
<td>1.28</td>
</tr>
<tr>
<td>810</td>
<td>1.48</td>
</tr>
</tbody>
</table>

### DATA RELEASE

**DIN NO.** M-33  
**PAGE NO.** 3  
**DATE** 7-17-70  
**MATERIAL** Lithium Hydride

**CONDITION**  
**TEST DIRECTION**

**SPEC. KOS.**  
**FORM** Compacted 99.2% Dense

**DATA BASIS**  
Category "C"  
Uncertainty ± 20% to 302°F;  
± 15% above 302°F.

**PROPERTY**  
Thermal Conductivity, K

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>K BTU/FT-HR-°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>122</td>
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<tr>
<td>212</td>
<td>3.8</td>
</tr>
<tr>
<td>302</td>
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</tr>
<tr>
<td>392</td>
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</tr>
<tr>
<td>482</td>
<td>3.1</td>
</tr>
<tr>
<td>572</td>
<td>2.98</td>
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</table>

**REFERENCE:** Technical Data Sheet, Lithium Hydride, Foote Mineral Co.
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.

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>$\rho$ LBS/IN.$^3$</th>
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</thead>
<tbody>
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<td>.0284</td>
</tr>
<tr>
<td>-260</td>
<td>.0283</td>
</tr>
<tr>
<td>-160</td>
<td>.0283</td>
</tr>
<tr>
<td>-60</td>
<td>.0282</td>
</tr>
<tr>
<td>80</td>
<td>.028</td>
</tr>
<tr>
<td>140</td>
<td>.0279</td>
</tr>
<tr>
<td>240</td>
<td>.0277</td>
</tr>
<tr>
<td>340</td>
<td>.0275</td>
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<td>440</td>
<td>.027</td>
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<td>540</td>
<td>.0271</td>
</tr>
<tr>
<td>740</td>
<td>.0265</td>
</tr>
</tbody>
</table>
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 so 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.
Three heats were tested at -423°F. Fracture occurred 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 TL 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 LH2 Tensile Test Results of Ti 5Al-2.5Sn ELI Forging, dated 27 February 1970.
AEROGAT-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

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>LOTS/HEATS</th>
<th>N</th>
<th>N_e</th>
<th>\bar{X}</th>
<th>K</th>
<th>S</th>
<th>COMPUTED VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT (R)</td>
<td>3</td>
<td>10</td>
<td>37</td>
<td>118</td>
<td>2.961</td>
<td>3.4</td>
<td>108</td>
</tr>
<tr>
<td>RT (C)</td>
<td>3</td>
<td>10</td>
<td>32</td>
<td>119</td>
<td>3.206</td>
<td>3.5</td>
<td>108</td>
</tr>
<tr>
<td>-320 (C)</td>
<td>3</td>
<td>11</td>
<td>48</td>
<td>188</td>
<td>2.869</td>
<td>3.4</td>
<td>178</td>
</tr>
<tr>
<td>-423</td>
<td>2</td>
<td>28</td>
<td>48</td>
<td>210</td>
<td>2.864</td>
<td>2.77</td>
<td>202</td>
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</table>

COMMENTS: References (a), (b) and (c).
## DATA RELEASE

**DRM NO.** M-4B  
**PAGE NO.** 4  
**DATE** 7-28-70  
**MATERIAL** Ti-5.1-2.5Sn ELI

**CONDITION** Annealed  
**TEST DIRECTION** Rad & Circum

**SPEC. NOS.**  
**FORM** Pancake Forging

**DATA BASIS** Category "A"  
**COMMENT**

**PROPERTY** Tensile Yield Strength

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>LOTS/HEATS</th>
<th>N</th>
<th>N&lt;sub&gt;e&lt;/sub&gt;</th>
<th>X</th>
<th>K</th>
<th>S</th>
<th>COMPUTED VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT (C &amp; R)</td>
<td>3</td>
<td>20</td>
<td>47</td>
<td>109</td>
<td>2.876</td>
<td>3.67</td>
<td>98</td>
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<tr>
<td>-320 (C)</td>
<td>3</td>
<td>11</td>
<td>47</td>
<td>175</td>
<td>2.876</td>
<td>4.18</td>
<td>163</td>
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<td>-423 (C)</td>
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<td>27</td>
<td>47</td>
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<td>4.15</td>
<td>179</td>
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**COMMENTS:**
## 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, $e$

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>LOTS/HEATS</th>
<th>N</th>
<th>$N_e$</th>
<th>$\bar{X}$</th>
<th>K</th>
<th>S</th>
<th>COMPUTED VALUE $\bar{X}$</th>
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</thead>
<tbody>
<tr>
<td>RT (C&amp;R)</td>
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<td>3.206</td>
<td>2.4</td>
<td>8.1</td>
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</table>

**COMMENTS:**
DATA RELEASE MEMORANDUM

SUBJECT: TENSILE YIELD DESIGN ALLOWABLES FOR AISI 347 TRIPLE BRAZE SHEET

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:

**DATA RELEASE**

**DEN 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. KOS.** FORM Sheet

**DATA BASIS** Category "C"  **COMMENTS**

**PROPERTY** Tensile Yield Strength

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>HEATS</th>
<th>DIRECTION</th>
<th>N</th>
<th>X KSI</th>
<th>TOLERANCE FACTOR</th>
<th>SW KSI</th>
<th>SH-H KSI</th>
<th>MINIMUM DESIGN VALUES (KSI)</th>
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<td>L*</td>
<td>33</td>
<td>54.5</td>
<td>2.097</td>
<td>2.17</td>
<td>2.63</td>
<td>43.8</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>-320</td>
<td>3</td>
<td>T*</td>
<td>36</td>
<td>53.0</td>
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<td>1.74</td>
<td>2.63</td>
<td>43.0</td>
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<td></td>
<td></td>
<td></td>
<td>2.326</td>
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<td></td>
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<td>T</td>
<td>14</td>
<td>49.5</td>
<td>3.128</td>
<td>1.57</td>
<td>2.51</td>
<td>38.8</td>
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<td>2.326</td>
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<td>2.326</td>
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<td></td>
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<td>0.86</td>
<td>2.41</td>
<td>38.4</td>
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<td>2.326</td>
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<td></td>
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<tr>
<td>75</td>
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<td></td>
<td></td>
<td>2.326</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

L* = Parallel to rolling direction.
T* = Transverse to rolling direction.
TRANVERSE AND PARALLEL SIMULATED BRAZE CYCLE

DATA RELEASE

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>HEATS</th>
<th>DIRECTION</th>
<th>N</th>
<th>ksi</th>
<th>X ksi</th>
<th>TOLERANCE FACTOR</th>
<th>SW ksi</th>
<th>SH-H KSI</th>
<th>MINIMUM DESIGN VALUE (KSI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>800</td>
<td>3</td>
<td>L</td>
<td>33</td>
<td>.257</td>
<td>2.952</td>
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<td>T</td>
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<td>T</td>
<td>35</td>
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<td>0.538</td>
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<td>L</td>
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<tr>
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<td>T</td>
<td>35</td>
<td>1.98</td>
<td>2.245</td>
<td>2.326</td>
<td>0.472</td>
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<td>0.517</td>
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</table>

TENSILE YIELD STRENGTH

CATEGORIES: "C"

DATA BASIS: SHEET

PROPERTY: TENSILE YIELD STRENGTH

SPEC. NO. 13S.

FORM: SHEET

CONSENT: 

AEROGT-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

A-108
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°F (-423°F), ± 15% to points from 37°F to 140°F (-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:


(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.
<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>C_p BTU/LB °F</th>
<th>UNCERTAINTY FACTOR %</th>
</tr>
</thead>
<tbody>
<tr>
<td>-300</td>
<td>0.0775</td>
<td>± 15</td>
</tr>
<tr>
<td>-200</td>
<td>0.09</td>
<td>± 10</td>
</tr>
<tr>
<td>-100</td>
<td>0.095</td>
<td>± 10</td>
</tr>
<tr>
<td>0</td>
<td>0.104</td>
<td>± 5</td>
</tr>
<tr>
<td>200</td>
<td>0.115</td>
<td>± 5</td>
</tr>
<tr>
<td>400</td>
<td>0.126</td>
<td>± 5</td>
</tr>
</tbody>
</table>

Data is from Alloy AISI 301 data

REFERENCE (2)
**AEROJET-CENTRAL NUCLEAR FUEl STORAGE AND PROCESS SECTION**

**DATA RELEASE**

**DRM NO.** M-10  
**PAGE NO.** 3  
**DATE** 8-3-70  
**MATERIAL** AISI 302

**CONDITION**  
**TEST DIRECTION**

**SPEC. NOS.**  
**FORM**  
Category "C"  
**DATA BASIS**  
Category "C" is from AISI 303 compatible material.

**PROPERTY**  
Thermal Conductivity

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>k BTU-FT/HR FT² °F</th>
<th>UNCERTAINTY FACTOR %</th>
</tr>
</thead>
<tbody>
<tr>
<td>-420</td>
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<td>± 20</td>
</tr>
<tr>
<td>-410</td>
<td>1.77</td>
<td>± 20</td>
</tr>
<tr>
<td>-360</td>
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</tr>
<tr>
<td>-320</td>
<td>4.5</td>
<td>± 15</td>
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<tr>
<td>-260</td>
<td>5.64</td>
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<td>-60</td>
<td>7.62</td>
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</tr>
<tr>
<td>-10</td>
<td>7.93</td>
<td>± 5</td>
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</tbody>
</table>

**REFERENCES** (1), (2), and (3).
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.
AEROTJ-CENRAL NUCLEAR ROCKET OPERATIONS
MATERIALS AND PROCESSES SECTION

DATA RELEASE

DMM NO. M-38 PAGE NO. 2 DATE 8-7-70 MATERIAL Alloy 22-13-5 Stainless Steel

CONDITION Annealed TEST DIRECTION

SPEC. NO. FORM 1-In. Diameter Bar

DATA BASIS Category "C" COMMENT Typical values reduced by 20%

PROPERTY Tensile Ultimate Strength

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>DESIGN VALUE ksi</th>
</tr>
</thead>
<tbody>
<tr>
<td>-320</td>
<td>181</td>
</tr>
<tr>
<td>-100</td>
<td>117</td>
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<tr>
<td>75</td>
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<tr>
<td>600</td>
<td>84</td>
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<tr>
<td>800</td>
<td>78</td>
</tr>
<tr>
<td>1000</td>
<td>74</td>
</tr>
<tr>
<td>1200</td>
<td>66</td>
</tr>
<tr>
<td>1350</td>
<td>56</td>
</tr>
<tr>
<td>1500</td>
<td>42</td>
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</tbody>
</table>
**DATA RELEASE**

**DRN NO.** M-38  **PAGE NO.** 3  **DATE** 8-7-70  **MATERIAL** 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

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>DESIGN VALUE ksi</th>
</tr>
</thead>
<tbody>
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<td>-320</td>
<td>102</td>
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<tr>
<td>-100</td>
<td>68</td>
</tr>
<tr>
<td>75</td>
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<td>600</td>
<td>37</td>
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<td>800</td>
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<td>1200</td>
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<td>1350</td>
<td>32</td>
</tr>
<tr>
<td>1500</td>
<td>27</td>
</tr>
<tr>
<td>TEMP °F</td>
<td>DESIGN VALUE % IN 2 IN.</td>
</tr>
<tr>
<td>--------</td>
<td>------------------------</td>
</tr>
<tr>
<td>-320</td>
<td>33.0</td>
</tr>
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<td>-100</td>
<td>39.6</td>
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<td>75</td>
<td>37.2</td>
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<tr>
<td>600</td>
<td>30.0</td>
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<td>800</td>
<td>24.0</td>
</tr>
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<td>1000</td>
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</tr>
<tr>
<td>1350</td>
<td>31.2</td>
</tr>
<tr>
<td>1500</td>
<td>34.4</td>
</tr>
</tbody>
</table>

DATA BASIS: Category "C"

COMMENT: Typical values reduced by 20%
1. SCOPE:

Tensile data from the two triple-brazed nozzle forgings were analyzed to develop minimum design allowable values for the following properties:

<table>
<thead>
<tr>
<th>Property</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Ultimate Strength</td>
</tr>
<tr>
<td>Elongation</td>
</tr>
</tbody>
</table>

This revision supercedes DRM M-281, 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 homogenous 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.
Although some data points were not homogeneus 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.


AEROGESN GENERAL NUCLEAR ROCKET OPERATIONS
MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. M-281 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

<table>
<thead>
<tr>
<th>TEMP °F</th>
<th>LOTS/HEATS</th>
<th>N</th>
<th>df*</th>
<th>Direction</th>
<th>$\bar{X}$ ksi</th>
<th>K</th>
<th>S ksi</th>
<th>COMPUTED VALUE ksi</th>
</tr>
</thead>
<tbody>
<tr>
<td>-100</td>
<td>2</td>
<td>23</td>
<td>8**</td>
<td>Axial</td>
<td>118</td>
<td>4.143</td>
<td>3.34</td>
<td>104</td>
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COMMENTS: *df = degrees of freedom
**$N_e$ calculation

A-118
## AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

### MATERIALS AND PROCESSES SECTION

**DATA RELEASE**

<table>
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**CONDITION** Triple Brazed  
**TEST DIRECTION** Axial and Circumferential

**SPEC. NOS.** Forging  
**DATA BASIS** Category "A"  
**PROPERTY** Tensile Elongation

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<th>df*</th>
<th>Direction</th>
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**COMMENTS:**
- df = degrees of freedom
- N = calculation.
SUBJECT: DESIGN ALLOWABLES FOR THERMOPHYSICAL PROPERTIES OF ALLOY 718

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 supersedes the linear thermal expansion data contained in Rev. 1, DRM M-1, dated 6-12-70.

5. REFERENCES:


### 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.:** All  
**FORM:** Estimated Maximum Variability

**DATA BASIS:** No Category Required  
**COMMENT:** Range ± 10%

**PROPERTY:** Coefficient of Linear Thermal Expansion

<table>
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<th>α IN/IN/°F X 10^{-6}</th>
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*From room temperature to temperature indicated.*

---


A-121
1. SCOPE:

The following design allowables for the Fe-21 Cr-6 Ni-9 Mn stainless steel alloy forgings are attached:

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<tr>
<th>Property</th>
<th>Value</th>
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<td>Tensile Ultimate Strength</td>
<td></td>
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<tr>
<td>Tensile Yield Strength</td>
<td></td>
</tr>
<tr>
<td>Elongation</td>
<td></td>
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</table>

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 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.
AEROGENT-GENERAL NUCLEAR ROCKET OPERATIONS
MATERIALS AND PROCESSES SECTION
DATA RELEASE

<table>
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<td>2</td>
<td>8-7-70</td>
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CONDITION: Triple Brazed
TEST DIRECTION: Circumferential and Radial

SPEC. NO.

FORM: Forging

DATA BASIS: Category "C"

PROPERTY: Tensile Ultimate Strength, $F_{tu}$

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<th>TEMP °F</th>
<th>LOTS/ HEATS</th>
<th>N</th>
<th>$N_e$</th>
<th>$\bar{X}$</th>
<th>K</th>
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<th>COMPUTED VALUE ksi</th>
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**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. NO.**  **FORM** Forging

**DATA BASIS** Category "C"  **COMMENT**

**PROPERTY** Tensile Yield Strength, $F_y$

<table>
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<th>N</th>
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**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. 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

<table>
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<th>TEMP °F</th>
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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.
4. CONCLUSIONS:

The data are rated category "C", a conservative estimate of the statistical allowable, according to directive SNPO 69-37.

5. REFERENCES:

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**Comments:**
AEROJET-GENERAL NUCLEA. ROCKET OPERATIONS
MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRU 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, $F_{ty}$

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COMMENTS:
AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS
MATERIALS AND PROCESSES SECTION
DATA RELEASE

Fe-21 Cr-6 Ni-9 Mn

DRM NO. N-36A PAGE NO. 5 DATE 8-7-70 MATERIAL

CONDITION Brazed TEST DIRECTION L & T

SPEC. NO. FORM Sheet

DATA BASIS Category "C" COMMENT

PROPERTY Elongation, e

<table>
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COMMENTS:

A-130
DATA RELEASE MEMORANDUM

NRO MATERIALS AND PROCESSES STAFF

AEROGENT-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

SheET 1 OF 5

SUBJECT: TENSILE DESIGN ALLOWABLES FOR TI 5AL-2.5SN ELI RING FORGINGS

DATE: 9-1-70

1. SCOPE:

Data furnished by WNL were analyzed to develop minimum design allowable values for the following mechanical properties:

- Tensile Ultimate Strength
- Tensile Yield Strength
- Tensile Elongation

This DRM supersedes 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 WNL-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.
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. 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:

WALT Quality Control Data on Ring Forgings and Test Data Requisition No. 51281, transmitted to Aerojet to R. Shollenberger.
**Data Release**

**Condition**: Annealed  
**Test Direction**: C & R  
**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

<table>
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<th>LOTS/HEATS</th>
<th>N</th>
<th>df</th>
<th>DIRECTION</th>
<th>MEAN ksi</th>
<th>K ksi</th>
<th>S ksi</th>
<th>COMPUTED VALUE ksi</th>
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<td>8</td>
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See Comments

*Ne = Satterthwaite's approximation  
**C = Circumferential; R = Radial.

**Reference**: 1.
AEROGENT-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

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<td>Ti 5Al-2.5Sn</td>
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CONDITION: Annealed  TEST DIRECTION: C & R

SPEC. Nos.: 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

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*Degrees of freedom, Satterthwaite's approximation.
**C = Circumferential; R = Radial

REFERENCE 1.

A-134
### MATERIALS AND PROCESSES SECTION

#### DATA RELEASE

**DRM NO.** M-4B  
**PAGE NO.** 5  
**DATE** 9-1-70  
**MATERIAL** Ti 5Al-2.5Sn

**CONDITION** Annealed  
**TEST DIRECTION** C & R

**SPEC. NO.**  
**FORM** Ring Forgings  
**DATA BASIS** Category "A"  
**COMMENT** Data from all 24 data groups were used to estimate the within-lot variance.

**PROPERTY** Elongation

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<th>df*</th>
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<th>( \bar{X} )%</th>
<th>K</th>
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<th>COMPUTED VALUE%</th>
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<td>2.812</td>
<td>1.735</td>
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*df* - Degrees of freedom  
**C** = Circumferential; **R** = Radial  
**S** = Satterthwaite's Approximation

**REFERENCE 1.**
DATA RELEASE MEMORANDUM
NRO MATERIALS AND PROCESSES STAFF
AEROJET-GENERAL CORPORATION
SACRAMENTO, CALIFORNIA

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 1/6-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 ±.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 ±.20.

The specific heat data are for manufactured graphite with an estimated uncertainty range of ±.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.
DATA RELEASE MEMORANDUM
NRO MATERIALS AND PROCESSES STAFF
AEROJET-GENERAL CORPORATION
SACRAMENTO, CALIFORNIA

SUBJECT: PHYSICAL PROPERTIES OF FIBROUS GRAPHITE COMPOSITE

DATE: 9-9-70

5. REFERENCES:


## DATA RELEASE

**Fibrous Graphite Composite**

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<th>SPEC. NOS.</th>
<th>FORM</th>
<th>DATA BASIS</th>
<th>COMMENT</th>
<th>PROPERTY</th>
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<td>1-In. and 1/4-In. Thick Block</td>
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<td></td>
<td>Category &quot;C&quot;</td>
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<td>Bulk Density</td>
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<table>
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<th>MINIMUM</th>
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REFERENCE (1)
**Data Release**

**DRM NO.** M-6H  **PAGE NO.** 4  **DATE** 9-9-70  **MATERIAL** Graphite

**CONDITION**  

**TEST DIRECTION**

**SPEC. NOS.**  

**FOR.**

**DATA BASIS**

**Category "C"**

**Certified**

**Uncertainty Range** ± 10%

**PROPERTY** Specific Heat

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REFERENCE (2).
### DATA RELEASE

**Fibrous Graphite Composite**

**DATE:** 9-9-70  
**MATERIAL:** Perpendicular and Parallel to Plies

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<td>12.0</td>
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**REFERENCE (1).**
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.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS
MATERIALS AND PROCESSES SECTION
DATA RELEASE

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<th>PAGE NO.</th>
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**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.
AEROSPACE GENERAL NUCLEAR ROCKET OPERATIONS
MATERIALS AND PROCESSES SECTION
DATA RELEASE

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**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, $F_{tu}$

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**COMMENTS:**
Mil Handbook 5 - Basis "A", dated 8 February 1966. Room temperature data obtained from Table 5.2.6.0(d), page 74; multiplication factors for other temperatures obtained from Figure 5.2.6.2.1(a), 100 hour exposure, page 325, of said reference.
AEROSPACE 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 "R" TD 69-28 COMMENT \( \leq 4.0 \) in. Thick

PROPERTY Ultimate Tensile Strength, \( F_{tu} \)

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<th>LOTS/HEATS</th>
<th>N</th>
<th>( N_e )</th>
<th>( \bar{X} ) ksi</th>
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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**

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<thead>
<tr>
<th>PROPERTY</th>
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<tr>
<th>TEMP °F</th>
<th>LOTS/HEATS</th>
<th>N</th>
<th>N_e</th>
<th>$\bar{X}$ ksi</th>
<th>K</th>
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**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**

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**CONDITION** T6  
**TEST DIRECTION** Transverse

**SPEC. NOS.**  
**DATA BASIS**  
**PROPERTY** Tensile Yield Strength, $F_{ty}$

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**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.
### DATA RELEASE

**DRM NO.** N-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"  
**COMMENT** ≤ 4.0 in. Thick

**PROPERTY** Tensile Yield Strength, $F_{ty}$

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<th>N</th>
<th>$N_e$</th>
<th>$X_{ksi}$</th>
<th>K</th>
<th>S ksi</th>
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**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.
### Data Release

**DRM No.** M-78  
**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

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<th>K</th>
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**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.
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<th>K</th>
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**DATA BASIS**
Category "B" TD 69-28

**COMMENT**
< 4.0 In. Thick

**PROPERTY**
Elongation, e

**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**

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<th>DATE</th>
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<td>6061</td>
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**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

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<th>Ne</th>
<th>X</th>
<th>K</th>
<th>S</th>
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**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
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<tr>
<th>SUBASSEMBLY</th>
<th>PREDICTED ENVIRONMENT</th>
<th>RADIATION</th>
<th>SELECTED MATERIAL AND CONDITION</th>
<th>PROBLEM</th>
<th>TEST PLAN</th>
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</thead>
<tbody>
<tr>
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<td>°F</td>
<td>ATMOS</td>
<td>NVT 10 HRS.</td>
<td>PRIME</td>
<td>BACKUP</td>
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<td>TURBINE ROTOR</td>
<td>RT to -423</td>
<td>(GH_2)</td>
<td>(10^{16} ) to (10^{17}) (F)</td>
<td>T1-5A1-2.5Sn ELI Forging Annealed</td>
<td>718 Forging HT (B)</td>
</tr>
<tr>
<td>MAIFOLU</td>
<td>RT to -160</td>
<td>(GH_2)</td>
<td>(10^{16} ) to (10^{17}) (F)</td>
<td>310 Sheet &amp; Forging Annealed</td>
<td>718 Sheet &amp; Forging HT (B)</td>
</tr>
<tr>
<td>HOUSING</td>
<td>RT to -423</td>
<td>(LH_2)</td>
<td>(10^{16} ) to (10^{17}) (F)</td>
<td>310 Sheet &amp; Forging Annealed</td>
<td>718 Sheet &amp; Forging HT (B)</td>
</tr>
<tr>
<td>IMPPELLER AND INDUCER</td>
<td>RT to -423</td>
<td>(LH_2)</td>
<td>(10^{16} ) to (10^{17}) (F)</td>
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<td>718 Forging HT (B)</td>
</tr>
<tr>
<td>BOLTS</td>
<td>RT to -423</td>
<td>(GH_2)</td>
<td>(10^{16} ) to (10^{17}) (F)</td>
<td>A286 CW Bar Aged</td>
<td>Multiphase</td>
</tr>
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<td>ROTOR TIE BOLTS</td>
<td>RT to -423</td>
<td>(LH_2)</td>
<td>(10^{16} ) to (10^{17}) (F)</td>
<td>718 CW Bar Aged</td>
<td>Multiphase</td>
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### Identification of Materials Problems

**Turnopump Assembly**

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<th>Predicted Environment</th>
<th>Selected Material and Condition</th>
<th>Problem</th>
<th>Test Plan Identity</th>
</tr>
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<tbody>
<tr>
<td>Dearing, Races and Rolling Elements</td>
<td>RT GH₂ 10¹⁶ to 10¹⁷ (F)</td>
<td>440C Prime</td>
<td>Fatigue Properties</td>
<td>M-13</td>
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<td>Forging</td>
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<td>Retainer</td>
<td>RT GH₂ γ-10⁹ to 10¹⁰ erg/gm</td>
<td>PBI-Glass Laminate Prime</td>
<td>Control and Reproducibility of Laminate Properties</td>
<td>M-11</td>
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<td>-423 LH₂</td>
<td>PBI-Graphite Laminate Backup</td>
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*(F) signifies fast neutrons with energies in excess of 1 Mev.*
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<th>PREDICTED ENVIRONMENT</th>
<th>SELECTED MATERIAL AND CONDITION</th>
<th>PROBLEM</th>
<th>TEST PLAN IDENTITY</th>
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<td>CYLINDER AND CLOSURE</td>
<td>300°F Air/Space</td>
<td>Prime 7039 A1, Backup 6061 A1</td>
<td>Cryogenic Fracture Toughness</td>
<td>M-3 M-7</td>
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<td></td>
<td>to -320°F GH₂</td>
<td>T-63 Forging</td>
<td>Fatigue Resistance</td>
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<td>Thermal Control Coating Stability</td>
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<td>Radiation Damage</td>
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<td>Stress Corrosion Resistance</td>
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<td>Anisotropy of Forging</td>
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<td>Mechanical Properties</td>
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<td>Physical Properties</td>
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<td>TBD Air/Space</td>
<td>Prime A-286, Backup 260 ksi Bolts</td>
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<td>Stress Corrosion Resistance</td>
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<td>THREADED INSERTS</td>
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<td>Bar 347 CRES</td>
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(F) signifies fast neutrons with energies in excess of 1 Mev.
<table>
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<tr>
<th>SUBASSEMBLY</th>
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<th>SELECTED MATERIAL AND CONDITION</th>
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<td>1240 °F, H₂</td>
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<td>Mechanical Properties</td>
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<td>to 10¹⁶ to 10¹⁸ (T) (10 HRS) 10¹⁷ to 10¹⁹ (F) (10 HRS)</td>
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<td>Forging</td>
<td>Radiation Damage</td>
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<tr>
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<td>-423 °F, L₂</td>
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<td>Hastelloy X</td>
<td>Anisotropy</td>
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<td>to 10¹⁶ to 10¹⁸ (T) (10 HRS) 10¹⁷ to 10¹⁹ (F) (10 HRS)</td>
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<td>Creep</td>
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<td>3000 °F, H₂</td>
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<td>Martensite Transformation</td>
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<td>Composite Sheet</td>
<td>AISI 347</td>
<td>Fabrication Development</td>
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(T) designates thermal neutron with energies below 0.4 ev.

(F) signifies fast neutrons with energies in excess of 1 Mev.
## IDENTIFICATION OF MATERIALS PROBLEMS

### LINE ASSEMBLIES

<table>
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<th>Subassembly</th>
<th>Predicted Environment</th>
<th>Radiation</th>
<th>Selected Material and Condition</th>
<th>Problem</th>
<th>Test Plan Identify</th>
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<tr>
<td>Upper Lines (POL, TIL, TL, SSSL, TIL, CSL)</td>
<td>RT to LH</td>
<td>10¹⁶ to 10¹⁷ (F)</td>
<td>718 Tube, HT (B)</td>
<td>Ti 5Al-2.5Sn (EL1)</td>
<td>M-1 M-4</td>
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<tr>
<td>Lower Lines (POL, TIL)</td>
<td>RT to LH</td>
<td>10¹⁷ to 10¹⁹ (F)</td>
<td>6061 Tube, T-6</td>
<td>5086-M32</td>
<td>M-7 M-20</td>
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<td>Low Pressure Lines (PIL)</td>
<td>RT to LH</td>
<td>10¹⁶ to 10¹⁷ (F)</td>
<td>347 SS Tube, Anneal</td>
<td>718 Tube, HT (B)</td>
<td>M-2 M-1</td>
</tr>
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<td>Cryogenic Bellows Bearing</td>
<td>RT to LH</td>
<td>10¹⁶ to 10¹⁷ (F)</td>
<td>718 CW Bar with Several Coatings</td>
<td>Waspaloy with Several Coatings</td>
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<td>RT to LH</td>
<td>10¹⁶ to 10¹⁷ (F)</td>
<td>718 Sheet, HT (B)</td>
<td>347 SS Sheet, Anneal</td>
<td>M-1 M-2</td>
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<tr>
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<td>RT to LH</td>
<td>10¹⁶ to 10¹⁷ (F)</td>
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<td>718 Bar Forging</td>
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<td>10¹⁶ to 10¹⁷ (F)</td>
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### Notes
- Mechanical Properties
- Fatigue Resistance
- Fracture Toughness
- Radiation Damage
- Hydrogen Embrittlement
- Weld Properties
- Friction and Wear
## Identification of Materials Problems

### Actuators and Valve Assemblies Including Pressure and Stage Pressurant Line Systems

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<th>Problem</th>
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<td>1300 (10^{15} ) GHz (F) ((1) HR)</td>
<td>301 SS Vespel</td>
<td>Radiation Damage M-10 M-14</td>
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<td>(10^{16} ) GHz (F) ((10) HR)</td>
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<td>Fatigue Resistance</td>
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<td>(\gamma \times 10^7 ) to (10^{10} ) ergs/gm ((1) HR)</td>
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<td>Creep</td>
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<td>(\gamma \times 10^8 ) to (10^{11} ) ergs/gm ((10) HR)</td>
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<td>Seal Actuator Interfaces</td>
<td>RT Vac.</td>
<td>1300 (10^{16} ) to (10^{17} ) GHz (F) ((10) HR)</td>
<td>Hard Cr Versus Au, MoS₂, Ag, MoSe₂, etc.</td>
<td>Friction and Wear M-11</td>
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<td>to -423 LH₂</td>
<td></td>
<td>Versus BéCu</td>
<td>Coating Adhesion</td>
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<td>Coating Process Control</td>
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<td>1300 (10^{15} ) GHz (F) ((10) HR)</td>
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<td>1300 (10^{15} ) GHz (F) ((10) HR)</td>
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(F) DESIGNATES FAST NEUTRON FLUENCE GREATER THAN 1 MEV OVER 10 HOURS.
## IDENTIFICATION OF MATERIAL PROBLEMS

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<td>Entrapment of Particles or Frozen Fluids</td>
<td>Lines - Bellows Convolutes</td>
<td>718, 6061, 347 Inconel 718, AISI 310</td>
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<td>300 Stainless</td>
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<td>Dry Storage, Transportation</td>
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<td>All Materials</td>
<td>Develop Packaging Procedures and Specifications</td>
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<td>Contamination Criteria</td>
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<td>All Materials</td>
<td>To Be Determined; Component Specifications</td>
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<td>Monitoring Corrosion in Storage</td>
<td>All Components</td>
<td>All Materials</td>
<td>Method to be Determined</td>
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<td>All Materials</td>
<td>To Be Determined</td>
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<td>Corrosion Generation of Particles</td>
<td>PV - Shell and Head</td>
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<td>Cryo Valve - Housing</td>
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<td>Protective Finish Interior Surfaces; Inert Atmosphere in Storage</td>
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<td>T! 5Al-2.5Sn ELI</td>
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<td>AISI 310</td>
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<td>Actuator Interfaces</td>
<td>Cr, Au, Mo5g</td>
<td>Wear Testing, Coating Quality Assurance</td>
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<td>Valve Roller Cam Tracks</td>
<td>Colmonoy Hard Facing</td>
<td>Wear Testing, Coating Quality Assurance</td>
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**IDENTIFICATION OF MATERIAL PROBLEMS**

**INSTRUMENTATION AND CONTROLS**

<table>
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<tr>
<th>SUBASSEMBLY</th>
<th>PREDICTED ENVIRONMENT</th>
<th>SELECTED MATERIAL AND CONDITION</th>
<th>PROBLEM</th>
<th>TEST PLAN</th>
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<tr>
<td><strong>THRUST CHAMBER</strong></td>
<td></td>
<td></td>
<td>Thermal Cycling 4100 to -300°F Effect of Grain Growth on Physical Properties and Low Temperature Ductility</td>
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<tr>
<td><strong>PROBE (TEMP.)</strong></td>
<td>-320 °F</td>
<td>Vac/GH₂, 10¹⁷ to 10¹⁹ (F)</td>
<td>Tungsten-25 Re</td>
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<td><strong>WIRING</strong></td>
<td>-350 °F</td>
<td>Air/Vac, 10¹⁵ to 10¹⁸ (F)</td>
<td>Polymide Ins. Sheathed Ceramic Insulated Wire Ekonol High Temp Polyester.</td>
<td>Ref. 7820:H950:</td>
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<tr>
<td><strong>HARNESS INSUL.</strong></td>
<td>to 450 °F</td>
<td>Below Disk Shield</td>
<td>High Temperature Degradation in Space Vacuum. Outgassing Problems.</td>
<td>HAF</td>
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<tr>
<td><strong>(560 at OD of Shield)</strong></td>
<td></td>
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<tr>
<td><strong>CONNECTORS</strong></td>
<td>-350 °F</td>
<td>Air/Vac, 10¹⁷ to 10¹⁸ (F)</td>
<td>Reinforced Polymer Insul. Ceramic Insul.</td>
<td>Ref. 7820:H910:</td>
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<tr>
<td><strong>POTTING MATERIAL</strong></td>
<td>to 400 °F</td>
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<td>brittleness of Electrical Insulation Surface Contamination.</td>
<td>RML</td>
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<td><strong>TRANSUDERS</strong></td>
<td>-300 °F</td>
<td>Air/Vac, 10¹³ to 10¹⁸ (F)</td>
<td>To Be Selected</td>
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<tr>
<td><strong>PRESSURE</strong></td>
<td>to 400 °F</td>
<td></td>
<td>Material Selection to Provide Adequate Properties at High &amp; Low Temperatures in Space. Must Not Outgas or Spall.</td>
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(F) - Designates fast neutron fluence greater than 1 MeV over 10 hours.
## IDENTIFICATION OF MATERIAL PROBLEMS
### DISK SHIELD ASSEMBLY

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<th>SUBASSEMBLY</th>
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<th>RADIATION - 10 HR</th>
<th>SELECTED MATERIAL AND CONDITION</th>
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<th>TEST PLAN IDENTITY</th>
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<tr>
<td></td>
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<td>°F</td>
<td>ATMOS</td>
<td>NVT</td>
<td>PRIME</td>
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<tr>
<td>GRAPHITE 3% BORON</td>
<td>-100 to 600</td>
<td>10^{14} to 10^{17}</td>
<td>Air/Space (Outside Housing)</td>
<td>10^{16} to 10^{18} (F)</td>
<td>UCC &quot;CS&quot; + B</td>
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<tr>
<td>LEAD SLABS</td>
<td>-100 to 600</td>
<td>10^{13} to 10^{17}</td>
<td>Air/Space (Outside Housing)</td>
<td>10^{14} to 10^{18} (T)</td>
<td>St. Joe &quot;DS Lead&quot;</td>
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<tr>
<td>LITHIUM HYDRIDE</td>
<td>-100 to 600</td>
<td>10^{12} to 10^{16}</td>
<td>GH, Internal (Outside Housing)</td>
<td>10^{15} to 10^{18} (T)</td>
<td>347 CRES Can or Housing</td>
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<tr>
<td>SHIELD CAIS</td>
<td>500 to 600</td>
<td>10^{11} to 10^{17}</td>
<td>Space</td>
<td>347 CRES</td>
<td>Boron Stainless</td>
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<tr>
<td>HOUSING</td>
<td>-100 to 600</td>
<td>5 x 10^{17}</td>
<td>Air (Salt Contamination)</td>
<td>347 CRES Outside</td>
<td>Alternate Coatings</td>
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</table>

(T) - Designates total neutron fluence over 10 hours.

(F) - Designates fast neutron fluence greater than 1 Mev over 10 hours.

Mechanical Properties
Physical Properties
Porosity/Homogeneity
Commercial Product Utilization

Dimensional Stability
Close Tolerance Control
Differential Thermal Expansion with Canning Material
Thermal Cycling and Distortion
Dispersion Harden Mech. Properties

GH4 Generation at High Service Temp.
Powder Compaction Parameters
Mechanical Properties
Physical Properties

Weld development
Dimensional Stability
Assembly Fit Up
Mechanical Properties
Physical Properties

Thermal Coating Reliability and Properties
Coating Application Integrity
Stability in Space Environment
APPENDIX C

PRELIMINARY TEST PLAN MATRICES
**TEST PLAN: M-1 718**

**COMPONENTS:** TPA, VALVES, LINES

<table>
<thead>
<tr>
<th>CONDITION/FORM</th>
<th>TEST TYPE</th>
<th>PROPERTY</th>
<th>RAD LEVEL***</th>
<th>HEATS</th>
<th>TEST TEMPERATURE, °F</th>
<th>TOTAL SPECS</th>
<th>TEST MATRIX BASIS</th>
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HT B/F, CH & AGE TEST SPECIFICATION

---

*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

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<th>HEATS</th>
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</table>

**FB** - Furnace Braze Condition

**ANH** - 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:** July 23, 1970

**Revision:** 1

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<th>Condition/Form</th>
<th>Property</th>
<th>Rad Level***</th>
<th>Heat S</th>
<th>Test Temperature °F</th>
<th>Test Direction</th>
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<td>Irradiated Toughness</td>
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<td>4</td>
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**Note:** 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  
**DATE:** 23 JULY 1970  
**COMPONENT:** LOWER THRUST STRUCTURE  

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<th>PROPERTY</th>
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<th>HEATS</th>
<th>TEST TEMPERATURE, °F</th>
<th>TOTAL SPECS</th>
<th>TEST MATRIX BASIS</th>
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***Fast Neutron Fluence, Energy Greater than 1 Mev.
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| ANN/EB W/F     | TENSILE        | 2          | 8     | 8                     | 24          | DESIGN            |
| ANN/F          | TOUGHNESS      | 2          | 10    | 10                    | 20          | DESIGN            |
| ANN/EB W/F     | TOUGHNESS      | 2          | 8     | 8                     | 24          | DESIGN            |
| ANN/F          | FATIGUE        | 2          | 60    |                        | 60          | DESIGN            |
| ANN/F          | IMPACT TENSILE | 1          | 30    |                        | 60          | DESIGN            |
| ANN/F          | IRRAD TENSILE  | 0,1,7,18,19| 1     | 16                    | 16          | SCREEN            |
| ANN/F          | IRRAD TOUGHNESS| 0,1,7,18,19| 1     | 16                    | 16          | SCREEN            |
| ANN/T          | TENSILE        | 2          | 4     | 4                     | 4           | 24                |
| ANN/TM         | TENSILE        | 2          | 4     | 4                     | 4           | 24                |
| ANN/T          | TOUGHNESS      | 2          | 4     | 4                     | 4           | 24                |
| ANN/TM         | TOUGHNESS      | 2          | 4     | 4                     | 4           | 24                |
| T              | FATIGUE        | 2          |       |                        | 60          | 60                |
| TW             | FATIGUE        | 2          |       |                        | 60          | 60                |
| S              | TENSILE        | 2          |       |                        | 4           | 4                 |
| SW             | TENSILE        | 2          |       |                        | 4           | 4                 |
| S              | FATIGUE        | .2         |       |                        | .2          | 32                |
| SW             | FATIGUE        | .2         |       |                        | .2          | 60                |
| 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

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*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.
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*CELL WALL TO LINER BOND STRENGTH.
**ONLY TO BE CONDUCTED ON FINAL CANDIDATE MATERIAL.
***5 x 10⁻⁸ NRT - FAST NEUTRON FLUENCE, ENERGY GREATER THAN 1 MEV., TEST CONTROLS.
## TEST PLAN: M-6 GRAPHITE COMPOSITE

**COMPONENT:** NOZZLE EXTENSION

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*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 May 1970

### Revision: 1

### Table: Total Test Matrix

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**Note:**
- 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-8 2024 Sheet/Plate; 2014 Forging/Extrusion

**Component:** Upper Thrust Structure

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| T6/F           | K, a, p, E        | 1         |       | 4                    | 4           | (Design)          |

( ) Low variability indicated by experience and/or literature. To 69-28 statistical rules not required.
**TEST PLAN:** M-9 Ti 6Al-4V
**COMPONENT:** LOWER THRUST STRUCTURE

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*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.
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(1) REFERENCE: MEMO 70-202, SOURCE CARBORUNDUM CO.  
(2) REFERENCE: ANSC QUOTE NO. (AQR) L-0135.
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### Test Plan: M-14 Polyimides

**Components:** Valves

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( ) Low variability indicated by experience and/or literature. TD 69-28 statistical rules not required.

*Gamma dose expressed in ergs/gm.
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( ) LOW VARIABILITY INDICATED BY EXPERIENCE AND/OR LITERATURE. TD 69-28 STATISTICAL RULES NOT REQUIRED
**TEST PLAN: M-20 AA 5086**

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*As-Welded

T/tj - Transition Joint.

***FAST NEUTRON FLUENCE, ENERGY GREATER THAN 1 MEV.
**TEST SUMMARY SHEET**

**7075-T73 ALUMINUM ALLOY FORGING, EXTRUDED**

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-320 TO RT

|               |                           |              |       |    |    |    |    |    |    |    |    |    |    |    |    |
|               |                           |              |       |    |    |    |    |    |    |    |    |    |    |    |    |

(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 H₂ Embrittlement

**Components:** TPA, Actuator, Nozzle

**Date:** 23 Jan 1970  
**Revision:** 1  
**Page 1 of 2**

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**TEST PLAN: M-22 HIGH PRESSURE GH$_2$ EMBRITTLEMENT**

**COMPONENTS:** TPA, ACTUATOR, NOZZLE

**DATE:** 23 S 1970

**REVISION:** 1

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*FB - Furnace Braze*
## TEST PLAN: M-23 GH₂, STRESS AND RADIATION SYNERGISTIC EFFECTS

**DATE**: 23 Nov 1970  
**REVISION**: 1

**COMPONENTS**: ALL

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**CONTROL TESTS TO ESTABLISH IF GH₂ + STRESS WILL FRACTURE SPECIMENS WITHOUT MACRO-DEFORMATION, IF FRACTURE DOES NOT OCCUR AT 1500 PSI, SUSTAINED STRESS WILL BE MAINTAINED FOR 10⁴ HOURS.**

**FLUENCE AND TEST PRESSURE DEPENDENCE.**

+ FAST NEUTRON FLUENCE, ENERGY GREATER THAN 1 MEV.

26 IRRAD EACH OF 3 MATERIALS.  
81 UNIRRADIATED 718 ONLY.
<table>
<thead>
<tr>
<th>CONDITION/FORM</th>
<th>PROPERTY</th>
<th>RAD LEVEL 10 PWR</th>
<th>HEATS</th>
<th>TEST TEMPERATURE, °F</th>
<th>TOTAL SPECS</th>
<th>TEST MATRIX BASIS</th>
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<td>1 MEASUREMENT (-100 TO 600°F)</td>
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<td>1</td>
<td>1 (AT ROOM TEMP)</td>
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<td>(DESIGN)</td>
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( ) LOW VARIABILITY INDICATED BY EXPERIENCE AND/OR LITERATURE. TD 69-28 STATISTICAL RULES NOT REQUIRED.
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<th>CONDITION/FORM</th>
<th>PROPERTY</th>
<th>RAD LEVEL</th>
<th>HEATS</th>
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### Test Plan: M-29 310 SS

**Components:** TPA Manifold and Housing

**Date:** 23 July 1970

**Revision:** 1

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<th>Property</th>
<th>RAD Level 10 1%</th>
<th>HEATS</th>
<th>Test Temperature, °F</th>
<th>Total Specs</th>
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**Thermal Expansion**

- 1 Measurement (RT to -160)

**Thermal Conductivity**

- 1 Measurement (RT to -160)

**Notes:**

- **M₁** = TIG Welding
- **V₂** = Electron Beam Welding
- Low variability indicated by experience and/or literature. TD 69-28 statistical rules not required.
<table>
<thead>
<tr>
<th>CONDITION/FORM</th>
<th>PROPERTY</th>
<th>RAD LEVEL***</th>
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</table>

( ) 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

**Component:** Actuator  
**Date:** 23 July 1970  
**Revision:** 1

### Total Test Matrix

<table>
<thead>
<tr>
<th>Condition/Form</th>
<th>Property</th>
<th>Rad Level***</th>
<th>10 Per Heat</th>
<th>Heats</th>
<th>Test Temperature, °F</th>
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<th>Test Matrix Basis</th>
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<td>L ST</td>
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<tr>
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***Fast Neutron Fluence, Energy Greater Than 1 MeV.***
### TEST PLAN: M-33 LITHIUM HYDRIDE

**COMPONENT:** SHIELD

<table>
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<th>PROPERTY</th>
<th>RAD LEVEL 10 PWR</th>
<th>HEATS</th>
<th>TEST TEMPERATURE, °F</th>
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( ) LOW VARIABILITY INDICATED BY EXPERIENCE AND/OR LITERATURE. TD 69-28 STATISTICAL RULES NOT REQUIRED.
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***Fast Neutron Fluence, Energy Greater Than 1 MeV.
### Test Plan: H-37 Phos Bronze

**Component:** Valves

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<th>Condition/Form</th>
<th>Property</th>
<th>RAD Level***</th>
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**Date:** 23 July 1970

**Revision:** 1

---

( ) Low variability indicated by experience and/or literature. Tu 69-28 statistical rules not required.

*** Fast neutron fluence, energy greater than 1 MeV.
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<th>CONDITION/FORM</th>
<th>PROPERTY</th>
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<th>HEATS</th>
<th>TEST TEMPERATURE, °F</th>
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TEST PLAN: M-30 STAINLESS STEEL 22-13-5

DATE: 11 AUGUST 1970

COMPONENT: NOZZLE

REVISION: 1

TEST TEMPERATURE, °F:
-RT: Room Temperature
-600
-1200
-320
-423
-100

TOTAL SPECS:
-80: DESIGN
-12: SCREEN
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*(LOW VARIABILITY INDICATED BY EXPERIENCE AND/OR LITERATURE. TD 69-28 STATISTICAL RULES NOT REQUIRED.)*