AGC - 2275 (Vol 4)

s131-DRM08-W1&7f4

MANUAL OF
MATERIALS DATA RELEASE MEMORANDA.
PART II: DRM 05 through 23.

NERVA Program

Contract SNP-1

APRIL 1971

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MASTER

K. Sato

K. Sato
Manager, Engineering Staff
Engineering Operations

Classification Category

UNCLASSIFIED

T. A. Ruffel
Classifying Officer

4/28/71
Date

DISTRICT

5

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05 - ALLOY A-286

DATA RELEASE MEMORANDUM

NRO MATERIALS AND PROCESSES STAFF

DRM
TYPE:

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

SHEET 1 OF 8

DRM NO.
05.01REV. NO.
0

SUBJECT: DESIGN ALLOWABLES FOR A-286 FORGINGS

DATE: 2-16-70

1. SCOPE:

The design allowables for the following mechanical and physical properties of Alloy A-286 forgings are attached:

Ultimate Tensile Strength
Tensile Yield Strength
Elongation
Modulus of Elasticity
Coefficient of Linear Thermal Expansion
Thermal Conductivity

2. TEST MATERIAL:

The room temperature properties were obtained from a compressor disc forging; the billet stock was consumable electrode melted. The forging was solution treated at 1650°F for 2 to 4 hours, oil or water quenched, and aged at 1300° to 1375°F for 16 hours. Low temperature data were obtained from bar material, solution treated at 1800°F and aged similar to the forgings.

3. DATA ANALYSIS:

The room temperature mechanical properties of Alloy A-286 are very sensitive to thermomechanical treatment resulting in a wide spread of data for forged material. Because the data are representative of particular shape by a particular forging source, selection was limited to compressor disc whose properties were conservative.

The room temperature tensile properties were obtained in the tangential and radial directions of the disc. The tensile strength and elongation data were pooled and found to be homogeneous in means and variance. The tensile yield strength data, similarly pooled, were homogeneous in means but heterogeneous in variance.

Low temperature (-100, -320 and -423°F) tensile values were based on published data for bar solution treated at 1800°F (standard solution treating temperature, 1650°F) but aged similar to the forgings. The higher solution treating treatment generally results in lower tensile properties; however, the bar data at room temperature were higher than the average obtained on forgings.

APPROVED BY <i>[Signature]</i>	DATE <i>3/17/70</i>	PREPARED FOR: E. B. W., L. Johnson	COMPONENT/ ASSEMBLY IDENT
PREPARED BY <i>[Signature]</i>		DATE <i>2/17/70</i>	
		AUTHORIZED CLASSIFIER <i>[Signature]</i>	DATE <i>19 Feb</i>

TPA
Valves

DATA RELEASE MEMORANDUM

NRO MATERIALS AND PROCESSES STAFF

DRM
TYPE:

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

SHEET 2 OF 8DRM NO.
05.01REV. NO.
0

SUBJECT: DESIGN ALLOWABLES FOR A-286 FORGINGS

DATE: 2-16-70

The design allowables for subzero temperatures were computed by assuming the same degree of variance ($\bar{X} - ks$) at low temperatures as obtained for room temperature.

Moduli and thermal expansion data are as reported in the literature. Thermal conductivity values were extrapolated from elevated temperature data using the low temperature behavior of AISI 347 as a guide.

4. CONCLUSIONS:

The data are rated Category "C", a conservative engineering estimate of statistical allowable values, because of limited data analysis and differences in form and heat treat condition of the data in the literature.

5. REFERENCES:

Materials Property Data Compilation A-286 Forgings and Castings, Part III, General Electric Co., Section B 8.8, February 1963.

Cryogenic Materials Data Handbook (Revised), Volume 1, Section B 11, August 1968.

Mil Handbook 5, Figure 6.2.1.1, page 645, February 8, 1966.

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

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 05.01 PAGE NO. 3 DATE 2-16-70 MATERIAL A-286Solution Treated and Aged at
CONDITION 1300/1375°F - 16 Hours TEST DIRECTION Tangential and RadialSPEC. NOS. AMS 5737 FORM ForgingDATA BASIS Category "C" COMMENT PROPERTY Ultimate Tensile Strength (F_{tu})

TEMP °F	LOPS/ HEATS	N	N _e	$\bar{X}$	K	S	COMPUTED VALUE ksi
70	1	8		153	4.354	2.87	140.5
-100	-	-		-			162
-320	-	-		-			196
-423	-	-		-			230

REFERENCE. Materials Property Data Compilation A286 Forgings and Castings,
Part III, General Electric Co., Section B 8.8, February 1963.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 05.01 PAGE NO. 4 DATE 2-16-70 MATERIAL A-286
CONDITION Solution Treated and Aged TEST DIRECTION Tangential and Radial
SPEC. NOS. AMS 5737 FORM Forging
DATA BASIS Category "C" COMMENT _____
PROPERTY Tensile Yield Strength (F_{ty})

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$	K	S	COMPUTED VALUE ksi
70	1	8		102.2	4.354	2.25	92.4
-100							100
-320							115
-423							132

REFERENCE: Materials Property Data Compilation A286 Forgings and Castings,
Part III, General Electric Co., Section B 8.8, February 1963.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DEM NO. 05.01 PAGE NO. 5 DATE 2-16-70 MATERIAL A-286

CONDITION Solution Treated
and Aged TEST DIRECTION Tangential and Radial

SPEC. NOS. AMS 5737 FORM Forging

DATA BASIS Category "C" COMMENT

PROPERTY Elongation, %

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$	s	S	COMPUTED VALUE %
70	1	8		24.4	4.354	2.125	15.2
<100							19.0
<320							26.0
<423							27.0

REFERENCE: Materials Property Data Compilation A286 Forgings and Castings,
Part III, General Electric Co., Section B 8.8, February 1963.

DATA RELEASE

PROPERTY Modulus of Elasticity, E

TEMP °F	LOTS/ HEATS	N	N _e	X̄	K	S	COMPUTED VALUE psi
70							28.8 x 10 ⁶
~100							28.5 x 10 ⁶
~320							29.6 x 10 ⁶
~423							30.0 x 10 ⁶
-	-	-	-	-	-	-	-

REFERENCE: Modulus of Elasticity of A286 Stainless Steel, Section B.11.ij,
Cryogenic Materials Data Handbook, AFML-TDR-64-280, August 1968.

DATA RELEASE

PROPERTY	Coefficient of Linear Thermal Expansion, α
Aluminum	23.6
Brass	19.0
Carbon Steel	12.5
Copper	16.6
Gold	14.2
Invar	0.6
Iron	11.8
Lead	29.0
Nickel	13.3
Platinum	9.0
Silver	19.3
Stainless Steel	16.5
Titanium	8.6
Zinc	26.0

[illegible]

REFERENCE: Coefficients of Linear Thermal Expansion Calculated using Data Taken from Figure B 11.t (Lower Curve), Cryogenic Materials Data Handbook, AFML-TDR-64-280, August 1968.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 05.01 PAGE NO. 8 DATE 2-16-70 MATERIAL A-286CONDITION _____ TEST DIRECTION Tangential and RadialSPEC. NOS. AMS 5737 FORM ForgingDATA BASIS Category "C" COMMENT _____PROPERTY Thermal Conductivity, K

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$	K	S	COMPUTED VALUE Btu/[hr-ft ² -°F/ft]
70	1						7
0							6.5
-100							5.5
-320							3.0
-423							1

REFERENCE: Thermal Conductivity Data Extrapolated from Elevated Temperature Data in Figure 6.2.1.1, page 645, Mil Handbook 5, February 8, 1966, and Extrapolated to Subzero Temperatures Using the Behavior of AISI 347 as a guide.

DATA RELEASE MEMORANDUM

NRO MATERIALS AND PROCESSES STAFF

DRM
TYPE:

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

DRM NO.
05.02

REV. NO.

0

SHEET 1 OF 4

SUBJECT: DESIGN ALLOWABLES FOR MECHANICAL
PROPERTIES OF A-286 ALLOY BOLTS,
COLD WORKED AND AGED

DATE: 2-24-70

1. SCOPE:

The design allowables for the following properties of A286 alloy bolts in the cold worked and aged condition are attached:

Ultimate Tensile Strength
Tensile Yield Strength
Elongation

2. TEST MATERIAL:

The raw material met the requirements of Specifications AMS 5735 or AMS 5737. The bar in the solution treated and cold worked condition was processed and aged to meet the specific strength requirements of 180 ksi TYS - 200 ksi UTS minimum.

3. DATA ANALYSIS:

The analysis was limited to the bolt lots which met the requirements of 180 ksi TYS - 200 ksi UTS minimums. In addition, two lots which had very high tensile values and marginal but passable yield strengths were classified as abnormal and not included in the data analysis. The bolts from these two lots were less than 1/2 in. dia. indicating a possible sensitivity to size. The tensile strength data for the three lots examined were homogeneous in mean variance but heterogeneous in among-lot variance. The tensile strength design allowable, calculated using the one-sided tolerance factor and the overall variance, is 186 ksi, a value below normal specification limits. The tensile yield values were heterogeneous in mean variance and among-lot variance; elongation data were homogeneous in mean variance but heterogeneous in among-lot variance.

Low temperature (-100, -320 and -423°F) properties and room temperature modulus data for cold worked and aged bolts were not available. Thermal expansion and thermal conductivity values for this alloy are included in DRM 5-B, A286 forgings; these data are applicable to bolts of the same material.

4. CONCLUSIONS:

Because of the heterogeneity of the raw data, a conservative estimate of the statistical design allowables was made, and the data is classified Category "C".

5. REFERENCES:

AGC Inspection or Test Referrals Nos. 15952, 34106 and 34177.

APPROVED BY <i>[Signature]</i>	DATE 3/10/70	PREPARED FOR: L. JOHNSON, E. BAIR DATE:	COMPONENT/ ASSEMBLY IDENT
PREPARED BY <i>[Signature]</i>		AUTHORIZED CLASSIFIER <i>[Signature]</i>	DATE 10 March 70

Pressure
Vess
Valve
TPA

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 05.02 PAGE NO. 2 DATE 2-24-70 MATERIAL A-286

CONDITION CW & Aged TEST DIRECTION _____

SPEC. NOS. AMS 5735 or 5737 FORM _____ Bolts (1/2 to 1 in. dia. max.)

DATA BASIS Category "C" COMMENT _____

PROPERTY Ultimate Tensile Strength

TEMP °F	LOTS/ HEATS	N	N _c	$\bar{X}$ ksi	K	S	COMPILED VALUE ksi
70	3	12		202	3.7	4.3	182
-320	1	3		265	10.553	2.08	243
-423	1	3		270.3	10.553	2.89	240

COMMENTS:

AGC Inspection or Test Referral Nos. 15952, 34106 and 34177.
Evaluation of Fasteners and Fastener Materials for Space Vehicles,
SPS Report, Dec. 1965

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 05.02 PAGE NO. 3 DATE 2-24-70 MATERIAL A-286

CONDITION CW & Aged TEST DIRECTION

SPEC. NOS. AMS 5735 or 5737 FORM Bolts (1/2 to 1 in. dia. max.)

DATA BASIS	Category "C"	COMMENT

PROPERTY	Tensile Yield Strength	
----------	------------------------	--

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$ ksi	K	S	COMPUTED VALUE ksi
70	3	12		180.4	3.7	5.6	159

COMMENTS: AGC Inspection and Test Referrals Nos. 15952, 34016 and 34177.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 05.02 PAGE NO. 4 DATE 2-24-70 MATERIAL A-286CONDITION CW & Aged TEST DIRECTION _____SPEC. NOS. AMS 5735 or 5737 FORM _____ Bolts, 1/2 to 1 in. dia.
max.DATA BASIS Category "C" COMMENT _____PROPERTY Elongation, %

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$ %	K	S	COMPUTED VALUE %
70	3	12		10.9	3.7	.94	7.4

COMMENTS: AGC Inspection or Test Referral Nos. 15952, 34016 and 34177.

DATA RELEASE MEMORANDUM

NRO MATERIALS AND PROCESSES STAFF

DRM
TYPE:

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

SHEET 1 OF 2

DRM NO.

05.03

REV. NO.

0

SUBJECT: THERMOPHYSICAL PROPERTIES OF A286

DATE: 8-3-70

1. SCOPE:

The design allowables for the following thermal properties of A-286 are attached:

Specific Heat

2. TEST MATERIAL:

Specific heat data for material which conforms to the chemical composition requirements for AISI 301 were taken from the literature.

3. ANALYSIS OF DATA:

The specific heat data of AISI 301 are a close approximation to that of Alloy A286 since both are austenitic, nickel-chromium steels. Uncertainty factors were estimated to be ± 15 percent at -300°F , $\pm 10\%$ from -200°F to RT, ± 5 percent at RT and higher.

4. CONCLUSIONS:

These data are categorized "C", a conservative engineering estimate of the properties with uncertainty ranges.

APPROVED BY	DATE	PREPARED FOR:	COMPONENT/
7/3/70	DATE:	ASSEMBLY
PREPARED BY		AUTHORIZED CLASSIFIER	IDENT
V E. 7/1/74		DATE	

AEROSPACE-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DDI NO. 05.03 PAGE NO. 2 DATE 8-3-70 MATERIAL AISI 660 (A286)

CONDITION _____ TEST DIRECTION _____

SPEC. NOS. _____ FORM _____
 DATA BASIS Category "C" COMMENT Data is for AISI 301, a close approximation to that of AISI 303

PROPERTY Specific Heat

TEMP °F	C _P BTU/LB °F	UNCERTAINTY FACTOR %				
-300	0.085	15				
-200	0.09	10				
-100	0.095	10				
0	0.104	5				
200	0.115	5				
400	0.126	5				

REFERENCE. Thermophysical Properties of High Temperature Solid Materials,
Thermophysical Properties Research Center, Purdue University,
Purdue, Indiana, Y. S. Touloukian, Editor.

06 - AGCarb 101

NRO MATERIALS AND PROCESSES STAFF

1.
TYPE:

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

DPM NO.

06.01

REV. NO.

0

SHEET 1 OF 27

SUBJECT:

AGCarb-101

DATE:

12-19-69

1. SCOPE: Data from the reference test program were analyzed to develop allowable values for the following properties:

Ultimate Tensile Strength
Compressive Strength
Interlaminar Shear Strength
Fatigue Strength
Fracture Toughness
Flexure Strength
Modulus of Elasticity
Thermal Expansion
Thermal Conductivity

2. TEST MATERIAL: Flat plates, 1 inch and 1/4 inch thick, from one material lot.

3. DATA ANALYSIS Data was statistically analyzed to provide $\bar{X}$ - Ks computed values for 99% reliability with 95% confidence. Analysis of variance to evaluate homogeneity of data was not conducted. Computed values were evaluated to provide conservative estimate of statistical allowable that would be applicable for NERVA material.

4. CONCLUSIONS: Data is Category "C" per interpretation of TD 69-37 requirements based upon:

a - Test material form and condition is not as used in NERVA.

b - Property data from only one lot is analyzed.

5. DATA REFERENCE:

"Fabrication and Properties of the Fibrous Reinforced Graphite Composite, AGCarb-101," Aerojet-General Corp., Liquid Rocket Div., Aug. 1969.

APPROVED BY	DATE 1/14/70	PREPARED FOR: L. S. Hurley DATE: 1/14/70	COMPONENT/ ASSEMBLY IDENT
PREPARED BY L. M. Sharp	AUTHORIZED CLASSIFIER AW Hurley	DATE 14 Jan 70	

SKIRT
EXT.

DEFINITION OF TERMS

06.01

a. Warp and Fill Directions of a Fabric Layer (Ply)

b. Block Tensile

c. Flexure (Perpendicular to Plys)

d. Flexure (Parallel to Plys)

E. Compressive (WARP DIRECTION)

F. INTERLAMINAR SHEAR

G. FRACTURE TOUGHNESS

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 06.01 PAGE NO. 4 DATE 12-19-69 MATERIAL AGCarb-10

CONDITION _____ TEST DIRECTION Warp Fiber Direction

SPEC. NOS. _____

DATA BASIS "C" per TD 69-37 COMMENT 1-in. Thick Plate
Flat Test Specimen

PROPERTY Ultimate Tensile Strength (Ftu)

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$ KSI	K	S	COMPUTED VALUE KSI
RT	1	20 ^x	-	11.27	3.295	.665	9.08

COMMENTS:

DATA RELEASE

MATERIAL AGCarb-101

TEST DIRECTION Warp Fiber Direction

SPEC. NOS. _____

1-in. Thick Plate
COMMENT Round Test Specimens

PROPERTY	Ultimate Tensile Strength (Ftu)
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[illegible]

COMMENTS :

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 06.01 PAGE NO. 5 DATE 12-19-69 MATERIAL AGCarb-101

CONDITION _____ TEST DIRECTION Warp Fiber Direction

SPEC. NOS. _____

DATA BASIS "C" per TD 69-37 COMMENT 1-in. Thick Plate Round Test Specimens

PROPERTY Ultimate Tensile Strength (Ftu)

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$ KSI	K	S	COMPUTED VALUE KSI
RT	1	41	-	10.45	2.932	.765	8.21
2000	1	10	0	11.53	3.98	.798	8.35
3000	1	5	-	12.78	5.74	.840	7.96

COMMENTS:

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 06.01 PAGE NO. 5 DATE 12-19-69 MATERIAL AGCarb-101

CONDITION _____ TEST DIRECTION Warp Fiber Direction

SPEC. NOS. _____

DATA BASIS "C" per TD 69-37 COMMENT 1-in. Thick Plate Round Test Specimens

PROPERTY Ultimate Tensile Strength (Ftu)

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$ KSI	K	S	COMPUTED VALUE KSI
RT	1	41	-	10.45	2.932	.765	8.21
2000	1	10	0	11.53	3.98	.798	8.35
3000	1	5	-	12.78	5.74	.840	7.96

COMMENTS:

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 06.01 PAGE NO. 6 DATE 12-19-69 MATERIAL AGCarb-101

CONDITION	TEST DIRECTION	Warp Fiber Direction
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SPEC. NOS. _____

DATA BASIS		COMMENT
"C" per TD 69-37		1/4-in. Thick Flat Round Test Specimens

PROPERTY	Ultimate Tensile Strength (Ftu)
1. 100% Break	100
2. 100% Break	100
3. 100% Break	100
4. 100% Break	100
5. 100% Break	100
6. 100% Break	100
7. 100% Break	100
8. 100% Break	100
9. 100% Break	100
10. 100% Break	100
11. 100% Break	100
12. 100% Break	100
13. 100% Break	100
14. 100% Break	100
15. 100% Break	100
16. 100% Break	100
17. 100% Break	100
18. 100% Break	100
19. 100% Break	100
20. 100% Break	100
21. 100% Break	100
22. 100% Break	100
23. 100% Break	100
24. 100% Break	100
25. 100% Break	100
26. 100% Break	100
27. 100% Break	100
28. 100% Break	100
29. 100% Break	100
30. 100% Break	100
31. 100% Break	100
32. 100% Break	100
33. 100% Break	100
34. 100% Break	100
35. 100% Break	100
36. 100% Break	100
37. 100% Break	100
38. 100% Break	100
39. 100% Break	100
40. 100% Break	100
41. 100% Break	100
42. 100% Break	100
43. 100% Break	100
44. 100% Break	100
45. 100% Break	100
46. 100% Break	100
47. 100% Break	100
48. 100% Break	100
49. 100% Break	100
50. 100% Break	100
51. 100% Break	100
52. 100% Break	100
53. 100% Break	100
54. 100% Break	100
55. 100% Break	100
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57. 100% Break	100
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60. 100% Break	100
61. 100% Break	100
62. 100% Break	100
63. 100% Break	100
64. 100% Break	100
65. 100% Break	100
66. 100% Break	100
67. 100% Break	100
68. 100% Break	100
69. 100% Break	100
70. 100% Break	100
71. 100% Break	100
72. 100% Break	100
73. 100% Break	100
74. 100% Break	100
75. 100% Break	100
76. 100% Break	100
77. 100% Break	100
78. 100% Break	100
79. 100% Break	100
80. 100% Break	100
81. 100% Break	100
82. 100% Break	100
83. 100% Break	100
84. 100% Break	100
85. 100% Break	100
86. 100% Break	100
87. 100% Break	100
88. 100% Break	100
89. 100% Break	100
90. 100% Break	100
91. 100% Break	100
92. 100% Break	100
93. 100% Break	100
94. 100% Break	100
95. 100% Break	100
96. 100% Break	100
97. 100% Break	100
98. 100% Break	100
99. 100% Break	100
100. 100% Break	100

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$	K	S	COMPUTED VALUE KSI
RT	1	40	-	11.40	2.94	1.09	8.20
2000	1	10	-	11.75	3.98	.89	8.21
3000	1	10	-	13.46	3.98	1.07	9.20

COMMENTS :

AEROJET-GENERAL NUCLEAR ROCKET' OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 06.01 PAGE NO. 7 DATE 12-19-69 MATERIAL AGCarb-101

CONDITION	TEST DIRECTION	Fill	Fiber	Direction
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SPEC. NOS. _____

DATA BASIS	"C" per TD 69-37	COMMENT	1-in. Plate Round Specimen
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PROPERTY	Ultimate Tensile Strength (Ftu)
1. 100% Break	100,000
2. 100% Break	100,000
3. 100% Break	100,000
4. 100% Break	100,000
5. 100% Break	100,000
6. 100% Break	100,000
7. 100% Break	100,000
8. 100% Break	100,000
9. 100% Break	100,000
10. 100% Break	100,000
11. 100% Break	100,000
12. 100% Break	100,000
13. 100% Break	100,000
14. 100% Break	100,000
15. 100% Break	100,000
16. 100% Break	100,000
17. 100% Break	100,000
18. 100% Break	100,000
19. 100% Break	100,000
20. 100% Break	100,000
21. 100% Break	100,000
22. 100% Break	100,000
23. 100% Break	100,000
24. 100% Break	100,000
25. 100% Break	100,000
26. 100% Break	100,000
27. 100% Break	100,000
28. 100% Break	100,000
29. 100% Break	100,000
30. 100% Break	100,000
31. 100% Break	100,000
32. 100% Break	100,000
33. 100% Break	100,000
34. 100% Break	100,000
35. 100% Break	100,000
36. 100% Break	100,000
37. 100% Break	100,000
38. 100% Break	100,000
39. 100% Break	100,000
40. 100% Break	100,000
41. 100% Break	100,000
42. 100% Break	100,000
43. 100% Break	100,000
44. 100% Break	100,000
45. 100% Break	100,000
46. 100% Break	100,000
47. 100% Break	100,000
48. 100% Break	100,000
49. 100% Break	100,000
50. 100% Break	100,000
51. 100% Break	100,000
52. 100% Break	100,000
53. 100% Break	100,000
54. 100% Break	100,000
55. 100% Break	100,000
56. 100% Break	100,000
57. 100% Break	100,000
58. 100% Break	100,000
59. 100% Break	100,000
60. 100% Break	100,000
61. 100% Break	100,000
62. 100% Break	100,000
63. 100% Break	100,000
64. 100% Break	100,000
65. 100% Break	100,000
66. 100% Break	100,000
67. 100% Break	100,000
68. 100% Break	100,000
69. 100% Break	100,000
70. 100% Break	100,000
71. 100% Break	100,000
72. 100% Break	100,000
73. 100% Break	100,000
74. 100% Break	100,000
75. 100% Break	100,000
76. 100% Break	100,000
77. 100% Break	100,000
78. 100% Break	100,000
79. 100% Break	100,000
80. 100% Break	100,000
81. 100% Break	100,000
82. 100% Break	100,000
83. 100% Break	100,000
84. 100% Break	100,000
85. 100% Break	100,000
86. 100% Break	100,000
87. 100% Break	100,000
88. 100% Break	100,000
89. 100% Break	100,000
90. 100% Break	100,000
91. 100% Break	100,000
92. 100% Break	100,000
93. 100% Break	100,000
94. 100% Break	100,000
95. 100% Break	100,000
96. 100% Break	100,000
97. 100% Break	100,000
98. 100% Break	100,000
99. 100% Break	100,000
100. 100% Break	100,000

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$ KSI	K	S	COMPUTED VALUE KSI
RT	1	8	-	4.56	4.35	.325	3.15

COMMENTS :

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 06.01 PAGE NO. 8 DATE 12-19-69 MATERIAL AGCarb-101

CONDITION _____ TEST DIRECTION _____ Block Direction
(Perpendicular to plies of fabric)

SPEC. NOS. _____

DATA BASIS	"C"	COMMENT
		1/4-in. Plate

PROPERTY	Ultimate Tensile Strength (Ftu)
1	100
2	100
3	100
4	100
5	100
6	100
7	100
8	100
9	100
10	100
11	100
12	100
13	100
14	100
15	100
16	100
17	100
18	100
19	100
20	100
21	100
22	100
23	100
24	100
25	100
26	100
27	100
28	100
29	100
30	100
31	100
32	100
33	100
34	100
35	100
36	100
37	100
38	100
39	100
40	100
41	100
42	100
43	100
44	100
45	100
46	100
47	100
48	100
49	100
50	100
51	100
52	100
53	100
54	100
55	100
56	100
57	100
58	100
59	100
60	100
61	100
62	100
63	100
64	100
65	100
66	100
67	100
68	100
69	100
70	100
71	100
72	100
73	100
74	100
75	100
76	100
77	100
78	100
79	100
80	100
81	100
82	100
83	100
84	100
85	100
86	100
87	100
88	100
89	100
90	100
91	100
92	100
93	100
94	100
95	100
96	100
97	100
98	100
99	100
100	100

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$ KSI	K	S KSI	COMPUTED VALUE KSI
RT	1	10		.638	3.98	.064	.383

COMMENTS :

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 06.01 PAGE NO. 9 DATE 12-19-69 MATERIAL AGCarb-201

CONDITION TEST DIRECTION Bias (45°) Direction to Warp and Fill Fibers

SPEC. NOS.

DATA BASIS "C" COMMENT 1-in. Plate Round Specimen

PROPERTY Ultimate Tensile Strength (Ftu)

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$ KSI	K	S	COMPUTED VALUE KSI
RT	1	5	-	4.43	5.74	.144	3.60

COMMENTS:

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 06.01 PAGE NO. 10 DATE 12-19-69 MATERIAL AGCarb-101

CONDITION TEST DIRECTION Bias (45°) Direction
To Warp and Fill Fibers

SPEC. NOS.

DATA BASIS "C" COMMENT 1/4-in. Plate
Round Specimen

PROPERTY Ultimate Tensile Strength (Ftu)

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$ KSI	K	S	COMPUTED VALUE KSI
RT	1	5	-	4.02	5.74	.158	3.11

COMMENTS:

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 06.01 PAGE NO. 11 DATE 12-19-69 MATERIAL AGCarb-101

CONDITION _____ TEST DIRECTION Block Tensile
(Perpendicular to plies of fabric)

SPEC. NOS. _____

DATA BASIS "C" COMMENT 1-in. Plate

PROPERTY Ultimate Tensile Strength (Ftu)

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$ KSI	K	S	COMPUTED VALUE KSI
RT	1	10	-	.644	3.98	.130	.127

COMMENTS:

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 06.01 PAGE NO. 12 DATE 12-19-69 MATERIAL AGCarb-101

CONDITION TEST DIRECTION Warp Direction

SPEC. NOS.

DATA BASIS "C" COMMENT 1/4-in. Plate

PROPERTY Compressive Strength (Ftu)

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$ KSI	K	S	COMPUTED VALUE KSI
RT	1	10		9.510	3.98	.702	6.717
2000	1	10		9.160	3.98	.477	7.26
3000	1	10		9.070	3.98	.650	6.48

COMMENTS:

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 06.01 PAGE NO. 13 DATE 12-19-69 MATERIAL AGCarb-101

CONDITION	TEST DIRECTION	Warp Direction
-----------	----------------	----------------

SPEC. NOS. _____

DATA BASIS	"C" per TD 69-37	COMMENT
		1-in. Plate

PROPERTY	Compressive Strength (Fcy)
----------	----------------------------

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$ KSI	K	S	COMPUTED VALUE KSI
RT	1	10		9.40	3.98	.760	6.38
2000	1	10		8.72	3.98	.92	5.06
3000	1	10		9.13	3.98	.59	6.78

COMMENTS :

DATA RELEASE

PROPERTY	Interlaminar Shear Strength (Fsu)
1. 100% Cure	10,000
2. 100% Cure	10,000
3. 100% Cure	10,000
4. 100% Cure	10,000
5. 100% Cure	10,000
6. 100% Cure	10,000
7. 100% Cure	10,000
8. 100% Cure	10,000
9. 100% Cure	10,000
10. 100% Cure	10,000
11. 100% Cure	10,000
12. 100% Cure	10,000
13. 100% Cure	10,000
14. 100% Cure	10,000
15. 100% Cure	10,000
16. 100% Cure	10,000
17. 100% Cure	10,000
18. 100% Cure	10,000
19. 100% Cure	10,000
20. 100% Cure	10,000
21. 100% Cure	10,000
22. 100% Cure	10,000
23. 100% Cure	10,000
24. 100% Cure	10,000
25. 100% Cure	10,000
26. 100% Cure	10,000
27. 100% Cure	10,000
28. 100% Cure	10,000
29. 100% Cure	10,000
30. 100% Cure	10,000
31. 100% Cure	10,000
32. 100% Cure	10,000
33. 100% Cure	10,000
34. 100% Cure	10,000
35. 100% Cure	10,000
36. 100% Cure	10,000
37. 100% Cure	10,000
38. 100% Cure	10,000
39. 100% Cure	10,000
40. 100% Cure	10,000
41. 100% Cure	10,000
42. 100% Cure	10,000
43. 100% Cure	10,000
44. 100% Cure	10,000
45. 100% Cure	10,000
46. 100% Cure	10,000
47. 100% Cure	10,000
48. 100% Cure	10,000
49. 100% Cure	10,000
50. 100% Cure	10,000
51. 100% Cure	10,000
52. 100% Cure	10,000
53. 100% Cure	10,000
54. 100% Cure	10,000
55. 100% Cure	10,000
56. 100% Cure	10,000
57. 100% Cure	10,000
58. 100% Cure	10,000
59. 100% Cure	10,000
60. 100% Cure	10,000
61. 100% Cure	10,000
62. 100% Cure	10,000
63. 100% Cure	10,000
64. 100% Cure	10,000
65. 100% Cure	10,000
66. 100% Cure	10,000
67. 100% Cure	10,000
68. 100% Cure	10,000
69. 100% Cure	10,000
70. 100% Cure	10,000
71. 100% Cure	10,000
72. 100% Cure	10,000
73. 100% Cure	10,000
74. 100% Cure	10,000
75. 100% Cure	10,000
76. 100% Cure	10,000
77. 100% Cure	10,000
78. 100% Cure	10,000
79. 100% Cure	10,000
80. 100% Cure	10,000
81. 100% Cure	10,000
82. 100% Cure	10,000
83. 100% Cure	10,000
84. 100% Cure	10,000
85. 100% Cure	10,000
86. 100% Cure	10,000
87. 100% Cure	10,000
88. 100% Cure	10,000
89. 100% Cure	10,000
90. 100% Cure	10,000
91. 100% Cure	10,000
92. 100% Cure	10,000
93. 100% Cure	10,000
94. 100% Cure	10,000
95. 100% Cure	10,000
96. 100% Cure	10,000
97. 100% Cure	10,000
98. 100% Cure	10,000
99. 100% Cure	10,000
100. 100% Cure	10,000

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$ KSI	K	S	COMPUTED VALUE KSI
RT	1	10		1.298	3.98	.067	1.031

COMMENTS:

DATA RELEASE

MATERIAL AGCarb-101

TEST DIRECTION Warp Direction

SPEC. NOS. _____

CO MENT 1-in. Plate

PROPERTY Interlaminar Shear (Fsu)

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$ KSI	K	S	COMPUTED VALUE KSI
RT	1	10		1.350	3.98	.160	.713

COMMENTS:

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 06.01 PAGE NO. 16 DATE 12-19-69 MATERIAL AGCarb-1.01

CONDITION _____ TEST DIRECTION Warp Direction

SPEC. NOS. _____

DATA BASIS	COMMENT
"C" per TD 69-37	Rotating Beam on 1/4-In. Plate

PROPERTY	Fatigue Strength (Ff)
----------	-----------------------

TEMP °F	LOTS/ HEATS	N	N _e	X KSI	K	S	COMPUTED VALUE KSI
RT	1	1 Ea 10 ⁷ Cycles		9.5			7.6

COMMENTS: Insufficient data for statistical analysis.

AEROJET-GENERAL NUCLEAR ROCKIT OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 06.01 PAGE NO. 17 DATE 12-19-69 MATERIAL AGCarb-101

CONDITION _____ TEST DIRECTION Warp Direction

SPEC. NOS. _____

DATA BASIS "C" per TD 69-37 COMMENT Rotating Beam on 1-In. Plate

PROPERTY Fatigue Strength at 10^7 Cycles (Ff)

TEMP °F	LOTS/ HEATS	N	N _e	X KSI	K	S	COMPUTED OR ESTIMATE VALUE KSI
RT	1	1 Ea 10^7 Cycles		8.750			7.0

COMMENTS: Insufficient data for statistical analysis.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 06.01 PAGE NO. 18 DATE 12-19-69 MATERIAL AGCarb-101

CONDITION	TEST DIRECTION	WARP DIRECTION

SPEC. NOS. WOI Test FORM

DATA BASIS	"C"	COMMENT	1-In. Plate

PROPERTY	Fracture Toughness (K_{IC})

TEMP °F	LOTS/ HEATS	N	N _e	$\frac{X}{\sqrt{In.}}$ KSI	K	S	ESTIMATED OR COMPUTED VALUE $\frac{X}{\sqrt{In.}}$ KSI
RT	1	2		8.50			7.0

COMMENTS: Insufficient Data for Statistical Analysis

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 06.01 PAGE NO. 19 DATE 12-19-69 MATERIAL AGCarb-101

CONDITION _____ TEST DIRECTION Fill Direction

SPEC. NOS. WOL Test FORM _____

DATA BASIS "C" per TD 69-37 COMMENT 1-In. Plate

PROPERTY Fracture Toughness K_{IC}

TEMP °F	LOTS/ HEATS	N	N_e	$\bar{X}$ KSI $\sqrt{\text{IN.}}$	K	S	ESTIMATED OR COMPUTED VALUE KSI $\sqrt{\text{IN.}}$
RT	1	2		6.44 6.70			6.0

COMMENTS: Insufficient data for Statistical Analysis

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 06.01 PAGE NO. 20 DATE 12-19-69 MATERIAL AGCarb-101

CONDITION _____ TEST DIRECTION WARP (1 to Plies)

SPEC. NOS. 3-Pt. Loading FORM _____

DATA BASIS "C" COMMENT 1/4-In. Plate

PROPERTY Flexure Strength

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$ KSI	K	S	ESTIMATED OR COMPUTED VALUE KSI
RT	1	10		17.59	3.98	1.00	13.61
3000	1	10		20.63	3.98	.895	17.07

COMMENTS:

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 06.01 PAGE NO. 21 DATE 12-19-69 MATERIAL AGCart-101

CONDITION _____ TEST DIRECTION Warp (Parallel to Plies)

SPEC. NOS. 3-Pt. Loading FORM 1/4-In. Plate

DATA BASIS "C" COMMENT _____

PROPERTY Flexure Strength

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$ KSI	K	S	COMPUTED VALUE KSI
RT	1	10		19.98	3.98	.626	17.49
3000	1	9		23.48	4.14	1.78	16.11

COMMENTS:

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 06.01 PAGE NO. 22 DATE 12-19-69 MATERIAL AGCarb-101

CONDITION _____ TEST DIRECTION Warp (Parallel to Plies)

SPEC. NOS. 3-Pt. Loading FORM

DATA BASIS	"C"	COMMENT
		1-In. Plate

PROPERTY	Flexure Strength
100% PPS	16,800 psi
90% PPS / 10% Kevlar	17,000 psi
80% PPS / 20% Kevlar	17,000 psi
70% PPS / 30% Kevlar	17,000 psi
60% PPS / 40% Kevlar	17,000 psi
50% PPS / 50% Kevlar	17,000 psi
40% PPS / 60% Kevlar	17,000 psi
30% PPS / 70% Kevlar	17,000 psi
20% PPS / 80% Kevlar	17,000 psi
10% PPS / 90% Kevlar	17,000 psi
0% PPS / 100% Kevlar	17,000 psi

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$ KSI	K	S	COMPUED VALUE KSI
RT	1	5		17.51	5.74	.597	14.08
3000	1	4		19.95	7.04	1.91	6.11

COMMENTS :

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 06.01 PAGE NO. 23 DATE 12-19-69 MATERIAL AGCarb-101

CONDITION	TEST DIRECTION	Warp (Perpendicular to Plies)
1. As Manufactured		
2. After 1000 Cycles		
3. After 2000 Cycles		
4. After 3000 Cycles		
5. After 4000 Cycles		
6. After 5000 Cycles		
7. After 6000 Cycles		
8. After 7000 Cycles		
9. After 8000 Cycles		
10. After 9000 Cycles		
11. After 10000 Cycles		
12. After 11000 Cycles		
13. After 12000 Cycles		
14. After 13000 Cycles		
15. After 14000 Cycles		
16. After 15000 Cycles		
17. After 16000 Cycles		
18. After 17000 Cycles		
19. After 18000 Cycles		
20. After 19000 Cycles		
21. After 20000 Cycles		
22. After 21000 Cycles		
23. After 22000 Cycles		
24. After 23000 Cycles		
25. After 24000 Cycles		
26. After 25000 Cycles		
27. After 26000 Cycles		
28. After 27000 Cycles		
29. After 28000 Cycles		
30. After 29000 Cycles		
31. After 30000 Cycles		
32. After 31000 Cycles		
33. After 32000 Cycles		
34. After 33000 Cycles		
35. After 34000 Cycles		
36. After 35000 Cycles		
37. After 36000 Cycles		
38. After 37000 Cycles		
39. After 38000 Cycles		
40. After 39000 Cycles		
41. After 40000 Cycles		
42. After 41000 Cycles		
43. After 42000 Cycles		
44. After 43000 Cycles		
45. After 44000 Cycles		
46. After 45000 Cycles		
47. After 46000 Cycles		
48. After 47000 Cycles		
49. After 48000 Cycles		
50. After 49000 Cycles		
51. After 50000 Cycles		
52. After 51000 Cycles		
53. After 52000 Cycles		
54. After 53000 Cycles		
55. After 54000 Cycles		
56. After 55000 Cycles		
57. After 56000 Cycles		
58. After 57000 Cycles		
59. After 58000 Cycles		
60. After 59000 Cycles		
61. After 60000 Cycles		
62. After 61000 Cycles		
63. After 62000 Cycles		
64. After 63000 Cycles		
65. After 64000 Cycles		
66. After 65000 Cycles		
67. After 66000 Cycles		
68. After 67000 Cycles		
69. After 68000 Cycles		
70. After 69000 Cycles		
71. After 70000 Cycles		
72. After 71000 Cycles		
73. After 72000 Cycles		
74. After 73000 Cycles		
75. After 74000 Cycles		
76. After 75000 Cycles		
77. After 76000 Cycles		
78. After 77000 Cycles		
79. After 78000 Cycles		
80. After 79000 Cycles		
81. After 80000 Cycles		
82. After 81000 Cycles		
83. After 82000 Cycles		
84. After 83000 Cycles		
85. After 84000 Cycles		
86. After 85000 Cycles		
87. After 86000 Cycles		
88. After 87000 Cycles		
89. After 88000 Cycles		
90. After 89000 Cycles		
91. After 90000 Cycles		
92. After 91000 Cycles		
93. After 92000 Cycles		
94. After 93000 Cycles		
95. After 94000 Cycles		
96. After 95000 Cycles		
97. After 96000 Cycles		
98. After 97000 Cycles		
99. After 98000 Cycles		
100. After 99000 Cycles		
101. After 100000 Cycles		

SPEC. NOS. 3-Pt. Loading FOPM

DATA BASIS	"C"	COMMENT
		1-In. Plate

- PROPERTY	Flexure Strength
------------	------------------

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$ KSI	K	S	COMPUTED VALUE KSI
RT	1	5		16.25	5.74	.90	11.08
3000	1	4		19.65	7.04	.64	15.15

COMMENTS:

AEROJET-GENERAL NUCLEAR ROCKIT OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 06.01 PAGE NO. 24 DATE 12-19-69 MATERIAL AGCarb-101

CONDITION TEST DIRECTION Warp Direction

SPEC. NOS. Dynamic Method FORM

DATA BASIS "C" COMMENT 1/4 and 1-In. Plates

PROPERTY Modulus of Elasticity

TEMP °F	LOTS/ HEATS	N	N _e	X PSI	K	S	COMPUTED OR ESTIMATED VALUE PSI
RT	1	1 ea 1/4-In. 1 ea 1-In.		2.94 x 10 ⁶ 2.86 x 10 ⁶			2.8 x 10 ⁶

COMMENTS: Insufficient data for Statistical Analysis

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 06.01 PAGE NO. 25 DATE 12-19-69 MATERIAL AGCarb-101
Perpendicular and Parallel to
Plies (Parallel in Warp Directio

CONDITION _____ TEST DIRECTION _____

SPEC. NOS. _____ FORM _____

DATA BASIS "C" COMMENT 1-In. Plate

PROPERTY Thermal Expansion (Total over indicated temperature range)

TEMP °F	LOTS/ HEATS	N	N _e	X IN./IN. $\times 10^{-3}$	K	S	COMPUTED OR ESTIMATED VALUE IN./IN. $\times 10^{-3}$
	<u>Parallel to Plies</u>						
RT to 1000	1	1		1.6			1.6
RT to 2000	1	1		3.2			3.2
RT to 3000	1	1		5.5			5.5
	<u>Perpendicular to Plies</u>						
RT to 1000	1	1		2.6			2.6
RT to 2000	1	1		5.3			5.3
RT to 3000	1	1		7.8			7.8

COMMENTS:

Insufficient Data for Statistical Analysis

AEROJET-GENERAL NUCLEAR ROCK IT OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 06.01 PAGE NO. 26 DATE 12-19-69 MATERIAL AGCarb-101
 CONDITION _____ TEST DIRECTION Perpendicular and Parallel to Plies (Warp) as Evaluated
 SPEC. NOS. Calculated from Thermal Diffusivity Data FORM _____
 DATA BASIS _____ COMMENT 1-In. Plates
 PROPERTY Thermal Conductivity

TEMP °F	LOTS/ HEATS	N	N _e	X	K	S	COMPUTED OR ESTIMATED VALUE BTU-FT/FT-HR-°F
<u>Parallel to Plies</u>							
1000	1	1		19			19
2000	1	1		15			15
3000	1	1		14			14
<u>Perpendicular to Plies</u>							
1000	1	1		12			12
2000	1	1		11			11
3000	1	1		10			10

COMMENTS: Insufficient Data for Statistical Analysis

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 06.01 PAGE NO. 27 DATE 12-19-69 MATERIAL AGCarb-101CONDITION _____ TEST DIRECTION N/A

SPEC. NOS. _____ FORM _____

DATA BASIS _____ COMMENT 1/4-In. and 1-In. PlatesPROPERTY Bulk Density

BLOCK #	TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$ g/CC	K	S	COMPUTED VALUE g/CC
1/4	RT	1	12		1.466	3.75	.024	1.374
1"	RT	1	7		1.481	4.64	.00976	1.436
1/4	RT	1	11		1.504	3.85	.0335	1.375
1	RT	1	12		1.485	3.74	.0055	1.459

COMMENTS:

DATA RELEASE MEMORANDUM

NRO MATERIALS AND PROCESSES STAFF

DRM
TYPE:

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

SHEET 1 OF 3

DRM NO.
06.02REV. NO.
0

SUBJECT: RADIATIVE PROPERTIES OF AGCARB-101

DATE: 3-23-70

1. SCOPE:

The following radiative properties of fibrous graphite composite, AGCarb-101, are attached:

1. Solar Absorptance
2. Total Hemispherical Emittance

2. TEST MATERIAL:

None

3. DATA ANALYSIS:

The solar absorptance and total hemispherical emittance values for manufactured graphites lie within a relatively narrow band, and separate variations are mainly attributed to surface conditions. Based on this assumption, the values of solar absorptance and total hemispherical emittance are estimated for AGCarb.

4. CONCLUSIONS:

The values listed are considered nominal for which category classification is not required.

5. DATA REFERENCE:

Thermophysical Properties of High Temperature Solid Materials, Vol. 1,
Y. S. Touloukian, Macmillan Co., 1967.

APPROVED BY <i>[Signature]</i>	DATE 3/24/70	PREPARED FOR: <i>L. Stanley</i> DATE: 3/24/70	COMPONENT/ ASSEMBLY IDENT <i>Ext. 5</i>
PREPARED BY <i>Calvin J. Goff</i>	<i>3/24/70</i>	AUTHORIZED CLASSIFIER <i>Unclassified</i> <i>C. G. Dufrenoy</i>	DATE 3/25/70

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 06.02 PAGE NO. 2 DATE 3-23-70 MATERIAL AGCarb-101CONDITION Machined TEST DIRECTION -SPEC. NOS. - FORM -DATA BASIS Nominal COMMENT No Category RequiredPROPERTY Total Hemispherical Emittance

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$	K	S	COMPUTED VALUE
1150							.85
2150							.86
2950							.87
4000							.88

COMMENTS: Data estimated from available data for manufactured graphites appearing in Thermophysical Properties of High Temperature Solid Materials, Vol. 1, Y. S. Touloukian, Macmillan Co., 1967.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 06.02 PAGE NO. 3 DATE 3-23-70 MATERIAL AGCarb-101CONDITION Machined TEST DIRECTION -SPEC. NOS. - FORM -DATA BASIS Nominal COMMENT No Category RequiredPROPERTY Solar Absorptance

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$	K	S	COMPUTED VALUE
70							.85

COMMENTS: Data estimated from available data on manufactured graphites appearing in Thermophysical Properties of High Temperature Solid Materials, Vol. 1, Y. S. Touloukian, Macmillan Co., 1967.

DRM
TYPE:

DATA RELEASE MEMORANDUM
NRO MATERIALS AND PROCESSES STAFF
AEROJET-GENERAL CORPORATION
SACRAMENTO, CALIFORNIA

DRM NO.
06.03
REV. NO. 0

SHEET 1 OF 5

SUBJECT: PHYSICAL PROPERTIES OF
FIBROUS GRAPHITE COMPOSITE

DATE: 9-9-70

1. SCOPE:

The following physical properties of fibrous graphite composite are attached and include estimates of variability:

Bulk Density
Thermal Conductivity
Specific Heat

2. TEST MATERIAL:

Fibrous graphite composite specimens from 1/4-in. and 1-in. thick plates were taken from one lot of material for bulk density and thermal conductivity data. The specific heat data are taken from manufactured graphite.

3. DATA ANALYSIS:

The bulk densities of specimens taken from 1/4-in. and 1-in. thick plates were measured at room temperature. The dimensions of the rectangular specimens were measured to within 0.0001 in. and the volume calculated. The specimen was weighed on an analytical balance capable of weighing to 0.1 Mg. The RT density was then calculated.

The minimum and maximum densities at temperatures other than RT were computed from thermal expansion data and the RT minimum-maximum values. The uncertainty range of the data is estimated to be $\pm .05$.

The thermal conductivity of fibrous graphite is estimated for 5 temperatures, RT to 3000°F from thermal diffusivity measurements. The uncertainty range of the data is estimated to be $\pm .20$.

The specific heat data are for manufactured graphite with an estimated uncertainty range of $\pm .10$ and is considered to be a good estimate of the specific heat of fibrous graphite.

4. CONCLUSIONS:

The data are classified as category "C" data since the values and uncertainty ranges were estimated.

APPROVED BY	DATE 9/9/70	PREPARED FOR: L. A. Shurley DATE: 9-9-70	COMPONENT/ ASSEMBLY IDENT
PREPARED BY U. E. Kallu		AUTHORIZED CLASSIFIER	DATE 9 Sept 70

Skirt
Extensor

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DRM NO.
06.03
REV. NO. 0

SHEET 2 OF 5

SUBJECT: PHYSICAL PROPERTIES OF
FIBROUS GRAPHITE COMPOSITE

DATE: 9-9-70

5. REFERENCES:

- (1) Davis H. O., Kotfila, R. J., and Schleicher, W. J., "The Fabrication and Properties of the Fibrous Reinforced Graphite Composite, AGCarl-101," Aerojet Nuclear Systems Company, RN-S-0549, March 1970.
- (2) The Industrial Graphite Engineering Handbook, Union Carbide Corp., Carbon Products Division, 270 Park Avenue, New York, New York.

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

AEROJET-CENTRAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 06.03 PAGE NO. 3 DATE 9-9-70 MATERIAL Fibrous Graphite Composite

CONDITION _____ TEST DIRECTION _____

SPEC. NOS. _____ FORM 1-In. and 1/4-In. Thick Block

DATA BASIS Category "C" COMMENT Uncertainty Range of $\pm 5\%$

PROPERTY Bulk Density

TEMP °F	DENSITY (LBS/IN. ³)					
	MAXIMUM	MINIMUM				
75	.0560	.0506				
250	.0559	.0505				
500	.0559	.0505				
1000	.0557	.0503				
2000	.0554	.0500				
3000	.0550	.0497				

REFERENCE (1).

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 06.03PAGE NO. 4DATE: 9-9-70MATERIAL Manufactured
Graphite

CONDITION _____

TEST DIRECTION _____

SPEC. NOS. _____

FORM _____

DATA BASIS _____

Category "C"

COMMENT _____

Uncertainty Range
 $\pm 10\%$

PROPERTY _____

Specific Heat

TEMP °F	SPECIFIC HEAT C _p (BTU/LB °F)					
	<u>MAXIMUM</u>	<u>MINIMUM</u>				
-100	.090	.109				
80	.155	.190				
170	.230	.188				
350	.304	.248				
530	.355	.291				

REFERENCE (2).

AEROJET-CENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 06.03 PAGE NO. 5 DATE 9-9-70 MATERIAL Fibrous Graphite Composite

CONDITION TEST DIRECTION Perpendicular and Parallel to Plies

SPEC. NOS. FORM

DATA BASIS Category "C" COMMENT Uncertainty Range is $\pm 20\%$

PROPERTY Thermal Conductivity, $\text{BUT}/\text{Hr}/\text{Ft}^2/^\circ\text{F}/\text{Ft}$

TEMP °F		PERPENDICULAR TO PLIES			PARALLEL TO PLIES		
		MINIMUM	MAXIMUM		MINIMUM	MAXIMUM	
80		14.0	21.0		26.4	39.6	
500		10.4	15.6		20.0	30.0	
1000		8.8	13.2		15.3	22.9	
2000		8.0	12.0		12.0	18.0	
3000		8.0	12.0		13.2	16.8	

REFERENCE (1).

07 - AA 6061

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DATA RELEASE MEMORANDUM
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ALROJET-GENERAL CORPORATION
SACRAMENTO, CALIFORNIA

SHEET 1 OF 7

Moore
DRM NO.
07.01

REV. NO.

SUBJECT: DESIGN ALLOWABLE MECHANICAL PROPERTIES FOR
6061-T6 ALUMINUM ALLOY SHEET AND PLATE

DATE: 3-18-70

1. SCOPE:

This revision is issued to include elongation values at cryogenic temperatures. The design allowable values for the following properties of 6061-T6 aluminum alloy are presented:

Ultimate Tensile Strength
Tensile Yield Strength
Elongation

2. TEST MATERIAL:

The data are applicable to sheet and plate from .010 to 2.00 inches thick.

3. DATA ANALYSIS:

The tensile ultimate and yield strengths are "A" basis data obtained from Mil Handbook 5 which meets NERVA requirements of 99% reliability with 95% confidence level. Room temperature elongation values are also "A" basis data; data for other than room temperature were calculated using a ratio obtained dividing "A" basis elongation by nominal elongation at room temperature. Other properties, such as modulus of elasticity, coefficient linear thermal expansion, conductivity, specific heat, thermal diffusivity, density, electrical resistivity, emittance and solar absorptance are contained in DRM M-7A, B, C, Revision 1, and those values listed are applicable for sheet and plate. The values listed are nominal and no data category is required for those properties.

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 was used to meet the intent of TD-28.

5. DATA REFERENCE:

Mil Handbook 5 insert, dated 8 February 1966.

APPROVED BY <i>[Signature]</i>	DATE 4/1/70	PREPARED FOR: L. Shurley/L. Johnson DATE:	COMPONENT/ ASSEMBLY IDENT Thrust Structure	Lines, Valves, Structu
PREPARED BY <i>[Signature]</i>		AUTHORIZED CLASSIFIER <i>[Signature]</i>	DATE 2 Apr-70	

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 07.01 PAGE NO. 2 DATE: 3-18-70 MATERIAL 6061CONDITION T-6 TEST DIRECTION LongitudinalSPEC. NOS. QQ-A-327 FORM Sheet and PlateDATA BASIS Category "B" COMMENT .010-2.0 In. ThickPROPERTY Ultimate Tensile Strength F_{tu}

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$	K	S	COMPUTED VALUE
70	-	-	-	-	-	-	42,000 psi
-320	-	-	-	-	-	-	54,500 psi
-423	-	-	-	-	-	-	67,200 psi

COMMENTS: MIL-HDBK-5 - Basis "a", dated 8 February 1966. Room temperature data obtained from Table 3.2.6.0 (b), page 322; multiplication factors for other temperatures obtained from Figure 3.2.6.2.1a, page 325, of said reference.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 07.01 PAGE NO. 4 DATE 3-18-70 MATERIAL 6061

CONDITION T6 TEST DIRECTION Longitudinal

SPEC. NOS. QQ-A-327 FORM Sheet and Plate

DATA BASIS Category "B" COMMENT .010-2.00 In. Thick

PROPERTY Tensile Yield Strength, F_{ty}

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$	K	S	COMPUTED VALUE
70				-			36,000 psi
-320				-			42,500 psi
-423				-			50,300 psi

COMMENTS: MIL-HDBK-5 - Basis "a", dated 8 February 1966. Room temperature data obtained from Table 3.2.6.0(b), page 322; multiplication factors for other temperatures obtained from Figure 3.2.6.2.1(a), page 325, of said reference.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 07.01 PAGE NO. 5 DATE 3-18-70 MATERIAL 6062

CONDITION	T-6	TEST DIRECTION	Long Transverse
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SPEC. NOS. QQ-A-327 FORM Sheet and Plate

DATA BASIS	Category "B"	COMMENT
		.010-2.0 In. Thick

PROPERTY Tensile Yield Strength, F_{ty}

TEMP °F	LOTS/ HEATS	N	N _c	X̄	K	S	COMPUTED VALUE psi
70							35,000
-320							41,300
-423							48,300

COMMENTS :

Mil Handbook 5 - Basis "a", dated 8 February 1966. Room temperature data obtained from Table 3.2.6.0(b), page 322; multiplication factors for other temperatures obtained from Figure 3.2.6.2.1(a), page 325, of said reference.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 07.01 PAGE NO. 6 DATE 3-18-70 MATERIAL 6061

CONDITION T-6 TEST DIRECTION Long Transverse

SPEC. NOS. QQ-A-327 FORM Sheet and Plate

DATA BASIS Category "B" COMMENT (a) 0.021-0.250 In. Thick
(b) 0.250-2.000 In. Thick

PROPERTY Elongation, e

	TEMP °F	LOTS/ HEATS	N	N _c	$\bar{X}$	K	S	COMPUTED VALUE %
(a)	70							10.0
	-320							16.0
123	-423							19.6
(b)	70							8.0
	-320							10.8
	-452							12.0

Room temperature data obtained from Table 3.2.6.0(c), page 323, Mil Handbook
 COMMENTS: basis "a", dated 8 February 1966; data for other temperatures scaled by
 a ratio of Class A room temperature data and nominal data. Source of data
 for other temperatures: Mechanical Properties of Several 2000 and 6000 Series
 Aluminum Alloys, J. L. Christian and J. F. Watson, Advances in Cryogenic Engineering,
 Plenum Press, 1964.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 07.01 PAGE NO. 7 DATE 3-18-70 MATERIAL 6061CONDITION T-6 TEST DIRECTION Long TransverseSPEC. NOS. QQ-A-327 FORM PlateDATA BASIS Nominal COMMENT No Category RequiredPROPERTY Reduction of Area

TEMP °F	LOTS/ HEATS	N	N _c	$\bar{X}$	K	S	COMPUTED VALUE %
70							22.1
-320							20.5
-452							17.6

COMMENTS: Mechanical Properties of Several 2000 and 6000 Series Aluminum Alloys, J. L. Christian and J. F. Watson, Advances in Cryogenic Engineering, Plenum Press, 1964. Data scaled by same ratio as elongation.

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NRO MATERIALS AND PROCESSES STAFF
AEROJET-GENERAL CORPORATION
SACRAMENTO, CALIFORNIA

DRM NO.
07.02
REV. NO.

SHEET 1 OF 23

SUBJECT: DESIGN ALLOWABLES FOR 6061-T6
ALUMINUM ALLOY, ALL WROUGHT PRODUCTS

DATE: 3-18-70

1. SCOPE:

The following design allowables for 6061-T6 aluminum alloy are attached:

Modulus of Elasticity
Modulus of Rigidity
Creep Strength
Rupture Strength
Fatigue
Impact Strength
Coefficient of Thermal Expansion
Specific Heat
Thermal Conductivity
Thermal Diffusivity
Density
Electrical Resistivity
Emittance
Solar Absorptance

2. TEST MATERIAL:

The data are applicable to all forms of the subject alloy unless noted specifically on the individual property sheets.

3. DATA ANALYSIS:

The axial load fatigue data were obtained from constant life diagrams in Mil Handbook 5. These data are based on values between the mean and the lower edge of the scatter band; as such, the data have a degree of conservatism.

The values for low temperature values for fatigue were obtained from published data. These data were average values and reflect the same degree of conservatism as for the room temperature data; a scatter band of 10 ksi was assumed. 2.5 ksi was subtracted from the published levels setting the values between the average and the lower limit of the scatter band. This degree of conservatism may not satisfy the NERVA requirements.

Notched fatigue strength data listed for information only.

APPROVED BY <i>[Signature]</i>	DATE 4/1/70	PREPARED FOR: DATE:	COMPONENT/ ASSEMBLY IDENT
PREPARED BY <i>[Signature]</i>		AUTHORIZED CLASSIFIER <i>[Signature]</i>	DATE 2 Apr 70

DATA RELEASE MEMORANDUM

NRO MATERIALS AND PROCESSES STAFF

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AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

DRM NO.
07.02

REV. NO.

SHEET 2 OF 23

SUBJECT: DESIGN ALLOWABLES FOR 6061-T6
ALUMINUM ALLOY, ALL WROUGHT PRODUCTS

DATE: 3-18-70

The data for modulus of elasticity, modulus of rigidity, impact strength, thermal conductivity, coefficient of thermal expansion, specific heat, density, electrical resistivity, emittance and solar absorptance are nominal values applicable to all wrought alloys unless exceptions are noted on the individual data sheets. The values are nominal and no category classification is required.

4. CONCLUSIONS:

The fatigue, creep and stress rupture data are classified Category "C". Nominal values are presented for all properties for which category classification is not required.

5. REFERENCES:

References are as noted on the individual data sheets.

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

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 07.02 PAGE NO. 3 DATE 3-18-70 MATERIAL 6061

CONDITION T-6 TEST DIRECTION -

SPEC. NOS. - FORM Wrought

DATA BASIS Nominal COMMENT No Category Required

PROPERTY Modulus of Elasticity

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$	K	S	COMPUTED VALUE psi x 10 ⁶
-423							11.5
-320							11.1
-100							10.3
RT							9.9
200							9.6
300							9.1

COMMENTS: Materials Data Handbook, J. Sessler and V. Weiss, Aluminum Alloy 6061, July 1966. Mil Handbook 5A, February 1966. Typical Mechanical Properties at Various Temperatures, unpublished data sheet, Alcoa Research Laboratories, December 1960.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 07.02 PAGE NO. 4 DATE 3-18-70 MATERIAL 6061

CONDITION T-6 TEST DIRECTION -

SPEC. NOS. _____ FC RM _____ Wrought _____

DATA BASIS	Nomina	COMMENT
		No category required.

PROPERTY	Modulus of Rigidity
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TEMP °F	LOIS/ HEATS	N	N _e	$\bar{X}$	K	S	COMPUTED VALUE psi x 10 ⁶
RT							3.8
200							3.7
300							3.6

COMMENTS: Aerospace Structural Metals Handbook, March 1966.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 07.02 PAGE NO. 5 DATE 3-18-70 MATERIAL 6061CONDITION T-6 TEST DIRECTION -SPEC. NOS. - FORM Wrought ProductsDATA BASIS Category "C" COMMENT -PROPERTY Stress to Rupture

TEMP °F	STRESS TO RUPTURE IN TIME, HOURS					COMPUTED VALUE
	10^{-1}	10^0	10^1	10^2	10^3	
RT	45.0	45.0	45.0	45.0	45.0	
212	41.0	40.0	39.0	38.0	37.0	
300	37.0	35.0	33.0	31.0	28.0	
400	31.0	28.0	24.0	20.0	14.0	
500	18.0	15.0	12.0	8.5	6.0	
Units for stress, psi x 1000						

COMMENTS: Unpublished Data Sheet, Alcoa Research Laboratories, "Typical Mechanical Properties at Various Temperatures, 6061 T6 and T651, December 1965.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 07.02 PAGE NO. 6 DATE 3-18-70 MATERIAL 6061

CONDITION T6 TEST DIRECTION -

SPEC. NOS. - FORM Wrought Products

DATA BASIS Category "C" COMMENT -

PROPERTY Creep

TEMP °F	STRESS FOR 1% CREEP IN TIME, HOURS					COMPUTED VALUE
	10^{-1}	10^0	10^1	10^2	10^3	
RT	45.0	45.0	44.0	44.0	43.0	
212	41.0	40.0	39.0	37.0	36.0	
300	36.0	35.0	33.0	31.0	27.0	
400	30.0	28.0	24.0	19.0	13.0	
500	17.0	14.0	11.0	7.0	4.4	
Units of stress, psi x 1000						

COMMENTS:

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 07.02 PAGE NO. 7 DATE 3-18-70 MATERIAL 6061

CONDITION T-6 TEST DIRECTION L, LT, & ST

SPEC. NOS. QQ-A-325, Mil-A-22771 FORM Wrought Products (except Sheet)

DATA BASIS Category "C", TD 69-28 COMMENT Axial Load

PROPERTY Fatigue (Axial), Cycles to Failure

TEMP °F	STRESS RATIO R	S _m MEAN STRESS, KSI	S _a ALTERNATING STRESS AMPLITUDE KSI	MAXIMUM STRESS, psi	LIFE CYCLES	COMPUTED VALUE
RT	-1.0	0	33.5	33.5	10 ⁴	
		0	24.5	24.5	10 ⁵	
		0	19.0	19.0	10 ⁶	
		0	14.0	14.0	10 ⁷	
	-0.8	4.0	32.0	36.0	10 ⁴	
		3.0	24.0	27.0	10 ⁵	
		2.5	19.0	21.5	10 ⁶	
		2.0	13.5	15.5	10 ⁷	
	-0.6	7.5	30.0	37.5	10 ⁴	
		6.0	23.0	29.0	10 ⁵	
		4.5	12.0	22.5	10 ⁶	
		3.5	13.0	16.5	10 ⁷	
	-0.4	12.0	27.0	39.0	10 ⁴	
		9.5	22.0	31.5	10 ⁵	
		8.0	18.0	26.0	10 ⁶	
		6.0	13.0	19.0	10 ⁷	

COMMENTS: R = Stress Ratio = the algebraic ratio of the minimum stress to the maximum stress in one cycle.

S_m = Mean Stress = the algebraic mean of the maximum and minimum stress in one cycle.

S_a = Alternating Stress Amplitude = one half the range of stress.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 07.02 PAGE NO. 8 DATE 3-18-70 MATERIAL 6061

CONDITION T-6 TEST DIRECTION L, LT, & ST

SPEC. NOS. QQ-A-325, Mil-A-22771 FORM Wrought Products (except Sheet)

DATA BASIS Category "C", TD 69-28 COMMENT Axial Load

PROPERTY Fatigue (Axial), Cycles to Failure

TEMP °F	STRESS RATIO R	S _m MEAN STRESS, KSI	S _a ALTERNATING STRESS AMPLITUDE KSI	MAXIMUM STRESS psi	LIFE CYCLES	COMPUTED VALUE
RT	-0.2	16.5	25.0	41.5	10 ⁴	
		14.0	21.0	35.0	10 ⁵	
		12.0	17.0	39.0	10 ⁶	
		9.0	13.0	22.0	10 ⁷	
	0.0	21.5	21.5	43.0	10 ⁴	
		18.5	18.5	37.0	10 ⁵	
		17.0	17.0	34.0	10 ⁶	
		13.0	13.0	26.0	10 ⁷	
	0.2	26.5	17.0	43.5	10 ⁴	
		24.0	16.0	40.0	10 ⁵	
		22.5	15.0	37.5	10 ⁶	
		18.0	12.0	30.0	10 ⁷	
	0.4	31.5	13.0	44.5	10 ⁴	
		29.5	12.5	42.0	10 ⁵	
		28.5	12.0	40.5	10 ⁶	
		24.5	10.5	35.0	10 ⁷	

COMMENTS: Data obtained from Figure 3.3.1(b), page 423, Mil Handbook 5, basis undefined, dated 8 February 1966.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 07.02 PAGE NO. 9 DATE 3-18-70 MATERIAL 6061

CONDITION T-6 TEST DIRECTION L, LT, & ST

SPEC. NOS. QQ-A-325, Mil-A-22771 FORM Wrought Products (except Sheet)

DATA BASIS Category "C", TD 69-28 COMMENT Axial Load

PROPERTY Fatigue (Axial), Cycles to Failure

TEMP °F	STRESS RATIO R	S _m MEAN STRESS, KSI	S _a ALTERNATING STRESS AMPLITUDE KSI	MAXIMUM STRESS KSI	LIFE CYCLES	COMPUTED VALUE
RT	0.6	36.5	9.0	45.5	10 ⁴	
		36.0	8.0	44.0	10 ⁵	
		36.0	8.0	44.0	10 ⁶	
		32.5	7.5	40.0	10 ⁷	
	0.8	41.0	5.0	46.0	10 ⁴	
		41.0	5.0	46.0	10 ⁵	
		41.0	5.0	46.0	10 ⁶	
		40.0	4.0	44.0	10 ⁷	

COMMENTS: Data obtained from Figure 3.3.1(b), page 423, Mil Handbook 5, basis undefined, dated 8 February 1966.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 07.02 PAGE NO. 10 DATE 3-18-70 MATERIAL 6061

CONDITION T-6 TEST DIRECTION -

SPEC. NOS. QQ-A-325 FORM Bar

DATA BASIS Category "C", TD 69-28 COMMENT Flexural Fatigue*

PROPERTY Fatigue, Cycles to Failure

TEMP °F	STRESS RATIO, R	MEAN STRESS, KSI	MAXIMUM STRESS KSI	FATIGUE LIFE CYCLES			COMPUTED VALUE
-110	-1.0	0	47.5	10 ⁴			
		0	31.5	10 ⁵			
		0	26.5	10 ⁶			
		0	21.5	10 ⁷			
-320	-1.0	0	62.5	10 ⁴			
		0	44.0	10 ⁵			
		0	39.5	10 ⁶			
		0	36.5	10 ⁷			

Data listed on this page obtained from "Mechanical Properties Including COMMENTS: Fatigue of Aircraft Alloys at Very Low Temperatures", by J. L. Zambrow and M. G. Fontana, Transactions of the American Society for Metals, p. 480, Vol. 41, 1949.

*Tested as bar in reciprocating or vibrating beam mode.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 07.02 PAGE NO. 11 DATE: 3-18-70 MATERIAL 6061

CONDITION T-6 TEST DIRECTION -

SPEC. NOS. QQ-A-525 FORM Bar

DATA BASIS Category "C" COMMENT

PROPERTY Fatigue (rotating beam), Cycles to Failure

TEMP °F	STRESS RATIO R	MEAN STRESS KSI	ALTERNATING STRESS KSI	MAXIMUM STRESS KSI	FATIGUE LIFE CYCLES	COMPUTED VALUE
300	-1	0	-	21.5 15.5 14.5 12.5	10 ⁵ 10 ⁶ 10 ⁷ 10 ⁸	
400	-1	0		16.5 12.5 8.5 6.0	10 ⁵ 10 ⁶ 10 ⁷ 10 ⁸	
500	-1	0		5.0 3.5 3.0 2.0	10 ⁵ 10 ⁶ 10 ⁷ 10 ⁸	

COMMENTS: Materials Data Handbook, Aluminum Alloy 6061, J. Sessler, B. Weiss, Syracuse Univ., 1966.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 07.02 PAGE NO. 12 DAT: 3-18-70 MATERIAL 6061

CONDITION T-6 TEST DIRECTION -

SPEC. NOS.	FORM	Bar
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DATA BASIS Nominal	COMMENT No Category Required
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PROPERTY Notched Fatigue Strength, $K_t > 10$

TEMP °F	STRESS RATIO, R	MEAN STRESS, KSI	ALTERNATING STRESS KSI	MAXIMUM STRESS, KSI	FATIGUE LIFE CYCLES	COMPUTED VALUE
RT	-1	0		26.5 14.5 9.5 5.5 4.5	10 ⁴ 10 ⁵ 10 ⁶ 10 ⁷ 10 ⁸	

COMMENTS: Materials Data Handbook, Aluminum Alloy 6061, J. Sessler and B. Weiss, Syracuse Univ., 1966.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 07.02 PAGE NO. 13 DATE 3-18-70 MATERIAL 6061

CONDITION T-6 TEST DIRECTION -

SPEC. NOS. - FORM Wrought

DATA BASIS Nominal COMMENT No Category Required

PROPERTY Coefficient of Thermal Expansion

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$	K	S	COMPUTED VALUE in/in $\times 10^{-6}$
RT to -423							- 8.8.
RT to -320							-10.2
RT to -100							-12.2
RT to 300							13.3

COMMENTS: Cryogenic Materials Data Handbook, Aluminum Alloy 6061, July 1966.
Mil Handbook 5A, November 1967.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 07.02 PAGE NO. 14 DATE 3-18-70 MATERIAL 6061CONDITION T-6 TEST DIRECTION -SPEC. NOS. FORM WroughtDATA BASIS Nominal COMMENT No Category RequiredPROPERTY Specific Heat

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$	K	S	COMPUTED VALUE BTU/LB
-423							.002
-325							.087
-100							0.19
81							.215
261							.225
441							.236

COMMENTS: Recommended Values of Thermophysical Properties of Eight Alloys,
Major Constituents and their Oxides, Y. S. Touloukian, February 1966.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 07.02 PAGE NO. 15 DATE 3-18-70 MATERIAL 6061

CONDITION T-6 TEST DIRECTION

SPEC. NOS. FORM Wrought

DATA BASIS Nominal COMMENT No Category Required

PROPERTY Thermal Conductivity

TEMP °F	LOTS/ REPTS	N	N _c	$\bar{X}$	K	S	COMPUTED VALUE BTU-ft hr-ft ² -°F
-414							20.2
-320							40.4
-100							78.6
81							89.6
261							95.9
351							97.7

COMMENTS: Recommended Values of Thermophysical Properties of Eight Alloys,
Major Constituents and their Oxides, Y. S. Touloukian, February 1966.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 07.02 PAGE NO. 16 DATE 3-18-70 MATERIAL 6061

CONDITION T-6 TEST DIRECTION -

SPEC. NOS. - FORM Wrought

DATA BASIS Nominal COMMENT No Category Required

PROPERTY Thermal Diffusivity

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$	K	S	COMPUTED VALUE sq ft/hr
414							27.72
324							3.31
100							2.27
81							2.30
441							2.48

COMMENTS: Recommended Values of Thermophysical Properties of Eight Alloys, Major Constituents, and their Oxides, Y. S. Touloukian, February 1966.

AEROJET-CENTRAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 07.02 PAGE NO. 17 DATE 3-18-70 MATERIAL 6061

CONDITION T-6 TEST DIRECTION -

SPEC. NOS. - FORM -

DATA BASIS Nominal COMMENT No Category Required

PROPERTY Sclar Absorptance

TEMP °F	SURFACE CONDITIONS					COMPUTED VALUE
40	As Received					.41*
	Mechanically Polished and Degreased					.35
	Sandblasted, 120 grit					.60
	Forged					.29
*Values are initial values with degradation (increase) likely to occur as result of exposure to radiation, or contamination.						

COMMENTS: Thermal Radiative Control Surfaces for Spacecraft, R. E. Gaumer and L. A. McKellar, LMSD 704014, March 1961.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 07.02 PAGE NO. 18 DATE 3-18-70 MATERIAL 6061

CONDITION T-6 TEST DIRECTION -

SPEC. NOS. - FORM Wrought

DATA BASIS Nominal COMMENT No Category Required

PROPERTY Emissance

TEMP °F						COMPUTED VALUE
-60	Forged Alloy					.09*
40						.09
140						.10
-60	Chemically Clean; Rolled					.06
40						.06
-140						.07
-60	Mechanically Polished and Degreased					.09
40						.10
140						.10
-100	Ideal Surface					.025
40						.035
260						.04
440						.05
*Values are initial values with degradation (increase) likely to occur from contamination.						

COMMENTS: Thermal Radiative Control Surfaces for Spacecraft, R. E. Gaumer and L. A. McKellar, LMSD 704014, March 1961.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 07.02 PAGE NO. 19 DATE 3-18-70 MATERIAL 6061

CONDITION T-6 TEST DIRECTION -

SPEC. NOS. - FORM Wrought

DATA BASIS Nominal COMMENT No Category Required

PROPERTY Density

TEMP °F	LOTS/ RLTS	N	N _c	$\bar{X}$	K	S	COMPUTED VALUE lbs/cu in.
-459							.0986
-279							.0983
- 99							.0979
81							.0975
261							.0968
441							.0961

COMMENTS: Thermophysical Properties of High Temperature Solid Materials, Vol. 1,
Y. S. Touloukian, Macmillan Company, 1967

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSLS SECTION

DATA RELEASE

DRM NO. 07.02 : PAGE NO. 21 DATE 3-18-70 MATERIAL 6061

CONDITION T-6 TEST DIRECTION -

SPEC. NOS. - FORM All Forms

DATA BASIS Nominal COMMENT No Category Required

PROPERTY Electrical Resistivity

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$	K	S	COMPUTED VALUE Microhm-in.
-423							.545
-320							.652
-100							1.2
32							1.551

COMMENTS: NBS - Boulder Labs, 31st Progress Report to NASA on Cryogenic Research & Development, J. G. Hurst, et. al., September 1968.

DRM
TYPE:

DATA RELEASE MEMORANDUM
NRO MATERIALS AND PROCESSES STAFF
AEROJET-GENERAL CORPORATION
SACRAMENTO, CALIFORNIA

DRM NO.
07.03
REV. NO.

SHEET 1 OF 10

SUBJECT: DESIGN ALLOWABLES FOR 6061-T6
ALUMINUM ALLOY FORGINGS

DATE: 9-3-70

1. SCOPE:

The design allowable values for the following properties of 6061-T6 aluminum alloy forgings are attached:

Ultimate Tensile Strength
Tensile Yield Strength
Elongation

This DRM supercedes the tensile data published in DRM M-7B, Rev. 1, dated 3-18-70 and adds detailed mean and standard deviation values for the computed values.

2. TEST MATERIAL:

The data are applicable to hand forgings or equivalent less than 4.00 inches thick and not exceeding 256 sq. in. cross-sectional area.

3. DATA ANALYSIS:

"A" basis Mil-Handbook-5 data were obtained which meet NERVA requirements of 99% reliability with 95% confidence level. The means and the standard deviations for room temperature and each direction were provided by R. Koffman of Alcoa. However, the number of specimens was not included. The one-sided tolerance factor (k) for room temperature was calculated and assumed to be the same for all temperatures. The standard deviations and means at temperatures other than room were calculated from the Mil-Hdbk-5 values and the assumed one-sided tolerance factor, k. The number of actual test values, N, may be inferred from the k factor.

4. CONCLUSIONS:

The data are classified category "B" according to interpretation of TD 69-37 which permits the use of handbook data providing the proper degree of statistics were used to meet the intent of TD 28.

5. DATA REFERENCE:

MIL-HDBK-5 insert, dated 8 February 1966, and 1 December 1968.

Private Communication from R. Koffman, Alcoa, dated 26 May 1970.

APPROVED BY	DATE	PREPARED FOR: L. D. Johnson/ DATE: L. A. Shurley	COMPONENT/ ASSEMBLY IDENT	Valves, Pressure Vessel
PREPARED BY		AUTHORIZED CLASSIFIER	DATE 10 Sept 70	

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 07.03 PAGE NO. 2 DATE 9-3-70 MATERIAL 6061

CONDITION T6 TEST DIRECTION Longitudinal

SPEC. NOS. MIL-A-22771 FORM Hand Forging

DATA BASIS Category "B" TD 69-28 COMMENT ≤ 4.0 in. Thick

PROPERTY Ultimate Tensile Strength, F_{tu}

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$ ksi	K	S ksi	COMPUTED VALUE ksi
-423				68.9	3.05	3.4	58.5
-320				57.5	3.05	2.8	49.0
70				44.7	3.05	2.2	38.0
300				35.9	3.05	1.8	30.4

COMMENTS: Mil Handbook 5 - Basis "A", dated 8 February 1966. Room temperature data obtained from Table 3.2.6.0(d), page 324; multiplication factors for other temperatures obtained from Figure 3.2.6.2.1(a), 100 hour exposure, page 325 of reference.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 07.03 PAGE NO. 3 DATE 9-3-70 MATERIAL 6061CONDITION T6 TEST DIRECTION TransverseSPEC. NOS. Mil-A-22771 FCRM Hand ForgingDATA BASIS Category "B" TD 69-28 COMMENT ≤ 4.0 in. ThickPROPERTY Ultimate Tensile Strength, F_{tu}

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$ ksi	K	S ksi	COMPUTED VALUE ksi
-423				69.5	3.94	2.8	58.5
-320				58.0	3.94	2.3	49.0
70				45.1	3.94	1.8	38.0
300				34.7	3.94	1.44	30.4

COMMENTS:

Mil Handbook 5 - Basis "A", dated 8 February 1966. Room temperature data obtained from Table 3.2.6.0(d), page 324; multiplication factors for other temperatures obtained from Figure 3.2.6.2.1(a), 100 hour exposure, page 325, of said reference.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 07.03 PAGE NO. 4 DATE 9-3-70 MATERIAL 6061

CONDITION T6 TEST DIRECTION Short Transverse

SPEC. NOS. Mil-A-22771 FORM Hand Forging

DATA BASIS Category "B" TD 69-28 COMMENT ≤ 4.0 in. Thick

PROPERTY Ultimate Tensile Strength, F_{tu}

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$ ksi	K ksi	S ksi	COMPUTED VALUE ksi
-423				71.0	4.79	2.9	57.0
-320				59.4	4.79	2.45	47.7
70				46.1	4.79	1.9	37.0
300				36.9	4.79	1.52	29.6

COMMENTS:

Mil Handbook 5 - Basis "A", dated 8 February 1966. Room temperature data obtained from Table 3.2.6.0(d), page 324; multiplication factor for other temperatures obtained from Figure 3.2.6.2.1(a), 100 hour exposure, page 325, of said reference.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 07.03 PAGE NO. 5 DATE 9-3-70 MATERIAL 6061CONDITION T6 TEST DIRECTION LongitudinalSPEC. NOS. Mil-A-22771 FORM Hand ForgingDATA BASIS Category "B" TD 69-28 COMMENT ≤ 4.0 in. ThickPROPERTY Tensile Yield Strength, F_{ty}

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$ ksi	K	S ksi	COMPUTED VALUE ksi
-423				55.9	2.89	2.62	48.3
-320				47.8	2.89	2.24	41.3
70				40.5	2.89	1.9	35.0
300				33.6	2.89	1.6	29.0

COMMENTS:

Mil Handbook 5 - Basis "A", dated 8 February 1966. Room temperature data obtained from Table 3.2.6.0(d), page 324; multiplication factors for other temperatures obtained from Figure 3.2.6.2.1(b), 100 hour exposure, page 326, of said reference.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 07.03 PAGE NO. 6 DATE 9-3-70 MATERIAL 6061
 CONDITION T6 TEST DIRECTION Transverse
 SPEC. NOS. Mil-A-22771 FORM Hand Forging
 DATA BASIS Category "B" TD 69-28 COMMENT ≤ 4.0 in. Thick
 PROPERTY Tensile Yield Strength, F_{ty}

TEMP °F	LOTS/ HEATS	N	N_e	$\bar{X}$ ksi	K	S ksi	COMPUTED VALUE ksi
-423				55.9	2.75	2.76	48.3
-320				47.8	2.75	2.36	41.3
70				40.7	2.75	2.0	35.0
300				33.6	2.75	1.66	29.0

COMMENTS:

Mil Handbook 5 - Basis "A", dated 8 February 1966. Room temperature data obtained from Table 3.2.6.0(d), page 324, multiplication factors for other temperatures obtained from Figure 3.2.6.2.1(b), 100 hour exposure, page 326, of said reference.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 07.03 PAGE NO. 7 DATE: 9-3-70 MATERIAL 5051
 CONDITION T6 TEST DIRECTION Short Transverse
 SPEC. NOS. Mil-A-22771 FORM Hand Forging
 DATA BASIS Category "B" TD 69-28 COMMENT ≤ 4.0 in. Thick
 PROPERTY Tensile Yield Strength, F_{ty}

TEMP °F	LOTS/ HEATS	N	N_e	$\bar{X}$ ksi	K	S ksi	COMPUTED VALUE ksi
-423				55.4	3.8	2.6	45.5
-320				47.4	3.8	2.24	38.9
70				40.3	3.8	1.9	33.0
300				33.5	3.8	1.6	27.4

COMMENTS:

Mil Handbook 5 - Basis "A", dated 8 February 1966. Room temperature data obtained from Table 3.2.6.0(d), page 324; multiplication factors for other temperatures obtained from Figure 3.2.6.2.1(b), 100 hour exposure, page 326, of said reference.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 07.03 PAGE NO. 8 DATE 9-3-70 MATERIAL 6061
 CONDITION T6 TEST DIRECTION Longitudinal
 SPEC. NOS. Mil-A-22771 FORM Hand Forging
 DATA BASIS Category "B" TD 69-28 COMMENT ≤ 4.0 in. Thick
 PROPERTY Elongation, e

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$ %	K	S %	COMPUTED VALUE %
-423				29.0	4.33	3.0	16.6
-320				25.0	4.33	2.5	14.0
70				17.8	4.33	1.8	10.0
200				13.7	4.33	1.7	9.4

COMMENTS:

Data obtained from Table 3.2.6.0(d), page 324, Mil Handbook 5, basis "A", dated 8 February 1966. Data for -320 and 200°F are to be acquired by test or from literature.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 07.03 PAGE NO. 9 DATE 9-3-70 MATERIAL 6061CONDITION T6 TEST DIRECTION TransverseSPEC. NOS. Mil-A-22771 FORM Hand ForgingDATA BASIS Category "B" TD 69-28 COMMENT ≤ 4.0 In. ThickPROPERTY Elongation, e

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$	K	S	COMPUTED VALUE
-320							-
70				14.3	2.86	2.2	8%
300							-

COMMENTS:

Data obtained from Table 3.2.6.0(d), page 324, Mil Handbook 5, dated 8 February 1966. Data for -320 and 300°F are to be acquired by test or from literature.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 07.03 PAGE NO. 10 DATE 9-3-70 MATERIAL 6061CONDITION T6 TEST DIRECTION Short TransverseSPEC. NOS. Mil-A-22771 FCRM Hand ForgingDATA BASIS Category "B" TD 69-28 COMMENT < 4.0 in. ThickPROPERTY Elongation, e

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$	K	S	COMPUTED VALUE
-320							-
70				12.7	3.66	2.1	5%
300							-

COMMENTS: Data obtained from Table 3.2.6.0(d), page 324, Mil Handbook 5,
dated 8 February 1966.

MATERIAL: AA 6061

DRM: 07.04

REVISION: 0

DATE: 1-20-71

PAGE 1 OF 5

AEROJET NUCLEAR SYSTEMS COMPANY

MATERIALS DATA RELEASE

CONTENTS

<u>MATERIAL</u>	<u>FORM</u>	<u>CONDITION</u>	<u>DIRECTION</u>	<u>PROPERTY</u>	<u>DATA CATEGORY</u>	<u>PAGE</u>
AA 6061	Sheet	T6	Transverse	Flexural Fatigue Cycle Life	C	2
AA 6061	Sheet	T6	Transverse	Flexural Fatigue Strength	C	3

APPROVALS

ORIGINATOR: *MSL*

REVIEW: *22* *D. J. Ramer* 22 Jan 71

CLASSIFICATION:

Unclassified
D. J. Ramer 22 Jan 71

DRM: 07.04
 REVISION: 0
 DATE: 1-20-71
 PAGE 2 OF 5

DESIGN DATA

MATERIAL AA 6061 FORM SHEET CONDITION T-6
 SPECIFICATIONS _____ DIRECTION TRANSVERSE
 PROPERTY Fatigue Strength at RT, ksi

NO. OF CYCLES	$\bar{X}$	s	DESIGN ALLOWABLE		DATA CATEGORY	SOURCE REFERENCE
			AS CALCULATED	DISCOUNTED**		
*3.16 x 10 ⁴	33.5	1.68	28.6	25.7	C	(1)
10 ⁵	28.0	1.44	24.0	21.6	C	(1)
3.16 x 10 ⁵	23.4	1.11	20.6	18.5	C	(1)
10 ⁶	20.0	0.88	17.6	15.8	C	(1)
3.16 x 10 ⁶	17.2	0.68	15.3	13.8	C	(1)

*3.16 x 10⁴ = 10^{4.5} = antilog (5.5)

**Reduced by 10% to allow for lot-to-lot variation.

DRM: 07.C
 REVISION: 0
 DATE: 1-20-71
 PAGE 3 OF 5

DESIGN DATA

MATERIAL AA 6061 FORM Sheet CONDITION T-6

SPECIFICATIONS DIRECTION Transverse

PROPERTY Flexural Fatigue Cycle Life at Room Temperature

STRESS (KSI)	NO. OF OBSERVATIONS	NO. OF LOTS	LOG OF CYCLES						NO. OF CYCLES		DATA CATEGORY	SOURCE REFERENCE
			MEAN* $\bar{X}$	STANDARD ERROR OF ESTIMATE s_e^*	m^{**}	f	k	$\bar{X}-ks_e$	MEAN	DESIGN ALLOWABLE		
31	2	1	4.72	.140	9.8	41	3.11	4.28	5.22×10^4	2.68×10^4	C	(1)
28	6	1	5.19	.140	14.3	41	3.04	4.56	1.56×10^5	3.66×10^4	C	(1)
24	6	1	5.43	.140	28.2	41	2.95	5.01	2.67×10^5	1.03×10^5	C	(1)
22	6	1	5.69	.140	39.3	41	2.92	5.28	4.90×10^5	1.92×10^5	C	(1)
20	7	1	5.99	.140	41.7	41	2.92	5.59	9.89×10^5	3.86×10^5	C	(1)
18	8	1	6.35	.140	27.8	41	2.95	5.94	2.24×10^6	8.67×10^5	C	(1)
16	8	1	6.77	.140	14.4	41	3.04	6.35	5.98×10^6	2.23×10^6	C	(1)

*Based on Regression Analysis

**Effective sample size for estimate of mean value.

DRM: 07.04
REVISION: 0
DATE: 1-20-71
PAGE 4 OF 5

1. TEST MATERIAL

Flexural fatigue tests were conducted at room temperature on 50 specimens of AA 6061-T6 .160-in. sheet from Harvey Aluminum Heat No. 333/6402-A. The testing was performed by Boeing Wichita per ANSC P.O. N-00235. Specimens were oriented so that flexing occurred perpendicular to the longitudinal grain flow direction. Testing was conducted at a number of stress levels, from 15 to 31 ksi, selected to produce failure at between 10^4 and 10^7 cycles.

2. DATA ANALYSIS

The data were analyzed by regression analysis following the general methodology of Reference (2).

Specimens which failed at the grips were excluded, as was one specimen which remained intact after 10^7 cycles at 15 ksi stress. After these exclusions, a total of 43 observations remained, at 7 stress levels.

The mean and variance of log cycle life were calculated for each stress level. The variance within stress levels was found to be homogeneous according to the Bartlett-Box test at the 0.1 level. Therefore, the use of regression analysis over the entire range of stress was justified. Log cycle life was assumed to be normally distributed within each stress level.

The computer program CURFT\$ on the G.E. Time-Sharing Computer System was used to select a regression model for log cycle life versus stress and to obtain the associated least squares regression equation. A power curve ($y = ax^b$) exhibited the best fit to the data. The regression equation was:

$$\hat{Y} = 30.84 X^{-.547}$$

where $\hat{Y}$ = log cycle life and X = stress, ksi. The standard error of estimate of the log transform, s_e , was .140 which was almost identical with the pooled within-group standard deviation. This correspondence indicates that the fit of the regression equation to the data is excellent, since virtually all of the error associated with $\hat{Y}$ is due to variation among replicates.

The effective sample sizes corresponding to each value of X were determined by a method given in Reference (3). These were used along with the number of degrees of freedom ($f = 41$) associated with s_e to obtain, from Reference (4), the appropriate 99/95 values of the tolerance limit factor, k .

DRM: 07.04
REVISION: 0
DATE: 1-20-71
PAGE 5 OF 5

The 99/95 lower tolerance limits were calculated as $\hat{Y} - k s_e$. The mean values and the lower limit, both in logarithmic form and converted back to numbers of cycles, are shown on page 2.

The mean and lower tolerance limits of 10_5 cycle life were plotted versus stress. From this plot, mean stress and allowable stress corresponding to various cycle lives were determined. Standard deviations associated with these estimates were calculated by a method based on paragraph 5.3.5 of Reference (2).

These results apply to one lot of material only. The calculated allowables have, therefore, been reduced by 10% to provide for the estimated effect of lot-to-lot variation. The data, shown on page 3, are categorized as "C".

3. REFERENCES

- (1) First Quarterly Report, CY 1971, NERVA Materials Development, sl31-MQR06-W187f2
- (2) NERVA Program Procedure R101-NRP502, "Sampling for Fatigue Test"
- (3) Weissberg, A., and Beatty, G. H., "Tables of Tolerance-Limit Factors for Normal Distributions," p. 10, Battelle Memorial Institute (1959)
- (4) Owen, D. B., "Factors for One-Sided Tolerance Limits and for Variables Sampling Plans," Monograph No. SCR-607, Sandia Corporation (1963-1964)

08 - AA 2024

NRO MATERIALS AND PROCESSES STAFF

DRM
TYPE:

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

DRM NO.
08.01

REV. NO

SHEET 1 OF 4

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

1. SCOPE:

The following radiative properties for 2024 aluminum alloy are attached:

Solar Absorptance
Total Hemispherical Emissance

2. TEST MATERIAL:

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

3. DATA ANALYSIS:

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

4. CONCLUSIONS:

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

APPROVED BY <i>R. J. Lawrence</i>	DATE 6/25/70	PREPARED FOR: <i>L. Shirley</i> DATE:	COMPONENT/ ASSEMBLY IDENT
PREPARED BY <i>Ralph J. Kotzick</i>	AUTHORIZED CLASSIFIER <i>WV</i>	DATE 25 June 70	

*Thrust
Structure*

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESS SECTION

DATA RELEASE

DRM NO. 08.01 PAGE NO. 2 DATE 6-16-70 MATERIAL 2024

CONDITION Base Material TEST DIRECTION -

SPEC. NOS. FORM Wrought

DATA BASIS No Category Required COMMENT

PROPERTY Solar Absorptance, α_s

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

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

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 08.01 PAGE NO. 3 DATE 6-16-70 MATERIAL 2024

CONDITION Base Material TEST DIRECTION -

SPEC. NOS. FORM Wrought

DATA BASIS No Category Required COMMENT

PROPERTY Total Hemispherical Emittance, ϵ

TEMP °F	SURFACE	CONDITION	MIN.	MAX.
-60	As Received		.02	.06
40			.02	.06
140			.02	.06
-60	Cleaned		.03	.11
40			.03	.12
140			.03	.12
-60	Mechanically Polished and Degreased		.03	.11
40			.03	.12
140			.03	.12
-60	Sandblasted with 1F mesh SiC at 18 inches		.20	.40
40			.20	.41
140			.20	.41
Values represent worse conditions with no further conservatism required for degradation in space.				

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

09 - Ti 6AL-4V

DEM
TYPE:

AERO MATERIALS AND PROCESSING STAFF

AERONAUTICAL CORPORATION

SACRAMENTO, CALIFORNIA

DEM NO.

09.01

REV. NO.

0

SHEET 1 OF 5

SUBJECT: Design Allowable Properties for
Ti 6Al-4V Titanium Alloy SheetDATE:
1-15-70

1. SCOPE:

2. METHODS:

3. CONCLUSIONS:

Design allowable data for the following properties of Ti-6Al-4V titanium alloy sheet are attached:

Ultimate Tensile Strength
Tensile Yield Strength
Elongation
Modulus of Elasticity

2. TEST MATERIAL.

The data are applicable to annealed sheet.

3. DATA ANALYSIS:

The data are Mil Handbook "A" basis which have been statistically analyzed for 99% reliability with a 95% confidence level. The data does not cover the temperature range of NERVA engine operation and additional values are required as noted in the individual data sheets.

4. CONCLUSIONS:

Data are rated Category "B" according to the interpretation of TD 69-37 requirements 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 Handbook 5 inserts, dated 8 February 1966 and 1 December 1968.

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

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 09.01 PAGE NO. 2 DATE 1-15-70 MATERIAL Ti-6Al-4VCONDITION Annealed TEST DIRECTION Longitudinal and TransverseSPEC. NOS. Mil-T-9046, Type III, Comp C FORM SheetDATA BASIS Category "B", TD 69-28 COMMENT PROPERTY Ultimate Tensile Strength, F_{tu}

TEMP °F	LOTS/ HEATS	N	N_e	$\bar{X}$	K	S	COMPUTED VALUE psi
-320							209,000
-100							158,000
70							134,000
200							122,000

COMMENTS: Room temperature data obtained from Mil Handbook 5, basis "a", Table 5.4.6.1(a), page unnumbered; multiplication factors for other temperatures obtained from Figure 5.4.6.2.1(a), page 608, dated 8 Feb. 1966. Test directions were not listed and the data were assumed to be equally applicable to the longitudinal and transverse directions.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 09.01 PAGE NO. 3 DATE 1-15-70 MATERIAL Ti-6Al-4V

CONDITION Annealed TEST DIRECTION Longitudinal and Transverse

SPEC. NOS. Mil-T-9046, Type III, Comp C FORM Sheet

DATA BASIS Category "B", TD 69-28 COMMENT

PROPERTY Tensile Yield Strength, F_{ty}

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$	K	S	COMPUTED VALUE psi
-320							202,000
-100							151,000
70							126,000
200							112,000

COMMENTS: Room temperature data obtained from Mil Handbook 5, basis "a", Table 5.4.6.1(a), page unnumbered, multiplication factors for other temperatures obtained from Figure 5.4.6.2.1(b), page 610. Test directions were not listed, and the data were assumed to be equally applicable to the longitudinal and transverse directions.

AEROJET-GENERAL NUCLEAR ROCK ET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 09.01 PAGE NO. 4 DATE 1-15-70 MATERIAL Ti-6Al-4VCONDITION Annealed TEST DIRECTION Longitudinal and TransverseSPEC. NOS. Mil-T-9046, Type III, Comp C FORM SheetDATA BASIS Category "B", TD 69-28 COMMENT PROPERTY Elongation, e

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$	K	S	COMPUTED VALUE %
~320							-
~100							-
70(a)							8
70(b)							10
200							-

COMMENTS: (a) 0.025 to 0.062 in. thick.
 (b) 0.062 inches and above.

Data obtained from Mil Handbook 5, basis "a", Table 5.4.6.1(a), page unnumbered, dated 1 Dec 68. Test directions were not listed and the data were assumed to be equally applicable to longitudinal and transverse directions. Data for other temperatures not applicable.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 09.01 PAGE NO. 5 DATE 1-15-70 MATERIAL Ti-6Al-4V

CONDITION Annealed TEST DIRECTION Longitudinal and Transverse

SPEC. NOS. Mil-T-9046, Type III, Comp C FCRM Sheet

DATA BASIS Category "B", TD 69-28 COMMENT

PROPERTY Modulus of Elasticity, E

TEMP °F	LOTS/ HEATS	N	N _c	$\bar{X}$	K	S	COMPUTED VALUE psi
-320							17.3×10^6
-100							16.5×10^6
70							16.0×10^6
200							15.4×10^6

COMMENTS: Room temperature data were obtained from Mil Handbook 5, Table 5.4.6.1(a), page unnumbered, dated 1 Dec. 68; multiplication factors for other temperatures obtained from Figure 5.4.6.2.4, page 613, dated 8 February 1966.

10 - AISI 301, 302, AND 303

DDM
TYPE:

DATA RELATIONSHIP
NRO MATERIALS AND PROCESSING STAFF
AEROJET-G 1 R & D CORPORATION
SACRAMENTO, CALIFORNIA

7732:MM 70-019

DDM NO.

10.01

REV. NO.

0

SHEET 1 OF 10

SUBJECT: Design Allowable Properties for
AISI 301 1/4 Hard Stainless Steel Sheet

DATE: 1-14-70

1. SCOPE:

Design allowable data for the following properties of AISI 301 1/4 hard stainless steel sheet are attached:

Ultimate Tensile Strength
Tensile Yield Strength
Elongation
Modulus of Elasticity
Thermal Conductivity

2. TEST MATERIAL

Data are applicable only to sheet.

3. DATA ANALYSIS

The data are Mil Handbook 5 basis "S" which are minimum allowable properties as contained in specifications. The data are therefore considered conservative and may be used until upgraded. The property values listed do not cover the projected range of NERVA engine operation as noted in the individual data sheets.

4. CONCLUSIONS

The data are rated "Category C" according to interpretation of TD 69-37 and may be regarded as a conservative engineering estimate of the design allowable according to TD-28.

5. DATA REFERENCE

Mil Handbook 5 insert, dated 8 February 1966.

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

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 10.01 PAGE NO. 2 DATE 1-14-70 MATERIAL AISI 301

CONDITION 1/4 Hard TEST DIRECTION Longitudinal

SPEC. NOS. Mil-S-5059 FORM Sheet

DATA BASIS Category "C", TD 69-28 COMMENT

PROPERTY Ultimate Tensile Strength, F_{tu}

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$	K	S	COMPUTED VALUE psi
70							125,000
-320							-
-423							-

COMMENTS: Data obtained from Mil Handbook 5, basis "s", Table 2.8.1.1(a), page 185, dated 8 February 1966. Data for temperatures of -320 and -423°F not available from this source.

DATA RELEASE

PROPERTY	Ultimate Tensile Strength, F_{tu}
1.0	100
2.0	100
3.0	100
4.0	100
5.0	100
6.0	100
7.0	100
8.0	100
9.0	100
10.0	100
11.0	100
12.0	100
13.0	100
14.0	100
15.0	100
16.0	100
17.0	100
18.0	100
19.0	100
20.0	100
21.0	100
22.0	100
23.0	100
24.0	100
25.0	100
26.0	100
27.0	100
28.0	100
29.0	100
30.0	100
31.0	100
32.0	100
33.0	100
34.0	100
35.0	100
36.0	100
37.0	100
38.0	100
39.0	100
40.0	100
41.0	100
42.0	100
43.0	100
44.0	100
45.0	100
46.0	100
47.0	100
48.0	100
49.0	100
50.0	100
51.0	100
52.0	100
53.0	100
54.0	100
55.0	100
56.0	100
57.0	100
58.0	100
59.0	100
60.0	100
61.0	100
62.0	100
63.0	100
64.0	100
65.0	100
66.0	100
67.0	100
68.0	100
69.0	100
70.0	100
71.0	100
72.0	100
73.0	100
74.0	100
75.0	100
76.0	100
77.0	100
78.0	100
79.0	100
80.0	100
81.0	100
82.0	100
83.0	100
84.0	100
85.0	100
86.0	100
87.0	100
88.0	100
89.0	100
90.0	100
91.0	100
92.0	100
93.0	100
94.0	100
95.0	100
96.0	100
97.0	100
98.0	100
99.0	100
100.0	100

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$	K	S	COMPUTED VALUE psi
70							125,000
-320							-
-423							-

COMMENTS: Data obtained from Mil Handbook 5, basis "s", Table 2.8.1.1(a), page 185, dated 8 February 1966. Data for temperatures of -320 and -423°F not available from this source.

AEROJET-GENERAL NUCLEAR ROCKIT OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 10.01 PAGE NO. 4 DATE 1-14-70 MATERIAL AISI 301

CONDITION 1/4 Hard TEST DIRECTION Longitudinal

SPEC. NOS. Mil-A-5059 FORM Sheet

DATA BASIS Category "C", TD 69-28 COMMENT

PROPERTY Tensile Yield Strength, F_{ty}

TEMP °F	LOTS/ HEATS	N	N_e	$\bar{X}$	K	S	COMPUTED VALUE psi
70							75,000
-320							-
-423							-

COMMENTS: Data obtained from Mil Handbook 5, basis "s", Table 2.8.1.1(a), page 185, dated 8 February 1966. Data for temperatures of -320 and -423°F not available from this source.

DATA RELEASE

PROPERTY	Tensile Yield Strength, F_{ty}
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[illegible]

COMMENTS: Data obtained from Mil Handbook 5, basis "s", Table 2.8.1.1(a), page 185, dated 8 February 1966. Data for temperatures of -320 and -423°F not available from this source.

DATA RELEASE

PROPERTY	Elongation, e
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TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$	K	S	COMPUTED VALUE %
70							25
-320							-
-423							-

COMMENTS: Data obtained from Mil Handbook 5, basis "s", Table 2.8.1.1(b), page 187, dated 8 Feb. 66. Data assumed to be applicable to longitudinal and transverse directions. Data for temperatures of -320 and -423°F not available from this source.

DATA RELEASE

PROPERTY	Elongation, e
1. Modulus of elasticity, E	29,000,000
2. Modulus of resilience, R	10.5
3. Modulus of toughness, T	10.5
4. Yield point, S_y	36,000
5. Tensile strength, S_u	58,000
6. Elongation in 2 in., e_2	22
7. Elongation in 4 in., e_4	14
8. Reduction of area, r	40
9. Average cross-sectional area, A	0.76
10. Area at fracture, A_f	0.47
11. Fracture energy, U	10.5
12. Impact energy, U	10.5
13. Charpy impact energy, U	10.5
14. Brinell hardness, H_B	10.5
15. Rockwell C hardness, H_R	10.5
16. Rockwell B hardness, H_R	10.5
17. Vickers hardness, H_V	10.5
18. Shore D hardness, H_S	10.5
19. Shore C hardness, H_S	10.5
20. Poisson's ratio, ν	0.3
21. Coefficient of thermal expansion, α	6.5
22. Coefficient of contraction, β	6.5
23. Coefficient of volume expansion, γ	6.5
24. Coefficient of volume contraction, δ	6.5
25. Coefficient of linear expansion, ϵ	6.5
26. Coefficient of linear contraction, ζ	6.5
27. Coefficient of area expansion, η	6.5
28. Coefficient of area contraction, θ	6.5
29. Coefficient of mass expansion, ϕ	6.5
30. Coefficient of mass contraction, ψ	6.5
31. Coefficient of density expansion, χ	6.5
32. Coefficient of density contraction, ω	6.5
33. Coefficient of specific volume expansion, λ	6.5
34. Coefficient of specific volume contraction, μ	6.5
35. Coefficient of specific mass expansion, ν	6.5
36. Coefficient of specific mass contraction, ξ	6.5
37. Coefficient of specific density expansion, η	6.5
38. Coefficient of specific density contraction, θ	6.5
39. Coefficient of specific area expansion, ϕ	6.5
40. Coefficient of specific area contraction, ψ	6.5
41. Coefficient of specific volume expansion, χ	6.5
42. Coefficient of specific volume contraction, ω	6.5
43. Coefficient of specific mass expansion, λ	6.5
44. Coefficient of specific mass contraction, μ	6.5
45. Coefficient of specific density expansion, ν	6.5
46. Coefficient of specific density contraction, ξ	6.5
47. Coefficient of specific area expansion, η	6.5
48. Coefficient of specific area contraction, θ	6.5
49. Coefficient of specific volume expansion, ϕ	6.5
50. Coefficient of specific volume contraction, ψ	6.5
51. Coefficient of specific mass expansion, χ	6.5
52. Coefficient of specific mass contraction, ω	6.5
53. Coefficient of specific density expansion, λ	6.5
54. Coefficient of specific density contraction, μ	6.5
55. Coefficient of specific area expansion, ν	6.5
56. Coefficient of specific area contraction, ξ	6.5
57. Coefficient of specific volume expansion, η	6.5
58. Coefficient of specific volume contraction, θ	6.5
59. Coefficient of specific mass expansion, ϕ	6.5
60. Coefficient of specific mass contraction, ψ	6.5
61. Coefficient of specific density expansion, χ	6.5
62. Coefficient of specific density contraction, ω	6.5
63. Coefficient of specific area expansion, λ	6.5
64. Coefficient of specific area contraction, μ	6.5
65. Coefficient of specific volume expansion, ν	6.5
66. Coefficient of specific volume contraction, ξ	6.5
67. Coefficient of specific mass expansion, η	6.5
68. Coefficient of specific mass contraction, θ	6.5
69. Coefficient of specific density expansion, ϕ	6.5
70. Coefficient of specific density contraction, ψ	6.5
71. Coefficient of specific area expansion, χ	6.5
72. Coefficient of specific area contraction, ω	6.5
73. Coefficient of specific volume expansion, λ	6.5
74. Coefficient of specific volume contraction, μ	6.5
75. Coefficient of specific mass expansion, ν	6.5
76. Coefficient of specific mass contraction, ξ	6.5
77. Coefficient of specific density expansion, η	6.5
78. Coefficient of specific density contraction, θ	6.5
79. Coefficient of specific area expansion, ϕ	6.5
80. Coefficient of specific area contraction, ψ	6.5
81. Coefficient of specific volume expansion, χ	6.5
82. Coefficient of specific volume contraction, ω	6.5
83. Coefficient of specific mass expansion, λ	6.5
84. Coefficient of specific mass contraction, μ	6.5
85. Coefficient of specific density expansion, ν	6.5
86. Coefficient of specific density contraction, ξ	6.5
87. Coefficient of specific area expansion, η	6.5
88. Coefficient of specific area contraction, θ	6.5
89. Coefficient of specific volume expansion, ϕ	6.5
90. Coefficient of specific volume contraction, ψ	6.5
91. Coefficient of specific mass expansion, χ	6.5
92. Coefficient of specific mass contraction, ω	6.5
93. Coefficient of specific density expansion, λ	6.5
94. Coefficient of specific density contraction, μ	6.5
95. Coefficient of specific area expansion, ν	6.5
96. Coefficient of specific area contraction, ξ	6.5
97. Coefficient of specific volume expansion, η	6.5
98. Coefficient of specific volume contraction, θ	6.5
99. Coefficient of specific mass expansion, ϕ	6.5
100. Coefficient of specific mass contraction, ψ	6.5

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$	K	S	COMPUTED VALUE
70							25%
-320							-
-423							-
.							
.							
.							

COMMENTS: Data obtained from Mil Handbook 5, basis "s", Table 2.8.1.1(b), page 187, dated 8 Feb. 66. Data assumed to be applicable to longitudinal and transverse directions. Data for temperatures of -320 and -423°F not available from this source.

DATA RELEASE

PROPERTY	Modulus of Elasticity, E
1	1000000
2	1000000
3	1000000
4	1000000
5	1000000
6	1000000
7	1000000
8	1000000
9	1000000
10	1000000
11	1000000
12	1000000
13	1000000
14	1000000
15	1000000
16	1000000
17	1000000
18	1000000
19	1000000
20	1000000
21	1000000
22	1000000
23	1000000
24	1000000
25	1000000
26	1000000
27	1000000
28	1000000
29	1000000
30	1000000
31	1000000
32	1000000
33	1000000
34	1000000
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36	1000000
37	1000000
38	1000000
39	1000000
40	1000000
41	1000000
42	1000000
43	1000000
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45	1000000
46	1000000
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83	1000000
84	1000000
85	1000000
86	1000000
87	1000000
88	1000000
89	1000000
90	1000000
91	1000000
92	1000000
93	1000000
94	1000000
95	1000000
96	1000000
97	1000000
98	1000000
99	1000000
100	1000000

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$	K	S	COMPUTED VALUE psi
70							27 x 10 ⁶
-320							-
-423							-
.							
.							
.							

COMMENTS: Data obtained from Mil Handbook 5, basis "s", Table 2.8.1.1(a), page 185, dated 8 February 1966. Data for temperatures of -320 and -423°F not available from this source.

DATA RELEASE

DRM NO. 10.01 PAGE NO. 9 DATE 1-14-70 MATERIAL AISI 301

CONDITION 1/4 Hard TEST DIRECTION Transverse

SPEC. NOS. Mil-S-5059 FORM Sheet

DATA BASIS	Category "C" , TD 69-28	COMMENT
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PROPERTY	Modulus of Elasticity, E
----------	--------------------------

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$	K	S	COMPUTED VALUL psi
70							28 x 10 ⁶
-320							-
-423							-

COMMENTS: Data obtained from Mil Handbook 5, basis "s", Table 2.8.1.1(a), page 185, dated 8 February 1966. Data for temperatures of -320 and -423°F not available from this source.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 10.01 PAGE NO. 10 DATE 1-14-70 MATERIAL AISI 301

CONDITION 1/4 Hard TEST DIRECTION _____

SPEC. NOS. Mil-S-5059 FORM Sheet

DATA BASIS	Category C, TD 69-28	COMMENT
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PROPERTY	Thermal Conductivity, K
----------	-------------------------

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$	K	S	COMPUTED VALUE
70							8.3 BTU/ (hr)(ft) ² / (°F)
-320							-
-423							-
.							
.							

COMMENTS: Data obtained from Mil Handbook 5, basis undefined, Figure 2.8.1.1, page 186, dated 8 February 1966. Data applicable to longitudinal and transverse directions. Values for temperatures of -320 and -423°F not available from this source.

DATA RELEASE MEMORANDUM

NRO MATERIALS AND PROCESSES STAFF

DRM
TYPE:

AEROJET-GENERAL CORPORATION

DRM NO.
10.02

SACRAMENTO, CALIFORNIA

REV. NO
0

SHEET 1 OF 3

SUBJECT: THERMOPHYSICAL PROPERTIES OF AISI 302

DATE: 8-3-70

1. SCOPE:

The design allowables for the following thermal properties of AISI 302 are attached:

Thermal Conductivity
Specific Heat

2. TEST MATERIAL:

Thermal conductivity data for material which conforms to the chemical composition requirements for AISI 302 were gathered from two literature sources. Data from AISI 303 were used at cryogenic temperature as a close approximation to the thermal conductivity of AISI 302 material.

The specific heat of alloy AISI 301 is reported as a close approximation to the specific heat of AISI 302.

3. ANALYSIS OF DATA:

The thermal conductivity data for AISI 302 were compiled from three literature sources, and uncertainty factors were estimated to be $\pm 20\%$ from 37°R (-423°F), $\pm 15\%$ to points from 37°R to 140°R (-320°F), $\pm 10\%$ from -320°F to RT, $\pm 5\%$ at RT and higher.

4. CONCLUSIONS:

These data are categorized "C", a conservative engineering estimate of the properties with uncertainty ranges.

5. CONCLUSIONS:

- (1) Cryogenic Materials Data Handbook, AFML-TDR-64-280, Supplement 4, Vol. I.
- (2) Thermophysical Properties of High Temperature Solid Materials, Thermophysical Properties Research Center, Purdue University, Purdue, Indiana, Y. S. Touloukian, Editor.
- (3) Aerospace Structural Metals Handbook, Syracuse University Institute, AFSC Project 7381, Contract AF33(615)-1184.

APPROVED BY <i>[Signature]</i>	DATE 5/1/71	PREPARED FOR: <i>D. Johnson</i> DATE:	COMPONENT/ ASSEMBLY IDENT <i>VALVES ACTUATOR</i>
PREPARED BY <i>[Signature]</i>		AUTHORIZED CLASSIFIER <i>[Signature]</i>	DATE 7 Aug 70

AEROJET-CENTRAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 10.02 PAGE NO. 2 DATE 8-3-70 MATERIAL AISI 302

CONDITION _____ TEST DIRECTION _____

SPEC. NOS. _____ FORM _____

DATA BASIS Category "C" COMMENT Data is from Alloy AISI 301 data

PROPERTY Specific Heat

TEMP °F	C_P BTU/LB °F	UNCERTAINTY FACTOR %				
-300	0.0775	± 15				
-200	0.09	± 10				
-100	0.095	± 10				
0	0.104	± 5				
200	0.115	± 5				
400	0.126	± 5				

REFERENCE (2)

AEROJET-CENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 10.02 PAGE NO. 3 DATE 8-3-70 MATERIAL AISI 302

CONDITION _____ TEST DIRECTION _____

SPEC. NOS. _____ FORM _____

DATA BASIS Category "C" COMMENT Data from 37°R to 137°R is from AISI 303 material.

PROPERTY Thermal Conductivity

TEMP °F	k BTU-FT/ HR FT ² °F	UNCERTAINTY FACTOR %				
-420	1.39	± 20				
-410	1.77	± 20				
-360	3.50	± 20				
-320	4.5	± 15				
-260	5.64	± 5				
-200	6.44	± 5				
-160	6.85	± 5				
- 60	7.62	± 5				
- 10	7.93	± 5				

REFERENCES (1), (2), AND (3).

DRM
TYPE:

NRO MATERIALS AND PROCESSES STAFF

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

SHEET 1 OF 2

DRM NO.
10.03

REV. NO.

SUBJECT:

THERMOPHYSICAL PROPERTIES OF AISI 303

DATE:

8-3-70

1. SCOPE:

The design allowables for the following thermal properties of AISI 303 are attached:

Specific Heat

2. TEST MATERIAL:

Specific heat data for material which conforms to the chemical composition requirements of AISI 301 were taken from the literature.

3. ANALYSIS OF DATA:

The specific heat data of AISI 301 are a close approximation to that of AISI 303 since the only difference between the alloys is 1% Cr and 2% Ni. Uncertainty factors were estimated to be 15% at -300°F, ± 10% from -200°F to RT, ± 5% at RT and higher.

4. CONCLUSION:

These data are categorized "C", a conservative engineering estimate of the properties with uncertainty ranges.

APPROVED BY <i>[Signature]</i>	DATE <i>8/5/70</i>	PREPARED FOR: DATE:	COMPONENT/ ASSEMBLY IDENT
PREPARED BY <i>V. E. K. L. G.</i>		AUTHORIZED CLASSIFIER DATE	

AERONAUTICAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DESI NO. 10.03 PAGE NO. 2 DATE 8-3-70 MATERIAL AISI 303

CONDITION _____ TEST DIRECTION _____

SPEC. NOS. _____ FORM _____

DATA BASIS Category "C" COMMENT Data is for AISI 301, a close approximation to that of AISI 303.PROPERTY Specific Heat

TEMP °F	C _P BTU/LB °F	UNCERTAINTY FACTOR %				
-300	0.085	± 15				
-200	0.09	± 10				
-100	0.095	± 10				
0	0.104	± 5				
200	0.115	± 5				
400	0.126	± 5				

REFERENCE: Thermophysical Properties of High Temperature Solid Materials,
Thermophysical Property Research Center, Purdue University,
Purdue, Indiana, Y. S. Touloukian, Editor.

11 - FRICTION

NRO MATERIALS AND PROCESSES STAFF

DRM
TYPE:

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

SHEET 1 OF 19DRM NO.
11.01REV. NO
0SUBJECT: DESIGN ALLOWABLES FOR COEFFICIENTS
OF FRICTION

DATE: 5-22-70

1. SCOPE:

Design allowables for coefficients of friction for pairs of materials, operating at conditions projected for the NERVA engine valves and actuators are attached.

2. TEST CONDITIONS:

The test conditions of the data do not duplicate the projected operating conditions of ultra-high vacuum, gaseous hydrogen environment and temperature.

3. DATA ANALYSIS:

The data are based primarily on laboratory friction tests which in some instances are corroborated by tests in space. Discrepancies in data were noted; such discrepancies are attributed to different test conditions as friction tests are not standardized. Where data discrepancies are noted, the more conservative (higher coefficients of friction) data are used. Conservatism is also applied to account for vacuum and gaseous hydrogen effects that are expected to increase frictional force characteristics. Coefficient of friction values are not to be related with wear life and actual wear test data of the material combinations listed must be developed in future tests.

4. REFERENCES:

All references are listed on the individual data sheets.

APPROVED BY <i>[Signature]</i>	DATE <i>5/25/70</i>	PREPARED FOR: DATE: <i>[Signature]</i>	COMPONENT/ ASSEMBLY IDENT
PREPARED BY <i>[Signature]</i>	DATE <i>5/25/70</i>	AUTHORIZED CLASSIFIER <i>[Signature]</i>	DATE <i>26 May 70</i>

<u>BASE MATERIAL COMBINATION</u>	<u>TYPE OF MOTION</u>	<u>COATING</u>	<u>VELOCITY sfm</u>	<u>LOAD LBS.</u>	<u>TEMP. °R</u>	<u>OPERATING ENVIRONMENT</u>	<u>COEFFICIENT OF FRICTION, μ</u>
440C on 440C	Rolling Sliding	MoS ₂	6000 (Rolling)	100/2000	40/620	LH ₂ /GH ₂	.05

The coefficient of friction will vary with the technique employed for coating of MoS₂. At light loads (100 gms) and low speeds (390 sfm), μ was determined to be .02; the lubricating property of LH₂ is poor and will not contribute significantly to lowering of the coefficient. The coefficient of friction value listed above is a conservative estimate based on the higher loads, speeds, and temperature range of operation. The value listed is applicable to sliding friction, for rolling, the coefficient of friction will be considerably lower (approximately .00005).

DATA REFERENCE:

- (a) Buckley, D. H., Swigert, M., and Johnson, R. L., "Friction, Wear and Evaporation Rates of Various Materials in Vacuum to 10^{-7} mm Hg," ASLE Trans., Vol. 5, No. 1, April 1962, pp. 8 - 23.

440C Versus Polyimide	Sliding	MoS ₂	0/1500	-	40/620	LH ₂ /GH ₂	.3
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Data are based on 440C (uncoated) versus polyimide. MoS₂ coated 440C versus polyimide may be lower; however, because of lack of data, the conservative coefficient listed above is recommended.

DATA REFERENCE:

Hammel, R. L., "Molecular Sink Vacuum Friction Test," November 1969.

<u>BASE MATERIAL COMBINATION</u>	<u>TYPE OF MOTION</u>	<u>COATING</u>	<u>VELOCITY sfm</u>	<u>LOAD LBS.</u>	<u>TEMP. °R</u>	<u>OPERATING ENVIRONMENT</u>	<u>COEFFICIENT OF FRICTION, μ</u>
9310 Versus 9310	Sliding	MoS ₂	0/200	100/1250	40/620	LH ₂ /GH ₂	.05

Carburized and heat treated 9310 steel will have equal or greater surface hardness than 440C, and, therefore, its substrate characteristics should be equivalent to 440C. When coated with a solid film lubricant such as MoS₂, the frictional characteristics of both materials should be equivalent.

DATA REFERENCE:

Buckely, D. H., Swigert, M., and Johnson, R. L., "Friction, Wear and Evaporation Rates of Various Materials in Vacuum to 10⁻⁷ mm Hg," ASLE Trans., Vol. 5, No. 1, April 1962, pp. 8 - 23.

Carbon -- Inconel X	Sliding	Hard Cr	5	30	280	GH ₂	.40
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Data based on carbon-graphite, chrome-plated mild steel couple. Test result of .36 for μ rounded off to .4. Because of light loads and low ambient and low sliding velocity of the application, large degree of conservatism is not required.

DATA REFERENCE:

"Friction Coefficients," Materials, 12.6-3/12.7-7, October 1960.

<u>BASE MATERIAL COMBINATION</u>	<u>TYPE OF MOTION</u>	<u>COATING</u>	<u>VELOCITY sfm</u>	<u>LOAD LBS.</u>	<u>TEMP. °R</u>	<u>OPERATING ENVIRONMENT</u>	<u>COEFFICIENT OF FRICTION, μ</u>
304 SS - Inconel X	Sliding	Gold	50 ft/min.	200	280	GH ₂	.1

Data based on tests of Inconel 718 (similar to Inconel X) versus 301 SS coated with gold. Test data ranged from initial .08 to .05 (low) before seizure occurred at the end of 140 cycles.

DATA REFERENCE:

Frictional Evaluation of Materials for Valve Applications, ANSC Report RN-TM-0393, October 1966.

Carbide Versus Inconel X	Rolling	Electrolyze	50	2000	280	GH ₂	.005
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Data are not available for this couple. The value listed is an extremely conservative figure for the coefficient of friction, rolling motion based on rolling contact friction coefficient of a cemented carbide versus 52100 steel at a 30 lb/load which is listed as .0001.

DATA REFERENCE:

Glaeser, W. A., "An Engineer's Guide to Friction, DMIC Memorandum 246, February 1970.

<u>BASE MATERIAL COMBINATION</u>	<u>TYPE OF MOTION</u>	<u>COATING</u>	<u>VELOCITY sfm</u>	<u>LOAD LBS.</u>	<u>TEMP. °R</u>	<u>OPERATING ENVIRONMENT</u>	<u>COEFFICIENT OF FRICTION, μ</u>
6061-T6/304	Static	None	-	6580	N/A	LH ₂ /Vacuum	1.5

Value based on conservative estimate of frictional coefficient of dissimilar metals as shown in "General Purpose Friction Chart, E. Rabinowicz, Product Engineering, Vol. 36, No. 6, March 15, 1965.

Phosphor Bronze - 304 SS	Static	-	0	6850	40	LH ₂ /Vacuum	1.20
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Value is conservative estimate of coefficient of friction based on static (dry) coefficient (.35)^(a) for phosphor bronze on mild steel in air. In vacuum or in non-oxidizing atmosphere, μ is expected to be considerably higher.

(a) General Purpose Friction Chart, Materials, Figure 12.7, Materials, October 1965.

Inconel X 750 - Verus 718	Static	None	-	Low	-	Vacuum/GH ₂	2.5
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Value based on coefficient of friction data for Ni-Ni couple ($\mu = 2.11$) in clean atmosphere of helium.

DATA REFERENCE:

Russell, J. A., Burton, R. A. Ku, P. M., "Research on Lubrication Behavior Under Extreme Low Temperature," Part II, Clean Metals, Oxide Films, and Organic Films, WADD Technical Report.61-161, Part II, November 1961.

<u>BASE MATERIAL COMBINATION</u>	<u>TYPE OF MOTION</u>	<u>COATING</u>	<u>VELOCITY sfm</u>	<u>LOAD LBS.</u>	<u>TEMP. °R</u>	<u>OPERATING ENVIRONMENT</u>	<u>COEFFICIENT OF FRICTION, μ</u>
Inconel 718 - Inconel X 750	Sliding	Electrolyze	5.5	Low	-	Vacuum/GH ₂	.4

Value based on data obtained in tests using "Electrolize" coating versus 301 SS ($\mu = 35$).

DATA REFERENCE:

Friction Evaluation of Materials for Valve Application, ANSC Report RN-TM-0393, October 1966.

Inconel X750 - 302	Sliding	Electrolyze	5.5	Low	-	Vacuum/GH ₂	.8
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Value obtained by tests of hard chrome versus hard chrome couples in air.

DATA REFERENCE:

Rothbart, H. A., Mechanical Design and Systems Handbook.

<u>BASE MATERIAL COMBINATION</u>	<u>TYPE OF MOTION</u>	<u>COATING</u>	<u>VELOCITY sfm</u>	<u>LOAD LBS.</u>	<u>TEMP. °R</u>	<u>OPERATING ENVIRONMENT</u>	<u>COEFFICIENT OF FRICTION, μ</u>
A-286 Versus A-286	Contact	None	0	60	-	-	1.0

Value based on data from space satellite.

DATA REFERENCE:

Jackson, E. G., Lubrication in Space Vehicles, Wear, Vol. 5, No. 6, pp. 417 - 434, Nov/Dec 1962.

Phosphor Bronze Versus 302	Contact	Electrolize Hd Cr	-	40/lin. in.	40	LH ₂	.15
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Value based on handbook data obtained for hard chrome versus bronze couple ($\mu = .05$) in air. The value listed is a conservative estimate for effects of atmosphere and temperature.

DATA REFERENCE:

Mantell, C. L., Engineering Materials Handbook, 1958.

<u>BASE MATERIAL COMBINATION</u>	<u>TYPE OF MOTION</u>	<u>COATING</u>	<u>VELOCITY sfm</u>	<u>LOAD LBS.</u>	<u>TEMP. °R</u>	<u>OPERATING ENVIRONMENT</u>	<u>COEFFICIENT OF FRICTION, μ</u>
Phosphor Bronze Versus 718	Contact	Thermospray	0	40/lin. in.	40	LH ₂	.3

Value based on dry kinetic coefficient of friction of flame plated LC-1 (CrC-Ni-Cr) versus Haynes 25 alloy ($\mu = 32$). It is expected that the frictional characteristics of the phosphor bronze is superior to that of Haynes 25; however, the value of .3 is considered to be a conservative estimate for the couple listed.

DATA REFERENCE:

Table 12.7, Static and Kinetic Friction Coefficients, Materials, October 1965.

302 SS Versus 302 SS	Contact	Au/Electrolize	0	40/lin. in.	40	LH ₂	.12
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Conservative value based on tests of electrolize coating versus gold of several thicknesses; μ values obtained ranged from .05 to .12. Value not expected to change appreciably under space conditions based on gold plated A-286 versus A-286 friction coefficient of .20 at space conditions.

DATA REFERENCES:

(a) Friction Evaluation of Materials for Valve Applications, ANSC Report RN-TM-0393.

(b) Jackson, E. G., "Lubrication in Space Vehicles," Wear, Vol. 5, No. 6, Nov/Dec 1962.

<u>BASE MATERIAL COMBINATION</u>	<u>TYPE OF MOTION</u>	<u>COATING</u>	<u>VELOCITY sfm</u>	<u>LOAD LBS.</u>	<u>TEMP. °R</u>	<u>OPERATING ENVIRONMENT</u>	<u>COEFFICIENT OF FRICTION, μ</u>
302 - Inconel 718	Contact	Au/Electrolize	0	40/lin. in.	40	LH ₂	.12

Value based on tests of Au/electrolize coatings with similar substrates. The highest value was selected from a series of tests using gold of varying thicknesses.

DATA REFERENCE:

Friction Evaluation of Materials for Valve Applications, ANSC Report RN-TM-0393.

Be-Ni Versus 302 SS	Contact	Electrolyze	0	55/lin. in.	40	LH ₂	.6
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Value based on sliding friction tests of electrolyze coating - 301 SS couple. The initial coefficient of friction (0.1) increased to .5 at the end of 300 cycles where some seizing and galling occurred. Data for Be-Ni in contact with other materials not available.

DATA REFERENCE:

Friction Evaluation of Materials for Valve Applications, ANSC Report RN-TM-0393, October 1966.

<u>BASE MATERIAL COMBINATION</u>	<u>TYPE OF MOTION</u>	<u>COATING</u>	<u>VELOCITY sfm</u>	<u>LOAD LBS.</u>	<u>TEMP. °R</u>	<u>OPERATING ENVIRONMENT</u>	<u>COEFFICIENT OF FRICTION, μ</u>
Be-Ni Versus Inconel 718	Contact	Electrolize	0	55/lin. in.	40	LH ₂	.6

No data are available on Be-Ni versus electrolize coating and above value is based on sliding tests of electrolize versus 301 SS couple. This value is considered conservative for the Be-Ni/electrolize couple.

DATA REFERENCE:

Friction Evaluation of Materials for Valve Applications, ANSC Report RN-TM-0393, October 1966.

Vespel - Inconel 718	Sliding	-	5	Low	40	LH ₂	1.2
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Value estimated on the basis of tests of hard chrome-Vespel tests where coefficients of friction ranged from .25 to .8. A Vespel-718 couple in LH₂ is expected to have a higher coefficient of friction.

DATA REFERENCE:

NERVA Materials Developments, Fourth Quarter, RN-S-0538, December 1969.

<u>BASE MATERIAL COMBINATION</u>	<u>TYPE OF MOTION</u>	<u>COATING</u>	<u>VELOCITY sfm</u>	<u>LOAD LBS.</u>	<u>TEMP. °R</u>	<u>OPERATING ENVIRONMENT</u>	<u>COEFFICIENT OF FRICTION, μ</u>
Inconel 718 - Inconel 718	Contact		0	1300	40	LH ₂	1.2

Conservative value based on static friction tests results of a nickel-chrome alloy versus a nickel-chrome alloy in UHV (average $\mu_s = .86$).

DATA REFERENCE:

Moeller, C. E. and Noland, M. C., "Cold Welding of Metals in Ultra-High Vacuum," ASLE Trans. 10, 146-157 (67)

Inconel 718 - 347 SS	Contact	-	-	1300	40	LH ₂	1.2
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Conservative value based on results of 321 SS versus 321 SS tests in UHV (average $\mu_s = .86$).

DATA REFERENCE:

Moeller, C. E., and Noland, M. C., "Cold Welding of Metals in Ultra-High Vacuum," ASLE Trans. 10, 146 - 157 (67).

<u>BASE MATERIAL COMBINATION</u>	<u>TYPE OF MOTION</u>	<u>COATING</u>	<u>VELOCITY sfm</u>	<u>LOAD LBS.</u>	<u>TEMP. °R</u>	<u>OPERATING ENVIRONMENT</u>	<u>COEFFICIENT OF FRICTION, μ</u>
321 SS - Inconel	Contact	-	0	Undetermined	40°	-	1.2

Conservative value based on test results from 321 versus 321 SS tests in UHV where average static coefficient of friction was determined to be .86.

DATA REFERENCE:

Moeller, C. E., and Noland, M. C., "Cold Welding of Metals in Ultra-High Vacuum," ASLE Trans. 10, 146-151 (67).

321 - Phosphor Bronze	Contact	None	0	Undetermined	40°	LH ₂	.7
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Conservative value based on static friction results of phosphor bronze on mild steel ($\mu_s = .35$) in air at ambient temperature.

DATA REFERENCE:

Table 12.7, "Static and Kinetic Friction Coefficients, Materials, October 1965

<u>BASE MATERIAL COMBINATION</u>	<u>TYPE OF MOTION</u>	<u>COATING</u>	<u>VELOCITY sfm</u>	<u>LOAD LBS.</u>	<u>TEMP. °R</u>	<u>OPERATING ENVIRONMENT</u>	<u>COEFFICIENT OF FRICTION, μ</u>
321 SS - 302 SS	Contact	None	0	Not Specified	40	LH ₂	1.2

Value based on average static coefficient of friction of 321 SS versus 321 at UHV conditions with a degree of conservatism (actual value .86).

DATA REFERENCE:

Moeller, C. E., and Noland, M. C., "Cold Welding of Metals in Ultra-High Vacuum," ASLE Trans. 10, 146-157 (67).

321 SS - Be-Ni	Contact	None	0	Undetermined	40	LH ₂	1.2
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Above value based on average static coefficient of friction of 321 SS versus 321 SS couple in ultra-high vacuum. Actual value (.86) increased to cover undetermined temperature effects.

DATA REFERENCE:

Moeller, C. E., and Noland, M. C., "Cold Welding of Metals in Ultra-High Vacuum," ASLE Trans. 10, 146-157 (67).

<u>BASE MATERIAL COMBINATION</u>	<u>TYPE OF MOTION</u>	<u>COATING</u>	<u>VELOCITY sfm</u>	<u>LOAD LBS.</u>	<u>TEMP. °R</u>	<u>OPERATING ENVIRONMENT</u>	<u>COEFFICIENT OF FRICTION, μ</u>
Be-Cu/302	Sliding	Electrolize	10	-	40-65	GH ₂	.5

Value based on kinetic coefficient of friction (.96) of Cu-Be alloy (1/4 H 3 R_c) versus 1095 steel (60 R_c) in high vacuum. BE-Cu versus hard chrome tested at a 360 # load showed a high of .5 with a low cycle wear life, and the above value is considered a conservative estimate for the conditions specified.

DATA REFERENCE:

Jellison, J., et. al, "Sliding Friction of Copper Alloys in Vacuum", ASLE Trans, Vol. 12, No. 2, pp. 171-182, April 1969. Third Quarter, NERVA Materials Developments, Contract Year 1969, RN-S-0527, p. 58.

Be-Cu Versus Inconel 718	Sliding	Electrolize	10	-	40-65	GH ₂	.5
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Value based on kinetic coefficient of friction (.96) of Cu-Be alloy (1/4H-38 R_c) versus 1095 steel (60 R_c) in high vacuum. The friction coefficient of hard chrome versus Be-Cu is expected to be lower and the above value is a conservative estimate of this property.

DATA REFERENCE:

Jellison, J., et. al., "Sliding Friction of Copper Alloys in Vacuum", ASLE Trans., Vol. 12, No. 2, pp. 171-182, April 1969.

<u>BASE MATERIAL COMBINATION</u>	<u>TYPE OF MOTION</u>	<u>COATING</u>	<u>VELOCITY sfm</u>	<u>LOAD LBS.</u>	<u>TEMP. °R</u>	<u>OPERATING ENVIRONMENT</u>	<u>COEFFICIENT OF FRICTION, μ</u>
Phosphor Bronze - 302 SS	Sliding	Electrolize	10	-	40-65	GH ₂	.20

Value based on handbook data for hard chrome versus bronze couple in air ($\mu = .05$). The value listed is a conservative estimate for the effects of atmosphere and temperature.

DATA REFERENCE:

Mantell, C. L., Engineering Materials Handbook, 1958.

Phosphor Bronze - 718	Sliding	Thermospray	10	-	40-65	GH ₂	.3
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Value based on flame plated LC-1 (CrC - Ni - Cr) versus Haynes 25. The frictional characteristics of phosphor bronze are expected to be superior to Haynes 25; and, therefore, the value listed is a conservative estimate for the conditions.

DATA REFERENCE:

Table 12.7, "Static and Kinetic Friction Coefficients," Materials, October 1965.

<u>BASE MATERIAL COMBINATION</u>	<u>TYPE OF MOTION</u>	<u>COATING</u>	<u>VELOCITY sfm</u>	<u>LOAD LBS.</u>	<u>TEMP. °R</u>	<u>OPERATING ENVIRONMENT</u>	<u>COEFFICIENT OF FRICTION, μ</u>
302 SS - 302 SS	Sliding	Au/Electrolyze	10	-	40-65	GH ₂	.12

Value based on highest data point obtained in test in air of Au/Cr coatings on 718 substrates. Highest point selected to compensate for atmosphere and temperature effects.

DATA REFERENCE:

Friction Evaluation of Materials for Valve Applications, ANSC Report RN-TM-0393, October 1966.

Phosphor Bronze - 718	Sliding	Thermospray (Metco 15 or Equiv)	10	-	40-65	GH ₂	.3
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Value based on literature data for LC-1 (Ni - Cr - C flame Plate) versus Haynes 25 couple ($\mu = .19-.32$) in air.

Phosphor bronze versus thermospray is expected to be lower; however, the higher value is used to compensate for unknown atmosphere and temperature effects.

DATA REFERENCE:

Table 12.7, "Static and Kinetic Friction Coefficients," Materials, October 1965.

<u>BASE MATERIAL COMBINATION</u>	<u>TYPE OF MOTION</u>	<u>COATING</u>	<u>VELOCITY sfm</u>	<u>LOAD LBS.</u>	<u>TEMP. °R</u>	<u>OPERATING ENVIRONMENT</u>	<u>COEFFICIENT OF FRICTION, μ</u>
302 SS - Inconel 718	Sliding	Au/Electrolyze	10	-	40-65	GH ₂	.12

Value based on highest point in tests in gaseous helium of Au/Cr coatings on 718 substrates. Highest point selected to compensate for atmosphere and temperature effects.

DATA REFERENCE:

Friction Evaluation of Materials for Valve Applications, ANSC Report RN-TM-0393, October 1966.

Be-Ni/302	Sliding	Electrolize	10	-	40-65	GH ₂	.6
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No data are available for Be-Ni versus 302 SS couples. Value based on tests in air for 301 versus hard chrome (electrolize) couple and the above value is considered conservative for the Be-Ni/electrolyze couple.

DATA REFERENCE:

Friction Evaluation of Materials for Valve Applications, ANSC Report RN-TM-0393, October 1966.

<u>BASE MATERIAL COMBINATION</u>	<u>TYPE OF MOTION</u>	<u>COATING</u>	<u>VELOCITY sfm</u>	<u>LOAD LBS.</u>	<u>TEMP. °R</u>	<u>OPERATING ENVIRONMENT</u>	<u>COEFFICIENT OF FRICTION, μ</u>
Be-Ni Versus 718	Sliding/	Electrolize	10	-	40-65	GH ₂	.6

No data are available for Be-Ni versus hard chrome coating. The above value based on test data of 718 versus hard chrome coating in air. It is expected that the Be-Ni versus hard chrome coefficient to be lower and the above value is a conservative estimate for this couple.

DATA REFERENCE:

Friction Evaluation of Materials for Valve Applications, ANSC Report RN-TM-0393, October 1966.

Vespel - 718	Sliding	None	5	-	40-65	GH ₂	1.0
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Value based on test results of Vespel versus hard chrome couple ($\mu = .5$). The frictional characteristic of 718 is expected to be inferior to hard chrome and the above value is a conservative estimate of μ for the conditions listed.

DATA REFERENCE:

NERVA Materials Developments, Fourth Quarter, RN-S-0538, December 1969.

<u>BASE MATERIAL COMBINATION</u>	<u>TYPE OF MOTION</u>	<u>COATING</u>	<u>VELOCITY sfm</u>	<u>LOAD LBS.</u>	<u>TEMP. °R</u>	<u>OPERATING ENVIRONMENT</u>	<u>COEFFICIENT OF FRICTION, μ</u>
440C - 440C	Rolling	None	Low	-	40-65	GH ₂	.0005

The above value based on stainless steel balls on 52100 plate coefficient of rolling friction of .00007. The value listed is a conservative estimate of the rolling coefficient of friction of 440C versus 440C at the conditions listed.

DATA REFERENCE:

Glaeser, W. A., "An Engineer's Guide to Friction," DMIC 246, February 1970.

440C - 440C	Rolling	Electrolyze	Low	-	40-65	GH ₂	.0005
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The above value based on stainless steel balls on 52100 plate coefficient of rolling friction of .00007. The value listed is a conservative estimate of the rolling coefficient of friction of 440C on hard chrome plate at the conditions listed.

DATA REFERENCE:

Glaeser, W. A., "An Engineer's Guide to Friction," DMIC Memorandum 246, February 1970.

16 - MARAGING STEEL, GRADE 250

DRM
TYPE:

DATA RELEASE MEMORANDUM
NRO MATERIALS AND PROCESSES STAFF
AEROJET-GENERAL CORPORATION
SACRAMENTO, CALIFORNIA

DRM NO.
16.01
REV. NO.
0

SHEET 1 OF 6

SUBJECT: RAD. ACTIVE AND THERMAL PROPERTIES OF
MARAGING STEEL GRADE 250

DATE: 3-23-70

1. SCOPE:

The following properties of Maraging Steel, Grade 250, are attached:

1. Total Hemispherical Emittance
2. Solar Absorptance
3. Coefficient of Thermal Expansion
4. Specific Heat
5. Thermal Conductivity

2. TEST MATERIAL:

Data are applicable to all forms of the subject alloy.

3. DATA ANALYSIS:

Emittance and absorptance are sensitive to surface conditions, and the values listed are applicable to the condition as listed. The values for these properties are estimated on the basis of published values for iron. Elevated temperature data for thermal expansion, specific heat and thermal conductivity are published measured values; values for below room temperature were extrapolated from the elevated temperature data.

The data are considered nominal for which category classification is not required.

5. REFERENCES:

High Strength Steel, 18 Ni Maraging, Processes and Properties Handbook,
A. M. Hall, et. al., DMIC, September 1968.

Thermophysical Properties of High Temperature Solid Materials, Vols. 1
and 3, Y. S. Touloukian, Macmillan Co., 1967.

APPROVED BY <i>[Signature]</i>	DATE <i>3/25/70</i>	PREPARED FOR: DATE: <i>[Signature]</i>	COMPONENT/ ASSEMBLY IDENT
PREPARED BY <i>[Signature]</i>	AUTHORIZED CLASSIFIER <i>[Signature]</i>	DATE <i>3/25/70</i>	

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRI NO. 16.01 PAGE NO. 2 DATE 3-23-70 MATERIAL Mar 250

CONDITION TEST DIRECTION

SPEC. NOS. FORM All Forms

DATA BASIS Nominal COMMENT No Category Required

PROPERTY Total Hemispherical Emittance

TEMP °F	SURFACE	CONDITION					COMPUTED VALUE
400	Surface	Polished					.11
40							.07
-200							.05

COMMENTS: Data estimated from values for total hemispherical emittance of iron, Thermophysical Properties of High Temperature Solid Materials, Vol. 3, Y. S. Touloukian, Macmillan Co., 1967.

AERONET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRL NO. 16.01 PAGE NO. 3 DATE 3-23-70 MATERIAL Mar 200

CONDITION _____ TEST DIRECTION _____

SPEC. NOS. _____ FORM _____

DATA BASIS Nominal COMMENT No Category RequiredPROPERTY Solar Absorptance

TEMP °F	SURFACE CONDITION					COMPUTED VALUE
400	Surface Polished					.36
RT						.37
-200						.39

COMMENTS: Data estimated from values for total hemispherical emittance of iron, Thermophysical Properties of High Temperature Solid Materials, Vol. 3, Y. S. Touloukian, Macmillan Co., 1967.

AEROJET-CENTRAL NUCLEAR POWER OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 16.01 PAGE NO. 4 DATE 3-23-70 MATERIAL Mar 250

CONDITION ST A TEST DIRECTION -

SPEC. NOS. FORM

DATA BASIS Nominal COMMENT No Category Required

PROPERTY Specific Heat

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$	K	S	COMPUTED VALUE BTU/LB
400							.12
200							.09
70							.07
-100							.047
-200							.02

COMMENTS: Elevated Temperature Conductivity - Iron Base Alloys, 18 Ni Maraging Steels, DMIC Processes and Properties Handbook, 1 September 1968; below room temperature, data extrapolated from elevated temperature data.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 16.01 PAGE NO. 5 DATE 3-23-70 MATERIAL Mar 250

CONDITION ST A TEST DIRECTION

SPEC. NOS. FORM All

DATA BASIS Nominal COMMENT No Category Required

PROPERTY Thermal Conductivity

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$	K	S	COMPUTED VALUE BTU-FT HR-FT ² -°F
400							16.7
200							15.5
RT							14.6
-100							12.2
-200							10.2

COMMENTS: Elevated Temperature Conductivity - Iron Base Alloys, 18 Ni Maraging Steels, DMIC Processes and Properties Handbook, 1 September 1968; below room temperature, data extrapolated from elevated temperature data.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 16.01 PAGE NO. 6 DATE 3-23-70 MATERIAL Mar 250

CONDITION	TEST DIRECTION
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SPEC. NOS. FORM A11

DATA BASIS	Nominal	COMMENT	No Category Required
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[illegible]

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$	K	S	COMPUTED VALUES IN/IN X 10 ⁻⁶
RT to 400							5.8
RT to -200							-5.7

COMMENTS: Elevated Temperature Conductivity - Iron Base Alloys, 18 Ni Maraging Steels, DMIC Processes and Properties Handbook, 1 September 1968; below room temperature, data extrapolated from elevated temperature data.

19 - AISI 440C

MATERIAL: AISI 440C

DRM: 19.01

REVISION: 0

DATE: 11-4-70

PAGE 1 OF 6

AEROJET NUCLEAR SYSTEMS COMPANY

MATERIALS DATA RELEASE

<u>MATERIAL</u>	<u>FORM</u>	<u>CONDITION</u>	<u>PROPERTY</u>	<u>DATA CATEGORY</u>	<u>PAGE</u>
AISI 440C	Bar	Quenched and Tempered	Compressive Yield Strength	D	2
			Elastic Modulus	C & D	3
			Poisson's Ratio	D	4
			Density	C & D	5

APPROVAL

ORIGINATOR:

Ralph J. Hefner

REVIEW:

M. Lammey

11/24/70

CLASSIFICATION:

UNCLASS

ALP

24 Nov 70

NOTE: Supersedes DRM M-19, Rev. 0, dated 9-23-70. F_{ty} and F_{tu} values are not to be utilized for NERVA service.

AEROJET-CENTRAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 19.01 PAGE NO. 2 DATE 11-4-70 MATERIAL AISI 440C

CONDITION 1900°F Sol Treated
 Tempered 300-600°F TEST DIRECTION

SPEC. NOS. FORM Bar .385" Round

DATA BASIS COMMENT

PROPERTY Compressive Yield Strength

TEMP °F	TYPICAL VALUE ksi	ESTIMATED ks ksi	DESIGN ALLOWABLE	DATA CATEGORY	REFERENCE
RT	275	25	25C	D	
-423	300*	40	260*	D	

*Estimated fracture stress - yield may not be detected at this temperature because of brittleness.

REVISION: 0
DATE: 11-4-70
PAGE 3 OF 6

AEROJET-CENTRAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 19.01 PAGE NO. 3 DATE 11-4-70 MATERIAL AISI 440C

CONDITION 1900°F Sol Treated
1000°F Temper TEST DIRECTION --

SPEC. NOS. FORM All

DATA BASIS Category "C" and "D" COMMENT Estimated from AISI 410 data.

PROPERTY Elastic Modulus

TEMP °F	TYPICAL VALUE x 10 ⁶	UNCERTAINTY RANGE %	DATA CATEGORY	REFERENCE
RT	29.2	± 5	C	1
-423	30.5	± 5	D	2

REVISION: 0
DATE: 11-4-70
PAGE 4 OF 5

AEROJET-CENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 19.01 PAGE NO. 4 DATE 11-4-70 MATERIAL AISI 440C

CONDITION 1850-1950°F Sol Treated
1000°F Temper TEST DIRECTION

SPEC. NOS. FORM All

DATA BASIS Category "C" COMMENT Estimated

PROPERTY Poisson's Ratio

TEMP °F		μ		UNCERTAINTY RANGE %		DATA CATEGORY	REFERENCE
All Temps		.284		± 5		C	2

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 19.01 PAGE NO. 5 DATE 11-4-70 MATERIAL AISI 440C

CONDITION 1900°F Sol Treated
 1000°F Temper TEST DIRECTION

SPEC. NOS. FORM All
 DATA BASIS Category "C" and "D" COMMENT Density at -423°F calculated from the RT value and thermal expansion data.

PROPERTY Density

TEMP °F	TYPICAL VALUE	UNCERTAINTY RANGE %	DATA CATEGORY	REFERENCE
RT	0.28 lb/in ³	± 5	C	1
-423	0.282 lb/in ³	± 5	D	2

DRM: 19.01
REVISION: 0
DATE: 11-4-70
PAGE 6 OF 6

1. TEST MATERIAL:

Material heat treated as .385 in. rounds and tested as a .375 in. round. The heat treatment was as follows:

Austenitize 1900°F/2 hours, oil quench
Snap draw 350°F/15 minutes, water quench
Temper 350-500°F/2 hours

The required heat treatment for AISI 440C in the NERVA environment is as follows:

Austenitize 1900°F/2 hours, oil quench
Temper 350°F/2 hours
Subzero (-320°F) Treat
Temper 350°F/2 hours

These properties resulting from this heat treatment will not differ markedly from those listed except for ductility and dimensional stability. Transforming any attained martensite and tempering the martensite will partially overcome brittle tendencies.

2. DATA ANALYSIS:

The room temperature compressive yield strength was estimated conservatively to be about 5% greater than the tensile fracture stress. The ks factor of 25 ksi was used because of its low ductility obtained with the low tempering temperature. The compressive weld at -423°F was also estimated from tensile strength; the ks factor was increased to 40 ksi to allow for brittleness and temperature control. X

Room temperature density [Reference (1)] and the thermal expansion characteristics of similar steels (AISI 410) were used to estimate the density at -423°F.

The modulus of elasticity of AISI 440C is equal to that of AISI 410 at room temperature and is assumed to be equal at -423°F.

Poisson's ratio was estimated on the basis of other steels, and further it was assumed to be invariant due to temperature.

3. REFERENCES:

- (1) Republic Stainless Steels, 1951.
- (2) Cryogenic Materials Data Handbook (Revised), Vol. 1, Section B, AFML-TDR-64-280, August 1968.

20 - AA 5083

DATA RELEASE MEMORANDUM

NAO MATERIALS AND PROCESSES STAFF

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

DRM
TYPE:DRM NO.
20.01

REV. NO.

SHEET 1 OF 50SUBJECT: Design Allowable Properties for
5083-H323 Aluminum Alloy Sheet

DATE: 1-23-70

1. SCOPE:

Design allowable data for the following properties of 5083-H323 aluminum alloy sheet are presented:

Ultimate Tensile Strength
Tensile Yield Strength
Elongation
Modulus of Elasticity

2. TEST MATERIAL:

Data are applicable to sheet .051 to .125 inches thick.

3. DATA ANALYSIS:

The "s" basis data, obtained from Mil Handbook 5, are minimum allowable properties as contained in specifications. The data are conservative and may be used until upgraded. These data do not cover the range of interest and additional data are required as noted in the individual data sheets.

4. CONCLUSIONS:

The data are rated "Category C" per TD 69-37 and may be regarded as a conservative engineering estimate of the design allowable.

5. REFERENCE:

Mil Handbook 5 insert, dated 8 February 1966.

APPROVED BY <i>D. Lawrence</i>	DATE <i>23 Jan 70</i>	PREPARED FOR: <i>L. Shortley</i> DATE: <i>23 Jan 70</i>	COMPONENT/ ASSEMBLY IDENT
PREPARED BY <i>John J. H. H. H.</i>		AUTHORIZED CLASSIFIER DATE	

LINES

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 20.01 PAGE NO. 2 DATE 1-23-70 MATERIAL 5083

CONDITION H 323 TEST DIRECTION Longitudinal

SPEC. NOS. QQ-A-250/6 FORM Sheet

DATA BASIS Category "C" - TD 69-28 COMMENT .051, .125 inches thick

PROPERTY Ultimate Tensile Strength, F_{tu}

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$	K	S	COMPUTED VALUE Ksi
70							45
-320							-
-423							-

COMMENTS: Data obtained from Table 3.2.21.0(b), page 388, Mil Handbook 5, basis "s", dated 8 February 1966.

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 20.01 PAGE NO. 3 DATE 1-23-70 MATERIAL 5083

CONDITION H323 TEST DIRECTION Longitudinal

SPEC. NOS. QQ-A-250/6 FORM Sheet

DATA BASIS Category "C", TD 69-28 COMMENT .051-.125 Inches Thick

PROPERTY Tensile Yield Strength, F_{ty}

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$	K	S	COMPUTED VALUE Ksi
70							34
-320							-
-423							-

COMMENTS: Data obtained from Table 3.2.21.0(b), page 388, Mil Handbook 5, basis "s", dated 8 February 1966.

DATA RELEASE

PROPERTY	Elongation, e
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TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$	K	S	COMPUTED VALUE %
70							8
-320							-
-423							-
.							
.							
.							

COMMENTS: Data obtained from Table 3.2.21.0(b), page 388, Mil Handbook 5, basis "s", dated 8 February 1966.

DATA RELEASE

PROPERTY Modulus of Elasticity, E

TEMP °F	LOTS/ HEATS	N	N _e	$\bar{X}$	K	S	COMPUTED VALUE psi
70							10.2 x 10 ⁶
-320							-
-423							-

COMMENTS: Data obtained from Table 3.2.21.0(b), page 388, Mil Handbook 5, basis "s", dated 8 February 1966.

21 - AA 7075

MATERIAL: 7075

DRM: 21.01

REVISION: 0
DATE: 12-7-70
PAGE 1 OF 6

AEROJET NUCLEAR SYSTEMS COMPANY

MATERIALS DATA RELEASE

CONTENTS

<u>MATERIAL</u>	<u>FORM</u>	<u>CONDITION</u>	<u>PROPERTY</u>	<u>DATA CATEGORY</u>	<u>PAGE</u>
Aluminum Alloy 7075	Al	T73	Specific Heat	B & C	2
			Thermal Conductivity	B & D	3
			Coefficient of Thermal Expansion	B & C	4
			Density	B & C	5

APPROVALS

ORIGINATOR:

Ralph J. Haffner

REVIEW:

DJ. Roman 12/8/70

CLASSIFICATION: UNCLASS

CEF 11 Dec 70

AEROJET-CENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 21.01 PAGE NO. 2 DATE 12-7-70 MATERIAL 7075

CONDITION TEST DIRECTION

SPEC. NOS. FORM All Forms and Directions

DATA BASIS COMMENT

PROPERTY Specific Heat

TEMP °F	BTU/ LB °F	UNCERTAINTY %	CATEGORY	REFERENCE
-320	.10	± 15	C	1
-200	.15	± 5	B	1
-100	.175	± 5	B	1
0	.195	± 5	B	1
70	.205	± 5	B	1
100	.21	± 5	B	1
200	.22	± 5	B	1
300	.23	± 5	B	1

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 21.01 PAGE NO. 3 DATE 12-7-70 MATERIAL 7075

CONDITION T73 TEST DIRECTION

SPEC. NOS. FORM

DATA BASIS COMMENT

PROPERTY Thermal Conductivity

TEMP °F		BTU-FT HR-FT ² -°F		UNCERTAINTY %		CATEGORY	REFERENCE
-320		50		± 10.		D	2
-200		63		± 10		D	2
-100		76		± 10		D	2
0		84		± 10		D	2
77		90		± 5		B	1
200		95		± 10		D	2

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 21.01 PAGE NO. 4 DATE 12-7-70 MATERIAL 7075

CONDITION T73 TEST DIRECTION A11

SPEC. NOS. FORM A11

DATA BASIS COMMENT

PROPERTY Coefficient of Linear Expansion

TEMP °F			UNCERTAINTY %		CATEGORY	REFERENCE
-423		8.54	+ 5		B	3
-320		10.2	+ 5		B	2
-200		11.3	+ 5		B	3
-100		12.02	+ 5		B	3
32		13.06	+ 5		B	3
200		13.15	+ 10		C	-

AEROJET-CENTRAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 21.01 PAGE NO. 5 DATE 12-7-70 MATERIAL 7075

CONDITION T73 TEST DIRECTION

SPEC. NOS. FORM All

DATA BASIS COMMENT

PROPERTY Density

TEMP °F	DENSITY LBS/IN. ³	UNCERTAINTY %	CATEGORY	REFERENCE
-423	.1023	± 10	B	(1)
-320	.1022	± 5	B	
-200	.1019	± 5	B	
-100	.1016	± 5	B	
32	.1012	± 5	B	
77	.1010	± 5	B	
200	.1015	± 10	C	

DRM: 21.01
REVISION: 0
DATE: 12-7-70
PAGE 6 OF 6

1. DATA ANALYSIS:

Specific heat data for the temperature range -200 to 200°F were obtained from Reference (1). The curve was extended based on the behavior of 7039 to -320°F. The reported data were classified category "B" and the extension of the curve from -200 to -320°F was classified category "C".

Based on data in Reference (1), the heat treat condition of 7075 greatly effects its thermal conductivity. In the T73 condition, the conductivity at room temperature is reported as 90 Btu-ft/hr-ft²-°F. This is essentially the value reported for 7039-T61, and, therefore, it was assumed that the behavior of the two alloys is similar and the conductivity versus temperature curves would be similar. The data at room temperature are classified category "B" and the remaining values category "D".

The mean coefficient of linear thermal expansion was obtained from Reference (2). The data are from NERVA sponsored tests and are classified category "B" except for the curve extension from RT to 200°F, which is classified category "C".

The density was calculated from the thermal expansion data, and the RT value of .101 lbs/in.³ obtained from Reference (1). These data are classified according to the CTE data used for its calculations.

2. REFERENCES:

- (1) Materials Data Handbook, Aluminum Alloy 7075, J. Sessler and Voker Siess, Contract NAS 8-11345, August 1966.
- (2) NERVA Data Book
- (3) Twenty Seventh Progress Report, NBS Report 9291, NBS, Boulder, Colorado, 30 September 1967.

MATERIAL: 7075

DRM: 21.02

DATE: 12-18-70
PAGE 1 OF 13

AEROJET NUCLEAR SYSTEMS COMPANY

MATERIALS DATA RELEASE

CONTENTS

<u>MATERIAL</u>	<u>FORM</u>	<u>CONDITION</u>	<u>DIRECTION</u>	<u>PROPERTY</u>	<u>DATA CATEGORY</u>	<u>PAGE</u>
7075	F	T73	Longitudinal	Tensile Strength	B	2
7075	F	T73	Long Transverse	Tensile Strength	B	3
7075	F	T73	Short Transverse	Tensile Strength	B	4
7075	F	T73	Longitudinal	Yield Strength	B	5
7075	F	T73	Long Transverse	Yield Strength	B	6
7075	F	T73	Short Transverse	Yield Strength	B	7
7075	F	T73	Longitudinal	Elongation	B	8
7075	F	T73	Long Transverse	Elongation	B & C	9
7075	F	T73	Short Transverse	Elongation	B & C	10
7075	F	T73	All	Modulus of Elasticity	B	11

APPROVALS

ORIGINATOR: *Ralph J. Ketchum*

REVIEW: *D.J. Lammerger* 12/21/70

CLASSIFICATION: *AWF* 21 Dec 70

AEROJET-CENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSING SECTION

DATA RELEASE

DRM NO. 21.02 PAGE NO. 2 DATE 12-18-70 MATERIAL 7075

CONDITION T73 TEST DIRECTION Longitudinal

SPEC. NOS. FORM Hand Forging

DATA BASIS Category B COMMENT 3-4 In. Thick

PROPERTY Tensile Ultimate Strength

TEMP °F	N.	LOTS	M	F	$\bar{X}$	k	s	DESIGN ALLOW- ABLE ksi	DATA CATEGORY	REFERENCE
-423					105.0	2.80	2.18	98.9	B	1 & 2
-320					91.0	2.80	2.18	84.9	B	1 & 2
-100					78.1	2.80	2.18	72.0	B	1 & 2
RT	65	19	42	66.8	72.2	2.80	2.18	66.1	B	1
212					63.3	2.80	2.18	57.2	B	1 & 2
300 (.5 hr)					52.4	2.80	2.18	46.3	B	1 & 2
300 (100 hr)					49.5	2.80	2.18	43.4	B	1 & 2

AEROJET-CENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 21.02 PAGE NO. 3 DATE 12-18-70 MATERIAL 7075

CONDITION T-73 TEST DIRECTION Long Transverse

SPEC. NOS. FORM Hand Forgings

DATA BASIS Category B COMMENT 3-4 In. Thick

PROPERTY Tensile Ultimate Strength

TEMP °F	N	LOTS	M	f	$\bar{X}$	k	s	DESIGN ALLOW- ABLE ksi	DATA CATEGORY	REFERENCE
-423					103.6	2.73	2.19	97.6	B	1 & 2
-320					90.0	2.73	2.19	84.0	B	1 & 2
-100					77.3	2.73	2.19	71.3	B	1 & 2
RT	68	20	68	83	71.4	2.73	2.19	65.4	B	1
200					62.6	2.73	2.19	56.6	B	1 & 2
300 (.5 Hr)					51.8	2.73	2.19	45.8	B	1 & 2
300 (100 Hr)					48.9	2.73	2.19	42.9	B	1 & 2

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 21.02 PAGE NO. 4 DATE 12-18-70 MATERIAL 7075

CONDITION T73 TEST DIRECTION Short Transverse

SPEC. NOS. FORM Hand Forging

DATA BASIS Category B COMMENT 3-4 In. Thick

PROPERTY Tensile Ultimate Strength

TEMP °F	N	LOTS	m	f	$\bar{X}$	k	s	DESIGN ALLOW- ABLE ksi	DATA CATEGORY	REFERENCE
-423					102.1	2.86	2.06	96.2	B	1 & 2
-320					88.6	2.86	2.06	82.7	B	1 & 2
-110					76.2	2.86	2.06	70.3	B	1 & 2
RT	61	17	32.6	52.6	70.4	2.86	2.06	64.5	B	1
212					61.7	2.86	2.06	55.8	B	1 & 2
300 (.5 Hr)					48.2	2.86	2.06	42.3	B	1 & 2
300 (100 Hr)					45.3	2.86	2.06	39.4	B	1 & 2

AEROJET-CENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 21.02 PAGE NO. 5 DATE 12-18-70 MATERIAL 7075

CONDITION T73 TEST DIRECTION Longitudinal

SPEC. NOS. FORM Hand Forging

DATA BASIS Category B COMMENT 3-4 In. Thick

PROPERTY Tensile Yield Strength

TEMP °F	N	LOTS	m	f	$\bar{X}$	k	s	DESIGN ALLOW- ABLE ksi	DATA CATEGORY	REFERENCE
-423					74.9	2.84	2.32	68.3	B	1 & 2
-320					69.1	2.84	2.32	62.5	B	1 & 2
-110					64.3	2.84	2.32	57.7	B	1 & 2
RT	62	18	36.2	58.8	60.5	2.84	2.32	53.9	B	1
212					56.6	2.74	2.32	50.0	B	1 & 2
300 (.5 Hr)					48.0	2.84	2.32	41.4	B	1 & 2
300 (100 Hr)					45.1	2.84	2.32	38.5	B	1 & 2

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 21.02 PAGE NO. 6 DATE 12-18-70 MATERIAL 7075

CONDITION T73 TEST DIRECTION Long Transverse

SPEC. NOS. FORM Hand Forging

DATA BASIS Category B COMMENT 3-4 In. Thick

PROPERTY Tensile Yield Strength

TEMP °F	N	LOTS	m	f	$\bar{X}$	k	s	DESIGN ALLOW- ABLE ksi	DATA CATEGORY	REFERENCE
-423					73.0	2.76	2.40	66.4	B	1 & 2
-320					67.4	2.76	2.40	60.8	B	1 & 2
-110					62.7	2.76	2.40	56.1	B	1 & 2
RT	68	20	52	76.5	59.0	2.76	2.40	52.4	B	1
210					55.3	2.76	2.40	48.7	B	1 & 2
300 (.5 Hr)					46.8	2.76	2.40	40.2	B	1 & 2
300 (100 Hr)					44.0	2.76	2.40	37.4	B	1 & 2

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 21.02 PAGE NO. 7 DATE 12-18-70 MATERIAL 7075

CONDITION T73 TEST DIRECTION Short Transverse

SPEC. NOS. FORM Hand Forging

DATA BASIS Category B COMMENT 3-4 In. Thick

PROPERTY Tensile Yield Strength

TEMP °F	N	LOTS	m	f	$\bar{X}$	k	s	DESIGN ALLOW- ABLE ksi	DATA CATEGORY	REFERENCE
-423					71.7	2.96	3.49	61.4	B	
-320					66.2	2.96	3.49	55.9	B	
-110					61.6	2.96	3.49	51.3	B	
RT	62	17	25.6	40.9	57.9	2.96	3.49	47.6	B	1
210					54.2	2.96	3.49	43.9	B	
300 (.5 Hr)					46.0	2.96	3.49	35.7	B	
300 (100 Hr)					43.2	2.96	3.49	32.9	B	

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 21.02 PAGE NO. 8 DATE 12-18-70 MATERIAL 7075

CONDITION T/3 TEST DIRECTION Longitudinal

SPEC. NOS. FORM Hand Forging

DATA BASIS Category "B" COMMENT 3-4 In. Thick

PROPERTY Elongation, %

TEMP °F	N	LOTS	m	f	$\bar{X}$	k	s	DESIGN ALLOW- ABLE ksi	DATA CATEGORY	REFERENCE
-423					13.2	2.92	1.12	9.9		2
-320					13.2	2.92	1.12	9.9		2
-110					13.2	2.92	1.12	9.9		2
RT	67	19	29	47	12.2	2.92	1.12	8.9	B	1
210					14.1	2.92	1.12	10.8		3
300					18.8	2.92	1.12	15.5		3

AEROJET-CENTRAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESS'S SECTION

DATA RELEASE

DRM NO. 21.02 PAGE NO. 9 DATE 12-18-70 MATERIAL 7075

CONDITION T73 TEST DIRECTION Long Transverse

SPEC. NOS. _____ FORM _____ Hand Forging _____

Categories B & C		3-4 In. Thick
DATA BASIS		COMMENT

PROPERTY Elongation, %

TEMP °F	N	LOTS	m	f	$\bar{X}$	k	s	DESIGN ALLOW- ABLE ksi	DATA CATEGORY	REFERENCE
-423								5.5	C	2
-320								5.5	C	2
-100								5.0	C	2
RT	69	20	30.8	50.3	9.5	2.90	1.63	4.8	B	1
200								6.0	C	3
300								8.0	C	3

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRY NO. 21.02 PAGE NO. 10 DATE 12-18-70 MATERIAL 7075

CONDITION T73 TEST DIRECTION Short Transverse

SPEC. NOS. FORM Hand Forging

DATA BASIS	Categories B and C	COMMENT	3-4 In. Thick
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PROPERTY	Elongation, %
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TEMP °F	N	LOTS	m	f	$\bar{X}$	k	s	DESIGN ALLOW- ABLE	DATA CATEGORY	REFERENCE
-423								1.0	C	2
-320								1.0	C	2
-100								1.0	C	2
RT	62	17	27.3	44.3	6.66	2.95	1.93	1.0	B	1
200								2.0	C	3
300								4.0	C	3

AEROJET-GENERAL NUCLEAR ROCKET OPERATIONS

MATERIALS AND PROCESSES SECTION

DATA RELEASE

DRM NO. 21.02 PAGE NO. 11 DATE 12-18-70 MATERIAL 7075

CONDITION T73 TEST DIRECTION All

SPEC. NOS. FORM Hand Forging

DATA BASIS Category B COMMENT 3-4 In. Thick

PROPERTY Modulus of Elasticity

TEMP °F	E X 10 ⁶ psi	VARI- ABILITY %	DATA CATEGORY	REFERENCE
-423	-			
-320	11.5	± 5	B	2
-110	10.8	± 5	B	2
75	10.3	± 5	B	2
212	9.8	± 5	B	2
300	9.1	± 5	B	2

21.02
DRM:

DATE: 12-18-70
PAGE 12 of 13

1. TEST MATERIAL:

The material consisted of forgings fabricated and heat treated in the thickness range 3.0 to 4.0 inches. All material was tested at room temperature only.

2. DATA ANALYSIS:

All test data were obtained from Appendix C, Large Hand Forgings, pp. 6, 7 and 8. Only data from forgings fabricated and heat treated in the 3.0 - 4.0 in. thickness range were considered. Heats or lots with single data values or with unusually high data spread were not included in the analysis.

The data were analyzed using the one-way analysis of variance for each direction and property. In all cases, the within-lot variances were homogeneous at the .10 level as determined by Box's modification to the Bartlett test. The effective number of specimens (m) and the approximate degrees of freedom for each direction-property combination were calculated using the SATT computer program (using equation listed in NERVA Program Procedure R101-NRP-503). Using these values of m and f, the one-sided tolerance factor, k, was obtained using the TFAC** computer program. The design allowables were calculated using the mean and the standard deviation from the one-way analysis of variance and the 99/95 one-sided tolerance factor (k).

For values above and below room temperature, the effect of test temperature on tensile properties of alloy in T73 condition (typical data) as listed in Reference (2) was used. A ratio room temperature TUS and TYS over Ftu and Fty, respectively, was obtained, and this ratio was applied to the typical readings in the group. Effect of exposure time to temperature (.5 hour and 100 hours) was similarly calculated; the thermal exposure has an effect above 200°F, and, therefore, only the 300°F temperature lists two values for Ftu and Fty. Data for elongation were available for the longitudinal direction only; the assumption was made that the behavior in LT and ST directions would be similar to that of the L direction. Modulus of elasticity at all temperatures was obtained from Reference (2).

The data are classified category "B" in accordance with SNPO-TD 69-28 with the exception of elongation at temperatures other than RT.

DRM: 21.02

DATE: 12-18-70
PAGE 13 OF 13

3. REFERENCES:

(1) Room Temperature Tensile Properties of Large 7075-T6 and 7075-T63 Aluminum Alloy Forgings, DMIC Memorandum 247, Battelle Memorial Institute, January 1970.

(2) Alcoa Alloy 7075-T73, Alcoa Green Letter, Aluminum Co. of America, January 1965.