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EVALUATION OF FASTENERS AND FASTENER MATERIALS FOR SPACE VEHICLES

by

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E. F. GOWEN, JR.

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STANDARD PRESSED STEEL CO.
JENKINTOWN, PENNSYLVANIA

SPS LABORATORIES
STANDARD PRESSED STEEL COMPANY
Jenkintown, Penna.

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FOREWORD

This report was prepared by the Contract Research Department, SPS Laboratories, Standard Pressed Steel Co., Jenkintown, Pennsylvania. The work was initiated under Contract No. NAS8-11125 for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. It was administered under the technical direction of the Propulsion and Vehicle Engineering Laboratory, Engineering Materials Division of the George C. Marshall Space Flight Center with Robert R. Rowe acting as Project Manager.

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ABSTRACT

This document is the final report for Contract NAS8-11125 for the "Evaluation of Fasteners and Fastener Materials for Space Vehicles". The objectives were to characterize existing fasteners and potential high strength fasteners most suitable at temperatures from -423°F (-253°C) to 1600°F (871°C). The entire effort was accomplished over the two year period of 1964 and 1965. During 1964, a total of twenty-one different classes of commercially available fasteners and five potential high strength fastener materials were evaluated and the results are recorded in NASA Report No. CR-357. A summary of the results is included in this report.

In 1965, four additional classes of commercially available fasteners and five potential high strength fastener materials were evaluated. From the total of ten potential high strength materials evaluated during the course of the contract, six were further evaluated as fasteners. The results show that fasteners fabricated from iron-base corrosion resistance alloys, nickel base alloys, and aluminum base alloys would be suitable for space vehicle applications from -423°F to their respective maximum utilization temperature.

In addition, a detailed discussion is presented on unique fastener tests to insure the reliability of fasteners for space vehicle applications. Noteworthy were the angle block tensile tests and tension impact tests to determine the effect of localized stresses and cryogenic temperatures on bolt properties. The results from the entire test program show that no one test is sufficient for determining a fastener's capability for space vehicle application; the fastener itself must be tested.

Conclusions and recommendations for fastener usage resulting from the two year study are included in the report along with recommendations for future study.

Author

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1.0 INTRODUCTION

Aerospace vehicles have come rapidly into prominence and importance bringing their own particular set of structural and environmental requirements. The speed with which knowledge has been needed and used in the aerospace vehicle technology has created a need for mechanical fastener information which could not be filled from data and design allowables used for airplane design. Furthermore, the field of mechanical fastening has been largely overlooked in data compilation programs and nowhere does an overall report on the state-of-the-art exist so that the information is readily usable in today's technology.

For these reasons the George C. Marshall Space Flight Center of the National Aeronautical and Space Administration initiated a program to evaluate existing high strength fasteners and potential high strength fastener materials and to characterize those most suitable for space vehicle applications at temperatures from -423°F (-253°C) to 1600°F (871°C). The entire effort was conducted over the two year period during 1964 and 1965. A total of 25 classes of commercially available fasteners and ten potential high strength fastener materials were evaluated. In addition, six of the potential high strength materials were further evaluated as fasteners. The complete evaluation for 1964 is recorded in NASA Report CR 357. The entire effort was accomplished in the following phases:

1. Survey
2. Evaluation of Commercially Available Fasteners
3. Potential High Strength Fastener Material Evaluation
4. Evaluation of Potential High Strength Materials as Fasteners
5. Environmental Corrosion Resistance Properties
6. Fastener Tests for Unique Space Vehicle Applications

The survey was undertaken to determine the space vehicle industry's present and future fastener requirements. Information was contributed by the aerospace industry consisting of NASA contractors, NASA installations and fastener manufacturers. Also, a thorough search was made of available literature containing data on fasteners and potential fastener materials. The information derived from the survey included present and future fastener materials, configurations, applications and design criteria, testing and test methods, and fastener information and specifications.

From the results of the survey, twenty-five different classes of existing fasteners were selected and evaluated. The selected fasteners consisted of variations of tension and shear bolts, semi blind bolts, structural rivets and companion fasteners fabricated from material within the specific base alloys of iron, nickel, titanium and aluminum. For the evaluation in 1964, the fasteners were procured from the various fastener manufacturers supplying the aerospace industry in addition to Standard Pressed Steel Co. In 1965, Standard Pressed Steel Co. manufactured all fasteners that were evaluated.

The evaluation developed usage and mechanical property data for the twenty-five classes of fasteners from -423°F to their respective maximum utilization temperatures. Tests included tensile, shear, tension impact, stress rupture, stress relaxation, nut reusability, nut vibration, corrosion resistance, effects of thermal cycling and the effects of relaxation on mechanical properties.

Ten alloys of iron, nickel, titanium and cobalt base were evaluated to determine their potential as high strength fasteners. The alloys were selected from the results of the survey on the basis of potential for high strength fastener applications and expectant future usage.

From the results of the material evaluation of the ten alloys, six alloys showed definite potential for high strength fastener applications. These alloys were then selected for further evaluation as fasteners. They underwent a comprehensive evaluation for fastener applications in the temperature range of -423°F to their maximum utilization temperature.

In addition to mechanical properties, the corrosion resistance properties of the fasteners were determined under sea coast and accelerated salt spray atmospheres. The properties were determined in conjunction with space vehicle structural materials of aluminum, stainless steel and titanium. Also, stress corrosion susceptibility of the fasteners and structural materials with various combinations of corrosion barriers, platings and coatings was investigated.

Finally, tests to insure the reliability of fasteners for space vehicle applications were determined. These tests were then to be recommended for either new specifications or inclusion in existing fastener procurement specifications.

2.0 Summary

As a result of the survey which is presented in Appendix II, twenty-five classes of commercially available fasteners and ten potential high strength fastener materials were selected for evaluation. Six of the ten materials were further evaluated as fasteners. The selected fasteners consisted of tension and shear bolts, semi blind fasteners, structural rivets, and their companion fasteners. The fasteners were fabricated from within the specific base alloys of iron, nickel, titanium, aluminum and cobalt. The fastener configurations and materials were:

Iron Base

A. Tension Bolts

1. AISI H-11 (220 ksi)
2. Vasco Max 300 18% Ni Maraging Steel
3. A-286 (200 ksi)
4. U-212

B. Shear Bolts

1. AISI H-11 (260 ksi)

C. Point Drive Fasteners

1. AISI 8740

D. Jo Bolts

1. AISI 4130
2. A-286 (140 ksi)

E. Semi Blind Rivet

1. A-286

Nickel Base

A. Tension Bolts

1. Inconel 718 (180 ksi)
2. Inconel 718 25% Cold Reduced
3. Udimet 630
4. Waspaloy (150 ksi)
5. Waspaloy 25% Cold Reduced
6. Rene 41
7. AF 1753

B. Point Drive Fasteners

1. Inconel 718 (180 ksi)
2. Waspaloy (150 ksi)
3. Waspaloy 25% Cold Reduced
4. AF 1753

Titanium Base

A. Tension Bolts

1. 1Al-8V-5Fe
2. 6Al-4V
3. 7Al-12Zr
4. 8Al-1Mo-1V
5. 5Al-2.5Sn (ELI)
6. 5Al-5Sn-5Zr

B. Shear Bolts

1. 6Al-4V

C. Point Drive Fasteners

1. 6Al-4V
2. 5Al-2.5Sn
3. 5Al-2.5Sn (ELI)

D. Solid Rivet

1. Comm. Pure Ti

Aluminum Base

A. Semi Blind Rivet

1. 2017-T4

B. Solid Rivet

1. 2024-T4

Cobalt Base

A. Tension Bolt

1. L605 30% Cold Reduced

B. Point Drive Fastener

1. L605 30% Cold Reduced

From the information gathered in the entire program, Chart 2.1 was constructed to illustrate the recommended temperature range for the tension fasteners evaluated. The fastener materials are listed by their base alloy group in descending order of room temperature tensile strength. The chart is general and does not reflect in all cases the absolute minimum or maximum temperatures to which the fastener material can be utilized. For example, the 18 percent nickel maraging steel fasteners, H-11 fasteners, and titanium fasteners, with the exception of Ti 5Al-2.5Sn (ELI), show a minimum utilization temperature of room temperature. This minimum utilization temperature may be lower than room temperature but is listed as room temperature for the following reasons:

a. No tests were conducted between -320°F and room temperature.

b. Insufficient data at -320°F.

c. Poor fastener performance at -320°F.

This also holds true for the maximum utilization temperature of the Udimet 630 and Ti 5Al-5Sn-5Zr fasteners. Their maximum utilization temperature is listed as room temperature because of poor fastener performance at the elevated temperatures of 1200°F and 750°F respectively. It may be at an intermediate point between room temperature and the maximum temperature at which they were tested.

Tables 2.1 and 2.2 list by numerical preference the usage of fasteners by base alloy group for tension and shear applications at cryogenic and moderate temperatures respectively.

Table 2.3 lists by numerical preference the usage of fasteners for elevated temperature applications. Numerical rating was based on short time tensile, stress rupture life and stress relaxation properties at the maximum utilization temperature of the fastener.

Charts 2.2 through 2.6 show the tensile strength to density ratio over the temperature range of -423°F to the maximum utilization temperature of tension fasteners evaluated. The charts were constructed by base alloy group and thread rolling sequence.

Charts 2.7 through 2.10 show the shear strength to density ratio over the temperature range of -423°F to the maximum utilization temperature of the fastener materials evaluated. The charts were constructed by base alloy group.

Charts 2.11 through 2.14 list the bolt tensile and shear properties of the tension fasteners evaluated. The charts were constructed by base alloy group and thread rolling sequence.

Charts 2.15 through 2.17 show the ultimate tensile and shear strength of the semi-blind fasteners evaluated while Charts 18 and 19 show the shear properties of the semi-blind and solid rivets.

Corrosion resistance properties under environmental corrosive atmospheres were determined for the various fasteners evaluated when installed in space vehicle structural materials of aluminum, stainless steel and titanium. The tests were conducted under sea coast and accelerated salt spray atmospheres employing various corrosive barriers. No correlation could be made between the two environments, except that corrosion occurred in a much shorter period of time in the accelerated salt spray tests. The results did show that a coating of zinc chromate primer afforded the best protection to aluminum structural materials when installed with any type fastener.

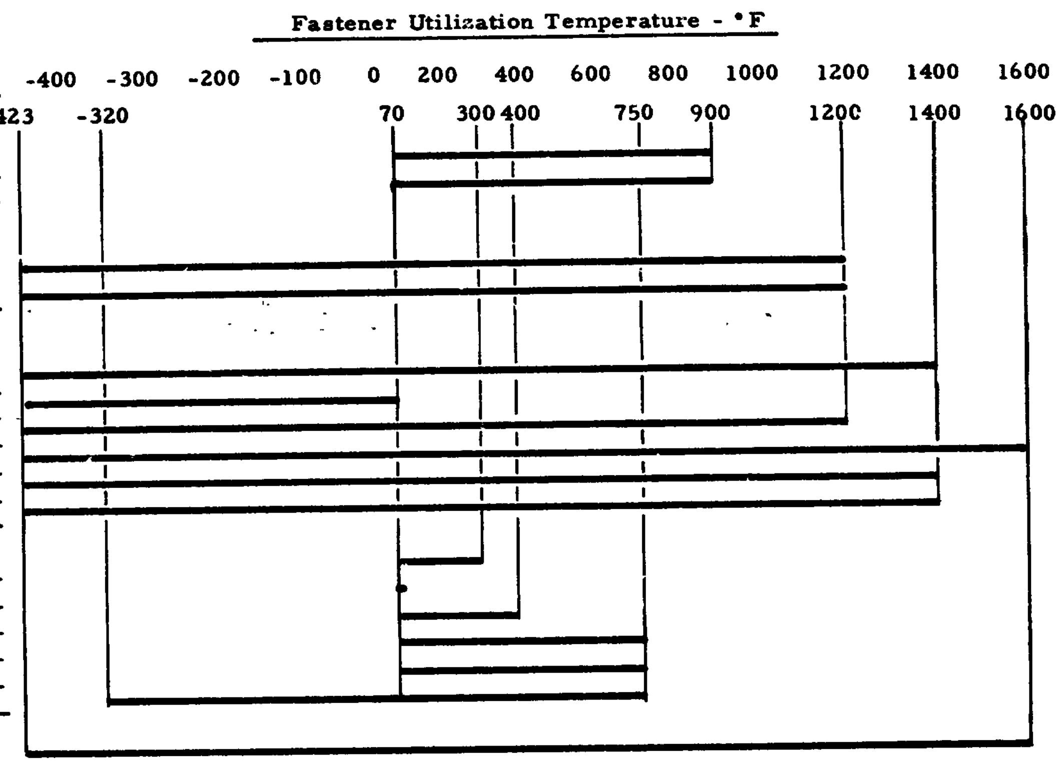
Finally, one of the main objectives of the program was to determine tests that should be employed in establishing the reliability of fasteners for space vehicle applications. From the overall test program, it was concluded that to determine a fastener's reliability, the fastener itself must be tested. These tests should include the following:

1. Tensile and Shear at -423°F
2. Angle Block Tensile Tests at Cryogenic Temperatures
3. Tension Impact of Bolt Threads at Cryogenic Temperatures
4. Tension-Tension Fatigue
5. Stress Rupture Tests at Elevated Temperatures
6. Stress Relaxation Tests at Elevated Temperatures.

CHART NO. 2.1

RECOMMENDED TEMPERATURE RANGE FOR HIGH STRENGTH MATERIALS FOR UTILIZATION AS FASTENERS FOR SPACE VEHICLE APPLICATIONS

Base Alloy	Material	Bolt U. T. S. @-423°F ksi	Bolt U. T. S. @ Room ksi
Fe Base Non Cres.	18% Nickel Maraging Steel	350	260
	AISI H-11	310*	220
Fe Base Cres	Cold Reduced A-286	285	200
	U-212	275	180
Ni Base	Cold Reduced Waspaloy	350	230
	Udimet 630	300	230
	Inconel 718	285	180
	AF 1753	240	180
	Waspaloy	225	150
	Rene 41	200	150
Ti Base	Ti 1-8-5	220*	200
	Ti 5-5-5	210*	160
	Ti 6-4	240*	160
	Ti 7-12	225*	150
	Ti 8-1-1	240*	140
	Ti 5-2.5 (ELI)	225	110
Co Base	Cold Reduced L605 (Unaged)	375	275



*No indication of bolt yield strength at -423°F.

TABLE 2.1

COMPARATIVE EVALUATION BY FASTENER USAGE PROPERTY FOR EACH ALLOY GROUP FOR CRYOGENIC APPLICATIONS

Numerical Rating (In order of decreasing recommended usage)

Fastener Material	Tension Axial	Tension 3° Angle Block	Shear
Fe Base			
18% Ni Maraging	1	Not Tested	N. R.
U-212	2	2	2
Cold Reduced (A-286)	3	1	3
H-11 (220 ksi)	N.R. Below -320°F	N. R. Below -320°F	1
Ni Base			
Cold Reduced Waspaloy	1	1	2
Cold Reduced Inco 718	2	7	3
U-630	3	3	1
Inco 718	4	2	4
Waspaloy	5	4	6
Rene 41	6	5	7
AF 1753	7	6	5
Ti Base			
6Al-4V	N.R.	N. R.	1
7Al-12Zr	N.R.	N. R.	2
8Al-1Mo-1V	N. R.	N.R.	3
5Al-2.5Sn (ELI)	1	N. R. Below -320°F	4
5Al-5Sn-5Zr	N. R.	N. R.	N. R.
1Al-8V-5Fe	N. R.	N. R.	N. R.
Co Base			
Cold Reduced L605 (unaged)	1	1	1
Cold Reduced L605 (aged)	N. R.	N. R.	N. R.

N. R. - Not Recommended

TABLE 2.2

COMPARATIVE EVALUATION BY FASTENER USAGE PROPERTY FOR EACH ALLOY GROUP FOR ROOM TO MODERATE TEMPERATURE APPLICATION

Numerical Rating (In order of decreasing recommended usage)

Fastener Material	Tension Axial	Tension 3° Angle Block	Shear
Fe Base			
18% Ni Maraging	1	Not Tested	1
U-212	3	2	3
Cold Reduced A-286	4	3	4
H-11 (220 ksi)	2	1	2
Ni Base			
Cold Reduced Waspaloy	2	2	2
Cold Reduced Inco 718	1	1	3
U-630	3	3	1
Inco 718	4	4	4
Waspaloy	5	5	6
Rene 41	6	6	7
AF 1753	7	7	5
Ti Base			
6Al-4V	2	1	2
7Al-12Zr	5	5	4
8Al-1Mo-1V	4	3	5
5Al-2.5Sn (ELI)	6	4	6
5Al-5Sn-5Zr	3	2	3
1Al-8V-5Fe	1	Not Tested	1
Co Base			
Cold Reduced L605 (Unaged)			

TABLE 2.3

COMPARATIVE EVALUATION BY FASTENER USAGE PROPERTY FOR ELEVATED TEMPERATURE APPLICATION

Numerical Rating (In order of decreasing recommended usage)

Fastener Material & Max. Temp. Usage	Short Time Tensile	Stress Rupture 100 hr. Life	Stress Relaxation 50 hours
750°F			
Ti 8Al-1Mo-1V	3	2	2
Ti 7Al-12Zr	2	1	1
Ti 5Al-2.5Sn(ELI)	4	3	3
Ti 5Al-5Sn-5Zr	1	N. R.	N. R.
900°F			
18% Ni Maraging	2	2	2
H-11 (220 ksi)	1	1	1
1200°F			
U-212	3	2	2
Cold Reduced A-286	4	3	3
Cold Reduced Inco 718	1	Not Tested	Not Tested
Inco 718	2	1	1
U-630	N. R.	N. R.	N. R.
1400°F			
Cold Reduced Waspaloy	3	3	3
Waspaloy	1	2	2
Rene 41	2	1	1
1600°F			
AF 1753	1	1	1
Cold Reduced L605	2	2	2

N. R. - Not Recommended

Tensile Strength to Density Ratio Versus Temperature of Iron Base Fasteners

Legend
- ○ AISI H-11 (220 ksi)
- △ Vasco Max 300
- □ A-286 (cold reduced)
- ⬡ U-212 (Roll Threads After Age)
- ■ U-212 (Roll Threads Before Age)

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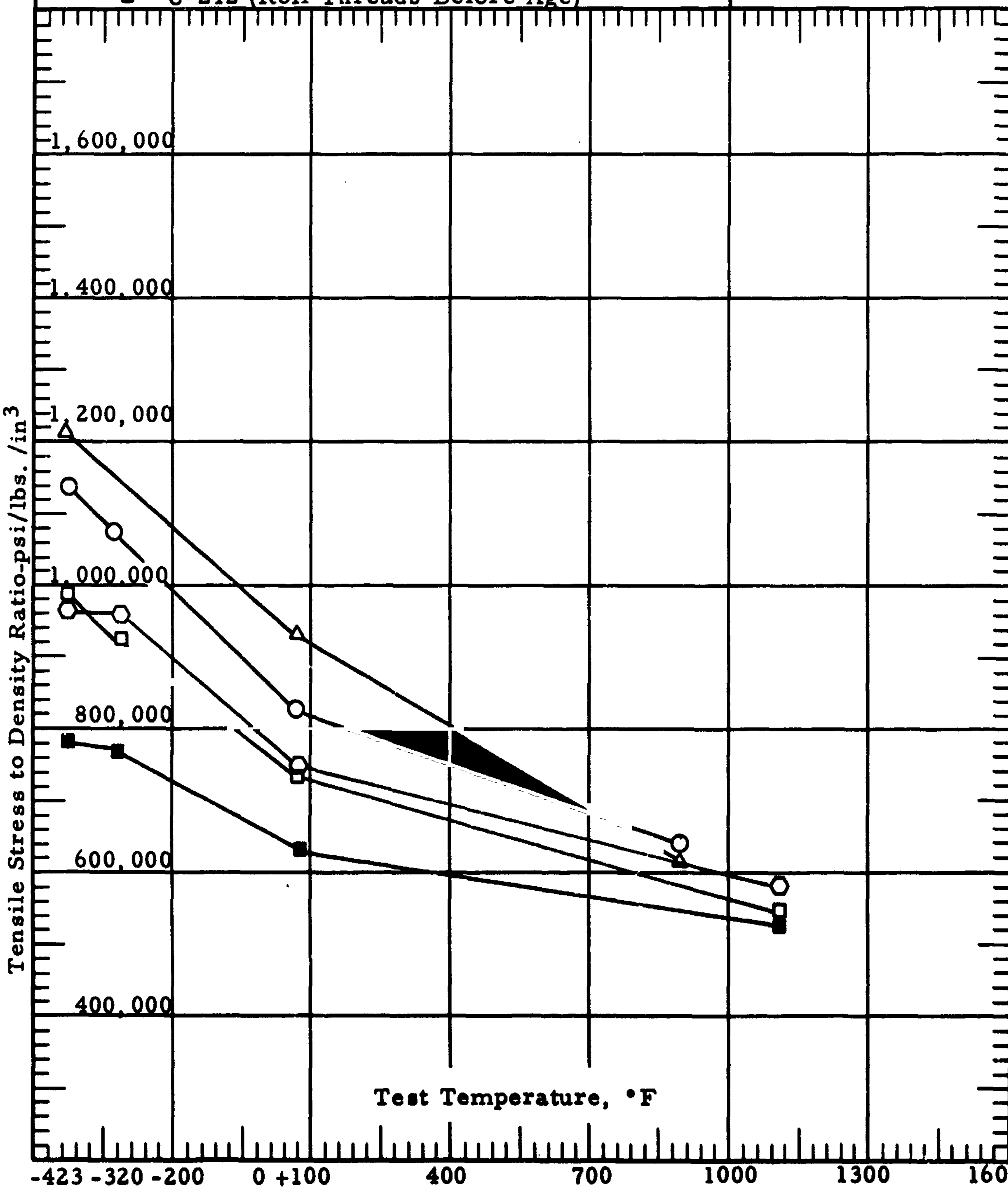
Chart No.: 2.2

Date:



Tensile Strength to Density Ratio Versus Temperature of Nickel Base Fasteners (Roll Threads Before Age Hardening)

Legend

- O Waspaloy
- △ Inco 718
- □ AF 1753
- ⬡ Rene 41

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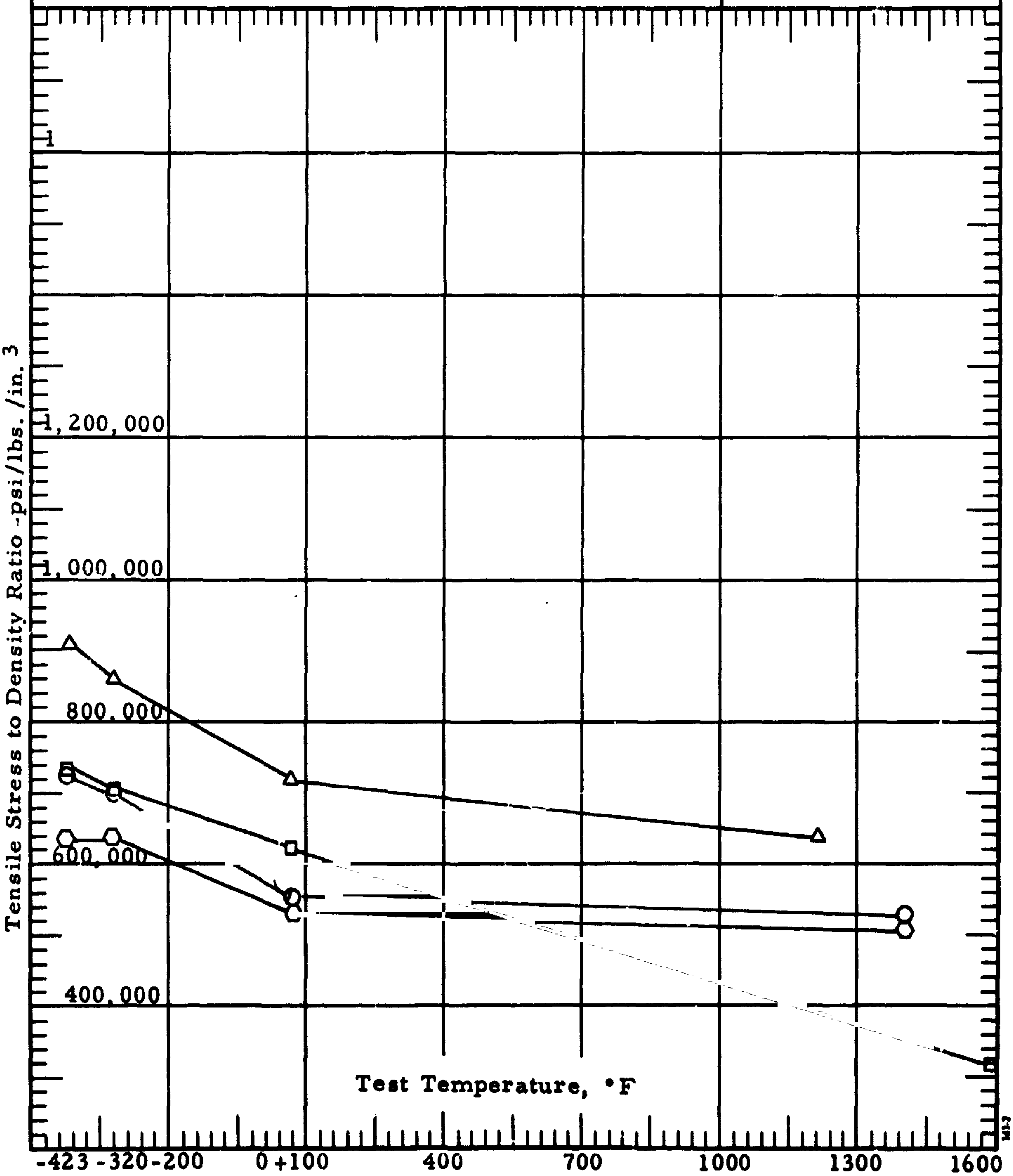
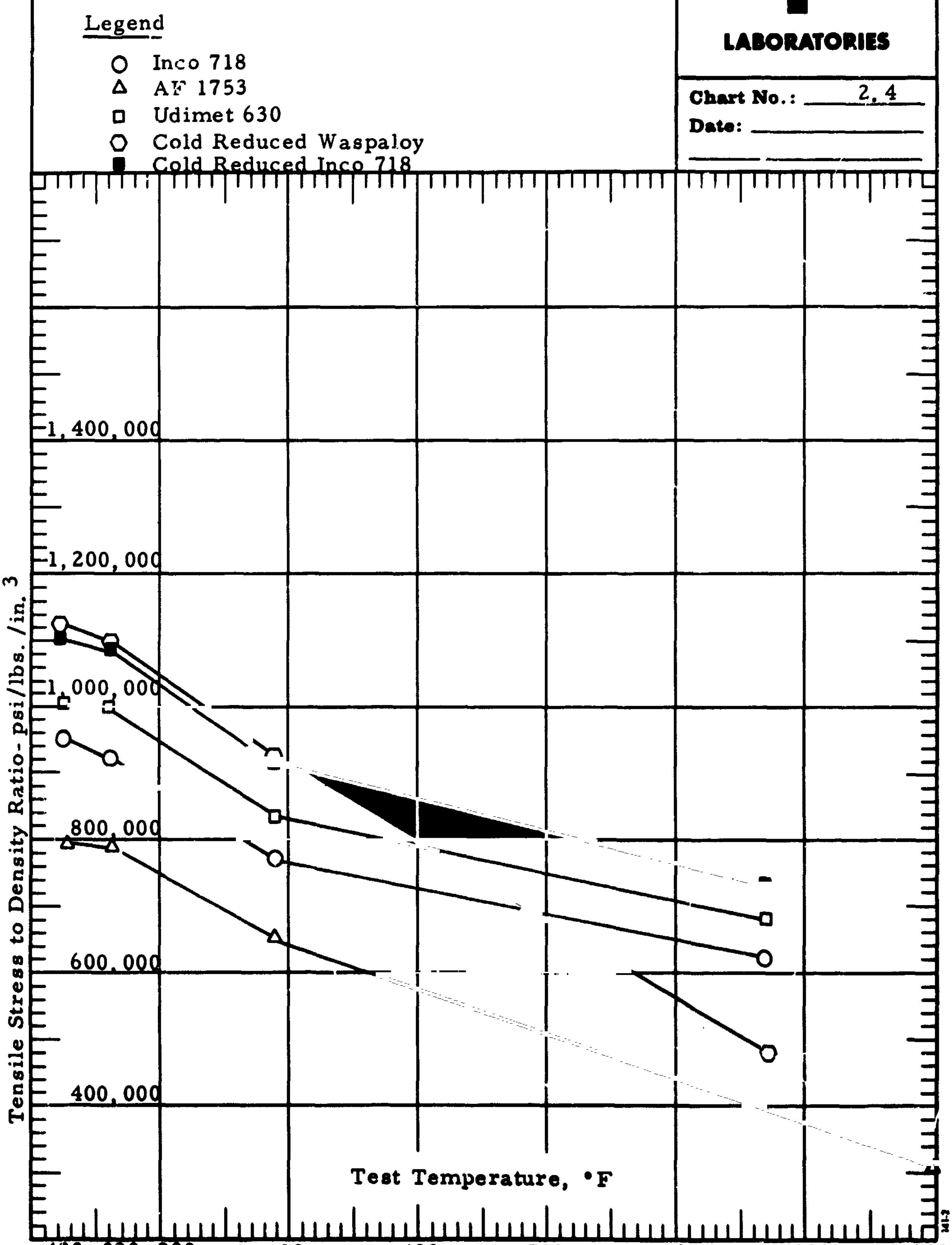
Chart No.: 2.3

Date:



Tensile Strength to Density Ratio Versus Temperature of Nickel Base Fasteners (Roll Thread After Age Hardening)



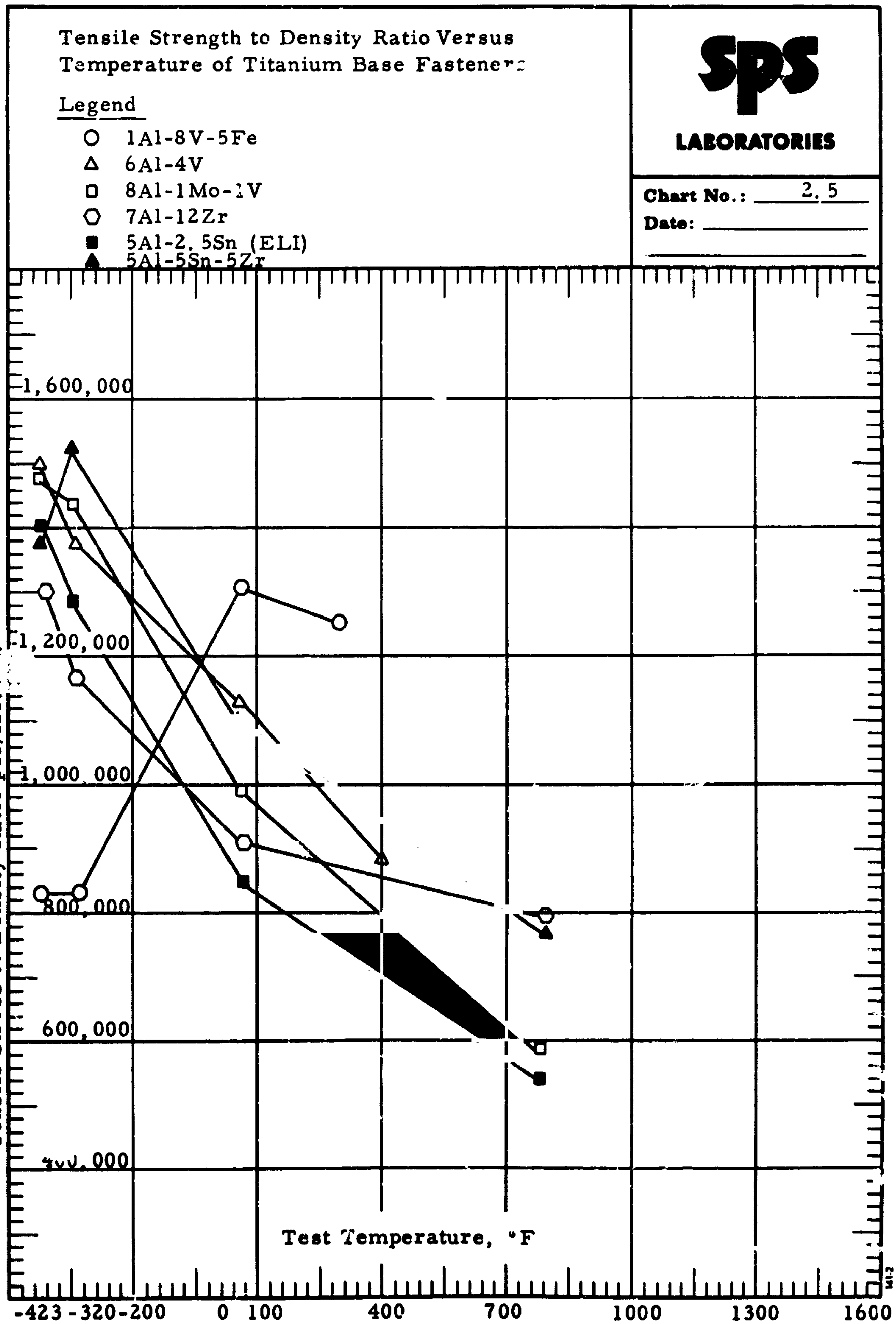

Tensile Strength to Density Ratio Versus
Temperature of Titanium Base Fasteners
Legend
1Al-8V-5Fe
6Al-4V
8Al-1Mo-1V
7Al-12Zr
5Al-2.5Sn (ELI)
5Al-5Sn-5Zr
SPS
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Chart No.: 2.5
Date:
1,600,000
1,200,000
1,000,000
800,000
600,000
400,000
Tensile Stress to Density Ratio-psi/lbs./in.3
Test Temperature, °F
-423
-320
-200
0
100
400
700
1000
1300
1600

Tensile Strength to Density Ratio Versus Temperature of Cobalt Base Fasteners

Legend

○ – 30% Cold Reduced L605 (Unaged Condition)
△ – 30% Cold Reduced L605 (Aged Condition)

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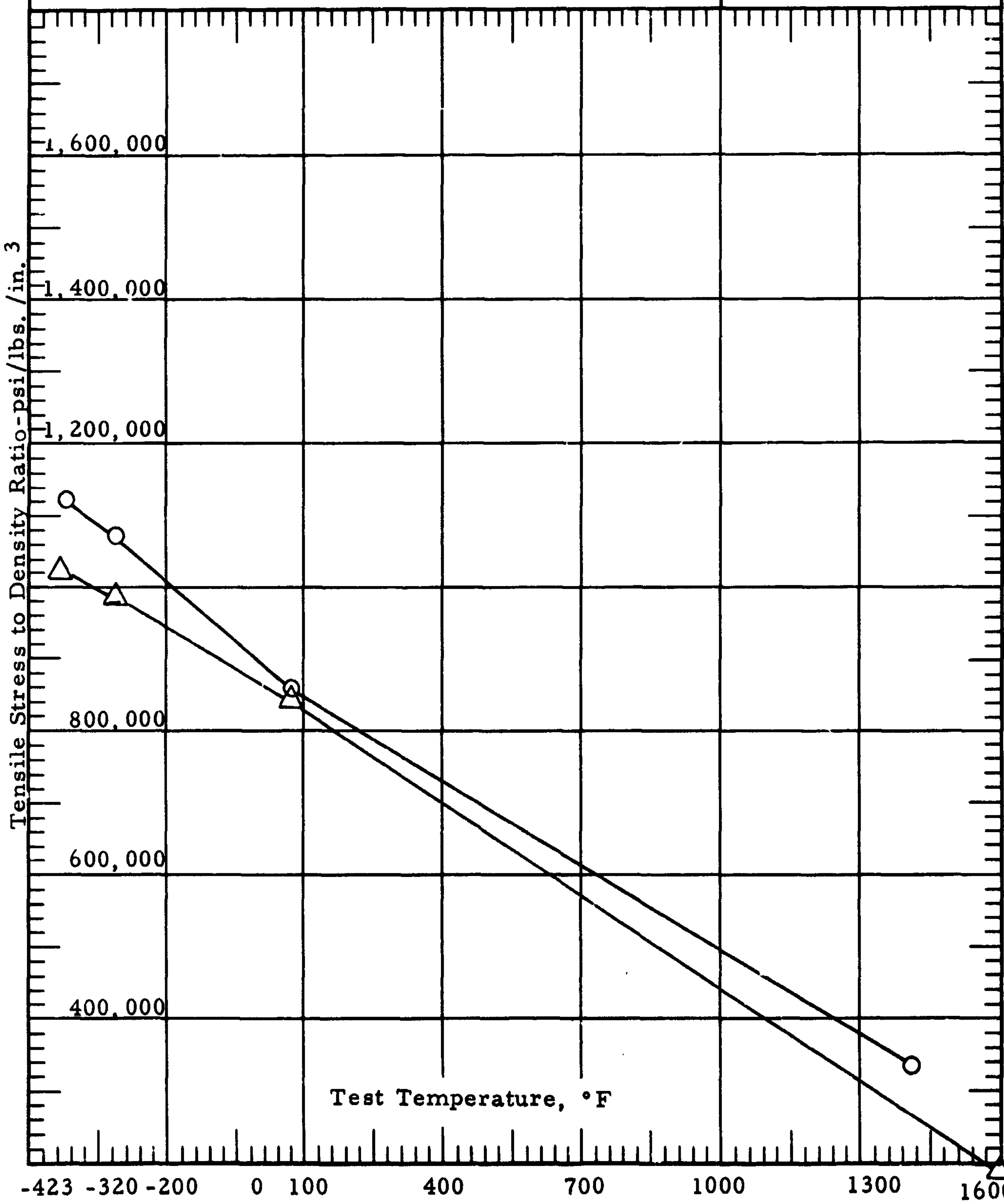
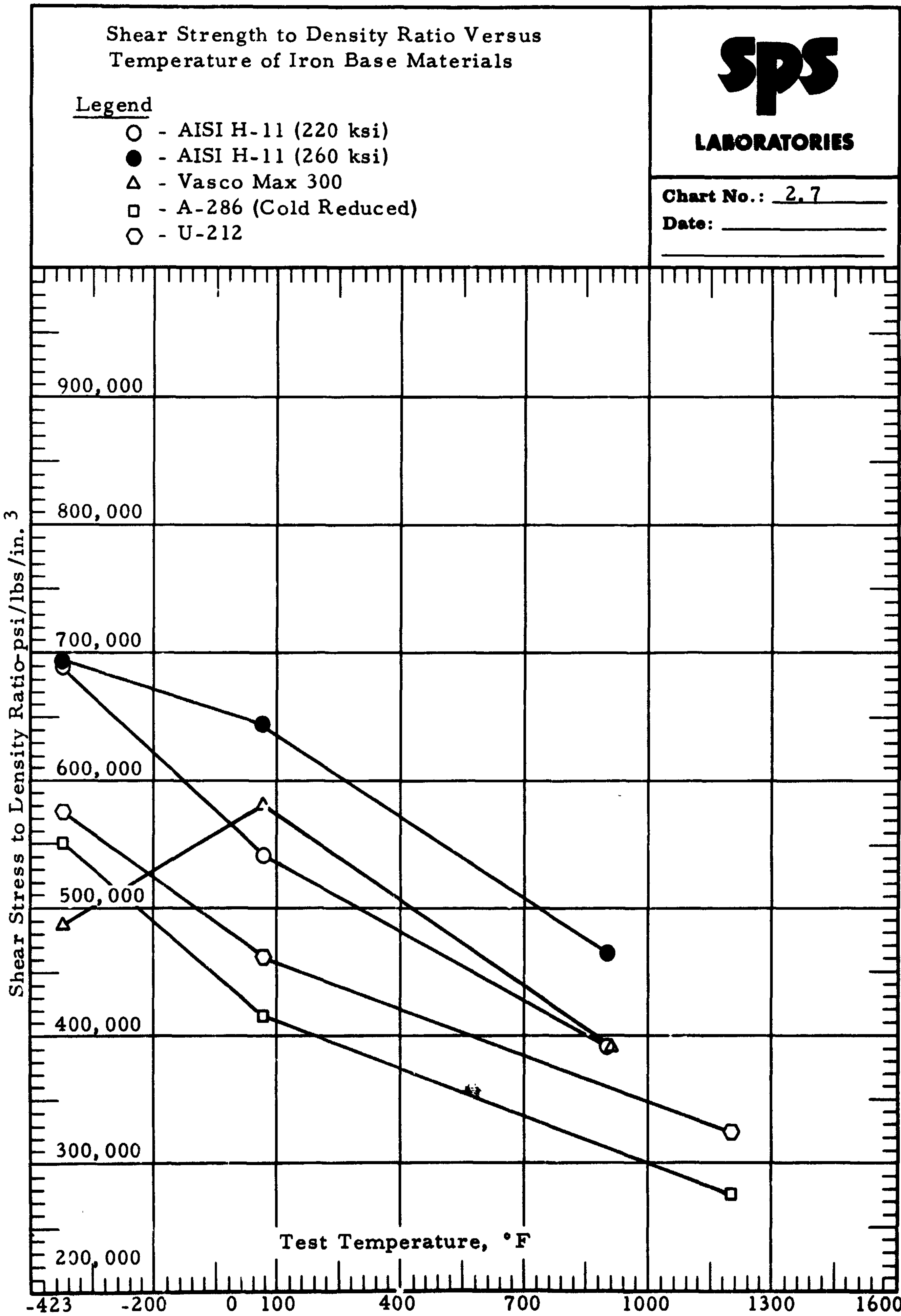
Chart No.: 2.6
Date:





Shear Strength to Density Ratio Versus
Temperature of Iron Base Materials
Legend
○ - AISI H-11 (220 ksi)
● - AISI H-11 (260 ksi)
△ - Vasco Max 300
□ - A-286 (Cold Reduced)
⬡ - U-212
SPS
LABORATORIES
Chart No.: 2.7
Date:
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
Shear Stress to Density Ratio-psi/lbs/in.3
Test Temperature, °F
-423
-200
0
100
400
700
1000
1300
1600

Shear Strength to Density Ratio Versus Temperature of Nickel Base Materials

Legend

- O - Conventional Waspaloy
- Δ - Conventional Inco 718
- □ - Udimet 630
- ⬡ - AF 1753
- ● - Cold Red. Waspaloy
- ▲ - Cold Red. Inco 718
- ■ - Rene 41

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Chart No.: 2.8

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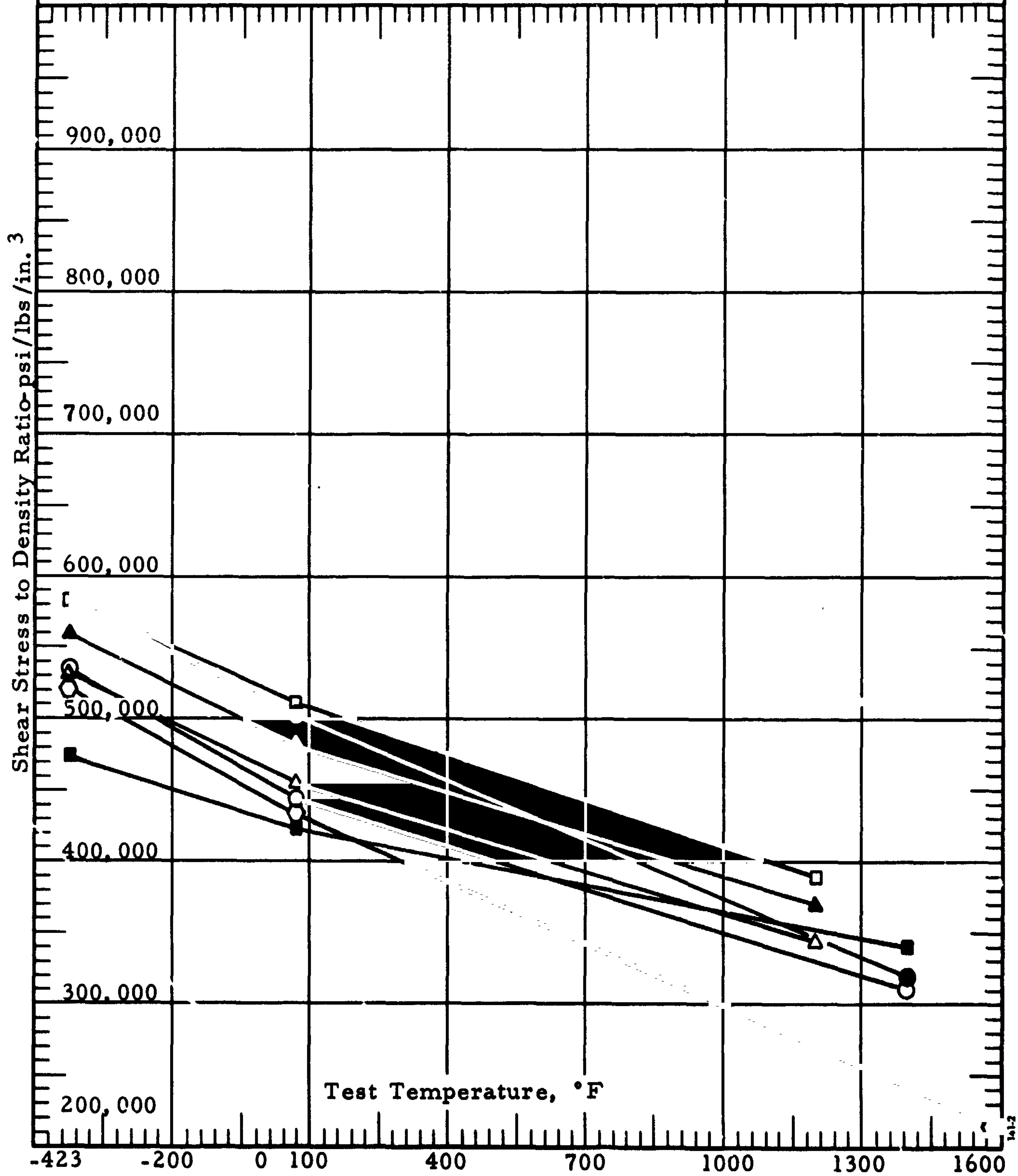

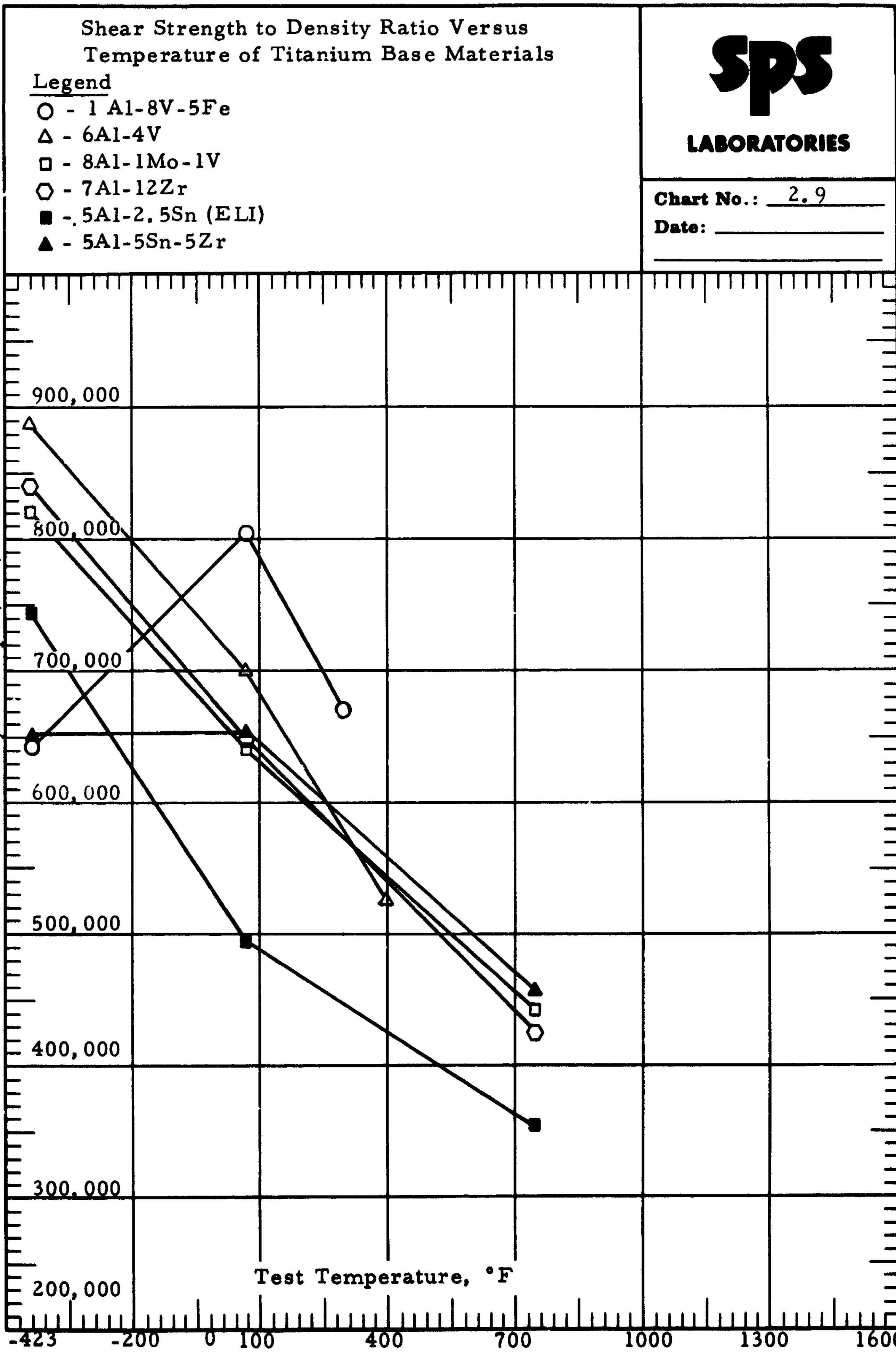
Shear Strength to Density Ratio Versus
Temperature of Titanium Base Materials
Legend
○ - 1 Al-8V-5Fe
△ - 6Al-4V
□ - 8Al-1Mo-1V
⬡ - 7Al-12Zr
■ - 5Al-2.5Sn (ELI)
▲ - 5Al-5Sn-5Zr
SPS
LABORATORIES
Chart No.: 2.9
Date:
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
Shear Stress to Density Ratio-psi/lbs/in.3
Test Temperature, °F
-423
-200
0
100
400
700
1000
1300
1600

Shear Strength to Density Ratio Versus Temperature of Cobalt Base Materials

Legend

○ - 30% Cold Red. L605 (Unaged)
△ - 30% Cold Red. L605 (Aged)

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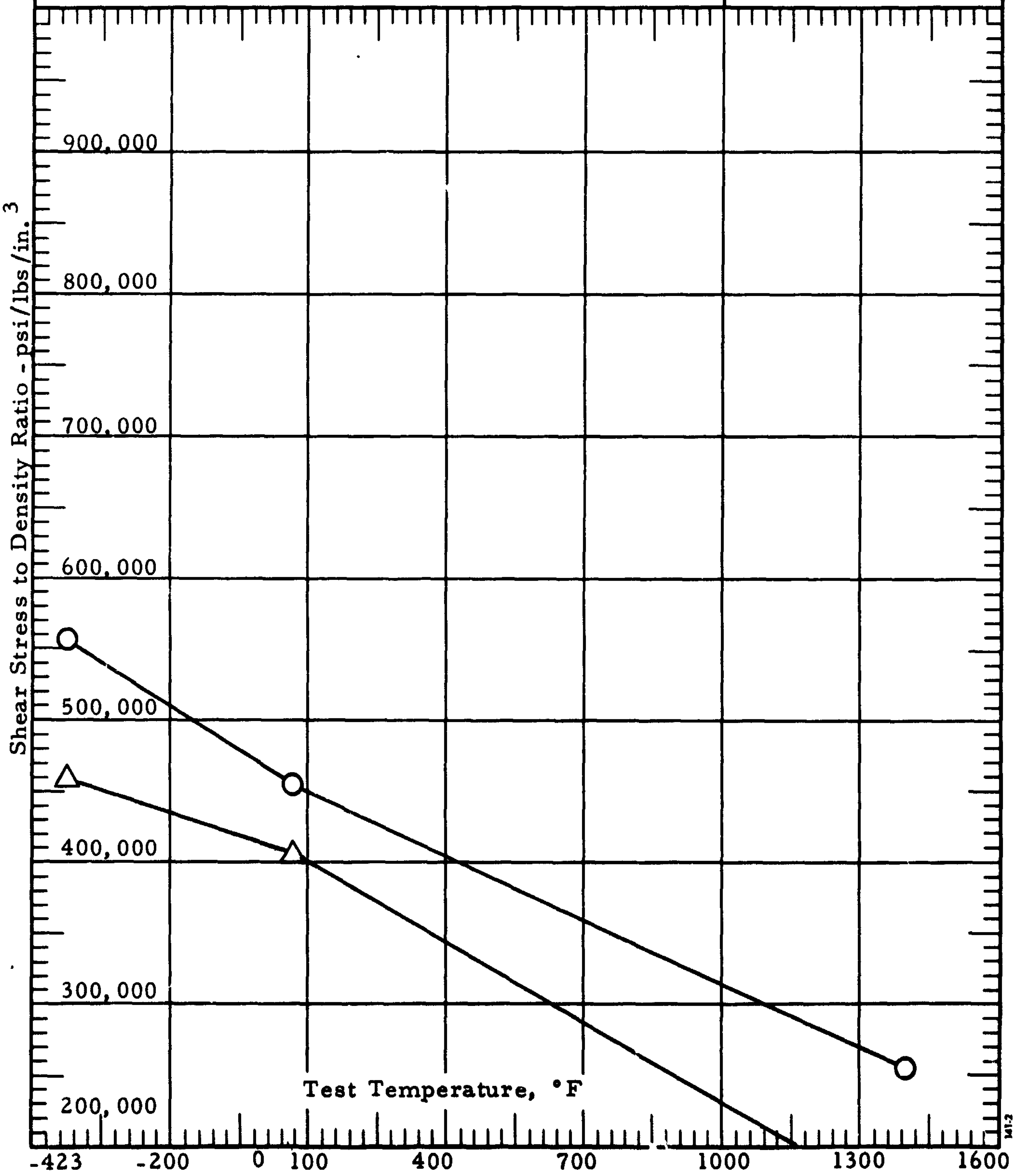
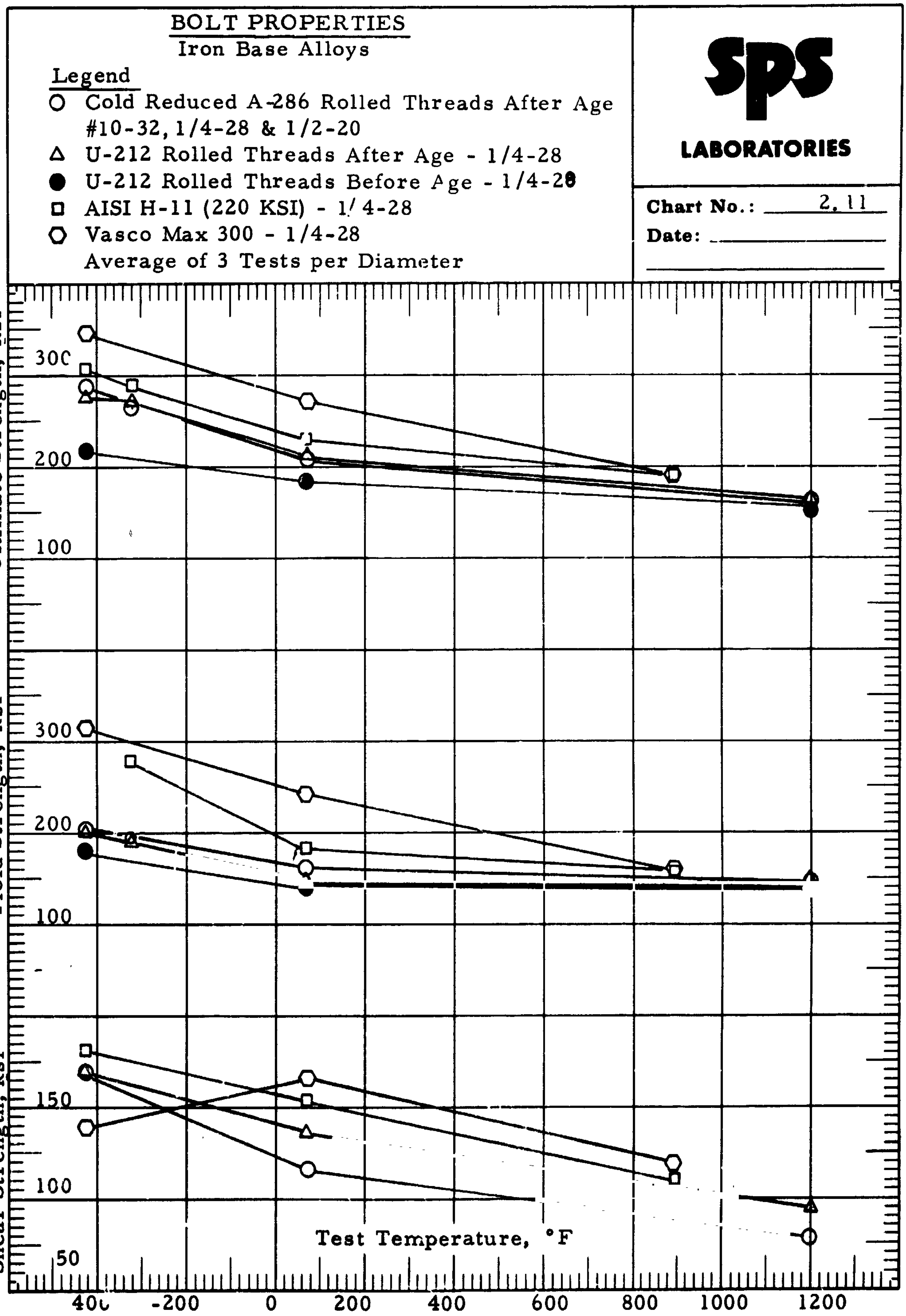
Chart No.: 2.10
Date:




BOLT PROPERTIES
Iron Base Alloys
Legend
○ Cold Reduced A-286 Rolled Threads After Age #10-32, 1/4-28 & 1/2-20
△ U-212 Rolled Threads After Age - 1/4-28
● U-212 Rolled Threads Before Age - 1/4-28
□ AISI H-11 (220 KSI) - 1/4-28
⬡ Vasco Max 300 - 1/4-28
Average of 3 Tests per Diameter
SPS LABORATORIES
Chart No.: 2.11
Date:
Ultimate Strength, ksi
Johnson's 2/3 Approx. Yield Strength, ksi
Shear Strength, ksi
300
200
100
50
150
Test Temperature, °F
-400
-200
0
200
400
600
800
1000
1200

BOLT PROPERTIES

Nickel Base Alloys

Rolled Threads Before Age

Legend

○ - Waspaloy - #10-32, 1/4-28, & 1/2-20
△ - Rene 41 - #10-32, 1/4-28, & 1/2-20
□ - AF 1753 - 1/4-28
⬡ - Inconel 718 - 1/4-28

Average of 3 Tests per Diameter

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Chart No.: 2.12

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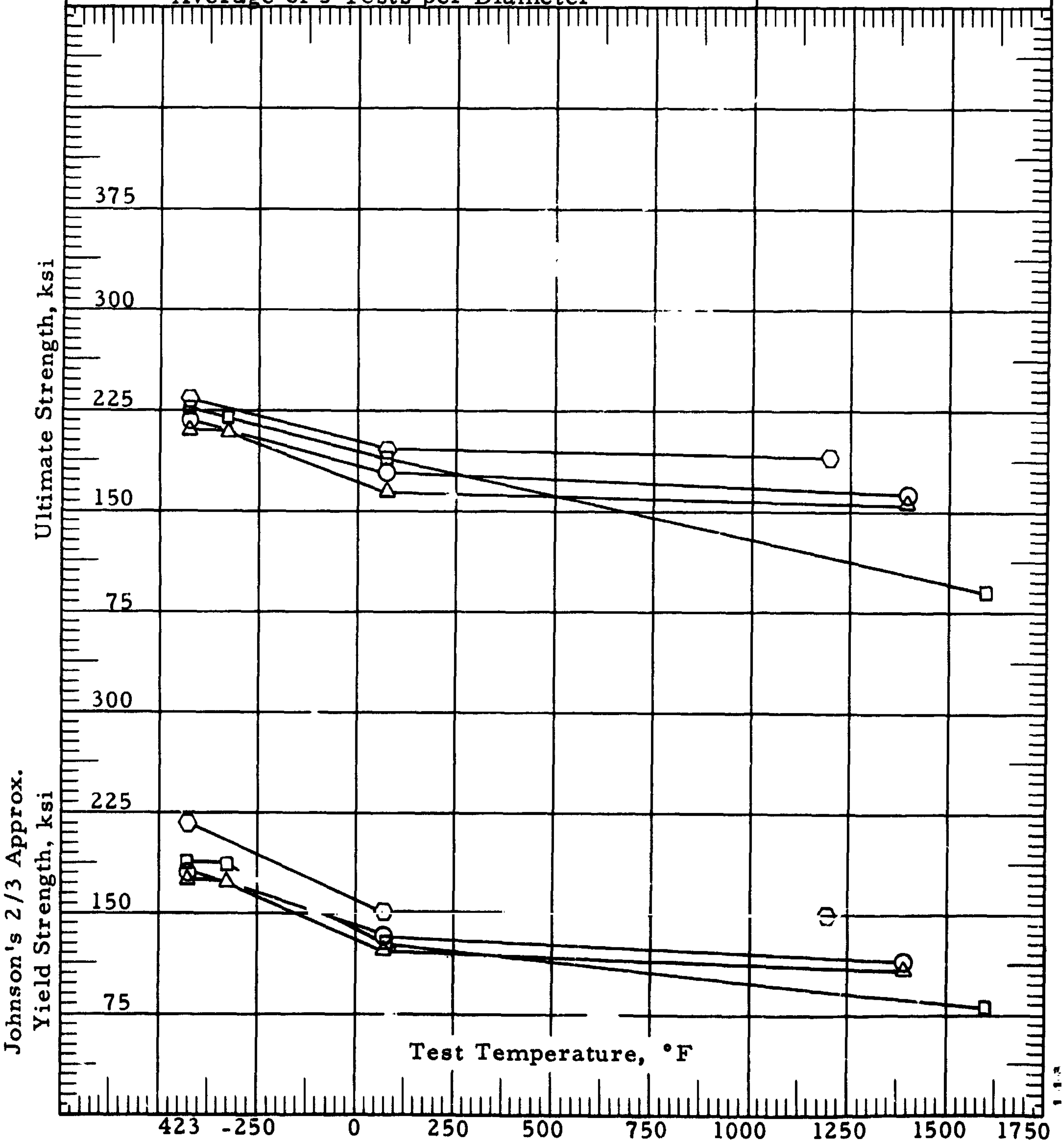

BOLT PROPERTIES

Nic'el Base Alloys
Rolled Threads After Aging

Legend
- □ - AF 1753 - 1/4-28 & 3/8-24
- ○ - Inconel 718 - 1/4-28 & 3/8-24
- ● - 25% Cold Reduced Waspaloy - 1/4-28
- ▲ - 25% Cold Reduced Inconel 718 - 1/4-28
- ■ - Udimet 630 - 1/4-28

Average of 3 Tests per Diameter

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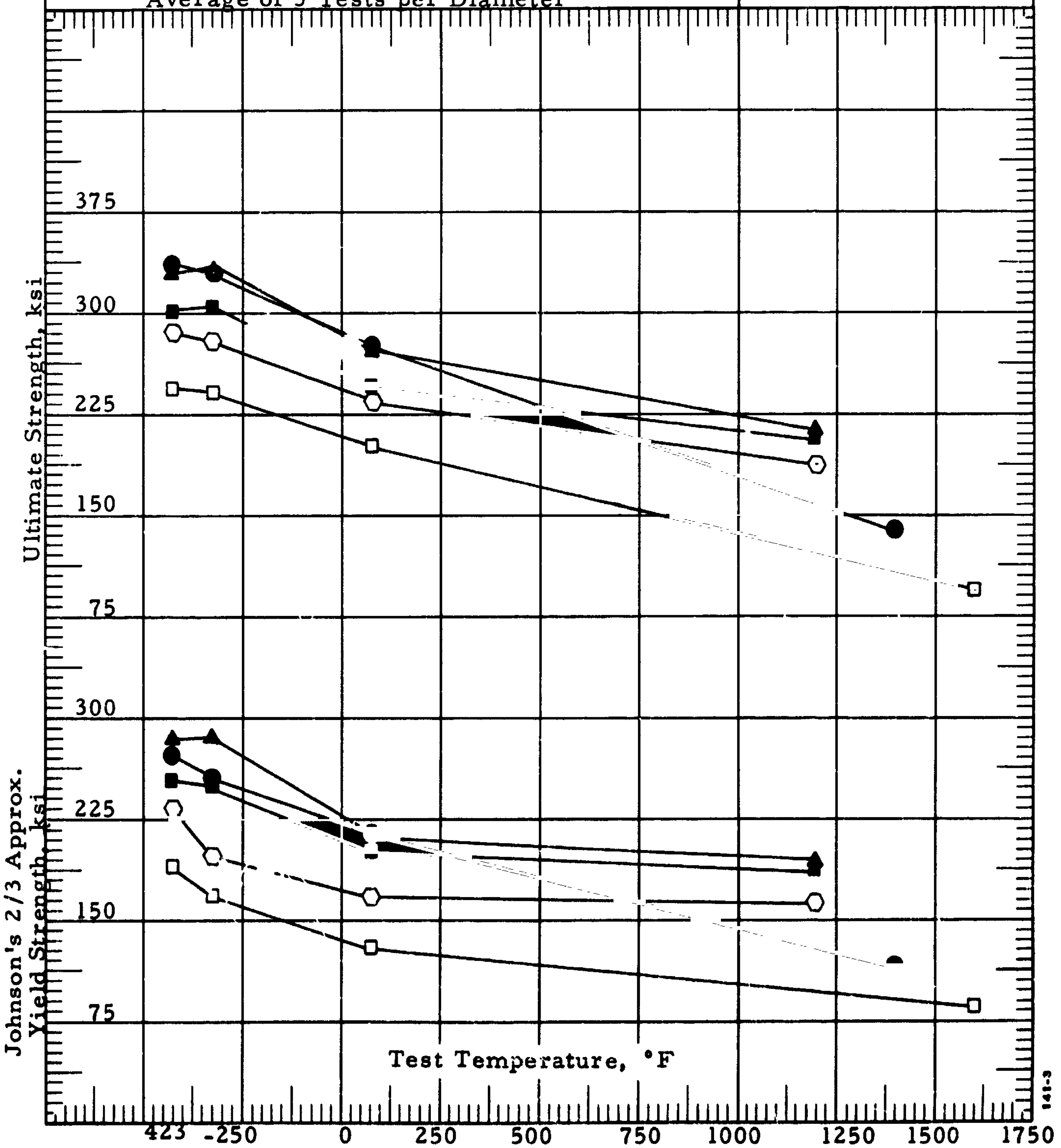
Chart No.: 2.13
Date:



BOLT PROPERTIES

Titanium Base Alloys

Legend

○ Ti 6Al-4V - #10-32, 1/4-28 & 1/2-20
△ Ti 7Al-12Zr - #10-32, 1/4-28 & 1/2-20
□ Ti 1Al-8V-5Fe - 1/4-28
⬡ Ti 8Al-1Mo-1V - #10-32, 1/4-28 & 1/2-20
● Ti 5Al-2.5Sn (ELI) - #10-32 & 3/8-24
▲ Ti 5Al-5Sn-5Zr - 1/4-28

Average of 3 Tests per Diameter

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Chart No.: 2.14

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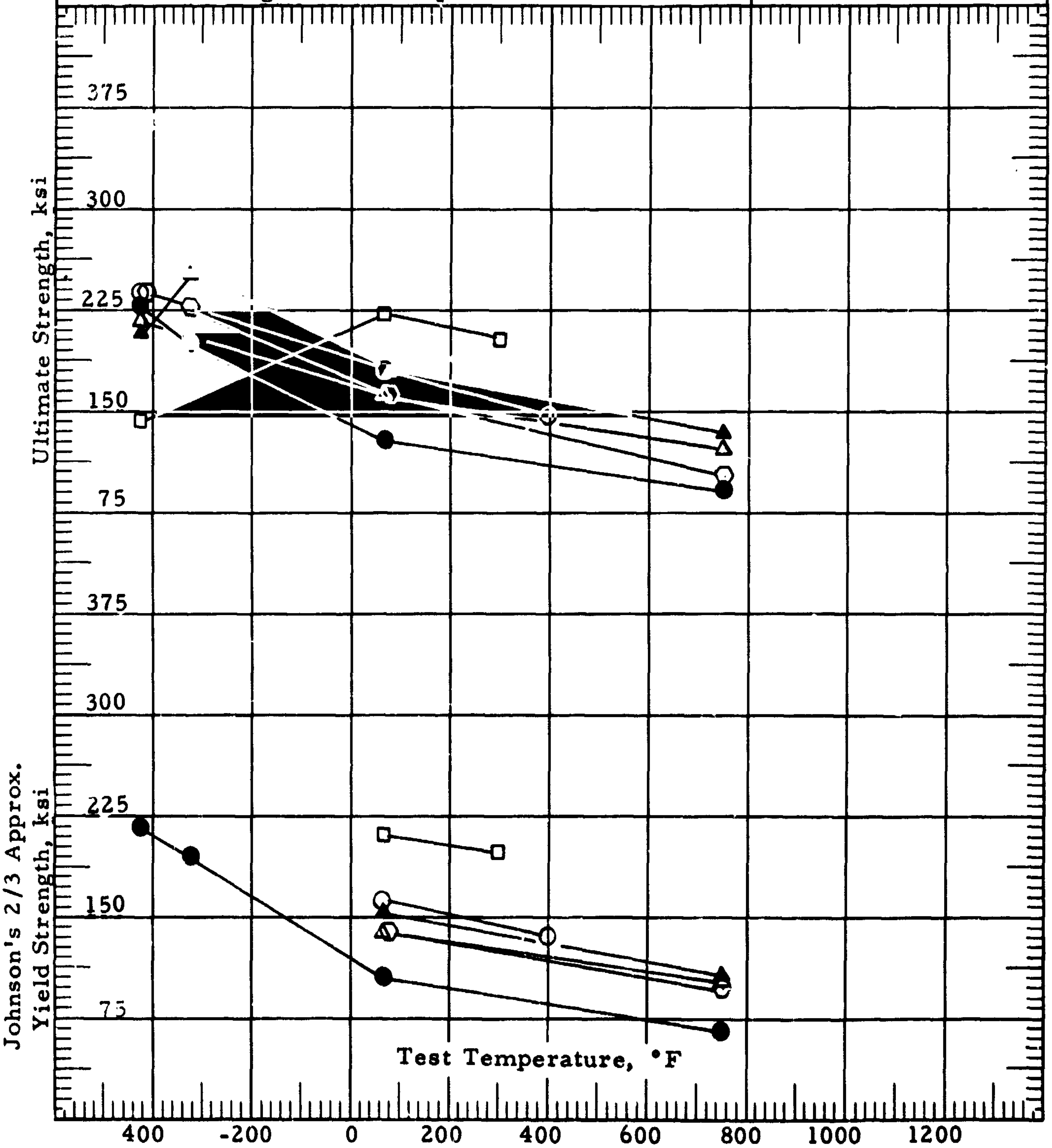


MECHANICAL PROPERTIES

Iron Base Point Drive & Jo Bolt Semi Blind Fasteners

Legend

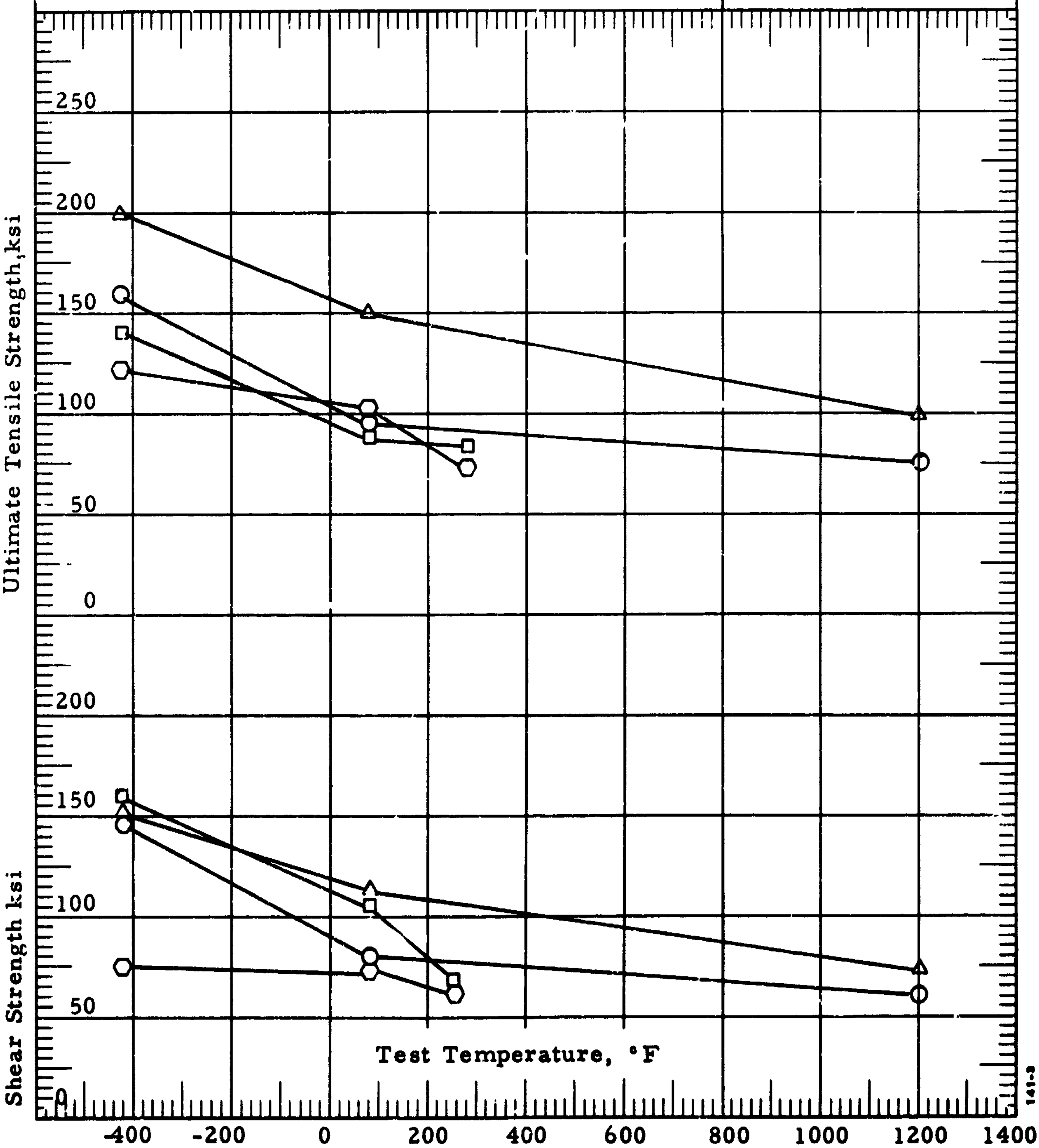
- ○ A-286 Jo Bolts - #10-32
- △ A-286 Point Drive Bolts - #10-32 & 1/4-28
- □ AISI 8740 - Point Drive Bolts - #10-32, 1/4-28 & 3/8-24
- ⬡ AISI 4130 Jo Bolts - #10-32

Average of 3 Tests per Diameter

SPS LABORATORIES

Chart No.: 2.15

Date:



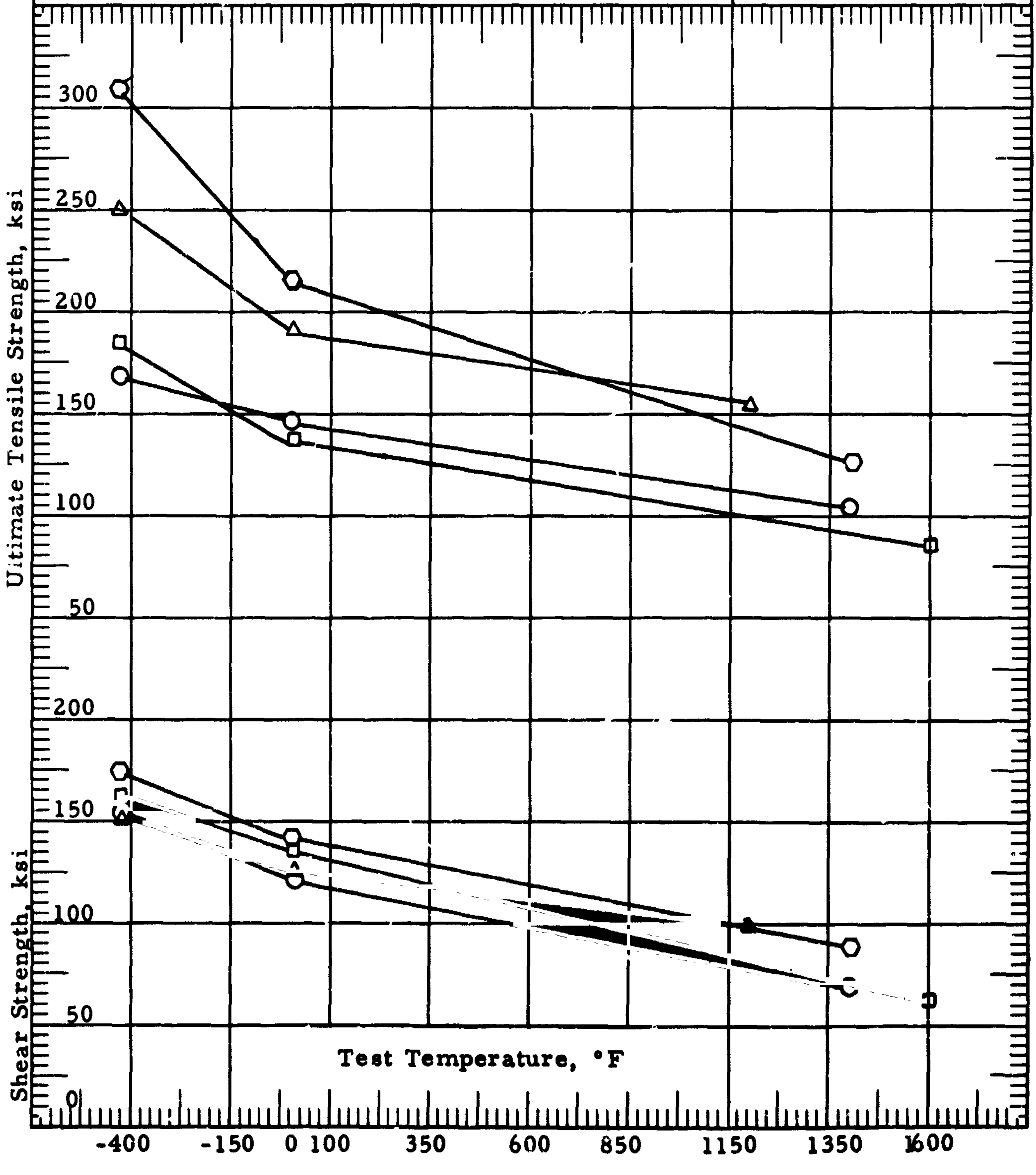
MECHANICAL PROPERTIES
Nickel Base Point Drive Bolts & Twist Off Nuts

Legend
- O Waspaloy & Waspaloy Nuts-#10-32, 1/4-28 & 3/8-24
- Δ Inconel 718 & Waspaloy Nuts -1/4-28 & 3/8-24
- □ AF1753 & Waspaloy Nuts - 1/4-28 & 3/8-24
- ⬡ 25% C.R. Waspaloy & Waspaloy Nuts - 1/4-28

Average of 3 Tests per Diameter

SPS LABORATORIES

Chart No.: 2.16
Date:



MECHANICAL PROPERTIES

Titanium Base Point Drive Bolts & Aluminum Twist Off Nuts

Legend

○ Ti 6Al-4V & Al2024-T4 Nut - #10-32, 1/4-28 & 3/8-24

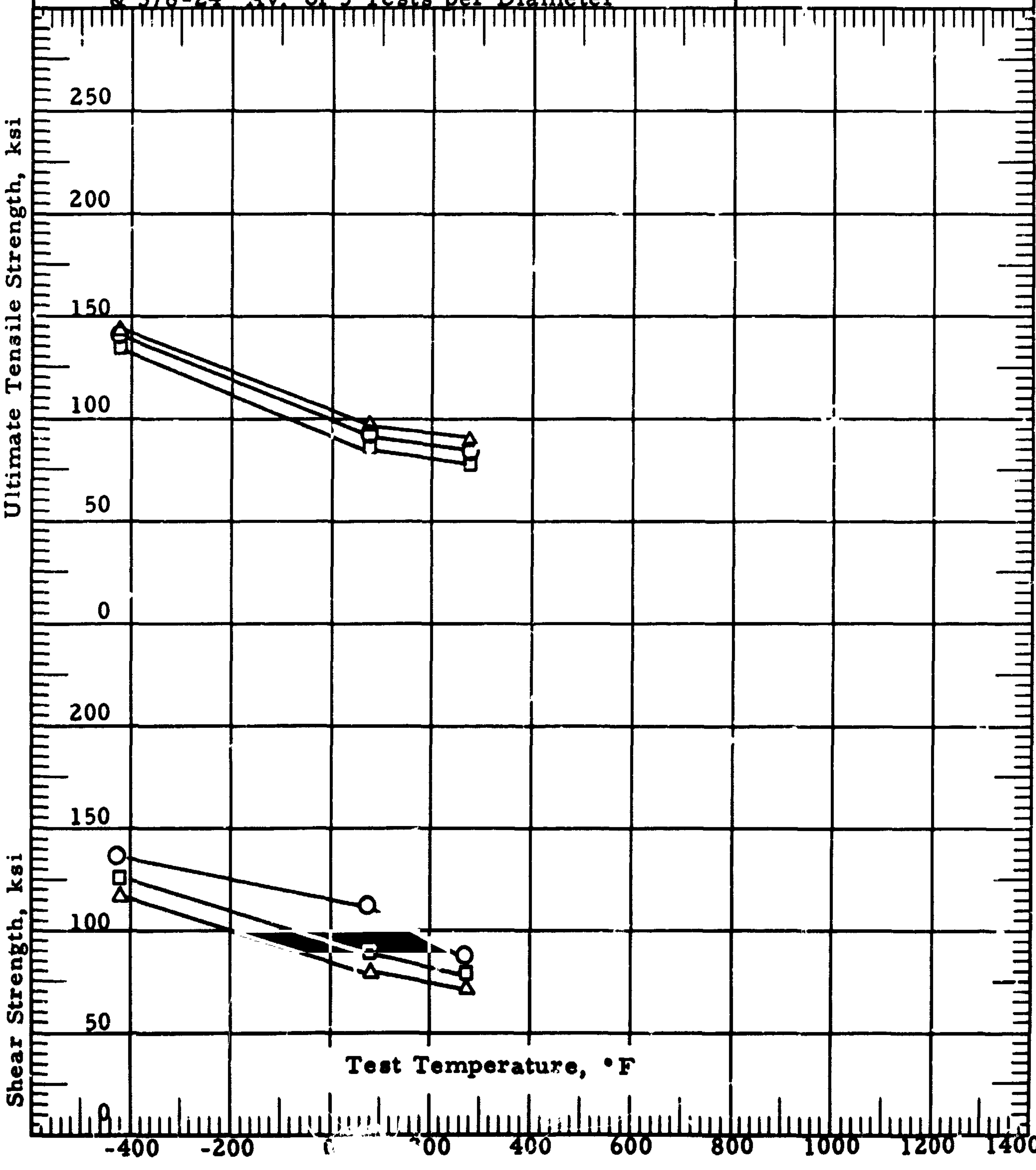
△ Ti 5Al-2.5Sn & Al2024-T4 Nut - #10-32, 1/4-28 & 3/8-24

□ Ti 5Al-2.5Sn (ELI) & Al2024-T4 Nut - 1/4-28 & 3/8-24 Av. of 3 Tests per Diameter

SPS LABORATORIES

Chart No.: 2.17

Date:



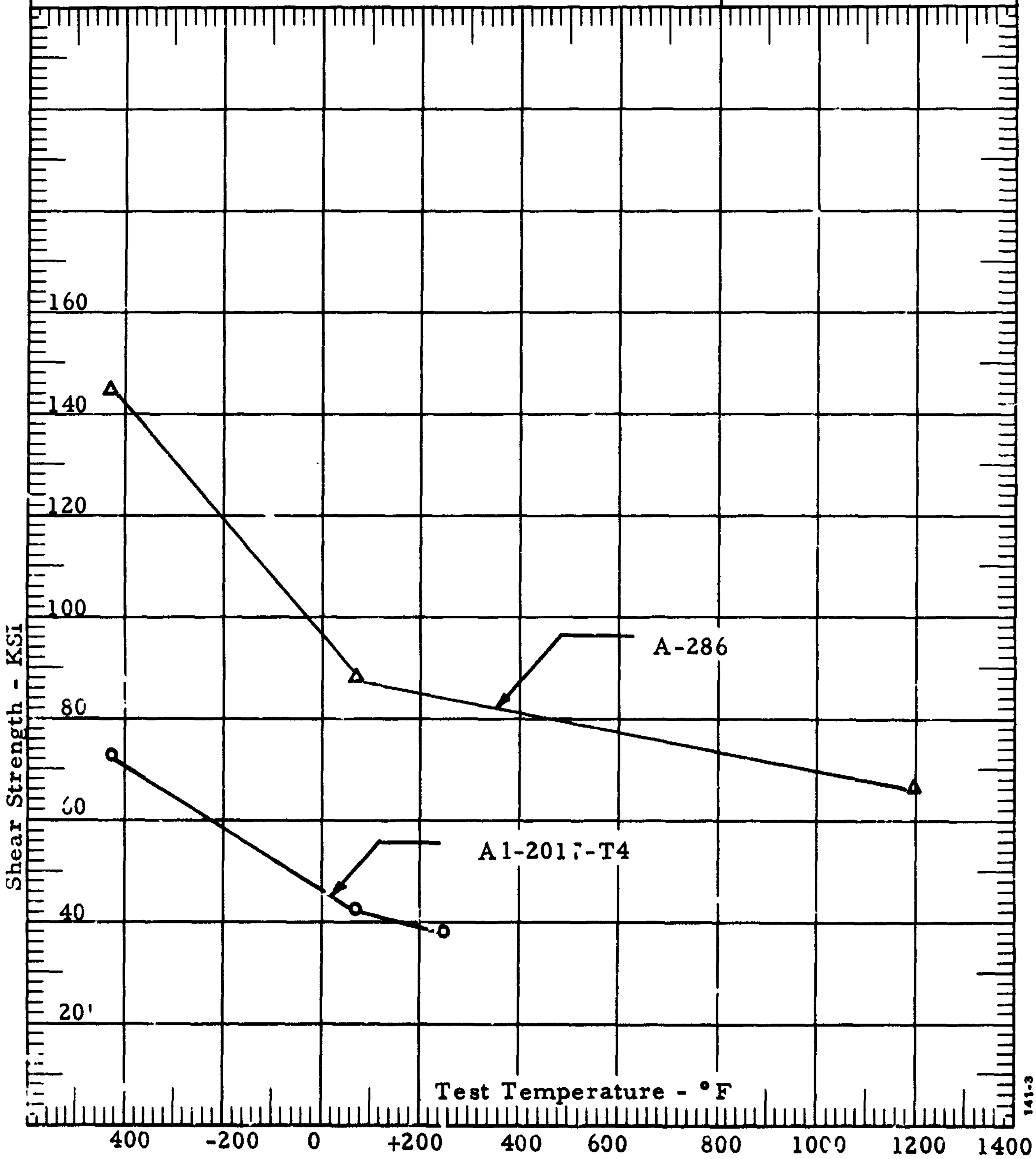
SHEAR PROPERTIES

Semi Blind Cherry Rivets
CR 2162 - Al 2017-T4
CR 2662 - A-286

Avg. of 9 Tests
3 Tests each of 1/8, 5/32 & 3/16 inch rivets

SPS LABORATORIES

Chart No.: 2.18
Date:



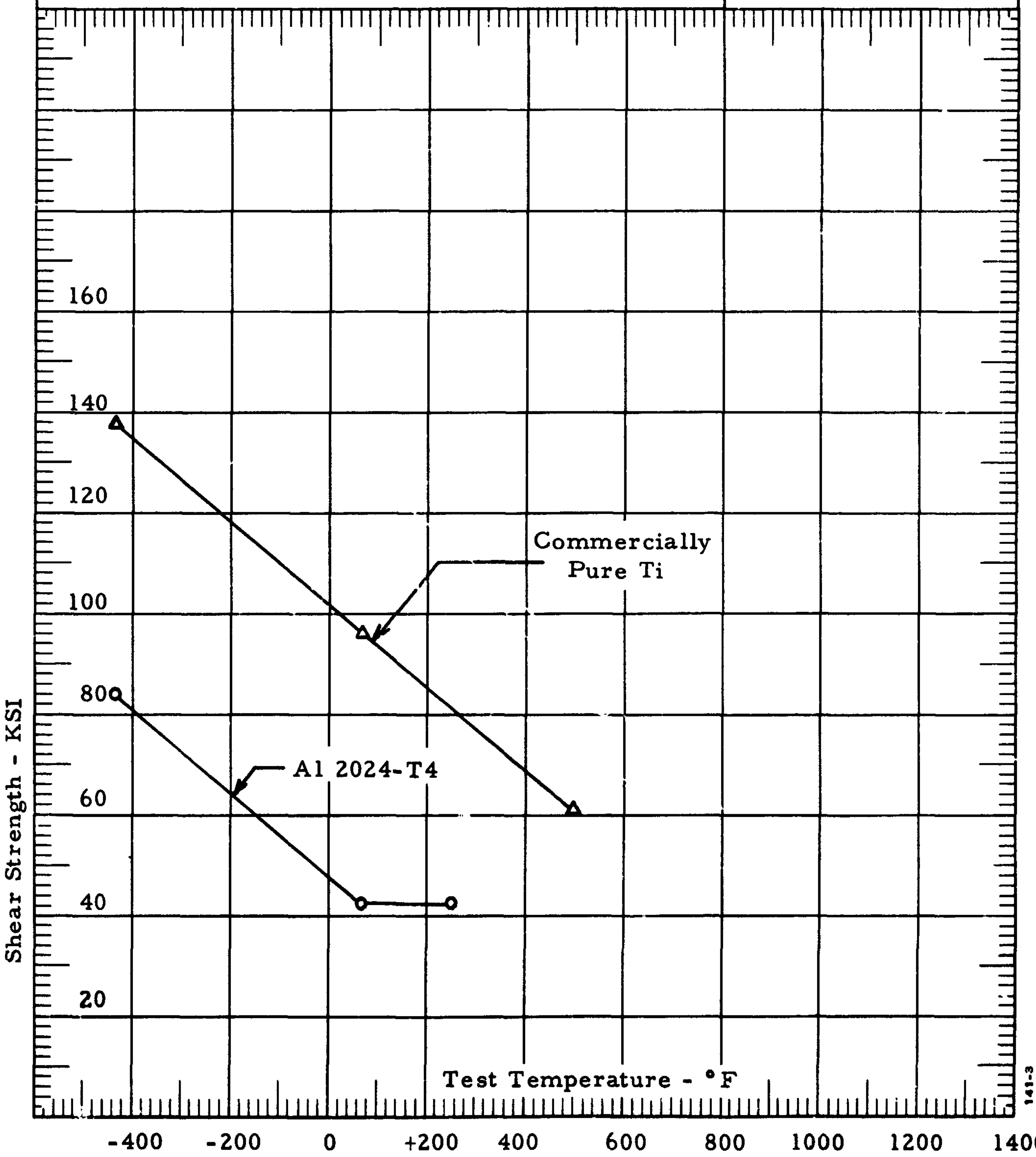
SHEAR PROPERTIES

Solid Rivets
MS 20426-Commercially Pure Titanium 1/8 & 3/16
MS 20426-A12024 - T4 1/8 & 3/16

Avg. of 6 Tests

SPS LABORATORIES

Chart No.: 2.19
Date:



3.0 Conclusions

The conclusions are based on the work accomplished over the two year period of the contract. They are divided into sub headings of temperature application - cryogenic, moderate and elevated temperatures - process effects, corrosion and fastener specification needs.

3.1 Cryogenic Temperature Applications

3.1.1 Fasteners of H-11 (220 ksi) material could be utilized down to -320°F; they are not recommended for use below -320°F because they are brittle and very sensitive to minimal bending conditions.

3.1.2 Vasco Max 300 (18% Ni Maraging Steel) fasteners would not be recommended for -423°F application because of poor shear properties.

3.1.3 Corrosion resistant fasteners of U-212 and cold reduced A-286 possess excellent properties for cryogenic applications down to -423°F.

3.1.4 Any of the nickel base fasteners tested could be utilized for cryogenic applications down to -423°F. All showed excellent cryogenic properties.

3.1.5 Fasteners of Ti 5Al-2.5Sn (ELI) material showed the best cryogenic properties of any of the titanium fasteners tested. However, they would not be recommended for application below -320°F where bending conditions were prevalent. Fastener properties were adversely affected by bending conditions at -423°F.

3.1.6 Titanium fasteners of Ti 7Al-12Zr, Ti 6Al-4V and Ti 8Al-1Mo-1V would not be considered reliable for cryogenic space vehicle applications because of their unpredictable behavior at the temperature of -423°F.

3.1.7 Cold reduced L605 fasteners would be recommended for cryogenic applications down to -423°F but in the unaged condition.

3.2 Moderate Temperature Applications

3.2.1 For room temperature to moderate temperature application, (450°F), fasteners of H-11 and Vasco Max 300 would be preferred before the U-212, cold reduced A-286 and the nickel base fasteners because of their higher strength.

3.2.2 The use of U-212, cold reduced A-286 and nickel base fasteners would be dependent upon application and environmental conditions. They would be recommended for severe corrosive atmospheres.

3.2.3 For weight critical areas at moderate temperatures to 400°F, titanium fasteners would be recommended. Ti 1Al-8V-5Fe fasteners should be given prime consideration because of their superior strength. On a strength-to-weight basis Ti 1-8-5 fasteners were the strongest fasteners evaluated in the contract.

3.3 Elevated Temperature Applications

3.3.1 H-11 and Vasco Max 300 fasteners with a protective plating of diffused nickel-cadmium retain excellent strength to 900°F.

3.3.2 For applications to 1200°F, conventional Inconel 718 fasteners would be recommended first, followed by U-212 and cold reduced A-286 fasteners.

3.3.3 Udimet 630 fasteners would not be recommended for prolonged applications at 1200°F. Fasteners become extremely notch brittle at room temperature after prolonged exposures at 1200°F.

3.3.4 Elevated temperature properties at 1400°F of conventional Waspaloy and Rene 41 fasteners were better than those of cold reduced Waspaloy fasteners.

3.3.5 For applications to 1600°F, AF 1753 fasteners offer adequate properties.

3.4 Process Effects

3.4.1 Cold reduction of A-286, Waspaloy and Inconel 718 alloys prior to fabrication into fasteners increases their cryogenic properties significantly at temperatures down to -423°F.

3.4.2 Fasteners of cold reduced L605 would be best suited for space vehicle applications in the unaged condition rather than the aged condition.

3.4.3 Fasteners to be used in applications involving cryogenic temperatures should have rolled threads after heat treatment for optimum properties.

3.4.4 For elevated temperature applications (1200°F to 1600°F) fasteners should have rolled threads before age hardening for optimum properties.

3.4.5 Udimet 630 fasteners should have rolled threads after age hardening. Fasteners with rolled threads before aging are notch brittle at room temperature.

3.4.6 More work is required in optimizing manufacturing processes for semi-blind fasteners fabricated from nickel and cobalt base alloys.

3.4.7 The use of SPS K3 lubricant on locknuts markedly enhanced the torque-tension relationship of all fastener combinations tested.

3.5 Corrosion

3.5.1 A correlation between the results of seacoast and accelerated salt spray atmospheres for the same fastener systems could not be made. However, when corrosion occurred in both environments, it occurred in a much shorter period of time in the accelerated salt spray atmosphere.

3.5.2 Aluminum structural materials with a coating of zinc chromate primer exhibited excellent corrosion resistance properties in both seacoast and accelerated salt spray atmospheres.

3.6 Specifications Needs

3.6.1 No individual material's test in itself can be used to ascertain the reliability of a fastener for space vehicle applications; the fastener should be tested.

3.6.2 Fastener tests to insure reliability should include axial tensile at cryogenic and elevated temperature, angle block tensile at cryogenic temperatures, tension impact of bolt threads at cryogenic temperatures, double shear at cryogenic temperatures, and stress rupture and stress relaxation at elevated temperatures.

3.6.3 More development is required for the acceptable cold reduced materials as large diameter fasteners.

3.6.4 Vibration tests at cryogenic temperatures appear insignificant because it is doubtful that failure will occur at cryogenic temperatures if it does not occur at room temperature.

3.6.5 Diameter appears to have an effect on the mechanical properties of fasteners at cryogenic temperature. An increase in diameter results in a decrease in tensile and shear strength at -423°F.

3.6.6 The locking characteristics of nuts were not affected by thermal cycling at cryogenic and elevated temperatures.

3.6.7 Stress relaxation at maximum temperatures does not affect the bolt properties except in cases where over aging and additional aging are encountered.

3.6.8 Thermal cycling from room temperature to -423° F and from room temperature to maximum utilization temperatures does not affect the mechanical properties and microstructure of fasteners and materials.

4.0 Recommended Areas for Future Fastener Investigations

Although many aspects of a fastener's reliability were covered during the course of this contract, several areas need more work. These consist of the design, reliability, application, and environmental areas.

4.1 Cryogenic Properties of Large Diameter Fasteners

The results of the tensile and shear tests at -423°F of the 1/2 inch diameter fasteners showed a slight decrease in strength compared to the #10 and 1/4 inch fastener of the same material. Work should be conducted to determine the effects of cryogenic temperatures on larger diameter fasteners above 1/2 inch.

4.2 Effects of Localized Stresses and Cryogenic Temperatures on the Mechanical Properties of Fasteners

The evaluation conducted in this contract was limited to tensile tests using a 3° angle at the nut bearing face. A number of fastener systems appeared insensitive to this test. However, since a greater angle than 3° may be encountered in service, studies should be initiated to determine the maximum angle that can be employed before properties decrease significantly.

Incorporated in the study should be finite fatigue and the effect of the angle at the bolt head bearing surface. Very little is known of this aspect at cryogenic temperatures.

4.3 Reliability of Fasteners for Space Vehicle Application

Because of the magnitude of this contract, data was generated only at -423°F, -320°F, room temperature, and maximum utilization temperature of the fastener. Three tests were conducted at each point and from one heat of material. From the standpoint of reliability, the minimum tests should be increased to about ten to twenty tests and the fasteners fabricated from at least two mill heats of material. In addition, the number of test temperatures should be increased over the utilization temperature range for a more complete picture of a fastener's capabilities as a function of intermediate temperatures.

4.4 Fatigue and Relaxation Properties of Fasteners in a Tightened Joint

The fatigue properties of various fasteners are well documented at room temperature in open joint conditions. Since these fasteners will be tightened in a joint of various structural materials in actual application, the fatigue properties of the joint under these conditions should be determined.

In addition, joint relaxation data has been determined, but with joints of the same material and condition as the fastener. As in the case of fatigue, relaxation properties should be determined for the joint in which the fasteners will be used.

4.5 Method for Tightening a Fastener or Fastener Combination in Application

An investigation should be initiated to provide a more useful method for installing fasteners in which closer load tolerances can be determined. Very little is known about what happens as the bolt is being installed, yet this is probably the most important part of joint design. Present techniques usually produce an induced load with a tolerance of plus or minus 25 percent.

4.6 Development of Cold Reduced Materials for Large Diameter Fasteners

The work during this contract has shown that cold reduction of A-286, Waspaloy, L605, and Inconel 718 alloys significantly increases the mechanical properties for fastener applications. It has also shown that these materials can be fabricated into headed fasteners in small diameters. Therefore, further investigation should be conducted to determine if these materials can be fabricated into large diameter fasteners without loss of properties.

4.7 Effects of High Vacuum on Fastener Coatings

Fasteners designed for space vehicle applications are expected to be subjected to atmospheres with reduced pressures or a vacuum. For this reason, the effects of the vacuum on the coatings, platings, and lubricants used in conjunction with the fasteners should be investigated and determined.

5.0 EVALUATION OF COMMERCIALLY AVAILABLE FASTENERS

From the results of the Survey and a continuous literature survey, twenty-five different classes of fasteners were selected for evaluation by the Contracting Officer's Technical Representative. The fasteners included variations in tensile and shear bolts, semi blind fasteners, blind fasteners, structural rivets and companion nuts. The selection of these fasteners was based on their present and future usage in the aerospace industry. Tables 5.1 and 5.2 list the types of fasteners, materials, strength levels and diameters that were evaluated over the two year period of 1964 and 1965.

In 1964, twenty-one classes of fasteners were evaluated. The fasteners were supplied by various fastener manufacturers in addition to Standard Pressed Steel Co. The manufacturers currently supply the aerospace industry. Manufacturing specifications and Tables of Results for the twenty-one classes are recorded in NASA Report No. CR-357.

In 1965, four classes of fasteners were evaluated. Manufacturing, heat treat processes and test programs for these fasteners are listed in this section. Composite photographs of these fasteners are shown in Figures 5.1 and 5.2, while Table 5.3 lists the nominal composition of the fastener materials.

5.1 Manufacturing -

Standard Pressed Steel Co. manufactured all the fasteners evaluated in 1965.

5.1.1 Manufacturing and Heat Treat Processes

5.1.1.1 12 Point Tension Bolt - #10-32 EWB22, 1/4-28 NAS 1271 and 1/2-20 NAS 1275 Material - Ti 8Al-1Mo-1V

a. Hot forged 12-point head
b. Duplex anneal - 1650°F - 1 hr., air cooled
1100°F - 24 hrs. air cooled
c. Rolled threads - MIL-S-7742

5.1.1.2 12 Point Tension Nut - FN 1216 - #10-32, 1/4-28 and 1/2-20
Material - A-286

a. Extruded locking collar
b. Extruded 12-point serration
c. Tap - MIL-S-7742
d. Squeezed locking collar
e. Age harden - 1325°F - 16 hrs., air cooled
f. Silver plate per AMS 2410

5.1.1.3 12 Point Tension Bolt - EWB 1615 #10-32, 1/4-28 and 1/2-20
Material - Rene 41

a. Hot forged 12-point head
b. Solution treated - 2150°F - 1/2 hr., oil quench
c. Rolled threads - MIL-S-8879 (.003 reduced pitch diameter)
d. Age harden - 1650°F - 4 hrs., air cooled

5.1.1.4 12 Point Tension Nut - FN 1418 - #10-32, 1/4-28 and 1/2-20
Material - Waspaloy

a. Hot forged 12-point serration
b. Solution treated - 1950°F - 1 hr, oil quench
c. Form locking collar
d. Solution treated - 1875°F - 4 hrs, air cooled
e. Tap - MIL-S-8879
f. Squeezed locking collar
g. Stabilize - 1550°F - 4 hrs, air cooled
h. Age harden - 1400°F - 16 hrs, air cooled
i. Silver plated per AMS 2410

5.1.1.5 Protruding Head Point-Drive Bolt - PDP 16 - #10-32, 1/4-28 and 3/8-24
Material - Ti 5Al-2.5Sn

a. Hot forged head
b. Annealed - 1500°F - 1 hr, air cooled
c. Rolled threads - MIL-S-8879
d. Broached hex at bolt point

5.1.1.6 Twist-Off Nut - HL 70W - #10-32, 1/4-28 and 3/8-24
Material - Al 2024-T4

These parts are from the same lot of nuts supplied by the Hi Shear Corporation and used for the 1964 evaluation of Ti6Al-4V point-drive bolts.

5.1.1.7 Protruding Head Point-Drive Bolt - PDP 16 #10-32, 1/4-28 and 3/8-24
Material - Waspaloy

a. Hot forged head
b. Solution treated - 1975°F - 4 hrs, oil quenched
c. Stabilize - 1550°F - 4 hrs, air cooled
d. Age harden - 1400°F - 16 hrs, air cooled
e. Rolled threads - MIL-S-8879
f. Broached hex at bolt point

5.1.1.8 Twist Off Nut - TN 12 - #10-32, 1/4-28 and 3/8-24
Material - Waspaloy

a. Solution treated - 1900°F - 1 hr, oil quenched
b. Drilled and formed
c. Tapped - MIL-S-8879
d. Milled hex
e. Silver plated per AMS 2410
f. Squeezed for locking torque

TABLE 5.1

SELECTED FASTENERS FOR EVALUATION IN - 1964

Diameter	Description	Material	Min. U. T. S. @70 F, KSI	Maximum Utilization Temp., °F
#10, 1/4 & 1/2	12 pt. Tension Bolt	AISI H-11	220	900
#10, 1/4 & 1/2	12 pt. Tension Nut	AISI H-11	220	900
#10, 1/4 & 1/2	12 pt. Tension Bolt	Waspaloy	150	1400
#10, 1/4 & 1/2	12 pt. Tension Nut	Waspaloy	180	1400
#10, 1/4 & 1/2	12 pt. Tension Bolt	Ti 7Al-12Zr	150	750
#10, 1/4 & 1/2	12 pt. Tension Bolt	Ti 6Al-4V	160	400
#10, 1/4 & 1/2	12 pt. Tension Nut	A-286	160	1200
#10, 1/4 & 1/2	12 pt Tension Bolt	A-286	200	1200
#10, 1/4 & 1/2	12 pt. Tension Nut	A-286	200	1200
#10, 1/4 & 1/2	12 pt. Shear Bolt	AISI H-11	260	900
#10, 1/4 & 1/2	12 pt. Shear Nut	AISI H-11	210	900
#10, 1/4 & 1/2	Hexagon Head Shear Bolt	Ti 6Al-4V	160	400
#10, 1/4 & 1/2	Hexagon Nut	AISI 4027	160	450
#10, 1/4 & 3/8	Point Drive Bolt	Ti 6Al-4V	160	400
#10, 1/4 & 3/8	Point Drive Bolt	AISI 8740	180	450
#10, 1/4 & 3/8	Twist-Off Nut	Al 2024-T4	-	250
#10, 1/4 & 3/8	Point Drive Bolt	A-286	140	1200
#10, 1/4 & 3/8	Twist-Off Nut	A-286	140	1200
#10	Jo Bolt	AISI 4130	180	450
#10	Jo Bolt	A-286	140	1200
1/8, 5/32 & 3/16	Cherry Rivet	Al 2017 T-4	-	250
1/8, 5/32 & 3/16	Cherry Rivet	A-286	-	1200
1/8 & 3/16	Solid Rivet	Comm. Pure Ti	-	500
1/8 & 3/16	Solid Rivet	Al 2024-T4	-	250

TABLE 5.2

SELECTED FASTENERS FOR EVALUATION IN 1965

Size	Description	Material	Min. U.T.S. @ 70°F, ksi	Maximum Utilization Temp., °F
#10, 1/4 & 1/2	12-Pt. Tension Bolt	Ti 8Al-1Mo-1V	140	750
#10, 1/4 & 1/2	12-Pt. Locknut	A-286	160	1200
#10, 1/4 & 1/2	12-Pt. Tension Bolt	Rene 41	150	1400
#10, 1/4 & 1/2	12-Pt. Locknut	Waspaloy	180	1400
#10, 1/4 & 3/8	Point-Drive Bolt	Ti 5Al-2.5 Sn	110	750
#10, 1/4 & 3/8	Twist-Off Nut	Al 2024-T4	70	250
#10, 1/4 & 3/8	Point-Drive Bolt	Waspaloy	150	1400
#10, 1/4 & 3/8	Twist-Off Nut	Waspaloy		1400

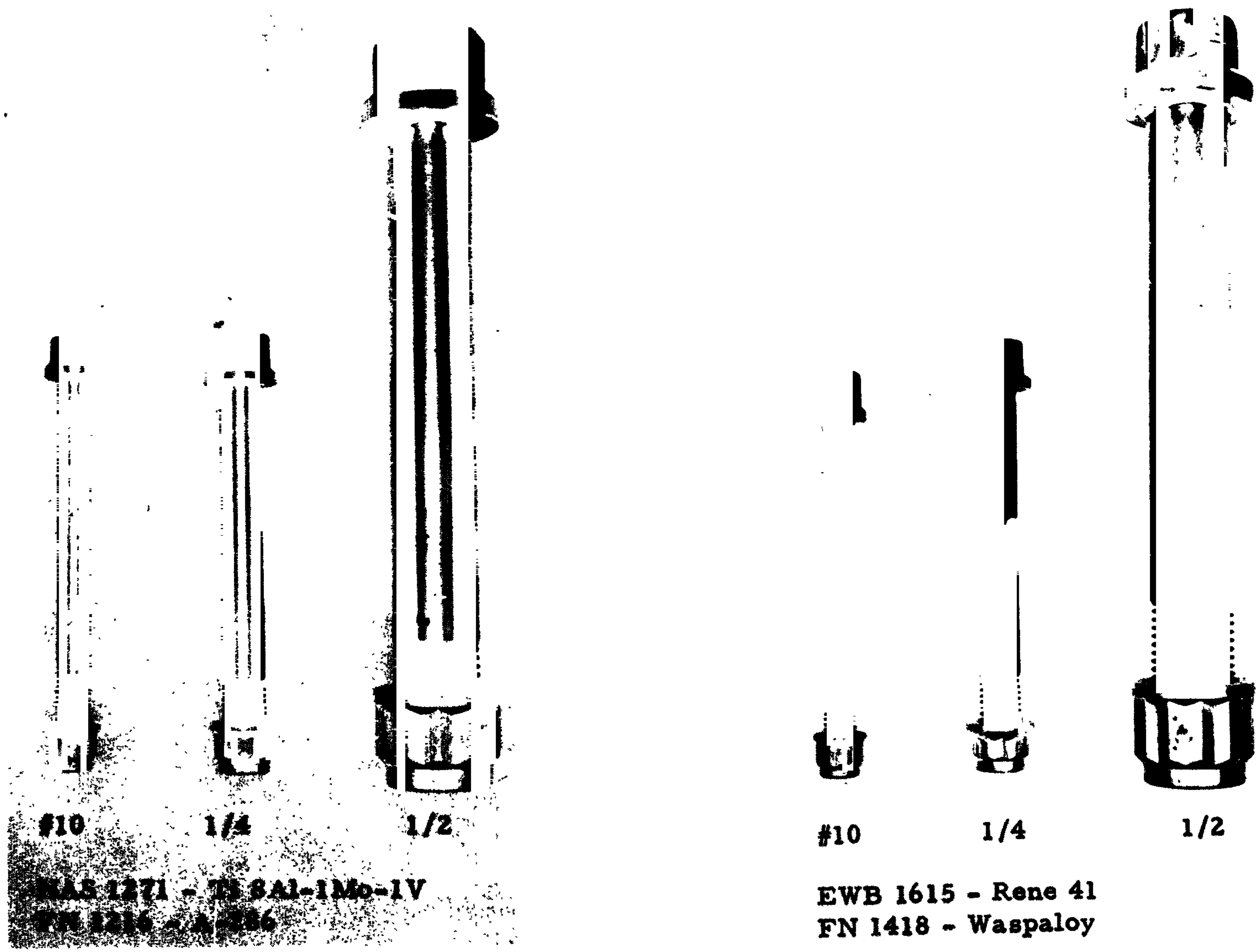
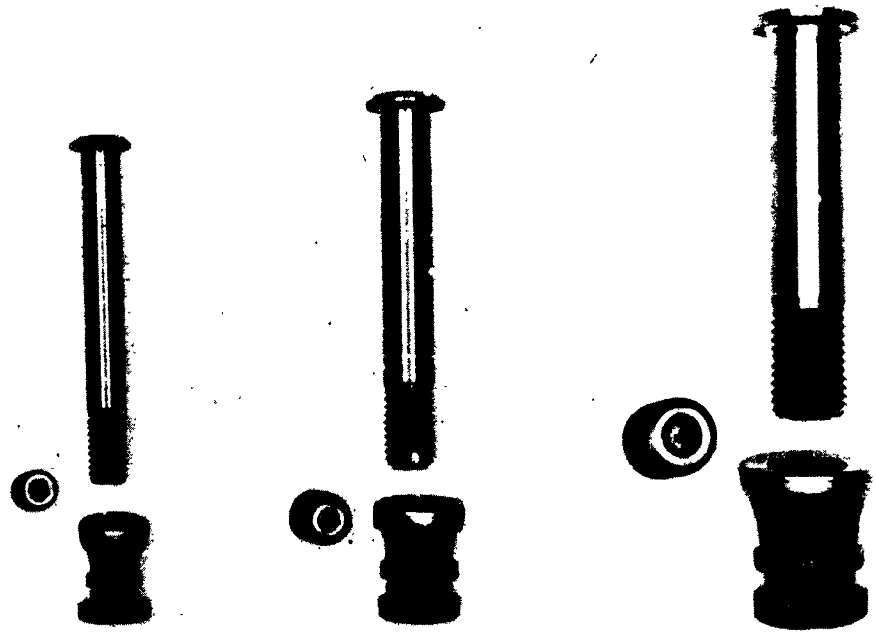
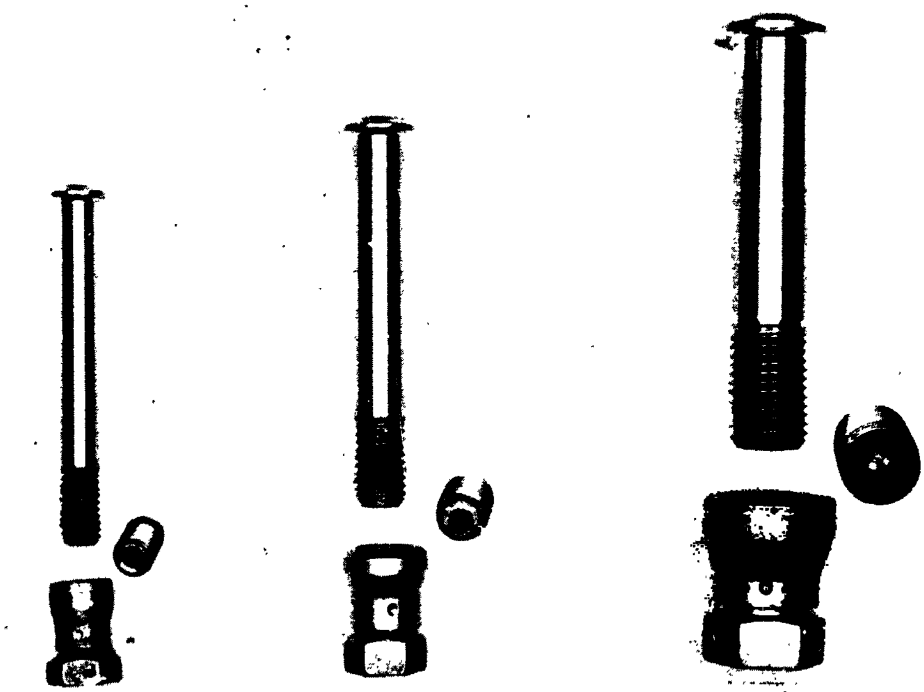


Figure 5. 1 Composite Photograph of Tension Fastener Evaluated in 1965



#10 1/4 3/8

PDP16 - Ti-5Al-2.5Sn
HL70W Nuts - Aluminum



#10 1/4 3/8

PDP16 - Waspaloy
TN12 Twist-Off Nuts - Waspaloy

Figure 5.2 Composite Photograph of Point Drive Fastener Evaluated in 1965.

TABLE 5.3

NOMINAL COMPOSITION OF FASTENER MATERIALS EVALUATED IN 1965

Material	Ti 8-1-1	A-286	Rene 41	Waspaloy	Ti 5-2.5	Al 2024
C	.02	.06	.08	.042	.025	
Mn		1.5	.03	.02	.006	.60
P		.03				
S		.02	.006	.004		
Si		.70	.10			.15
Ni		25.0	Bal.	Bal.		
Cr		15.0	18.6	11.65		.01
Mo	1.0	1.25	9.95	4.44		
Ti	Bal.	2.0	3.11	2.99	Bal.	.01
Co			11.2	13.46		
Al	8.0	.30	1.47	1.26	5.0	Bal.
Cu				.02		4.30
Zr				.062		
Sn					2.5	
B		.006	.005			
V	1.0	.30	.80	.54	.30	
Fe	.11	Bal.		.23		.23
O_2	.10				.15	
N	.01				.020	
H	.0074				.011	
Zn						.05
Mg						1.45

5.2 Test Program

Since the fasteners evaluated in 1965 consisted of tension fasteners and companion locknuts and point drive bolts with their companion twist off nuts, they were tested under separate test programs as shown in Figures 5.3 and 5.4. The test programs were similar to those conducted for the fastener evaluation in 1964 except for the addition of the specialized tests outlined in Section 8. Tests deleted from the program were thermal cycling and nut reusability at cryogenic and elevated temperatures. It was concluded from the evaluation in 1964 that the mechanical properties of fasteners were not affected after being subjected to the cycling tests. The test procedures and equipment employed for the test programs are presented in Appendix I. The outline for the test programs was as follows:

5.2.1 Tensile

5.2.1.1 Axial Tensile

Axial tensile tests to determine ultimate strengths and yield strengths.

5.2.1.2 Angle Block Tensile Tests

Angle block tensile tests were conducted to determine the dual effect of localized stresses and cryogenic temperatures.

5.2.1.3 Preload

5.2.2 Double Shear

5.2.3 Tension Impact

Tension impact properties of the bolt threads were determined.

5.2.4 Tension-Tension Fatigue

5.2.5 Stress Rupture

The stress rupture tests were conducted at the maximum utilization temperature of the fastener assembly.

5.2.6 Stress Relaxation

5.2.6.1 Cylinder Relaxation Tests

Cylinder stress relaxation tests of tension fasteners were conducted to determine residual stresses after ten and fifty hours at the maximum utilization temperature of the fastener assembly.

5.2.6.2 Machine Relaxation Tests

Residual stresses were determined for the Waspaloy point drive fastener assemblies employing one initial preload at the maximum utilization temperature of the assemblies. The initial stresses were converted from room temperature preload results.

5.2.6.3 Effects of Relaxation Tests

The effect of the fifty hour relaxation tests on the ultimate strength, yield strength and shear strength were determined at room temperature.

5.2.7 Nut Reuse and Galling Tendencies

Nut reuse and galling tendencies were determined simultaneously at room temperature.

5.2.8 Alma #10 Vibration Tests

5.2.9 Torque Versus Induced Load

The tests were conducted to determine the initial preloads to be employed for the cylinder relaxation tests.

5.2.10 Corrosion Resistance

In addition to corrosion resistance properties, susceptibility to stress corrosion was studied by tightening the fastener assemblies in the space vehicle structural materials prior to testing. The tension fastener assemblies were tightened to a torque value equivalent to 50 percent of their torque versus induced load yield strength. Seating torques of the point drive fasteners were recorded as that torque required to fracture the twist-off portion of the nut.

TEST PROGRAM - 1965

TENSION BOLT & NUT

Part No.

Tensile

Specimens			
-423°F	.113	.113	.357
70°	.113	.113	.357
Max.	.113	.113	.357

Bolts			
-423°F	#10	1/4	1/2
70°	#10	1/4	1/2
Max.	#10	1/4	1/2

Angle Block Test

-423°	#10	1/4	1/2
-320°	#10	1/4	1/2
70°	#10	1/4	1/2

Tension Impact

-423°	#10	1/4
-320°	#10	1/4
70°	#10	1/4

Shear

-423°	#10	1/4	1/2
70°	#10	1/4	1/2
Max.	#10	1/4	1/2

Tension-Tension Fatigue One Stress

70°	#10	1/4	1/2

Stress Rupture

1 hr.	#10	1/4	1/2
10 hr.	#10	1/4	1/2
100 hr	#10	1/4	1/2

Stress Relaxation

Prel-A	#10	1/4	1/2
Prel-B	#10	1/4	1/2

Nut Reusability

70°	#10	1/4	1/2

Vibration (Alma #10)

-320°	#10	1/4	1/2
70°	#10	1/4	1/2

Torque Vs. Induced Load

70°	#10	1/4	1/2

Corrosion Resistance Sea Coast & Salt Spray

7075 Al	#10
2219 Al	#10
2014 Al	#10
Ti-6Al-4V	#10
321 S/S	#10

As Relaxed

Preload A			
70°	#10	1/4	1/2

Preload B			
70°	#10	1/4	1/2

Figure 5.3

TEST PROGRAM - 1965

Point Drive Bolt & Twist-Off Nut

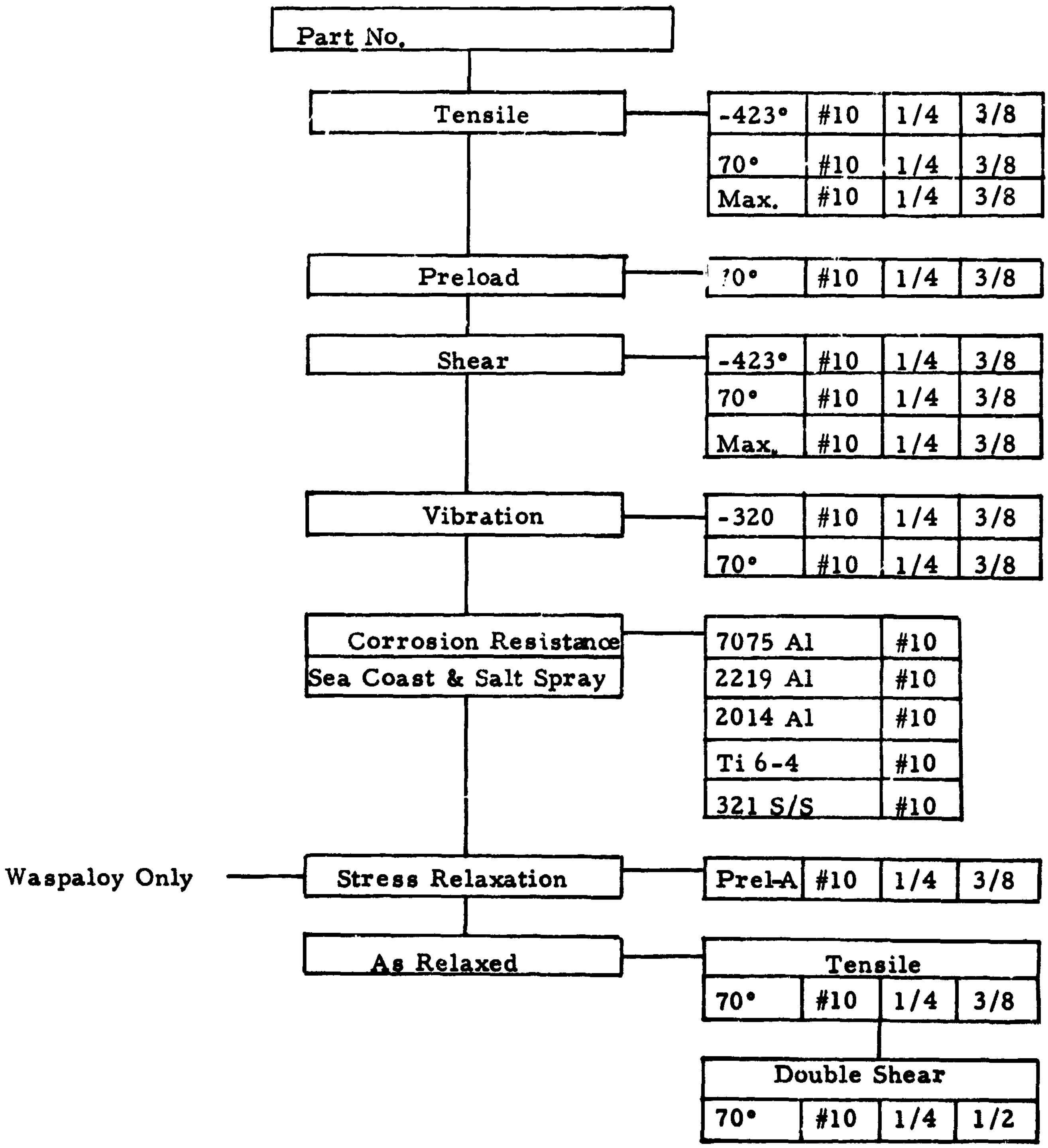


Figure 5.4

5.3 Discussion of Results

5.3.1 Tension Fasteners

5.3.1.1 Iron Base Alloys

The results of the evaluation indicate that the utilization temperature range for H-11 fasteners is room temperature to 900°F. The results of tensile and tension impact tests indicate that the range may be extended down to -320°F but further testing would be required to substantiate it. Although fasteners attained the potential strength of material at -423°F, they experienced a significant decrease in ductility and were very sensitive to bending conditions.

The test data on the high strength A-286 material and fasteners show them to possess excellent properties for fastener application over the temperature range of -423°F to 1200°F. Thread strength exceeded material strength at all temperature levels. Material ductility actually increased at -423°F. Mechanical properties were slightly affected by the 50 hour relaxation test at 1200°F, but this was attributed to overaging from response to test temperature which lowered base material hardness with resultant lower bolt strength. Where design criteria called for a high strength iron base corrosion resistant fastener, A-286 would be an excellent choice, particularly at cryogenic temperatures.

5.3.1.2 Nickel Base Alloys

The two nickel base fasteners evaluated under this phase of the contract were conventional waspaloy and Rene 41. The initial evaluation of the conventional waspaloy was conducted to 1600°F. At this temperature, nut galling and seizure was prevalent for the silver plated locknuts during the application torque tests. Hence the maximum temperature was decreased to 1400°F at which temperature there was no indication of galling or seizure. The evaluation of Rene 41 was subsequently conducted to 1400°F since this fastener employs the same waspaloy nut as a companion fastener.

The test data for both the conventional waspaloy and Rene 41 fasteners indicate that they would be suitable for space vehicle applications from -423°F to 1400°F. At -423°F, the conventional waspaloy fasteners exhibited slightly higher properties. Otherwise properties for these two alloys are about the same to 1400°F. It should be noted that the conventional waspaloy and Rene 41 fasteners were evaluated with rolled threads before age hardening.

5.3.1.2 Nickel Base Alloys (continued)

The evaluation of nickel base fasteners listed in Section 6 indicates that the cryogenic properties would be improved with rolled threads after age hardening.

5.3.1.3 Titanium Base Alloys

Although the titanium alloys of Ti 6Al-4V, Ti 7Al-12Zr and Ti 8Al-1Mo-1V exhibit high strength with good ductility at -423°F, it appears that fasteners fabricated from these materials are notch sensitive at -320°F and -423°F. The tensile strength of these fasteners at -423°F was significantly lower than the the material strength with no determinable yield strengths. The shear strength of the three alloys increased at -423°F, however the shear to ultimate strength ratio decreased in comparison with room temperature results. Ratios were on the order of 0.49 at -423°F and 0.62 (Ti 6-4 and Ti 7-12) to 0.68 (Ti 8-1-1) at room temperature.

The Ti 7-12 and Ti 8-1-1 alloys were primarily developed for elevated temperature applications to 750°F; however, work being conducted in the fastener industry indicates that the fatigue properties fall off after prolonged exposure to 750°F. Investigations in this area were not conducted in the test program.

It should be noted that past history of titanium fasteners indicates that the fastener properties are sensitive to fabrication techniques. Hence the bolts from the heats of titanium alloys evaluated in this program may show different properties than other heats of the same titanium alloy. Therefore, it can be concluded that tension fasteners fabricated from the Ti 6-4, Ti 7-12 and Ti 8-1-1 alloys used for this program would not be suitable for cryogenic applications at -320°F and -423°F.

For room temperature application, fasteners of Ti 6-4 would warrant consideration over Ti 7-12 and Ti 8-1-1 because of its higher strength. On a strength to density basis, fasteners of Ti 6-4 would be equivalent to H-11 fasteners at a 320 ksi stress level which cannot be heat treated by conventional methods to this stress level.

Evaluations of the ELI grade of Ti 6Al-4V by the Aerojet General Corporation, DMIC report of October 9, 1964, shows it to have good ductility and notched to unnotched tensile ratios at -423°F. Notched to unnotched tensile ratios were above unity at -423°F for specimens with a stress concentration factor of Kt 6. This would indicate that the ELI grade of Ti 6-4 and possibly Ti 7-12 and Ti 8-1-1 have better potential cryogenic fastener application than the conventional materials and would warrant investigation.

5.3.2 Shear Bolts

5.3.2.1 Iron Base Alloys

Shear bolts of H-11 alloy heat treated to a strength level of 260 ksi exhibited the highest shear strength at room temperature of any fastener material in the program. Shear strengths at room temperature were on the order of 175 ksi. At 900°F, the material still retains relatively high strength as evidenced by a shear strength on the order of 120 ksi. However, at -423°F, the material becomes brittle with shear strengths lower than those recorded at room temperature. Further evidence of the material's brittleness at -423°F was noted for the material tensile properties which were also lower than those at room temperature and having little or no ductility. Therefore, from the results of this evaluation, the utilization temperature range for these fasteners appears to be from room temperature to 900°F. The minimum temperature may be lower than room temperature, but further work would have to be conducted between -423°F and room temperature to determine this temperature.

5.3.2.2 Titanium Alloys

The shear strength of Ti 6Al-4V shear bolts were the same as those reported for the Ti 6-4 tension bolts. Shear strength increased with decreasing temperature, but the shear to ultimate tensile strength ratio also decreased. For room temperature shear applications where weight reduction is a prime concern, shear bolts of Ti6-4 should be considered. Shear strength of Ti 6-4 bolts was on the order of 110 ksi which would be the equivalent of steel bolts with a 190 ksi shear strength on a strength to weight basis. By contrast, available alloy steels cannot be heat treated by conventional methods to this strength level.

5.3.3 Semi Blind Fasteners (Point Drive and Jo Bolts)

5.3.3.1 Iron Base Alloys

Evaluated in this category were point drive bolts of AISI 8740 with 2024-T4 aluminum twist off nuts and Jo Bolts of AISI 4130. Shear strength of the point drive bolts increased significantly with decreasing temperature. Tensile tests at -423°F produced head failures for the 3/8 inch diameter in some cases below the room temperature strength. This may be the result of head design in conjunction with material brittleness. Specimens of this material were not tested. The 2024-T4 aluminum nuts failed the Alma #10 vibration test in less than 20,000 cycles. This test is a severe vibration test and is not called out in the specification requirements of this part. On the basis of shear strength, 8740 point drive bolts could be utilized from -423°F to 450°F.

On the other hand, Jo Bolts of AISI 4130 could not be considered for -423°F application because of the inconsistent shear results at that temperature. The data shows the shear strength in one test to be below room temperature strength.

5.3.3.2 Nickel Base Alloys

Evaluated in this category were point drive fasteners and twist off nuts of conventional waspaloy. Although they were evaluated as an existing fastener, they should be considered a development item because fasteners of this type were never manufactured in the fastener industry to our knowledge. Never-the-less, point drive fasteners of this material offer good potential for space vehicle application from -423°F to 1400°F. Tensile and shear strength increase significantly at -423°F.

5.3.4 Titanium Base Alloys

Point drive fasteners of conventional Ti 5Al-2.5Sn appear to have the greatest potential for cryogenic application of the titanium point drive fasteners tested. Results of shear tests at -423°F were consistent and showed a marked increase in strength above room temperature strength. For -423°F shear applications where weight reduction is essential and design criteria is not a deciding factor, point drive fasteners of Ti 5-2.5 warrant definite consideration. On a strength to weight basis at -423°F, alloy steel or nickel base fasteners would have to have a shear strength of 230 ksi to be the equivalent Ti 5-2.5 fasteners. The results of Ti 6-4 point drive fasteners would fall in line with those previously discussed in paragraph 5.3.2.2.

5.4 Rivets

The data show that the shear strength of all rivets tested increased appreciably at -423°F. This included Cherry rivets of 2017-T4 aluminum and A-286, and solid rivets of 2024 T4 aluminum and commercially pure titanium. The tensile strength of the commercially pure titanium solid rivets decreased at -423°F below room temperature values. This could be an indication of brittleness but the shear properties do not indicate it. However, since rivets are designed for shear applications, rivets of 2017-T4, 2024-T4, A-286 and possibly commercially pure titanium appear feasible for space vehicle applications from -423°F to their maximum utilization temperature.

6.0 POTENTIAL HIGH STRENGTH FASTENER MATERIAL EVALUATION

From the results of the survey, ten alloys of iron, nickel, titanium and cobalt base were selected for evaluation. The alloys listed in Table 6.1 were selected on the basis of potential for high strength fastener applications and expectant future usage in the aerospace industry. The evaluation of these materials was conducted over the two year period of the contract and were selected with the approval of the Contracting Officer's Technical Representative. Listed in Tables 6.2 and 6.3 are the material suppliers and fastener configuration evaluated.

TABLE 6.1

SELECTED POTENTIAL HIGH STRENGTH FASTENER MATERIALS

Iron Base	Nickel Base	Titanium Base	Cobalt Base
U-212	Inco 718	Ti 1Al-8V-5Fe	L605 (30% Cold Reduced)
Vasco Max 300 (18% Ni Maraging)	Udimet 630	Ti 5Al-2.5Sn (ELI)	
	Waspaloy (25% Cold Reduced)	Ti 5Al-5Sn-5Zr	
	AF 1753		

6.1 Manufacturing

The ten alloys were fabricated into 1/4-28 twelve point tension bolts with the exception of the 25 percent cold reduced waspaloy material which was made into a stud. The bolts were tested with nut slugs fabricated from the same material and heat treatment as the companion bolt. Figures 6.1 and 6.2 list the selected materials fabricated into fasteners for evaluation. Listed in Tables 6.4 and 6.5 are the chemical compositions of the ten alloys.

6.1.1 Manufacturing and Heat Treat Processes

6.1.1.1 U-212

a. Hot forged 12 point head
b. Solution treat - 1850°F 2 hrs. water quenched
c. Stabilized - 1425°F 2 hrs. air cooled
e. Age hardened - 1250°F - 16 hrs. air cooled

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6.1.1.2 Vasco Max 300

a. Hot forged 12 point head
b. Solution treated - 1500°F - 1 hr. air cooled
c. Age hardened - 900°F - 3 hrs. air cooled
d. Rolled threads

6.1.1.3 Inconel 718

a. Hot forged 12 point head
b. Solution treated - 1800°F 1 hr. water quenched
c. Rolled threads
d. Age hardened - 1325°F - 8 hrs. furnaced cooled to 1150°F held 8 hrs - air cooled

6.1.1.4 Waspaloy (25% Cold Reduced)

a. Solution treated - 1900°F 1 hr. water quenched
b. Cold extruded (.312 inches to .268 inches)
c. Age hardened - 1400°F 16 hrs. air cooled
d. Rolled threads

6.1.1.5 Udimet 630

a. Hot forged 12 point head
b. Solution treated 1900°F - 1 hr. air cooled
c. Age hardened 1400°F - 8 hrs. air cooled
d. Age hardened 1200°F - 10 hrs. air cooled
e. Rolled threads

6.1.1.6 AF 1753

a. Hot forged 12 point head
b. Solution treated - 1900°F - 2 hrs. water quenched
c. Rolled threads
d. Age hardened - 1400°F - 16 hrs. air cooled

6.1.1.7 Ti 1Al-8V-5Fe

a. Hot forged 12 point head
b. Solution treated - 1425°F - 1 hr. water quenched
c. Age hardened - 950°F - 2 hrs. air cooled
d. Rolled threads

6.1.1.8 Ti 5Al-2.5 Sn (ELI)

a. Hot forged 12 point head
b. Annealed - 1500°F - 1 hr. air cooled
c. Rolled threads

6.1.1.9 Ti 5Al-5Sn-5Zr

a. Hot forged 12 point head
b. Annealed - 1650°F - 4 hrs. air cooled
c. Rolled Threads

6.1.1.10 L605 (30% Cold Reduced)

a. Solution treated - 2225°F - 1/2 hr. water quenched
b. Cold extruded (.320 inches to .268 inches)
c. Forged 12 point head
d. Rolled threads

TABLE 6.2

POTENTIAL HIGH STRENGTH FASTENER MATERIALS EVALUATED IN 1964

Material	Base Alloy	Supplier	Fastener Configuration	Thread Form	Plating	Min. UTS @70°F-ksi	Max. Util. Temp. °F
Ti 1Al-8V-5Fe	Titanium	Reactive Metals Products	12 Pt Tension Bolt	Mil-S-8879		200	300
U-212	Iron	Universal Cyclops	12 Pt Tension Bolt	Mil-S-8879		180	1200
VascoMax 300	Iron	Vanadium Alloys	12 Pt Tension Bolt	Mil-S-8879	AMS 2416	260	900
Pyromet 718	Nickel	Carpenter Steel	12 Pt Tension Bolt	Mil-S-8879		180	1200
*25% Cold Red. Waspaloy	Nickel	Carpenter Steel	Stud	Mil-S-8879		220	1400

*Cold Reduction Process performed by SPS Laboratories

TABLE 6.3

POTENTIAL HIGH STRENGTH FASTENER MATERIALS EVALUATED IN 1965

Material	Base Alloy	Supplier	Fastener Configuration	Thread Form	Minimum Ultimate Tensile Strength @ 70°F, ksi	Maximum Utilization Temperature °F
*30% Cold Reduced L605	Cobalt	Haynes Stellite Co.	12-point Tension Bolt	MIL-S-8879 (.003 Reduced Pitch Diameter)	220	1400
Udimet 630	Nickel	Special Metals, Inc.	12-point Tension Bolt	MIL-S-8879 (.003 Reduced Pitch Diameter)	220	1200
AF 1753	Nickel	Universal Cyclops	12-point Tension Bolt	MIL-S-8879 (.003 Reduced Pitch Diameter)	180	1600
Ti 5Al-2.5Sn (ELI)	Titanium	Crucible Steel Co.	12-point Tension Bolt	MIL-S-8879	110	750
Ti 5Al-5Sn-5 Zr	Titanium	TMCA	12-point Tension Bolt	MIL-S-8879	160	750

*Cold Reduction Process performed by SPS Laboratories

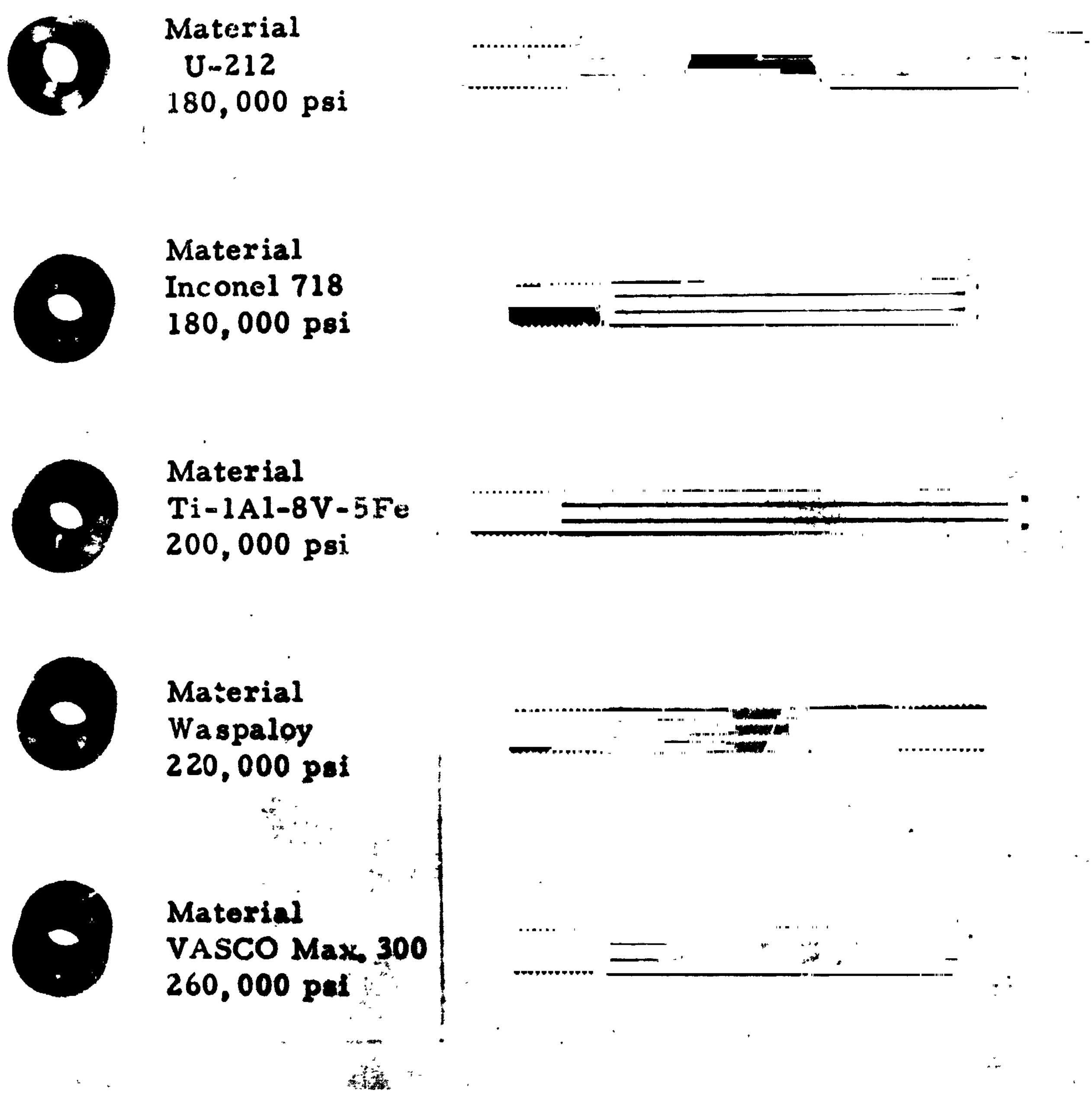


Figure No. 6.1 Composite Photograph of Tension Fasteners Evaluated in 1964.

MATERIAL

L605

220,000 PSI

MATERIAL

UDIMET 630

220,000 PSI

MATERIAL

AF 1753

180,000 PSI

MATERIAL

Ti 5Al-2.5Sn (ELI)

110,000 PSI

MATERIAL

Ti 5Al-5Sn-5Zr

160,000 PSI

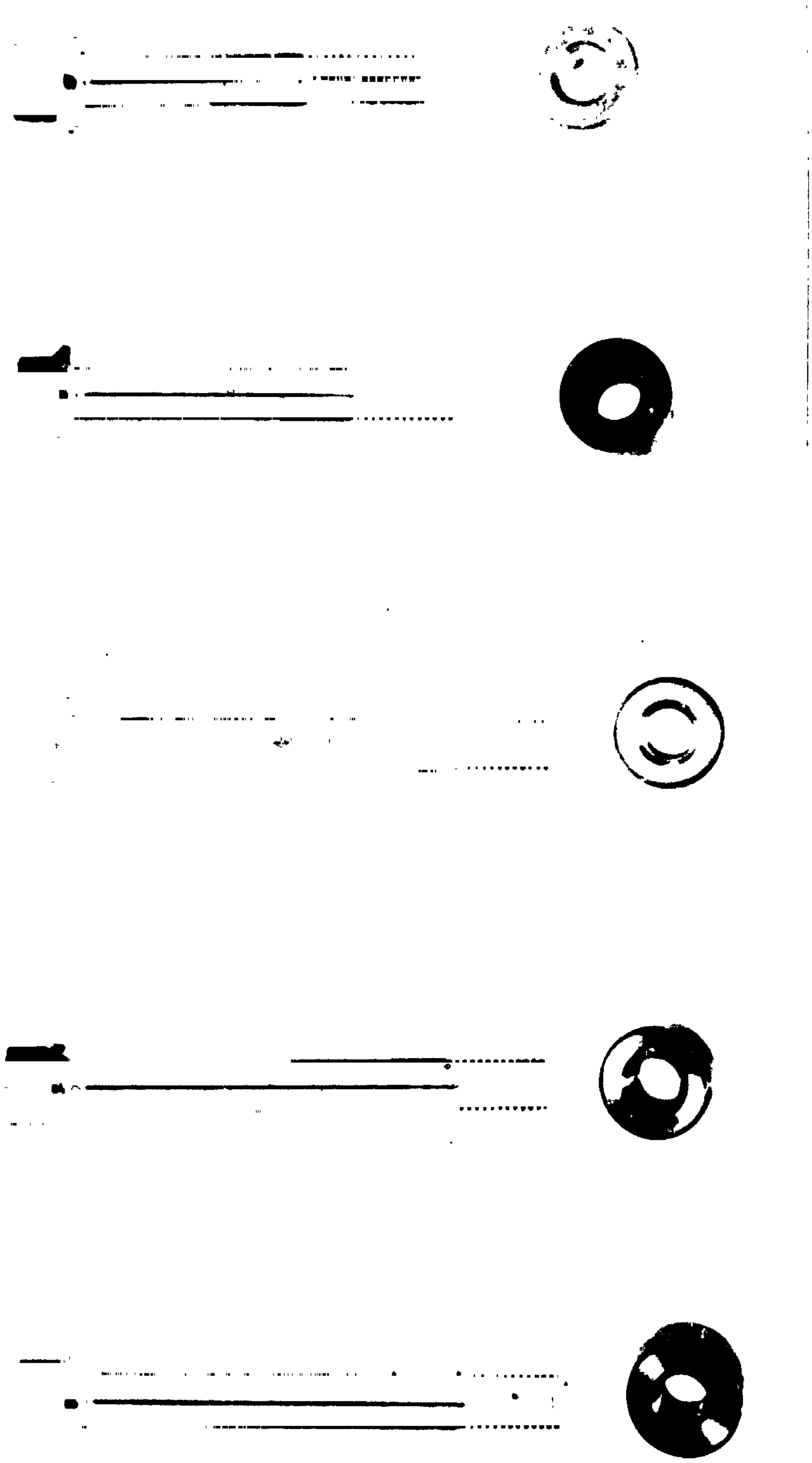


Figure 6.2 Composite Photograph of Tension Fasteners Evaluated in 1965

TABLE 6.4

CHEMICAL COMPOSITION OF MATERIALS
EVALUATED IN 1964

Material	Ti 1Al-8V-5Fe	U-212	Vasco Max 300 (18% Ni Maraging)	Inconel 718	25% C. R. Waspaloy
Heat No.	30106	KA1661	07144	V-90108	V-11968
C	.03	.087	.03	.07	.07
Mn		.05	.06	.15	.03
Si		.038	.08	.23	.08
S		.005	.008	.008	.007
P		.003	.004	.016	.004
Cr		16.10		18.92	19.57
W					
Zr			.006		.08
Ni		25.24	18.95	Bal.	Bal.
Mo			4.79	2.98	4.45
Co			8.95		13.22
Fe	4.9	Bal.	Bal.		.34
Al	1.7	.038	.10	.70	1.21
Ti	Bal.	3.98	.59	1.01	2.92
B		.066	.002	.0046	.004
N	.011				
O	.36				
H	41/49				
Cb & Ta		.44		5.65	
Cu				.01	.01
Sn					
Ca			.05		
V	7.5				

TABLE 6.5

CHEMICAL COMPOSITION OF MATERIALS EVALUATED IN 1965

Material	L 605	Udimet 630	AF 1753	Ti 5Al-2.5Sn(ELI)	Ti 5Al-5Sn-5Zr
Heat No.	L2-1461	6-3596	KH-689	2224-D1	D-1793
C	.09	.04	.21	.014	.027
Mn	1.29	.21	.02	.05	
Si	.47	.10	.03		
S	.014	.004	.005		
P	.016	.01	.002		
Cr	20.27	17.5	16.64		
W	14.71	2.75	8.53		
Zr			.049		4.9
Ni	9.89	Bal.	Bal.		
Mo		2.90	1.62		
Co	Bal.	.10	7.46		
Fe	2.12	17.2	8.60	.063	.04
Al		.61	1.96	5.58	5.0
Ti		1.05	2.96	Bal.	Bal.
B		40 ppm	.007		
N				.010	.012
O_2				.10	
H				.0048	.0075
Cb & Ta		6.20			
Cu		.10			
Sn				2.56	4.8

6.2 Test Program

The test program for the evaluation of potential high strength fastener materials is shown in Figure 6.3.

6.2.1 Tensile

6.2.1.1 Axial Tensile Tests

To determine ultimate strength and yield strength.

6.2.1.2 Angle Block Tensile Tests

To determine the dual effect of localized stresses and cryogenic temperatures.

6.2.1.3 Smooth Specimens

To determine the ultimate strength, yield strength and ductility of the base alloy from which the bolts were fabricated.

6.2.1.4 V-Notch Specimens

To determine the notch to smooth tensile relationship of the alloys from which the bolts were fabricated. V-Notch specimens with a stress concentration factor of Kt8 were used because this conformed with the requirements of the contract.

6.2.2 Tension Impact

To determine the impact properties of the bolt threads.

6.2.3 Double Shear

6.2.4 Tension-Tension Fatigue

6.2.5 Stress Rupture

To determine the stress required for ten hour life at the maximum utilization temperature of the bolt.

6.2.6 Stress Relaxation

Machine relaxation tests to determine the residual stresses after 50 hour exposure at maximum utilization temperature were determined employing one initial preload. The initial preloads were 80 percent of the bolt maximum utilization temperature yield strength.

6.2.7 Corrosion Resistance

6.2.8 Coefficient of Thermal Expansion

Coefficient of thermal expansion were derived from existing data listed in General Electric JED Materials Property Data Book, Aerospace Structural Metals Handbook or the Alloy Digest.

TEST PROGRAM
POTENTIAL HIGH STRENGTH FASTENER MATERIAL - 1965
EWB Tension Bolts

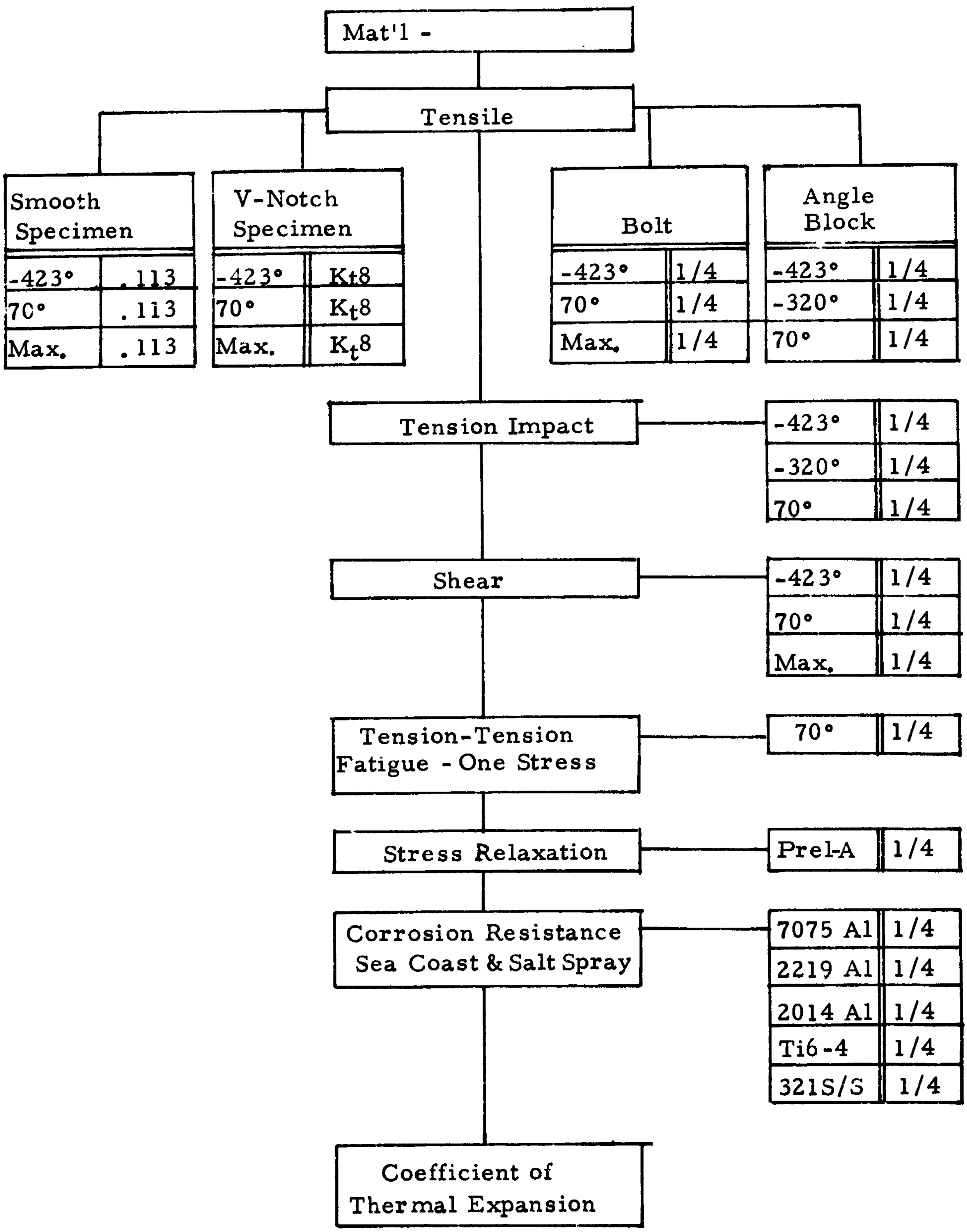


Figure 6, 3

6.3 Results

Six of the ten materials were selected for further evaluation as potential high strength fasteners. A detailed discussion of these materials as potential high strength fasteners is presented in Section 7.0. The selected materials were:

1. U-212
2. Inconel 718
3. 25% Cold Reduced Waspaloy
4. AF 1753
5. Ti 5Al-2.5Sn (ELI)
6. 30% Cold Reduced L605

The remaining four materials were not selected for further evaluation as fasteners because they did not exhibit the overall capabilities for potential high strength fasteners for space vehicle applications. These materials were:

1. Vasco Max 300 (18% Nickel Maraging Steel)
2. Udimet 630
3. Ti 1Al-8V-5Fe
4. Ti 5Al-5Sn-5Zr

6.4 Discussion of Results

6.4.1 Vasco Max 300 (18% Nickel Maraging Steel)

It appears that the temperature utilization range for fasteners of this material is room temperature to 900°F. Limited data indicates that the lower limit may be extended to -320°F but more work is needed to substantiate it.

At - 423°F, however, fastener strength was inconsistent and double shear strength decreased below room temperature values. The shear to ultimate tensile ratio at - 423°F was .35 compared to .62 at room temperature. Consequently, fasteners of Vasco Max 300 were not selected.

6.4.2 Udimet 630

Udimet 630 fastener with rolled threads after age hardening shows good potential for cryogenic application down to -423°F. Bolt and material strength at -423°F was 300 ksi with good ductility. Shear strength of Udimet 630 material at -423°F was the highest of any of the materials evaluated in this phase of the program.

Fasteners subjected to prolonged exposure at 1200°F became notch sensitive at room temperature. Indications of this were noted on fasteners subjected to the 50 hour relaxation tests at 1200°F.

6.4.2 (continued)

Subsequent tensile tests at room temperature of these parts showed a 33 percent decrease in tensile strength compared to "as received" strength. Further indication of this notch sensitivity was noted for fasteners with threads rolled before age hardening. Tensile tests at room temperature of these parts indicated that they were notch sensitive. Material strength was 234 ksi while the thread strength was 161 ksi, a decrease of 31 percent. A micro hardness survey of the threaded area, shown in Figure 6.4, shows a marked increase in hardness at the thread surface compared to the core hardness. This would probably account for the notch sensitivity and resultant low tensile properties at room temperature. Because of this sensitivity to the elevated temperature of 1200°F, fasteners of Udimet 630 material were not selected for further evaluation.

6.4.3 Ti 1Al-8V-5Fe

The evaluation of this alloy indicated that the operating temperature range for fasteners would be room temperature to 300°F. This material had the highest strength of all the titanium fasteners evaluated in the program. On a strength-to-density basis at room temperature, fasteners of Ti 1-8-5 were the strongest of any of the fasteners evaluated in the contract. To further emphasize this point, steel fasteners would have to be heat treated and/or mechanically worked to a strength level of 370 ksi to be the equivalent of Ti 1-8-5 fasteners on a strength-to-weight basis.

At cryogenic temperatures, however, the material becomes brittle and extremely notch sensitive. Tensile and double shear strengths at -423°F were markedly lower than room temperature strengths. Further indications of the material's notch sensitivity were noted in tests of the V-notch specimens. Notch (Kt 8) to smooth tensile ratio at -423°F was .28 compared to 1.10 at room temperature. Consequently, fasteners of Ti 1-8-5 were not selected for further evaluation as fasteners because of poor cryogenic properties.

6.4.4 The Ti 5-5-5 alloy would not be suitable for space vehicle applications. At -423°F, the material appears to be extremely notch sensitive with no indications of yield strength. Double shear strength at -423°F in some cases was below room temperature values. A severe drop was noted for the shear to ultimate tensile ratio at -423°F. At -423°F it was .36 compared to .63 at room temperature.

Exposure at the elevated temperature of 750°F appears to have an adverse effect on the room temperature tensile properties. Tensile strength of "as relaxed" fasteners decreased with no indications of yield strength which would indicate the fasteners were notch sensitive after exposure. Therefore, fasteners of Ti 5-5-5 were not considered for further evaluation because of poor cryogenic and elevated temperature properties.

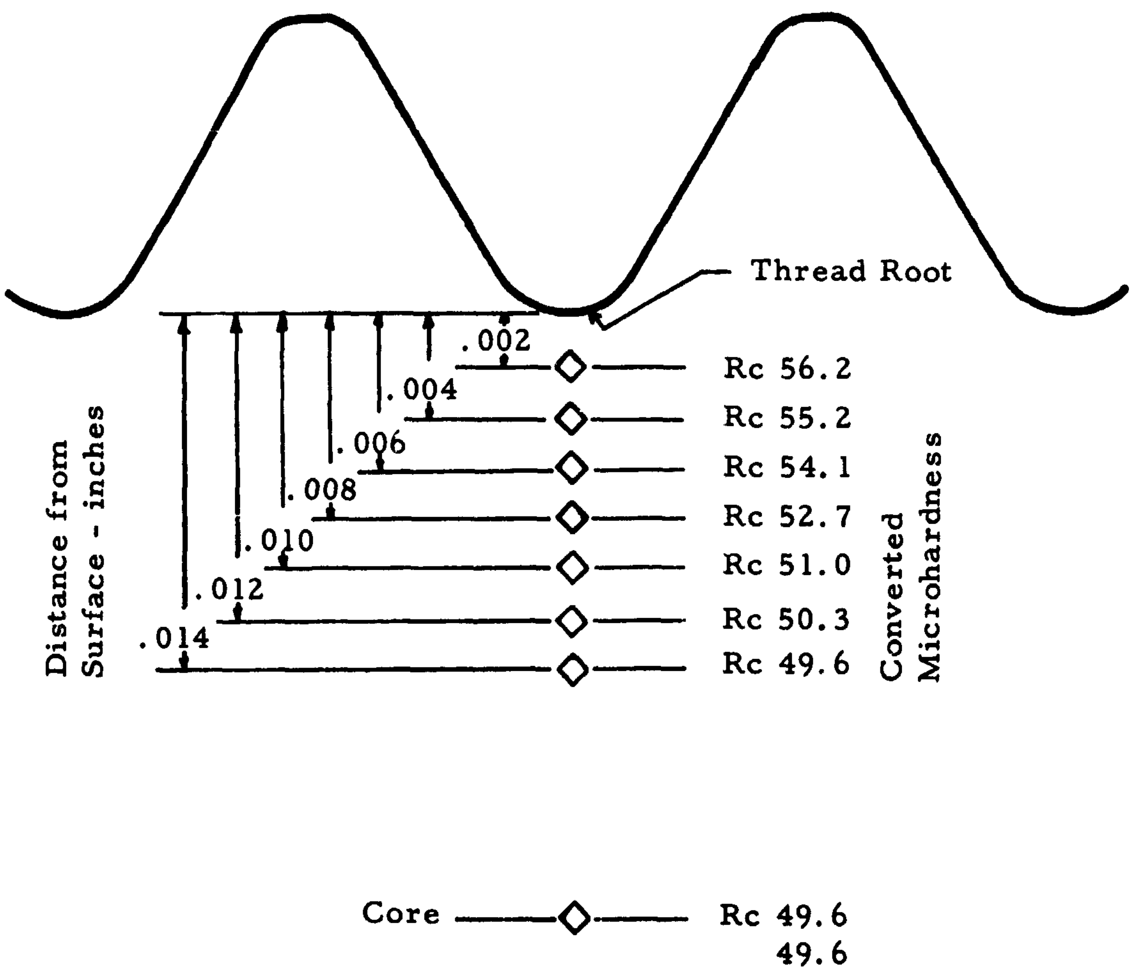


Figure 6.4 Microhardness Survey at the Thread Root of a 1/4-28 Thread of Udimet 630 Alloy.

The Threads were rolled prior to an age hardening of 1200° F for 10 hours. The hardnesses are converted from a 200 gram D.P.H. (Diamond Pyramid Hardness) value.

7.0 EVALUATION OF POTENTIAL HIGH STRENGTH MATERIALS AS FASTENERS

From the results of the potential high strength fastener materials evaluations conducted in 1964 and 1965, six of the ten materials evaluated were selected for further evaluation as fasteners. The selected materials and fastener configurations are listed in Tables 7.1 and 7.2. The materials and configurations were mutually selected by the Contracting Officer's Technical Representative and SPS Personnel. They are considered representative of the optimum requirements for space vehicle applications. Representative photographs of the fasteners evaluated are presented in Figures 7.1 and 7.2.

TABLE 7.1

SELECTED POTENTIAL HIGH STRENGTH MATERIALS AND CONFIGURATION FOR EVALUATION AS TENSION FASTENERS

Bolt Material	Ti 5Al-2.5 Sn (ELI	U-212 RTAA*	Inco 718 RTAA*	Waspaloy RTAA* (220 ksi)	L605 RTAA* (220 ksi)	AF1753 RTAA*
Bolt Configuration	12-pt. tension	12-pt. tension	12-pt. tension	12-pt. tension	12-pt. tension	12-pt. tension
Diameter, inches	1/4 & 3/8	1/4	1/4 & 3/8	1/4	1/4	1/4 & 3/8
Nut Material	A-286 (FN1216)	A-286 129FW	A-286 129FW	Waspaloy	L605	AF1753
Nut Plating	Silver	Silver	Silver	Silver	Silver	Silver

*RTAA - Rolled Threads After Aging

TABLE 7.2

SELECTED POTENTIAL HIGH STRENGTH MATERIAL AND CONFIGURATION FOR EVALUATION AS SEMI BLIND FASTENERS

Bolt Material	Ti 5Al-2.5 Sn (ELI)	Inco 718	Waspaloy (220 ksi)	L605 (220 ksi)	AF 1753
Bolt Configuration	100° Flush head point drive	100° Flush head point drive	100° Flush head point drive	100° Flush head point drive	100° Flush head point drive
Diameter	1/4 & 3/8	1/4 & 3/8	1/4	1/4	1/4 & 3/8
Nut Material	Aluminum 2024-T4	Waspaloy	Waspaloy	Waspaloy	Waspaloy
Nut Configuration	Hexagon Twist-off	Hexagon Twist-off	Hexagon Twist-off	Hexagon Twist-off	Hexagon Twist-off
Nut Plating	Anodized	Silver plated	Silver plated	Silver plated	Silver plated

7.1 Manufacturing

Since the semi-blind fasteners were fabricated from the same materials as the tension fasteners, heat treatment where possible was done simultaneously for both fastener systems of the same alloy. This produced interchangeable data, such as tensile and shear properties of the material.

7.1.1 Twelve Point Tension Bolts

7.1.1.1 EWBT815 - Ti 5Al-2.5 Sn(ELI)
Hot forge 12 point head
Annealed - 1500°F - 1 hr. air cooled
Rolled threads - Mil-S-8879

7.1.1.2 EWB 1615 - U-212
Hot forged 12 point head
Solution treated - 1850°F - 2 hrs. water quenched
Stabilized - 1425°F - 2 hrs. air cooled
Age hardened - 1250°F - 16 hrs. air cooled
Rolled threads - Mil-S-8879 (.003 reduced pitch diameter)

7.1.1.3 EWB 1615 - Inconel 718
Hot forged 12 point head
Solution treated - 1800°F - 1 hr. water quenched
Aged hardened - 1325°F - 8 hrs. furnace cooled to 1150°F
held 8 hrs. air cooled
Rolled threads - Mil-S-8879 (.003 reduced pitch diameter)

7.1.1.4 EWB 1615 - AF 1753
Hot forged 12 point head
Solution treated - 1900°F - 2 hrs. water quenched
Age hardened - 1400°F - 16 hrs. air cooled
Rolled threads - Mil-S-8879 (.003 reduced pitch diameter)

7.1.1.5 EWB 1615 - 25% Cold Reduced Waspaloy
Solution treated - 1900°F - 1 hr. oil quenched
Cold extruded - 25% (.312 inches to .268 inches)
Forged - 12 point head
Age hardened - 1400°F - 16 hours air cooled
Rolled threads - Mil-S-8879 (.003 reduced pitch diameter)

7.1.1.6 EWB 1615 - 30% Cold Reduced L605
Solution treated - 2225°F - 1/2 hr. water quenched
Cold extruded - 30% (.320 inches to .268 inches)
Forged - 12 point head
Age hardened - 1100°F - 4 hrs. air cooled
Rolled threads - Mil-S-8879 (.003 reduced pitch diameter)

A major portion of the bolts manufactured by this process exhibited longitudinal cracks after age hardening which were not present prior to aging. A sufficient quantity had no cracks and the evaluation was conducted using those parts.

7.1.1.7 Stud-25% Cold Reduced Inconel 718
Solution treated - 1800°F - 1 hr. water quenched
Cold reduced - 25% (.312 inches to .268 inches)
Age hardened - 1325°F - 8 hrs. furnace cooled to 1150°F
held 8 hrs. air cooled
Rolled threads - Mil-S-8879

7.1.2 Tension Nuts

7.1.2.1 FN 1216-A-286

Manufacturing process for these parts was the same as that listed in Section 5.1.1.2.

7.1.2.2 129FW - A-286
Extruded locking collar
Extruded 12 point serration
Tapped - Mil-S-7742 thread
Squeezed locking collar
Age hardened - 1325°F - 16 hrs. air cooled
Silver plated - per AMS 2410

7.1.2.3 FN 26-AF 1753
Hot forged nut blank with 12 point serration
Solution treated - 1900°F - 2 hrs. water quenched
Formed locking collar
Solution treated - 1875°F - 1 hr. water quenched
Tapped - Mil-S-8879 thread
Squeezed locking collar
Age hardened - 1400°F 16 hrs. air cooled
Silver plated per AMS 2410

7.1.2.4 FN26 - Waspaloy
Hot forged nut blanks with 12 point serration
Solution treated - 1950°F - 1 hr. oil quenched
Formed locking collar
Solution treated - 1875°F - 4 hrs. air cooled
Tapped - Mil-S-8879 thread
Squeezed locking collar
Stabilized - 1550°F - 4 hrs. air cooled
Age hardened - 1400°F - 16 hrs. air cooled
Silver plated per AMS 2410

7.1.3 100° Flush Head Point Drive Bolts

7.1.3.1 PTF 16 - Ti 5Al-2.5 Sn (ELI)
Hot forged 100° flush head
Annealed - 1500°F - 1 hr. air cooled
Rolled threads - Mil-S-8879
Broached hexagon recess at bolt point

7.1.3.2 63439 - Inconel 718
Hot forged 100° flush head
Solution treated - 1800°F - 1 hr. water quenched
Age hardened - 1325°F - 8 hrs. furnace cooled to 1150°F held 8 hrs. air cooled
Rolled threads - Mil-S-8879
Broached hexagon recess at bolt point

7.1.3.3 63439 - AF 1753
Hot forged 100° flush head
Solution treated - 1900°F - 2 hrs. water quenched
Rolled threads - Mil-S-8879
Broached hexagon recess at bolt point
Age hardened - 1400°F - 16 hrs. air cooled.

7.1.3.4 63439 - 25% Cold Reduced Waspaloy

Same process as that for tension bolts except for the forging of a 100° flush head and broached hexagon recess at bolt point after thread rolling.

7.1.3.5 63439 - 30% Cold Reduced Waspaloy

Same process as that for tension bolts except the solution treatment of 2225°F for 1/2 hour prior to cold extrusion was not used.

7.1.4 Twist Off Nuts

7.1.4.1 HL 70W - Al 2024-T4

These parts were supplied by the Hi Shear Corporation which were also used for the 1964 evaluation of Ti 6-4 point drive bolts.

7.1.4.2 TN 12-Waspaloy
Solution treated - 1900°F 1 hr. oil quenched
Drilled and formed
Tapped - Mil-S-8879
Milled hex
Silver plated per AMS 2410
Squeezed for locking torque

Although it was originally planned to evaluate the AF 1753 and cold reduced L605 point drive bolts with hexagon nuts of the same respective materials, preliminary tensile tests showed that Waspaloy twist-off nuts would develop the full tensile potential of these bolts at room and 1600°F. For this reason, the evaluation of the AF 1753 and cold reduced L605 point drive bolts were conducted using the Waspaloy twist-off nuts.

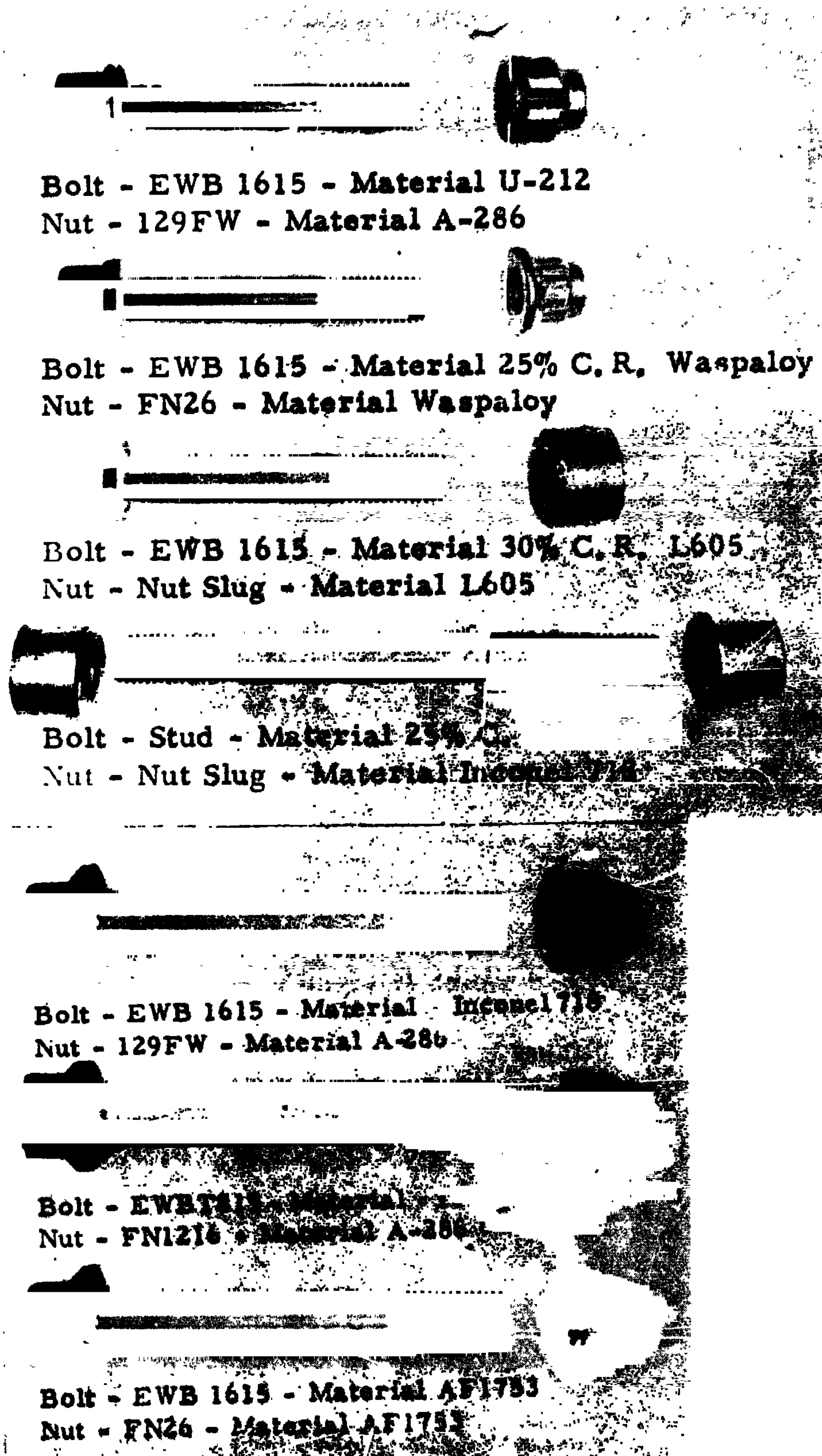
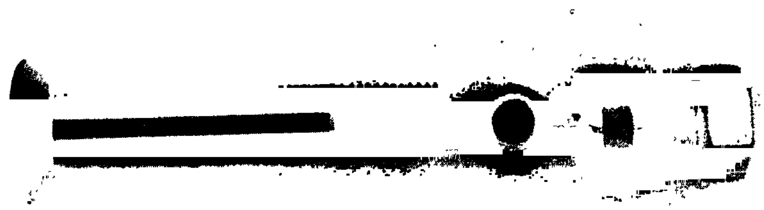
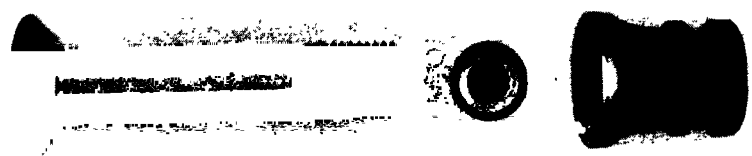


Figure 7.1. Composite Photograph of Potential High Strength Tension Fasteners Evaluated.

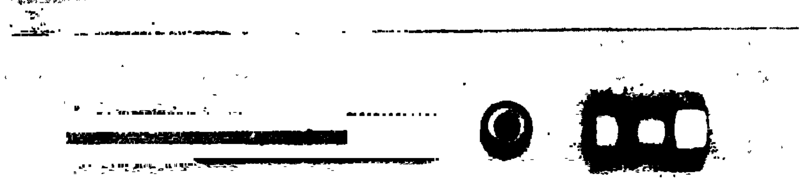


Bolt - 63439 - Material Inconel 718
Nut - TN12 - Material Waspaloy

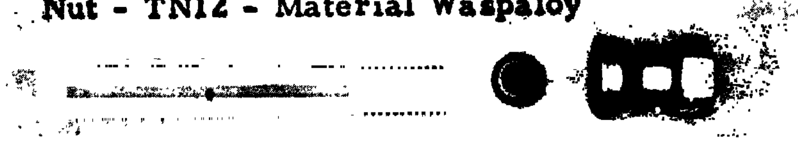


Bolt - PTF 16 - Material Ti 5Al-2.5 Sn (ELI)
Nut - HL70W - Material Al2024 - T4

Bolt - 63439 - Material AF 1753
Nut - TN 12 - Material Waspaloy



Bolt - 63439 - Material 25% C.R. Waspaloy
Nut - TN12 - Material Waspaloy



Bolt - 63439 - Material 30% C.R. L605
Nut - TN12 - Material Waspaloy

Figure 7.2 Composite Photograph of Evaluated Potential High Strength Semi Blind Fasteners

7.2 Test Program

The test programs for the potential high strength fasteners are shown in Figures 7.3 and 7.4. The scope of the test programs were considered comprehensive for the determination of fastener utilization for space vehicle applications.

7.2.1 Tensile

7.2.1.1 Bolt and Companion Nut (Axial)

Ultimate tensile and yield strengths were determined for the fastener combinations.

7.2.1.2 Bolt and Companion Nut (Angle Block)

The angle block tensile tests with the 3° angle at the nut bearing face proved to be a very effective test for determining the sensitivity of a fastener to localized stresses. For that reason it was included in the test program.

7.2.1.3 Specimens

To evaluate the base alloy from which the bolts were fabricated, it was deemed necessary that standard tensile tests specimens made from the bolts should be tested at the same temperatures as the bolts.

7.2.1.4 Preload

Since semi-blind fasteners were selected for evaluation, determination of preload was recorded at room temperature.

7.2.2 Stress Durability

The stress durability tests were included in the test program to determine a fastener's capability to sustain high preloads over a prolonged period of time. The tests were conducted at room temperature for tension fasteners.

7.2.3 Tension Impact

Test data from Phase I and II indicate that tension-impact properties were affected at cryogenic temperatures. Therefore, the inclusion of this test was warranted for determining a fasteners suitability for space vehicle applications.

7.2.4 Double Shear

These tests warrant inclusion in the test program because of the adverse effect cryogenic temperatures had on the shear properties of maraging steel and some of the titanium alloys.

7.2.5 Stress Rupture

To determine the capabilities of a fastener for sustaining loads at its maximum utilization temperature, stress rupture tests were included in the program. The stress required to cause rupture for one, ten and one-hundred hours was determined at the maximum utilization temperature of the fastener assemblies.

7.2.6 Stress Relaxation

In addition to the stress rupture tests, relaxation tests were conducted to further determine the fastener assembly's elevated temperature properties. The tests were conducted at the maximum utilization temperature of the fastener assemblies employing an initial preload of 80 percent of the elevated temperature yield strength.

Since the relaxation tests were included in the test program, it was axiomatic that the effects of these tests should be determined on the tensile strength, yield strength and shear strength of the fasteners.

7.2.7 Nut Reusability

Since the locknuts to be evaluated were never tested with the selected bolts, the determination of nut reusability and galling tendencies was warranted.

7.2.8 Torque versus Induced Load

Torque versus induced load tests were conducted primarily to establish preloads for relaxation tests. Data was needed to determine the torque-tension relationship of the locknuts and tension bolts. The tests were conducted at room temperature on lubricated and unlubricated locknuts.

TEST PROGRAM - POTENTIAL HIGH STRENGTH

TENSION BOLTS AND COMPANION NUTS

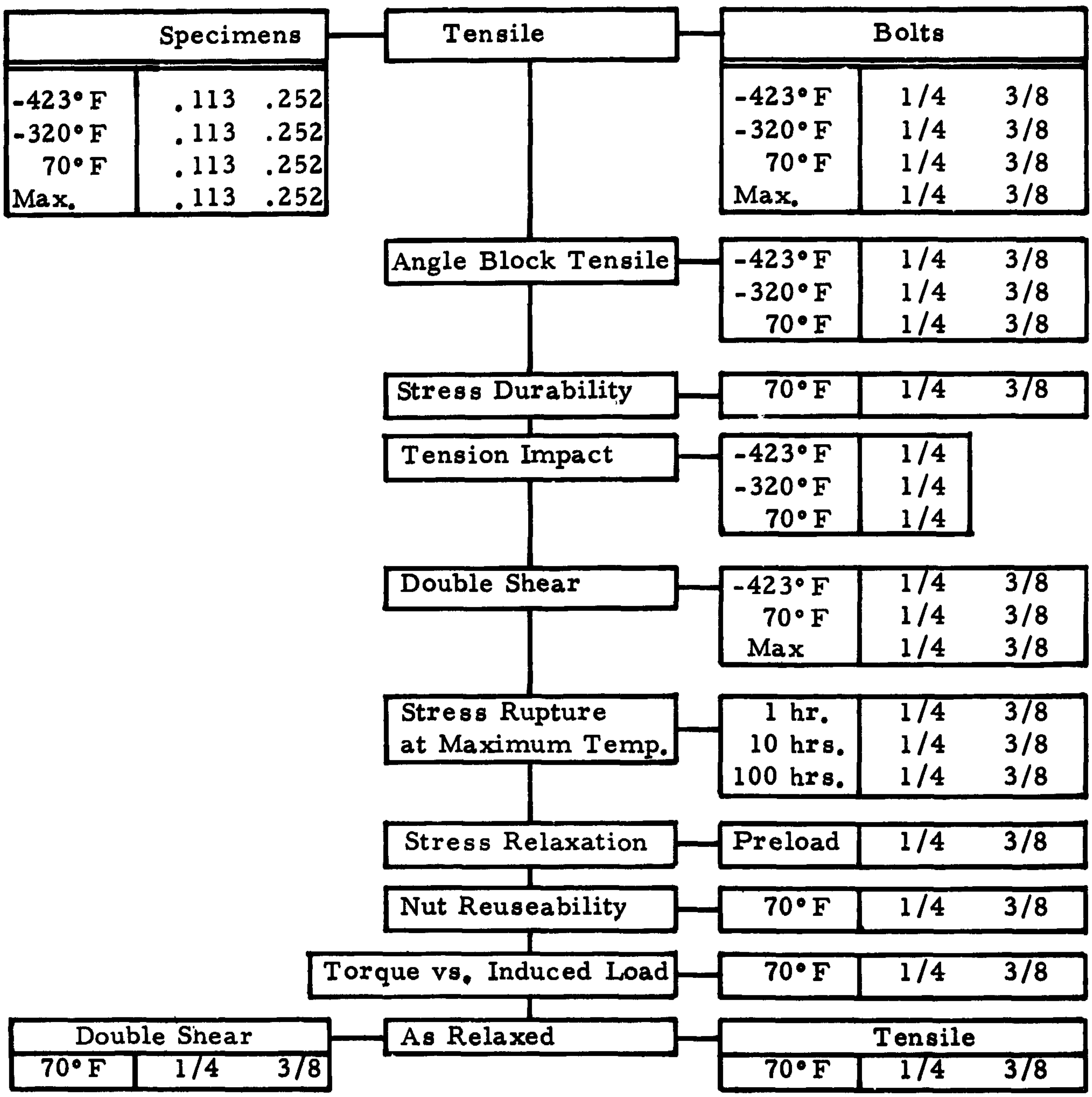


Figure 7.3

TEST PROGRAM - POTENTIAL HIGH STRENGTH

SEMI BLIND FASTENERS

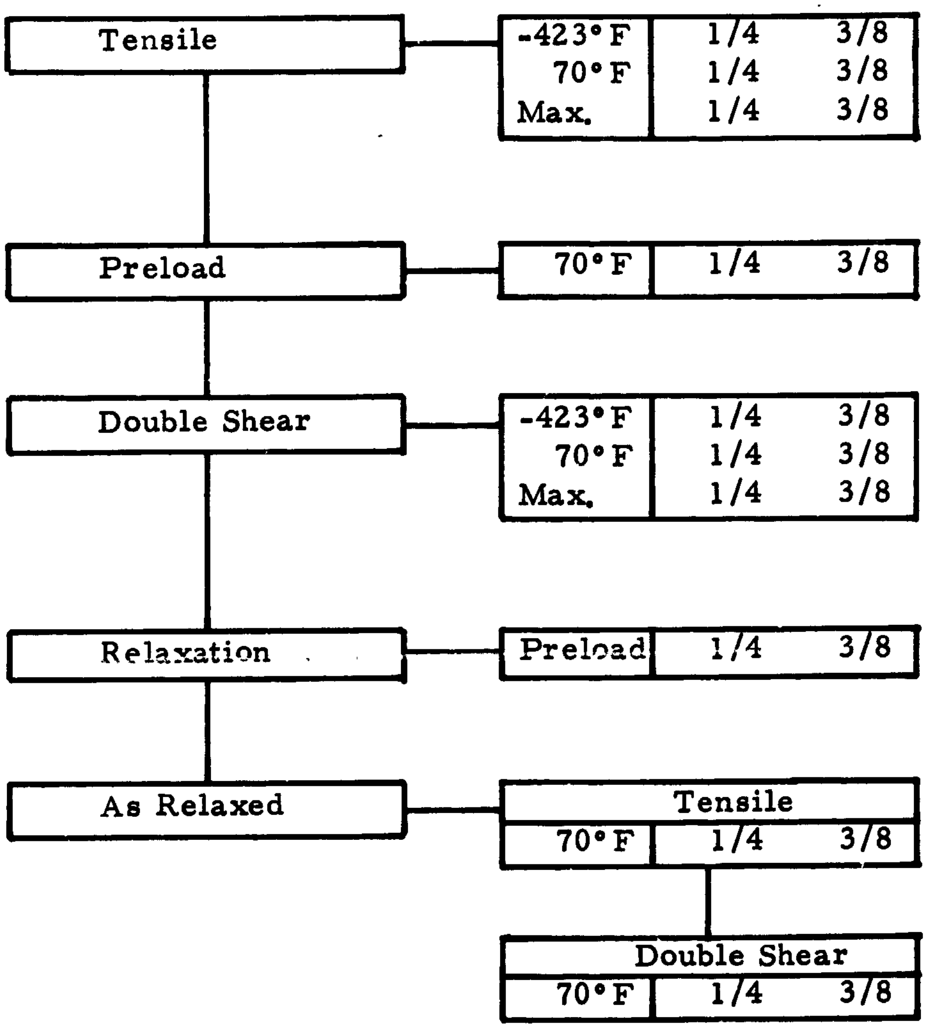


Figure 7.4

7.3 Discussion of Results

7.3.1 U-212 Fasteners

Fasteners fabricated from U-212 alloy showed definite potential for space vehicle applications in the temperature range of -423°F to 1200°F. Fasteners of this material possess excellent strength and ductility over the entire temperature range. The evaluation showed that U-212 fasteners with rolled threads after age hardening to have superior cryogenic properties over those with rolled threads before age hardening. This was particularly noted for the tensile and tension impact results at -423°F. The bolt to material tensile ratio at -423°F for bolts with rolled threads after age hardening was 1.0 as compared to the ratio for bolts with rolled threads before aging which was .81. A 60 percent increase in tension impact strength at -423°F was realized with rolled threads after aging.

For elevated temperature applications, rolled threads before age hardening would be recommended for optimum properties.

7.3.2 Inconel 718 Fasteners

From the results of the material and fastener evaluation, it was concluded that fasteners fabricated from conventional Inconel 718 material would be recommended for space vehicle application. Fasteners of this material showed excellent strength with good ductility over the temperature range of -423°F to 1200°F. As in the case of U-212 fasteners, cryogenic properties are particularly enhanced with rolled threads after age hardening. Tensile strength at -423°F of bolts with rolled threads after aging was on the order of 280-290 ksi. This resulted in a bolt to material tensile ratio of 1.05 which was exceedingly higher than the .82 ratio for bolts with rolled threads before aging. Hence for cryogenic applications Inconel 718 fasteners should have threads rolled after age hardening. Conversely, fasteners for elevated temperature applications should have rolled threads before age hardening.

Point drive bolts of Inconel 718 could be utilized, but more development is needed to optimize the hexagon recess configuration and overall machining practices. Tensile strength of the point drive bolts was considerably lower than the strength recorded for tension bolts even though failure occurred in the thread area. This was attributed to the deep drill and broach depth of the hexagon recess.

7.3.3 25% Cold Reduced Inconel 718

In place of the 3/8 inch diameter U-212 fasteners which could not be evaluated because of material availability, 1/4 inch studs of 25 percent cold reduced Inconel 718 were chosen for evaluation. A limited number of these parts were on hand in sufficient quantity to permit a comprehensive evaluation, particularly at cryogenic temperatures.

The mechanical properties of studs fabricated from 25 percent cold reduced Inconel 718 indicate that this material shows good potential for space vehicle fastener applications. Tensile strengths on the order of 330 ksi were recorded at -423°F with a shear strength at the same temperature on the order of 165ksi.

The studs appeared to be sensitive to minimal bending conditions at cryogenic temperatures. This was evident from the inconsistent results of the angle block tensile tests at -320°F and -423°F. More development would be required to fabricate this material into a headed fastener to further determine its suitability for space vehicle application.

7.3.4 25% Cold Reduced Waspaloy

Fasteners of cold-reduced and aged Waspaloy were selected for evaluation because this material showed definite promise for cryogenic fasteners application down to -423°F. The material had high strength and notch-ductility over the entire temperature range of -423°F to 1400°F. Bolt and material strength at -423°F was on the order of 350 ksi with an elongation of 14 percent in .5 inches.

The problem of strain age cracking was encountered during the fabrication of this material. Initially, 30 percent cold reduction was attempted but cracking developed during the aging cycle. The reduction was then dropped to 25 percent but cracks were still evident after aging. A sufficient quantity, however, had no indication of cracks and the evaluation was conducted.

Although strain age cracking was encountered in the fabrication of studs, it was not encountered in the fabrication of bolts evaluated. For small diameter fasteners, under 5/16 inches, cold reduced waspaloy should be considered for cryogenic applications down to -423°F. The material exhibited high strength with excellent ductility at cryogenic temperatures. More development would be required to fabricate this material into large diameter fasteners. Figure 7.5 shows the microstructure of "as received" and 25% cold reduced waspaloy alloy.

At the elevated temperature of 1400°F, head failures resulted in the stress rupture tests for 10 and 100 hour lives. The stress to produce 100 hours life at 1400°F was 40 ksi which was well below the 70 ksi stress for conventional Waspaloy fasteners. Therefore, at elevated temperatures the conventional Waspaloy fasteners should be considered rather than cold reduced fasteners.

7.3.5 AF 1753

Fasteners fabricated from AF 1753 showed considerable potential for space vehicle applications. Fasteners of this alloy exhibited high strength and good ductility over the entire temperature range of -423°F to 1600°F. As in the case of the U-212 and Inconel 718 fasteners, the AF 1753 fasteners with rolled threads after age hardening exhibited superior cryogenic properties over fasteners with rolled threads before age hardening. Tensile strength at -423°F of bolts with rolled threads after aging was 245 ksi compared to 225 ksi for bolts with rolled threads before aging.

On the other hand, it appears that bolts with threads rolled before age hardening offer better properties at the elevated temperature of 1600°F. This was noted for the stress relaxation tests at 1600°F where initial stresses of approximately 75 ksi were used. Residual stresses for bolts with rolled threads before aging retained stresses of 12 to 18 ksi after 50 hours exposure while the residual stresses for bolts with rolled threads after aging were non-existent in less than 50 hours. Further evidence of the better elevated temperature properties of rolled threads before aging was noted for the stress rupture tests at 1600°F. A stress of 50 ksi produced the same life as a stress of 30 ksi for bolts with rolled threads after aging.

Thus, AF 1753 fasteners should have rolled threads after age hardening for cryogenic applications and rolled threads before age hardening for elevated temperature applications.

7.3.6 30% Cold Reduced L605

The evaluation of cold reduced and unaged L605 indicates that fasteners of this material offer good potential for space vehicle applications. Material and bolt strength at -423°F was on the order of 350-370 ksi with good ductility. However, more work is required to develop optimum manufacturing methods.

A drawback for the cold reduced and unaged fasteners is the low yield to tensile ratio relationship at all temperatures. Initial attempts to age harden this material resulted in strain age cracking as shown in Figure 7.6. A sufficient quantity, however, did not show indications of cracks and they were used for the fastener evaluation.

Although the yield to ultimate tensile ratio was improved by aging the cold reduced material, the overall properties were not as good as those for the unaged fastener. Shear and tension impact properties were significantly lower and the fasteners were sensitive to minimal bending conditions at cryogenic temperatures. Ductility for the aged fasteners was markedly lower than for the unaged parts which may explain the low impact and shear properties.

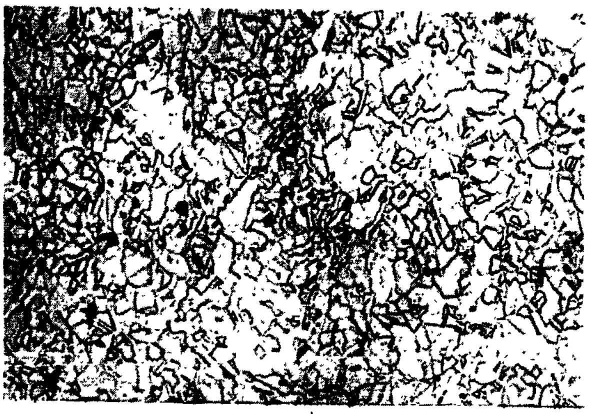
Thermal treatment prior to cold reduction may be a determining factor in whether the parts will crack after subsequent aging. The material used in the fabrication of fasteners was given a 2250°F solution treatment at the mill. An additional solution treatment of 2225°F prior to cold reduction, as used for the tension bolts, resulted in cracked parts after age hardening. The additional solution treatment of 2225°F was used because previous history in the manufacturing of L605 bolts at SPS employed this treatment. The cracks were not evident on the point drive bolts which were not subjected to 2225°F solution treatment. Photomicrostructures of tension and point drive bolts in the transverse and longitudinal direction are shown in Figure 7.7.

7.3.7 Ti 5Al-2.5Sn(ELI)

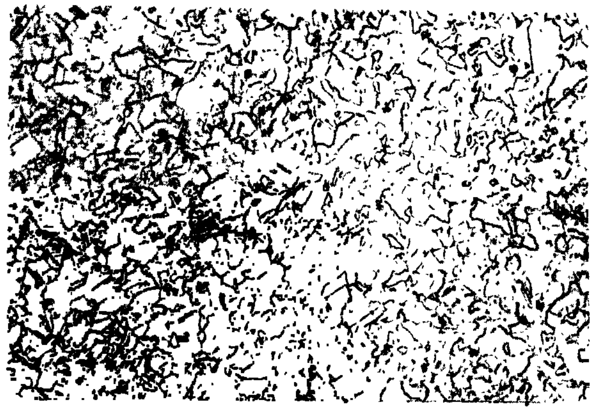
The fastener evaluation of Ti 5-2.5 (ELI) indicated that tension and semi blind fasteners of this material would be suitable for space vehicle cryogenic applications where weight reduction was a prime consideration. It was the only titanium alloy evaluated in the contract that was considered notch ductile at -423°F. Bolt and material tensile strength increased 100 percent at -423°F with a slight decrease in ductility.

Fastener strength of this material, however, is adversely affected by minimum bending conditions below -320°F. However, at temperatures of -320°F and higher, it is not affected; a trait which none of the other titanium fasteners exhibited. In any case, these fasteners should not be used below -320°F where excessive bending may be prevalent.

It should be noted that the tension fasteners were evaluated with silver plated locknuts. These nuts were selected before the results of a recent investigation by the Flight Propulsion Division of General Electric were published. The investigation showed that above 650°F, silver and silver chloride reduce the stress rupture life of Ti 5Al-2.5Sn alloy. The stress rupture properties for 100 hour life at 750°F for fasteners evaluated in this contract did not appear to be affected by the silver plated locknuts. However, on the basis of General Electric's investigation, caution should be exercised in the use of silver plated locknuts in conjunction with titanium fasteners. Also, unpublished SPS work with AgCl coatings on Ti bolts shows an adverse effect at 750°F under load.



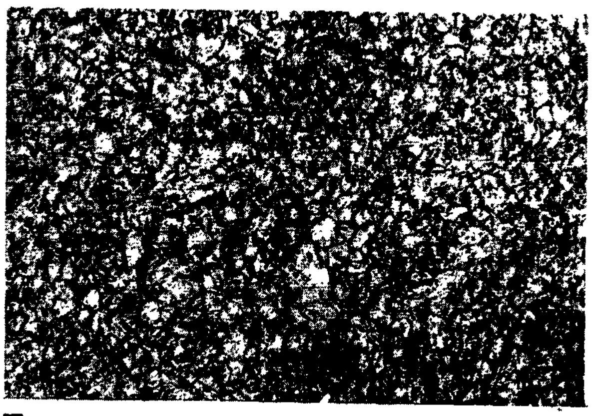
Transverse X100 Mag.



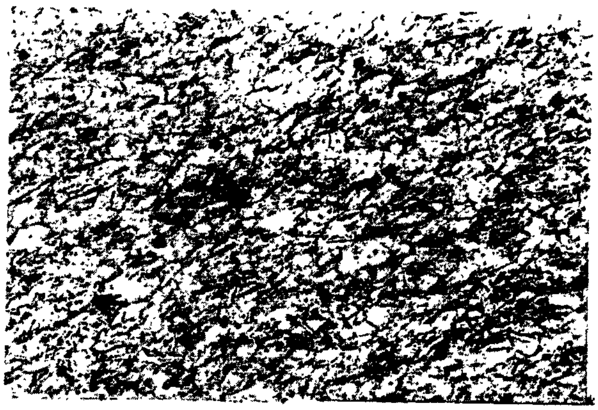
Longitudinal X100 Mag.

"As Received" Waspaloy - Solution Annealed - Hardness - Rb 97

Etchant: Electrolytic
29.7 grams citric acid
400 ML distilled H_2O



Transverse X100 Mag.



Longitudinal X100 Mag.

Solution treated - 1900°F - 1 hour, cold reduced 25 per cent and age hardened 1400°F - 16 hrs. air cooled - Hardness Rc 45-46.

Figure 7.5 Photomicrostructure of Waspaloy Material in the "As Received" and Cold-Reduced and Aged Condition.

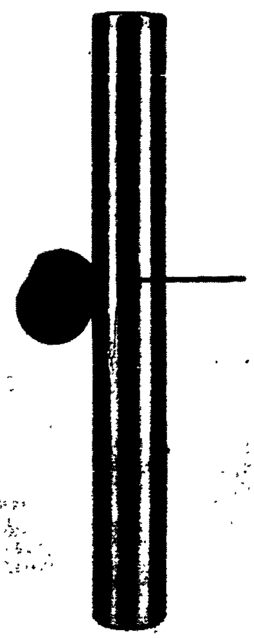
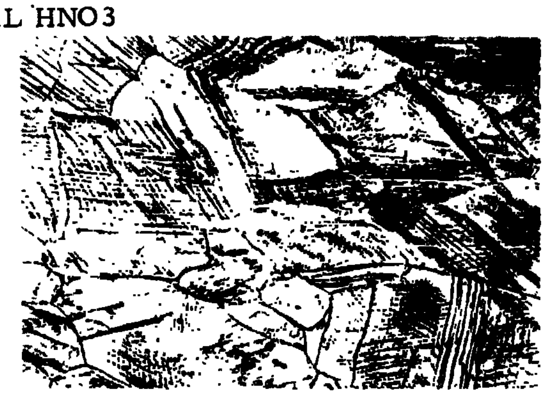


Figure 7.6 Photomacrograph of 30% Cold Reduced and Aged L605 (Haynes 25) Alloy

The material was solution treated at 2225°F for 1/2 hour and water quenched, cold extruded and then aged at 1100°F for 4 hours. The crack indicated by the arrow was not evident prior to aging.

Transverse X100 Mag. Longitudinal X100 Mag.

"As Received" L605 - Solution treated 2250°F 1/2 hr. water quenched.
Hardness Rb 98 Etchant: 92 ML HCl
5 ML H_2SO_4
3 ML HNO_3



Transverse X100 Mag. Longitudinal X100 Mag.

Cold reduced 30 per cent and age hardened 1100°F - 4 hrs. air cooled.
Hardness Rc 47
Fasteners manufactured with this process showed no indications of cracks after age hardening.

Transverse X100 Mag. Longitudinal X100 Mag.

Solution treated 2225°F 1/2 hr., cold reduced 30 per cent and aged 1100°F - 4 hrs. - Hardness Rc 47.
Fasteners manufactured with this process exhibited longitudinal cracks after age hardening.

Figure 7.7 Photomicrostructures of L605 Material in the "As-Received" and Cold-Reduced and Aged Conditions.

8.0 ENVIRONMENTAL CORROSION RESISTANCE PROPERTIES

Fasteners to be used for space vehicle applications will be subjected to environmental corrosive atmospheres particularly those encountered at the launching site. In some cases these vehicles may be exposed for as long as three months to a sea coast environmental atmosphere. For this reason, the corrosion resistance properties were determined under simulated conditions for the various fasteners evaluated when installed in space vehicle structural materials of 7075-T6 aluminum, 2014-T6 aluminum, 2219-T87 aluminum, annealed Ti 6Al-4V and annealed 321 stainless steel. The test procedures and equipment for this evaluation are listed in Appendix I.

A determined effort was made to correlate the results of sea coast environmental tests with those obtained under accelerated salt spray atmospheres. A definite correlation could not be made. In all cases where corrosion was noted at the sea coast, it was evident in a much shorter period of time during the salt spray tests. Where suspected stress corrosion occurred in tests conducted in 1964, none occurred in the 1965 program. Two failures were recorded from a combined total of over 300 tests. The failed material in both cases was 7075-T6 structural material which was tested under conditions not normally experienced in applications. Tables 8.1 through 8.4 list the results of all corrosion tests conducted over the two year period of the contract.

8.1 Discussion of Results

8.1.1 Iron Base Fasteners (Non Cres)

8.1.1.1 Aluminum Structural Material

Cadmium plated H-11 fasteners in cylinders of 2219 and 7075 aluminum with treated surfaces of a chemical conversion coating per Mil-C-5541 and an additional coating of zinc chromate primer showed good resistance to corrosion in both sea coast and accelerated salt spray atmospheres. There was no indications of fastener or cylinder corrosion after four months.

The same type of aluminum cylinders in the anodized condition showed evidence of corrosion after nine days in salt spray and ten weeks at the seacoast.

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8.1.1.2 321 Stainless Steel and Ti 6Al-4V Structural Material

Nickel plate afforded very little protection to H-11 fasteners against seacoast and salt spray atmospheres. Nickel plated H-11 fasteners installed in cylinders of 321 stainless steel and 6-4 titanium cylinder showed indications of red rust after one day in salt spray and two weeks at the sea coast.

8.1.2 Iron Base Fasteners (Cres)

8.1.2.1 Aluminum Structural Material

The best protection afforded aluminum structural material in conjunction with plated and unplated A-286 fasteners was with the surfaces of the aluminum treated per MIL-C-5541 and an additional coating of zinc chromate primer. The aluminum in conjunction with plated A-286 showed signs of corrosion after six days in salt spray and eight weeks at the sea coast, but no corrosion was noted with unplated semi-blind rivets after four months.

It should be noted that a galvanic reaction appears to occur with silver plated A-286. Red rust was noted on the A-286 nuts after one day in salt spray and two weeks at the shore location.

The corrosion resistance properties of aluminum structural material in conjunction with U-212 fasteners appears slightly better than those exhibited with the A-286 fasteners. The anodized and alodined 7075-T6 aluminum showed no indications of corrosion under the sea coast environment with U-212 fasteners.

8.1.2.2 Ti 6Al-4V Structural Material

The combination of bare Ti 6-4 cylinders and fasteners of A-286 or U-212 showed good resistance to corrosion. Red rust was noted at the bearing surface of cylinders installed with the A-286 fasteners after 2 1/2 months in the salt spray atmosphere.

8.1.3 Nickel Base Fasteners

8.1.3.1 Aluminum Structural Material

The corrosion resistance properties of the aluminum structural materials was essentially the same for all the nickel base fasteners tested in conjunction with them. Under sea coast environments, the tested aluminum materials showed excellent resistance to corrosion. Pitting of the anodized 2219-T87 aluminum material in conjunction with AF 1753 fasteners occurred

8.1.3.1 Aluminum Structural Material (continued)

after 120 days. This was the shortest period of time that corrosion was noted for any of the treated assemblies under these conditions.

It should be noted that the alodined and zinc chromate primer coated 7075-T6 cylinder installed with an AF 1753 fastener split after 30 days exposure in the accelerated salt spray atmosphere. Investigation of this cylinder indicated that failure was probably due to defective material in conjunction with the high seating load. A breakdown of the coating was not evident near the cracked surface which would rule out stress corrosion.

8.1.3.2 321 Stainless Steel Structural Material

A galvanic reaction was noted for all the nickel base fasteners installed in 321 stainless steel cylinders in both the sea coast and accelerated salt spray environments. In most instances the reaction was very minimal with very small deposits of red rust at the bearing surfaces. However, the reaction was more severe with Udimet 630 fasteners for the accelerated salt spray test. Heavy deposits of red rust were evident at the bearing surfaces.

8.1.3.3 Ti 6Al-4V Structural Material

The combination of nickel base fasteners installed in Ti 6-4 cylinders exhibited excellent corrosion resistance properties under both atmospheric conditions. Slight red rust was noted at the bearing surface of the cylinders installed with Udimet 630 fasteners. This was after 40 days exposure in salt spray and no indications were evident for the sea coast tests.

8.1.4 Titanium Base Fasteners

8.1.4.1 Aluminum Structural Material

Aluminum structural materials treated per MIL-C-5541 and then coated with zinc chromate primer exhibited excellent corrosion resistance properties in conjunction with titanium fasteners with a coating of zinc chromate primer and installed wet. Corrosion was not evident at the bearing surfaces in either atmosphere after 175 days. Indications of corrosion were noted at areas where the zinc chromate primer coating apparently chipped off leaving an exposed surface. This was noted for the accelerated salt spray tests but not for the sea coast tests.

The corrosion resistance of anodized aluminum could be considered fair but does not approach the corrosion resistance properties of the zinc chromate primer coated aluminum. Evidence of corrosion was noted after 30 days for the 7075-T6 material at the sea coast.

8.1.4.2 321 Stainless Steel Structural Material

The corrosion resistance properties of 321 stainless steel in conjunction with titanium fasteners was good. A slight reaction was noted at the bearing surfaces after 14 days in salt spray and 45 days at the shore location. This was noted for the Ti 5Al-5Sn-5Zr fasteners.

8.1.5 Cobalt Base Fasteners

The corrosion resistance properties of the various space vehicle structural materials installed with cold reduced L605 fasteners was the same as those reported for nickel base fasteners.

TABLE 8.1

RESULTS OF SEA COAST ENVIRONMENTAL CORROSION TESTS-1964

Fastener Material	Fastener Coating	Structural Material	Material Structural Coating	Remarks
AISI H-11	Bare	7075 Al	Bare	Heavy red rust on fastener after 2 weeks.
	Cadmium Plated	7075 Al	Mil-A-8625	Flaking of cadmium plate on bolt serration 16 weeks.
	Cadmium Plated	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	Flaking of cadmium plate on bolt serration 16 weeks.
	Bare	321 S/S	Bare	Heavy red rust on fastener after 2 weeks.
	Nickel Plated	321 S/S	Bare	Slight red rust on fastener after 2 weeks.
	Bare	Ti6Al-4V	Bare	Heavy red rust on fastener after 2 weeks.
	Nickel Plated	Ti6Al-4V	Bare	Slight red rust on fastener after 2 weeks.
Waspaloy	Bare	7075 Al	Bare	$Al(OH)_3$ at bearing surface of cylinder - 4 weeks.
	Cadmium Plated	7075 Al	Mil-A-8625	$Al(OH)_3$ at bearing surface of cylinder - 10 weeks.
	Cadmium Plated	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	Flaking of cadmium plate on nut serration - 12 weeks.
	Bare	2219 Al	Bare	$Al(OH)_3$ at bearing surface of cylinder - 2 weeks.
	Cadmium Plated	2219 Al	Mil-A-8625	$Al(OH)_3$ at bearing surface of cylinder - 6 weeks.
	Cadmium Plated	2219 Al	Mil-C-5541 & $ZnCr_2O_3$	$Al(OH)_3$ at bolt bearing surfaces of cylinder - 6 weeks.
	Bare	321 S/S	Bare	Slight red rust at bearing surfaces of cylinder - 10 weeks.
	Bare	Ti6Al-4V	Bare	No indications
Ti7Al-12Zr	Bare	7075 Al	Bare	$Al(OH)_3$ at bearing surface of cylinder - 2 weeks.
	Bare	7075 Al	Mil-A-8625	$Al(OH)_3$ at bearing surface of cylinder - 10 weeks.
	$ZnCr_2O_3$	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	No indications.
	Bare	2219 Al	Bare	$Al(OH)_3$ at bearing surface of cylinder - 4 weeks.
	Bare	2219 Al	Mil-A-8625	$Al(OH)_3$ at bearing surface of cylinder - 6 weeks.
	$ZnCr_2O_3$	2219 Al	Mil-C-5541 & $ZnCr_2O_3$	No indications.
	Bare	321 S/S	Bare	Red rust at head bearing surface - 6 weeks.
Ti6Al-4V	Bare	7075 Al	Bare	$Al(OH)_3$ at bearing surface - 8 weeks.
	Bare	7075 Al	Mil-A-8625	$Al(OH)_3$ at bearing surface - 8 weeks.
	$ZnCr_2O_3$	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	No indications.
	Bare	2219 Al	Bare	$Al(OH)_3$ at bearing surface - 4 weeks.
	Bare	2219 Al	Mil-A-8625	$Al(OH)_3$ at bearing surface - 4 weeks.
	$ZnCr_2O_3$	2219 Al	Mil-C-5541 & $ZnCr_2O_3$	No indications.
	Bare	321 S/S	Bare	Red rust at cylinder joint - 12 weeks.
A-286	Bare	7075 Al	Bare	$Al(OH)_3$ at bearing surface - 2 weeks.
Bolt	Cadmium Plated	7075 Al	Mil-A-8625	$Al(OH)_3$ at bearing surface - 2 weeks.
Bolt	Bare	7075 Al	Mil-A-8625	$Al(OH)_3$ at bearing surface - 2 weeks.
Bolt	Cadmium Plated	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	$Al(OH)_3$ at nut bearing surface - 8 weeks.
Rivet	Bare	7075 Al	Mil-A-8625	Failed in stress corrosion in 4 weeks.
Rivet	$ZnCr_2O_3$	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	No indications.
Rivet	Bare	Ti6Al-4V	Bare	Light red rust on swaged collar - 2 weeks.
Bolt	Bare	Ti6Al-4V	Bare	Light red rust on bolt serrations - 2 weeks.
Nut with 6-4 Ti	Silver Plated	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	Light red rust on nut - 4 weeks.
Nut with 7-12 Ti	Silver Plated	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	Light red rust on nut - 4 weeks.
2024 Al nut with 6-4 Ti bolt	Mil-A-8625	7075 Al	Mil-A-8625	$Al(OH)_3$ gelatin noted on twist off nut - 10 weeks.
	Nut / Bolt			
2024 Al nut with	Mil-A-8625 / $ZnCr_2O_3$	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	$Al(OH)_3$ gelatin noted on twist off nut - 16 weeks.
6-4 Ti bolt	Mil-A-8625 / $ZnCr_2O_3$	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	$Al(OH)_3$ gelatin noted on twist off nut - 16 weeks.
2024 Al nut with	Mil-A-8625 / Cad. Plate	7075 Al	Mil-A-8625	$Al(OH)_3$ gelatin noted on twist off nut - 10 weeks.
AISI 8740 bolt	Mil-A-8625 / Cad. Plate	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	$Al(OH)_3$ gelatin noted on twist off nut - 12 weeks.
Pure Ti	Bare	7075 Al	Bare	Light $Al(OH)_3$ at bearing surfaces - 2 weeks Apparent stress corrosion of cylinder - 14 weeks.
	Bare	7075 Al	Mil-A-8625	Same as Bare 7075 Al
	$ZnCr_2O_3$	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	No indications.
	Bare	2219 Al	Bare	Light $Al(OH)_3$ at bearing surfaces - 2 weeks.
	Bare	2210 Al	Mil-A-8625	Light $Al(OH)_3$ at bearing surface - 2 weeks.
	$ZnCr_2O_3$	2219 Al	Mil-C-5541 & $ZnCr_2O_3$	No indications.
	Bare	321 S/S	Bare	Red rust at bearing surface of S/S - 4 weeks.
U-212	Bare	7075 Al	Bare	$Al(OH)_3$ at bearing surface of cylinders - 2 weeks.
	Cd. Plated	7075 Al	Mil-A-8625	No indications.
	Cd. Plated	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	No indications.
	Bare	Ti6Al-4V	Bare	Light red rust at bearing surfaces - 8 weeks.
Ti1Al-8V-5Fe	Bare	7075 Al	Bare	$Al(OH)_3$ at bearing surface - 2 weeks - cylinder cracked -12wks
	Bare	7075 Al	Mil-A-8625	$Al(OH)_3$ at bearing surface - 4 weeks - cylinder cracked -14wks
	$ZnCr_2O_3$	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	No indications.
	Bare	321 S/S	Bare	Red rust at joint surface - 12 weeks.
Inco 718	Bare	7075 Al	Bare	$Al(OH)_3$ at bearing surface - 2 weeks.
	Cd. Plated	7075 Al	Mil-A-8625	No indications
	Cd. Plated	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	No indications
	Bare	Ti6Al-4V	Bare	No indications

Vasco Max. 300 - Results were similar to those of H-11 fasteners and structural material.

TABLE 8.2

RESULTS OF SEA COAST ENVIRONMENTAL CORROSION TESTS-1965

Fastener Material	Test No.	Fastener Coating	Structural Material	Structural Material Coating	Hours Exposed	Weight Grams Before	Weight Grams After	Seating Torque In-Lbs.	Remarks
Ti 8-1-1 & A-286 Locknut	135	Bare	Al 7075-T6	Bare	4104	20.50	20.48	60	Slight indication of cylinder corrosion after fourteen days.
	137	Bare	"	Anodized Mil-A-8625	4104	20.52	20.48	60	Slight indication of cylinder corrosion after thirty days.
	139	$ZnCr_2O_3$ Wet	"	Mil-C-5541 $ZnCr_2O_3$	4104	20.97	21.10	60	No indication of corrosion except for red rust on silver plated A-286 after fourteen days.
	141	Bare	Al 2219-T87		4104	24.09	24.10	60	Slight indication of cylinder corrosion after fourteen days.
	143	Bare	"	Anodized Mil-A-8625	4104	23.52	23.72	60	Very slight indications of cylinder corrosion at nut bearing surface after fourteen days.
	145	$ZnCr_2O_3$ Wet	"	Mil-C-5541 $ZnCr_2O_3$	4104	24.16	24.20	60	No indications.
	147	Bare	Al 2014-T6	Bare	4104	20.38	20.48	60	Very slight indications of cylinder corrosion at nut bearing surface after fourteen days.
	149	Bare	"	Anodized Mil-A-8625	4104	20.56	20.52	60	Slight indications of corrosion cylinder at nut bearing surface after thirty days.
	151	$ZnCr_2O_3$ Wet	"	Mil-C-5541 $ZnCr_2O_3$	4104	20.78	20.75	60	No indications.
	153	Bare	321 S/S	Bare	4104	46.27	46.28	60	Slight indication of red rust at head bearing surface after forty-five days.
Rene 41 & Waspaloy Locknut	155	Bare	Al 7075-T6	Bare	4104	25.86	25.98	62.5	Slight indication of cylinder corrosion at bearing surface after fourteen days.
	157	Cad. Plate	"	Anodized Mil-A-8625	4104	25.98	[illegible]	[illegible]	Cadmium plate flaking after one-hundred and thirty-five days.
	159	Cad. Plate	"	Mil-C-5541 $ZnCr_2O_3$	4104	26.09	26.08	[illegible]	No indications.
	161	Bare	Al 2219-T87	Bare	4104	29.37	29.38	62.5	Slight indication of cylinder corrosion : bearing surface after fourteen days.
	163	Cad. Plate	"	Anodized Mil-A-8625	4104	29.08	29.12	62.5	Cadmium plate on nut flaking after forty-five days.
	165	Cad. Plate	"	Mil-C-5541 $ZnCr_2O_3$	4104	29.52	29.45	62.5	No indications.
	167	Bare	Al 2014-T6	Bare	4104	[illegible]	25.98	[illegible]	Slight indication of cylinder corrosion at bearing surfaces after fourteen days.
	169	Cad. Plate	"	Anodized Mil-A-8625	4104	25.82	25.88	62.5	Very slight indication of cylinder corrosion at nut bearing surface after one-hundred thirty five days.
	171	Cad. Plate	"	Mil-C-5541 $ZnCr_2O_3$	4104	26.06	26.20	62.5	No indications.
	173	Bare	321 S/S	Bare	4104	51.01	51.28	62.5	Slight indication of red rust at nut bearing surface after sixty days.
	175	Bare	Ti	Bare	4104	35.59	35.45	62.5	No indications.
Ti 5Al-2.5Sn & 2024-T4 Aluminum Nut	177	Bare	Al 7075-T6	Bare	4104	14.09	14.10	28	Slight indication of cylinder corrosion at bearing surfaces after fourteen days.
	179	Bare	"	Anodized Mil-A-8625	4104	14.00	14.02	27	Indication of corrosion at break-off surface of twist-off nut after thirty days.
	181	$ZnCr_2O_3$ Wet	"	Mil-C-5541 $ZnCr_2O_3$	4104	14.33	14.30	33	No indications.
	183	Bare	Al 2219-T87	Bare	4104	16.48	16.42	28	Slight indication of cylinder corrosion at bearing surfaces after fourteen days.
	185	Bare	"	Anodized Mil-A-8625	4104	16.18	16.28	29	Indication of corrosion at break-off surface of twist-off nut after thirty days.
	187	$ZnCr_2O_3$ Wet	"	Mil-C-5541 $ZnCr_2O_3$	4104	16.52	16.50	29	No indications.
	189	Bare	Al 2014-T6	Bare	4104	13.83	14.02	27	Slight indications of cylinder corrosion at bearing surfaces after fourteen days.
	191	Bare	"	Anodized Mil-A-8625	4104	13.90	13.98	28	Indication of corrosion at break-off surface of twist-off nut after forty-five days.
	193	$ZnCr_2O_3$ Wet	"	Mil-C-5541 $ZnCr_2O_3$	4104	14.26	14.22	27	No indications.
	195	Bare	321 S/S	Bare	4104	32.55	32.68	29	Indications of corrosion at break-off surface of twist-off nut after thirty days.
Waspaloy	197	Bare	Al 2014-T6	Bare	4104	18.09	17.78	52	Slight indication of cylinder corrosion at bearing surface after fourteen days.
	199	Cad. Plate	"	Anodized Mil-A-8625	4104	17.74	17.85	90	Blistering of Cadmium Plate after ninety days
	201	Cad. Plate	"	Mil-C-5541 $ZnCr_2O_3$	4104	17.92	17.72	65	No indications.

TABLE 8.2 (continued)

RESULTS OF SEA COAST ENVIRONMENTAL CORROSION TESTS-1965

Fastener Material	Test No.	Fastener Coating	Structural Material	Structural Material Coating	Hours Exposed	Weight Grams Before	Weight Grams After	Seating Torque In-Lbs.	Remarks
Ti 5Al 5Sn 5Zr	203	Bare	Al 7075-T6	Bare	4104	26.60	26.42	200	Slight indications of cylinder corrosion after fourteen days.
	205	Bare	"	Anodized Mil-A-8625	4104	26.59	26.32	200	Indications of cylinder corrosion at bearing surface after ninety days.
	207	$ZnCr_2O_3$ Wet	"	Mil-C-5542 $ZnCr_2O_3$	4104	26.84	26.78	200	No indications.
	209	Bare	Al 2219-T87	Bare	4104	30.00	29.72	200	Same as 205.
	211	Bare	"	Anodized Mil-A-8625	4104	29.42	29.22	200	Same as 205.
	213	$ZnCr_2O_3$ Wet	"	Mil-C-5541 $ZnCr_2O_3$	4104	30.40	30.38	200	No indications.
	215	Bare	Al 2014-T6	Bare	4104	26.65	26.42	200	Same as 203.
	217	Bare	"	Anodized Mil-A-8625	4104	26.49	26.25	200	Same as 205.
	219	$ZnCr_2O_3$ Wet	"	Mil-C-5541 $ZnCr_2O_3$	4104	27.00	26.38	200	No indications.
	221	Bare	321 S/S	Bare	4104	48.38	48.18	200	Indications of red rust at bearing surfaces after forty-five days.
AF 1753	223	Bare	Al 7075-T6	Bare	4104	37.99	37.98	175	Slight indications of cylinder corrosion at bearing surface after fourteen days.
	225	Cad. Plate	"	Anodized Mil-A-8625	4104	38.60	38.58	175	No indications.
	227	Cad. Plate	"	Mil-C-5541 $ZnCr_2O_3$	4104	38.95	38.72	175	No indications.
	229	Bare	Al 2219-T87	Bare	4104	41.5	41.5	175	Same as 223.
	231	Cad. Plate	"	Anodized Mil-A-8625	4104	41.71	41.62	175	Slight indication of cylinder pitting after one-hundred twenty days.
	233	Cad. Plate	"	Mil-C-5541 $ZnCr_2O_3$	4104	42.16	42.05	175	No indications.
	235	Bare	Al 2014-T6	Bare	4104	38.53	38.35	175	Same as 223.
	237	Cad. Plate	"	Anodized Mil A-8625	4104	38.62	38.40	175	No indications.
	239	Cad. Plate	"	Mil-C-5541 $ZnCr_2O_3$	4104	38.81	38.62	175	No indications.
	241	Bare	321 S/S	Bare	4104	60.21	60.08	175	Slight indications of red rust at bearing surfaces after ninety days.
	243	Bare	6-4 Ti	Bare	4104	46.91	46.58	175	No indications.
Udimet 630	245	Bare	Al 7075-T6	Bare	4104	30.72	30.78	175	Slight indication of cylinder corrosion at bearing surfaces after fourteen days.
	247	Cad. Plate	"	Anodized Mil-A-8625	4104	31.86	31.80	175	No indications.
	249	Cad. Plate	"	Mil-C-5541 $ZnCr_2O_3$	4104	31.99	31.92	175	No indications.
	251	Bare	Al 2219-T87	Bare	4104	34.55	34.28	175	Same as 245.
	253	Cad. Plate	"	Anodized Mil-A-8625	4104	34.37	34.05	175	No indications.
	255	Cad. Plate	"	Mil-C-5541 $ZnCr_2O_3$	4104	34.69	34.48	175	No indications.
	257	Bare	Al 2014-T6	Bare	4104	31.94	31.65	175	Same as 245.
	259	Cad. Plate	"	Anodized Mil-A-8625	4104	32.13	32.02	175	No indications.
	261	Cad. Plate	"	Mil-C-5541 $ZnCr_2O_3$	4104	32.33	31.85	175	No indications.
	263	Bare	321 S/S	Bare	4104	47.03	47.05	175	Indications of red rust at bearing surfaces after ninety days.
	265	Bare	6-4 Ti	Bare	4104	36.91	[illegible]	175	No indications.
L605	267	Bare	Al 7075-T6	Bare	4104	31.89	31.62	175	Slight indications of cylinder corrosion at bearing surfaces after fourteen days.
	269	Cad. Plate	"	Anodized Mil-A-8625	4104	31.82	31.88	175	No indications.
	271	Cad. Plate	"	Mil-C-5541 $ZnCr_2O_3$	4104	32.09	31.72	175	No indications.
	273	Bare	Al 2219-T87	Bare	4104	33.80	33.72	175	Same as 267.
	275	Cad. Plate	"	Anodized Mil-A-8625	4104	33.80	33.52	175	No indications.
	277	Cad. Plate	"	Mil-C-5541 $ZnCr_2O_3$	4104	34.27	34.08	175	No indications
	279	Bare	Al 2014-T6	Bare	4104	31.81	[illegible]	175	Same as 267.
	281	Cad. Plate	"	Anodized Mil-A-8625	4104	31.39	31.85	175	No indications.
	283	Cad. Plate	"	Mil-C-5545 $ZnCr_2O_3$	4104	31.93	31.72	175	No indications.
	285	Bare	321 S/S	Bare	4104	[illegible]	44.92	175	Indications of red rust at bearing surfaces after ninety days.
	287	Bare	6-4 Ti	Bare	4104	36.80	36.65	175	No indications.

TABLE 8.3

RESULTS OF ACCELERATED SALT SPRAY (5% NaCl) CORROSION TESTS - 1964

Fastener Material	Fastener Coating	Structural Material	Structural Material Coating	Remarks
AISI H-11	Bare	7075 Al	Bare	Heavy red rust on bolt and nut - one day.
	Cadmium Plated	7075 Al	Mil-A-8625	Al $(OH)_3$ on end of cylinder - 9 days.
	Cadmium Plated	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	Nut turning black - 9 days.
	Bare	321 S/S	Bare	Heavy red rust on bolt and nut - one day.
	Nickel Plated	321 S/S	Bare	Red rust or bolt threads - one day.
	Bare	Ti6Al-4V	Bare	Heavy red rust on bolt and nut - one day.
	Nickel Plated	Ti6Al-4V	Bare	Red rust on bolt threads - one day.
Waspaloy	Bare	7075 Al	Bare	Al $(OH)_3$ gelatin at bearing surface - one day.
	Cadmium Plated	7075 Al	Mil-A-8625	Al $(OH)_3$ gelatin at bearing surface - 4 weeks.
	Cadmium Plated	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	Discoloration at bearing surface - light $Al(OH)_3$ 8 weeks.
	Bare	2219 Al	Bare	Al $(OH)_3$ gelatin at bearing surface - one day.
	Cadmium Plated	2219 Al	Mil-A-8625	Al $(OH)_3$ gelatin at bearing surface - 7 days.
	Cadmium Plated	2219 Al	Mil-C-5541 & $ZnCr_2O_3$	Discoloration at bearing surface - light $Al(OH)_3$ - 4 weeks.
	Bare	321 S/S	Bare	Discoloration at bearing surface - 8 days.
	Bare	Ti6Al-4V	Bare	Discoloration at bearing surface - 8 days.
Ti7Al-12Zr	Bare	7075 Al	Bare	$Al(OH)_3$ at bearing surface - one day.
	Bare	7075 Al	Mil-A-8625	$Al(OH)_3$ at bearing surface - 4 days.
	$ZnCr_2O_3$	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	$Al(OH)_3$ at bearing surface - 8 days.
	Bare	2219 Al	Bare	$Al(OH)_3$ at bearing surface - one day.
	Bare	2219 Al	Mil-A-8625	$Al(OH)_3$ at bearing surface - one day.
	$ZnCr_2O_3$	2219 Al	Mil-C-5541 & $ZnCr_2O_3$	No Indications
	Bare	321 S/S	Bare	
Ti6Al-4V	Bare	7075 Al	Bare	$Al(OH)_3$ at bearing surface - one day.
	Bare	7075 Al	Mil-A-8625	$Al(OH)_3$ at bearing surface - 3 days.
	$ZnCr_2O_3$	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	No indications of $Al(OH)_3$ - head discoloration - 6 weeks
	Bare	2219 Al	Bare	$Al(OH)_3$ at bearing surface - one day.
	Bare	2219 Al	Mil-A-8625	$Al(OH)_3$ at bearing surface - one day.
	$ZnCr_2O_3$	2219 Al	Mil-C-5541 & $ZnCr_2O_3$	No indication of $Al(OH)_3$
	Bare	321 S/S	Bare	
A-286	Bare	7075Al	Bare	$Al(OH)_3$ gelatin at bearing surface - 3 days.
Bolt	Cadmium Plated	7075 Al	Mil-A-8625	$Al(OH)_3$ gelatin at bearing surface - 3 days.
Bolt	Bare	7075 Al	Mil-A-8625	
Bolt	Cadmium Plated	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	$Al(OH)_3$ at nut bearing surface - 6 days.
Rivet	Bare	7075 Al	Mil-A-8625	$Al(OH)_3$ at bearing surfaces - 2 days.
Rivet	$ZnCr_2O_3$	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	Slight indication of $Al(OH)_3$ - 4 weeks no heavier - 12 weeks.
Rivet	Bare	Ti6Al-4V	Bare	Light red rust on head - one day - remove after one month.
Bolt	Bare	Ti6Al-4V	Bare	Light red rust on nut - 3 days - no change - 6 weeks.
Nut with 6-4Ti bolt	Silver Plate	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	Slight red rust on nut - 3 days.
Nut with 7-12 Ti bolt	Silver Plate	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	Slight red rust on nut - one day.
2024 Al with 6-4 Ti Bolt	Mil-A-8625 (Nut); Bolt	7075 Al	Mil-A-8625	$Al(OH)_3$ gelatin on twist off nut - one day.
2024 Al with 6-4 Ti Bolt	Mil-A-8625 $ZnCr_2O_3$; Mil-A-8625 $ZnCr_2O_3$	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	$Al(OH)_3$ gelatin on twist off nut - 6 weeks.
2024 Al nut with AISI8740 Bolt	Mil-A-8625 Cd. Plate	7075 Al	Mil-A-8625	$Al(OH)_3$ gelatin on twist off nut - 8 days.
	Mil-A-8625 Cd. Plate	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	$Al(OH)_3$ gelatin on twist off nut - 9 days.
Pure Ti	Bare	7075 Al	Bare	$Al(OH)_3$ gelatin at bearing surface - one day.
	Bare	7075 Al	Mil-A-8625	$Al(OH)_3$ gelatin on bearing surface - 2 days.
	$ZnCr_2O_3$	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	No indications
	Bare	2219 Al	Bare	$Al(OH)_3$ gelatin at bearing surface - 3 days.
	Bare	2219 Al	Mil-A-8625	$Al(OH)_3$ gelatin at bearing surface - 3 days.
	Zn Cr_2O_3	2219 Al	Mil-C-5541 & $ZnCr_2O_3$	No indications
	Bare	321 S/S	Bare	Red rust at bearing surface - 7 weeks.
U-212	Bare	7075 Al	Bare	$Al(OH)_3$ gelatin at bearing surface - one day.
	Cd. Plated	7075 Al	Mil-A-8625	Discoloration of bolt head - one week.
	Cd. Plated	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	Discoloration of bolt head - one week.
	Bare	Ti6Al-4V	Bare	Red rust on nut and bolt - 7 days.
Ti1Al-8V-5Fe	Bare	7075 Al	Bare	$Al(OH)_3$ gelatin at bearing surface - one day.
	Bare	7075 Al	Mil-A-8625	$Al(OH)_3$ gelatin at bearing surface - 5 days.
	$ZnCr_2O_3$	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	No indications.
	Bare	321 S/S	Bare	No indications.
Inco 718	Bare	7075 Al	Bare	$Al(OH)_3$ gelatin at bearing surface - one day.
	Cd. Plated	7075 Al	Mil-A-8625	Discoloration at bearing surfaces - no other indications.
	Cd. Plated	7075 Al	Mil-C-5541 & $ZnCr_2O_3$	Flaking of Cd. Plate - 7 weeks.
	Bare	Ti6Al-4V	Bare	Slight red rust at joints - 14 days.

Vasco Max. 300 - Results were similar to those of H-11 fasteners and structural material.

TABLE 8.4

RESULTS OF ACCELERATED SALT SPRAY (5% NaCl) CORROSION TESTS - 1965

Fastener Material	Test No.	Fastener Coating	Structural Material	Structural Material Coating	Hours Exposed	Weight Grams Before	Weight Grams After	Seating Torque In-Lbs.	Remarks
Ti 8-1-1 & A-286 Locknut	136	Bare	Al 7075-T6	Bare	696	20.52	20.40	60	Indication of cylinder corrosion after one day.
	138	Bare	"	Anodized Mil-A-8625	696	20.39	20.14	60	Corrosion of cylinder at bearing surface after five days.
	140	$ZnCr_2O_3$ Wet	"	Mil-C-5541 $ZnCr_2O_3$	4200	20.99	21.00	60	Slight indication of cylinder corrosion after sixty-nine days.
	142	Bare	Al 2219-T87	Bare	696	23.90	23.60	60	Indication of cylinder corrosion after one day.
	144	Bare	"	Anodized Mil-A-8625	696	23.57	23.47	60	Corrosion of cylinder at bearing surface after two days.
	146	$ZnCr_2O_3$ Wet	"	Mil-C-5541 $ZnCr_2O_3$	4200	24.43	24.50	60	Slight red rust of silver plated A-286 nut after twenty days.
	148	Bare	Al 2014-T6	Bare	696	20.47	20.32	60	Indication of cylinder corrosion after one day.
	150	Bare	"	Anodized Mil-A-8625	696	20.38	20.16	60	Corrosion of cylinder at bearing surface after six days.
	152	$ZnCr_2O_3$ Wet	"	Mil-C-5541 $ZnCr_2O_3$	4200	21.03	20.92	60	Slight red rust of silver plated A-286 nut after twenty days.
	154	Bare	32/ S/S	Bare	696	44.74	44.68	60	Red rust on A-286 nut after three days.
Rene 41 & Waspaloy Locknut	156	Bare	Al 7075-T6	Bare	696	25.87	25.78	62.5	Indication of cylinder corrosion after one day.
	158	Cad. Plate	"	Anodized Mil-A-8625	4200	25.83	26.02	62.5	Corrosion of cylinder at bearing surface after fourteen days.
	160	Cad. Plate	"	Mil-C-5541 $ZnCr_2O_3$	4200	26.00	26.12	62.5	No indications.
	162	Bare	Al 2219-T87	Bare	696	29.23	29.19	62.5	Corrosion of cylinder after one day.
	164	Cad. Plate	"	Anodized Mil-A-8625	4200	29.10	24.20	62.5	Corrosion of cylinder at bearing surface after fourteen days.
	166	Cad. Plate	"	Mil-C-5541 $ZnCr_2O_3$	4200	29.63	29.78	62.5	No indications.
	168	Bare	Al 2014-T6	Bare	696	25.90	25.65	62.5	Corrosion of cylinder after one day.
	170	Cad. Plate	"	Anodized Mil-A-8625	4200	25.81	25.85		Flaking and blistering of plating after forty-four days.
	172	Cad. Plate	"	Mil-C-5541 $ZnCr_2O_3$	4200	26.14	26.18	62.5	No indications.
	174	Bare	321 S/S	Bare	4200	51.02	51.20	62.5	Slight red rust at bearing surface after thirty-seven days.
	176	Bare	6-4 Ti	Bare	4200	35.58	35.60	62.5	No indications.
Ti 5Al-2.5Sn & 2024-T4 Aluminum Nut	178	Bare	Al 7075-T6	Bare	4200	13.81	13.90	30	Corrosion of cylinder after one day.
	180	Bare	"	Anodized Mil-A-8625	4200	14.02	14.10	27	Corrosion of cylinder after six days.
	182	$ZnCr_2O_3$ Wet	"	Mil-C-5541 $ZnCr_2O_3$	4200	14.33	14.30	30	No indications.
	184	Bare	Al 2219-T87	Bare	864	16.33	16.43	28	Corrosion of cylinder after one day.
	186	Bare	"	Anodized Mil-A-8625	4200	16.12	16.28	33	Corrosion of cylinder after six days.
	188	$ZnCr_2O_3$ Wet	"	Mil-C-5541 $ZnCr_2O_3$	4200	16.45	16.32	30	Slight corrosion of nut after thirty-three days.
	190	Bare	Al 2014-T6	Bare	696	14.02	13.79	28	Corrosion of cylinder after one day.
	192	Bare	"	Anodized Mil-A-8625	4200	13.80	13.82	29	Corrosion of cylinder after one day.
	194	$ZnCr_2O_3$ Wet	"	Mil-C-5541 $ZnCr_2O_3$	4200	14.27	14.17	28	Slight corrosion of nut after forty-one days.
	196	Bare	321 S/S	Bare	816	32.72	32.78	28	Corrosion of nut after fourteen days.
Waspaloy	198	Bare	Al 2014-T6	Bare	696	17.68	17.51	49	Corrosion of cylinders after one day.
	200	Cad. Plate	"	Anodized Mil-A-8625	4200	17.57	17.62	75	Corrosion of cylinder after fifty days.
	202	Cad. Plate	"	Mil-C-5541 $ZnCr_2O_3$	4200	18.19	18.00	75	No indications.

TABLE 8. 4 (continued)

RESULTS OF ACCELERATED SALT SPRAY (5% NaCl) CORROSION TESTS - 1965

Fastener Material	Test No.	Fastener Coating	Structural Material	Structural Material Coating	Hours Exposed	Weight Grams Before	Weight Grams After	Seating Torque In-Lbs.	
Ti 5Al-5Sn 5Zr	204	Bare	Al 7075-T6	Bare	984	26.60	26.28	200	Corrosion of cylinder after one day.
	206	Bare	"	Anodized Mil-A-8625	984	26.64	26.40	200	Corrosion of cylinder after three days.
	208	Zr Cr_2O_3 Wet	"	Mil-C-5541 Zn Cr_2O_3	4200	26.73	26.82	200	Corrosion of cylinder because coating chipped off after 60 days.
	210	Bare	Al 2219-T87	Bare	864	29.70	29.50	200	Corrosion of cylinder after one day.
	212	Bare	"	Anodized Mil-A-8625	864	29.50	29.18	200	Corrosion of cylinder after two days.
	214	Zn Cr_2O_3 Wet	"	Mil-C-5541 Zn Cr_2O_3	4200	30.50	30.58	200	Corrosion of cylinder after forty-three days because coating was chipped.
	216	Bare	Al 2014-T6	Bare	864	26.89	26.45	200	Corrosion of cylinder after one day.
	218	Bare	"	Anodized Mil-A-8625	864	26.49	26.27	200	Corrosion of cylinder after two days.
	220	Zn Cr_2O_3 Wet	"	Mil-C-5541 Zn Cr_2O_3	4200	27.20	27.18	200	Corrosion of cylinder after sixty days where coating was chipped.
	222	Bare	321 S/S	Bare	696	47.88	47.50	200	Red rust at bearing surfaces after fourteen days.
AF 1753	224	Bare	Al 7075-T6	Bare	4200	38.20	38.27	175	Corrosion of cylinder after one day.
	226	Cad. Plate	"	Anodized Mil-A-8625	4200	38.63	38.70	175	Corrosion of cylinder after seven days.
	228	Cad. Plate	"	Mil-C-5541 $ZnCr_2O_3$	840	38.69	38.50	175	Cylinder split after thirty days - believed to be defective material.
	230	Bare	Al 2219-T87	Bare	984	41.79	41.82	175	Corrosion of cylinder after one day.
	232	Cad. Plate	"	Anodized Mil-A-8625	4200	41.35	41.50	175	Corrosion of cylinder after seven days.
	234	Cad. Plate	"	Mil-C-5541 $ZnCr_2O_3$	4200	42.02	41.95	175	No indications.
	236	Bare	Al 2014-T6	Bare	864	38.62	38.62	175	Corrosion of cylinder after one day.
	238	Cad. Plate	"	Anodized Mil-A-8625	4200	38.50	38.60	175	Corrosion of Cylinder after seven days.
	240	Cad. Plate	"	Mil-C-5541 $ZnCr_2O_3$	4200	38.70	38.60	175	No indications.
	242	Bare	321 S/S	Bare	4200	60.40	60.55	175	Red rust at bearing surface after thirty-three days.
	244	Bare	6-4 Ti	Bare	4200	46.56	46.50	175	Slight indication of red rust at bolt point and head after thirty-three days.
Unimet 630	246	Bare	Al 7075-T6	Bare	4200	31.52	31.38	175	Corrosion of cylinders after one day.
	248	Cad. Plate	"	Anodized Mil-A-8625	4200	32.20	32.22	175	Corrosion of cylinder after three days.
	250	Cad. Plate	"	Mil-C-5541 $ZnCr_2O_3$	4200	31.61	31.78	175	No indications.
	252	Bare	Al 2219-T87	Bare	984	34.32	34.29	175	Corrosion of cylinder after one day.
	254	Cad. Plate	"	Anodized Mil-A-8625	4200	34.22	34.35	175	Corrosion of cylinder after six days.
	256	Cad. Plate	"	Mil-C-5541 $ZnCr_2O_3$	4200	34.70	34.70	175	No indications
	258	Bare	Al 2014-T6	Bare	4200	30.63	30.25	175	Corrosion of cylinder after one day.
	260	Cad. Plate	"	Anodized Mil-A-8625	4200	32.21	32.12	175	Corrosion of cylinder after six days.
	262	Cad. Plate	"	Mil-C-5541 $ZnCr_2O_3$	4200	32.20	32.25	175	No indications.
	264	Bare	321 S/S	Bare	3888	46.63	46.57	175	Indications of red rust at bearing surfaces after fourteen days.
	266	Bare	6-4 Ti	Bare	4200	36.73	36.85	175	Indications of red rust at bearing surfaces after forty days.
L605	268	Bare	Al 7075-T6	Bare	4200	31.73	31.76	175	Corrosion of cylinder after one day.
	270	Cad. Plate	"	Anodized Mil-A-8625	4200	31.80	31.95	175	Corrosion of cylinder after two days.
	272	Cad. Plate	"	Mil-C-5541 $ZnCr_2O_3$	4200	32.10	32.20	175	No indications.
	274	Bare	Al 2219-T87	Bare	984	33.57	33.46	175	Corrosion of cylinder after one day.
	276	Cad. Plate	"	Anodized Mil-A-8625	4200	34.18	34.38	175	Corrosion of cylinder after six days.
	278	Cad. Plate	"	Mil-C-5541 $ZnCr_2O_3$	4200	33.92	34.00	175	Corrosion of cylinder at sharp corner where coating chipped off - twenty-two days.
	280	Bare	Al 2014-T6	Bare	840	31.39	31.55	175	Corrosion of cylinder after one day.
	282	Cad. Plate	"	Anodized Mil-A-8625	4200	31.73	31.78	175	Corrosion of cylinder after six days.
	284	Cad. Plate	"	Mil-C-5541 $ZnCr_2O_3$	4200	31.84	31.90	175	Corrosion of cylinder where coating chipped off - forty-four days.
	286	Bare	321 S/S	Bare	4200	45.24	45.23	175	Red rust at bearing surface after fourteen days.
	288	Bare	6-4 Ti	Bare	4200	36.80	37.20	175	Slight discoloration at bearing surfaces after seventy days.

9.0 FASTENER TESTS FOR UNIQUE SPACE VEHICLE APPLICATIONS

One of the objectives of the program was to determine, through the survey, what special tests were required to insure reliability in fasteners to be used in the unique conditions experienced by space vehicles. The tests were then to be conducted, and if the tests were significant, to be suggested for incorporation into either new or existing specifications.

From the survey it was determined that space vehicles as presently conceived, would encounter several load conditions and environments not generally experienced by commercial machinery or aircraft. Some of these are:

a. Severe cryogenic temperature to -423° F
b. Extremely fast rate of heating and cooling
c. Outer space conditions of vacuum, magnetic fields and radiation.

The net result was that the following were suggested for detailed investigation.

a. Mechanical properties of fastener shear and tensile strength at liquid hydrogen temperatures of -423° F.
b. Effects of bending stresses on bolt properties at cryogenic temperatures.
c. Impact properties at cryogenic temperatures.
d. Vibration of loaded nut-bolt combination at -320° F.
e. Tension-tension fatigue at room temperature.
f. Effects of thermal cycling at cryogenic temperatures on the mechanical properties of fasteners.
g. Effects of thermal cycling at elevated temperature on the mechanical properties of fasteners.
h. Stress rupture properties at elevated temperatures.
i. Stress relaxation properties at elevated temperatures.
j. Nut reusability
k. Stress corrosion properties
l. Effects of radiation and vacuum

9.1 Discussion of Work Accomplished

The suggested areas for investigation were completed with the exception of radiation and vacuum effects which were not part of the contract.

9.1.1 Mechanical Properties at -423°F

The tensile, yield and shear strengths of all the fastener combinations and their base alloys were determined at -423°F in liquid hydrogen. The value of these tests was demonstrated by the variations in results. In cases of severe embrittlement, all strength values fell below those at room temperature. And where there was no indication of embrittlement, the properties at -423°F increased over those at room temperature.

In addition to these two clear cut cases, some fasteners showed an increased tensile strength at -423°F while the shear strength at the same temperature decreased below room temperature properties. The conclusion is that fasteners to be utilized at -423°F should be inspection tested at -423°F in tensile and shear. Requirements based on statistical sampling should be added to existing specifications.

9.1.2 Effects of Bending Stresses on Bolt Tensile Properties at Cryogenic Temperatures

The effects of bending stresses on bolt tensile properties were determined at -320°F and -423°F. The bending stresses were obtained by placing a 3° angle bushing at the nut bearing surface of the tension fasteners. This test closely approximates the wedge test called out in ASTM test method standard. The significance of this test can readily be seen in Charts 8.1 through 8.14. These charts show the wide discrepancies in tensile results between fasteners of one base alloy group compared to those of another group. In cases where the fasteners were adversely affected by the bending conditions at -423°F the tensile strength decreased below that of the room temperature axial strength. This was especially noted for the H-11 and titanium base fasteners which are shown in Charts 8.1 and 8.9 through 8.13 respectively.

Iron base (CRES) and nickel base fasteners were insensitive to the bending conditions encountered in this test at -320°F and were slightly sensitive at -423°F. Since these slight decreases were noted with a 3° angle and the angle encountered in service may be greater, further work in this area should be conducted for these fasteners to determine the angle at which a significant decrease in strength is noted.

From these results, it can be concluded that fasteners to be used for cryogenic applications should be inspection tested for angle block tensile properties at cryogenic temperatures employing an angle that would be encountered in service.

9.1.3 Tension Impact Properties at Cryogenic Temperatures

From the work concluded in the test program, it appears that the fastener design, heat treatment and thread rolling sequence affect the tension impact properties of fasteners at cryogenic temperatures. Charts 8.15 through 8.18 summarize the results of tension impact tests conducted in the program.

In design, Chart 8.17 shows that the tension impact properties of cold reduced waspaloy studs were significantly higher than those of bolts fabricated from the same reduced material, particularly at -320°F and -423°F.

In the case of heat treatment, Chart 8.17 shows that bolts of cold reduced L605 had higher impact properties in the unaged condition than in the aged condition.

And in thread rolling sequence, Chart 8.15 shows that the tension impact properties of U-212 bolts were substantially higher with rolled threads after age hardening than with rolled threads before age hardening.

Therefore, since the design, heat treatment, and thread rolling sequence do have an effect on the cryogenic properties of fasteners, the tension-impact test should be included in procurement specifications to insure reliability of fasteners.

9.1.4 Tension-Tension Fatigue

Tension-tension fatigue tests at room temperature are already incorporated in existing specifications for aerospace fasteners. However, very little data is available on the cryogenic fatigue properties of fasteners which should be investigated. Cryogenic fatigue was not conducted as a part of this program.

9.1.5 Vibration of Locknuts at -320°F

The locking characteristics of all locknuts tested were unaffected by the Alma #10 vibration tests at -320°F. Failures that were recorded for room temperature tests were not evident after the -320°F tests. Hence, it becomes apparent that motion failure of locknuts at cryogenic temperatures would be improbable, but the susceptibility to cracking may be possible. However, evidence of cracking was not encountered in any tests. Therefore, the inclusion of vibration tests at cryogenic temperatures in fastener specification would be insignificant for determining a locknut's reliability.

9.1.6 Effects of Thermal Cycling at -423°F

The results of cycling loaded fasteners between -423°F and room temperature showed that neither the mechanical properties nor the material structure were affected. For this reason, no requirements need be added to any fastener specification.

9.1.7 Effects of Thermal Cycling at Elevated Temperatures

The loaded fasteners were also thermal cycled from room temperature to the maximum utilization temperature of the fastener combination. One of the chief concerns was the very fast rate at which the fasteners were heated. Fast heating proved to be no different than slow heating. Also, the mechanical results proved no different than would be expected after static exposure under the same conditions. No additional specification requirements are needed to cover high temperature thermal cycling.

9.1.8 Stress Rupture Tests at Elevated Temperatures

Stress rupture tests at elevated temperatures are already included in existing aerospace fastener specifications.

9.1.9 Stress Relaxation Properties

Where stress relaxation properties are required for a fastener, they are included in the procurement specifications. However, these are only for the bolt and are tested with a relaxation machine. For actual application though, the fasteners will be installed in some structural material and seated to a specific stress. Therefore, cylinder relaxation tests should be conducted employing cylinders fabricated from space vehicle structural materials. The cylinder materials and initial stresses would be governed by design criteria. The many combinations of joint design do not lend themselves easily to incorporating cylinder relaxation requirements into a fastener specification, but could be specified on a purchase order.

9.1.10 Nut Reusability

Nut reusability tests are already incorporated in existing aerospace specifications for determining the locking characteristics of locknuts. These requirements are for room temperature and elevated temperatures. The results of cryogenic tests at -423°F indicate no requirements at this temperature need be added to existing specifications.

9.1.11 Stress Corrosion

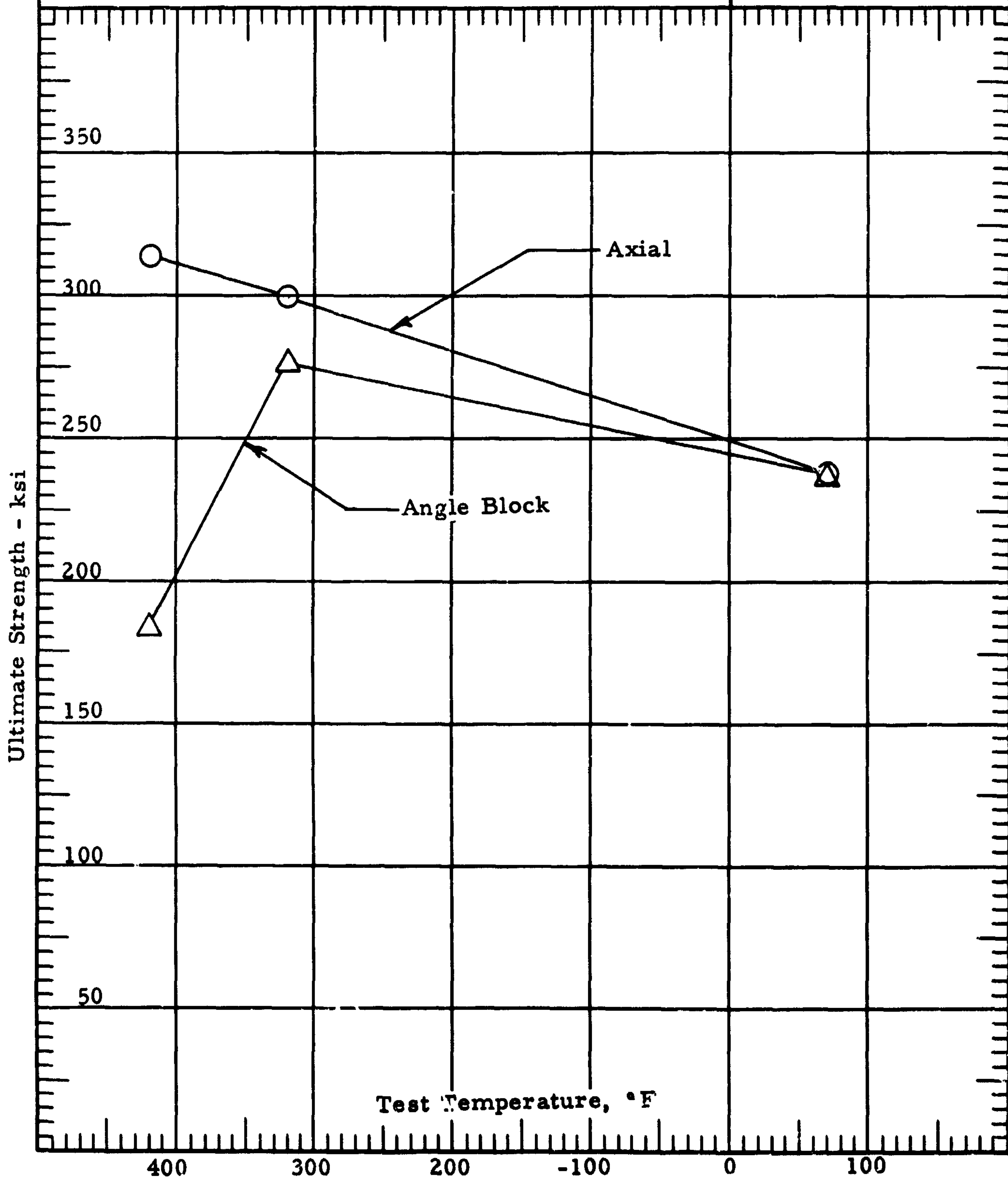
A program described in Section 8.0 was conducted to determine the fastener stress corrosion susceptibility with various combinations of corrosion barriers, coatings and structural alloys. This was done in a salt spray cabinet and at the ocean side. While there was no straight line correlation of the results obtained by both methods, in some cases the results indicated by the sea coast tests were more severe than the salt spray cabinet tests. The designer of aerospace vehicles should be sure that the fastener joint has been tested under conditions closely simulating actual application. This would include sea coast atmospheres to insure stress corrosion reliability of the joint design. As in the case of stress relaxation tests, the many combinations of joint design do not lend easily to incorporating stress corrosion requirements into general fastener specifications.

AXIAL VERSUS ANGLE BLOCK TENSILE PROPERTIES

Bolt - EWBTM9 - Material - H-11 (220 ksi)
Nut - EWNTM9 - Material - H-11 (220 ksi)
Bolt Diameter - 1/4-28
3° Angle at Nut Bearing Face

SPS LABORATORIES

Chart No.: 8.1
Date:

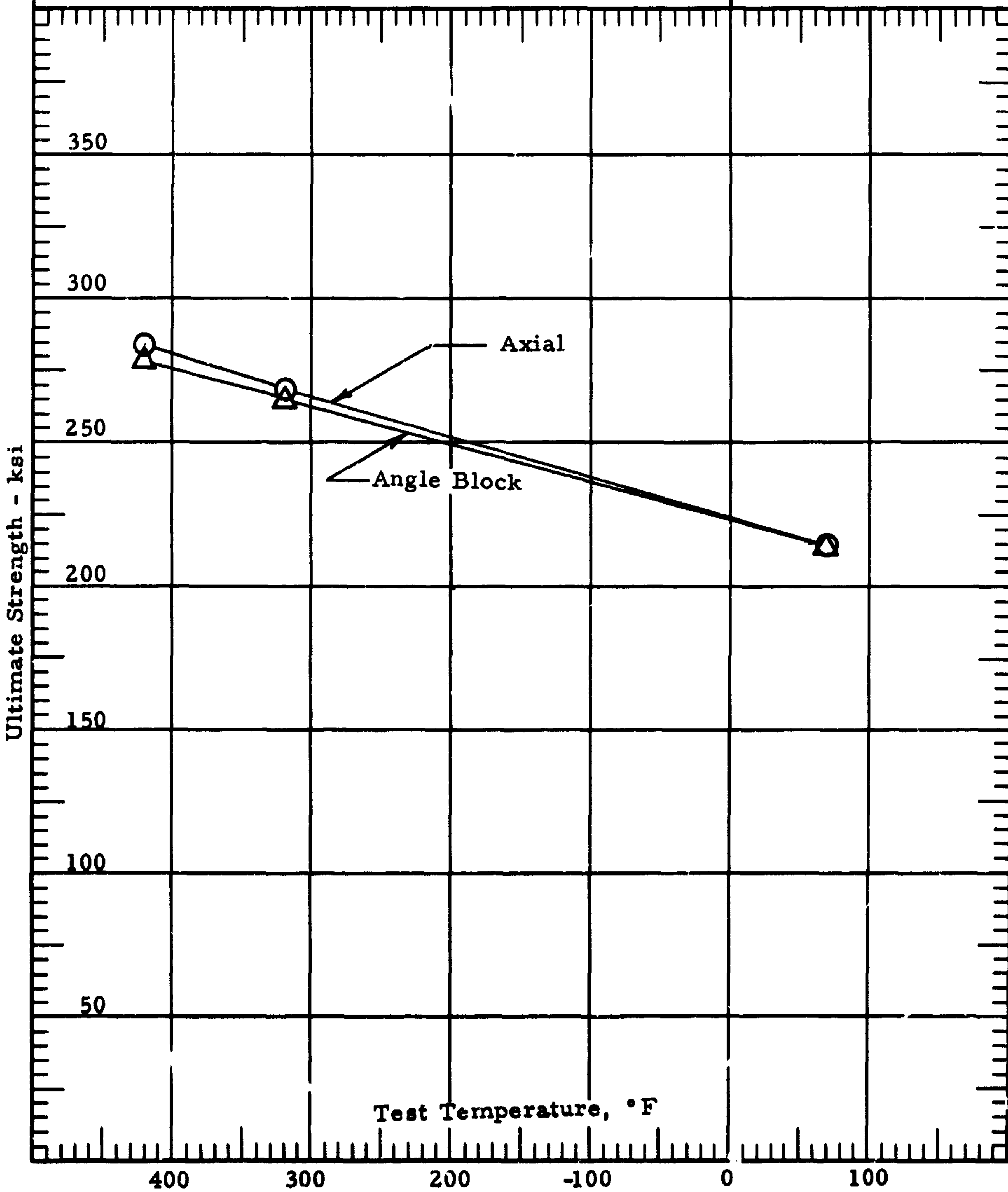


AXIAL VERSUS ANGLE BLOCK TENSILE PROPERTIES

Bolt - VS 2502 - Material A-286 (200 ksi)
Nut - VN 466B - Material A-286
Bolt Diameter - #10-32, 1/4-28 & 1/2-20
3° Angle at Nut Bearing Face

SPS LABORATORIES

Chart No.: 8.2
Date:



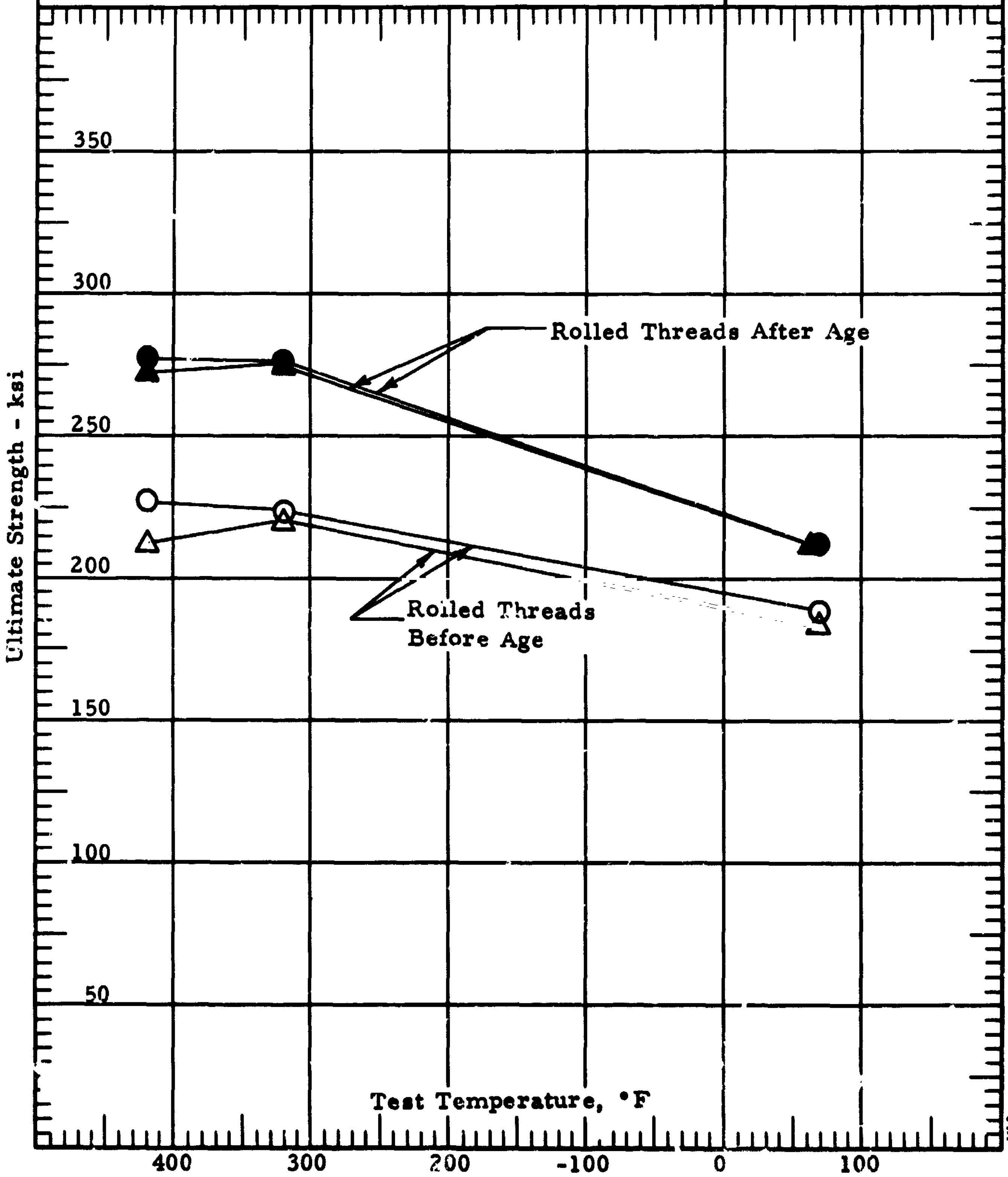
AXIAL VERSUS ANGLE BLOCK TENSILE PROPERTIES

Bolt - EWB 1615 - Material - U-212
Nut - 129 FW - Material - A-286
Bolt Diameter - 1/4-28
3° Angle at Nut Bearing Face

Legend
○ ● - Axial
△ ▲ - Angle Block

SPS LABORATORIES

Chart No.: 8.3
Date:



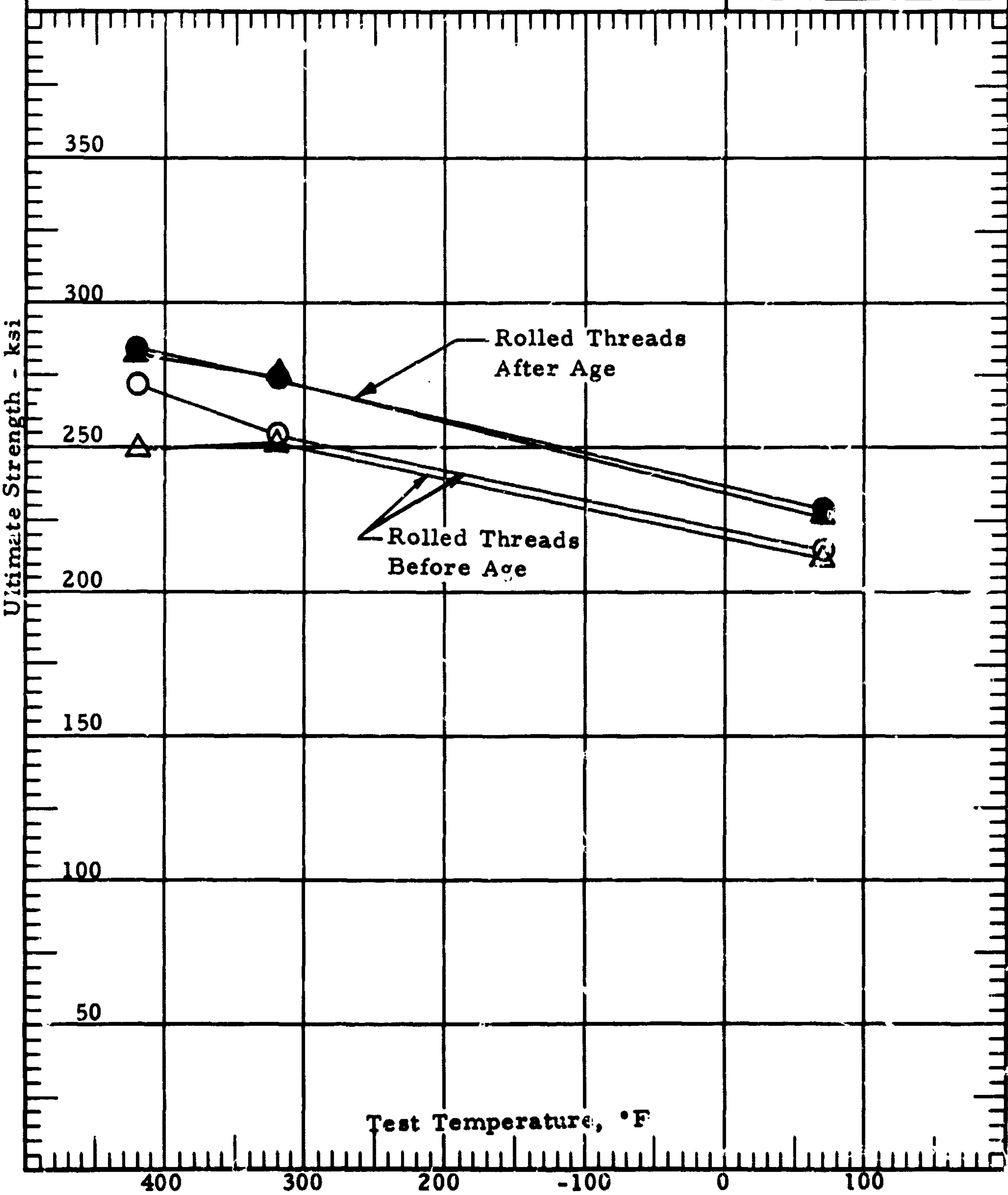
AXIAL VERSUS ANGLE BLOCK
TENSILE PROPERTIES

Bolt - EWB - Material Inconel 718
Nut - 129 FW - Material A-286
Bolt Diameter - 1/4-28 & 3/8-24
3° Angle at Nut Bearing Face

Legend
○ ● - Axial
△ ▲ - Angle Block

SPS LABORATORIES

Chart No.: 8.4
Date:

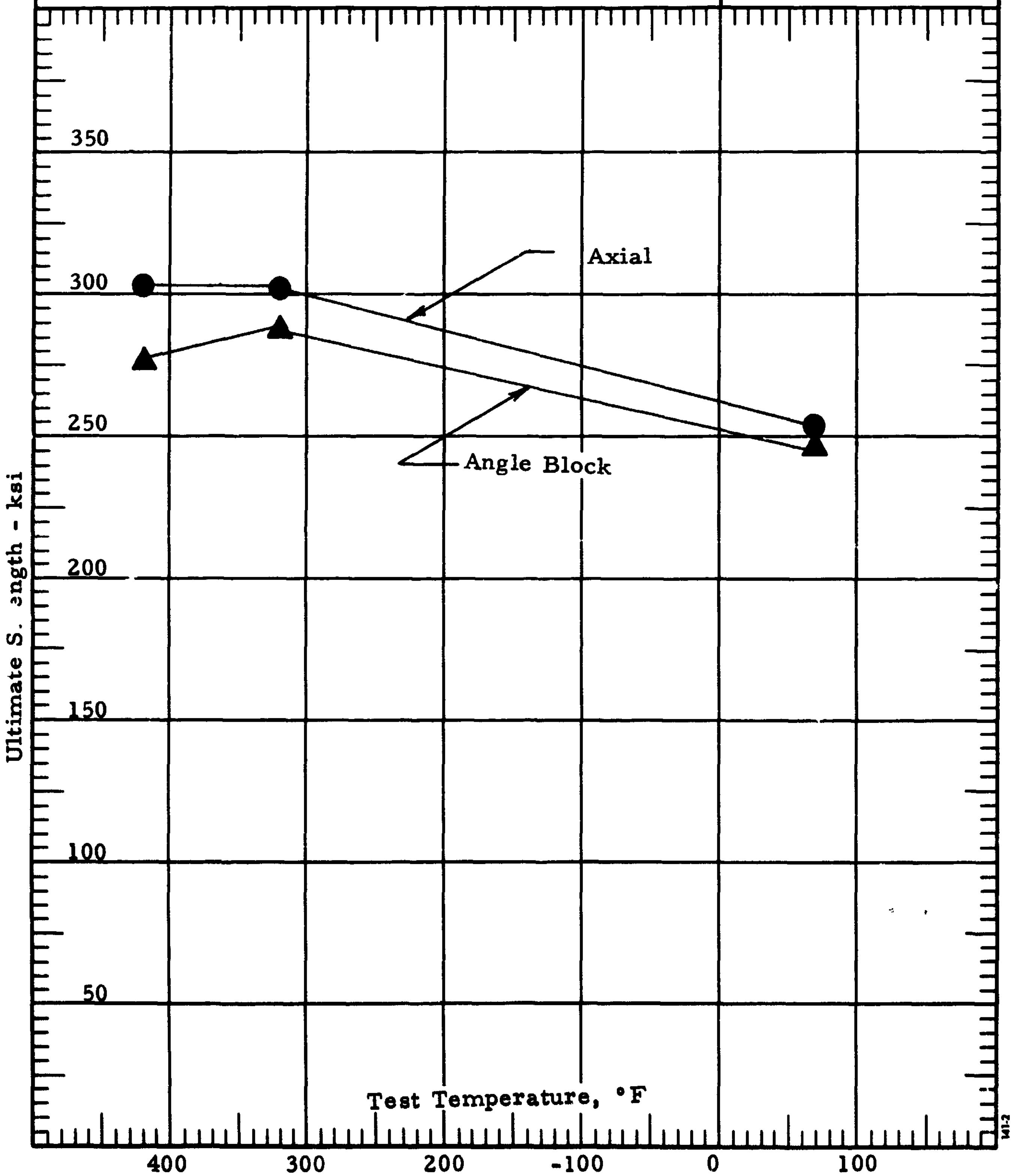


AXIAL VERSUS ANGLE BLOCK TENSILE PROPERTIES

Bolt - EWB 22 - Material Udimet 630
Nut - Nut Slug - Material Udimet 630
Bolt Diameter - 1/4-28
3° Angle at Nut Bearing Face

SPS LABORATORIES

Chart No.: 8.5
Date:



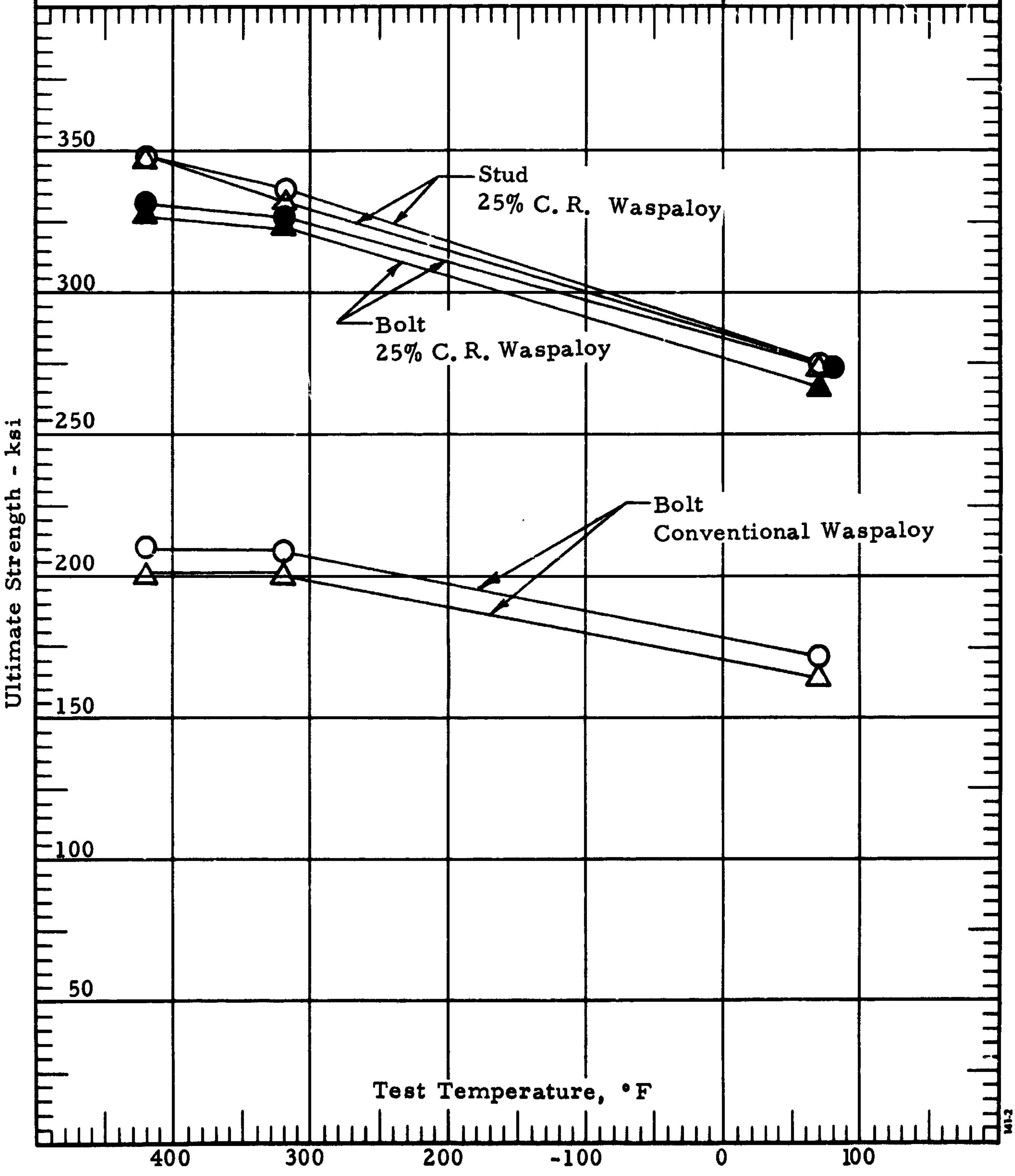
AXIAL VERSUS ANGLE BLOCK
TENSILE PROPERTIES

Bolt - 1615 & Stud
Material - Conventional & 25% Cold Reduced Waspaloy
Nut - FN1418 and FN26
Material - Waspaloy
Bolt Diameter - 1/4-28
3° Angle at Nut Bearing Face

Legend
○ ● -Axial
△ ▲ -Angle Block

SPS LABORATORIES

Chart No.: 8.6
Date:

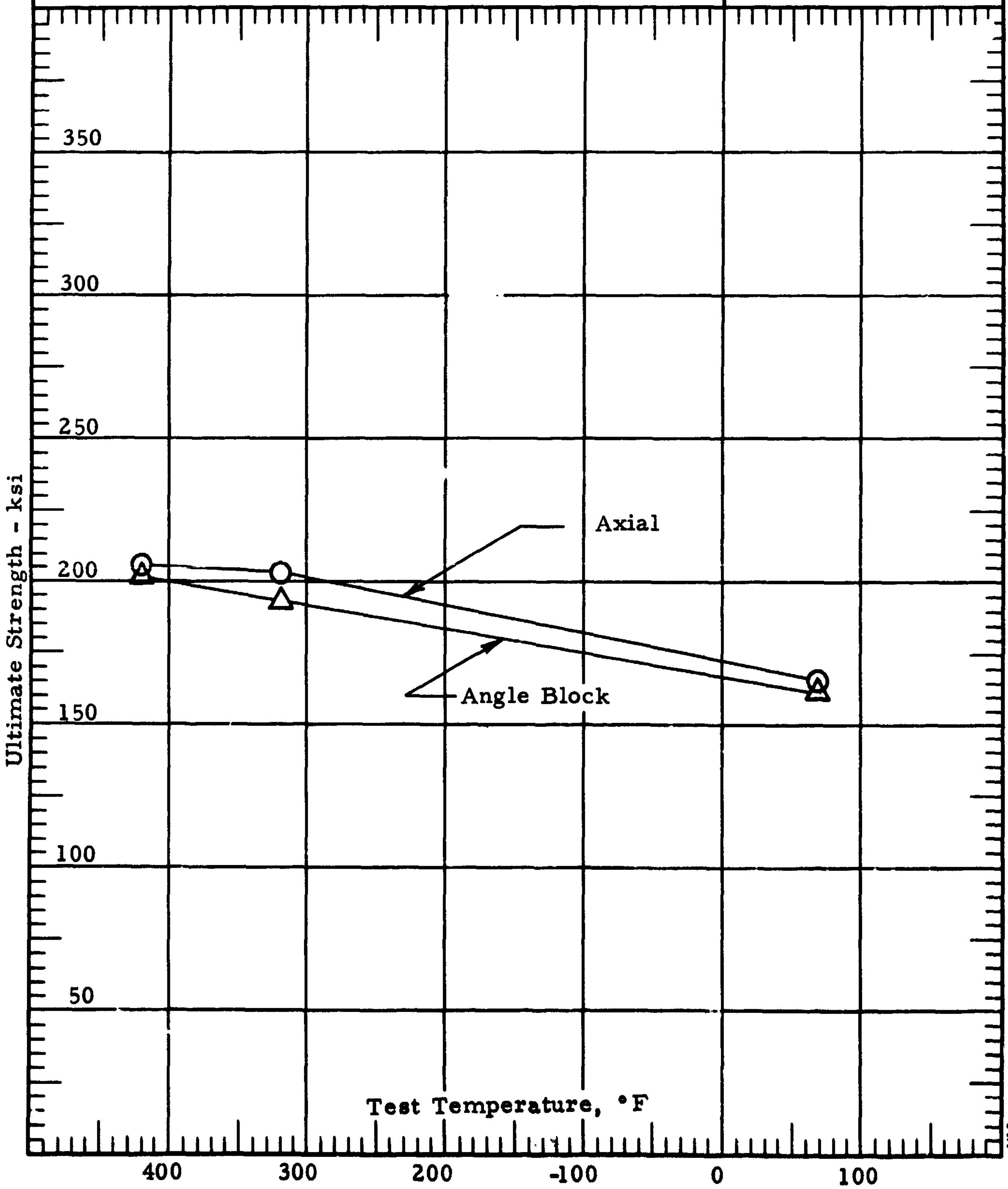


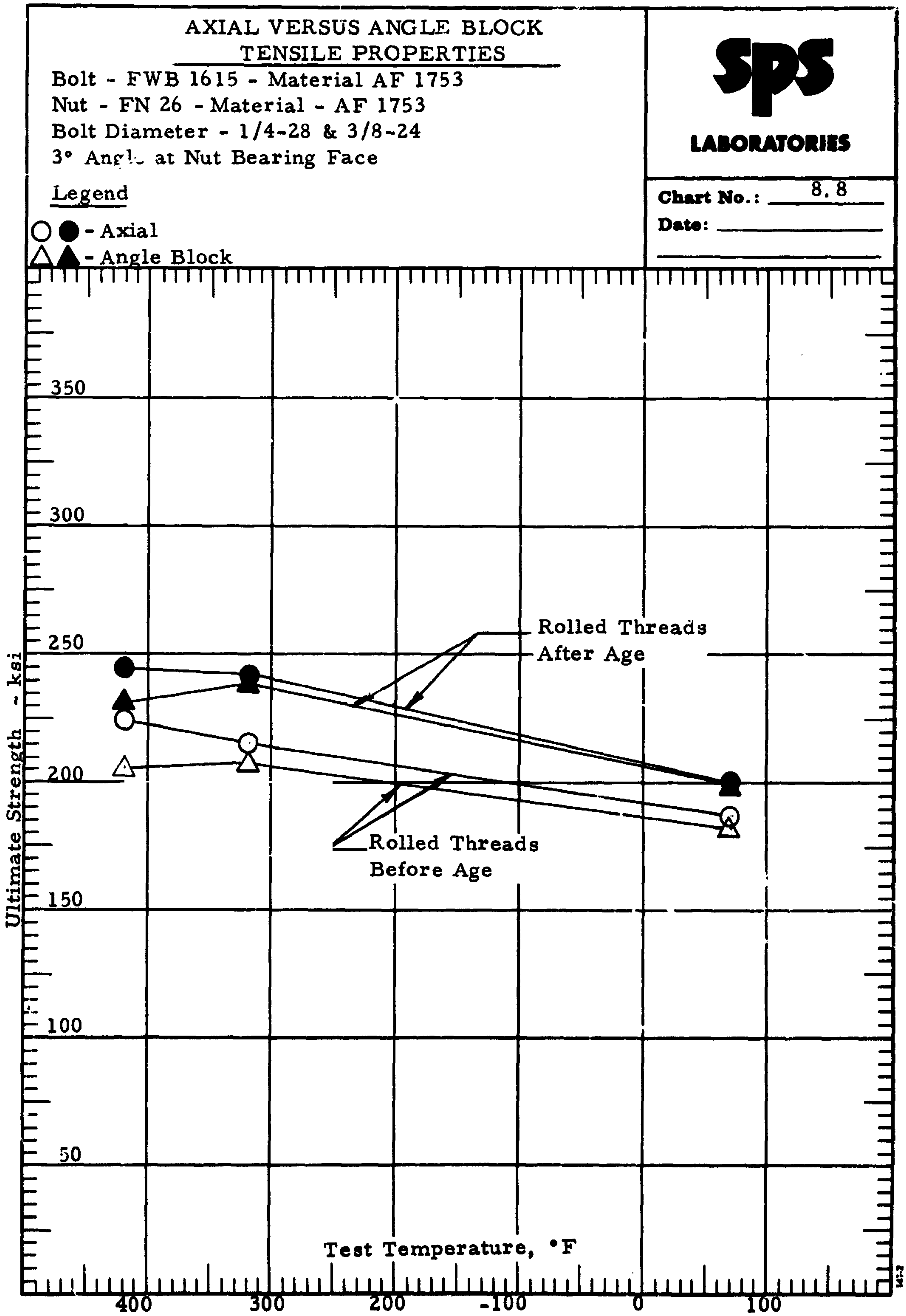
AXIAL VERSUS ANGLE BLOCK TENSILE PROPERTIES

Bolt - EWB 1615 - Material Rene 41
Nut - FN 1418 - Waspaloy
Bolt Diameter - #10-32, 1/4-28 & 1/2-20
3° Angle at Nut Bearing Face

SPS LABORATORIES

Chart No.: 8.7
Date:



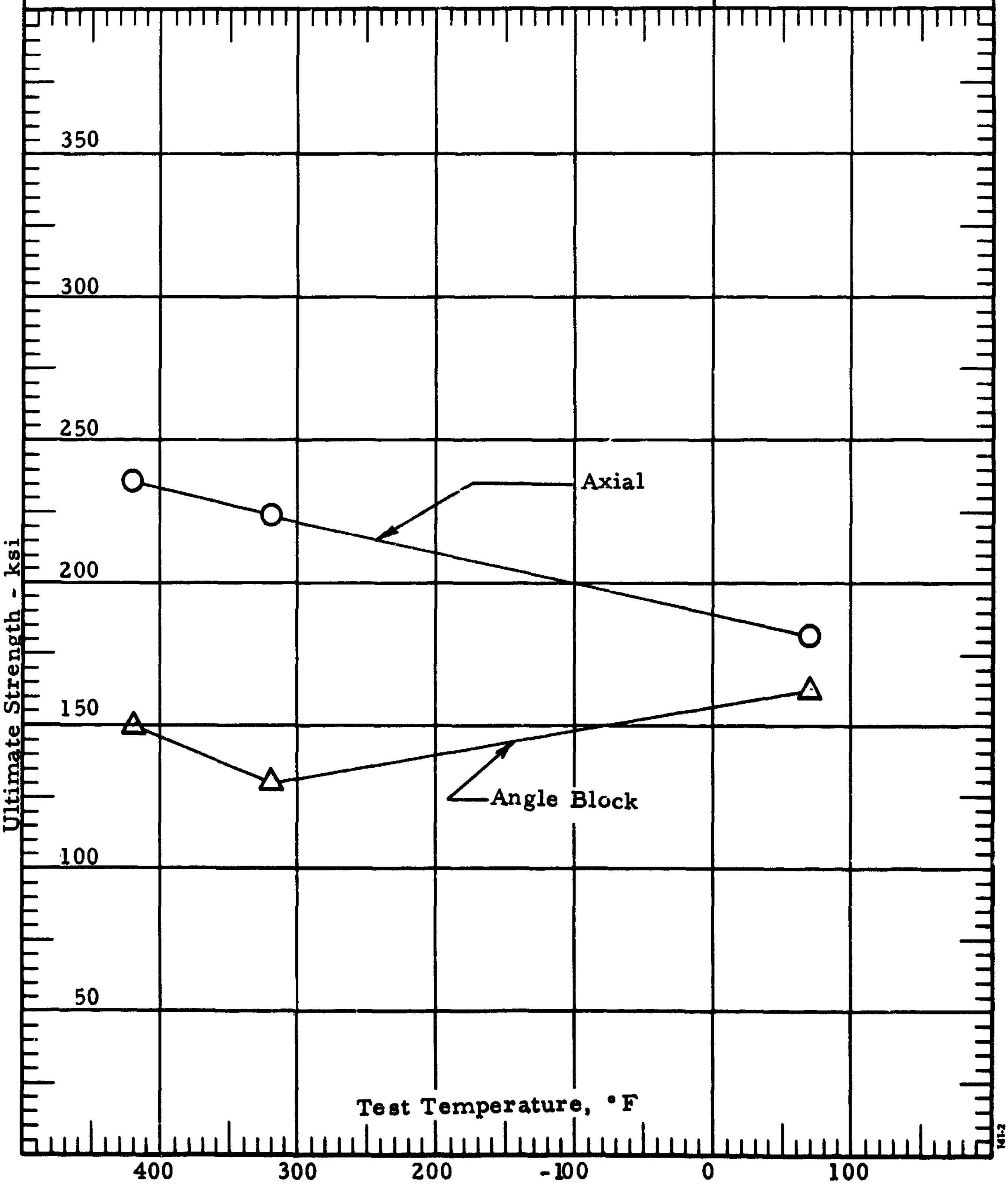

AXIAL VERSUS ANGLE BLOCK
TENSILE PROPERTIES
Bolt - FWB 1615 - Material AF 1753
Nut - FN 26 - Material - AF 1753
Bolt Diameter - 1/4-28 & 3/8-24
3° Angle at Nut Bearing Face
Legend
- Axial
- Angle Block
SPS
LABORATORIES
Chart No.: 8.8
Date:
Rolled Threads
After Age
Rolled Threads
Before Age
Ultimate Strength - ksi
350
300
250
200
150
100
50
Test Temperature, °F
400
300
200
-100
0
100

AXIAL VERSUS ANGLE BLOCK TENSILE PROPERTIES

Bolt - 12 Point Tension - Material Ti6Al-4V
Nut - FN 1216 - Material A-286
Bolt Diameter - #10-32, 1/4-28 & 1/2-20
3° Angle at Nut Bearing Face

SPS LABORATORIES

Chart No.: 8.9
Date:

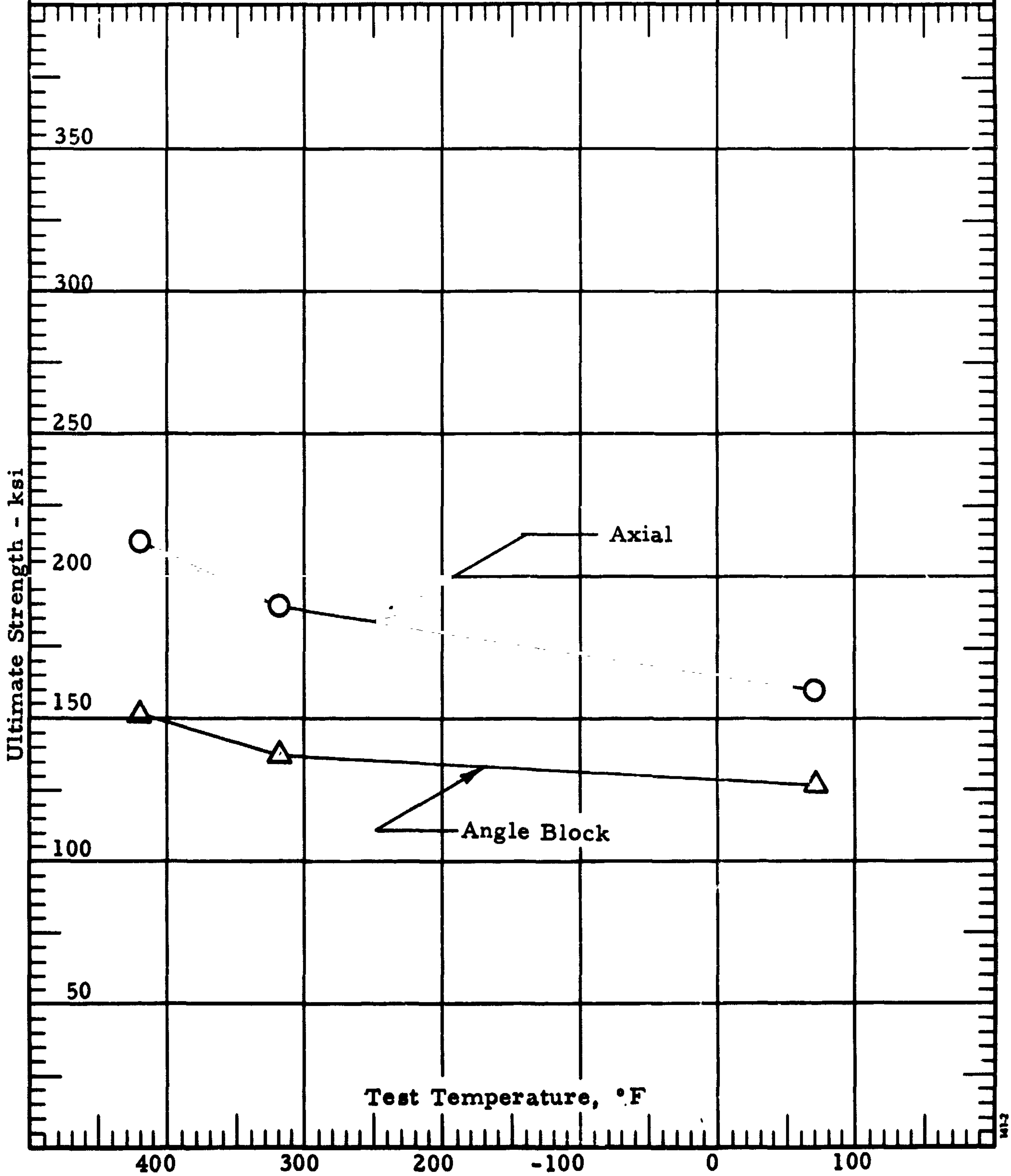


AXIAL VERSUS ANGLE BLOCK
TENSILE PROPERTIES

Bolt - EWBT 815 - Material Ti 7Al-12Zr
Nut - FN 1216 - Material A-286
Bolt Diameter - #10-32 & 1/2-20
3° Angle at Nut Bearing Face

SPS LABORATORIES

Chart No.: 8.10
Date:

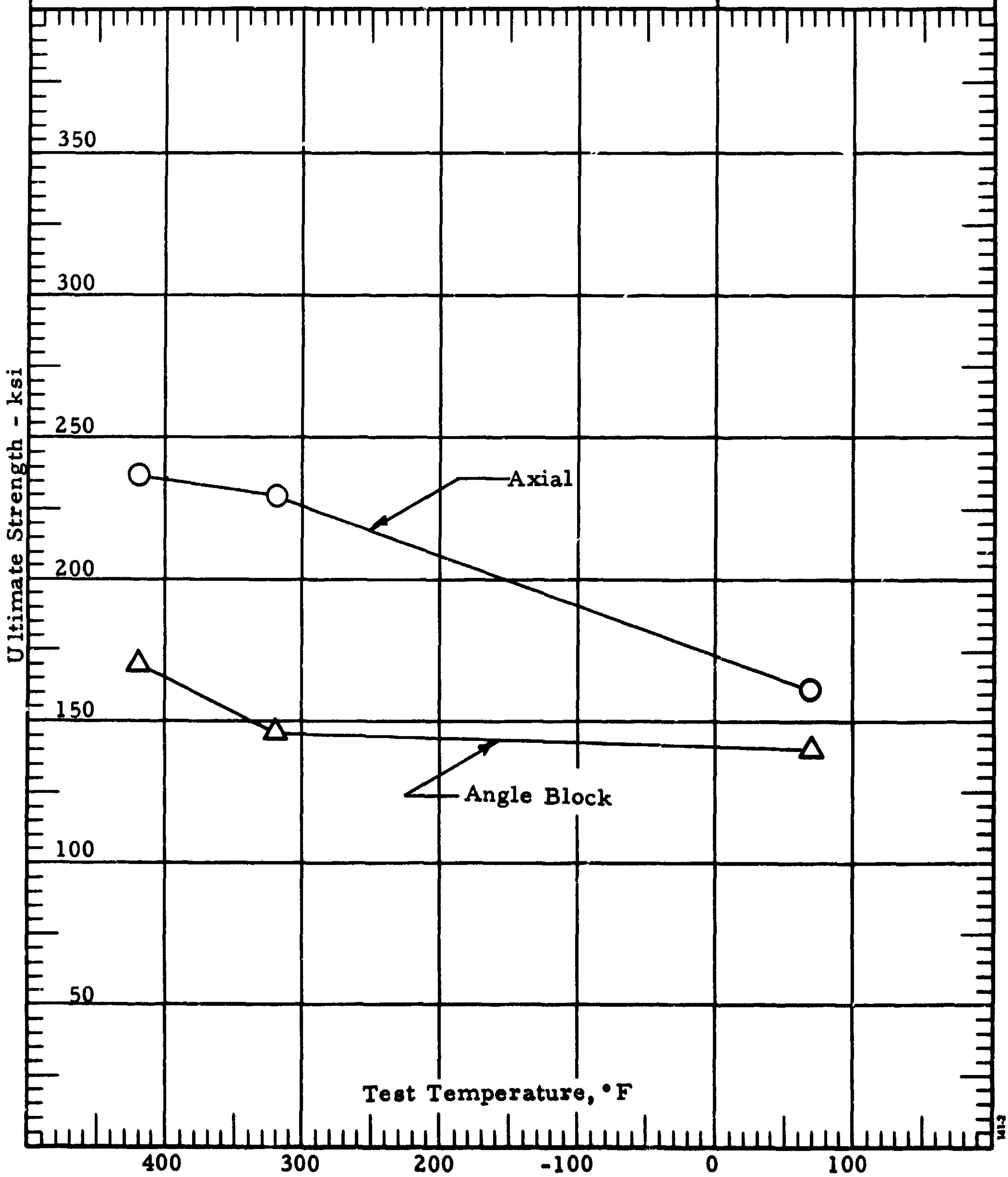


AXIAL VERSUS ANGLE BLOCK TENSILE PROPERTIES

SPS LABORATORIES

Bolt - 12 Point Tension-Material - Ti8Al-1Mo-1V
Nut - FN 1216 - Material - A286
Bolt Diameter - #10-32, 1/4-28 & 1/2-20
3° Angle at Nut Bearing Face

Chart No.: 8.11
Date:

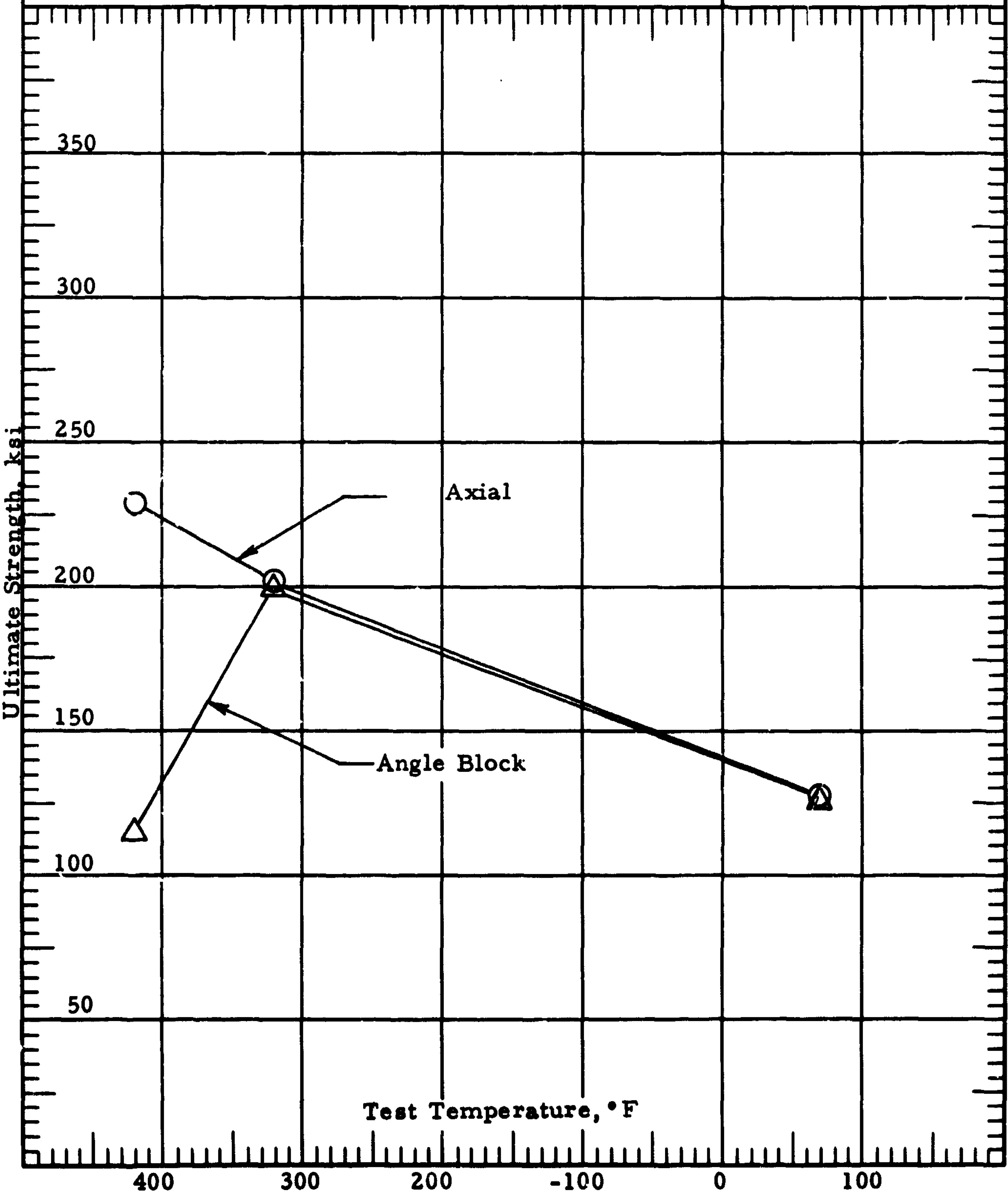


AXIAL VERSUS ANGLE BLOCK TENSILE PROPERTIES

Bolt - EWBT 815 - Material Ti 5Al-2.5Sn (ELI)
Nut - FN 1216 - Material A-286
Bolt Diameter - 1/4-28 & 3/8-24
3° Angle at Nut Bearing Face

SPS LABORATORIES

Chart No.: 8.12
Date:

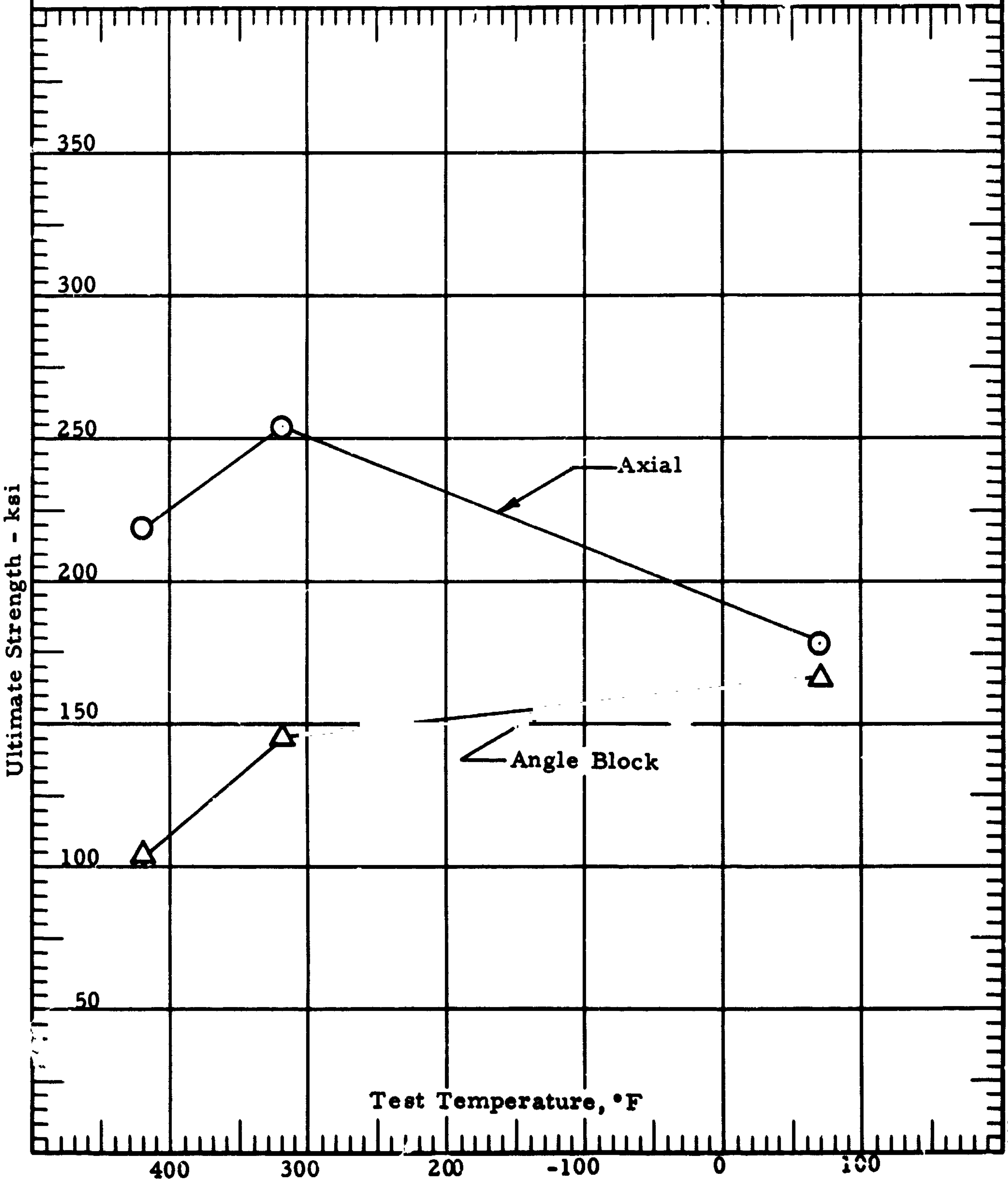


AXIAL VERSUS ANGLE BLOCK TENSILE PROPERTIES

SPS LABORATORIES

Chart No.: 8.13
Date:

Bolt - EWBT 815 - Material Ti 5Al-5Sn-5Zr
Nut - Nut Slug - Material - Ti 5-5-5
Bolt Diameter - 1/4-28
3° Angle at Nut Bearing Face



AXIAL VERSUS ANGLE BLOCK TENSILE PROPERTIES

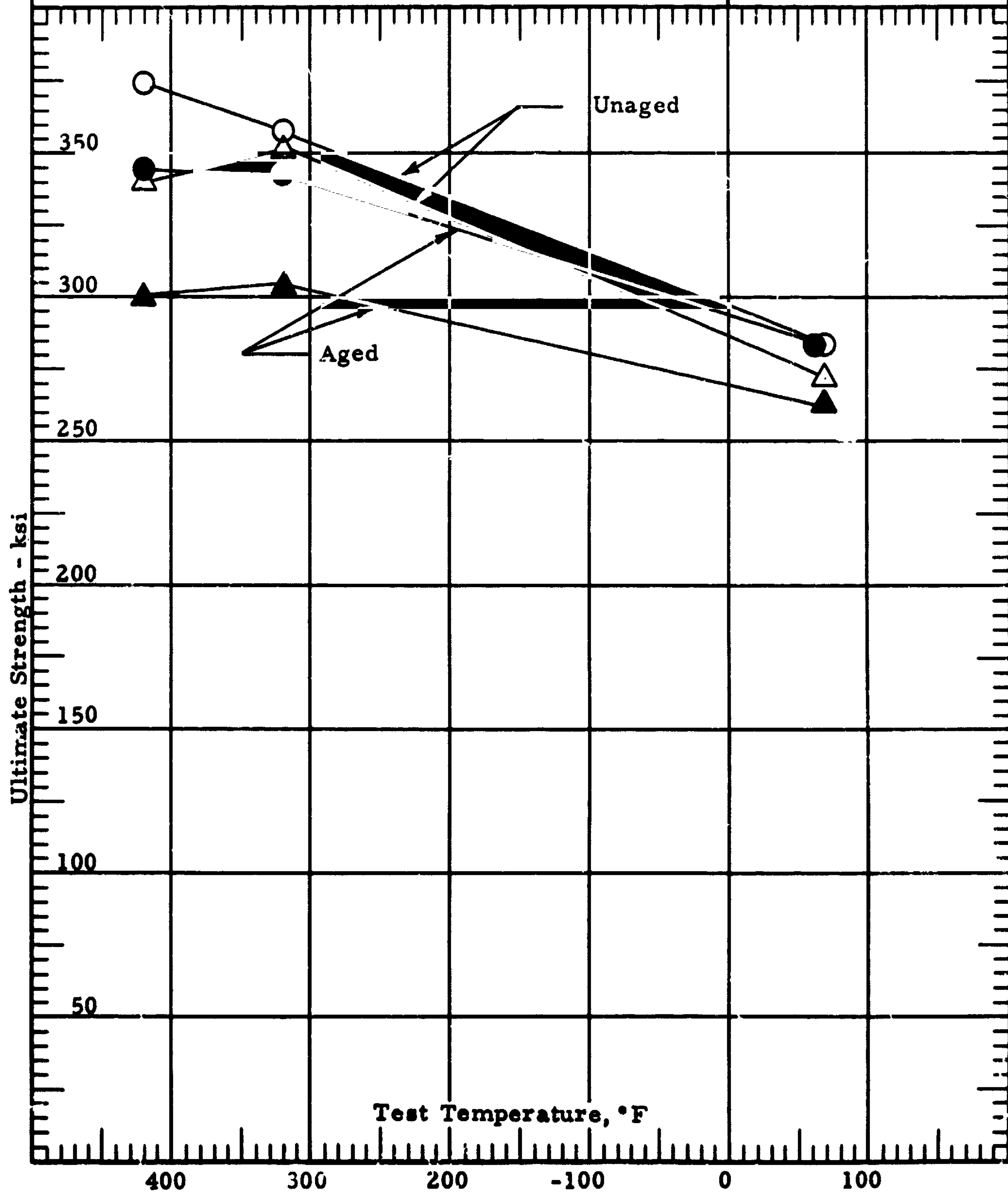
Bolt - EWB 1615 - Material 30% C.R. L605
Nut - Nut Slug - Material - L605
Bolt Diameter - 1/4-28
3° Angle at Nut Bearing Face

Legend

○ ● - Axial
△ ▲ - Angle Block

SPS LABORATORIES

Chart No.: 8.14
Date:



BOLT TENSION IMPACT PROPERTIES

Iron Base Alloys

External Wrenching Tension Bolts

Bolt Diameter 1/4-28

Legend

○ - Cold Reduced A-286 - Rolled Th'ds. After Age

△ - U-212 Rolled Th'ds. Before Age

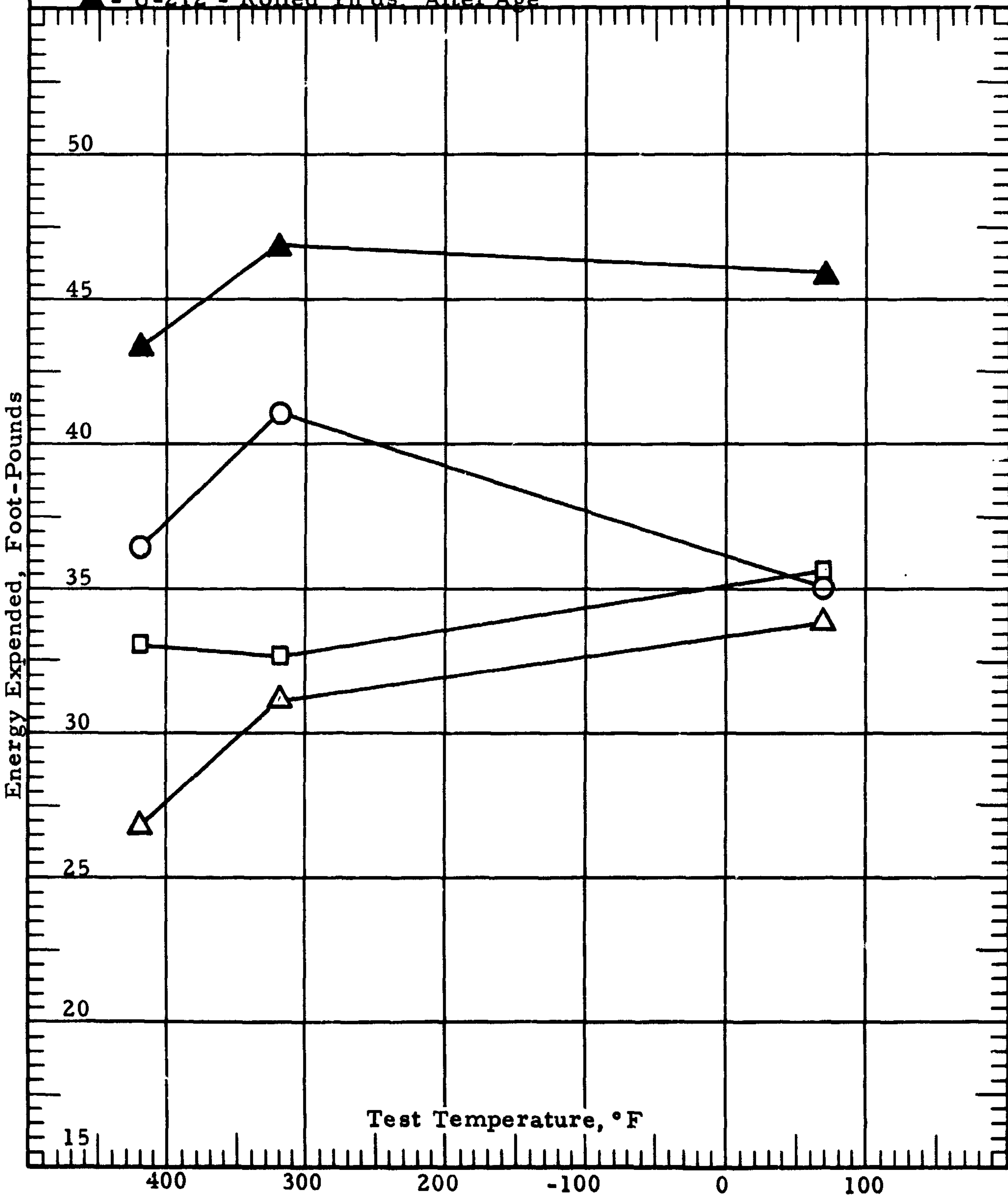
□ - H-11 - Rolled Th'ds. After Heat Treat

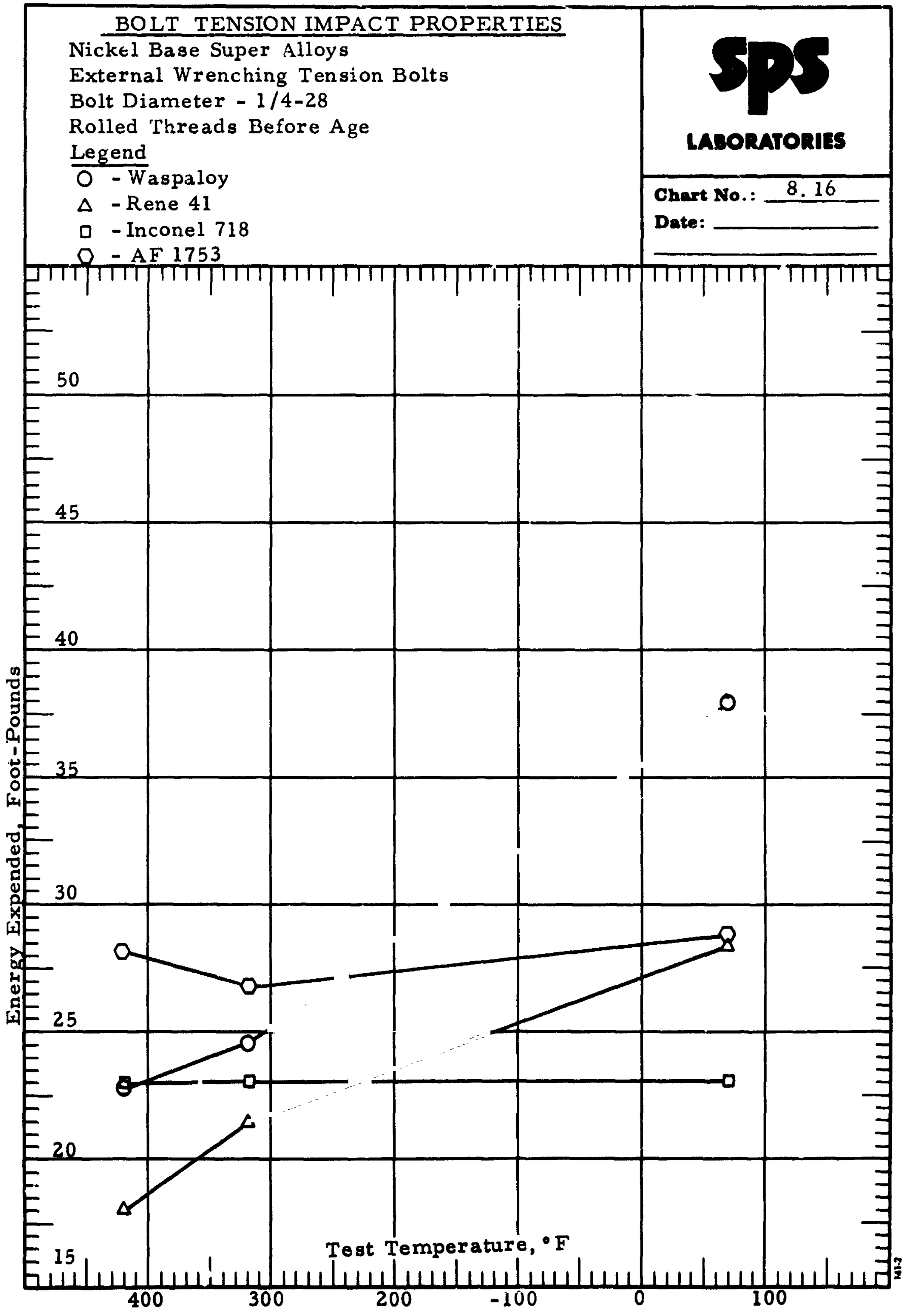
▲ - U-212 - Rolled Th'ds. After Age

SPS LABORATORIES

Chart No.: 8.15

Date:





BOLT TENSION IMPACT PROPERTIES
Nickel Base Super Alloys
External Wrenching Tension Bolts
Bolt Diameter - 1/4-28
Rolled Threads Before Age
Legend
O - Waspaloy
Δ - Rene 41
□ - Inconel 718
⬡ - AF 1753
SPS LABORATORIES
Chart No.: 8.16
Date:
50
45
40
35
30
25
20
15
Energy Expended, Foot-Pounds
Test Temperature, °F
400
300
200
-100
0
100

BOLT TENSION IMPACT PROPERTIES

Cobalt & Nickel Base Super Alloys

External Wrenching Tension Bolts - Bolt Dia. 1/4-28

Rolled Threads After Age

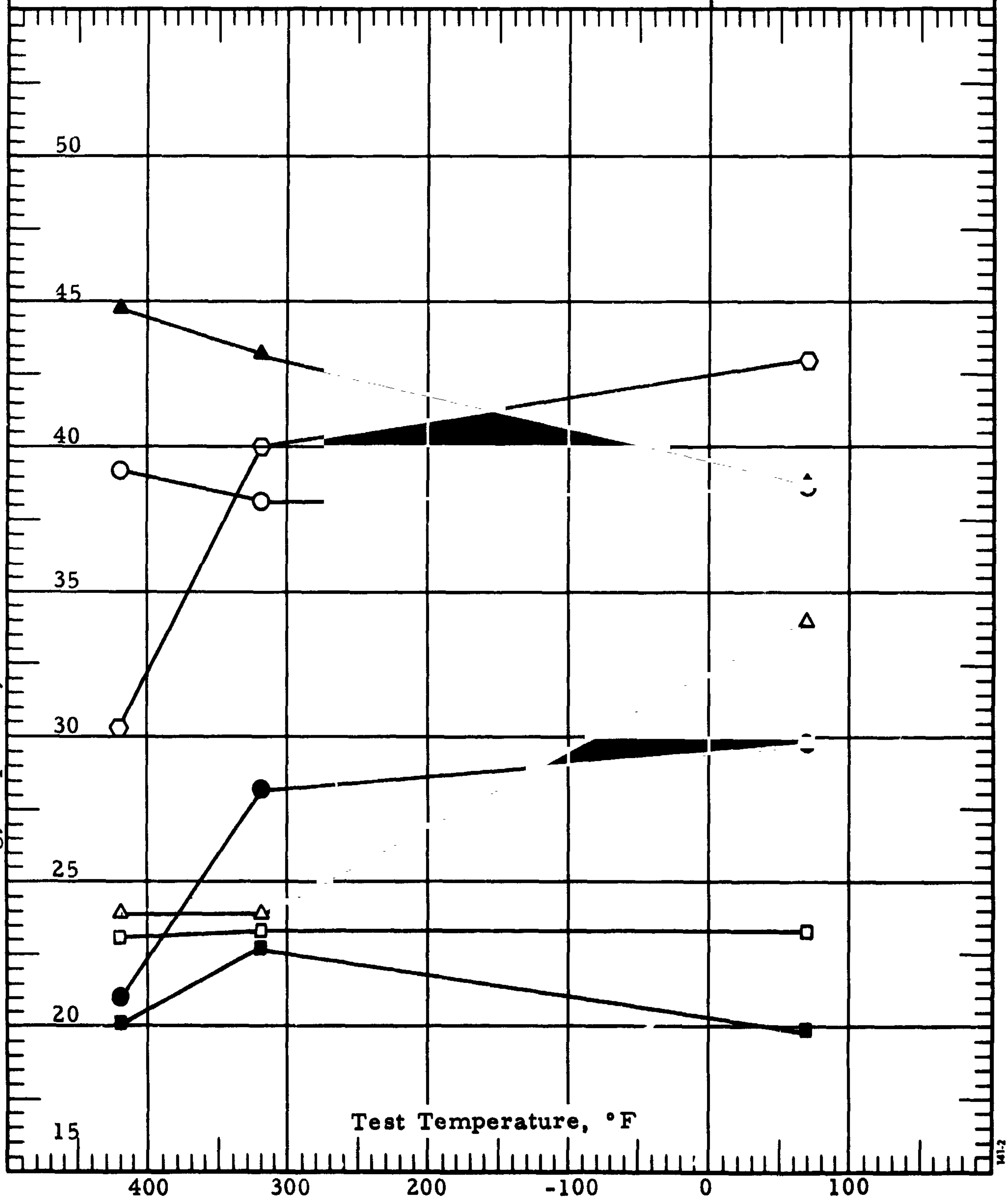
Legend

- ○ - 25% Cold Reduced Waspaloy(Stud)
- △ - 25% Cold Reduced Waspaloy
- □ - Inconel 718
- ⬡ - AF 1753
- ● - Udimet 630
- ▲ - 30% Cold Reduced L605 (unaged)
- ■ - 30% Cold Reduced L605 (aged)

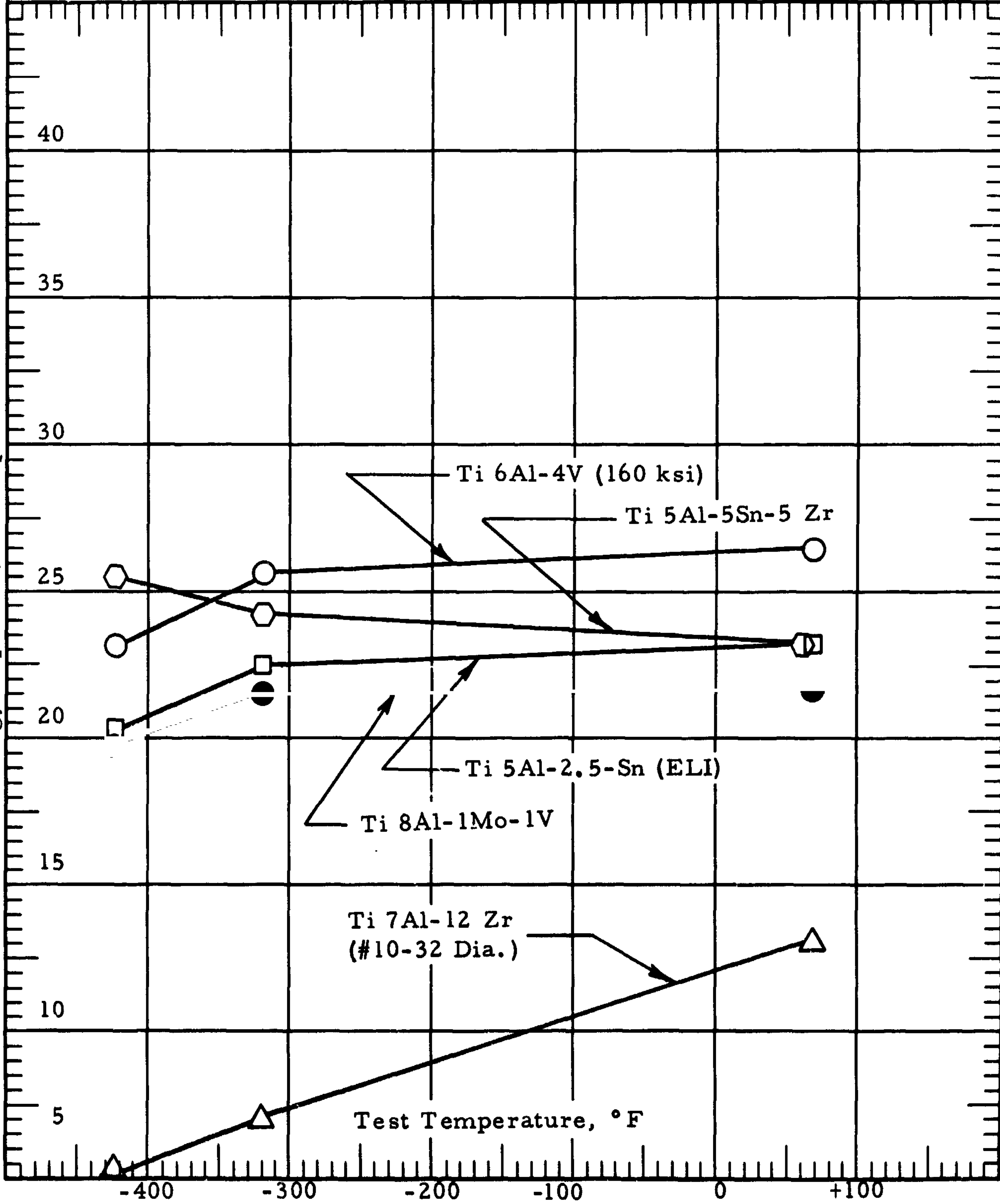
SPS LABORATORIES

Chart No.: 8.17

Date:



BOLT TENSION-IMPACT PROPERTIES Titanium Base Alloys External Wrenching Tension Bolts Bolt Diameter - 1/4-28 Average of 3 Tests	**SPS LABORATORIES** **Chart No.:** 8.18 **Date:**



10.0 RECOMMENDED TYPICAL FASTENER PROCUREMENT SPECIFICATION FOR SPACE VEHICLE APPLICATION

From the results of the test program, the fastener procurement specification presented in this section would be considered typical for cryogenic and elevated temperature utilization for space vehicle applications. The alloy U-212 was used as the example bolt material. The general outline follows existing specifications for such fasteners except for inclusion of cryogenic tests and the separation of the bolt requirements into two classes depending on sequence of the thread rolling process.

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1.0 Scope

This specification covers External Wrenching Bolts, Class I and II with room temperature tensile strength of 180,000 psi.

Class I - For Cryogenic Application to -423°F.
Class II - For Elevated Temperature Application to 1200°F.

2.0 Applicable Specifications, Other Publications, and Drawings

2.1 The following publications, of the issue in effect on date of invitation for bids, shall form a part of this specification to the extent specified herein:

Specifications

Military

MIL-H-6875	Heat Treatment of Steels (Aircraft) Process for
MIL-I-6866	Inspection Process, Fluorescent Penetrant
MIL-S-8879	Screw Threads, Controlled Radius Root with Increased Minor Diameter

SPS

SPS-M-134	Steel, High Strength, Corrosion and Heat Resistant
SPS-U-128	Packaging, Bolts and Nuts

Standards

Federal

No. 151	Federal Test Standard-Metals, Test Method

Military

MIL-STD-10	Surface Roughness, Waviness, and Lay
MIL-STD-105	Sampling Procedures and Tables for Inspection by Attributes

ASTM

E8-61T	Tension Testing of Metallic Materials
E139-58T	Recommended Practice for Conducting Creep and Time for Rupture Tension Tests of Materials
E23-64	Notched Bar Impact Testing of Metallic Materials

Drawings

Applicable Drawings

3.0 Requirements

3.1 Dimensions

The dimensions of the finished bolts shall conform to the applicable drawing.

3.2 Material -

The bolts shall be made from alloy steel conforming to specification SPS-M-134.

3.3 Heat Treatment

The bolts shall be heat treated in accordance with specification MIL-H-6875 to develop the mechanical properties specified herein.

Solution treat at 1850°F for 2 hours; water quench. Age at 1425°F for 2 hours; air cool. Age at 1250°F for 16 hours; air cool.

3.4 Heads

The bolt heads shall be forged. Forged or machined lightening holes are acceptable.

3.4.1 Bearing Surface

The bearing surface of the bolt heads shall be at right angles to the shank within limits shown in Figure 1. The angular variation of the underside of the head must be uniform around the shank within a tolerance of 10 minutes, as measured from the bearing surface of the head at a length approximately equal to the diameter of the bolt.

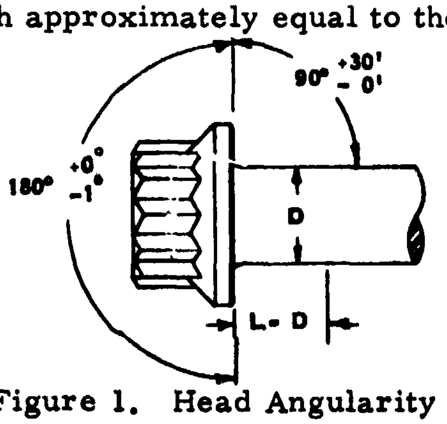

Figure 1. Head Angularity

3.4.2 Head Structure and Grain Flow

A section of the head shall show no defects. Flow lines in the fillet area immediately below the surface shall closely conform to the fillet contour as shown in Figure 2. The grain flow lines may be slightly broken by finish machining or grinding. The metal removed from the bearing surface shall be as little as necessary to obtain a clean, smooth surface. The intersection of the longitudinal axis of the bolt and the approximate transverse axis of the flow lines shall not be less than D/7 inches from the bearing surface, where "D" is the nominal diameter of the bolt.

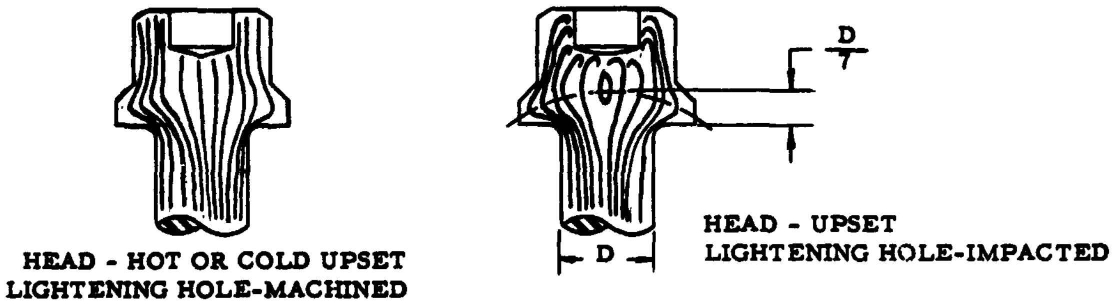

Figure 2. Head Structure and Grain Flow

3.5 Threads

3.5.1 Form and Dimensions

Unless otherwise specified, the threads shall be right hand. The dimensions, form, and contour of the threads shall conform to specification Mil-S-8879, except the pitch diameter shall be reduced by .003 inches for Class II bolts.

3.5.1.1 Gages

Indicating type gages are recommended for measuring thread elements. However, if functional type gages are used, the go gage minor diameter shall conform to Table I.

TABLE I

GO GAGE MINOR DIAMETER

Size	Go Gage Minor Diameter Max. (1)	Min.
#10-32	.1565	.1560
1/4-28	.2122	.2117
5/16-24	.2689	.2684
3/8-24	.3313	.3308
7/16-20	.3857	.3852
1/2-20	.4482	.4477

(1) The values listed are calculated to engage 75% of the basic thread depth at a pitch diameter reduced by .003 inch.

3.5.2 Thread Rolling

Class I - Threads shall be fully formed by a single rolling process after age hardening.

Class II - Threads shall be fully formed by a single rolling process subsequent to solution treatment and prior to age hardening.

3.5.3 Incomplete Threads

Incomplete threads are permitted at the chamfered end of the bolt and adjacent to the grip. Thread runout adjacent to the grip shall consist of a two pitch maximum and a one pitch minimum and shall include extrusion angle for rolled threads. The runout shall fair into the shank thereby eliminating abrupt changes in cross sectional area. Bottom and sides of threads contained in runout may deviate from true form, but shall be smooth and free from tool marks. The point end of the bolt shall be flat and chamfered. The chamfer may be incomplete at pitch diameter and major diameter, but shall be complete and within tolerance at a distance of two pitches from the point end of the bolt.

3.5.4 Grain Flow

The grain flow in the thread shall be continuous and shall follow the general thread contour with the maximum density at the bottom of the root radius as shown in Figure 3.

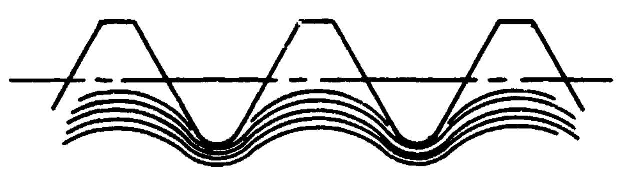

Figure 3. Grain Flow

3.6 Fillet (Head-to-Shank) -

The head-to-shank fillet radius shall be cold worked subsequent to the heat treatment of the bolt. The fillet shall show no evidence of seams or inclusions when examined as specified in Section 5. Cold working of head-to-shank fillet may cause distortion of the fillet area. Distortion shall not exceed .002 above (A) or below (B) contour shown on fastener drawing. Distorted area shall not extend beyond "C" as illustrated in Figure 4.

NOMINAL SIZE	UNDER 5/16	5/16 AND 3/8	7/16 AND 1/2
C Max.	0.062	0.094	0.125

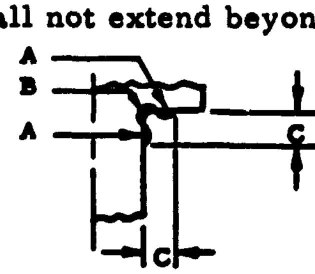

Figure 4. Permissible Distortion

3.7 Surface Roughness

The surface roughness of the bolts shall not exceed the values shown in Table II. The surface roughness shall be measured in accordance with MIL-STD-10.

TABLE II
SURFACE ROUGHNESS

Area	RHR (Maximum)
Shank and Underside of Head	63
Head-to-Shank Fillet	32
Sides of Thread and Root Area	32
Other Surfaces	125

3.8 Straightness

The straightness of the bolt shank shall be within the values specified in Table III when the bolt is rolled on a surface plate and the point of greatest deviation is measured with a feeler gage.

TABLE III
STRAIGHTNESS OF SHANK

Bolt Size	Deviation of Bolt Shank from Plate Inch per Inch of Bolt Length (Maximum)
#10 thru 5/16	0.0030
3/8 and 7/16	0.0025
1/2	0.0020

3.9 Identification of Product

Each bolt shall be marked in accordance with the requirements of the applicable drawings. Markings may be raised or indented and may be formed by forging or stamping.

4.0 Mechanical Properties

4.1 Ultimate Tensile Load

The finished bolts shall develop the ultimate tensile load listed in Table V and VI.

4.1.1 Sampling

Samples for ultimate tensile tests shall be selected in accordance with Table IV.

4.1.2 Tests

4.1.2.1 Axial Tensile

The bolts shall be tested in accordance with applicable requirements of ASTM specification E8-61T. Class I bolts will be tested at -423°F and room temperature and Class II bolts will be tested at room temperature and 1200°F. The bolts shall be tested in tension between the head of the bolt and a threaded member of sufficient size to develop the full strength of the bolt without stripping the threads. The threaded member shall be assembled on the bolt leaving two to three threads unengaged.

4.1.2.3 Tension Impact - (Class I Only)

The bolts shall be tested in accordance with applicable requirements based on ASTM specification E23-60. The bolts shall be tested at -423°F and room temperature. In the event that the bolt diameter is too large to conduct the tension impact test, the test may be made on smaller diameter bolts fabricated from the same stock and processed in the same manner as the larger diameter bolt.

4.1.2.4 Double Shear - (Class I Only)

The bolts shall be double shear tested using a fixture conforming substantially to NAS 498 specification except bearing surface of inserts shall be equal to the bolt diameter being tested. If bolt is too short for double shear test, acceptability shall be based on hardness tests. The bolts shall be tested at -423°F and room temperature.

TABLE IV

SAMPLING FOR TENSILE, WORK EFFECT, HARDNESS, HEAD STRUCTURE AND GRAIN FLOW

Lot Size	Sample Size	Acceptance No.	Rejection No.
Under 500	10	0	1
500 and Over	20	0	1

The acceptance-rejection provisions of Table IV shall apply separately to each of the tests.

TABLE V

MECHANICAL PROPERTIES - CLASS I

Size	(a) Threads per Inch	Tensile Stress Area	Ultimate Tensile Load Pounds - Minimum				Tension-Impact Ft-lbs. Minimum	
			Axial		3° Angle Block			
			-423°F(1)	Room(2)	-423°F(3)	Room(3)	-423°F	Room
10	32	.01999	5,197	3,598	4,677	3,598	--	--
1/4	28	.03637	9,456	6,546	8,510	6,546	36	40
5/16	24	.05805	15,093	10,449	14,312	10,449	--	--
3/8	24	.08781	22,830	15,806	20,547	15,806	--	--
7/16	20	.1187	30,862	21,366	27,775	21,366	--	--
1/2	20	.1599	41,574	28,782	37,416	28,782	--	--

Size	Double Shear Load Pounds-Minimum	
	-423°F(4)	Room(5)
10	8,505	7,088
1/4	14,725	12,270
5/16	22,935	19,112
3/8	33,120	27,600
7/16	45,000	37,500
1/2	58,905	49,087

(1) The listed ultimate tensile load values are based on the tensile stress area of the external thread and 260,000 psi.

(2) The listed ultimate tensile load values are based on the tensile stress area of the external thread and 180,000 psi.

(3) The listed ultimate tensile load values are based on 90 percent of the axial load.

(4) The listed ultimate double shear load values are based on the cross sectional area and 150,000 psi.

(5) The listed ultimate double shear load values are based on the cross sectional area and 125,000 psi.

(a) SPS Specification Q-1003, "Calculation Procedures for Areas and Stress Values for Threaded Fasteners.

TABLE VI

MECHANICAL PROPERTIES (CLASS II)

Size	Threads per Inch	Tensile Stress Area (Reduced P. D.)	Ultimate Tensile Load Pounds-Minimum		Stress Rupture 1200°F for 23 Hours (3)
			At Room Temp(1)	At 1200°F (2)	
10	32	.01925	3,470	2,500	1,930
1/4	28	.03537	6,370	4,600	3,540
5/16	24	.05677	10,200	7,380	5,680
3/8	24	.08626	15,500	11,200	8,630
7/16	20	.1169	21,000	15,200	11,700
1/2	20	.1579	28,400	20,500	15,800

(1) The listed ultimate tensile load values are based on the tensile stress area of the external thread and 180,000 PSI.

(2) The listed ultimate tensile load values are based on the tensile stress area of the external thread and 130,000 PSI.

(3) The listed stress rupture loads are based on a minimum strength of 100,000 PSI and the tensile stress area of the external thread.

4.2 Rupture Strength - (Class II Only)

4.2.1 Sampling

Two samples in each lot shall be tested.

4.2.2 Tests

Bolts shall be tested at 1200°F by carrying the constant load listed in Table VI in tension between the head of the bolt and a threaded member of sufficient size to carry the load without stripping the threads. Test to be in accordance with ASTM designation E139-58T.

4.3 Hardness

The finished bolt shall have a minimum Rockwell hardness of C 40.

4.3.1 Sampling

Sampling shall be in accordance with Table IV.

4.3.2 Tests

The Rockwell Hardness Test shall be performed on the point end of the finished bolt in accordance with Federal Test Method Standard No. 51.

5.0 Metallurgical Requirements

5.1 Work Effect

The threads and head-to-shank fillet shall show evidence of working.

5.1.1 Sampling

Samples for work effect examination shall be selected in accordance with Table IV.

5.1.2 Tests

5.1.2.1 Threads

The working of the threads shall be determined by microexamination. Samples shall be taken from the finished bolt as shown in Figure 7. The etchant shall be Marble's reagent or its equivalent. Microscopic examination shall be made at a magnification of 100 diameters.

5.1.2.2 Fillet

Working of the head-to-shank fillet radius shall be determined by visual examination.

5.2 Discontinuities

The bolts shall be acceptable provided they do not contain discontinuities which equal or exceed the values specified herein.

5.2.1 Types

5.2.1.1 Laps and Seams

Bolts may possess laps and seams except in specified locations as described herein, provided the depths do not exceed the limits of Table VII.

5.2.1.2 Inclusions

Bolts may possess small inclusions not indicative of unsatisfactory quality except in locations specified herein.

5.2.1.3 Cracks

Bolts shall be free from cracks in any direction or location. A crack is defined as a clean crystalline break passing through a grain or grain boundary, without the inclusion of foreign elements.

5.2.2 Locations

5.2.2.1 Heads

The bolt heads shall not possess seams, inclusions, or folds along the top or sides exceeding twice the depth limits shown in Table VII. Bolts having seams on the bearing surface exceeding the limits shown in Table VIII shall be rejected. Discontinuities shall not be permitted on the head-to-shank fillet.

5.2.2.2 Threads

Threads shall have no laps at the root or on the sides (Figure 6). Laps are permissible at the crest which do not exceed 20% of the basic thread depth, and on the sides outside the pitch diameter (Figure 5). Slight deviation from the thread contour is permissible at the crest of the thread as shown in Figure 5. The incomplete thread at each end of the thread may also slightly deviate from the thread contour.

TABLE VII

Bolt Size (Inches)	#10 thru 5/16	3/8	7/16	1/2
Seam Depth (Inch)	0.005	0.006	0.007	0.008

5.2.3 Sampling

Each bolt shall be inspected for discontinuities.

5.2.4 Tests

The presence of discontinuities in the bolts shall be determined by fluorescent penetrant inspection. Fluorescent penetrant indications of themselves shall not be cause for rejection. If in the opinion of the inspector, the indications are cause for rejection, representative samples shall be taken from those bolts showing indications and shall be further examined by microexamination to determine whether the indicated discontinuities are in accordance with the limits specified herein.

5.2.4.1 Fluorescent Penetrant Inspection

Fluorescent penetrant inspection shall be performed in accordance with Specification MIL-I-6866. Such inspection shall be performed, in general, on the finished bolts, but in any case subsequent to any processing which could adversely affect the part.

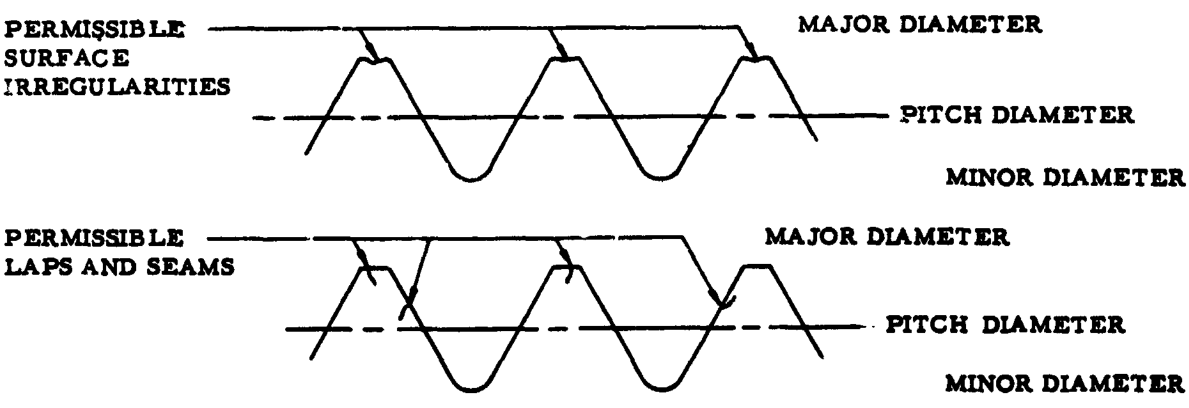

Figure 5. Permissible Laps, Seams, and Surface Irregularities.

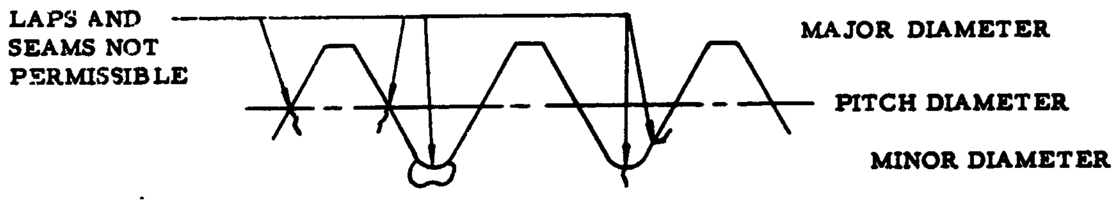

Figure 6. Non-Permissible Laps, Seams, and Surface Irregularities.

5.3 Head Structure and Grain Flow

5.3.1 Sampling

Samples for head structure and grain flow shall be determined by macroexamination in accordance with Table IV. Specimens shall be taken from the finished bolt as shown in Figure 7. The bolts shall be etched in Marble's reagent, or its equivalent, for sufficient time to reveal the macrostructure properly.

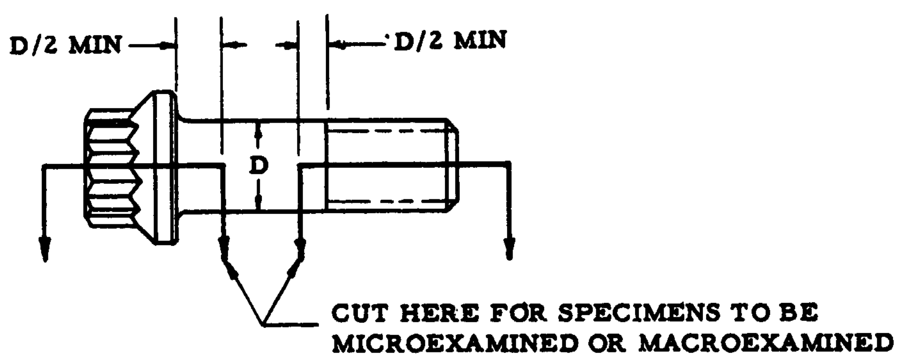

Figure 7. Metallurgical Specimens

6.0 General Tests

6.1 Classification of Tests

The inspection and testing of the bolts shall be classified as product design test and inspection test.

6.1.1 Product Design Tests

Product design tests are those tests accomplished on samples for evaluation of the product.

6.1.1.1 Sampling

The product design test samples shall consist of 20 bolts for each diameter upon which design data is required. The same samples may be used for each of the tests, provided that the known characteristics of the samples do not alter the integrity of the test involved, and provided that none of the characteristics of the bolt are altered during the test procedure.

6.1.1.2 Tests

The product design tests of bolts shall consist of all the tests of the specification. Finish, dimensions, and surface roughness shall be checked visually and by means of applicable gages. In case of controversy, gages certified by Government laboratories shall be used.

6.1.2 InspectionTests

Inspection tests are those tests accomplished on bolts manufactured and submitted for acceptance under contract.

6.1.2.1 Sampling

Random samples shall be selected for the inspection tests according to the applicable requirements of the respective tests. Sampling for threads, finish, dimensions, and surface roughness shall be at random in accordance with MIL-STD-105 Inspection Level II. The same samples may be used for each of the tests provided that the known characteristics of the samples do not alter the integrity of the test involved, and provided that none of the characteristics of the bolt are altered during the test procedure.

6.1.2.2 Tests

The inspection tests of the bolts shall consist of the following tests:

(a) Examination of the product (finish, dimensions, and surface roughness)
(b) Tensile tests
    1. Axial and angle block at -423°F and room temperature (ClassI)
    2. Axial at room temperature and 1200°F (Class II)
(c) Metallurgical examination (work effect, head structure and grain flow, cracks, and discontinuities)
(d) Hardness test

(e) Stress rupture test
(f) Double shear tests
    1. -423°F and room temperature (Class I)
(g) Tension Impact Tests at -423°F and room temperature (Class I)

6.2 Lots

A lot shall consist of finished bolts which are of the same part number, fabricated by the same process from the same mill heat of steel, and heat treated as one batch.

6.3 Responsibility of Tests

The vendor shall be responsible for accomplishing the required tests. When government inspection is conducted at the vendor's plant, all inspection shall be under the surveillance of the Government Inspector. The vendor shall maintain a record available to the Inspector or customer of the quantitative results of all tests required by this specification.

6.4 Rejection and Retest

If any sample of a given lot fails to conform to the acceptance requirements specified herein for threads, finish, and dimensions, the lot shall be rejected, or at the discretion of the Inspector, each bolt of the lot shall be reinspected for the test property in which it failed, and all defective bolts rejected.

6.5 Classification of Defects

The classification of defects shall be in accordance with Table VIII.

TABLE VIII

CLASSIFICATION OF DEFECTS

Classification	AQL	Dimensional Characteristics
Major	1.5 percent	Thread size and form Shank diameter Imperfect threads Grip length Radius under head Drilled holes in head missing (when required) Squareness between head and shank (bearing surface) Straightness of shank Surface roughness Burrs and tool marks Surface finish Identification
Minor A	2.5 percent	Over-all length Head diameter Head height Lightening hole dimensions Concentricity of head and shank Concentricity of shank and thread pitch diameter Drilled hole diameters and location
Minor B	4.0 percent	Chamfer of thread end Flange height

7.0 **Preparation for Delivery**

7.1 The packaging, packing and marking requirements shall be as specified in Specification SPS-U-128.

APPENDIX I

TEST PROCEDURES AND EQUIPMENT

I. 1. Tensile

I. 2. Tension Impact

I. 3. Double Shear

I. 4. Tension-Tension Fatigue

I. 5. Stress Rupture

I. 6. Stress Relaxation

I. 7. Nut Reuse and Galling Tendency

I. 8. Alma #10 Vibration

I. 9. Torque Versus Induced Load

I. 10. Stress Durability

I. 11. Corrosion Resistance

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TEST PROCEDURES AND EQUIPMENT

I.1.0 Tensile

The tensile tests were conducted in accordance with ASTM E-8-61 T designation on Tinius Olsen Universal Testing Machines employing a uniform loading rate of 65,000 psi per minute for bolts and .005 inches per inch per minute for specimens. For the bolt and companion nut tests, the nuts were assembled on the bolts leaving two to three threads unengaged prior to testing.

I.1.1 Tensile Test Specimens

I.1.1.1 Smooth Specimens

To evaluate the base alloy from which the bolts were fabricated, standard tensile test specimens in accordance with ASTM E-8-61 T designation were machined from finished bolts. The specimen is shown in Figure I.1.

I.1.1.2 V-Notch Specimens

V-notch specimens with a stress concentration factor of K_t8 were machined from finished bolts. The specimen is shown in Figure I.2. The K_t8 stress concentration factor was in accordance with the contract requirements.

I.1.2 Yield Strengths

Material yield strengths were determined by the 0.2 per cent offset method described in ASTM designation A370-61T. Bolt yield strengths were determined using Johnson's two thirds approximation method. Figure I.3 shows how these methods were accomplished for determining yield strengths.

Standard methods with Tinius Olsen "S" type extensometers attached to the test specimen were used for determining the room temperature yield strengths. This type of extensometer exceeds the requirements of the ASTM B-1 type. At cryogenic and elevated temperatures, alternate methods as shown in Figure I.4 and I.5 were used for plotting stress-strain curves for the determination of yield strengths. In the case of cryogenic tests, the adapters for the extensometer were attached to the undercut section of the .357 specimens and to the full shank of .113 inch and .252 inch specimens. For bolts, it was attached to the bushing adapters at the bearing surfaces of the bolt and nut.

I. 1. 3 Elongation

The per cent elongation was determined using a gage length of 4D, where D was the specimen diameter. The gage lengths employed were 0.5 inches for .113 inch specimens, 1.0 inch for .252 specimens, and 1.4 inches for .357 inch specimens.

I. 1. 4 Angle Block Tensile Tests

The angle block tensile tests were run using a hardened (Rc 47-50) 3° angle bushing at the bearing surface of the nut as shown in Figure I.6

I. 1. 5 Preload

Preload determinations for the point drive fasteners were conducted at room temperature using the fixture shown in Figure I.7 Prior to assembly, shims were inserted at the joint surfaces. The fasteners were then installed and tested in tension on a tensile machine. While the load was being applied, a pull of approximately five pounds was exerted on the shims until they could be moved, at which point the load was recorded and determined as the preload.

I. 1. 6 Stress Calculations

The cross sectional areas used for determining the stress values of threaded fasteners varied, depending on the type of fastener tested. The selection of areas was in accordance with SPS Specification Q-1003, "Calculation Procedure for Areas and Stress Values for Threaded Fasteners". The basis of these calculations is that they closely approximate the stress values obtained from smooth specimens fabricated from the same material and heat treatment. The calculation procedures for determining areas used in the test programs were as follows:

I. 1. 6. 1 Cross Sectional Area

$$A = \pi R^2$$

Where: $R = \dfrac{\text{Nominal Diameter}}{2}$

I. 1. 6. 2 Area at Basic Pitch Diameter

$$A = .785398\ (\text{Basic Pitch Diameter})^2$$

Where: $.785398 = \dfrac{3.1416}{4}$

Basic Pitch Diameter = From H-28 Screw Thread Standards for Federal Service

I. 1. 6. 3 Tensile Stress Area of External Threads

$$A = \pi \left(\frac{E}{2} - \frac{3H}{16}\right)^2$$

Where: E = Basic Pitch Diameter
H = Height of Thread to Sharp V

I. 1. 6. 4 Tensile Stress Area of .003 Reduced Pitch Diameter

$$A = \pi \left(\frac{E}{2} - \frac{3H}{16}\right)^2$$

Where: E = Basic Pitch Diameter minus .003 inches
H = Height of Thread to Sharp V

I. 1. 7 Cryogenic Temperature Tests

The cryogenic tensile tests were conducted using a cryostat shown in Figure I. 8. For the -423°F tests, the test specimens were completely submerged in liquid nitrogen (LN_2) for a minimum period of three minutes, after which the LN_2 was immediately purged out with helium gas and replaced with liquid hydrogen (LH_2). The test specimens were then kept submerged in the LH_2 for a period of three minutes before the test was initiated. The only deviation from this procedure was for the #10 and 1/4 inch fastener. These were subsequently held for one minute while immersed in the LH_2.

For the -320°F tests, the test specimens were assembled in the cryostat, which in turn was filled with LN_2. The test specimens were submerged in the LN_2 for three minutes before the test was initiated. Figure I. 9 shows the cryostat in conjunction with a 60,000 pound tensile machine.

I. 1. 8 Elevated Temperature Tests

Tensile tests at elevated temperatures were conducted, employing an infra-red furnace. The maximum utilization temperature of all fasteners tested was reached within one minute and held for ten minutes before the test was initiated. The infra-red furnace in conjunction with a 30,000 pound tensile machine is shown in Figure I. 10

I.2.0 Tension Impact

The tension impact tests were conducted on a Tinius Olsen Impact Machine shown in Figure I.11. The procedures and equipment used were based on ASTM Designation E23-60. Dimensional drawings of the fixtures and adapters are shown in Figure I.12. For the -320°F and room temperature tests, the test setup illustrated in Figure I.13 was used. For -423°F tests, the test setup shown in Figure I.14 was used. With the exception of the transfer line for the cryogenic liquid, the -320°F and -423°F tests were identical.

For the cryogenic tests, the determination of test temperature was obtained employing a Copper-Constantan thermocouple in conjunction with a Leeds and Northrup Portable Precision Potentiometer capable of recording cryogenic temperatures. Prior to testing, a hole was drilled in the center of a 3/8 inch test bolt and the Copper-Constantan thermocouple inserted in it. The test bolt with the thermocouple was then placed in a cryostat, and the cryostat in turn was attached to the test adapter of the impact machine. The cryostat was filled with either LN_2 or LH_2, depending on the test temperature, making sure the cryogenic liquid did not come in contact with the thermocouple. This was accomplished by enclosing the thermocouple in plastic tubing and attaching by means of an interference fit to the bolt head. The junction at which temperatures were recorded was located at a point midway between the thread runout and thread point of the bolt. A recorded temperature at both -320°F and -423°F was attained after 15 seconds immersion. For the actual tests, the bolts were held at the cryogenic temperature for a period of one minute prior to testing. As near as could be determined visually, the bolt threads were still immersed in the cryogenic liquids of LN_2 and LH_2 at the moment of impact.

I.3.0 Double Shear

The double shear tests were conducted using the fixtures shown in Figures I.15 & I.16. The test setup was similar to the requirements of NAS 498 specification except that the bearing surface of the inserts was equal to the diameter of the fastener tested. The test fixtures were fabricated from Vasco Max 300 (18 percent nickel maraging steel) for #10 and 1/4 inch fastener cryogenic tests and A-286 for 3/8 and 1/2 inch fastener cryogenic tests. AF 1753 alloy was used for the elevated temperature fixtures.

I.3.1 Cryogenic Temperature Tests

These tests were conducted the same as those outlined for tensile tests in section 1.7.

I.3.2 Elevated Temperature Tests

Elevated temperature tests required that the maximum utilization temperature of each fastener be reached within one minute. In preliminary tests, a thermocouple was placed at the center of the test specimen and one at the end as shown in Figure I.17 to determine the variance in temperature between the two points and the time required to reach unity at the test temperature. The results showed that the time required to reach unity for the 1/4 inch and 1/2 inch diameter fasteners at 1600°F was four and six minutes respectively.

Subsequently, the #10 and 1/4 inch diameter fasteners were held for 14 minutes at maximum temperature while the 3/8 and 1/2 inch diameters were held for 16 minutes. Figure I.18 shows the test fixture and location of thermocouples in conjunction with the infra-red furnace for elevated temperature double shear tests.

I.4.0 Tension-Tension Fatigue

The tension-tension-fatigue tests were conducted at room temperature on a 15,000 pound Krouse Fatigue Machine for the #10, 1/4, and 3/8 inch fasteners and on a 60,000 pound Ivy Fatigue Machine for the 1/2 inch fasteners. Both machines ran at an approximate rate of speed of 1200 cycles per minute.

Fatigue life at one stress level was determined. The maximum stress used was derived from existing fatigue specifications for the particular fastener assembly, and where none existed, a maximum stress of 52 per cent of the rated ultimate strength of the fastener assembly was used. The maximum stresses were derived from existing S/N curves where an average fatigue life of 65,000 cycles was required. Minimum load for all tests was 10 per cent of the maximum load.

I.5.0 Stress Rupture

These tests were run on Arcweld Stress Rupture Machines shown in Figure I.19. These machines employ a lever arm that has a ratio of 20:1. Load is applied by dead weights that insure a constant load for the duration of the test. The fixtures shown in Figure I.20 are fabricated from super alloys of Waspaloy, L605 and AF 1753 capable of withstanding the test load without deformation at test temperatures up to 1600°F and provide uniaxial loading conditions.

I.6.0 Stress Relaxation

The stress relaxation tests were conducted employing cylinders fabricated from the same material as the bolt. The exceptions to this procedure were the Ti 8-1-1 fasteners which were tested with Ti 6-4 cylinders and the Inconel 718 fasteners which were tested with U 500 cylinders. These cylinder materials were used because their coefficients of thermal expansion matched the fasteners tested.

The initial preloads employed were fifty and eighty per cent of the room temperature yield strengths as determined from torque versus induced load tests. The loads closely approximate the actual loads that could be induced in a joint in normal application. Figure I.21 shows the mean load as the recommended seating torque which is usually applied by a torquing device that has a tolerance of plus or minus 20 percent. Inititally, a preload of 90 percent was anticipated in the work conducted in 1964, but tests employing this load indicated fastener assemblies in some cases exceeded their elastic limit at room temperature. Therefore, the high initial preload was decreased to 80 percent. The preloads were converted into the stress the fastener assemblies actually experienced at the test temperature. Figure I.22 shows how this was accomplished.

I.6.1 Determination of Residual Stresses

I.6.1.1 Nomenclature

L - Load
E - Elongation
l_0 - Initial Bolt Length
l_1 - Loaded Bolt Length
l_2 - Exposed, Loaded Bolt Length
l_3 - Exposed, Unloaded Bolt Length
l_4 - $l_1 - l_2$
l_5 - $l_3 - l_0$
l_6 - $l_4 - l_5$

I.6.1.2 Formula

$$\text{Elongation} = \frac{\text{Load X Length}}{\text{Cross Sectional Area X Mod. of Elasticity}}$$

I.6.1.2.1 From the torque versus induced load curve the desired 50 percent and 80 percent yield strengths were obtained, (L).

I.6.1.2.2 From the companion fastener tensile load extension curve the elongation (E) required for the desired load (L) was determined.

I.6.1.2.3 Both ends of the bolts were spot drilled and the length measured (l_0) on a Pratt and Whitney Super Micrometer.

I.6.1.2.4 The fastener assemblies were loaded in the cylinders to the elongation established in (I.6.1.2.2).

I.6.1.2.5 The assemblies were then exposed to their maximum utilization temperature in an electric furnace for the desired period of time.

I.6.1.2.6 The assemblies were cooled to room temperature and the length was measured while still in the stressed condition (l_2).

I.6.1.2.7 The assembly was disassembled and the bolt length measured (l_3).

I.6.1.2.8 Joint relaxation was then calculated (l_6).

I.6.1.2.9 From the modulus of elasticity data of the fastener material, load extension curves were plotted at the test temperature the fastener assembly was exposed to.

I.6.1.2.10 From (l_6) and the curve in (i), the residual stress at temperature was determined.

I.6.1.3 Example

Bolt	- EWB 1615-4-38
Nut	- FN 1418-428
Size	- 1/4-28
Material	- Waspaloy (150 KSI)
Test Temperature	- 1400°F
Time	- 10 hours

L - 2,342 pounds
E - .0039 inches
l_0 - gauge plus .9045
l_1 - .9084
l_2 - .9078
l_3 - .9051
l_4 - $l_1 - l_0$ = .9084 - .9078 = .0006
l_5 - $l_3 - l_0$ = .9051 - .9045 = .0006
l_6 - $l_4 + l_5$ = .0006 + .0006 = .0012
Residual Elongation = .0039 - .0012 = .0027
From Figure I.23-Residual Load = 1,350 pounds

I.6.1.4 Calculations for Determining Initial Stress for Paragraph 6.1.3 as shown in Figure I.23.

Preload A - 3903 pounds
Shank Area - .049 square inches - shank length = 2.375 inches
Thread Area - .03256 square inches - thread length = .250 inches
Modulus of elasticity at 70°F - 31.9×10^6 psi
Modulus of elasticity at 1400°F - 24.6×10^6 psi

At 70°F with a load of 3903 pounds:

$$\text{Elongation of shank} - \frac{3903 \times 2.375}{.049 \times 31.9 \times 10^6} = .0059 \text{ inches}$$

$$\text{Elongation of thread} - \frac{3903 \times .250}{.03256 \times 31.9 \times 10^6} = .00095 \text{ inches}$$

At 1400°F with a load of 3903 pounds:

$$\text{Elongation of shank} - \frac{3903 \times 2.375}{.049 \times 24.6 \times 10^6} = .0077 \text{ inches}$$

$$\text{Elongation of thread} - \frac{3903 \times 2.50}{.03256 \times 24.6 \times 10^6} = .0012 \text{ inches}$$

For a load of 3903 pounds:

70°F elongation - .0059 + .00095 = .00685 inches
1400°F elongation - .0077 + .0012 = .0089 inches

Initial stress at 1400°F = 3,000 pounds

I.6.1.5 Machine Relaxation Tests

The point drive fastener assemblies were tested on Arcweld Stress Relaxation Machines. These machines maintain a constant distance between the bearing surfaces of the bolt head and nut face and plot the change in load on a continuous time - temperature chart.

I.6.1.6 Effects of Relaxation Tests

The fastener assemblies subjected to the fifty hour relaxation tests were subsequently tested in tension and shear at room temperature to determine the effects of the relaxation tests on the mechanical properties.

I.7.0 Nut Reuse and Galling Tendency

Nut reuse and galling tendency tests were conducted simultaneously. The test procedure employed was similar to AMS 7250 Specification except that the tests were conducted only at room temperature. The fastener assemblies were seated in hardened steel cylinders of H-11 material (Rc 49) at 54 percent of the rated ultimate strength of the fastener assembly. The loads were determined by elongation using a Pratt and Whitney super micrometer. The application was repeated five times with the breakaway and prevailing torques being recorded after each application.

I.8.0 Alma #10 Vibration

The vibration tests were conducted on a modified Sonntag Fatigue Machine in accordance with Alma #10 specification. The test fixtures are shown in Figure I.24.

The locknuts were seated to twice their maximum locking torque requirements for four applications, at which time the test unit was relubricated, retightened, and placed in the test fixture with five similarly prepared specimens. Relubrication of the test fixture was employed only for the room temperature tests. SAE 20 oil was used. The vibration tests were conducted at 1750 to 1800 cycles per minute at an amplitude of .450 inches. The tests were run for 30,000 cycles with intermittent checks every 5,000 cycles after which the nuts were inspected for rotation and cracks. Cracks visible under 10X magnification and/or rotation exceeding 360 degrees constituted a failure.

For the -320°F tests, the test setup shown in Figure I.25 was used The -320°F temperature was obtained by completely immersing the test specimens in liquid nitrogen (LN_2) for three minutes prior to initiating the test. Throughout the test, a steady stream of LN_2 was sprayed constantly on each individual test nut. The LN_2 in the test chamber was kept at a predetermined level to insure that the test assembly on the machine would maintain resonance while the test was in progress.

The determination of the test temperature was obtained using the method described in paragraph 2.0. Figure I.26 shows the location of the thermocouple and junction where temperatures were recorded before and after testing. A recorded temperature of -320°F was attained after two minutes immersion in the LN_2 and also after 30,000 cycles. The temperature after 30,000 cycles was recorded after the LN_2 was completely evacuated from the test chamber.

I. 9. 0 Torque Versus Induced Load

The torque versus induced load tests were run on a North Bar Torque Tension Machine. For Phase I and II, the tests were run primarily for the determination of torque versus induced load yield strengths to be used in conjunction with relaxation tests. No lubricants were used. In Phase III, the torque-tension relationship was established between lubricated and unlubricated locknuts. The lubricant used for these tests was a proprietary lubricant of SPS issued under the name of SPS K3 Lube.

I. 10. 0 Stress Durability

The stress durability tests were run to determine a fastener's capability to sustain high preloads over a prolonged period of time. This test was conducted at room temperature by installing the fastener assemblies in hardened steel cylinders of H-11 material (Rc 49). The threads of the bolt, the seating surface of the bolt head, and the seating surface of the nut were lubricated with SPS K2 lubricant prior to installation. The assemblies were loaded to approximately 90 percent of the fastener assembly yield strengths. The load was determined by elongation using a super micrometer and was sustained for a minimum period of 24 hours. The fasteners were then disassembled and inspected for cracks by appropriate ASTM methods.

I. 11. 0 Corrosion Resistance

Corrosion resistance tests were conducted under accelerated salt spray and seacoast environments. The test specimens were installed in space vehicle construction material of 7075-T6 aluminum, 2219-T87 aluminum, 2014-T6 aluminum, annealed Ti 6Al-4V and annealed 321 stainless steel. Applicable seating torques were unavailable for any specific fastener assembly when installed in the previously mentioned structural materials; therefore, the fasteners were tightened, where applicable, to torques equivalent to 50 percent of the torque versus induced load yield strength of the specific fastener assembly being tested. The conditioning of the test specimens and structural material prior to the environment tests is shown in Table I. 1.

I. 11. 1 Accelerated Salt Spray Tests

The accelerated salt spray environmental tests were conducted in accordance with Federal Test Method Standard 151, Method 811. The specimens were monitored on a daily basis.

I. 11. 2 Seacoast Environmental Tests

The seacoast environmental corrosion tests were conducted at Long Beach Island, New Jersey. The specimens were situated at a distance of 190 feet from the water's edge. They were set at an angle of 45 degrees with the horizontal plane of the test station fixture and faced toward the ocean. Figure 1. 27 shows the test stand in relation to the shore line. The specimens were monitored on a bimonthly basis for the first two months and then monthly thereafter for the remainder of the contract.

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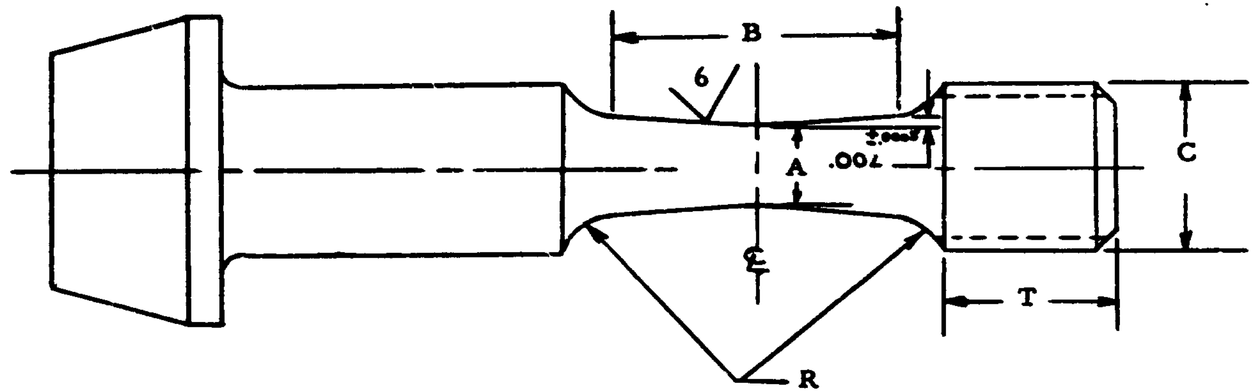


Item	A ±.002	B ±.005	C	R	T +1/4 -.000	Tracer Template
1	.505	2.25	3/4	.375	3/4	TR - 390
2	.437	2.00	5/8	.375	5/8	TR - 391
3	.357	1.75	1/2	.250	1/2	TR - 392
4	.252	1.25	3/8	.180	3/8	TR - 393
5	.113	.625	1/4	.090	1/4	TR - 424

Note - There shall be no indications of tool marks on the undercut surface. This includes the radii.

Standard Tensile Test Specimens for NASA Contract NAS8-11125

TOLERANCE UNLESS SPECIFIED
FRACTIONS ±
DECIMALS ±
ANGLES ±
SURFACE FINISH

STANDARD PRESSED STEEL COMPANY
JENKINTOWN, PENNSYLVANIA

DRAWN BY James Glackin
DATE 9-21-64

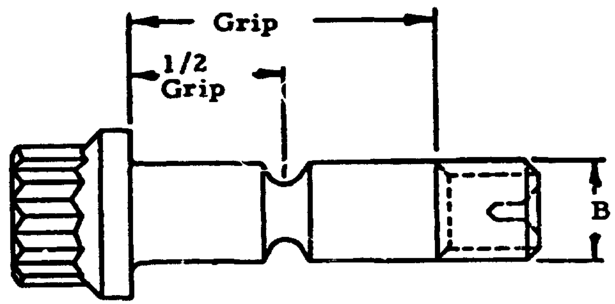
MATERIAL AND HEAT TREAT

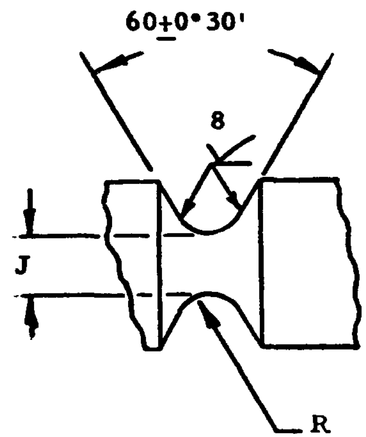
1071-1 REV. 661

Figure I.1

PD • 300 • 61036

REVISION AND DATE





V- NOTCH DETAIL

ITEM	B +.000 -.001	J ±.0005	R +.0000 -.0003
1	.250	.1765	.001

Note - 1. Diameter "J" to be concentric with diameter "B" within .001 TIR.

V-NOTCH SPECIMEN
FOR NASA CONTRACT NAS8-11125
STRESS CONCENTRATION FACTOR = K_t8

TOLERANCE UNLESS SPECIFIED
FRACTIONS ±
DECIMALS ±
ANGLES ±
SURFACE FINISH

DRAWN BY J. Glackin
DATE 2-20-64

STANDARD PRESSED STEEL COMPANY
JENKINTOWN, PENNSYLVANIA

MATERIAL AND HEAT TREAT

1071-1 REV. 861

Figure I. 2

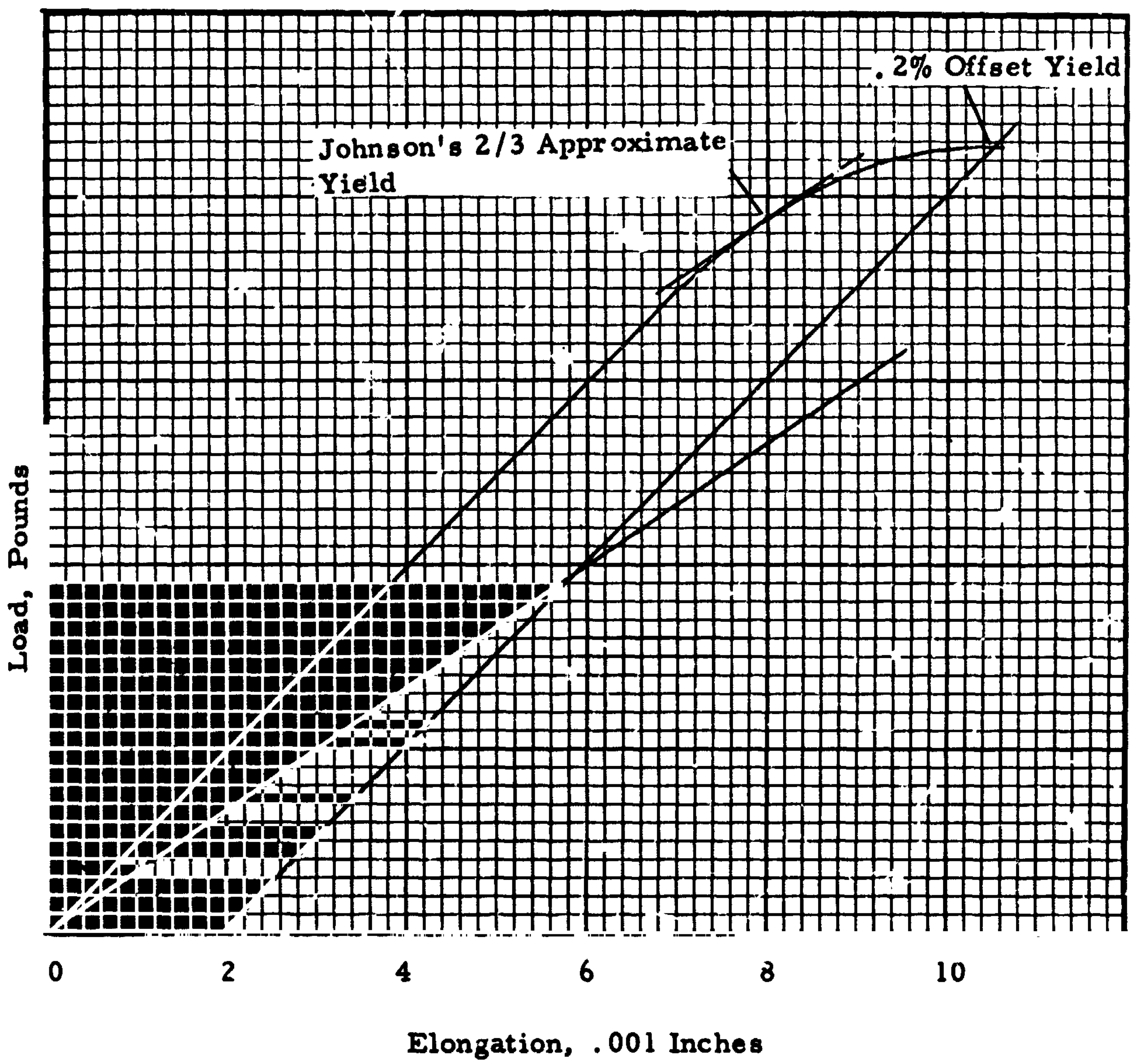


Figure I. 3   Two Yield Strength Determination Methods. Johnson's 2/3 approximate yield method is used for bolt yield determination and .2% offset yield is used for material specimen yield determination.

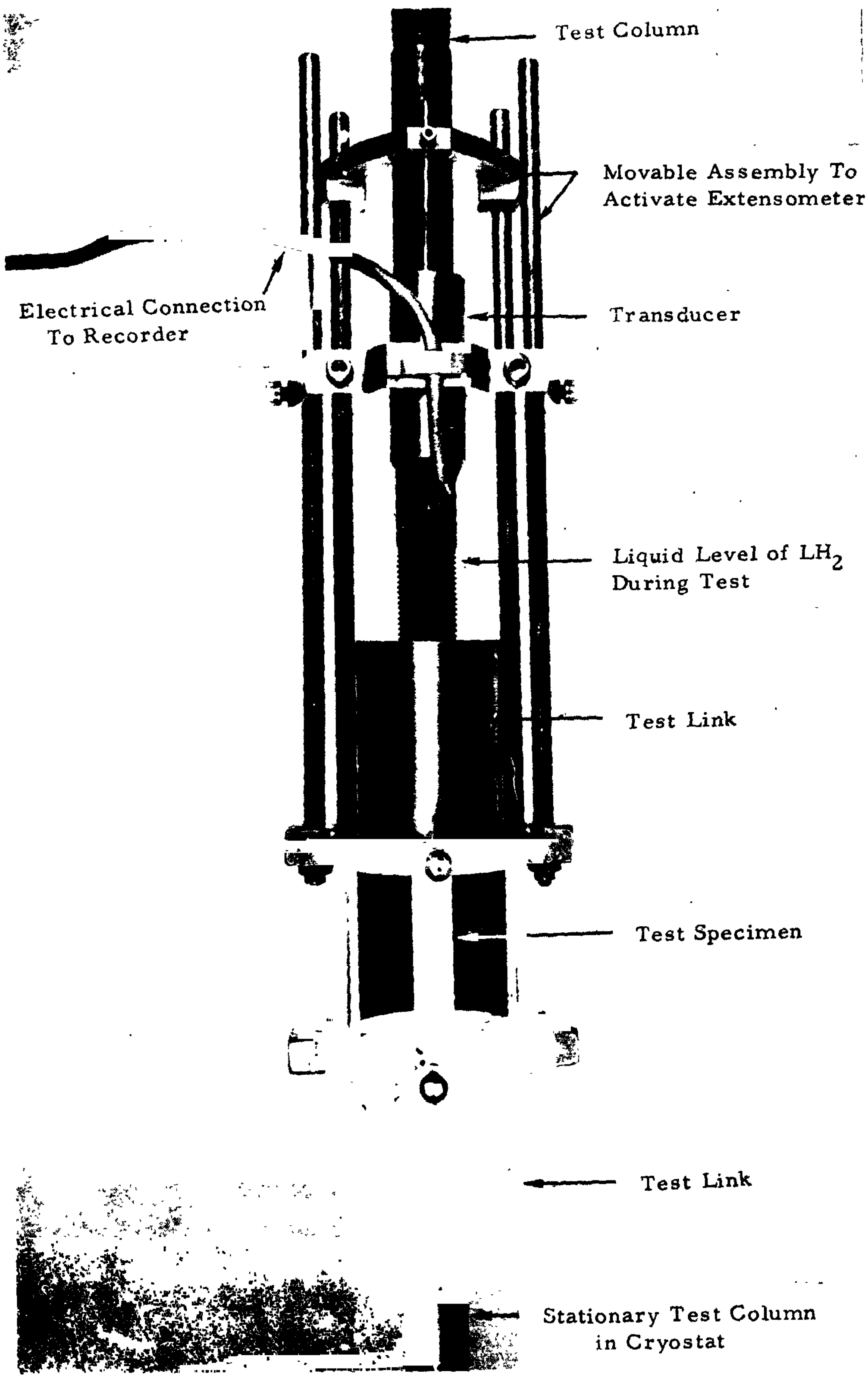


Figure I. 4 Load Extensometer Used for Plotting Stress-Strain Curves at Cryogenic Temperatures.

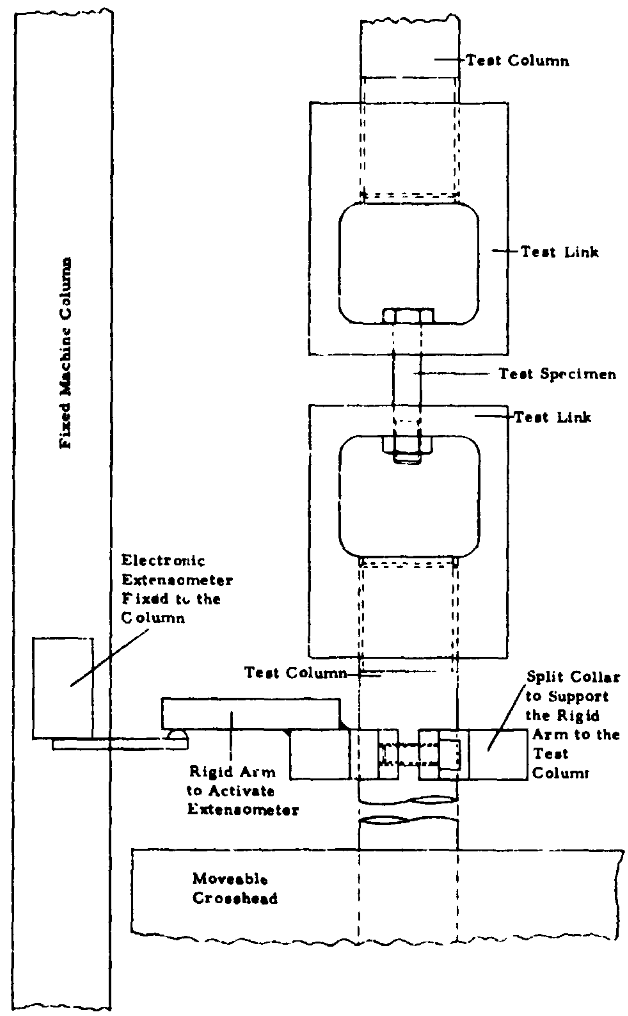


Figure I.5 Alternate Stress-Strain Plotting Method for Elevated Temperatures.

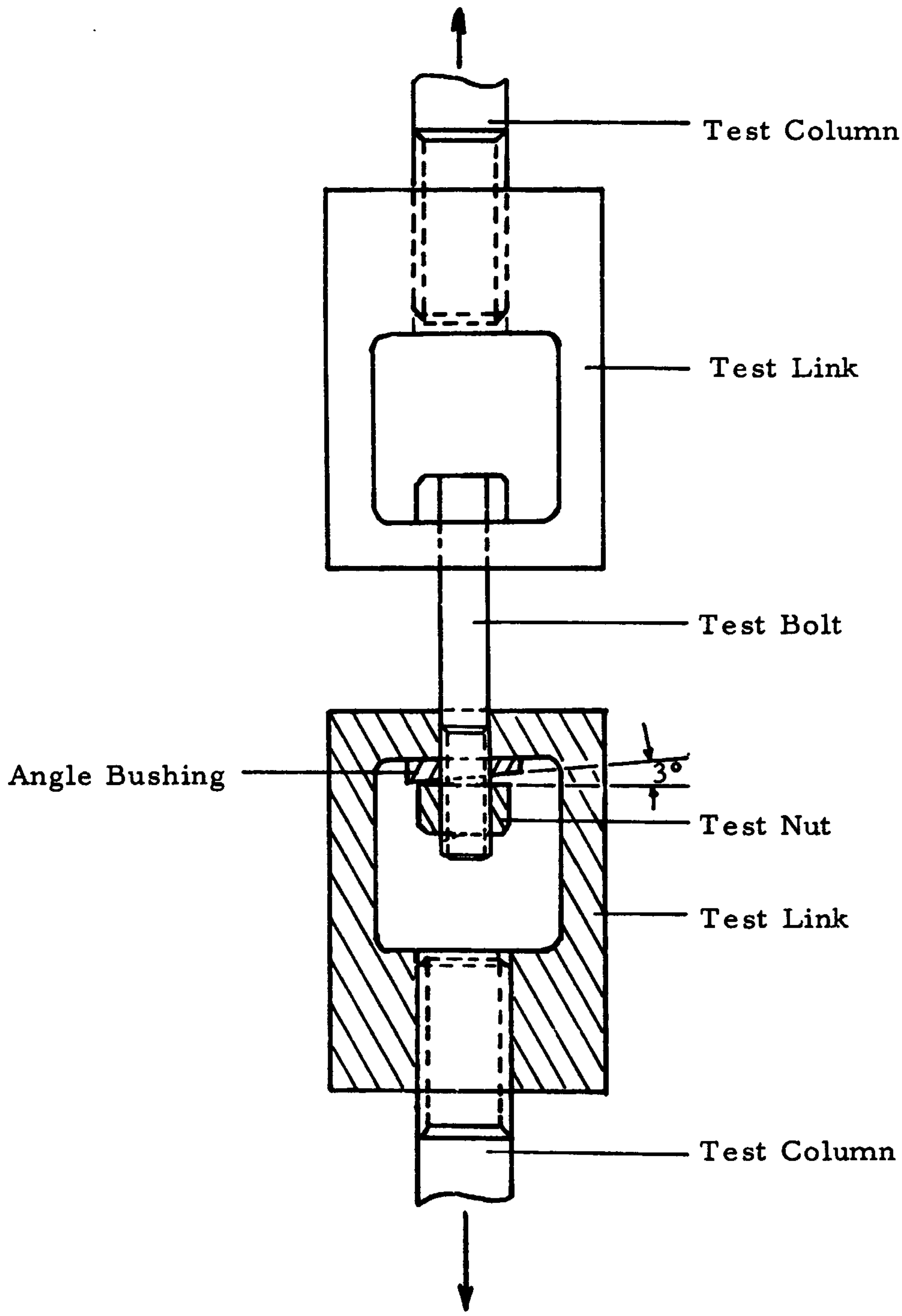


Figure I. 6 Test Setup for 3° Angle-Block Tensile Test

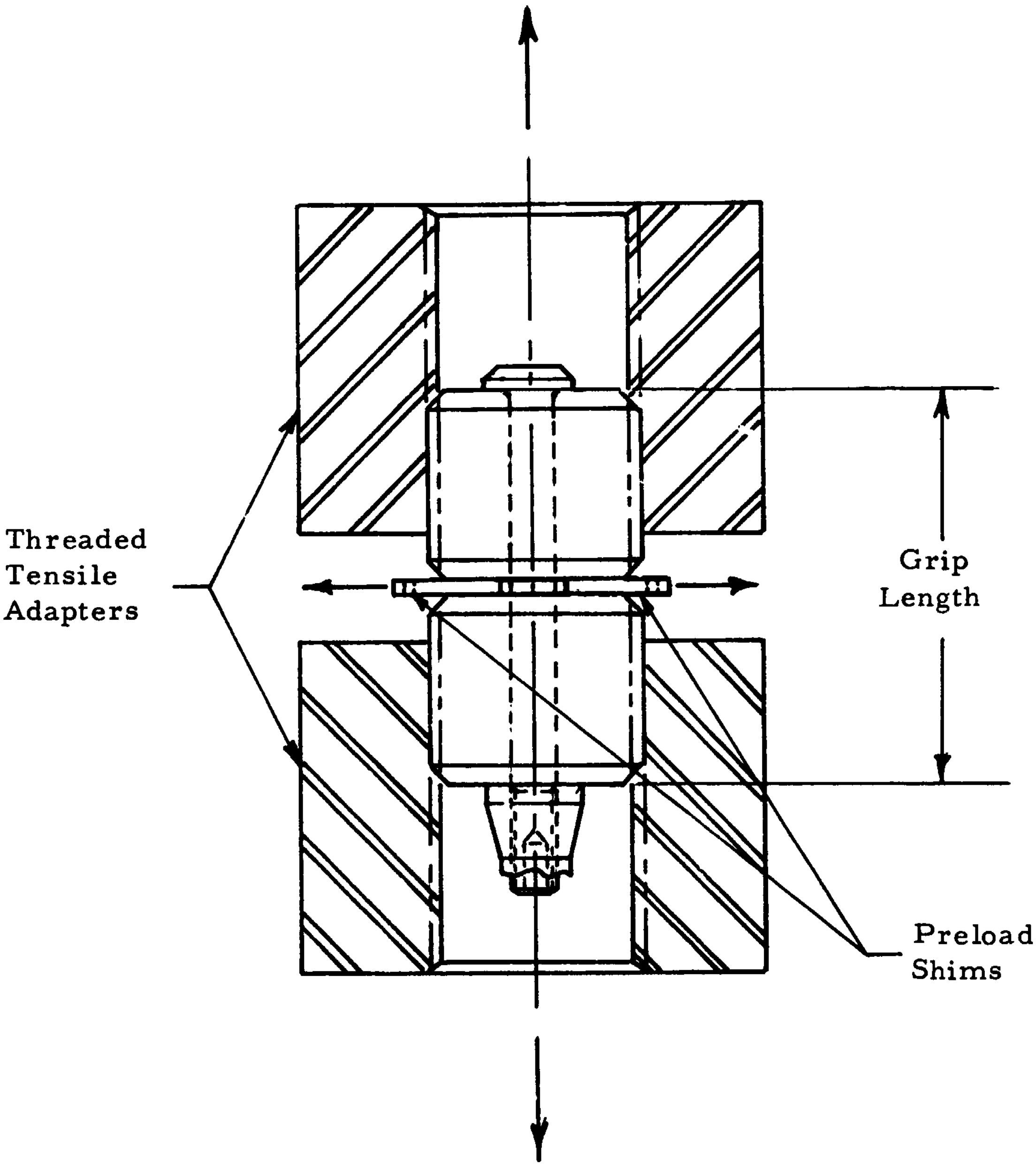


Figure I.7 Fixture Setup for Preload and Tensile Testing Point Drive Fasteners

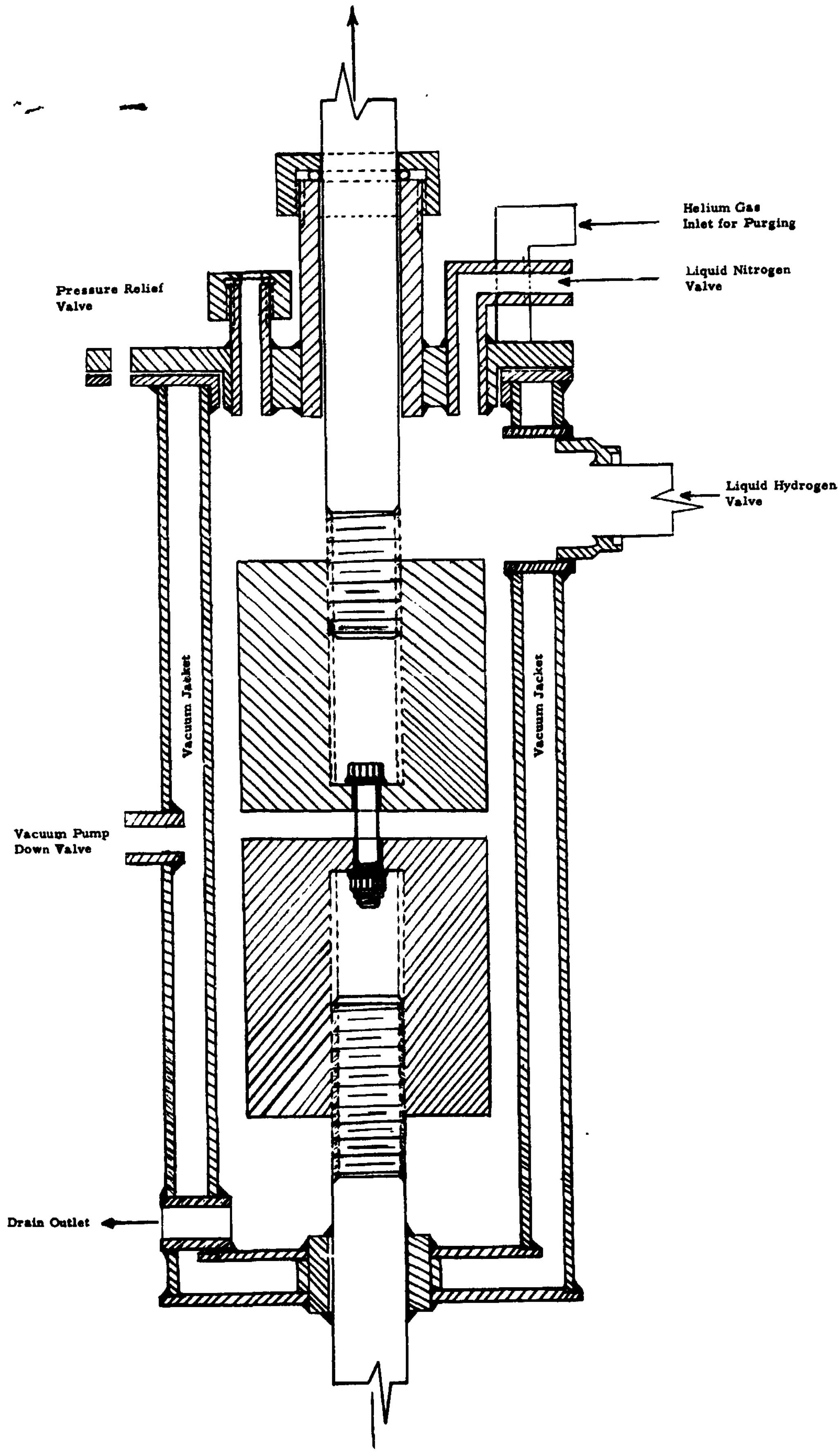


Figure I.8 Schematic Sketch of Cryostat Used for Cryogenic Tensile and Shear Tests.

Figure I.9 Cryogenic Test Station with Cryostat.

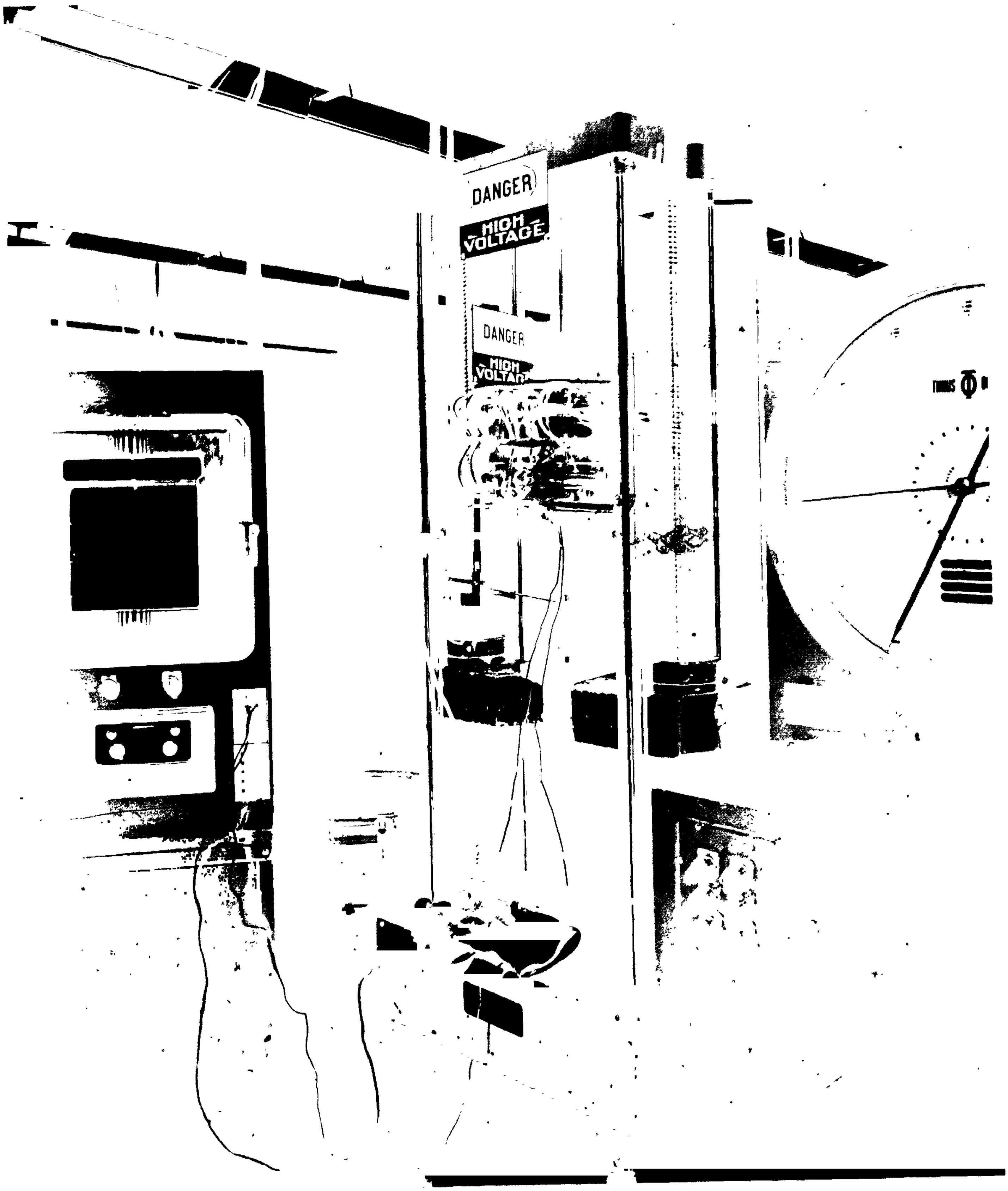


Figure I. 10 Infra-red Furnace in Conjunction with 30,000 Pound Tinius Olsen Tensile Machine.

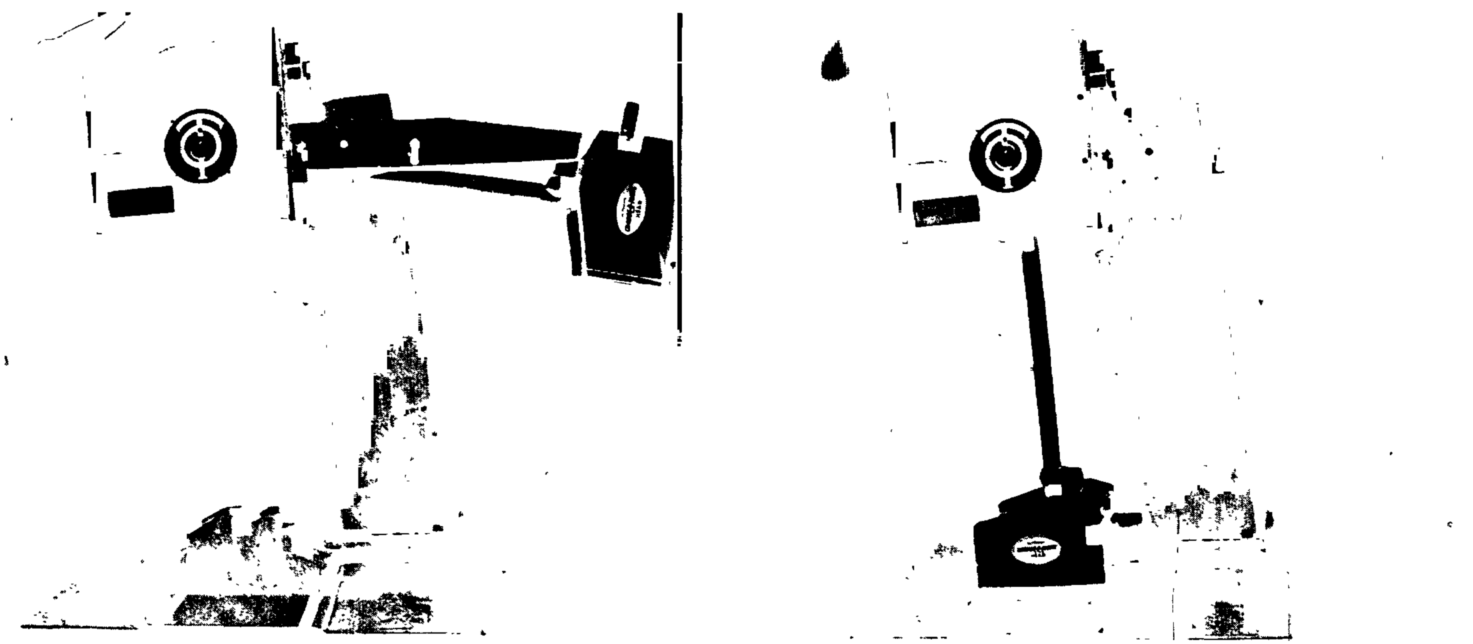


Figure I. 11 Tinius Olsen Impact Machine

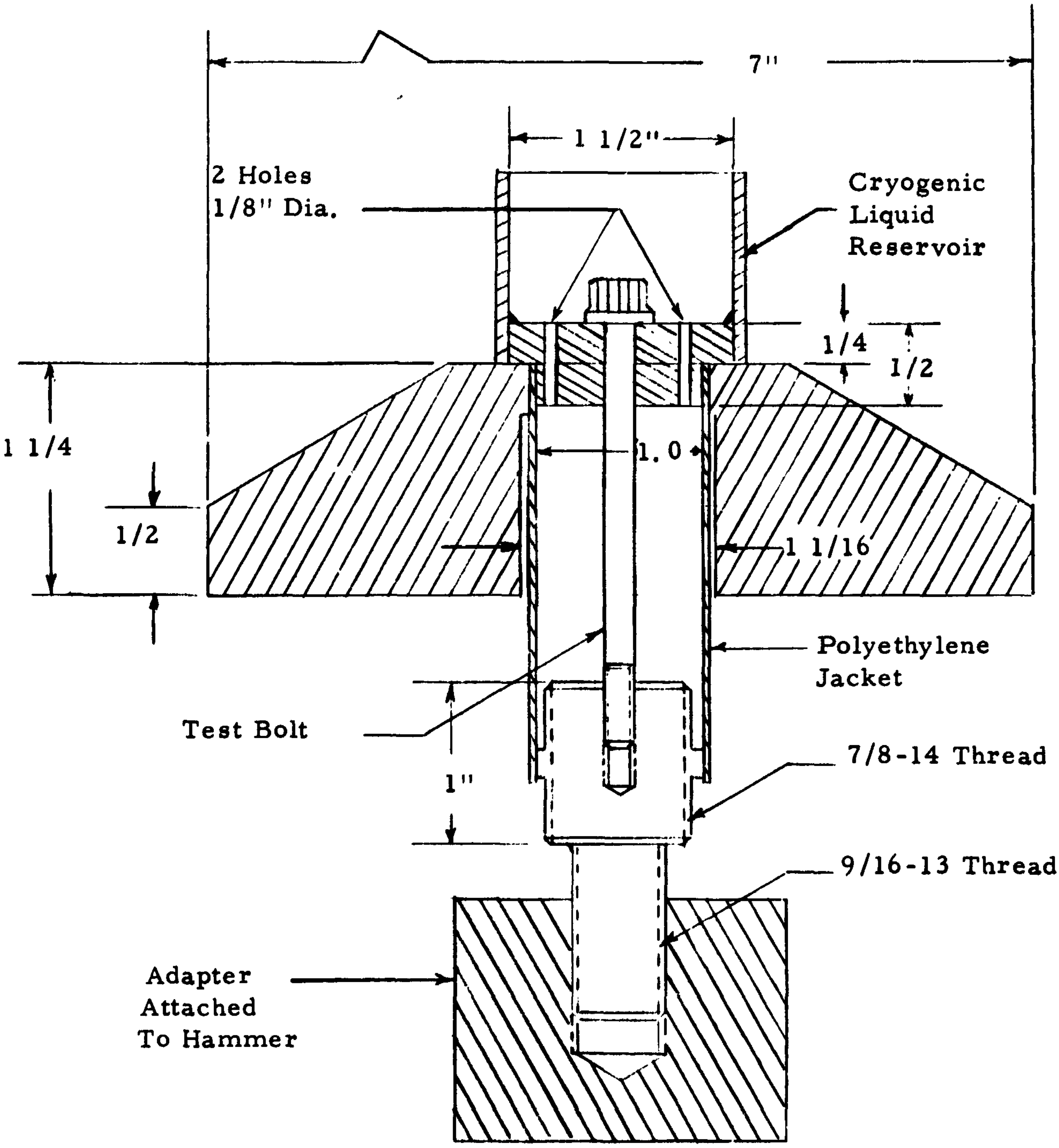
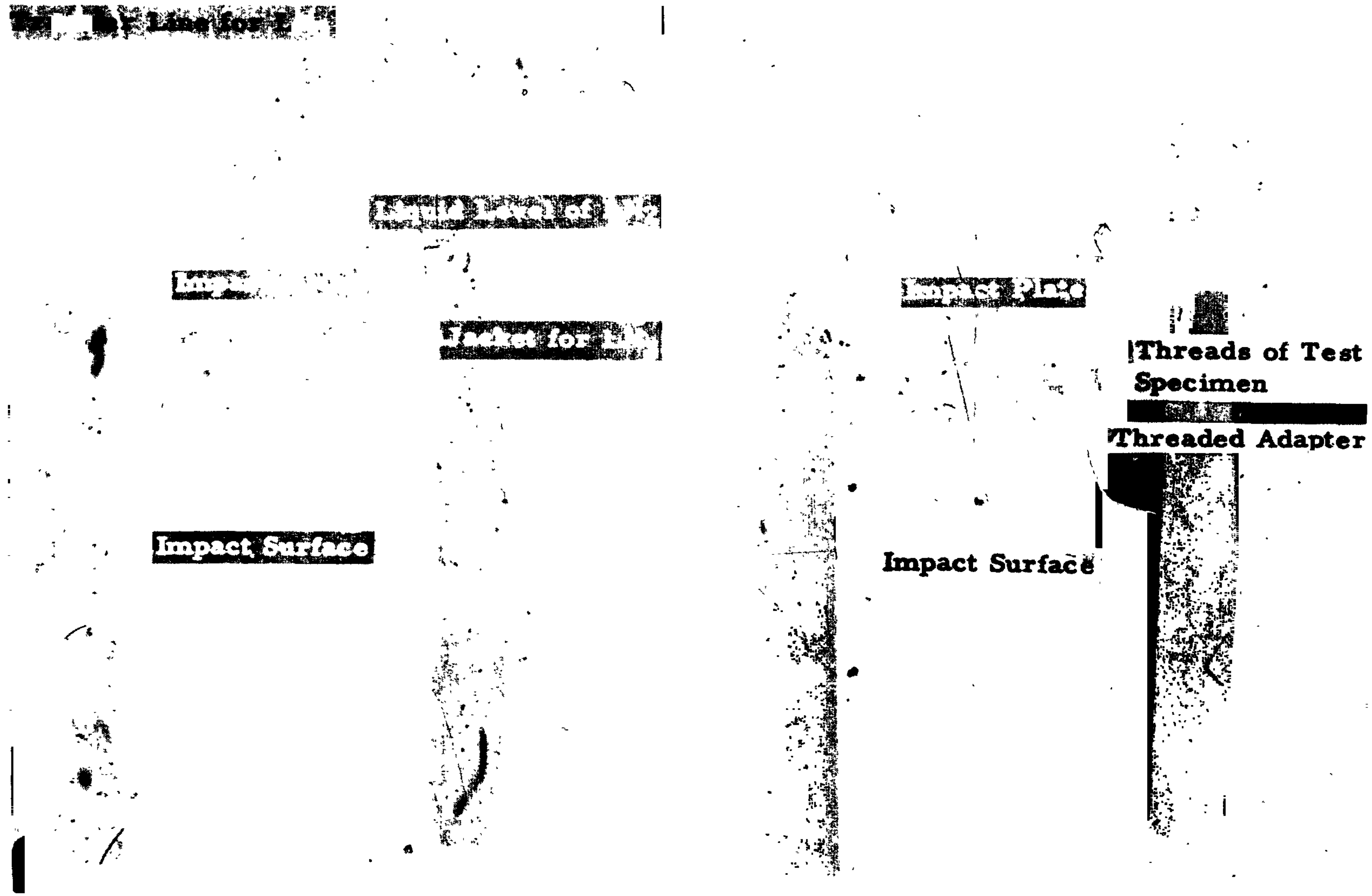


Figure I. 12. Fixtures for Tension Impact Test at Cryogenic Temperatures.



@ — 320 °F

@ Room Temperature

Figure I. 13 Test Setup for Tension-Impact Tests at -320°F and Room Temperature

Figure I. 14 Test Setup for Tension Impact Tests
at -423° F.

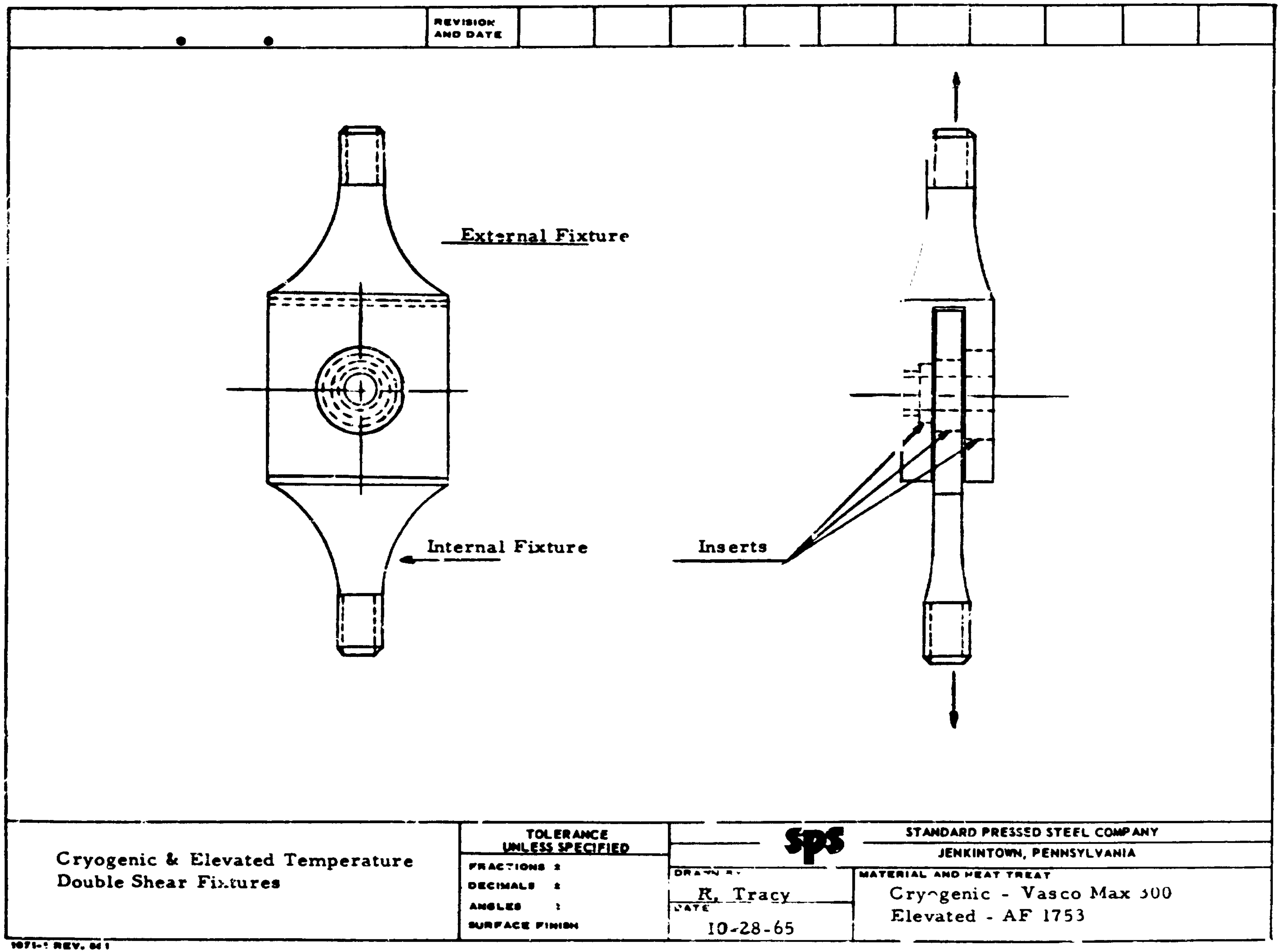
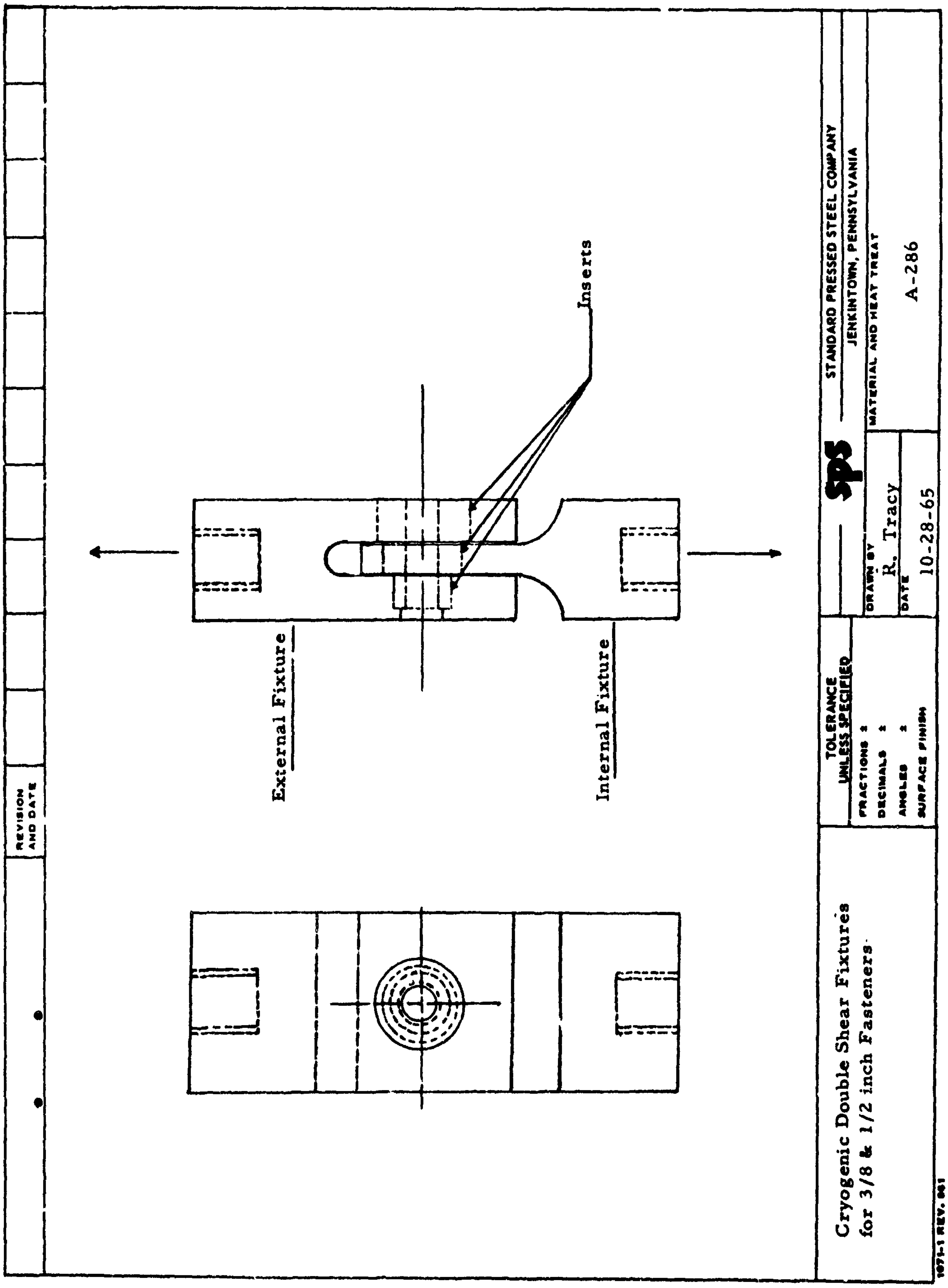

REVISION AND DATE
External Fixture
Internal Fixture
Inserts
Cryogenic & Elevated Temperature
Double Shear Fixtures
TOLERANCE UNLESS SPECIFIED
FRACTIONS ±
DECIMALS ±
ANGLES ±
SURFACE FINISH
SPS
STANDARD PRESSED STEEL COMPANY
JENKINTOWN, PENNSYLVANIA
DRAWN BY
R. Tracy
DATE
10-28-65
MATERIAL AND HEAT TREAT
Cryogenic - Vasco Max 300
Elevated - AF 1753
1071-1 REV. 861

Figure I. 15



REVISION AND DATE
Inserts
External Fixture
Internal Fixture
Cryogenic Double Shear Fixtures
for 3/8 & 1/2 inch Fasteners
TOLERANCE UNLESS SPECIFIED
FRACTIONS ±
DECIMALS ±
ANGLES ±
SURFACE FINISH
SPS
DRAWN BY
R. Tracy
DATE
10-28-65
STANDARD PRESSED STEEL COMPANY
JENKINTOWN, PENNSYLVANIA
MATERIAL AND HEAT TREAT
A-286

Figure I. 16

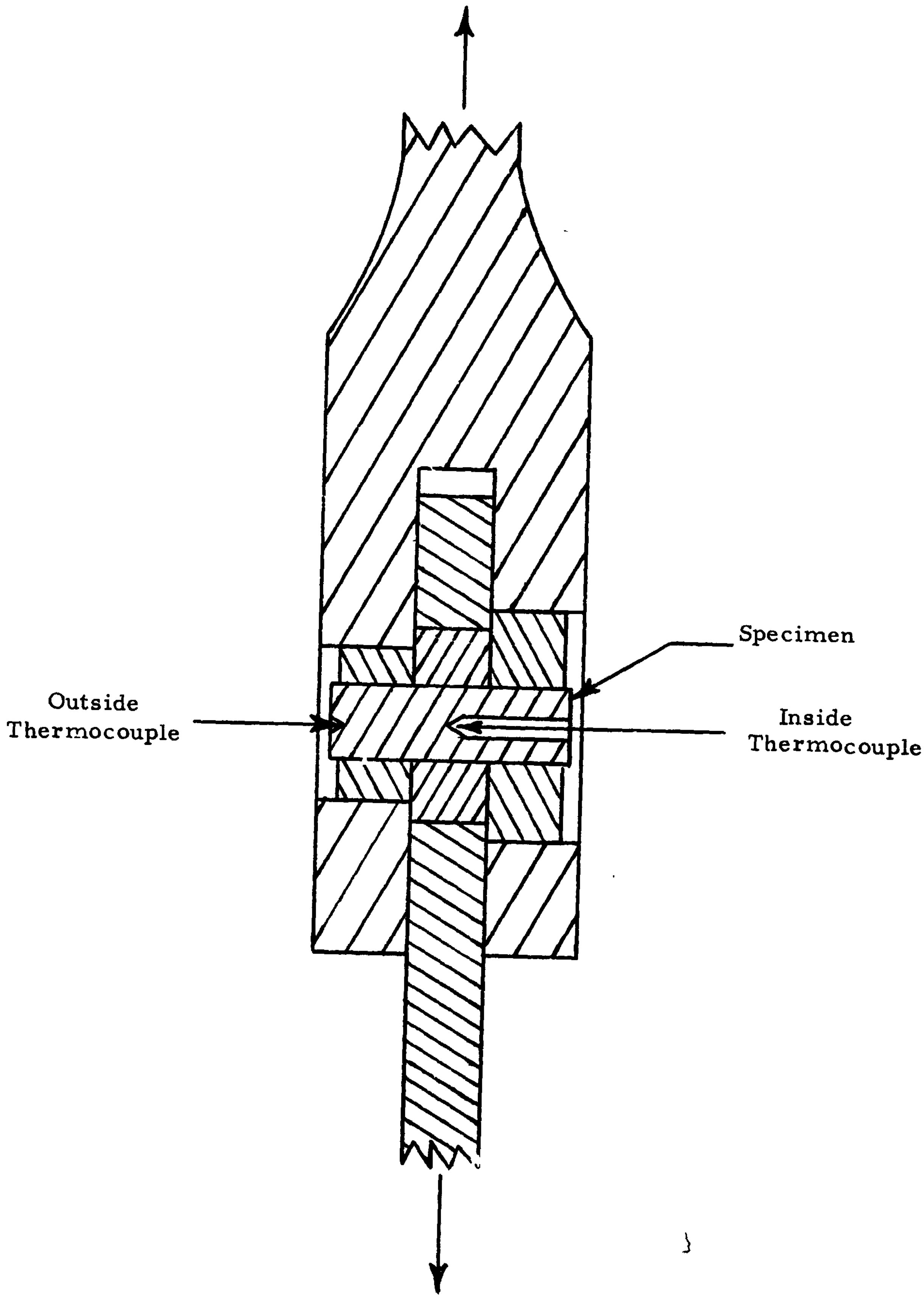


Figure I.17 Thermocouple Location for Temperature Determination for Elevated Temperature Dcuble Sheaı Tests.

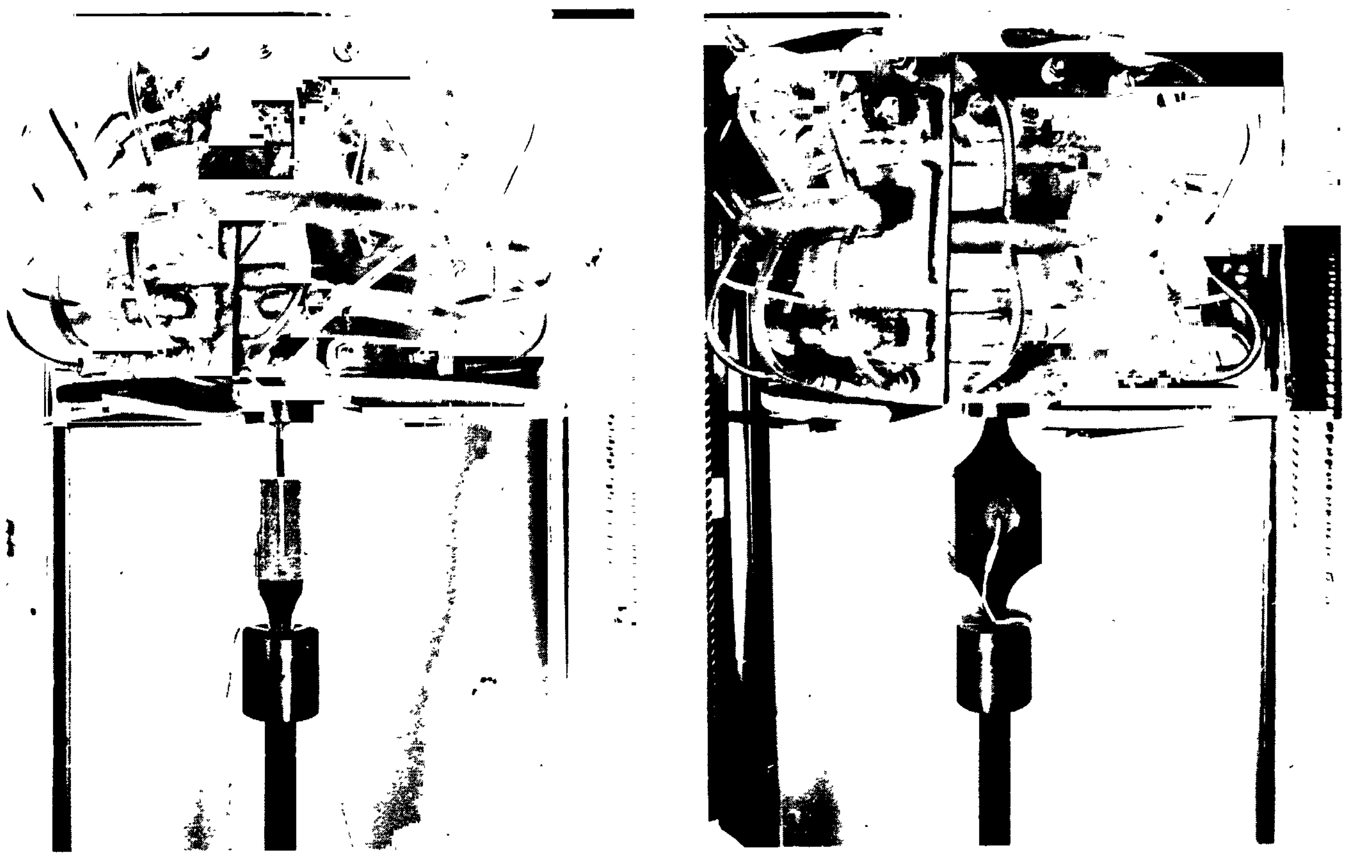


Figure 1.18 Test Setup for Elevated Temperature Double Shear Tests.

Figure I. 19 Arcweld Stress-Rupture Testing Machine-20,000 Pounds 2000°F Capacity.

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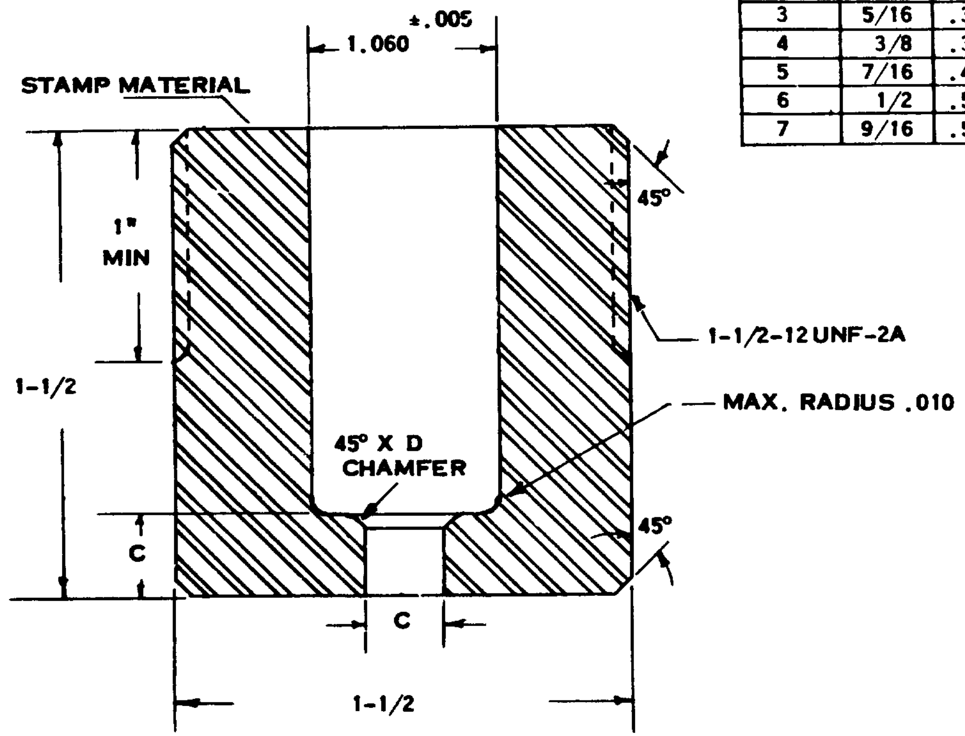
BREAK SHARP EDGES

ITEM	SIZE	C		D	
		MAX	MIN	MAX	MIN
1	#10	.200	.190	.025	.015
2	1/4	.260	.250	.025	.015
3	5/16	.322	.312	.040	.030
4	3/8	.385	.375	.040	.030
5	7/16	.450	.440	.040	.030
6	1/2	.510	.500	.040	.030
7	9/16	.572	.562	.040	.030



Stress Rupture Fixture	TOLERANCE UNLESS SPECIFIED FRACTIONS ± 1/16 DECIMALS ± .010 ANGLES ± 2° SURFACE FINISH	S·P·S DRAWN BY A. MARCHANT DATE 11/18/59	STANDARD PRESSED STEEL COMPANY JENKINTOWN, PENNSYLVANIA MATERIAL AND HEAT TREAT PER ORDER

Figure I.20

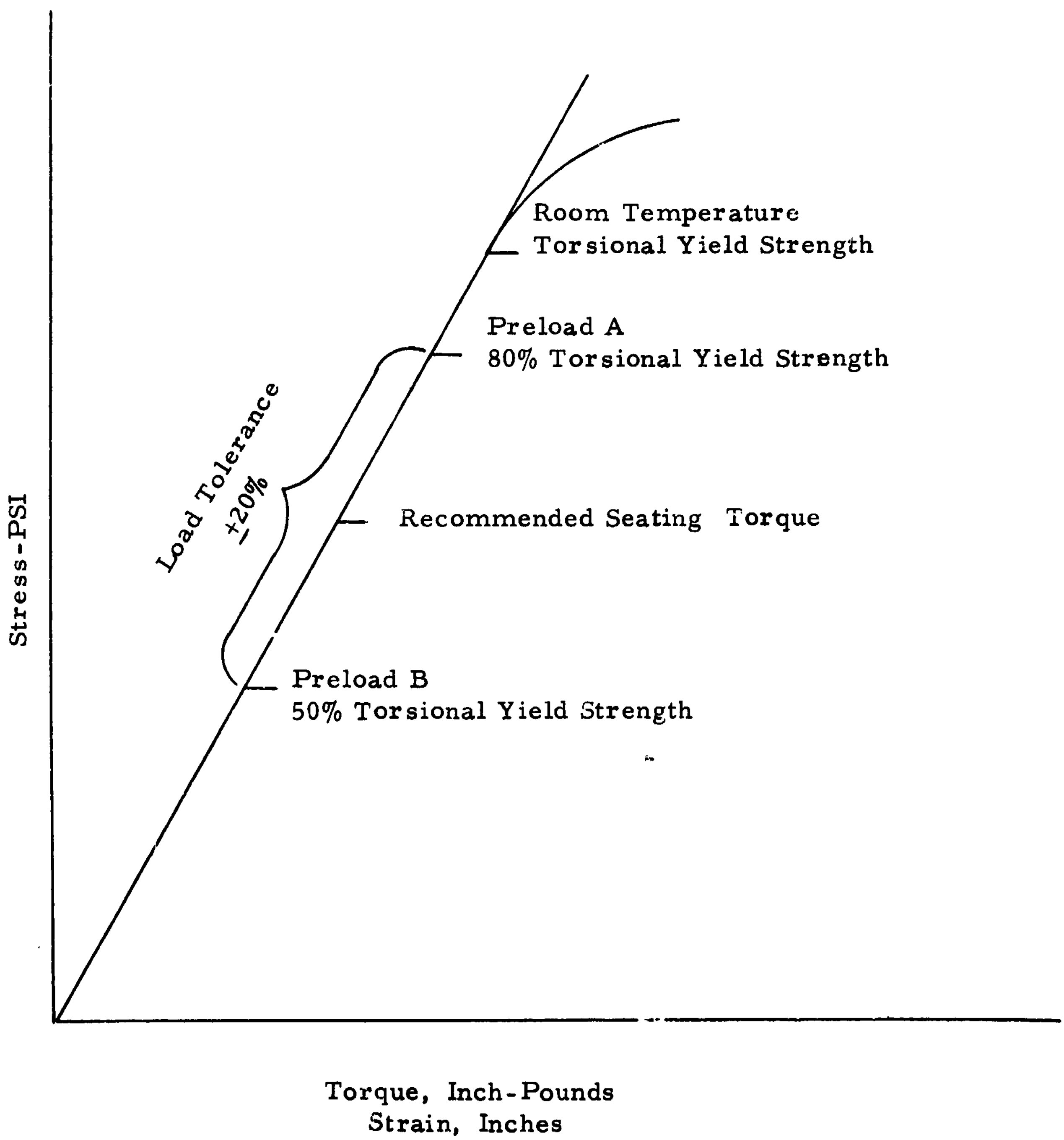


Figure I. 21 Method for Determining Preloads for Relaxation Tests with Cylinders.

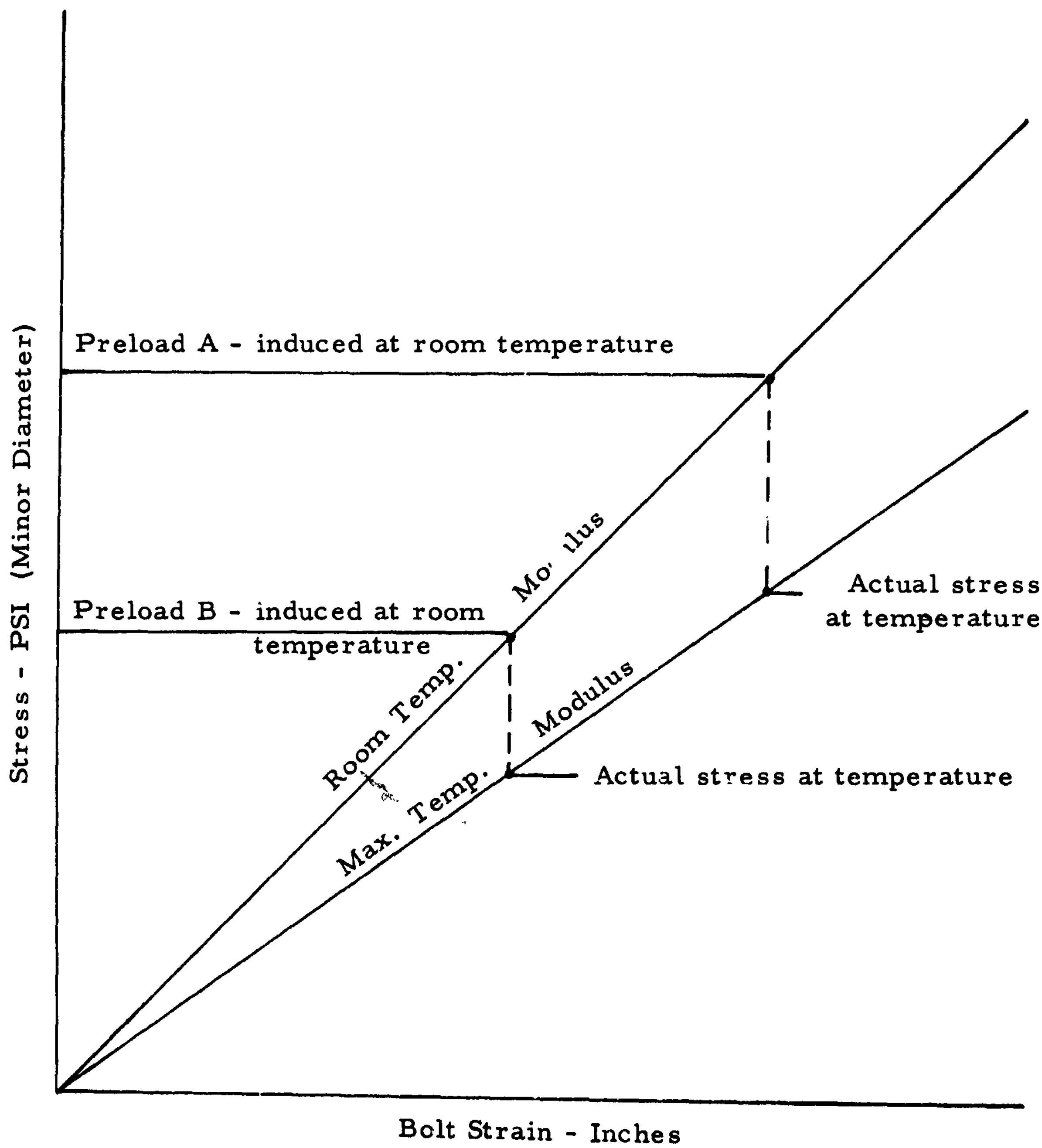


Figure I. 22 Method for Determining Cylinder Relaxation Stress at Maximum Temperature

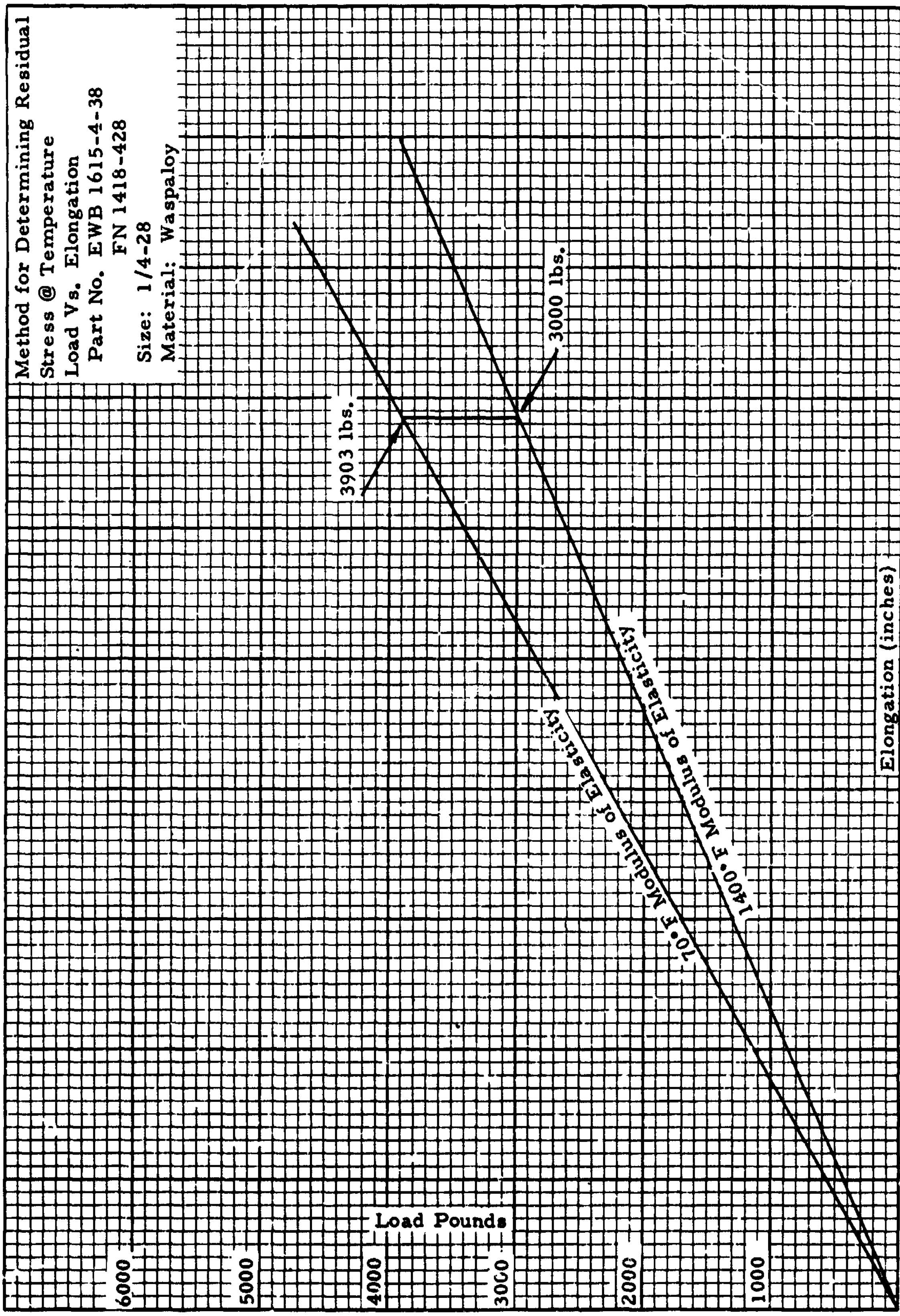
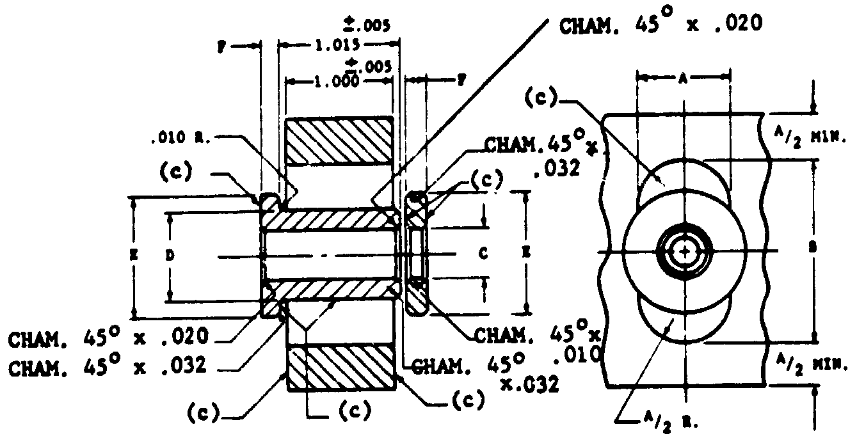

Method for Determining Residual
Stress @ Temperature
Load Vs. Elongation
Part No. EWB 1615-4-38
FN 1418-428
Size: 1/4-28
Material: Waspaloy
3903 lbs.
3000 lbs.
70°F Modulus of Elasticity
1400°F Modulus of Elasticity
Load Pounds
1000
2000
3000
4000
5000
6000
Elongation (inches)
.001
.002
.003
.004
.005
.006
.007
.008
.009
.0010

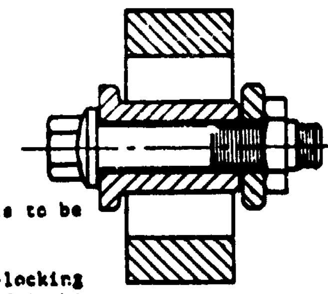
Figure I. 23

AIRCRAFT LOCKNUT STANDARD

AIRCRAFT LOCKNUT MANUFACTURERS ASSOCIATION, 53 PARK PLACE, NEW YORK 7, N. Y.



SIZE	SLOT WIDTH A +.005 -.002	SLOT HEIGHT B ±.002	WASHER AND CYLINDER I.D. C ±.002	CYLINDER O.D. D ±.002	WASHER O.D. E ±.005	WASHER FACE THICKNESS F ±.002
10	.328	1.071	.200	.322	.550	.123
1/4	.500	1.245	.265	.495	.750	.163
5/16	.625	1.370	.328	.620	.875	.163
3/8	.750	1.495	.390	.745	1.000	.163
7/16	.875	1.620	.452	.870	1.200	.188
1/2	1.000	1.745	.515	.990	1.375	.188
9/16	1.125	1.870	.578	1.115	1.550	.213
5/8	1.250	1.995	.640	1.240	1.700	.213



a—Material: Steel, AMS6304

b—Heat Treatment: R_c 40-45.

c—Surface Roughness: On surfaces coded (c) the finish is to be 32 micro inches RHR max.

d—Use: This fixture is used in vibration tests of self-locking nuts. An assembly of the fixtures, bolt and self-locking nut is shown.

REVISION

APPROVAL DATE 4/8/63

CUSTODIAN: TECHNICAL COMMITTEE, AIRCRAFT LOCKNUT MANUFACTURERS ASSN.

PROCUREMENT SPECIFICATION	TITLE FIXTURES-VIBRATION TEST — SELF-LOCKING NUTS	AL-118 SHEET 1 OF 1

Figure I. 24

BEFORE TEST

AFTER TEST

Figure I.25 Test Setup for Alma #10 Vibration Test at -320°F

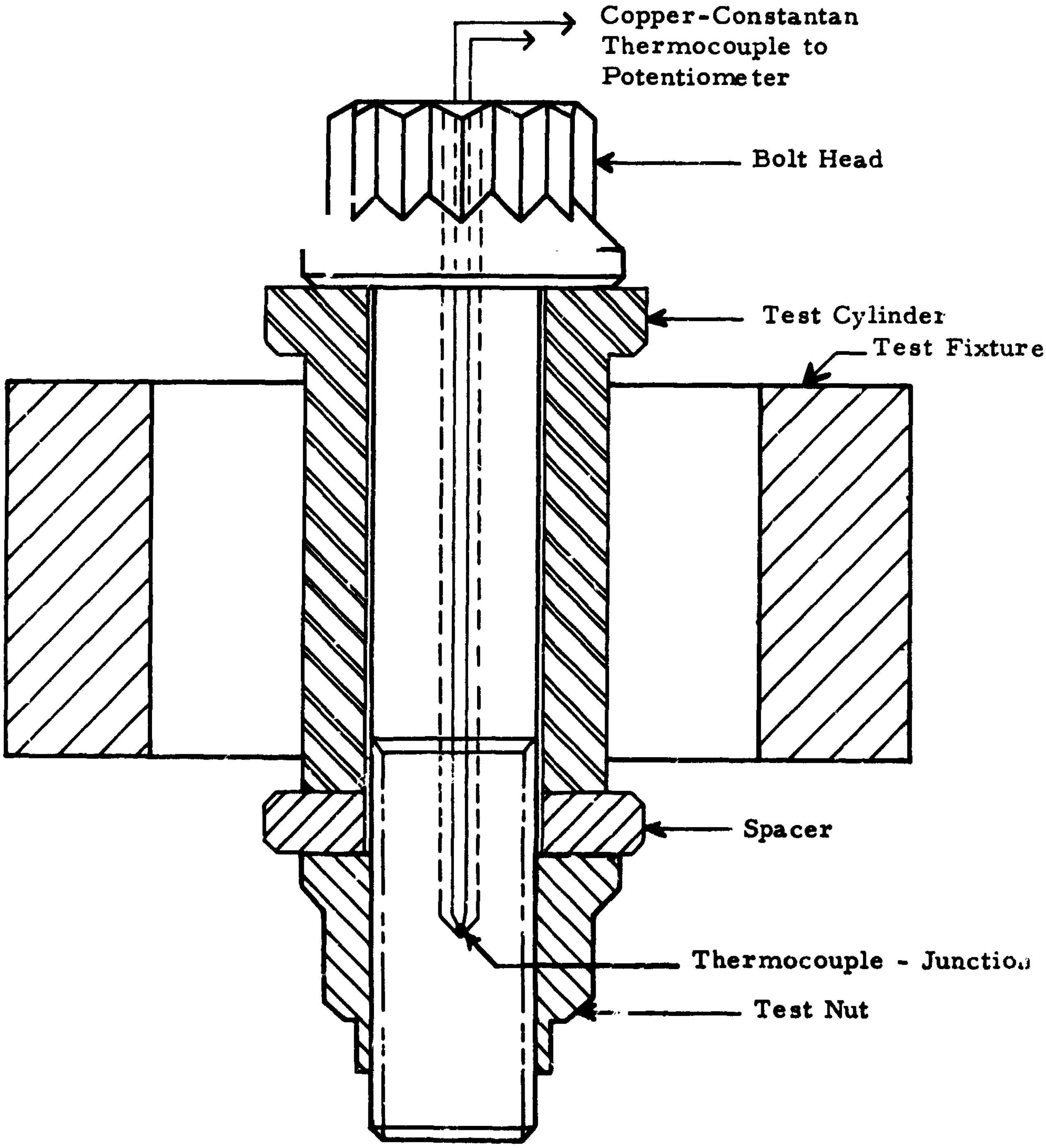


Figure I. 26 Thermocouple Location for Temperature Determination of Alma #10 Vibration Test at -320°F.

TABLE I.1

SURFACE CONDITIONS OF FASTENER ASSEMBLIES FOR CORROSION RESISTANCE TESTS

Fastener Material	Structural Metal	Conditions: Fastener Material	Conditions: Structural Metal
Iron Base	Al-7075-T6		Bare
(Non-Cres)	Al-2219-T87	Cd Plate	Anodized
1. H-11		Cd Plate	Mil-C-5541 plus
2. 8740			Zinc Chromate Primer
3. Vasco Max 300			
(18% Ni Marage)	321 S/S	Bare	Bare
		Ni Plate	Bare
	Ti 6Al-4V	Bare	Bare
		Ni Plate	Bare
Iron Base	Al-7075-T6	Bare	Bare
(Cres)	Al-2219-T87	Cd Plate	Anodized
1. A-286		Cd Plate	Mil-C-5541 plus
2. U-212			Zinc Chromate Primer
	Ti 6Al-4V	Bare	Bare
Nickel Base			
1. Waspaloy	Al-7075-T6	Bare	Bare
2. Inco 718	Al-2219-T87	Cd Plate	Anodized
3. Rene 41	Al-2014-T6	Cd Plate	Mil-C-5541 plus
4. Udimet 630			Zinc Chromate Primer
5. AF 1753 and			
Cobalt Base	321 S/S	Bare	Bare
6. L605			
	Ti 6Al-4V	Bare	Bare
Titanium Base			
1. Ti 6Al-4V	Al-7075-T6	Bare	Bare
2. Ti 7Al-12Zr	Al-2219-T87	Bare	Anodized
3. Ti 1Al-8V-5Fe	Al-2014-T6	Zinc Chromate Primer (Wet)	Mil-C-5541 plus Zinc Chromate Primer
4. Ti 8Al-1Mo-1V			
5. Ti 5Al-2.5Sn			
6. Ti 5Al-5Sn-5Zr	321 S/S	Bare	Bare
Aluminum Base			
1. Al 2024-T4	Al-7075-T6	Bare	Bare
2. Al 2017-T4	Al-2219-T87	Anodized	Anodized

Figure I. 27 Site at Seacoast of Environmental Corrosion Resistance Tests

APPENDIX II

SURVEY

II. SURVEY

A survey was conducted to ascertain present and future requirements for fastener utilization in the space vehicle industry and to determine which fasteners and which materials should be evaluated in the program.

The primary source of information was the aerospace industry comprising the NASA contractors and NASA installations shown in Table II. 1. In addition, the fastener manufacturers shown in Table II. 2 were contacted for information. The information sought fell into five major categories:

1. Materials, Fasteners, and Structures

2. Fastener Configurations

3. Application and Design Criteria

4. Testing and Test Methods

5. Fastener Information and Specifications

II.1 Fastener Materials - Present Usage

The present usage of fastener material falls into the categories of aluminum, alloy steel, stainless steel, nickel base alloys, titanium, and refractory alloys. Table II. 3 lists the present usage of fastener materials.

II.1.1 Aluminum

Aluminum (particularly the 2000 series aluminum) is used mainly in the fabrication of rivets with very few applications for bolts. The universal and the semi-blind rivet with swaged collars are used extensively in skins and other sheet areas. Good ductility and compatibility with structures are the chief assets of aluminum.

II.1.2 Alloy Steel

The use of alloy steel is wide and varied; except for use in the semi-blind point drive bolts, quantities of any specific material are small. Habit and reluctance to change seem to prescribe the large use of 1100 and 4000 series materials at moderate stress levels. However, loading factors are on the increase and resultant higher strength requirements are forcing greater consideration of higher strength fasteners. Generally though, the regular alloy steels are not included in these considerations.

TABLE II. 1

NASA CONTRACTORS AND INSTALLATIONS

1. Grumman Aircraft Engineering Corp., Bethpage, New York
2. Republic Aviation Corp., Farmingdale, New York
3. Martin-Marietta Corp., Baltimore 3, Md.
4. Thiokol Chemical Corp., Elkton, Md.
5. General Electric Co., Phila., Pa.
6. Langley Research Center, Hampton, Va.
7. Goddard Space Flight Center, Greenbelt, Md.
8. Boeing Co., Seattle, Wash.
9. North American Aviation, Canoga Park, Calif.
10. North American Aviation, Downey, Calif.
11. Lockheed Missile & Space Co., Sunnyvale, Calif.
12. United Technology Corp., Sunnyvale, Calif.
13. Cal Tech Jet Propulsion Lab, Pasadena, Calif.
14. Space Technology Labs, Redondo Beach, Calif.
15. Martin Marietta Corp., Denver, Colo.
16. Lewis Research Center, Cleveland, Ohio.
17. McDonnell Aircraft Corp., St. Louis, Mo.
18. Pratt & Whitney Aircraft, West Palm Beach, Fla.
19. Boeing Co., New Orleans, La.
20. Chrysler Corp., New Orleans, La.
21. Marshall Space Flight Center, Huntsville, Ala.
22. General Dynamics, Astronautics, San Diego, Calif.

TABLE II.2

FASTENER MANUFACTURERS SOLICITED

1.	Briles Manufacturing Co.	-	El Segundo, California
2.	Camcar Screw & Manufacturing Co.	-	Rockford, Illinois
3.	Elastic Stop Nut Corp. of America	-	Union, N J.
4.	H. M. Harper Co.	-	Morton Grove, Illinois
5.	Huck Manufacturing Co.	-	Detroit, Mich.
6.	Hi Shear Rivet Tool Co.	-	Torrance, Calif.
7.	Kaynar Manufacturing Co.	-	Fullerton, Calif.
8.	Lamson & Sessions Co.	-	Cleveland, Ohio
9.	Screw Corporation	-	City of Industry, Calif.
10.	Townsend Company		
	a. Boots Aircraft Nut Div.	-	Norwalk, Conn.
	b. Cherry Rivet Division	-	Santa Ana, Calif.
11.	Standard Pressed Steel Co.	-	Jenkintown, Pa.
12.	Valley Bolt Corporation	-	N. Hollywood, Calif.
13.	Voi-Shan Manufacturing Co.	-	Culver City, Calif.

TABLE II. 3

FASTENER MATERIALS - PRESENT USAGE

Company	Aluminum	Alloy Steel	Stainless Steel	Nickel Base	Titanium	Other
Chrysler-New Orleans	2024, 5056	1100 series, 4000 series 8000 series	A-286 300 series	Monel		
Martin-Denver	2024	H-11(small amount)	A-286, 15-7 Mo	Inconel X Monel		
NAA-Downey			A-286, 300 series			
NAA-Canoga Park		4000 series, 8000 series	A-286 (140, 200 ksi)	K Monel (-350°F) Inconel X (160 ksi - Room) Rene 41 (180 ksi 1400°F)	6-4	
LMSC	5056, 2117, 7075	almost none	A-286	M-252, Inconel X Rene 41	6-4, 4-4	
United Tech	7075, 6061	H-11. D6 AC	A-286			Temp. Requirements of -70°F to +500°F
Boeing-Seattle	2017, 2117, 5056 2024 rivets 7075 bolts	4037, 4130, 8630 8740, 4340, (160/180) H-11 (220/260)	A-286, 303, 321	Monel (rivets) Inconel X, M-252 Rene 41, Waspalov	6-4, 4-4	TZM, D-36
Thiokol-Elkton		H-11, 4130, 4140, 4340	410, 17-4PH, 304			Very little high temperature
Martin Baltimore	2024, 2017, rivets 5056, 1100	4130, 1025, 4340 H-11	A-286, 300 series 431, 17-4 PH	Inconel	6-4, 4-4 (small amount)	
McDonnell	7075, 2024	H-11, 4300 series	A-286, 300 series	Monel (rivets) AF1753, Inconel	6-4	L605 Co Base Cb, TZM, D-14
Grumman	2024, 2117, 5056	4130, 4340, 4037	A-286, 437 300 series			
Republic	2017, 2024	4130, 4340, 8000 series	300 series			
Lewis Research Center	2024 (rivets)	1100 series, 4000series	300 series	None	None	Mo
Marshall Space Flight Center	2024, 5056, 7075	1100 series, 4000series 6000 series, 8000series	A-286, 300 series			
Jet Propulsion Lab	2024 (rivets)		A-286 (160 ksi) 300 series		6-4 (160 ksi)	
PWA-West Palm Beach			A-286	Waspaloy, InconelX		
Boeing New Orleans	2024, 5056, 7075	4140, 4340, 6150 8735, 8740, 4037	A-286			
Space Tech Labs	2024, 6061, 2014 2017	Undesignated alloys (small amount)	A-286, 300 series 17-4 PH		6-4	Si-Bronze Al-Bronze Be-Cu
G. E. Phila	2024 (nuts)	1100, 4000, 8000 series Maraging	A-286, 431 300 series	None	None	
General Dynamics/ Astronautics		H-11	A-286 (140 ksi)		6-4	
NASA, Langley			316 S/S			Super Alloys to 1600°F

II. 1. 3 Stainless Steel

For cryogenic and moderate to high temperature applications, corrosion environments, critical impact and sonic vibrational areas, the stainless steels of the 300 series, 17-4 PH, 15-7 Mo, and A-286 are used. The A-286 alloy commands the most usage.

II. 1. 4 Nickel Base Alloys

With the exception of Waspaloy and Monel which have exhibited good cryogenic properties, most of the nickel base alloys are being used for high temperature requirements up to approximately 1800°F. The applications are primarily for engines and nearby structures and on re-entry vehicles on which exposures are for a relatively short duration. Stress rupture and stress relaxation properties are the governing factors in the selection of nickel base alloys.

II. 1. 5 Titanium Alloys

The use of titanium alloys is on the increase in space vehicle applications. The material offers the advantage of good strength-to-density ratio, corrosion resistance, and low magnetic properties. At present, the primary interest is the Ti-6Al-4V alloy thermal treated to 160 ksi. However, increasing interest has been expressed in the low interstitial alpha-beta alloys and the super alpha alloys for cryogenic and elevated temperature applications.

II. 1. 6. Refractory Alloys

The refractory alloys are primarily used in re-entry vehicles. Except for molybdenum and columbium alloys for high temperature applications above 2000°F, there are very few other materials being utilized.

II. 2 Fastener Materials - Expected Future Usage

At present, there does not appear to be a great demand for new and better fastener materials. Most people are thinking in terms of presently available materials with which they have had some experience; while others expressed interest in upgraded materials that are similar to present types. Those materials which are being considered for future use are listed in Table II. 4.

TABLE II. 4

FASTENER MATERIALS - EXPECTED FUTURE USAGE

	Refractory Alloys	Nickel Base	Stainless Steel	Titanium	Al'oy Steel	Other+Remarks
Chrysler, New Orleans		1600° Usage	A-286 HS	6-4		
Martin-Denver	Mo, Cb - 2500°F re-entry	Waspaloy, M252 (3000-4000° for 4-5 sec. duration)		Undesignated-NAS 1273 & 1153 around engine compartment & fluid lines Titan III		
NAA-Downey	Mo, Cb (bette- than present)					Some, but not much concern for cryogenic materials
NAA-Canoga Park		Waspaloy, Inconel 718 (270 ksi)				Gas g nerators have highest temp. (1400°F)
LMSC		AM 367		Undesignated	18% Ni Mar-aging	Lockalloy (60 Be 40 Al) (composite) Be
United Technology		Inconel (220-260 ksi)			Better toughness than H-1 1 and D6 AC 9% Ni Mar-aging	
Boeing-Seattle	Tungsten, pure Mo, Ta, better Cb, better Mo					-452° to +4500° 325 ksi
Thiokol Elkton	Tungsten			Undesignated	Mar-aging	Be
Martin Baltimore	Tantalum, Zr, W Mo, Cb	Waspaloy(cryogenic)	A-286 (cryogenic) 300 series			6061, 5456 (cryogenic)
McDonnell	Ta, W (3500°-5000°) new Mo and Cb alloys (B-66)	Waspaloy, U-700 undesignated Astraloy TD Ni (1800°-2400°)	U-212 undesignated aust. stainless steel for cryogenic	Low interstitial Ti 8-8-1 Ti (700°)		Be, Need materials with cryogenic & high temp. prop., in one.
Grumman	Undesignated			6-4, 4-4 undesignated		Be
Republic	Cb, B66, Ta, Cb 752	Rene 41, Hastelloy X T.D. Ni		6-4, Hi Strength Ti		Be, Composite heat barrier fasteners
Lewis Research Center	Undesignated-4000°					Be
Marshall Space Flight Center	Tantalum, Molybdenum columbium, tungsten		U-212			Be
Jet Propulsion Lab						
PWA-West Palm Beach		Inconel 718				
Boeing-New Orleans		1500° Usage				
Space Tecn. Lab	Tungsten	K Monel, Inconel 718				
G. E. -Phila.						
NASA Langley						Existing fasteners are adequate
General Dynamics		Inco 718, Rene 41, Rene 62	A-286 (200 ksi)	6-4 ELI		

II. 2. 1 Alloy Steels

The only alloy steel given any consideration for future fastener usage was the 18 per cent nickel maraging steel. The number of people considering this alloy were very few. In general, alloy steels are not being considered for future applications.

II. 2. 2 Stainless Steels

Outside of U-212, high strength A-286 and several austenitic stainless steels, no other materials were suggested in this category by the people contacted as being significantly worthy of development.

II. 2. 3 Nickel Base Alloys

Many nickel base alloys are being considered for future application. These alloys include Waspaloy, Rene 41, Hastelloy X, Inconel 718, and M-252. Applications for these materials encompass a wide range. First, there is the cryogenic area with a need for high strength, above 200 ksi, with good toughness and impact strength down to LH_2 temperatures.

Corrosion resistance to fuels, oxidizers, high humidity, and other atmospheres is an important characteristic of the nickel base alloys.

II. 2. 4 Titanium Alloys

Titanium alloys have been accorded increased consideration for future boosters, but some companies are not thinking beyond presently available materials such as 6-4 and 4-4 alloys. However, the need is recognized for reliable titanium alloy fasteners with higher usable strength and higher temperature performance.

II. 2. 5 Refractory Alloys

Future use of refractory alloys points to limited application for molybdenum alloys, expanded application for columbium alloys, and the additional use of tantalum base alloys. In each case, the utilization of a specific alloy or alloy series is limited more by the state of the coating art than by structural considerations.

II. 3 Fastener Configurations

Where possible, most companies are using standard fasteners as called out by AN, NAS, and MS drawings. Where standards do not exist in the area of higher strength and higher quality fasteners, the companies are creating their own standards, or in some cases using the standards of fastener manufacturers. Table II.5 lists the present types of fasteners being used.

II.4 Applications and Design Criteria

Information was obtained about application conditions and factors which influence the selection of fasteners and the materials from which they are fabricated. Such items were examined as types of loading experienced by fasteners, environments which may affect fastener performance, torque versus induced load concepts, preferred platings and lubricants, compatibility of fasteners with structural materials and installation and installation problems.

II.4.1 Types of Loading

The majority of users indicated that the various fasteners in their structures underwent combinations of all possible types of loading. These consist of tension, shear, combination of tension and shear, torsion shear, bending, static, dynamics, impact, vibration, and "G" loading. But very few of the types of loads are significant at any one time or place.

Shear is most prominent because design practices favor it. Structures, skins, and attachments are designed in shear. Tension usually with bending was next in area of thrust structures, engine mounts, fins, bulkheads, pump flanges and injector domes. In tension application most loading is static. Dynamic and impact loads were at a minimum.

II.4.2 Environments

The two most significant environmental conditions to be contended with today are all types of corrosive influences and cryogenic influences.

The indicated problem areas of corrosion are:

a. Room and cryogenic corrosion because of fuels and oxidizers

b. High humidity and salt atmosphere corrosion

c. High temperature corrosion

d. Stress corrosion

e. Galvanic corrosion

TABLE II. 5

PRESENT FASTENER USAGE

Company	AN	NAS	MS	Others + Remarks
Chrysler	3-20 362 173 366 363 123508 361	1297 3003 687 1023 624-44 1298 563 696 686 1299 679 1032 680 698 509 1025 697 1033 671 1068 624 1003 1021 1024 1031	20073 35305 21046 9033 20074 35306 20501 20365 20033 20500 20426 20364 35298 21042 20470 35692 35304 21044 20435 35691 35649 21045 35650 35690	Huck (largest quan.) Threaded 40% Hi Lok Rivets 20% Threaded - #2-1 1/2 Huck 40% Non-threaded - 1/8-3/8 Hi Lok Total fasteners/veh = 10,000
Martin-Denver	3-20 Steel 3-20 A-286	A-286 624 (increasing) 1291	A-286 20004	A-286 H-11 15-7 *Hi Lok 140 EWB(few) EWB (280) EWSN26 and (220-260) EWSB FN22 160 to Inconel X 42FW 200 ksi Rivets *Expected big quan.
NAA-Downey		A-286 1003 501 1100 686 (140 ksi) 1630 1620 1151	A-286 21043 (140 ksi)	A-286 (NA) (Phillips, flush, & pan) EWB (8879 th'ds.) (heads up to 140 ksi) EWSB EWN (over 140 ksi) (Torq-set drive over 140 ksi) Most parts other than standard items are under NAA drawings
NAA-Canoga Park		A-286 Ti 1000 623 - 625 (R D dwg longer th'd)	A-286 20004 21277 (full P. D.) 21250 (tank area)	RD dwgs. 111-1000 series (hex) 111-3000 series (int. hex) 140 ksi 111-.000 series (12pt.) 200 ksi (Use of Ti expected to increase.) Undesignated EWB&EWSB (Inconel) (E-25 criteria) (Rene 41)
LMSC			20426 Rivets	Ti (6-4) Al Huck Huck Hi Lok
Boeing-Seattle	3-20 774 500-26 775 310 6289 315 924 316 320	1103-20 623 1303-20 1189 583-90 1191 1503-10 679-90 600-06 514	9441-59 20004-24 20364 9433-37 200073&74 20365 9399-402 16995-98 35649 9449-50 35297&98 35650 9360 21262#295 25082 9107-08 24615-630 21042 20500 21043	BAC 21 AS-CE N10ED-DN
Boeing-New Orleans		1103	21[illegible] 200[illegible]	A-286 Hi Lok Hex hd. (160-180) A-286 12pt. tension(180)few Steel 12pt. nuts (180) Titanium (increasing)
Thiokol-Elkton	3-20 363	1398 (M4-2) 686 687 1144 1102	20427 (M3 & M4 -4-6) 24677 21250	Mostly tension fasteners LWB 22 EWB type Stainless Steel Special SHCS Stainless Steel
Martin-Baltimore	3-20	220 - 227 464 679 334	20004	EWB 26 Martin 26D Martin 8 Martin 9 Martin 15
G. E. - Phila.		(Almost all miniature plate nuts) 1291 1102 A-286 333 (600/veh)	431 Stainless Steel 20004 (600/veh)	(100% Phillips Drive) where applicable Swage Nuts Cherry Rivets Hi Lok Bolts Jo Bolts (6000/veh) Milson (100/veh) Majority of applic. are shear, sizes Sizes are 1/4 and below.
Space Tech. Labs	300 series 500 series	Ti 653 (NAS 621) 1100 Undesignated	Undesignated	STL miniature Size range below 0-80 to #10 Huck blind rivets Jo bolts (A-286 few)
Jet Propulsion Lab.			2004 (A-286 and 6-4) (JPL dwg.) (160 ksi) 21043	Dome Rivets Size range - #2 to 1/4 -200° temp. limit
Republic	3-20 C	1132 1217C 1133 C3 1151 to 1153 C7 1154		Undesignated specials of Ti, Waspaloy, and Rene
McDonnell		560H		3M 133 3M 123 Monel rivets Approx. 300 threaded fasteners per Asset vehicle.
Marshall Space Flight Center	4-16 509 DD 4-16 DD 508 42B-49B	1221 1104-16 1352 1221C 1218C 1352C 1218 1221C 1304 1586 584-90 1004 1351 564-72 1351C		Mc 624 625 626 611 612 613 614
General Dynamics/ Astronautics	3-20 509 427M	514 1102 1151 464 1003 1020 501 673 1351 1352 1100 1141	35289 20500 20601B 2004 21043 20600B 17829 20426B 20601MP 21042 20470DD	H-11 EWB-22 Current fasteners will be used in the future

Where feasible the first three problem areas have been remedied with A-286 and other stainless steels and nickel base alloys.

Cadmium plating between the A-286 and aluminum structure appears to prevent galvanic and stress corrosion in most cases. However, there are many specific problems in this field about which there is very little knowledge.

The effects of cryogenic temperatures on fastener properties are the second major environmental condition. Although considerable fastener data has been generated at -100°F and some at -320°F, very little fastener data at -423°F is available. Therefore, tensile and shear testing at -423°F is clearly indicated, with impact and fatigue testing needed as soon as possible.

Other environments that influence fastener selection are high temperatures, cycling between temperature extremes, vacuum, and radiation.

Elevated temperature problems are relatively straightforward and considerable advancements have been accomplished in this area.

Temperature cycling between temperature limits has not been investigated to any great extend but warrants definite investigation because fasteners do experience this condition both on the ground, under fuel cyclingconditions, and in space. However, because there are very few applications involving cycling between cryogenic and elevated temperatures, studies should be conducted by cycling from room to -423°F to room and from room to maximum applicable temperature to room temperature. Ten cycles was a reasonable figure to start with on the basis of comments.

Vacuum and radiation properties are considered of prime importance by space vehicle builders. The vacuum environment presents problems because many platings sublimate and redeposit elsewhere, and those platings which do not sublimate do not always provide sufficient corrosion protection or prevention of galling between external and internal threaded fasteners.

Radiation was indicated as a potential fastener problem by only three groups. At this point, it seems doubtful that anyone has enough data on the problems connected with radiation and it has been classified as a future area of study.

Table II. 6 shows a condensed summary of the various loading conditions and environments reported by the users.

II. 4. 3 Tightening

Survey information on torque versus induced load applications indicate that a lack of information prevails in this area. Many users refer to HIAD values for general conditions and company or vendor generated data in the non critical areas. Table II. 7 gives a breakdown of preferences.

II. 4. 4 Platings, Coatings, and Lubricants

II. 4. 4. 1 Platings and Coatings

The number of protective finishes used in various space vehicles is extensive. Table II. 8 illustrates this variation

Cadmium, the largest single item, is used in two areas. One application is the conventional corrosion resistance on alloy steel bolts for use up to 450° F. Specifications for this type of plating are usually QQ-P-416a (Type II) or MIL-C-8837 (Type I). The other application is to prevent galvanic corrosion on A-286 or other stainless steel bolts and aluminum structures. Generally QQ-P-416a, Type I or II is employed.

Diffused nickel-cadmium is used as a protective finish for alloy steels for applications up to 900° F temperature. AMS 2416 specification covers this type of plating.

Silver is primarily a lubricant for high temperature applications on corrosion resistant fasteners in steel and other structures where galvanic corrosion is not a problem. It is also used because it does not sublimate. The specification is usually AMS 2410.

Gold and aluminum are thermal control platings. In addition, gold is satisfactory where sublimation in vacuum is a problem. Other coatings such as Electrofilm are really lubricants and provide minimal corrosion protection.

II.4. 4. 2 Lubricants

Molybdenum disulphide in various formulations is the most extensively used lubricant. However, it is restricted in two areas - liquid oxygen proximity and vacuum conditions. Other lubricants for the most part are rather selective in

TABLE II. 6

APPLICATIONS & DESIGN CRITERIA

Company	Loading Conditions	Environments	Other
Chrysler	Primarily shear a few tension areas on fins no fatigue problems	Corrosion - atms., galvanic, fuel a few high temp. areas (1000°F) cryogenic temp. (-423°F) Lox compatability important	Mil Hdbk 5 D. A. (design allowables) Hi Lok and Huck Bolts difficult to pull up in Stainless Steel
Martin-Denver	Some tension - More shear Bending, but not a problem	Temp. cycling -423°F to 2500°F Future fuel and oxidizer corrosion Unknown space environs - future	Mil Hdbk 5 + Martin Hdbk D. A. wt. generally not a consideration Going toward fewer but larger fasteners
NAA-Downey	Primarily shear-go out of way to use double shear - single shear next. Some bending engine mount & flanges. Some tension - High sonic vibration levels (170db) but structures are weak spot-fatigue loading due to vibration	Temp cycling -423°F to room Temp limits - 423°F to + 1600°F a few to + 2400°F Corrosion - oxidizer + fuel + atms.	Mil Hdbk 5 modified by company generated data for D. A. Strength/ density important but not critical Going toward larger but fewer fasteners higher reliability
NAA-Canoga Park	Primarily tension - Some shear Some bending - flanges - Most loads are static, but some short duration, high amplitude dynamic loading - increasing criticality High magnitude (700), instantaneous G loads	Corrosion - atms. temp., fuel & oxidizer - Temp. limits -423°F and 1000° - Space vacuum - no major probs. Radiation no problem - Temp. coeff. of expansion important	Coeff. of expansion compatability Except higher loadings and more corrosion for future. Mil Hdbk 5 + NA design manualD. A. Safety factor of 1.5 - Strength/[illegible] density ratio not critical now - be- coming more important. Higher reliability increasing.
LMSC	90% shear applications Some tension - Some bending No fatigue "G" loads in tension and bending	Atms. corrosion - Temp. limits -70° to + 800° Space vacuum sublimates some coatings. Radiation not problem at present	Mil Hdbk 5 + Lockheed documents on A-286 for D. A. No yield at limit load allowed - Size limitations - #10 screws and 1/8" rivets min. in primary structure.
Boeing -New Orleans	Many shear - Few tension No fatigue now but will increase due to ultrasonic vibration	Temp. cycling -423°F to room a few applications -423°F to + 1500°F galvanic and fuel corrosion	Mil Hdbk 5 + Boeing Hdbk D. A.
Boeing - Seattle	All types of loading Shear - torsion (75%) on Dyna Soar - Some impact Some vibration	Short time stress corrosion Space vacuum for plating Temp. cycling Galvanic corrosion	Mil Hdbk 5 modified D. A. Strength/ density important - Moving toward generally tighter AQLS and statistical evaluations. Problem of putting refractory bolts together
Thiokol	Tension & bending in pressure vessel bulkheads + impact, vibration and "G" loads	High humidity atms. corrosion fuel corrosion	Mil Hdbk 5 + vendor data for D. A. Strength/density very important
Martin-Baltimore	Primarily shear - Some tension Some fatigue - Sonic vibration	Fuel corrosion	Mil Hdbk 5 + Fastener specs. (less 15%) D. A.
G. E. - Phila.	Primarily shear - Some tension No fatigue - Vibration "G" loads (12 max.)	High humidity - long duration - corrosion - Oxidizer and fuel corrosion Temp. limits -100° to +350° High vacuum - Radiation no concern	Mil Hdbk 5 modified D. A.
Space Tech. Lab	Both tension and shear + fatigue, vibration, impact	Temp. limits for internal spacecraft fasteners 30° to 95°F - External limits -250 to +250°F - Outgassing problems fuel corrosion on engines	Mil Hdbk 5 + analysis of critical applications for D.... - Fasteners and structures must have compatible electrolytic potentials and thermal properties
Marshall Space Flight Center	Largely shear - All others in varying degrees. Increased mag- nitudes in future due to higher speeds and accelerations	Corrosion - Lox, seacoast, galvanic stress	Mil Hdbk 5 Safety factors 1.1 for yield 1.4 for ultimate strength/density only minor
McDonnell	All conditions of loading	Temp. limits -423° to +5000°F Galvanic and temp. corrosion unwanted bonding in vacuums	Mil Hdbk 5 + MAC 339 Want fasteners with good cryogenic and elevated temp. properties together. Advocate "total joint" information
General Dynamics/ Astronautics	Some tension Combined tension & shear vibration, but not severe	-423°F to 600°F with expectations to 2700°F - corrosion - salt spray - vacuum & radiation hazards FLOX - LOX & LH_2	Mil Hdbk 5 formulated turn of the nut method

TABLE II.7

TORQUE VS. INDUCED LOAD STANDARDS

Company	Standard	Remarks
Chrysler, New Orleans	ABMA 18 CCSD 60C06006	
Boeing, New Orleans	BAC-5009	Similar to HIAD
Marshall Space Flight Center	ABMA 18 MSFC10M 100515	
Martin, Denver	Martin generated values. Vendor TT curves	
North American, Downey	NA generated values	
North American, Canoga Park	NA generated values	Arthur H. Korn formula (Prod. Eng. Nov. 1943)
Lockheed, Sunnyvale	HIAD LAC generated values	
Boeing, Seattle	HIAD BAC generated data	
Thiokol, Elkton	Vendor supplied TT curves	
Martin, Baltimore	Martin generated values	Planning to use Bureau of Standards Handbook
G. E., Philadelphia	HIAD Vendor TT curves	
Space Technology Labs	HIAD	
McDonnell	HIAD Vendor TT curves	
General Dynamics/ Astronautics	Skidmore-Wilhelm Approach	

TABLE II.8

PLATINGS AND COATINGS

1. Marshall Space Flight Center	Cadmium	Protection & lubricant on steel. Lubricant & galvanic barrier on stainless steel.
	Silver	Lubricant
2. Chrysler, New Orleans	Cadmium	Same as 1.
3. Martin, Denver	Cadmium	Lubricant & galvanic barrier on stainless steel.
	Silver	Lubricant
	Azorizing (Cr)	Wear resistance
4. North American, Downey	Cadmium	Same as 3.
	Silver	Lubricant
5. North American, Canoga Park	Silver	Lubricant
	Ni Cd	900° corrosion protection
6. Lockheed, Sunnyvale	Electrofilm	Lubricant
	Silver	Lubricant
7. Boeing, Seattle	Cadmium	Same as 3.
	Silver	Lubricant
8. Thiokol	Cadmium	Protection and lubricant on steel
9. Martin, Baltimore	Cadmium	Same as 1.
	Ni Cd	Same as 5.
10. G.E., Philadelphia	Cadmium	Same as 8.
11. Space Technology Labs	Aluminum	Thermal control
	Passivated	Corrosion
	Gold	Thermal Control
	Chromium	Wear resistance
	Silver	Lubrication & thermal control
12. McDonnell	Cadmium	Same as 1.
	Silver	Same as 1.

application and for this reason are not commented on further. Table II.9 lists the various types of lubricants.

II.4.5 Installation Problems

Very few companies indicated that they had any serious installations problems. Several firms did say that galling of A-286 and high nickel alloy fasteners presented an installation problem. This indicates that more work is needed in lubricant development or at least proper utilization of available lubes. Mention was made of inconsistent preloading which ties in with lubrication and lends weight for the need to establish standard torque tension methods and conditions of testing.

One other problem concerned wrenchability of internal wrenching parts and 12 point external drives. Investigations in this area are presently in progress by the Naval Air Engineering Center (NAEC), Philadelphia Navy Yard.

II.4.6 Design Allowables

Almost without exception MIL Handbook Five was a source for this data, but also without exception, company manuals supplemented Handbook Five. Most concerns felt the need to be more conservative and discount some of the data for their use.

II.4.7 Weight and Space Considerations

The majority of replies to questions on this subject indicated consideration for high strength-to-density ratios in design, mainly because of vehicle weight criticality.

II.5 Tests and Test Methods

It is reasonable to conclude that there are gaps in the overall knowledge of fastener properties and performance under specified conditions. Accordingly, a number of suggestions were made as to how these gaps should be filled by the generation of new or improved tests and test methods. Recommended new or improved tests are shown in Table II.10.

II.6 Fastener Information

Specifications governing the procurement of fasteners usually lag well behind their introduction and use. In the case of NAS and MS specifications and drawings the time gap can run anywhere from two to to five years. Consequently, a void is created which must be filled and usually is by the fastener manufacturer. As the users continue

TABLE II. 9

LUBRICANTS

Company	Type of Lubricant	Remarks
Chrysler, New Orleans	Moly Kote Z Dow Corning FS1280 & 1281 Grease Teflon Other MoS_2	
Martin, Denver	Dri Lube 842 Dri Lube 701 Silver Fluorocarbon Paste Wax	
North American, Downey	North American MoS_2	
North American, Canoga Park	Silver Dri Lube 701 Kel F 90 LOX - Lube	450° - 1200°F -423° - 450°F
Lockheed, Sunnyvale	Electrofilm Silver MIL-L-8937	
Boeing, Seattle	Silver "goop" Silver BMS 3-3 (MoS_2)	
Thiokol	MIL-T-5544 MoS_2	
G. E., Philadelphia	MoS_2	As supplied on parts by vendors
Space Technology Labs	Everlube 811B Micro Seal Teflon Metal Powders in Resins Graphite	
McDonnell	MoS_2 Teflon	
General Dynamics/ Astronautics	Oxylube 702 & 703 Lox Safe Kel F 90	Compatibility with LOX Expected future problems with compatibility with FLOX

TABLE II.10

RECOMMENDED NEW OR IMPROVED TESTS

Boeing-New Orleans	Relaxation - residual stress
Martin-Denver	Vibration of locknuts
North American-Cancga Park	Fatigue, elongation at .2% yield
LMSC	Yield strength A-286, torque tension
Boeing-Seattle	Torsion-Shear, elevated temperature test fixtures
Martin-Baltimore	Torque tension, vibration of locknuts
G. E. - Philadelphia	Yield strength
Space Technology Labs	Torque tension, magnetic permeability
Jet Propulsion Labs	Magnetic permeability
Lewis Research Center	Vibration
Republic	Vibration, thermal cycling, creep
McDonnell	Stress durability, elevated temperature, relaxation, vibration of locknuts, elevated fatigue, metallographic check after temperature
General Dynamics/Astronautics	Effects of rapidly applied loads of short duration at low temperatures, corrosion resistance under load

to purchase a product, the user's requirement for a specification grows and it is generally obtained by lifting portions almost word for word from the manufacturer's specification.

The fastener manufacturers who responded to the request for their recommendation of fasteners to be evaluated in the test program are listed in Table II. 11. Included are the materials and configurations of fasteners they presently supply to the aerospace industry.

II. 7 Literature Survey

In addition to the user survey, a continuing literature survey of materials was conducted to collect available fastener data and materials data for evaluating potential fastener utilization. The survey included materials within the base alloy groups of iron, nickel, cobalt, titanium, and aluminum. Final selection of materials for inclusion in the program was based on the user's survey, available fastener data, DMIC memorandums, supplier information, high strength considerations, and NASA reports and information. During the past year the following alloys were investigated.

Iron Base	Nickel Base	Cobalt Base	Titanium Base
AISI H-11	Inco 718	L-605	Ti-6Al-4V
Vasco Max 300	Waspaloy		Ti-5Al-2.5Sn
A-286	AF 1753		Ti-1Al-8V-5Fe
U-212	Udimet 700		Ti-8Al-1V-1Mo
AFC 77	Monel		Ti-7Al-12Zr
	Rene 41		
	Rene 62		
	Udimet 630		

II. 7. 1 Iron Base Alloys

II. 7. 1. 1 AISI H-11

AISI H-11 alloy is a high strength 5 per cent chromium tool steel employed in the fabrication of precision fasteners for the aerospace industry. Minimum ultimate strength of 260 ksi with good ductility can be obtained with H-11 material at room temperature. At present, the temperature range for this material is from room to 900°F applications. However data have been generated on the cryogenic properties of fasteners down to -320°F (Ref. 1)*. Short-time tensile tests show an increase in strength with decreasing temperature with a slight decrease in ductility at -320°F.

*See References p. 206.

Table II. 11

FASTENER MANUFACTURERS CONFIGURATIONS & RECOMMENDATIONS FOR EVALUATION

Company	Fastener Type	Material		Specifications (applicable)	Recommendations
Elastic Stop Nut Corporation	Self Locking Nuts				
	NAS 3250	Alloy Steel		NAS 3350	for use to 450°F
	MS21084 & MS21085	Alloy Steel	220 ksi thru 260 ksi	MIL-N-8922	for use to 450°F
	Alma Project 46	A-286		Alma Spec. 12	-423°F to 800°F
	Alma Project 29	Waspaloy-Rene 41 and M-252		AMS 2410	-423°F to 1600°F
				Alma Project 29	Use Esna lube 382 for application 1200°F through 1600°F
Huck Manufacturing Company	Blind Bolt	A-286		Not Included	-
	S3L Lockbolt	A-286		Not Included	-
	MLS Blind Rivet	Monel & 17-4 PH		Not Included	-
	SAL Lockbolt	Ti-6Al-4V		Not Included	-
	ALP Lockbolt	Ti-6Al-4V		Not Included	-
Townsend Co. Cherry Rivet Div.	Blind Rivet	Al Alloy		NAS 1400	to 250°F
	Blind Rivet	A-286		NAS 1400	to 1200°F
	Blind Rivet	Al Alloy		Cherry Rivet	to 250°F
	Blind Rivet	Monel		Cherry Rivet	to 900°F
	Lock Bolt	Alloy Steel		NAS 1413	to 800°F
	Lock Bolt	Aluminum		NAS 1413	to 250°F
	Lock Bolt	A-286		Cherry Rivet	to 1200°F
Valley Bolt Corp.	12 Pt. & Hex Hd.	A-286	160 ksi Ftu thru 200 ksi Ftu	VAI-6450, 6650 & 6750	-423°F to 1200°F for Nuclear
	12 Pt. EWB	Waspaloy	220 ksi thru 260 ksi	VAI - 6822	Cryogenic Application
	12 Pt & Hex Hd.	Waspaloy	180 ksi - Ftu	VAI - 3800	Room to 1600°F
	12 Pt. EWB	17-4 PH	200 ksi - Ftu	N/A	Exotic Fuel Areas
	12 Pt. EWB	15-7 Mo	220 ksi - Ftu	N/A	Exotic Fuel Areas Hi Strength
	12 Pt. hex hd. & specials	H-11	220 ksi thru 260 ksi	VAI 6220, 6260, 6820, 4260	Various
	12 Pt. EWB & speicals	Mar-aging	250 ksi	N/A	Cryogenic to 800°F
Voi-Shan Manufacturing Company	The Voi-Shan Co. did not specify any specific type of fasteners, but recommended general types of fasteners that should be considered. These consisted of Hi Lok Bolts, Hi Shear Rivets, Huck Lok Bolts and similar types of fasteners. The materials they recommended were high strength to nickel base and ferrous nickel alloys such as tensilized A-286, Waspaloy, Inconel 718 and similar alloys. They also mentioned titanium alloys for cryogenic and higher temperature exposures.				
Standard Pressed Steel Company	The fasteners supplied by SPS to the Aero Space Industry are many and varied. The list presented here represents a select few that we feel should be evaluated in this program.				
	EWB 922	H-11	220 ksi	SPS M107 AMS 2416	for use to 900°F
	EWSB 926	H-11	260 ksi	SPS M107 AMS 2416	for use to 900°F
	FN 922	H-11	220 ksi	SPS M107 AMS 2416	for use to 900°F
	EWSN 926	H-11	260 ksi	SPS M107 AMS 2416	
	EWB 0420	A-286	200 ksi	AMS 5735	for use to 1200°F
	EWB Hi Ti 20	1-8-5 Ti	200 ksi	SPS M174	for use to 300°F
	EWBT 815	7-12 Ti	150 ksi	SPS M179	for use to 750°F
	EWB 1218	U-212	180 ksi	SPS M134	for use to 1200°F
	EWB 1615	Waspaloy	150 ksi	SPS M175	for use to 1600°F

Standard charpy impact results indicated that a ductile to brittle transition occurs around -100°F; however, similar tension impact results of bolt threads do not correlate with these findings. The energy required to fracture a 1/4-28 bolt thread was essentially the same at -320°F as at 70°F.

From the limited amount of information available, a more thorough evaluation of H-11 for cryogenic fastener application to -423°F was considered justifiable. Also, the H-11 fasteners would provide a comparison standard for the performance of other materials under unique environment or tests investigated during the program. Therefore, tension and shear bolts and companion fasteners of H-11 were selected for fastener evaluation in this program.

II. 7. 1. 2 Vasco Max 300

The maraging steels, particularly the 18 per cent nickel grade with cobalt and molybdenum, are receiving extensive consideration for non-corrosion resistant, low temperature application. The various steel producers report this material to have high ultimate and yield strengths with excellent ductility and notched to unnotched ratios. They state that this material possesses superior hot and cold workability, ease of heat treatment, weldability and adequate impact properties at cryogenic temperatures which would make it a suitable material for wide applications in existing and experimental engines, air frames and missile systems (Refs. 2, 3 and 4).

An evaluation by SPS of maraging steel as a possible material for high strength cryogenic fastener application showed tensile and yield strengths of bolts and specimens increased significantly with decreasing temperatures with very little change in ductility. Ultimate strength at -320°F was on the order of 350 ksi with 10 per cent elongation. At present, the temperature range for this material (Ref. 5) is from -320°F to 900°F.

II. 7. 1. 3 A-286

Conventional A-286 is one of the prime materials used for cryogenic and moderate to high temperature applications. There appears to be more data available on the -423°F properties of A-286 than any other heat and corrosion resistant material. The National Aeronautics and Space Administration reports that A-286 material is recognized as an invaluable material for fasteners at cryogenic and elevated temperatures. However, in the extremely cold worked condition its application is limited (Ref. 6). A-286 exhibits good elevated temperature properties to 1200°F which gives this material a utilization range of -423°F to 1200°F. High strength A-286 (200 ksi)was selected for fastener evaluation in the program.

II.7.1.4 U-212

The National Aeronautics and Space Administration also concluded from tests of U-212 fasteners that this material shows considerable promise as a low temperature fastener material but that the material cost is relatively high compared to A-286 alloy (Ref. 6). Applications for U-212 alloy would be the same as for A-286. U-212 was selected for evaluation as a potential high strength fastener material.

II.7.1.5 AFC 77

AFC 77 alloy is a high strength, elevated temperature stainless steel developed by the Crucible Steel Company under an Air Force contract. Depending on the heat treatment employed, AFC 77 appears to have either potential cryogenic or high temperature application to 1200°F. Although AFC 77 exhibits high strength at -320°F, it was not considered for evaluation because of low ductility in comparison to those materials selected.

II.7.2 Nickel Base Alloys

II.7.2.1 Inconel 718

Available information procured from the steel producer literature indicates this material possesses excellent cryogenic properties to -423°F (Ref. 7). Tensile strengths on the order of 260 ksi with 15 per cent elongation were recorded at -423°F. Evaluation of Inco 718 as a fastener material also shows it to exhibit excellent elevated temperature properties to 1200°F. Inconel 718 was selected for evaluation as a potential high strength fastener material in this program.

II.7.2.2 Waspaloy

Waspaloy is another of the nickel base alloys that appears to have the potential for cryogenic fastener application. Data on the -423°F properties of Waspaloy were confined mostly to charts illustrating a comparison to U-212 and A-286. Notched to unnotched tensile ratio was higher at -423°F (.86) than at 70°F (.81) for a notch stress concentration factor of K_t10. Tensile strength of specimens increased appreciably with decreasing temperature (Ref. 6).

Waspaloy was developed for high temperature application to 1600°F. Existing fastener data show it to possess good short time elevated temperature properties to 1600°F. Therefore, the potential temperature range for this material as a fastener appears to be from -423°F to 1600°F. Standard Waspaloy was selected for fastener evaluation while cold reduced Waspaloy was selected for evaluation as a potential high strength fastener material in the test program.

II. 7. 2. 3 AF 1753

The Air Force completed a program which developed the alloy AF 1753 which shows good potential for fastener use as high as 1800°F. Material data on this nickel base alloy indicate a possibility for cryogenic utilization. AF 1753 has the highest strength of the so-called super alloy series. Fastener data generated by SPS show it to possess good elevated temperature properties to 1600°F (Ref. 8). Because of these attributes, AF 1753 has been selected for future evaluation as a potential high strength fastener material in 1965.

II. 7. 2. 4 Udimet 700

Udimet 700, and its modification known as Astroloy, is another of the highly alloyed nickel base super alloys. Although there is no data to support it, this material, a nickel base alloy, probably will exhibit good cryogenic properties to -423°F. Available fastener data show it to have good elevated temperature properties to 1600°F (Ref. 9). In general, U-700 is stronger than the run of the mill super alloys of Rene 41, M-252, Waspaloy, and U-500. U-700 and Astroloy are not being considered for evaluation because they are not commercially available at the present time.

II. 7. 2. 5 Monel

Monel was investigated because of the possibility of making rivets and other cold deformable type fasteners. This alloy consists of a series of nickel-copper base alloys known to have excellent corrosion resistance. The temperature range of the material appears to be from -423° F to 1800° F Impact and tensile tests show monel increases in strength as the temperature decreases. There is no apparent ductile to brittle transition down to liquid hydrogen temperature. However, monel was not considered for evaluation because it is not considered applicable for NASA needs because of low strength.

II. 7. 2. 6 Rene 41

The alloy Rene 41 is another of the nickel base super alloys. It was developed by the General Electric Laboratories for high temperature structural usage. Fasteners of Rene 41 have been in application since late 1958.

Because Rene 41 is over six years old, there is a wealth of fastener and material data available including an Air Force study on the effect of creep-exposure on the mechanical properties (Ref. 10).

Available cryogenic data for Rene 41 show that the notch ratio (K_t 6. 3) increases while ductility decreases (Ref. 11). Nonetheless, this material appears to have good potential from -423° F to 1600° F temperatures and was selected for future fastener evaluation in 1965 under this contract.

II. 7. 2. 7 Rene 62

Rene 62 is a nickel base precipitation hardening super alloy developed by the General Electric Company (Ref. 12). Maximum applicable temperature is reported to be 1500° F, but could probably be used for higher temperatures in limited applications. Interest has been focused on the material because of its high strength obtained through heat treatment. Cryogenic application would also appear feasible because of its high nickel content. Rene 62 was not considered for evaluation because of its relative newness and uncertainty of availability from the suppliers.

II. 7.2.8 Udimet 630

Udimet 630 is a vacuum induction melted precipitation hardening nickel base alloy with high tensile and yield strength over the range of 70°F to 1300°F. It is reported to have good notch ductility, cryogenic properties, and weldability. Tensile strengths on the order 300 ksi were obtained at -423°F with 7.0 per cent elongation which indicates that this material exhibits good potential from -423°F to 1300°F (Ref. 13). Based on these findings, Udimet 630 was selected for future evaluation as a potential high strength fastener material in 1965 under the present contract.

II. 7.3 Cobalt Base Alloys

II. 7.3.1 L-605

The alloy L-605 is a cobalt base, high temperature alloy also known as Haynes Alloy No. 25. The temperature range appears to be from -423°F to 1800/2000°F depending on the application.

Tensile and notched tensile data at -423°F show L-605 in the 20 per cent cold reduced condition to have high strength with excellent ductility and good notched to unnotched tensile ratio (Ref. 11). Smooth and notched (K_t 6.3) tensile strengths at -423°F were on the order of 260 ksi with 20 per cent elongation.

In addition, the corrosion resistance of L605 appears very good and the alloy can be used without a protective coating.

L605 alloy with 30 per cent cold reduction has been selected for future evaluation as a potential high strength fastener material in 1965 under the present contract.

II. 7.4 Titanium Base Alloys

II. 7.4.1 Ti 6Al-4V

Ti 6Al-4V is an alpha-beta titanium alloy which has had extensive use in pressure vessel application down to -320°F. Interest is being focused to extend the useful temperature of application to -423°F for liquid hydrogen application.

The results of tests by the Astronautics Division of General Dynamics for TMCA show 6-4 Ti to have a pronounced increase in strength as temperature decreases (Ref. 14).

In addition, 6-4 Ti retains reasonable elongation and notch strength (K_t 6.3) when the temperature decreases to -423°F, if the oxygen level is controlled. However, all testing has been performed on sheet material with primary interest in pressure vessel applications. Because of their wide use in aerospace applications, tension and shear bolts of 6-4 Ti were selected for fastener evaluation in the test program.

II. 7. 4. 2 Ti 5Al-2.5Sn (Standard and ELI Grade)

Ti 5Al-2.5Sn is an all alpha non-heat treatable titanium alloy developed by TMCA. It is reported to have excellent properties in the temperature range of -423°F to 800°F. It has been used principally for pressure vessels and cryogenic fuel tanks. The useful application of this material has been extended down to LH_2 temperature by the lowering of the interstitial content which also increases toughness at low temperatures (Ref. 15).

A tensile strength of 240 ksi with 15 per cent elongation was obtained with 5-2.5 Ti material at -423°F temperature.

Data available on the fastener properties consist of stabilization tests which indicated mechanical properties are not affected after exposure at 800°F. From this, it appears that the 5-2.5 Ti has a useful utilization range of -423°F to 800°F. Therefore, standard 5-2.5 Ti was selected for future fastener evaluation and 5-2.5 Ti ELI grade was selected for future evaluation as a potential high strength fastener material in 1965 under this contract.

II. 7. 4. 3 Ti 1Al-8V-5Fe

Ti 1Al-8V-5Fe is an alpha-beta titanium alloy that can be heat treated to 200 ksi minimum tensile strength at room temperature. It has been developed primarily as a fastener material for room temperature applications with a maximum applicable temperature of 300°F. Cryogenic properties of 185 Ti are nonexistent and investigations in this area would be justifiable because of the high strength exhibited at room temperature. Ti 1-8-5 was selected for evaluation as a potential high strength fastener material in this program.

II. 7. 4. 4 Ti 8Al-1V-1Mo

The 8-1-1 titanium alloy has recently come into national prominence as a leading candidate alloy for the supersonic transport. It has the highest modulus and lowest density of the commercially available titanium alloys (Ref. 16). It is an all-alpha titanium alloy requiring no solution treatment and age.

Cryogenic data of 8-1-1 Ti show that as the temperature decreases from room temperature to -423°F the notch ratio decreases considerably. The tests were conducted employing a notch factor of K_t 6.3 which is normally used to evaluate fastener potential. If the ratio of notched to smooth bar falls below 1.0, the future of the material for fastener utilization appears limited. This could be the case with 8-1-1 Ti.

Since 8-1-1 Ti is an all-alpha alloy, elevated temperature properties are good to 750°F. In addition, the material remains relatively stable after long exposures at 750°F. However, fatigue life decreases as a result of long-time exposures.

In light of the limited amount of cryogenic properties on 8-1-1 Ti, it was selected for future fastener evaluation in 1965 under the present contract.

II. 7.4.4 Ti 7Al-12Zr

The 7-12 titanium alloy is presently used in the fabrication of fasteners for elevated temperature application to 750°F. It is a super-alpha titanium alloy requiring no solution treatment and age. Since it was developed for high temperature fastener application, stability of this material is relatively good after long exposures at 750°F although loss in fatigue life has been noted after long expsoure at 750°F.

Cryogenic properties of 7-12 Ti are non-existent, but the potential as a cryogenic fastener material appears to be present. Therefore, 7-12 Ti was selected for fastener evaluation in the test program.

MATERIAL SURVEY

REFERENCES

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(2) Special Metals, Inc. Technical Release "Alloy Performance Data - Minimum Properties Guarantees of Udimet B (18% Nickel Steel)" (1962)

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(5) R. A. Walker and G. W. Gries "Evaluation of Mar-aging Steel Fasteners" Standard Pressed Steel Laboratories Report No. 1062 (Oct. 1963)

(6) J. W. Montano "Low Temperature Mechanical Properties of 'Unitemp' 212 Alloy" Engineering Material Branch, Propulsion and Vehicle Engineering Division, George C. Marshall Space Flight Center (Jan. 1963)

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(8) J. Glackin - "Comparison of the Mechanical Properties to 1600°F of Refined Grain AF 1753 versus Standard AF 1753 Material". SPS Laboratory Report No. 943

(9) E. F. Gowen, Jr. - "Evaluation of Udimet 700 As a 1600°F Fastener Material" SPS Lab Note No. 93

(10) J. V. Gluck and J. W. Freeman - "Effect of Creep Exposure on Mechanical Properties of Rene 41" ASD Technical Report 61-73

(11) Paul H. Denke - "Problems in Selecting Alloys For The Supersonic Transport" Metals Progress, March 1963, pp 70-76

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(14) Titanium Metals Corp. of America "ELI Titanium for Liquid Hydrogen Applications" Titanium Data Release for the Aerospace Industry (1963)

(15) TMCA - Titanium Data for the Aerospace Industry

(16) Aerospace Structural Metals Handbook, Volume II, Code 3709

APPENDIX III

TABLES OF RESULTS

TENSION FASTENERS

III. 1 Iron Base

III. 2 Nickel Base

III. 3 Titanium Base

III. 4 Cobalt Base

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APPENDIX III. 1

Iron Base Fasteners

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MATERIAL PROPERTIES

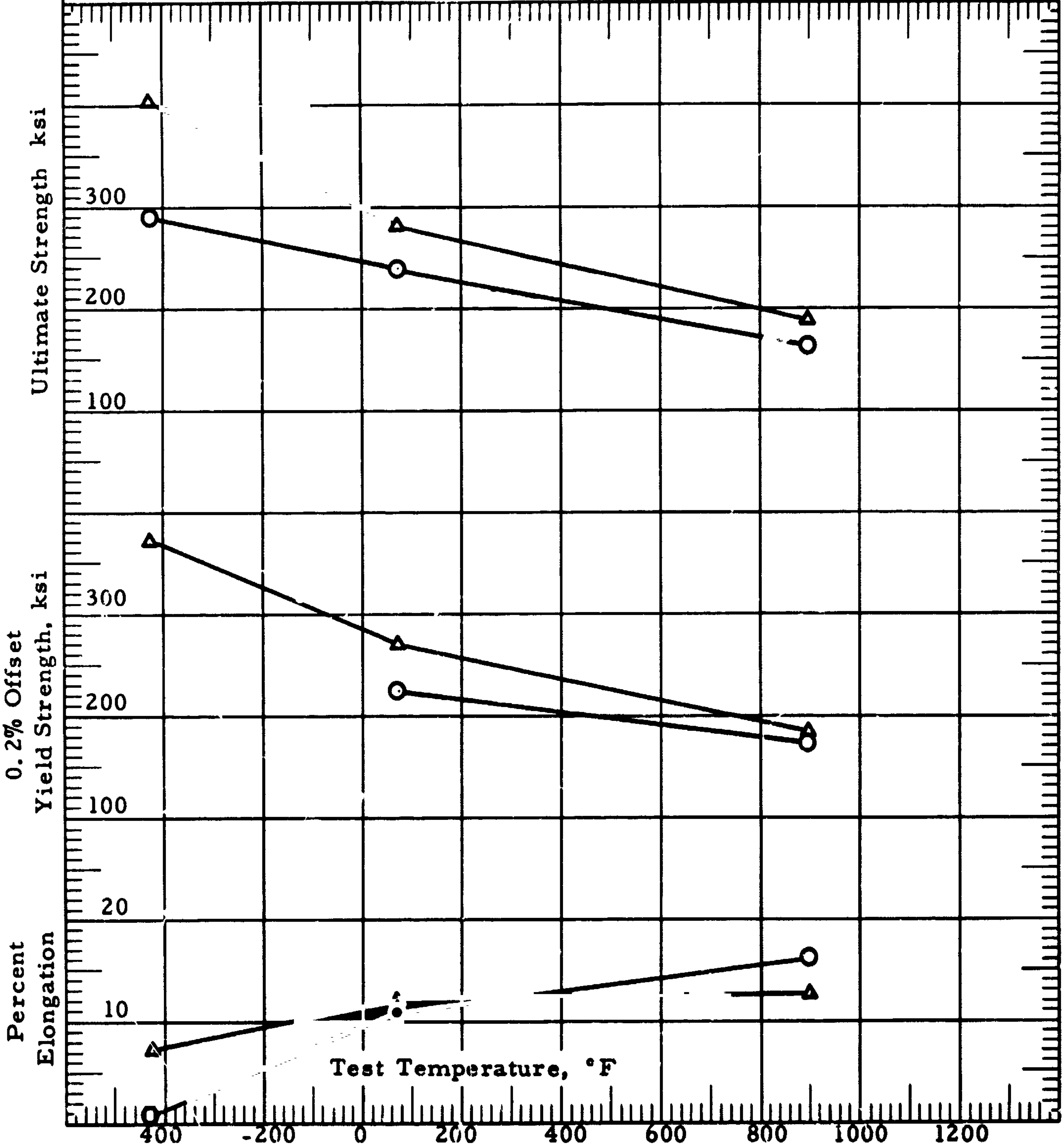
Iron Base (Non Cres) Alloys

Legend

O - AISI H-11 (220 Ksi)
Δ - 18% Nickel Maraging Steel
(Vasco Max 300)

SPS LABORATORIES

Chart No.: III. 1. 1
Date:



MATERIAL PROPERTIES

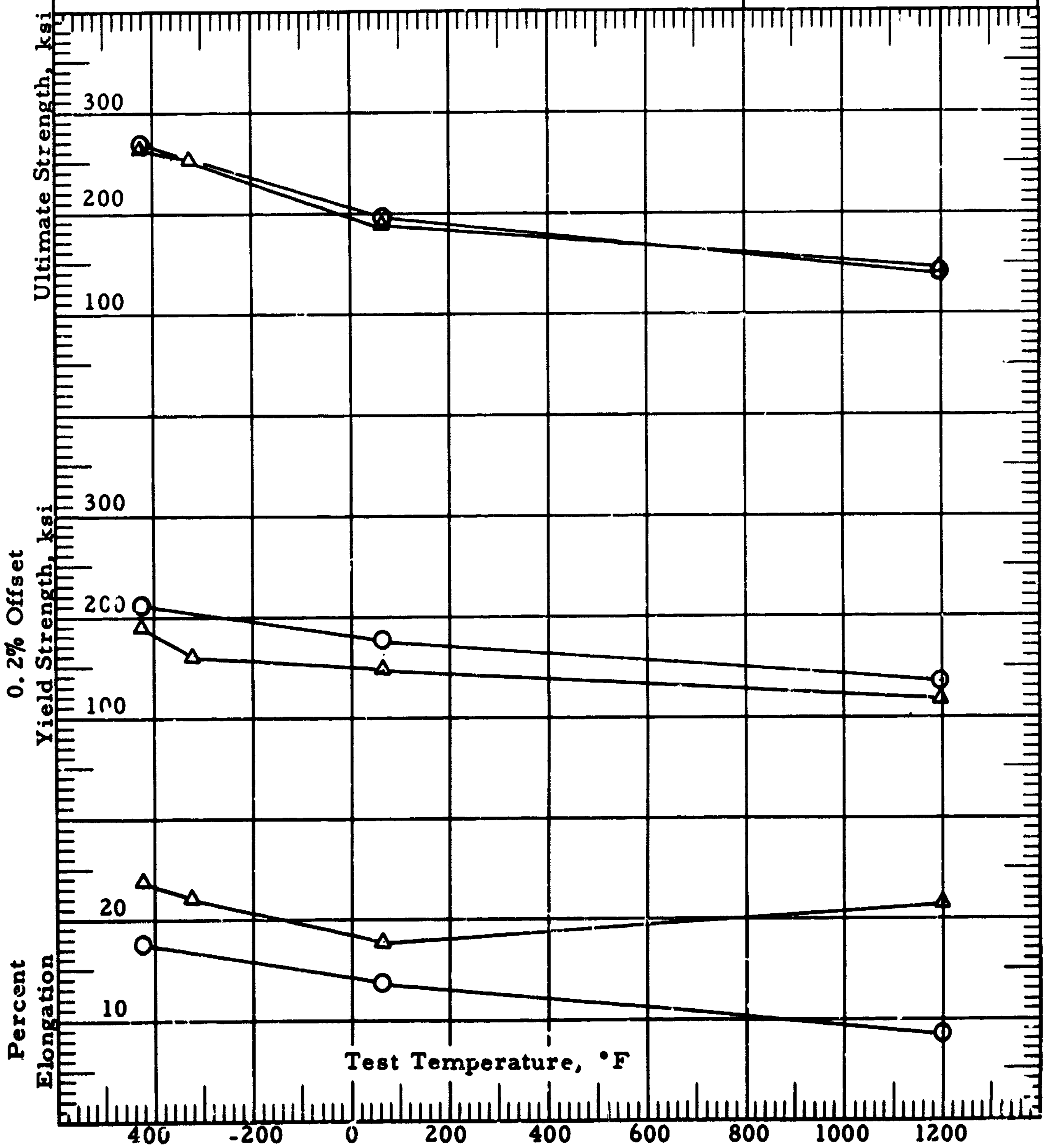
Iron Base (Cres) Alloys

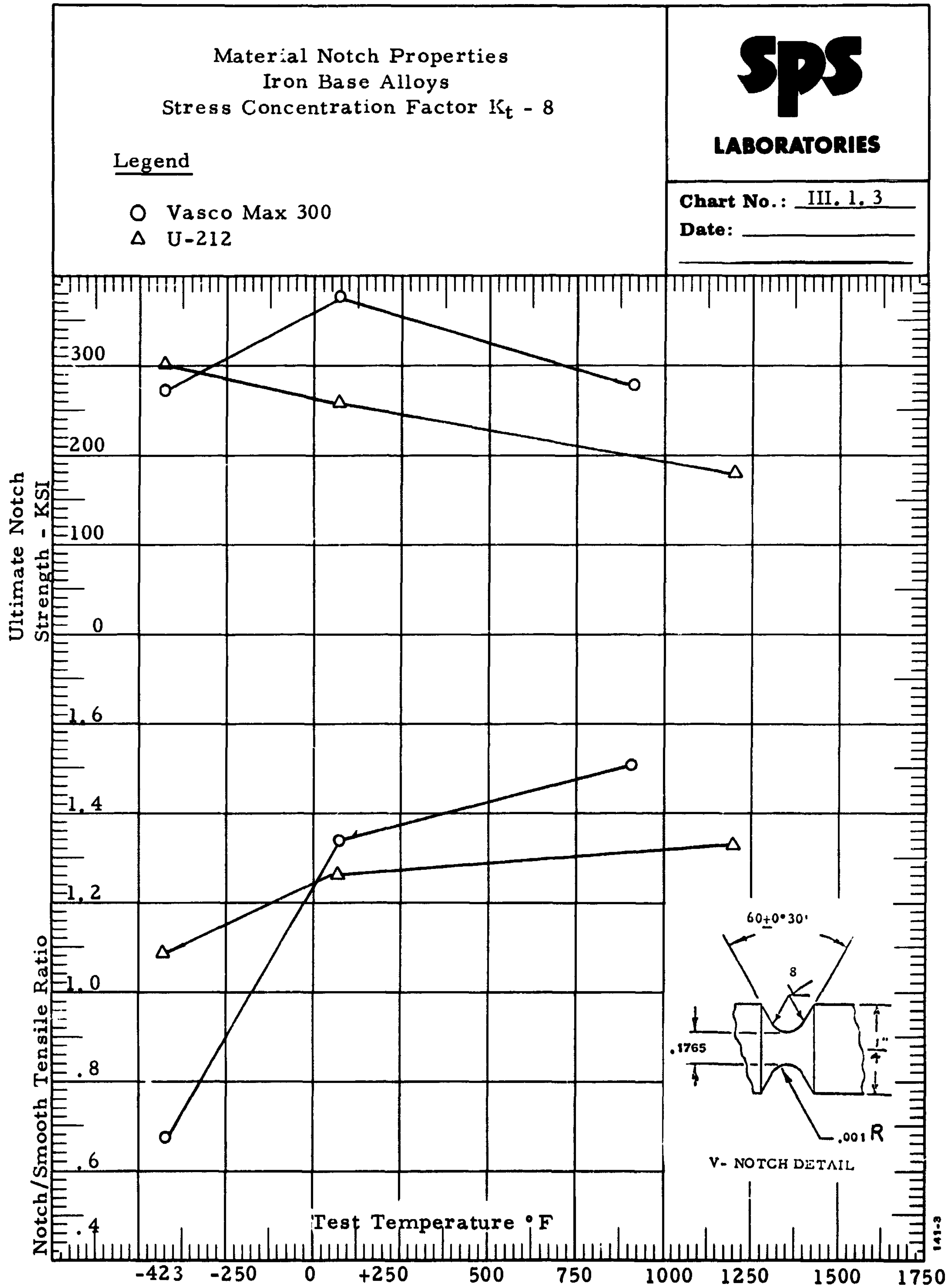
Legend

○ - Cold Reduced A-286
△ - U-212

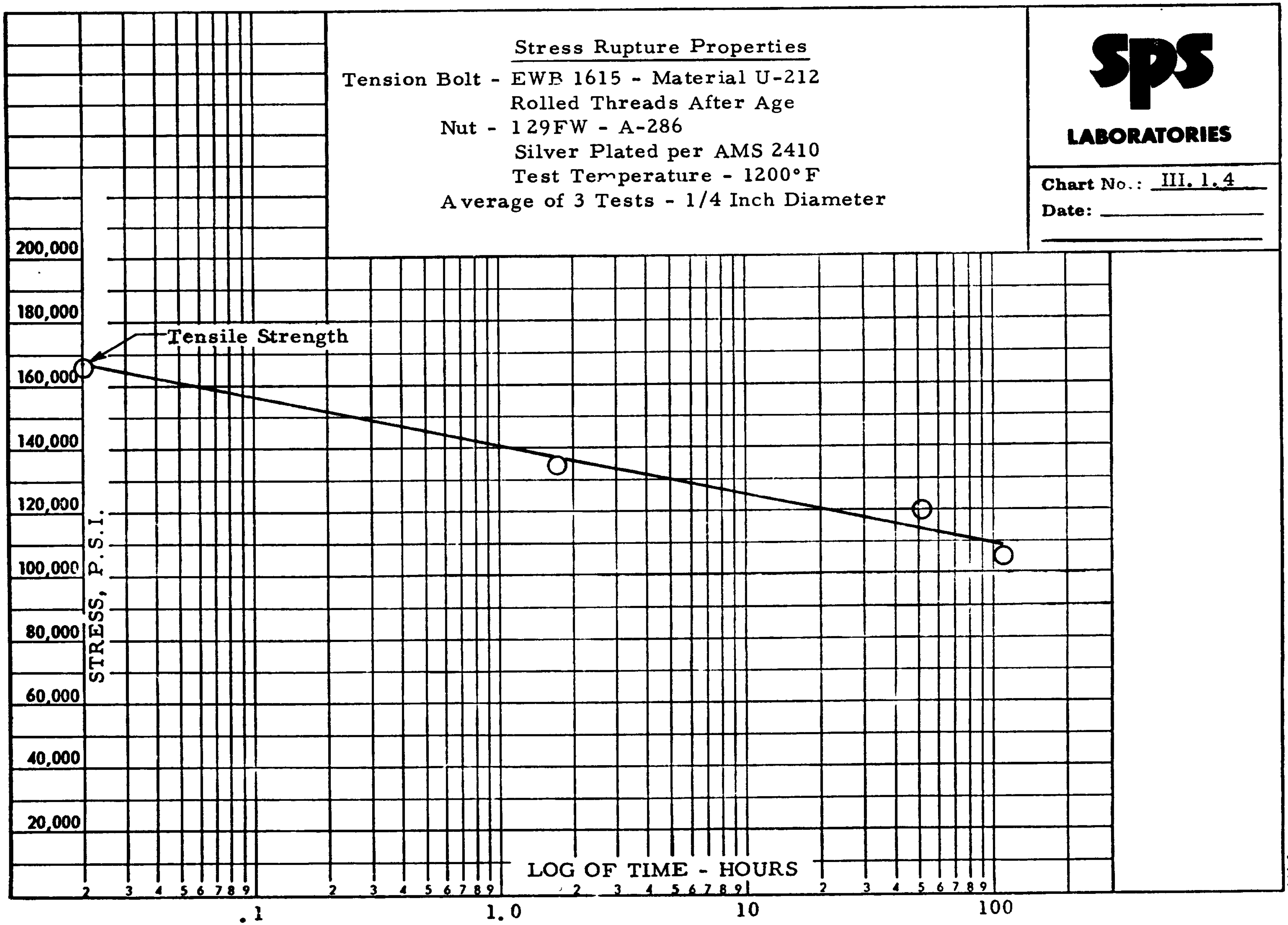
SPS LABORATORIES

Chart No.: III. 1. 2
Date:





Material Notch Properties
Iron Base Alloys
Stress Concentration Factor K_t - 8
Legend
○ Vasco Max 300
Δ U-212
SPS LABORATORIES
Chart No.: III. 1. 3
Date:
Ultimate Notch Strength - KSI
300
200
100
0
1.6
1.4
1.2
1.0
.8
.6
.4
Notch/Smooth Tensile Ratio
60±0°30'
8
.1765
1/4"
.001 R
V- NOTCH DETAIL
Test Temperature °F
-423
-250
0
+250
500
750
1000
1250
1500
1750

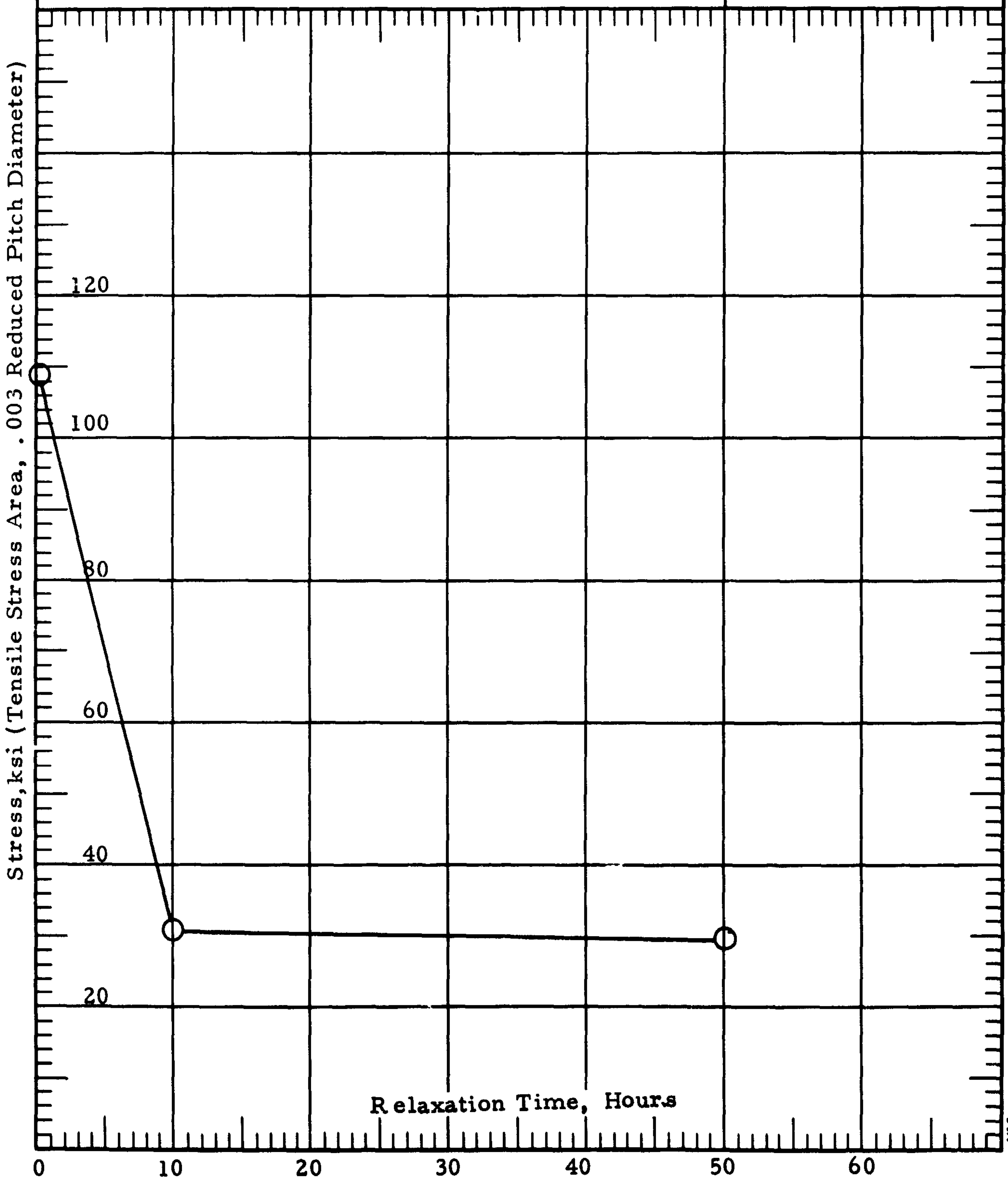

Stress Rupture Properties
Tension Bolt - EWB 1615 - Material U-212
Rolled Threads After Age
Nut - 129FW - A-286
Silver Plated per AMS 2410
Test Temperature - 1200°F
Average of 3 Tests - 1/4 Inch Diameter
SPS
LABORATORIES
Chart No.: III. 1.4
Date:
Tensile Strength
STRESS, P.S.I.
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
LOG OF TIME - HOURS
.1
1.0
10
100

CYLINDER STRESS RELAXATION

Tension Bolt - EWB 1615
Material - U-212 (Rolled Threads After Age)
Nut - 129 FW - Material - A-286
Silver Plated per AMS 2410
Test Temperature - 1600°F
Bolt Diameter - 1/4-28

SPS LABORATORIES

Chart No.: III. 1. 5
Date:



TORQUE VERSUS INDUCED LOAD	SPS LABORATORIES
Tension - Bolt EWB 1615 - Material - U-212 (Rolled Threads After Age) Nut - 129FW - Material A-286 Silver Plated per AMS 2410 Test Temperature - Room Bolt Diameter - 1/4-28 Average 3 Tests	Chart No.: III. 1. 6 Date:

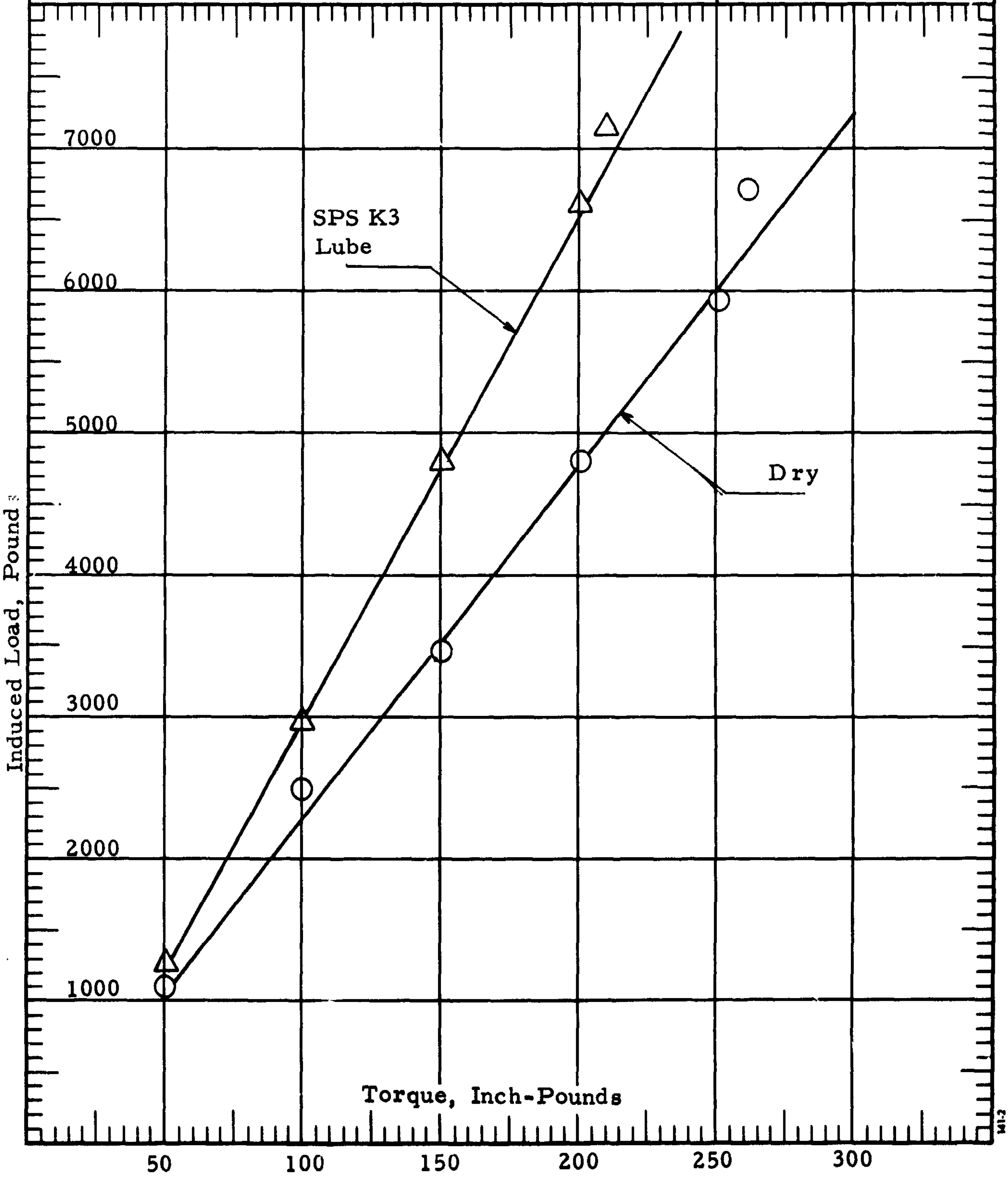


TABLE III. 1. 1

MECHANICAL PROPERTIES

Part No. Bolt - EWB TM 9-4-28 Material AISI H-11 (220 KSI)
Nut - EWN TM 9-428
Size - 1/4-28

1. Tensile

A. Axial Bolt Properties

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
1	-423	12,600	322,500 (H)
2	-423	12,200	310,400 (H)
3	-423	11,140	287,100 (H)
4	-320	11,700	302,000
5	-320	11,640	300,000
6	-320	11,600	299,000
7	70	9,300	239,700
8	70	9,300	241,200
9	70	9,180	236,600

B. Angle Block Bolt Properties (3°∠ @ Nut Bearing Face) *

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
10	-423	4,400	113,400
11	-423	9,500	244,800 (H)
12	-423	4,700	121,100
13	-320	10,300	265,500
14	-320	11,200	288,700
15	-320	10,800	278,400
16	70	9,280	239,200
17	70	9,520	245,400
18	70	9,160	236,100

(1) Stress calculated at Basic Pitch Diameter Area of .0388 square inches.
(H) Head Failure
* Bolt grip length 1.75 inches

TABLE III. 1. 1 (continued)

Part No. Bolt - EWB TM 9-4-28 Material AISI H-11 (220 KSI)
Nut - EWN TM 9-428
Size - 1/4-28

2. Tension Impact

Test No.	Test Temperature, °F	Energy Expended ft. -lbs.
1	-423	32.0
2	-423	30.0
3	-423	38.0
4	-320	34.0
5	-320	28.0
6	-320	36.5
7	70	37.0
8	70	34.5
9	70	36.0

3. Tension-Tension Fatigue @70°F

Test No.	Min. Load, lbs.	Min. Stress, psi	Max. Load, lbs.	Max. Stress, psi(3)	Cycles to Failure	Location of Failure
1	375	11,500	3,750	115,000	1,470,000	Thread
2	375	11,500	3,750	115,000	10,445,000	No Failure
3	375	11,500	3,750	115,000	268,000	Thread

(3) Stress calculated at Basic Minor Diameter area of 0.03256 square inches.

TABLE III. 1. 2

MECHANICAL PROPERTIES

Part No. Bolt - EWB TM 9-8-48 Material AISI H-11 (220 KSI)
Nut - EWN TM 9-820
Size - 1/2-20

1. Tensile

A. Axial Bolt Properties

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
1	-423	41,000	238,900 (H)
2	-423	38,400	223,800 (H)
3	-423	30,800	179,500 (H)
4	-320	51,000	297,200
5	-320	51,200	298,400
6	-320	50,800	296,000
7	70	41,600	242,400
8	70	41,400	241,300
9	70	42,000	244,800

B. Angle Block Bolt Properties (3°∠ @ Nut Bearing Face)*

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
10	-423	40,200	234,300 (H)
11	-423	36,150	210,700 (H)
12	-423	37,100	216,200 (H)
13	-320	50,000	291,400
14	-320	50,000	291,400
15	-320	49,300	287,300
16	70	42,400	247,100
17	70	41,900	244,200
18	70	41,700	243,000

(1) Stress calculated at Basic Pitch Diameter Area of .1716 square inches.
H - Head Failure.
* Bolt grip length 3.0 inches.

TABLE III. 1. 2 (continued)

Part No. EWB TM 9-8-48
EWN TM 9-820
Size - 1/2-20

Material - AISI H-11 (220 KSI)

2. Double Shear

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
1	-423	59,500	151,500
2	-423	60,000 (N. F.)	152,800
3	-423	60,000 (N. F.)	152,800

3. Tension-Tension Fatigue @70°F

Test No.	Min. Load, lbs.	Min. Stress, psi	Max. Load lbs.	Max. Stress, psi(3)	Cycles to Failure	Location of Failure
1	1,710	11,500	17,100	115,000	505,000	Th'd.
2	1,710	11,500	17,100	115,000	93,000	Th'd.
3	1,710	11,500	17,100	115,000	761,000	Th'd.

(2) Stress calculated at Twice Nominal Dia. area, 0.3927 square inches.
N. F. - No Failure - Load exceeded capacity of machine.
(3) Stress calculated at Basic Minor Diameter area of 0.1486 square inches.

TABLE III. 1. 3

MECHANICAL PROPERTIES

Part No. Bolt - VS 2502-3-40 Material - A-286 (200 KSI)
Nut - VN466B-02
Size - #10-32 (Rolled Thread After Age)

1. Tensile

A. Axial Bolt Properties

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
1	-423	5,860	287,000
2	-423	5,800	290,000
3	-423	5,820	291,000
4	-320	5,300	265,100
5	-320	5,300	265,100
6	-320	5,320	266,100
7	70	4,280	214,100
8	70	4,250	212,600
9	70	4,280	214,100

B. Angle Block Bolt Properties (3°∠ @ Nut Bearing Face)*

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
10	-423	5,630	281,600
11	-423	5,740	287,100
12	-423	5,520	276,100
13	-320	5,480	274,100
14	-320	5,460	273,100
15	-320	5,430	271,600
16	70	4,190	209,600
17	70	4,260	213,100
18	70	4,260	213,100

(1) Stress calculated at Tensile Stress Area of 0.01999 square inches.
* Bolt grip length 2.5 inches.

TABLE III. 1. 3 (continued)

Part No. VS 2502-3-40 Material - A-286 (200 ksi)
VN 466B-02
Size - #10-32 (Rolled Thread After Age)

2. Tension Impact

Test No.	Test Temperature, °F	Energy Expended ft.-lbs.
1	-423	14.0
2	-423	14.0
3	-423	12.5
4	-320	19.0
5	-320	18.0
6	-320	17.5
7	70	13.0
8	70	12.0
9	70	13.0

3. Tension-Tension Fatigue @70°F

Test No.	Min. Load, lbs.	Min. Stress, psi	Max. Load, lbs.	Max. Stress, psi(2)	Cycles to Failure	Location of Failure
1	182	10,400	1,823	104,000	73,000	Thread
2	182	10,400	1,823	104,000	90,000	Thread
3	182	10,400	1,823	104,000	221,700	Thread

4. Vibration - ALMA #10 -

Test No.	Test Temperature, °F	Maximum Installation, 1st	5th	Seating Torque, in.-lbs.	No. of Cycles	Degrees Movement	10X Mag. Visual Insp.	Remarks
1	-320	9	10	30	30,000	0°	No cracks	Passed
2	-320	10	7	30	30,000	0°	No cracks	Passed
3	-320	10	6	30	30,000	0°	No cracks	Passed
4	70	13	6	30	30,000	5°	No cracks	Passed
5	70	10	4	30	30,000	20°	No cracks	Passed
6	70	12	6	30	30,000	45°	No cracks	Passed
7	70	9	5	30	30,000	15°	No cracks	Passed
8	70	12	7	30	30,000	0°	No cracks	Passed

(2) Stress calculated at Basic Minor Diameter Area of 0.01753 square inches.

TABLE III. 1.4

MECHANICAL PROPERTIES

Part No. Bolt - VS 2502-4-44 Material - A-286 (200 KSI)
Nut - VN 466B-048
Size - 1/4-28 (Rolled Threads After Age)

1. Tensile

A. Axial Bolt Properties

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
1	-423	10,700	294,200
2	-423	10,600	291,400
3	-423	10,500	288,700
4	-320	9,600	264,000
5	-320	9,800	269,500
6	-320	9,900	272,200
7	70	7,860	216,100
8	70	7,760	213,300
9	70	7,780	213,900

B. Angle Block Bolt Properties (3°∠ @ Nut Bearing Face)*

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
10	-423	10,400	285,900
11	-423	10,300	283,200
12	-423	10,100	277,700
13	-320	9,800	269,500
14	-320	10,000	274,900
15	-320	9,800	269,500
16	70	7,830	218,000
17	70	7,800	214,500
18	70	7,780	213,900

(1) Stress calculated at Tensile Stress Area of 0.03637 square inches.
* Bolt grip length 2.75 inches.

TABLE III. 1. 4 (continued)

Part No. VS 2502-4-44 Material - A-286 (200 ksi)
VN 466 B-048
Size - 1/4-28 (Rolled Threads After Age)

2. Tension Impact

Test No.	Test Temperature, °F	Energy Expended, ft. - lbs.
1	-423	38.0
2	-423	[illegible]2.0
3	-423	39.0
4	-320	41.0
5	-320	43.5
6	-320	39.0
7	70	35.0
8	70	34.0
9	70	36.0

3. Tension-Tension Fatigue @70°F

Test No.	Min. Load, lbs.	Min. Stress, psi	Max. Load, lbs.	Max. Stress, psi (2)	Cycles to Failure	Location of Failure
1	339	10,400	3,386	104,000	133,500	Thread
2	339	10,400	3,386	104,000	115,500	Thread
3	339	10,400	3,386	104,000	130,400	Thread

4. Vibration - ALMA #10

Test No.	Test Temperature, °F	Maximum Installation, 1st	5th	Seating Torque, in.-lbs.	No. of Cycles	Degrees Movement	10X Mag. Visual Insp.	Remarks
1	-320	20	17	60	30,000	0°	No Cracks	Passed
2	-320	22	20	60	30,000	0°	No Cracks	Passed
3	-320	21	12	60	30,000	0°	No Cracks	Passed
4	-320	17	15	60	30,000	0°	No Cracks	Passed
5	-320	12	8	60	30,000	0°	No Cracks	Passed
6	70	10	15	60	30,000	0°	No Cracks	Passed
7	70	10	15	60	30,000	0°	No Cracks	Passed
8	70	10	15	60	30,000	0°	No Cracks	Passed
9	70	10	15	60	30,000	0°	No Cracks	Passed
[illegible]	70	15	20	60	30,000	0°	No Cracks	Passed

(2) Stress calculated at Basic Minor Diameter Area of 0.03256 square inches.

TABLE III. 1. 5

MECHANICAL PROPERTIES

Part No. Bolt - VS 2502-8-48 Material - A-286 (200 KSI)
Nut - VN466B-080
Size - 1/2-20 (Rolled Threads After Age)

1. Tensile

A. Axial Bolt Properties

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
1	-423	43,500	272,000
2	-423	42,800	267,700
3	-423	43,500	272,000
4	-320	42,200	263,900
5	-320	42,600	266,400
6	-320	42,800	267,700
7	70	35,000	218,800
8	70	34,700	217,000
9	70	34,700	217,000

B. Angle Block Bolt Properties (3°∠ @ Nut Bearing Face) *

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
10	-423	43,300	270,800
11	-423	42,100	263,300
12	-423	41,800	261,400
13	-320	42,800	267,700
14	-320	42,100	263,300
15	-320	42,000	262,700
16	70	34,200	213,900
17	70	33,850	211,700
18	70	34,400	215,100

(1) Stress calculated at Tensile Stress Area of 0.1599 square inches.
* Bolt grip length 3.0 inches.

TABLE III. 1. 5 (continued)

2. Tension-Tension Fatigue @70°F

Test No.	Min. Load, lbs.	Min. Stress, psi	Max. Load, lbs.	Max. Stress, psi (2)	Cycles to Failure	Location of Failure
1	1,545	10,400	15,450	104,000	37,500	Thread
2	1,545	10,400	15,450	104,000	30,200	Thread
3	1,545	10,400	15,450	104,000	31,600	Thread

3. Vibration - ALMA #10 -

Test No.	Test Temperature °F	Installation 1st	Installation 5th	Seating Torque in.-lbs.	No. of Cycles	Degrees Mov't	10X Mag. Visual Insp.	Remarks
1	-320	55	40	300	30,000	0°	No cracks	Passed
2	-320	50	25	300	30,000	0°	No cracks	Passed
3	-320	50	35	300	30,000	0°	No cracks	Passed
4	70	90	40	300	30,000	0°	No cracks	Passed
5	70	75	60	300	30,000	0°	No cracks	Passed
6	70	50	40	300	30,000	0°	No cracks	Passed
7	70	60	30	300	30,000	45°	No cracks	Passed
8	70	80	40	300	30,000	0°	No cracks	Passed

(2) Stress calculated at Basic Minor Diameter Area of 0.1486 square inches

TABLE III. 1. 6

MECHANICAL PROPERTIES

Part No. Bolt - EWB 1615-4-38 Material - U-212 (180 KSI)
Nut - Nut Slug
Size - 1/4-28 (Rolled Threads Before Age)

1. Tensile

A. Axial Bolt Properties

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
1	-423	8,140	223,800
2	-423	8,250	226,800
3	-423	8,200	225,500
4	-320	8,000	220,000
5	-320	8,125	223,400
6	-320	8,125	223,400
7	70	6,800	187,000
8	70	6,900	189,700
9	70	6,850	188,300

B. Angle Block Bolt Properties (3°∠ @ Nut Bearing Face)*

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
10	-423	7,500	206,200
11	-423	7,600	209,000
12	-423	7,920	217,800
13	-320	8,280	227,700
14	-320	8,160	224,400
15	-320	8,150	224,100
16	70	6,720	184,800
17	70	6,720	184,800
18	70	6,780	186,400

(1) Stress calculated at Tensile Stress Area of 0.03637 square inches.
* Bolt grip length 2.375 inches.

TABLE III. 1. 6 (continued)

Part No. EWB 1615-4-38 Nut Slug

Material - U-212 (180 ksi)

Size - 1/4-28 (Rolled Threads Before Age)

2. Tension Impact

Test No.	Test Temperature, °F	Energy Expended, ft. -lbs.
1	-423	30.0
2	-423	29.0
3	-423	21.0
4	-320	38.0
5	-320	28.0
6	-320	28.0
7	70	32.5
8	70	34.5
9	70	34.5

3. Tension-Tension Fatigue @ 70°F

Test No.	Minimum Load, lbs.	Minimum Stress, psi	Maximum Load, lbs.	Maximum Stress, psi(2)	Cycles to Failure	Location of Failure
1	305	9,360	3,048	93,600	57,500	Thread
2	305	9,360	3,048	93,600	55,700	Thread
3	305	9,360	3,048	93,600	119,500	Thread

(2) Stress calculated at Basic Minor Diameter Area of 0.03256 square inches.

TABLE III. 1. 7

MECHANICAL PROPERTIES

Part No. Bolt - EWB 1615-4-16 Material - U-212
Part No. Nut - 129 FW-428 Material - A-286
Size - 1/4-28 (Rolled Threads After Age)

1. Tensile

A. Base Material Properties (As Received) 0.113 inches specimen

Test No.	Test Temperature, °F	Ultimate Stress, psi	0.2% Offset Yield Stress, psi	Elongation Gage, .5 in. %	Reduction of Area %
1	-423	280,000	191,000	24.0	41.0
2	-423	275,000	187,500	22.0	35.0
3	-423	274,000	168,500	24.0	40.0
4	-320	260,000	157,500	22.0	43.5
5	-320	257,200	150,400	22.0	42.8
6	-320	257,500	160,000	22.0	43.5
7	70	190,000	151,000	18.0	40.3
8	70	192,500	149,000	18.0	40.3
9	70	195,900	153,000	18.0	35.4
10	1200	145,000	121,000	24.0	46.0
11	1200	148,400	123,100	22.0	38.9
12	1200	146,000	122,500	20.0	42.0

TABLE III. 1. 7 (continued)

Part No. EWB 1615-4-16 Material - U-212
129 FW-428 A-286
Size - 1/4-28 (Rolled Threads After Age)

1. Tensile (continued)

B. Axial Bolt Properties (As Received)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (1)	Johnson's 2/3 Approximation Yield Load, lbs.	Johnson's 2/3 Approximation Yield Stress, psi
13	-423	9,800	277,100	7,300	206,400
14	-423	9,700	274,200	6,950	196,500
15	-423	9,980	282,200	7,400	209,200
16	-320	9,750	275,600	6,750	190,800
17	-320	9,800	277,000	6,800	192,200
18	-320	9,700	274,200	6,450	182,300
19	70	7,560	213,700	5,300	149,800
20	70	7,570	214,000	5,300	149,800
21	70	7,540	213,100	4,800	135,700
22	1200	5,860	165,600	5,200	147,000
23	1200	5,900	166,800	5,250	148,400
24	1200	5,980	169,000	5,300	149,800

C. Angle-Block Bolt Properties (3°∠ @Nut Bearing Face)*

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (1)
25	-423	9,460	267,500
26	-423	9,880	279,300
27	-423	9,600	271,400
28	-320	9,860	278,800
29	-320	9,750	275,200
30	-320	9,600	271,400
31	70	7,650	216,300
32	70	7,560	213,700
33	70	7,640	216,000

D. As-Relaxed Bolt Properties (50 Hours)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (1)	Yield Load, lbs.	Yield Stress, psi
34	70	7,200	203,600	5,600	158,300
35	70	6,640	187,700	5,600	158,300
36	70	7,100	200,700	5,200	147,000

(1) Stress Calculated at Tensile Stress Area (.003 reduced pitch diameter of 0.03537 square inches.

* Bolt grip length 1.0 inches.

TABLE III. 1. 7 (continued)

Part No. EWB 1615-4-16 — Material - U-212
129 FW-428 — Material - A-286
Size - 1/4-28 (Rolled Threads After Age)

2. Stress Durability @ 70°F

Test No.	Seated Stress, lbs.	Seated Stress, psi(1)	Torque to Induce Stress, in.-lbs.	Length of Test Hours	Remarks
1	4,617	130,500	180	24	Passed
2	4,617	130,500	180	24	Passed
3	4,617	130,500	180	24	Passed

3. Tension-Impact

Test No.	Test Temperature, °F	Energy Expended, ft.-lbs.
1	-423	47.0
2	-423	45.0
3	-423	38.0
4	-320	47.5
5	-320	47.5
6	-320	47.0
7	70	47.0
8	70	45.5
9	70	46.6

(1) Stress Calculated at the Tensile Stress Area (.003 reduced pitch diameter) of 0.03537 square inches.

TABLE III. 1. 7 (continued)

Part No. - EWB 1615-4-16 Material - U-212
129 FW-428 Material - A-286
Size - 1/4-28 (Rolled Threads After Age)

4. Double Shear

A. As-Received

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
1	-423	16,500	168,100
2	-423	16,300	166,000
3	-423	16,000	163,000
4	70	13,000	132,400
5	70	13,000	132,400
6	70	13,000	132,400
7	1200	8,900	90,700
8	1200	9,050	92,200
9	1200	9,400	95,800

B. As-Relaxed (50 Hours)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
10	70	12,000	122,200
11	70	12,300	125,300
12	70	12,200	124,300

(2) Stress Calculated at Twice the Nominal Diameter Area, 0.09817 square inches.

TABLE III. 1. 7 (continued)

Part No. - EWB 1615-4-16 Material - U-212
129 FW-428 Material - A-286
Size - 1/4-28 (Rolled Threads After Age)

5. Stress Rupture

Test No.	Test Temperature, °F	Load, lbs.	Stress, psi(1)	Hours to Failure	Location of Failure
1	1200	4,775	135,000	1.5	Thread
2	1200	4,775	135,000	2.5	Thread
3	1200	4,775	135,000	1.5	Thread
4	1200	4,244	120,000	31.3	Thread
5	1200	4,244	120,000	87.4	Thread
6	1200	4,244	120,000	37.6	Thread
7	1200	3,714	105,000	77.2	Thread
8	1200	3,714	105,000	98.8	Thread
9	1200	3,714	105,000	169.0	No Failure

6. Stress Relaxation @1200°F

Initial Stress - 109,000 psi

Test No.	Hours Run	Residual Stress lbs.	Residual Stress psi(1)
1	10	1233	34,900
2	10	Bolt Fractured While Being Disassembled	
3	10	Bolt Fractured While Being Disassembled	
4	50	1190	33,600
5	50	1318	37,300
6	50	1190	33,600

(1) Stress Calculated at the Tensile Stress Area (.003 reduced pitch diameter) of 0.03537 square inches.

TABLE III. 1. 7 (continued)

Part No. EWB 1615-4-16 / 129 FW-428

Material - U-212 / A-286

Size - 1/4-28 (Rolled Threads After Age)

7. Nut Reuse and Galling Tendency @70°F

Seated Stress - 97,200 psi

Test No.	Maximum Installation, inch-pounds,	Torque to Induce Stress, inch-pounds	Torque, inch-pounds Breakaway	Torque, inch-pounds Removal
1st Application				
1	19	150	120	11
2	22	155	115	10
3	20	170	140	11
4	20	145	110	10
5	20	145	105	11
2nd Application				
1	13	140	105	11
2	12	140	105	10
3	14	155	120	11
4	12	135	95	9
5	10	130	90	10
3rd Application				
1	13	140	105	11
2	11	140	105	10
3	13	150	115	10
4	10	140	100	9
5	10	130	95	10
4th Application				
1	13	140	105	10
2	10	140	105	10
3	11	155	115	10
4	10	145	105	9
5	11	135	95	10
5th Application				
1	11	140	105	10
2	9	140	105	9
3	11	150	110	10
4	10	140	105	9
5	10	135	95	10

(1) **Stress calculated at Tensile Stress Area (.003 reduced pitch diameter) of 0.03537 square inches.**

TABLE III. 1. 7 (continued)

Part No. EWB 1615-4-16   Material - U-212
129 FW-428   A-286
Size - 1/4-28 (Rolled Threads After Age)

8. Torque vs. Induced Load @ 70°F

Torque inch-pounds	Test No. 1 Load, pounds	Test No. 2 Load, pounds	Test No. 3 Load, pounds
Dry			
50	1000	1200	1200
100	2550	2500	2450
150	3500	3500	3750
200	4950	4900	4800
250	6100	6050	5800
275	6700 B. F.	6750 B. F.	6550 B. F.
SPS K3 Lube			
50	1450	1000	1250
100	2950	3150	2750
150	4250	5150	5250
200	6100	6750	6750
210	6800 B. F.	7300 B. F.	7250 B. F.

B. F. - Bolt Fractured

APPENDIX III. 2

Nickel Base Fasteners

MATERIAL PROPERTIES

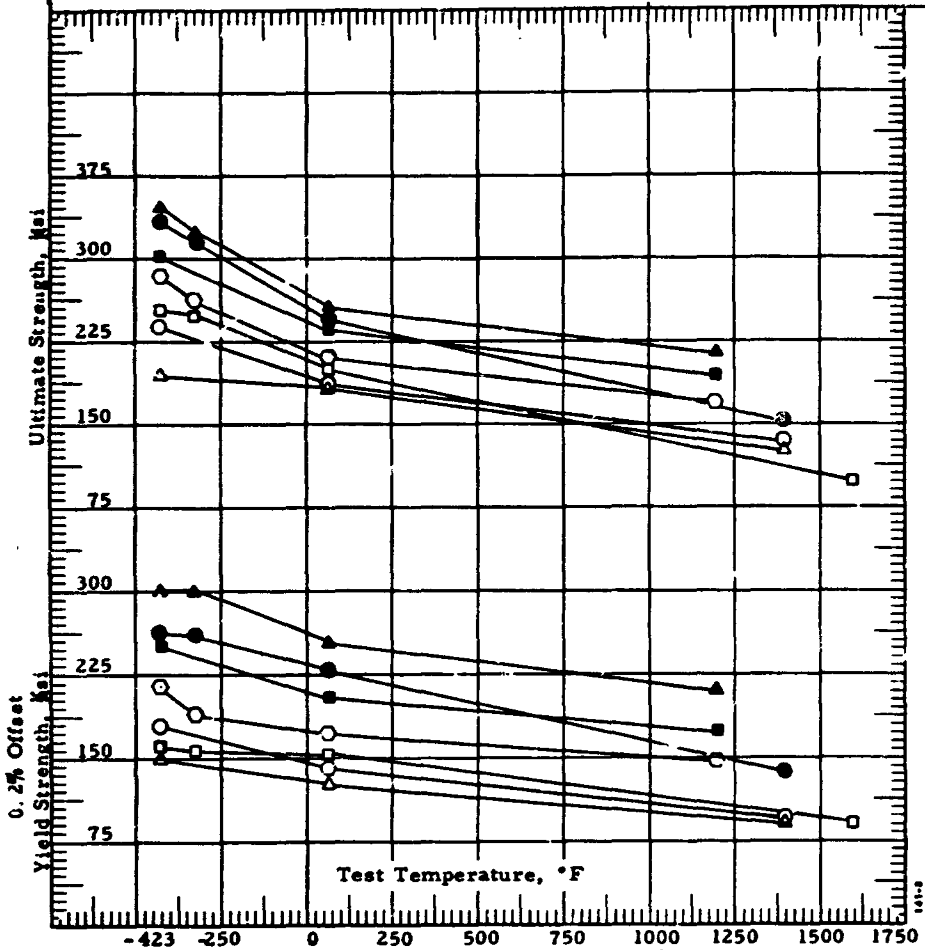
Nickel Base Alloys

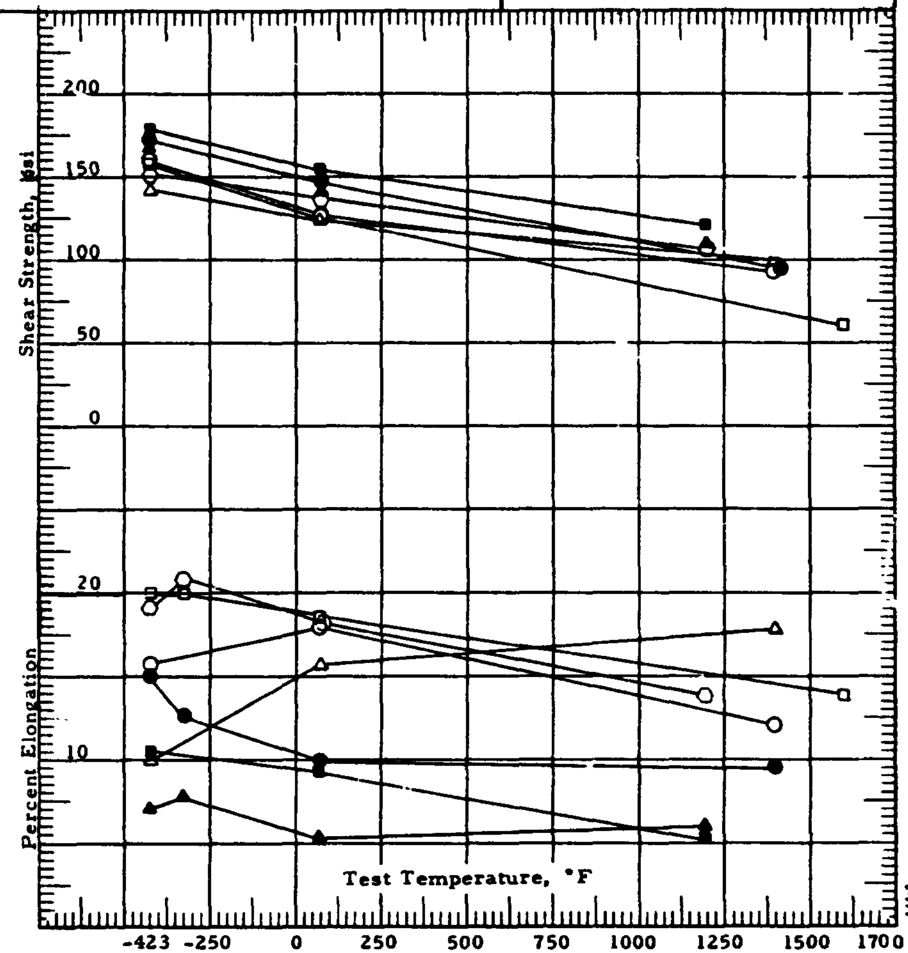
Legend

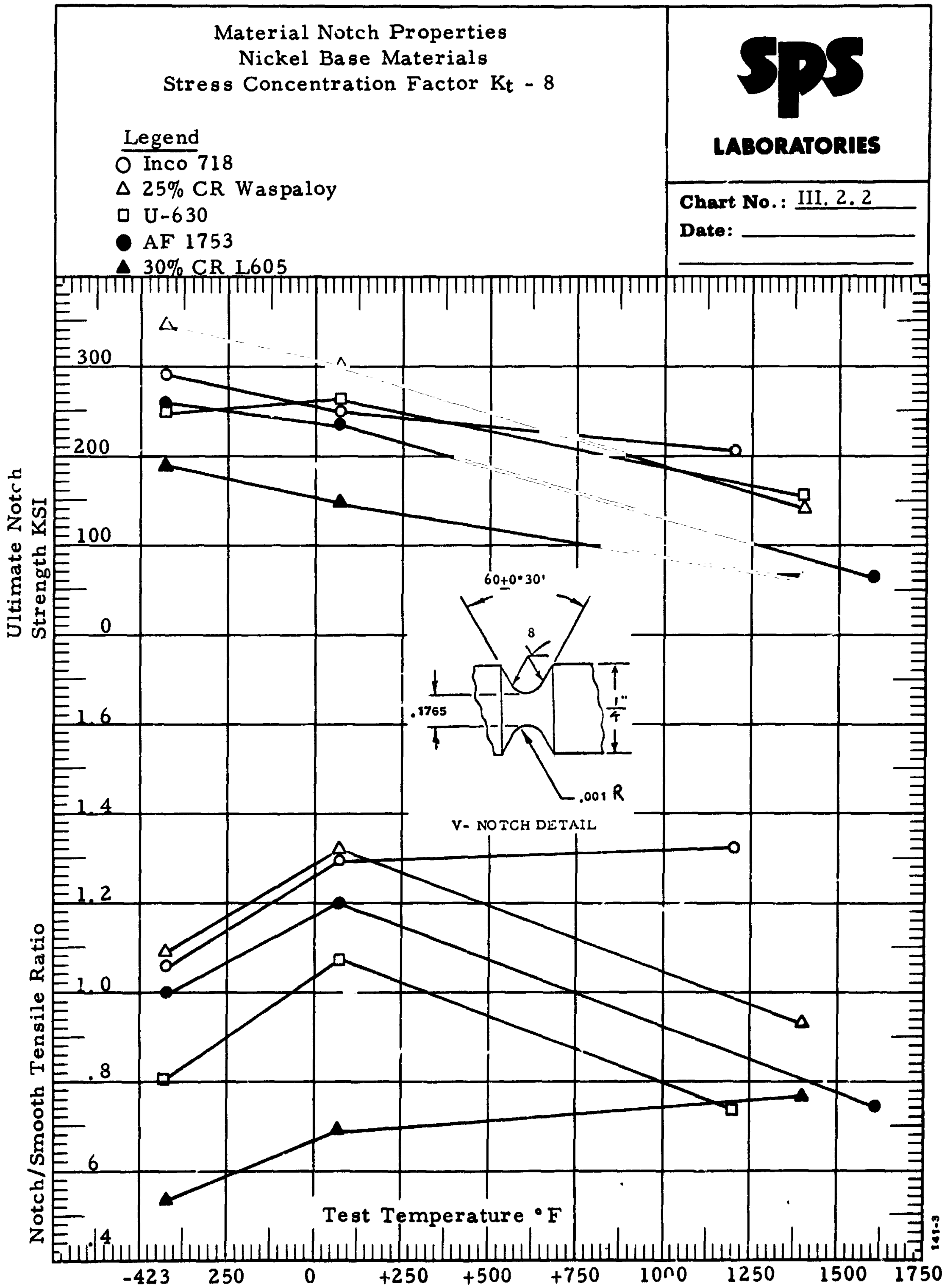
○ —Waspaloy
△ —Rene 41
□ —AF 1753
⬡ —Inconel 718
● —25% Cold Reduced Waspaloy
▲ —25% Cold Reduced Inconel 718
■ —Udimet 630

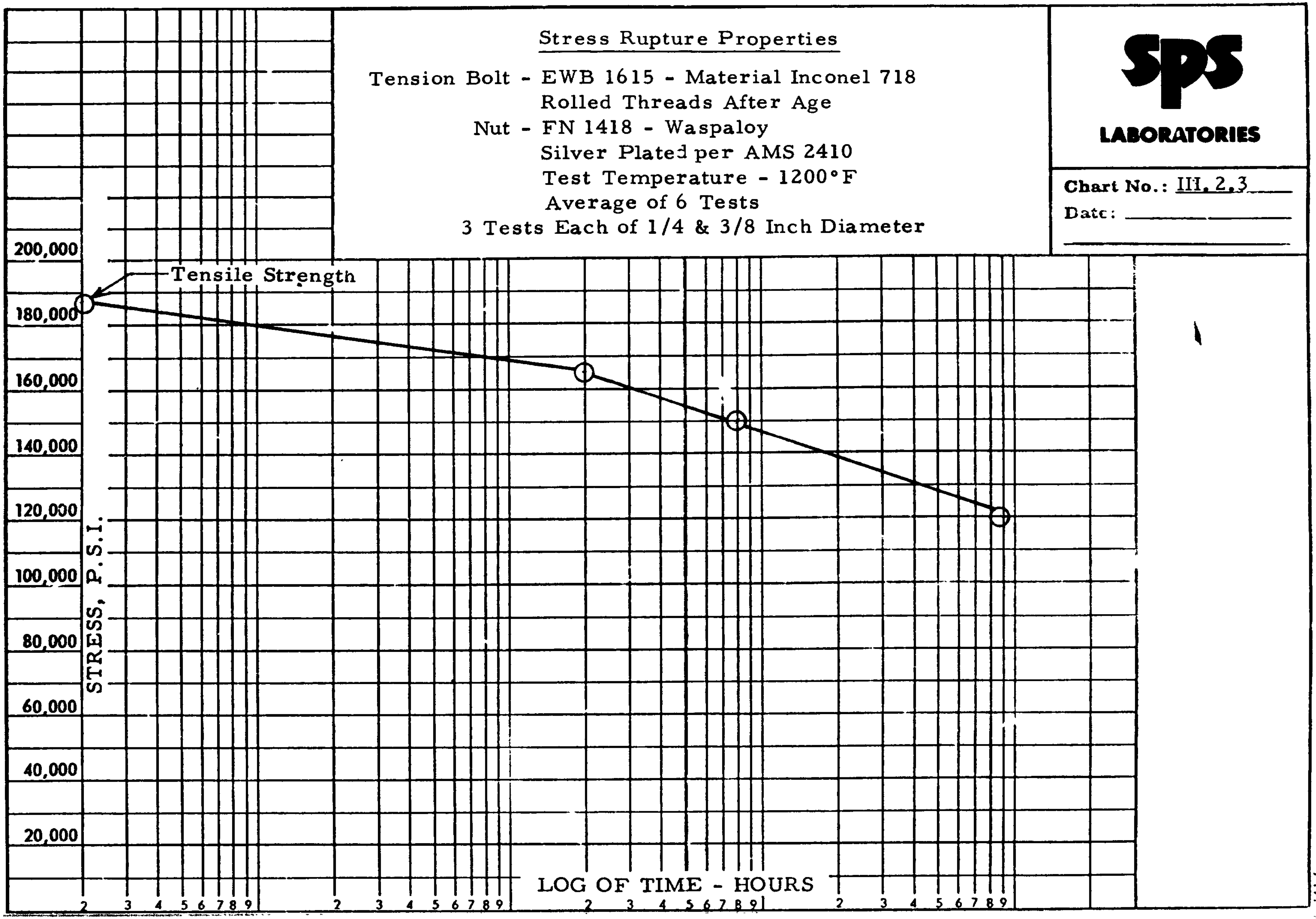
SPS LABORATORIES

Chart No.: III. 2. 1
Date:

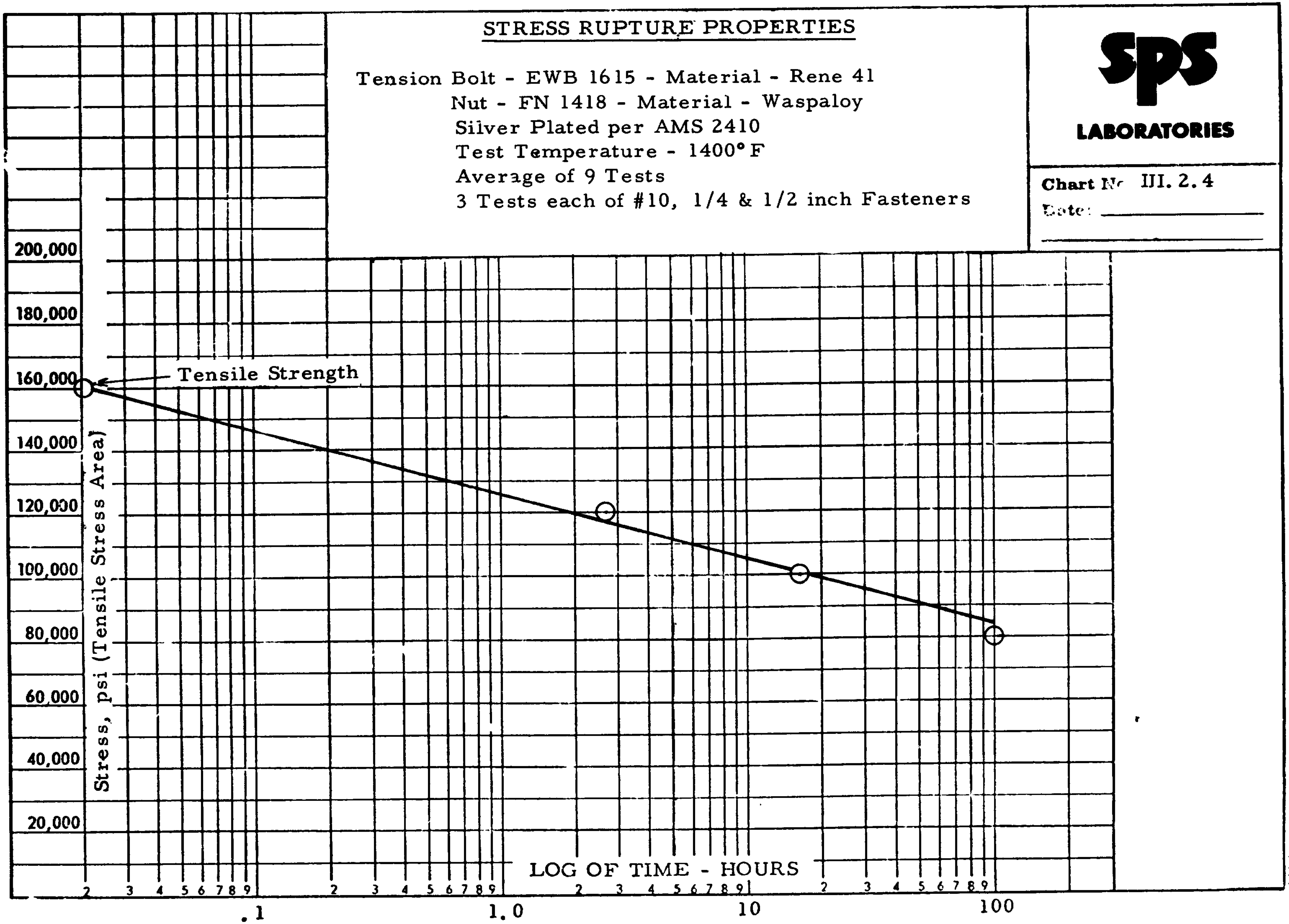


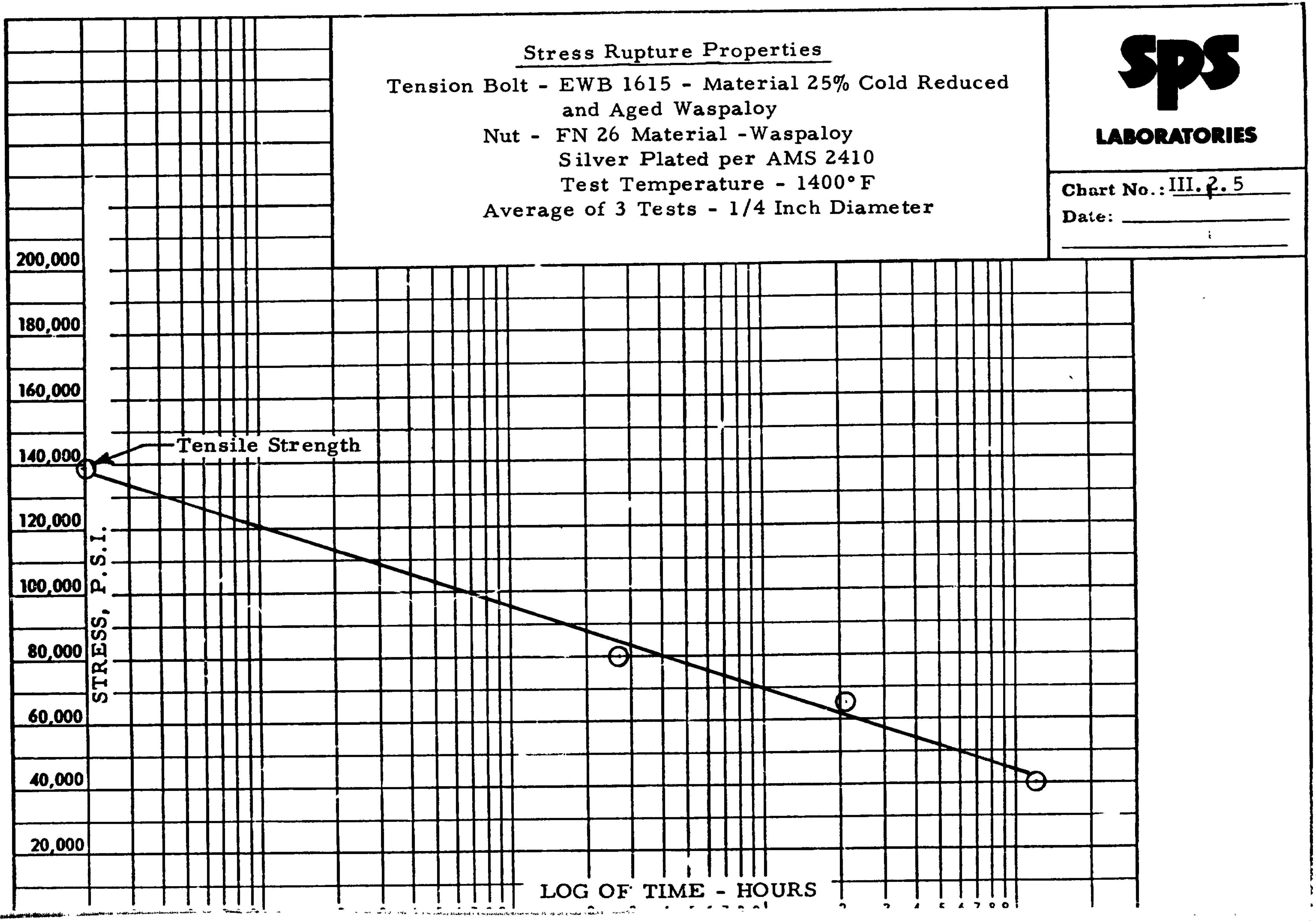


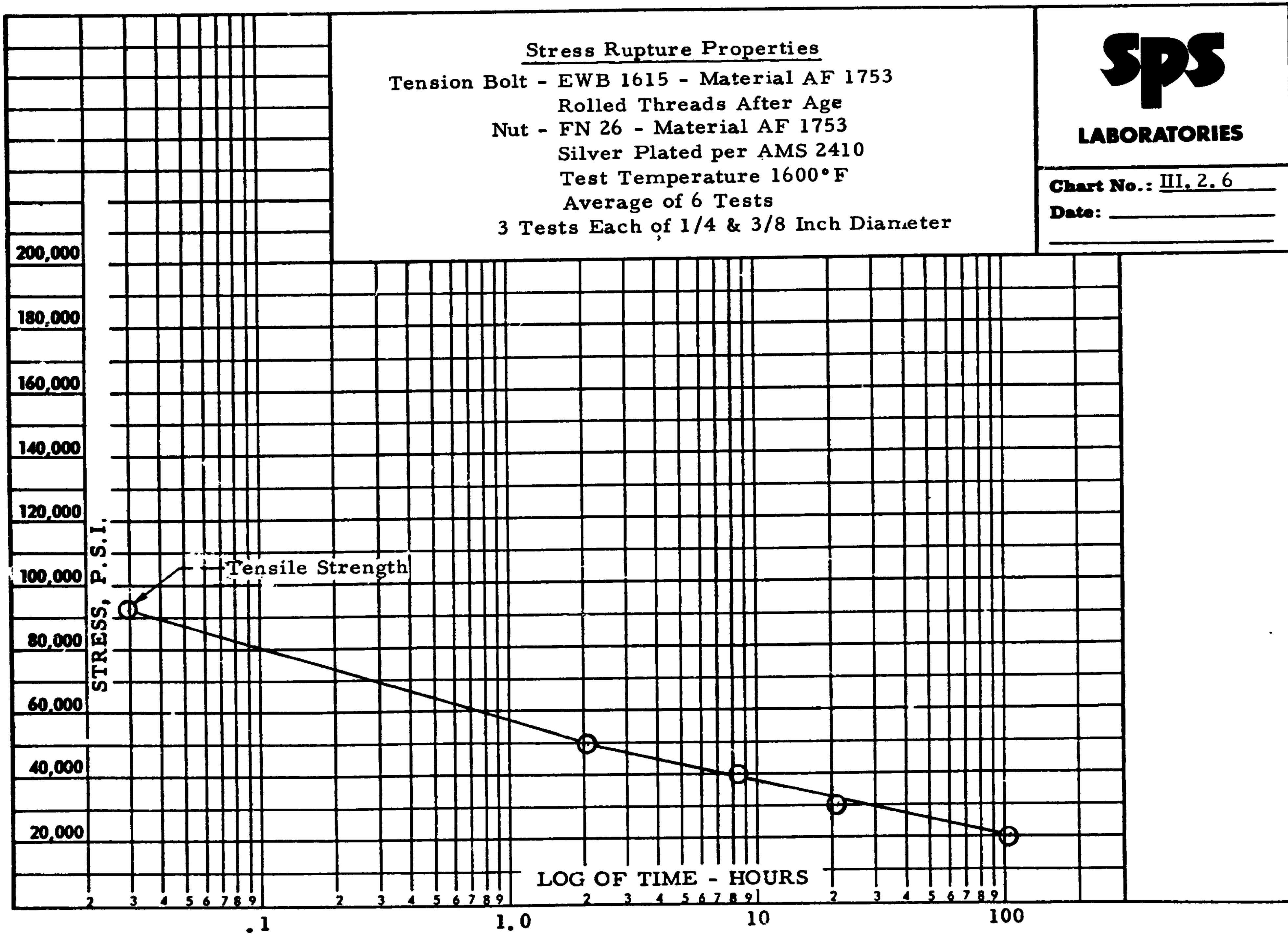

Material Notch Properties
Nickel Base Materials
Stress Concentration Factor Kt - 8
Legend
O Inco 718
Δ 25% CR Waspaloy
□ U-630
● AF 1753
▲ 30% CR L605
SPS
LABORATORIES
Chart No.: III. 2. 2
Date:
Ultimate Notch Strength KSI
300
200
100
0
60±0°30'
8
.1765
1/4"
.001 R
V- NOTCH DETAIL
Notch/Smooth Tensile Ratio
1.6
1.4
1.2
1.0
.8
6
.4
Test Temperature °F
-423
250
0
+250
+500
+750
1000
1250
1500
1750
141-3



SPS
LABORATORIES
Chart No.: III. 2.3
Date:
Stress Rupture Properties
Tension Bolt - EWB 1615 - Material Inconel 718
Rolled Threads After Age
Nut - FN 1418 - Waspaloy
Silver Plated per AMS 2410
Test Temperature - 1200°F
Average of 6 Tests
3 Tests Each of 1/4 & 3/8 Inch Diameter
Tensile Strength
STRESS, P.S.I.
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
LOG OF TIME - HOURS
2 3 4 5 6 7 8 9 2 3 4 5 6 7 8 9 2 3 4 5 6 7 8 9 2 3 4 5 6 7 8 9


STRESS RUPTURE PROPERTIES
Tension Bolt - EWB 1615 - Material - Rene 41
Nut - FN 1418 - Material - Waspaloy
Silver Plated per AMS 2410
Test Temperature - 1400° F
Average of 9 Tests
3 Tests each of #10, 1/4 & 1/2 inch Fasteners
SPS
LABORATORIES
Chart No III. 2. 4
Date:
Tensile Strength
Stress, psi (Tensile Stress Area)
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
LOG OF TIME - HOURS
.1
1.0
10
100


SPS LABORATORIES
Chart No.: III.2.5
Date:
Stress Rupture Properties
Tension Bolt - EWB 1615 - Material 25% Cold Reduced and Aged Waspaloy
Nut - FN 26 Material -Waspaloy
Silver Plated per AMS 2410
Test Temperature - 1400°F
Average of 3 Tests - 1/4 Inch Diameter
Tensile Strength
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
STRESS, P.S.I.
LOG OF TIME - HOURS



Stress Rupture Properties
Tension Bolt - EWB 1615 - Material AF 1753
Rolled Threads After Age
Nut - FN 26 - Material AF 1753
Silver Plated per AMS 2410
Test Temperature 1600°F
Average of 6 Tests
3 Tests Each of 1/4 & 3/8 Inch Diameter
SPS
LABORATORIES
Chart No.: III. 2. 6
Date:
Tensile Strength
STRESS, P.S.I.
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
LOG OF TIME - HOURS
.1
1.0
10
100

SPS LABORATORIES

Chart No.: III. 2. 7

Date:

Stress Rupture Properties

Tension Bolt - EWB 1615 - Material 30% Cold Reduced and Aged L605

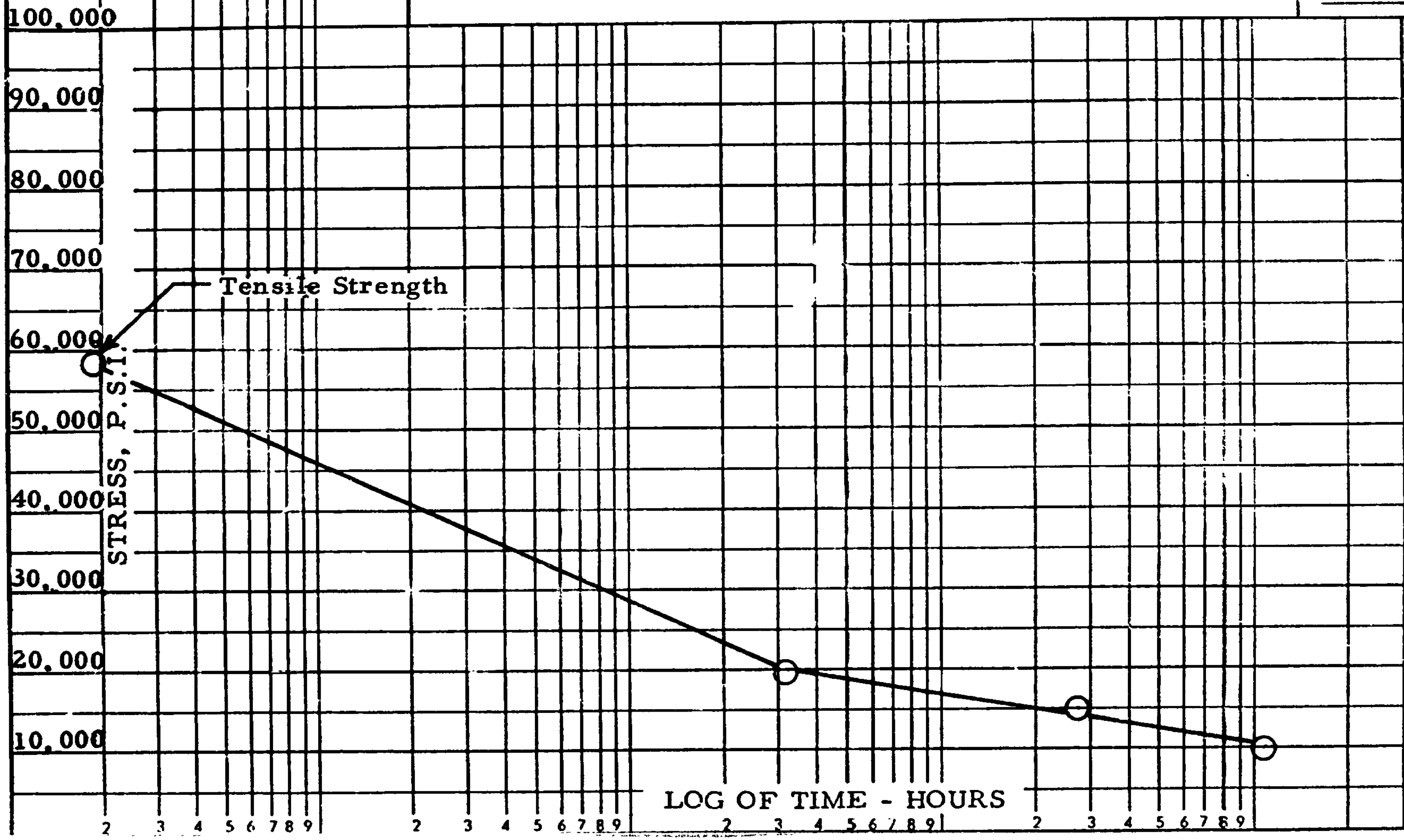
Rolled Threads After Age

Nut - Nut Slug - Material L605

Silver Plated per AMS 2410

Test Temperature - 1600°F

Average of 3 Tests - 1/4 Inch Diameter

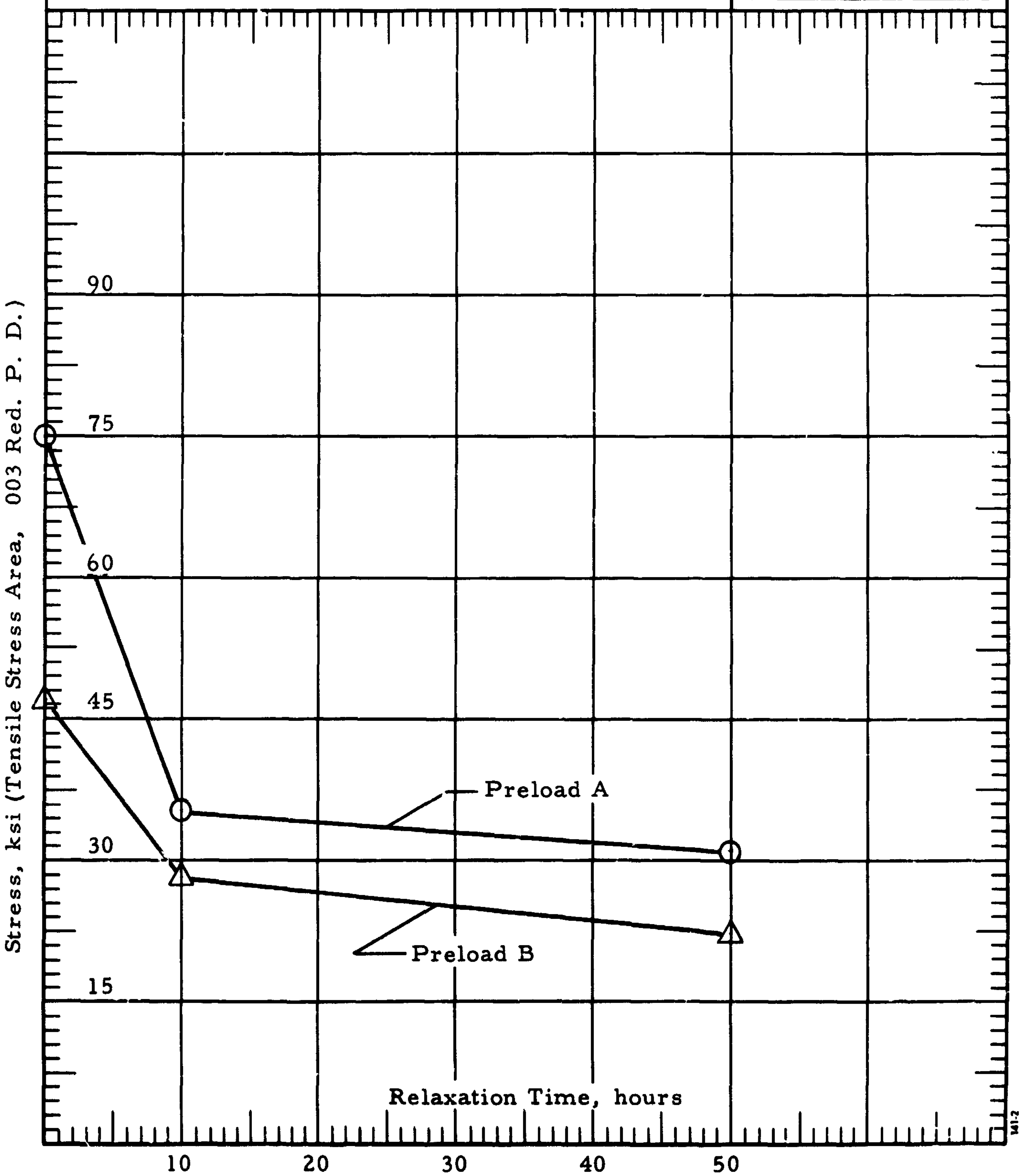


CYLINDER STRESS RELAXATION

Tension Bolt - EWB 1615
Material - Rene 41
Nut - FN 1418 - Material - Waspaloy
Silver Plated per AMS 2410
Test Temperature - 1400° F
Average of 9 Tests
3 Tests each of #10, 1/4 & 1/2 inch Fasteners

SPS LABORATORIES

Chart No.: III. 2. 8
Date:

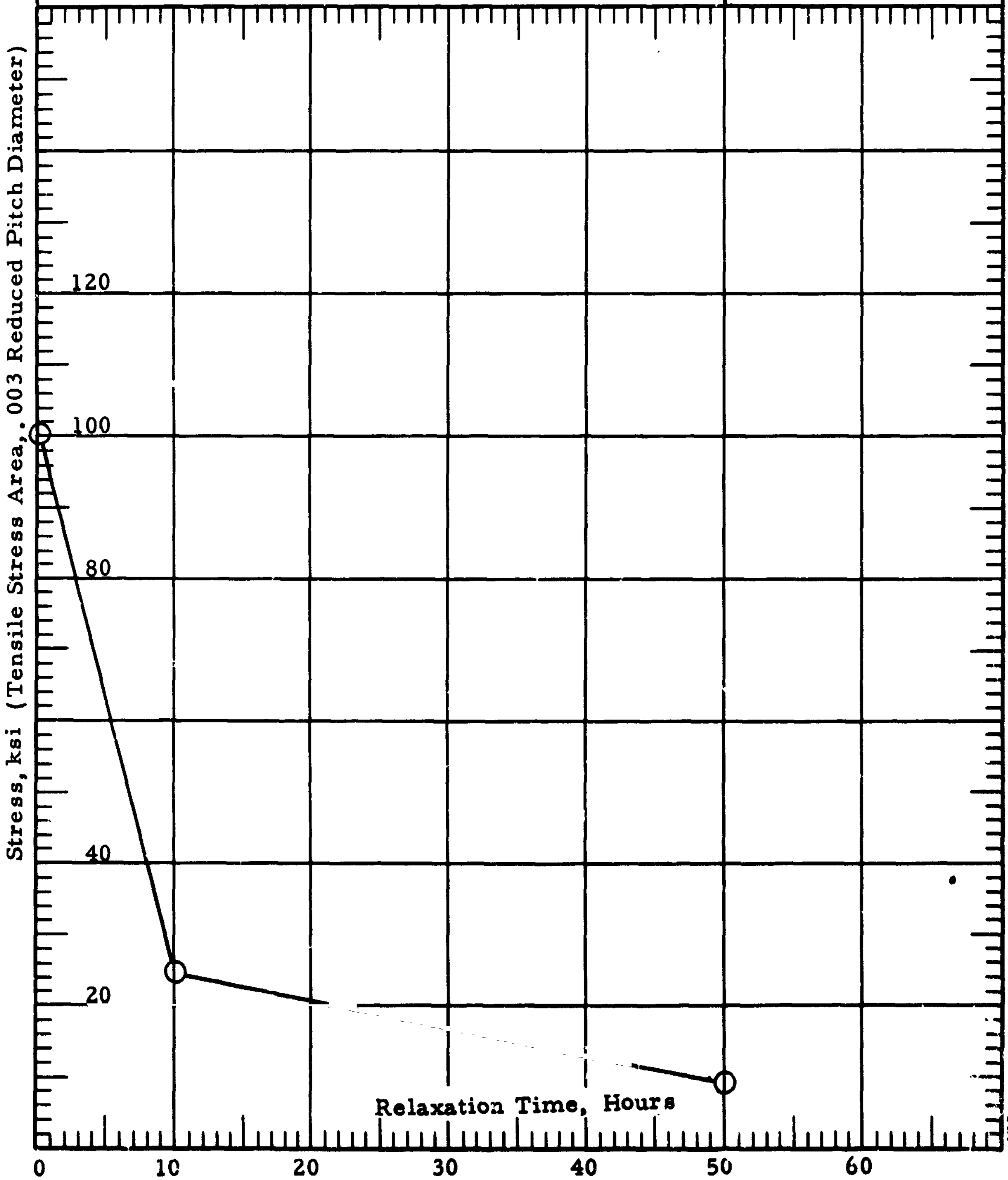


CYLINDER STRESS RELAXATION

Tension Bolt - EWB 1615
Material - 25% C. R. Waspaloy (Rolled Threads After Age)
Nut - FN 26 - Material Waspaloy
Silver Plated per AMS 2410
Test Temperature - 1400°F
Bolt Diameter 1/4-28

SPS LABORATORIES

Chart No.: III. 2. 9
Date:

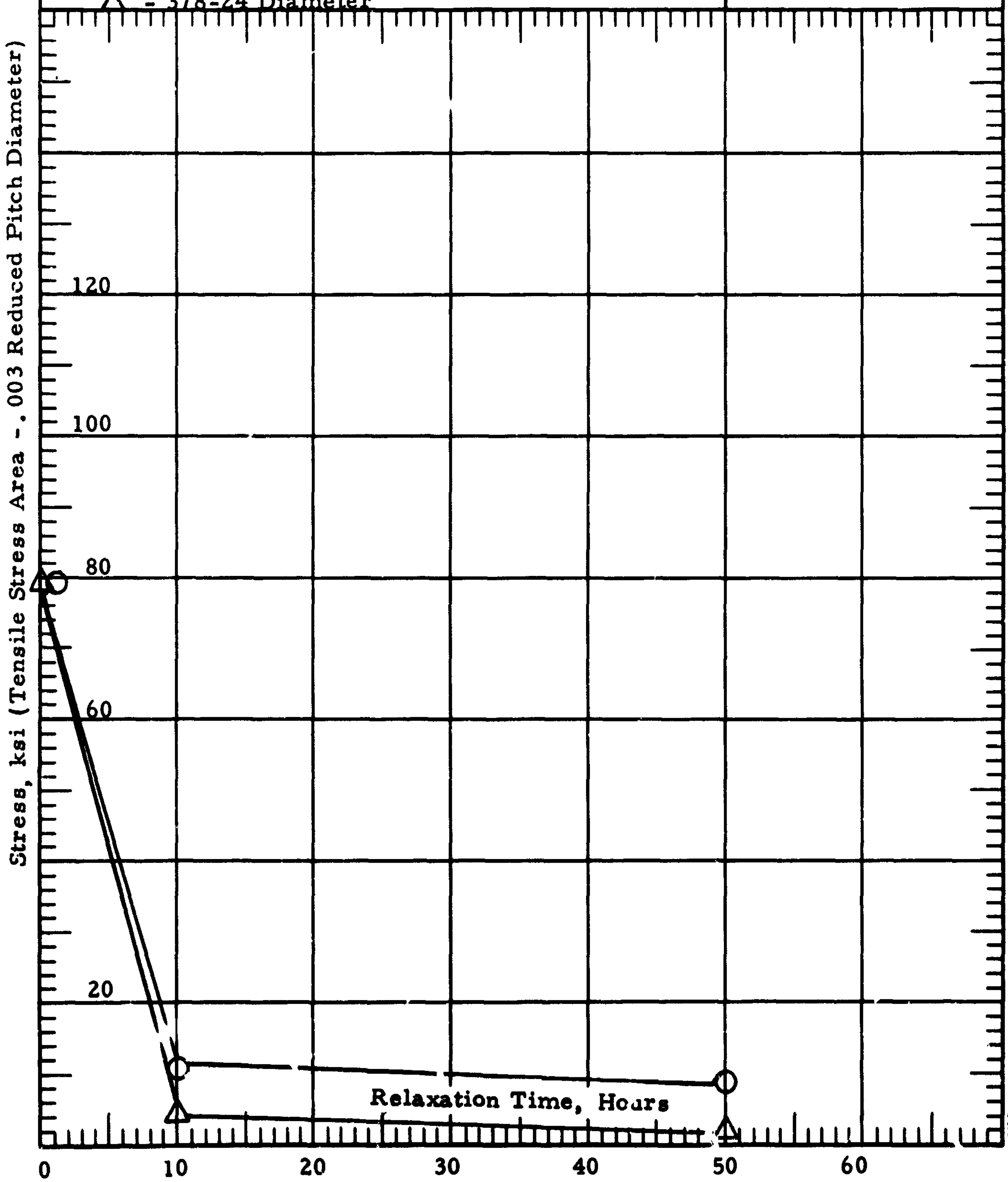


CYLINDER STRESS RELAXATION

Tension Bolt - EWB 1615- Material AF 1753
(Rolled Threads After Age)
Nut - FN 26 - Material AF 1753
Silver Plated per AMS 2410
Test Temperature - 1600°F
Legend
○ - 1/4-28 Diameter
△ - 3/8-24 Diameter

SPS LABORATORIES

Chart No.: III. 2. 10
Date:

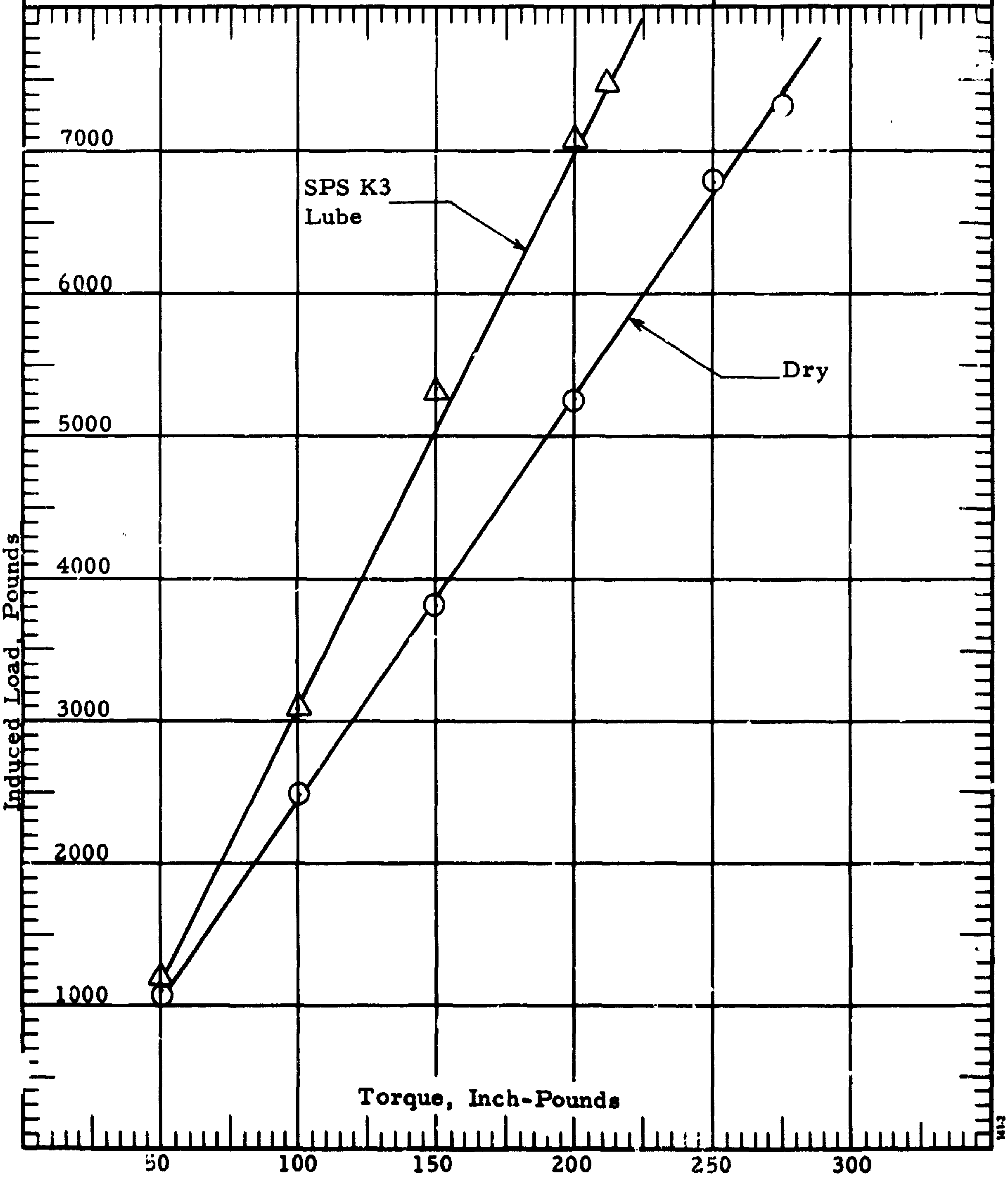


TORQUE VERSUS INDUCED LOAD

Tension Bolt - EWB 1615 - Material - Inco 718
(Rolled Threads After Age)
Nut - 129 FW - Material A-286
Silver Plated per AMS 2410
Test Temperature - Room
Bolt Diameter - 1/4-28
Average 3 Tests

SPS LABORATORIES

Chart No.: III. 2. 11
Date:

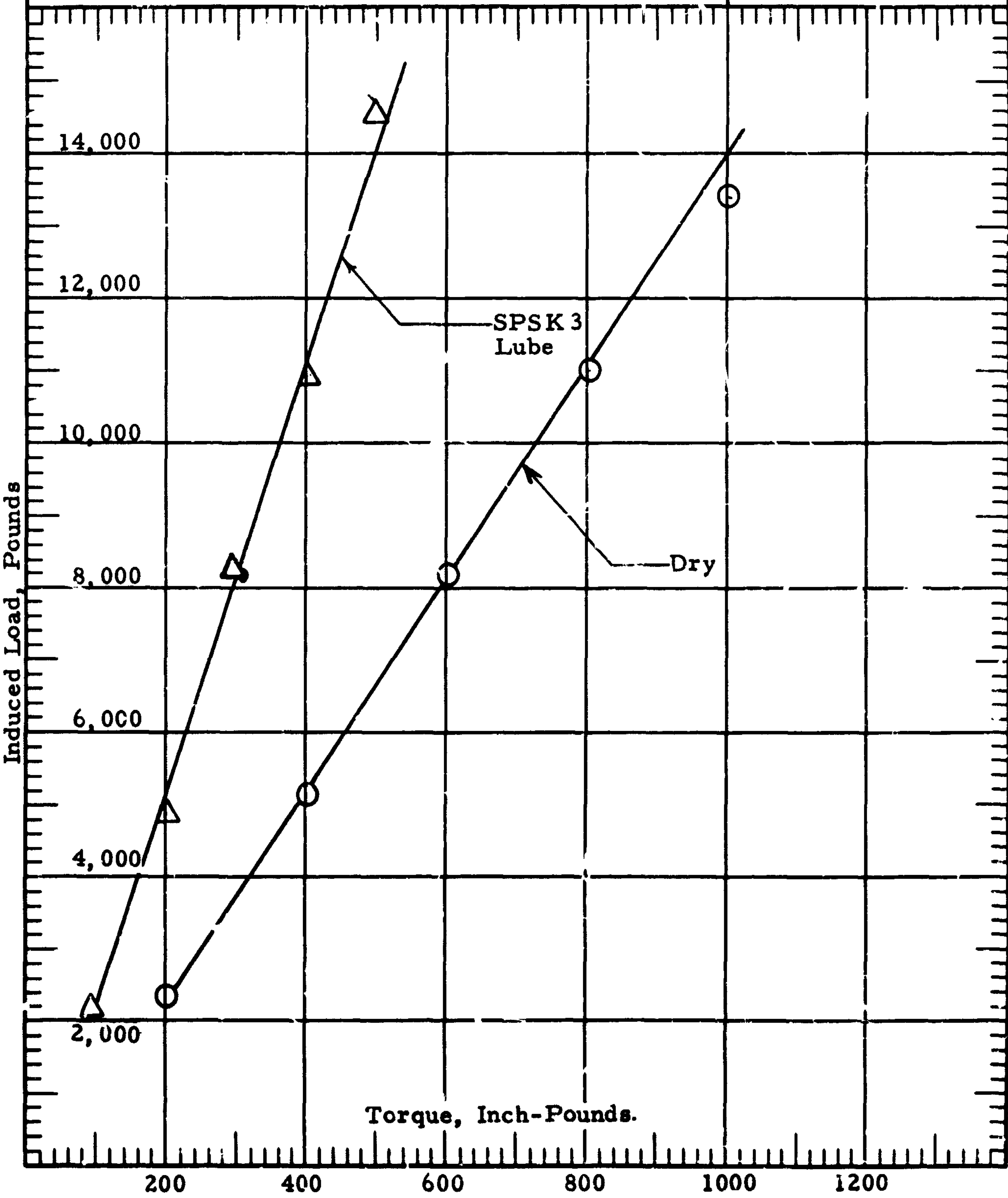


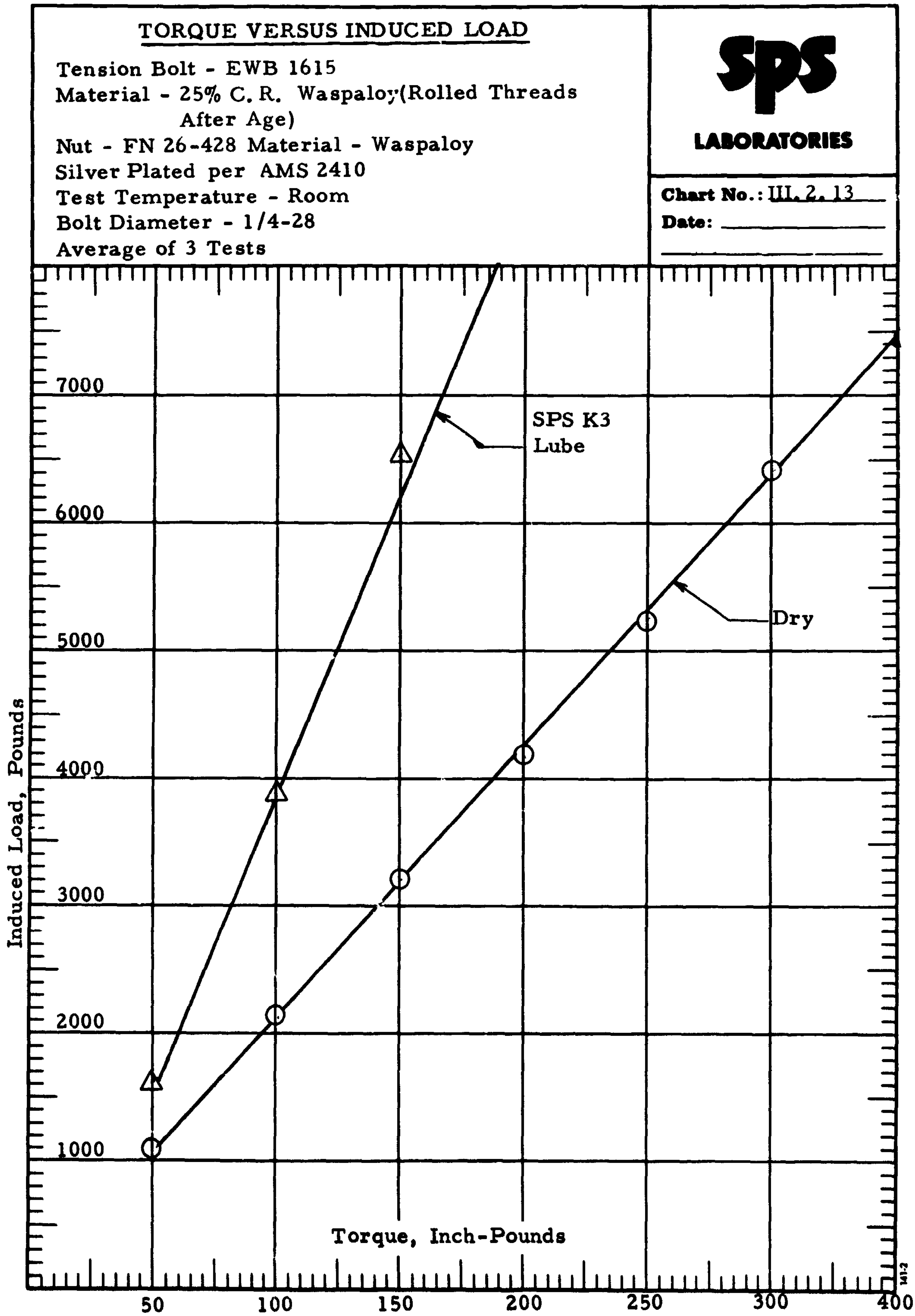
TORQUE VERSUS INDUCED LOAD

Tension Bolt - EWB 1615 - Material Inco 718
Nut - FN 129FW - Material A-286
Silver Plated AMS 2410
Test Temperature - Room
Bolt Diameter - 3/8-24
Average 3 Tests

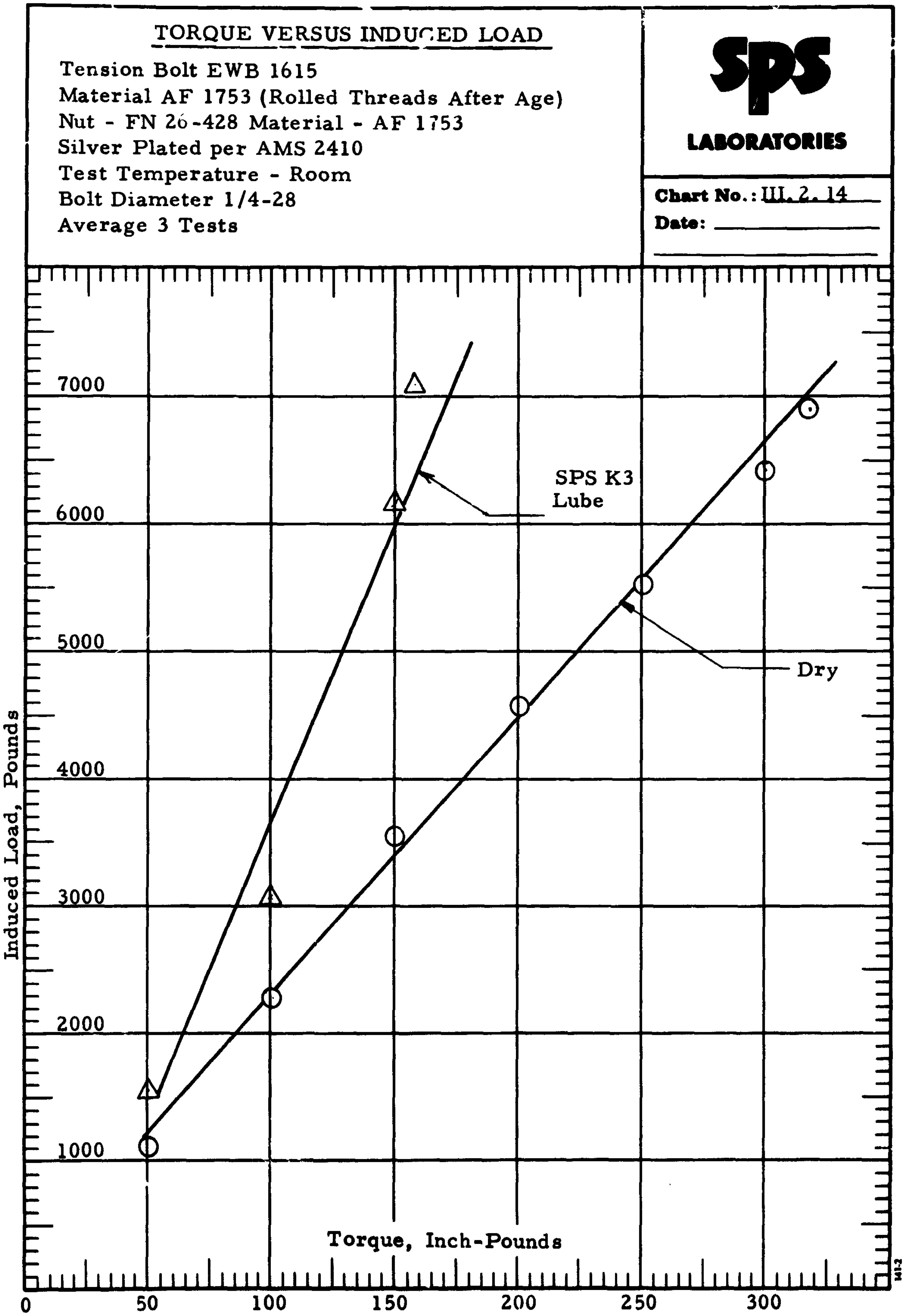
SPS LABORATORIES

Chart No.: III. 2. 12
Date:





TORQUE VERSUS INDUCED LOAD
Tension Bolt - EWB 1615
Material - 25% C.R. Waspaloy(Rolled Threads After Age)
Nut - FN 26-428 Material - Waspaloy
Silver Plated per AMS 2410
Test Temperature - Room
Bolt Diameter - 1/4-28
Average of 3 Tests
SPS
LABORATORIES
Chart No.: III. 2. 13
Date:
SPS K3 Lube
Dry
Induced Load, Pounds
7000
6000
5000
4000
3000
2000
1000
Torque, Inch-Pounds
50
100
150
200
250
300
400


TORQUE VERSUS INDUCED LOAD
Tension Bolt EWB 1615
Material AF 1753 (Rolled Threads After Age)
Nut - FN 26-428 Material - AF 1753
Silver Plated per AMS 2410
Test Temperature - Room
Bolt Diameter 1/4-28
Average 3 Tests
SPS
LABORATORIES
Chart No.: III. 2. 14
Date:
7000
6000
5000
4000
3000
2000
1000
Induced Load, Pounds
SPS K3
Lube
Dry
Torque, Inch-Pounds
0
50
100
150
200
250
300

TORQUE VERSUS INDUCED LOAD

Tension Bolt 1615- Material AF 1753 (Rolled Threads After Age)
Nut - FN 26 - Material AF 1753
Silver Plated per AMS 2410
Test Temperature - Room
Bolt Diameter - 3/8-24
Average 3 Tests

SPS LABORATORIES

Chart No.: III. 2. 15
Date

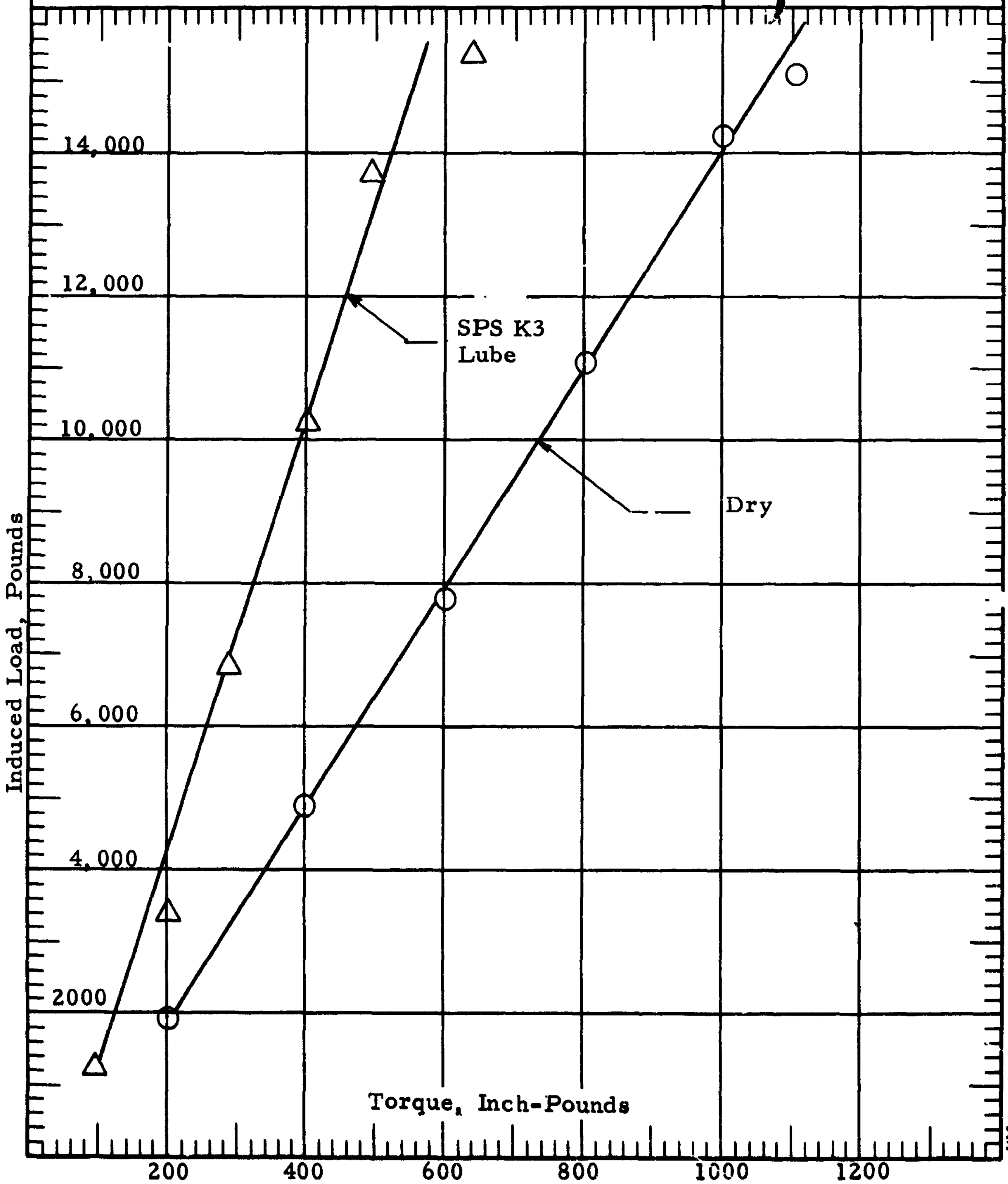


TABLE III.2.1

MECHANICAL PROPERTIES

Part No. Bolt - EWB 22-4-34 Material - Inconel 718 (180 KSI)
Nut - Nut Slug
Size - 1/4-28 (Rolled Threads Before Age)

1. Tensile

A. Axial Bolt Properties

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
1	-423	9,900	272,200
2	-423	9,840	270,600
3	-423	9,820	270,000
4	-320	9,320	256,300
5	-320	9,440	259,600
6	-320	9,240	254,100
7	70	7,820	215,000
8	70	7,900	217,200
9	70	7,820	215,000

B. Angle Block Bolt Properties (3°∠ @ Nut Bearing Face) *

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
10	-423	9,300	255,700
11	-423	9,100	250,200
12	-423	8,900	244,700
13	-320	9,200	253,000
14	-320	9,350	257,100
15	-320	9,700	266,200
16	70	7,990	220,000
17	70	7,900	217,200
18	70	7,930	218,100

(1) Stress calculated at Tensile Stress Area of 0.03637 square inches.
* Bolt grip length 2.125 inches.

TABLE III. 2. 1 (continued)

Part No. EWB 22-4-34 Nut Slug — Material - Inconel 718 (180 ksi)

Size - 1/4-28 (Rolled Threads Before Age)

2. Tension Impact

Test No.	Test Temperature, °F	Energy Expended, ft. - lbs.
1	-423	22.0
2	-423	23.5
3	-423	23.5
4	-320	33.0
5	-320	30.0
6	-320	32.0
7	70	31.5
8	70	32.5
9	70	33.5

3. Tension-Tension Fatigue @ 70°F

Test No.	Minimum Load, lbs.	Minimum Stress, psi	Maximum Load, lbs.	Maximum Stress, psi (2)	Cycles to Failure	Location of Failure
1	305	9,360	3,048	93,600	42,000	Thread
2	305	9,360	3,048	93,600	44,000	Thread
3	305	9,360	3,048	93,600	38,000	Thread

(2) Stress calculated at Basic Minor Diameter Area of 0.03256 square inches.

TABLE III. 2. 2

MECHANICAL PROPERTIES

Part No. Bolt - EWB 1615-4-18 — Material - Inconel 718
Part No. Nut - 129 FW-428 — Material - A-286
Size - 1/4-28 (Rolled Threads After Age)

1. Tensile

A. Base Material Properties (As Received) 0.113 inches specimen

Test No.	Test Temperature, °F	Ultimate Stress, psi	0.2% Offset Yield Stress, psi	Elongation Gage, .5 in. %	Reduction of Area %
1	-423	279,200	206,000	20.0	25.2
2	-423	278,000	205,000	20.0	31.0
3	-423	278,000	220,000	22.0	29.0
4	-320	257,800	181,500	24.0	27.0
5	-320	263,100	200,000	22.0	33.0
6	-320	261,300	178,900	22.0	35.8
7	70	202,500	172,500	18.0	37.9
8	70	208,300	179,400	22.0	35.0
9	70	209,000	179,000	20.0	35.0
10	1200	164,700	144,100	16.0	23.1
11	1200	164,200	147,000	20.0	36.2
12	1200	166,600	147,000	18.0	39.1

TABLE III. 2. 2 (continued)

Part No. EWB 1615-4-18
129 FW-428
Size - 1/4-28 (Rolled Threads After Age)

Material - Inconel 718
A-286

1. Tensile (continued)

B. Axial Bolt Properties (As Received)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (1)	Johnson's 2/3 Approximation Yield Load, lbs.	Johnson's 2/3 Approximation Yield Stress, psi
13	-423	10,400	294,000	8,500	240,300
14	-423	10,200	288,400	7,950	224,800
15	-423	10,320	291,800	8,650	244,600
16	-320	10,000	282,700	8,200	231,800
17	-320	9,500	268,500	7,000	197,400
18	-320	9,800	277,000	7,250	204,900
19	70	7,950	224,800	6,250	176,700
20	70	8,020	226,700	6,100	172,500
21	70	7,970	225,300	6,000	169,600
22	1200	6,700	189,400	6,050	171,000
23	1200	6,550	185,100	6,000	169,600
24	1200	6,600	186,500	5,950	168,200

C. Angle-Block Bolt Properties (3°∠ @Nut Bearing Face)*

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (1)
25	-423	9,940	281,000
26	-423	10,040	283,900
27	-423	10,400	294,000
28	-320	9,880	279,300
29	-320	10,000	282,700
30	-320	10,300	291,200
31	70	8,000	226,200
32	70	8,080	228,400
33	70	8,100	229,000

(1) Stress calculated at Tensile Stress Area (.003 reduced pitch diameter) of 0.03537 square inches.

* Bolt grip length 1.125 inches.

TABLE III. 2. 2 (continued)

Part No. EWB 1615-4-18   Material - Inconel 718
129 FW-428   Material - A-286
Size - 1/4-28 (Rolled Threads After Age)

2. Stress Durability @70° F

Test No.	Seated Stress, lbs.	Seated Stress, psi(1)	Torque to Induce Stress, in. -lbs.	Length of Test, Hours	Remarks
1	5, 500	155, 500	220	24	Passed
2	5, 500	155, 500	220	24	Passed
3	5, 500	155, 500	220	24	Passed

3. Tension-Impact

Test No.	Test Temperature, ° F	Energy Expended, ft. lbs.
1	-423	21. 0
2	-423	28. 0
3	-423	21. 0
4	-320	29. 0
5	-320	22. 0
6	-320	20. 0
7	70	21. 0
8	70	30. 0
9	70	20. 0

(1) Stress Calculated at the Tensile Stress Area (. 003 reduced pitch diameter) of 0. 03537 square inches.

TABLE III. 2. 2 (continued)

Part No. - EWB 1615-4-18 Material - Inconel 718
129 FW-428 Material - A-286
Size - 1/4-28 (Rolled Threads After Age)

4. Double Shear

A. As-Received

Test No.	Test Temperature °F	Ultimate Load, lbs.	Ultimate Stress, psi (2)
1	-423	16,600	169,100
2	-423	17,000	173,200
3	-423	16,000	163,000
4	70	13,500	137,500
5	70	13,600	138,500
6	70	13,600	138,500
7	1200	10,400	105,900
8	1200	10,450	106,400
9	1200	10,300	104,900

(2) Stress Calculated at Twice the Nominal Diameter Area, 0.09817 square inches.

TABLE III. 2. 2 (continued)

Part No. - EWB 1615-4-18 Material - Inconel 718
129 FW-428 Material - A-286
Size - 1/4-28(Rolled Threads After Age)

5. Stress Rupture

Test No.	Test Temperature, °F	Load, lbs.	Stress, psi(1)	Hours to Failure	Location of Failure
1	1200	5,836	165,000	0.8	Thread
2	1200	5,836	165,000	1.7	Thread
3	1200	5,836	165,000	2.1	Thread
4	1200	5,300	150,000	5.6	Thread
5	1200	5,300	150,000	10.5	Thread
6	1200	5,300	150,000	7.1	Thread
7	1200	4,775	135,000	37.8	Thread
8	1200	4,598	130,000	55.0	Thread
9	1200	4,244	120,000	98.7	Thread

6. Stress Relaxation @1200°F

Initial Stress - 129,000 psi (1)

Test No.	Hours Run	Residual Stress lbs.	Residual Stress psi(1)
1	10	Unable to determine residual stress because bolts fractured when being disassembled after exposure at 1200°F for 10 and 50 hours.	
2	10		
3	10		
4	50		
5	50		
6	50		

(1) Stress Calculated at the Tensile Stress Area (.003 reduced pitch diameter) of 0.03537 square inches.

TABLE III. 2. 2 (continued)

Part No. EWB 1615-4-18
129 FW-428
Size - 1/4-28 (Rolled Threads After Age)

Material - Incorel 718
A-286

7. Nut Reuse and Galling Tendency @70° F

Seated Stress - 97,200 psi (1)

Test No.	Maximum Installation, inch-pounds	Torque to Induce Stress, inch-pounds	Torque, inch-pounds Breakaway	Removal
1st Application				
1	22	150	115	13
2	19	140	100	11
3	24	150	110	12
4	20	145	100	13
5	22	150	110	13
2nd Application				
1	15	160	110	12
2	14	135	95	11
3	15	150	110	13
4	14	140	100	12
5	13	150	95	11
3rd Application				
1	14	150	110	12
2	12	140	100	11
3	14	155	115	13
4	13	150	110	13
5	12	145	110	12
4th Application				
1	14	150	115	12
2	13	150	110	10
3	15	160	115	12
4	14	145	120	13
5	12	150	115	12
5th Application				
1	14	155	115	12
2	12	155	115	10
3	15	160	115	12
4	13	150	120	13
5	13	155	110	12

(1) Stress calculated at Tensile Stress Area (.003 reduced pitch diameter) of 0.03537 square inches.

TABLE III. 2. 2 (continued)

Part No. EWB 1615-4-18 — Material - Inconel 718
129 FW-428 — A-286
Size - 1/4-28 (Rolled Threads After Age)

8. Torque vs. Induced Load @70°F

Torque inch-pounds	Test No. 1 Load, pounds	Test No. 2 Load, pounds	Test No. 3 Load, pounds
Dry			
50	1000	1100	1250
100	2750	2350	2400
150	4150	3750	3750
200	5550	5400	4950
250	6900	7000	6700
275	7300 B. F.	7350 B. F.	7300 B. F.
SPS K3 Lube			
50	1250	1000	1150
100	3150	2900	3100
150	5400	4950	5700
200	7150	6900	7250
210	7500 B. F.	7450 B. F.	7500 B. F.

B. F. - Bolt Fractured

TABLE III. 2. 3

MECHANICAL PROPERTIES

Part No. Bolt - EWB 1615-6-28 Material - Inconel 718
Part No. Nut - 129 FW-624 Material - A-286
Size - 3/8-24 (Rolled Threads After Age)

1. Tensile

A. Base Material Properties (As Received) 0.252 inch specimen

Test No.	Test Temperature, °F	Ultimate Stress, psi	0.2% Offset Yield Stress, psi	Elongation, Gage, .5 in. %	Reduction of Area, %
1	-423	278, 100	210, 800	14.0	12.3
2	-423	277, 500	213, 200	19.0	30.1
3	-423	275, 700	200, 600	21.0	32.2
4	-320	265, 100	202, 400	18.0	41.6
5	-320	263, 200	201, 500	21.0	34.0
6	-320	260, 600	197, 300	21.0	35.3
7	70	204, 000	173, 000	16.0	36.6
8	70	206, 100	173, 400	16.0	34.7
9	70	204, 800	173, 000	17.0	35.3
10	1200	165, 300	153, 000	9.0	18.4
11	1200	172, 000	158, 900	10.0	19.0
12	1200	171, 400	155, 100	10.0	19.0

TABLE III. 2. 3 (continued)

Part No. EWB 1615-6-28 Material - Inconel 718
129 FW-624 A-286
Size - 3/8-24 (Rolled Threads After Age)

1. Tensile (continued)

B. Axial Bolt Properties (As Received)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (1)	Johnson's 2/3 Approximation Yield Load, lbs.	Johnson's 2/3 Approximation Yield Stress, psi
13	-423	25,000	289,900	19,500	226,100
14	-423	23,500	272,500	18,500	214,500
15	-423	23,500	272,500		
16	-320	24,200	280,600	18,000	208,700
17	-320	23,700	274,800	16,500	191,300
18	-320	23,000	266,700	16,800	194,800
19	70	20,600	238,900	14,200	164,700
20	70	20,100	233,100	14,300	165,800
21	70	19,900	230,800	13,750	159,400
22	1200	16,020	185,800	13,600	157,700
23	1200	15,860	183,900	13,400	155,400
24	1200	16,200	187,800	13,900	161,200

C. Angle-Block Bolt Properties (3° ∠ @Nut Bearing Face)*

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (1)
25	-423	24,800	287,600
26	-423	23,500	272,500
27	-423	24,100	279,500
28	-320	24,000	278,300
29	-320	24,000	278,300
30	-320	23,500	272,500
31	70	19,400	225,000
32	70	19,700	228,400
33	70	20,200	234,200

(1) Stress calculated at Tensile Stress Area (.003 reduced pitch diameter) of 0.08624 square inches.
* Bolt grip length 1.75 inches.

TABLE III.2.3 (continued)

Part No. EWB 1615-628 — Material - Inconel 718
129 FW-624 — Material - A-286

Size - 3/8-24 (Rolled Threads After Age)

2. Stress Durability @70°F

Test No.	Seated Stress, lbs.	psi(1)	Torque to Induce Stress, in.-lbs.	Length of Test, Hours	Remarks
1	12,600	146,100	630	24	Passed
2	12,600	146,100	600	24	Passed
3	12,600	146,100	650	24	Passed

3. Double Shear

A. As-Received

Test No.	Test Temperature, °F	Ultimate, Load, lbs.	Ultimate, Stress psi(2)
1	-423	33,100	150,000
2	-423	32,250	146,100
3	-423	31,700	143,600
4	70	29,500	133,600
5	70	29,100	131,800
6	70	29,200	132,200
7	1200	21,500	97,400
8	1200	24,000	108,700
9	1200	20,000	90,600

(1) Stress Calculated at the Tensile Stress Area (.003 reduced pitch diameter of 0.08624 square inches.

(2) Stress Calculated at Twice the Nominal Diameter Area, 0.2208 square inches.

TABLE III. 2. 3 (continued)

Part No. EWB 1615-6-28 Material - Inconel 718
FN 1418-624 * Waspaloy

Size - 3/8-24 (Rolled Threads After Age)

4. Stress Rupture

Test No.	Test Temperature, °F	Load, lbs.	Stress, psi (1)	Hours to Failure	Location of Failure
1	1200	14,230	165,000	2.3	Thread
2	1200	14,230	165,000	3.1	Thread
3	1200	14,230	165,000	2.0	Thread
4	1200	12,936	150,000	7.5	Thread
5	1200	12,936	150,000	6.5	Thread
6	1200	12,936	150,000	11.8	Thread
7	1200	10,349	120,000	68.2	Thread

5. Stress Relaxation @ 1200°F

Initial Stress - 129,000 psi (1)

Test No.	Hours Run	Residual Stress lbs.	psi(1)
1	10	Unable to determine residual stresses because bolts fractured when being disassembled after exposure at 1200°F for 10 and 50 hours.	
2	10		
3	10		
4	50	It was determined that lack of sufficient lubricant causing galling of the mating parts was the cause.	
5	50		
6	50		

(1) Stress calculated at the Tensile Stress Area (.003 reduced pitch diameter) of 0.08624 square inches.

* Used in place of the 129 FW-624 A-286 Nut

TABLE III. 2. 3 (continued)

Part No. EWB 1615-6-28 — Material - Inconel 718
129 FW-624 — A-286

Size - 3/8-24 (Rolled Threads After Age)

6. Nut Reuse and Galling Tendency @70°F

Seated Stress - 97,200 psi (1)

Test No.	Maximum Installation, inch-pounds	Torque to Induce Stress, inch-pounds	Torque, inch-pounds Breakaway	Removal
1st Application				
1	50	500	425	25
2	40	525	450	35
3	40	500	375	30
4	40	500	425	35
5	40	500	425	30
2nd Application				
1	25	475	400	20
2	30	500	375	22
3	30	475	375	25
4	32	450	375	30
5	28	450	375	30
3rd Application				
1	20	475	375	20
2	22	475	400	20
3	28	450	350	22
4	30	475	400	25
5	30	450	400	25
4th Application				
1	20	475	375	20
2	25	500	350	20
3	23	450	375	22
4	28	475	375	25
5	30	450	350	22
5th Application				
1	22	475	375	18
2	20	475	375	20
3	22	450	375	22
4	30	450	350	25
5	30	450	350	22

(1) Stress calculated at Tensile Stress Area (.003 reduced pitch diameter) of 0.08624 square inches.

TABLE III. 2. 3 (continued)

Part No. EWB 1615-6-28 — Material - Inconel 718
129 FW-624 — Material - A-286
Size - 3/8-24 (Rolled Threads After Age)

7. Torque vs. Induced Load @70°F

Torque in.-lbs.	Test No. 1 Load, lbs.	Test No. 2 Load, lbs.	Test No. 3 Load, lbs.
DRY			
200	2,590	2,305	2,255
400	5,430	5,255	4,855
600	8,730	8,055	7,805
800	11,560	10,755	10,755
1000	13,855	13,255	13,255
SPS K3 Lube			
100	2,420	1,615	2,155
200	5,920	4,170	5,245
300	9,215	7,265	8,200
400	12,100	9,145	11,435
500	14,660	14,500	14,500

TABLE III. 2. 4

MECHANICAL PROPERTIES

Part No. STUD
Nut Slug
Size - 1/4-28 (Rolled Threads After Age)

Material - 25% C. R. Inconel 718
Material - Inconel 718

1. Tensile

A. Base Material Properties (As Received) 0. 113 inch specimen

Test No.	Test Temperature, °F	Ultimate Stress, psi	0. 2% Offset Yield Stress, psi	Elongation, Gage, . 5 in. %	Reduction of Area, %
1	-423	377, 500		6. 0	16. 4
2	-423	337, 000		6. 0	14. 0
3	-423	339, 800	301, 000	8. 0	17. 2
4	-320	321, 400	290, 800	3. 0	20. 1
5	-320	322, 900	302, 000	8. 0	18. 5
6	-320	328, 100	299, 400	8. 0	17. 0
7	70	260, 800	257, 400	4. 0	15. 5
8	70	265, 000	264, 500	6. 0	15. 5
9	70	264, 700	258, 800	6. 0	13. 5
10	1200	215, 600	208, 300	6. 0	35. 0
11	1200	215, 600	210, 000	5. 0	30. 8
12	1200	218, 100	213, 200	8. 0	26. 1

TABLE III. 2. 4 (continued)

Part No. - STUD Material - 25% C. R. Inconel 718
Nut Slug Material - Inconel 718
Size - 1/4-28 (Rolled Threads After Age)

1. Tensile (continued)

B. Axial Bolt Properties (As Received)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)	Johnson's 2/3 Approximation Yield Load, lbs.	Johnson's 2/3 Approximation Yield Stress, psi
13	-423	12,300	338,200	10,250	281,800
14	-423	11,400	313,400	10,250	281,800
15	-423	12,200	335,400	----	-----
16	-320	12,000	329,900	10,500	288,600
17	-320	12,000	329,900	10,400	285,900
18	-320	11,950	328,500	10,375	285,200
19	70	10,150	279,000	8,000	219,900
20	70	10,060	276,600	7,900	217,200
21	70	10,000	274,900	7,950	218,600
22	1200	7,800	214,400	7,150	196,500
23	1200	7,920	217,700	7,200	197,900
24	1200	7,800	214,400	6,600	181,400

C. Angle-Block Bolt Properties (3°∠ @Nut Bearing Face)*

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
25	-423	10,500	288,700
26	-423	10,500	288,700
27	-423	10,900	299,700
28	-320	10,250	281,800
29	-320	9,000	247,500
30	-320	11,400	313,400
31	70	10,000	275,000
32	70	10,140	278,800
33	70	10,020	275,500

(1) Stress Calculated at Tensile Stress Area of 0.03637 square inches.
* Stud grip length 1.75 inches.

TABLE III. 2. 4 (continued)

Part No. - STUD
Nut Slug
Size - 1/4-28 (Rolled Threads After Age)

Material - 25% C. R. Inconel 718
Material - Inconel 718

, Double Shear

A. As Received

Test No.	Test Temperature °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
1	-423	16,200	165,000
2	-423	16,600	169,100
3	-423	16,000	163,000
4	70	14,000	142,600
5	70	14,100	143,600
6	70	14,000	142,600
7	1200	11,320	115,300
8	1200	10,160	103,500
9	1200	10,840	110,400

(2) Stress Calculated at Twice the Nominal Diameter Area, 0.09817 square inches.

TABLE III.2.5

MECHANICAL PROPERTIES

Part - EWB 22-4 - Material - Udimet 630 (200 ksi)

Size - 1/4-28 - Rolled Threads Before Age Hardening

1. Tensile

Base Material Properties
.113 inch Specimens

Test No.	Test Temperature, °F	Ultimate Stress, psi	0.2% Offset Yield Stress, psi	Elongation, (Gage, .5 in.) %	Reduction of Area, %
1	70	239,700	214,200	8.0	15.5
2	70	229,500	201,500	8.0	10.5
3	70	233,500	211,500	10.0	26.5
4	1200	195,000	180,000	4.0	11.9
5	1200	193,800	180,600	8.0	10.5
6	1200	192,000	180,000	6.0	10.5

Bolt Properties

Test No.	Test Temperature °F	Ultimate Load, pounds	Ultimate Stress, psi (1)	Johnson's 2/3 Approximation Yield Load, pounds	Johnson's 2/3 Approximation Yield Stress, psi
7	70	6,300	173,200	5,850	160,800
8	70	5,230	148,800	N.Y.	-
9	70	6,100	167,700	5,800	159,500
10	1200	7,150	196,600	6,400	176,000
11	1200	7,125	195,900	6,525	179,400
12	1200	7,725	212,400	7,250	199,300

2. V-Notch Properties (K_t8)

Test No.	Test Temperature °F	Ultimate Load, pounds	Ultimate Stress, psi	Notch-to-Smooth Tensile Ratio
13	70	5,860	252,600	1.08
14	70	5,960	254,700	1.09
15	70	5,720	245,500	1.05

(1) Stress calculated at tensile stress area of 0.03637 square inches.

TABLE III. 2. 6

MECHANICAL PROPERTIES

Part No. EWB 22-4-20
Size - 1/4-28 x 1.750

Material Udimet 630
(Rolled Threads After Aging) *

1. Tensile

A. Base Material Properties (As Received) .113 inches specimen

Test No.	Test Temperature, °F	Ultimate Stress, psi	0.2% Offset Yield Stress, psi	Elongation Gage, .5 in. %	Reduction of Area, %
1	-423	310,000	264,000	10.0	17.1
2	-423	306,000	244,000	10.0	15.5
3	-423	302,000	247,000	12.0	15.5
4	70	239,700	214,200	8.0	15.5
5	70	229,500	201,500	8.0	10.5
6	70	233,500	211,500	10.0	26.5
7	1200	195,000	180,000	4.0	11.9
8	1200	193,800	180,600	8.0	10.5
9	1200	192,000	180,000	6.0	10.5

B. V-Notch Properties (K_t 8)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi	Notch to Smooth Tensile Ratio
10	-423	6,200	265,000	0.87
11	-423	5,820	250,000	0.82
12	-423	5,360	231,000	0.75
13	70	5,860	252,600	1.08
14	70	5,960	254,700	1.09
15	70	5,720	245,500	1.05
16	1200	3,660	156,400	0.81
17	1200	3,050	130,900	0.68
18	1200	3,310	142,700	0.74

*Threads of untested bolts with rolled threads before age were cut off and the blanks were reground and thread rolled. Thread rolling sequence would not affect material tensile properties.

TABLE III. 2. 6 (continued)

Part No. EWB 22-4-20
Size - 1/4-28 x 1.750

Material Udimet 630
(Rolled Threads After Aging)

1. Tensile (continued)

C. Axial Bolt Properties

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)	Johnson's 2/3 Approximation: Yield Load, lbs.	Johnson's 2/3 Approximation: Yield Stress, psi(1)
19	-423	11,300	310,700	9,250	254,300
20	-423	10,800	297,000	9,250	254,300
21	-423	11,100	305,200	9,000	247,500
22	-320	11,240	309,000	8,730	240,000
23	-320	10,900	299,700	8,740	240,300
24	-320	11,100	305,200	9,180	252,400
25	70	9,340	256,800	7,250	200,000
26	70	9,200	253,000	7,300	200,700
27	70	9,400	258,500	7,400	203,500
28	1200	7,350	202,100	6,375	175,300
29	1200	7,500	206,200	7,000	192,500
30	1200	7,600	209,000	7,050	193,800

D. Angle Block Bolt Properties (3° ∠ @ Nut Bearing Face)*

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
31	-423	10,000	275,000
32	-423	9,500	261,200
33	-423	10,900	299,700
34	-320	10,960	301,300
35	-320	10,020	275,500
36	-320	10,360	284,800
37	70	8,800	242,000
38	70	9,300	255,700
39	70	8,950	246,100

(1) Stress calculated at Tensile Stress Area of 0.03637 square inches.
* Bolt grip length 1.25 inches.

TABLE III.2.6 (continued)

Part No. EWB 22-4-20
Size - 1/4-28 x 1.750

Material Udimet 630
(Rolled Threads After Aging)

1. Tensile (continued)

E. As Relaxed Bolt Properties (50 Hours)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)	Yield Load, lbs.	Yield Stress, psi(1)
40	70	6,280	172,700	No Yield	
41	70	6,500	178,700	No Yield	
42	70	5,250	144,300	No Yield	

2. Tension Impact

Test No.	Test Temperature, °F	Energy Expended ft.-lbs.
1	-423	22.0
2	-423	20.0
3	-423	--
4	-320	27.5
5	-320	32.0
6	-320	27.5
7	70	30.0
8	70	31.0
9	70	29.5

(1) Stress calculated at Tensile Stress Area of 0.03637 square inches.

TABLE III. 2. 6 (continued)

Part No. EWB22-4-20
Size - 1/4-28 x 1.750

Material Udimet 630
(Rolled Threads After Aging)

3. Double Shear

A. As Received

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
1	-423	17,000	173,200
2	-423	17,250	175,700
3	-423	17,750	180,800
4	70	15,200	154,800
5	70	14,900	151,800
6	70	15,500	157,900
7	1200	11,650	118,700
8	1200	12,000	122,200
9	1200	11,000	112,100

B. As Relaxed (50 Hours)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
10	70	15,400	156,900
11	70	15,400	156,900
12	70	15,200	154,800

4. Tension-Tension Fatigue @70°F

Test No.	Min. Load, lbs.	Min. Stress, psi	Max. Load, lbs.	Max. Stress, psi(3)	Cycles to Failure	Location of Failure
1	375	11,500	3,750	115,000	163,000	Head
2	375	11,500	3,750	115,000	350,000	Head
3	375	11,500	3,750	115,000	111,000	N.S.

(2) Stress calculated at twice Nominal Diameter Area of 0.09817 square inches.
(3) Stress calculated at Basic Minor Diameter Area of 0.03256 square inches.
N.S. - Nut Stripped.

TABLE III. 2. 6 (continued)

Part No. EWB 22-4-20
Size - 1/4-28 x 1.750

Material Udimet 630
(Rolled Threads After Aging)

5. Stress Relaxation @ 1200° F

Initial Stress - 151,200 psi

Test No.	Hours Run	Residual Stress Pounds	Residual Stress psi(1)
1	1	4,440	122,100
	10	3,560	97,900
	50	2,760	75,900
2	1	4,280	117,700
	10	3,760	103,400
	50	3,040	83,600
3	1	4,400	121,000
	10	3,440	94,600
	50	2,840	78,100

6. Stress Rupture

Test No.	Test Temperature, °F	Load, lbs.	Load Stress, psi(1)	Hours to Failure	Location of Failure
1	1200	6,500	180,000	0.4	Thread
2	1200	6,180	170,000	0.6	Thread
3	1200	5,820	160,000	0.8	Thread
4	1200	5,456	150,000	1.0	Thread
5	1200	5,092	140,000	3.0	Thread
6	1200	4,910	135,000	4.0	Thread
7	1200	4,910	135,000	6.0	Thread

7. Coefficient of Thermal Expansion

Temperature Inches/Inch/°Fx10^6

Data is not available at the present time.

(1) Stress calculated at Tensile Stress Area of 0.03637 square inches.

TABLE III. 2. 7

MECHANICAL PROPERTIES

Part No. Bolt - EWB 1615-4-38 Material - Waspaloy (150 KSI)
Nut - FN 1418-428
Size - 1/4-28 (Rolled Threads Before Age)

1. Tensile

A. Axial Bolt Properties

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
1	-423	8,000	226,200
2	-423	7,700	220,000
3	-423	7,900	223,400
4	-320	7,450	210,600
5	-320	7,400	209,200
6	-320	7,460	210,900
7	70	6,080	171,800
8	70	6,110	172,700
9	70	6,100	172,400

B. Angle Block Bolt Properties (3°∠ @ Nut Bearing Face) *

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
10	-423	6,900	195,100
11	-423	7,500	212,000
12	-320	7,200	203,600
13	-320	7,100	200,700
14	70	5,840	165,100
15	70	5,850	165,400

(1) Stress calculated at Tensile Stress Area (.003 Reduced Pitch Diameter) of 0.03537 square inches.

* Bolt grip length 2.375 inches.

TABLE III. 2. 7 (continued)

Part No. EWB 1615-4-38 Material - Waspaloy (150 KSI)
FN 1418-428
Size - 1/4-28 (Rolled Threads Before Age)

2. Tension Impact

Test No.	Test Temperature, °F	Energy Expended, ft. -lbs.
1	-423	29.0
2	-423	16.5
3	-320	23.0
4	-320	26.0
5	70	39.0
6	70	37.0

3. Tension-Tension Fatigue @70°F

Test No.	Min. Load, lbs.	Min. Stress, psi	Max. Load, lbs.	Max. Stress, psi(2)	Cycles to Failure	Location of Failure
1	254	7,800	2,540	78,000	70,200	Thread
2	254	7,800	2,540	78,000	180,000	Thread

4. Vibration - ALMA #10 -

Test No.	Test Temperature °F	Maximum Installation 1st	5th	Seating Torque in. -lbs.	No. of Cycles	Degrees Mov't	10X Mag. Visual Insp.	Remarks
1	-320	15	9	60	30,000	0°	No cracks	Passed
2	-320	20	15	60	30,000	0°	No cracks	Passed
3	-320	15	10	60	30,000	0°	No cracks	Passed
4	70	18	9	60	30,000	30°	No cracks	Passed
5	70	17	11	60	30,000	30°	No cracks	Passed
6	70	22	11	60	30,000	30°	No cracks	Passed
7	70	22	12	60	30,000	60°	No cracks	Passed
8	70	16	10	60	30,000	15°	No cracks	Passed

(2) Stress calculated at Basic Minor Diameter of 0.03256 square inches.

TABLE III. 2. 8

MECHANICAL PROPERTIES

Part No. Bolt - EWB 1615-8-48 Material - Waspaloy (150 KSI)
Nut - FN 1418-820
Size - 1/2-20 (Rolled Threads Before Age)

1. Tensile

A. Axial Bolt Properties

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
1	-423	31,800	201,000
2	-423	32,600	206,200
3	-423	31,500	199,000
4	-320	34,000	215,500
5	-320	33,800	214,200
6	-320	34,100	216,100
7	70	26,400	167,300
8	70	26,500	167,900
9	70	26,700	169,200

B. Angle Block Bolt Properties (3°∠ @ Nut Bearing Face)*

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
10	-423	30,700	194,600
11	-423	31,350	198,700
12	-320	30,200	191,400
13	-320	31,200	197,700
14	70	25,500	161,600
15	70	22,800	141,300

(1) Stress calculated at Tensile Stress Area (.003 Reduced Pitch Diameter) of 0.1578 square inches.
* Bolt grip length 3.0 inches.

TABLE III. 2. 8 (continued)

Part No. EWB 1615-8-48 Material - Waspaloy (150 KSI)
FN 1418-820
Size - 1/2-20 (Rolled Threads Before Age)

2. Double Shear

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
1	-423	53,500	136,200
2	-423	55,800	142,100

3. Tension-Tension Fatigue @70°F

Test No.	Min. Load, lbs.	Min. Stress, psi	Max. Load, lbs.	Max. Stress, psi(3)	Cycles to Failure	Location of Failure
1	1,159	7,800	11,591	78,000	38,500	Thread
2	1,159	7,800	11,591	78,000	60,000	Thread

(2) Stress calculated at Twice Nominal Diameter Area, 0.3927 square inches.

(3) Stress calculated at Basic Minor Diameter Area of 0.1486 square inches.

TABLE III.2.9

MECHANICAL PROPERTIES

Part No. - Stud
Nut Slug
Size - 1/4-28 (Rolled Threads After Age)

Material - Waspaloy (220 KSI)

1. Tensile

A. Axial Bolt Properties

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
1	-423	12,700	349,200
2	-423	13,050	358,800
3	-423	12,000	330,000
4	-320	12,300	338,200
5	-320	12,150	334,100
6	-320	12,180	334,900
7	70	10,020	275,500
8	70	9,940	273,300
9	70	10,000	275,000

B. Angle Block Bolt Properties (3°∠ @ Nut Bearing Face)*

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
10	-423	12,800	351,900
11	-423	12,500	343,700
12	-423	12,400	340,900
13	-320	12,100	332,700
14	-320	12,090	332,400
15	-320	12,040	331,000
16	70	10,200	280,500
17	70	9,880	271,700
18	70	9,980	274,400

(1) Stress calculated at Tensile Stress Area of 0.03637 square inches.
* Bolt grip length 1.5 inches.

TABLE III. 2. 9 (continued)

Part No. - Stud
Nut Slug

Material - Waspaloy (220 ksi)

Size - 1/4-28 (Rolled Threads After Age)

2. Tension Impact

Test No.	Test Temperature, °F	Energy Expended, ft. - lbs.
1	-423	40.0
2	-423	38.0
3	-423	40.0
4	-320	41.0
5	-320	35.0
6	-320	39.0
7	70	34.5
8	70	40.0
9	70	41.5

3. Tension-Tension Fatigue @ 70°F

Test No.	Minimum Load, lbs.	Minimum Stress, psi	Maximum Load, lbs.	Maximum Stress, psi (2)	Cycles to Failure	Location of Failure
1	375	11,500	3,750	115,000	1,181,000	Thread
2	375	11,500	3,750	115,000	1,342,000	Thread
3	375	11,500	3,750	115,000	1,209,000	Thread
4	440	13,500	4,400	135,000	136,000	Thread
5	440	13,500	4,400	135,000	278,400	Thread
6	440	13,500	4,400	135,000	207,800	Thread

(2) Stress calculated at Basic Minor Diameter Area of 0.03256 square inches.

TABLE III. 2. 10

MECHANICAL PROPERTIES

Part No. Bolt - EWB 1615-4-16
Part No. Nut - FN 26-428
Size - 1/4-28 (Rolled Threads After Age)

Material - 25% C. R. Waspaloy
Material - Waspaloy

1. Tensile

A. Base Material Properties (As Received)

Test No.	Test Temperature, °F	Ultimate Stress, psi	0.2% Offset Yield Stress, psi	Elongation, Gage, .5 in. %	Reduction of Area, %
1	-423	326,000	255,000	14.0	27.7
2	-423	330,500	273,600	14.0	28.4
3	-423	328,500	265,300	16.0	31.0
4	-320	314,200	265,300	12.0	31.0
5	-320	307,500	260,000	12.0	30.9
6	-320	317,300	278,000	12.0	21.9
7	70	242,100	218,400	10.0	33.0
8	70	240,000	215,000	10.0	35.0
9	70	251,000	229,500	10.0	28.0
10	1400	153,000	137,700	28.0	54.0
11	1400	159,000	145,000	26.0	54.7
12	1400	150,500	132,600	26.0	54.0

TABLE III. 2. 10 (continued)

Part No. EWB 1615-4-16 — Material - 25% C. R. Waspaloy
FN 26-428 — Material - Waspaloy
Size - 1/4-28 (Rolled Threads After Age)

1. Tensile (continued)

B. Axial Bolt Properties (As Received)

Test No.	Test Temperature °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)	Johnson's 2/3 Approximation Yield Load, lbs.	Johnson's 2/3 Approximation Yield Stress, psi
13	-423	12,000	339,300	10,000	282,700
14	-423	11,800	333,600	9,250	261,500
15	-423	11,600	328,000	9,625	272,100
16	-320	11,700	330,800	9,000	254,500
17	-320	11,500	325,100	8,875	250,900
18	-320	11,500	325,100	9,350	264,300
19	70	9,800	277,100	7,800	220,500
20	70	9,760	275,900	7,350	207,800
21	70	9,570	270,600	7,650	216,300
22	1400	4,900	138,500	4,180	118,200
23	1400	4,900	138,500	3,900	110,300
24	1400	4,980	140,800	4,150	117,300

C. Angle-Block Bolt Properties (3°∠ @ Nut Bearing Face) *

Test No.	Test Temperature °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)	Johnson's 2/3 Approximation Yield Load, lbs.	Johnson's 2/3 Approximation Yield Stress, psi
25	-423	12,500 (n. s.)	353,400		
26	-423	11,000	311,000		
27	-423	11,150	315,200		
28	-320	11,650	329,400		
29	-320	11,250	318,100		
30	-320	11,450	323,700		
31	70	9,620	272,000		
32	70	9,500(n. s.)	268,600		
33	70	9,500(n.s.)	268,600		

D. As-Relaxed Bolt Properties (50 Hours)

Test No.	Test Temperature °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)	Johnson's 2/3 Approximation Yield Load, lbs.	Johnson's 2/3 Approximation Yield Stress, psi
34	70	8,640	244,300	6,950	196,500
35	70	8,660	244,900	7,400	209,200
36	70	8,620	243,700	7,350	207,800

(1) Stress Calculated at Tensile Stress Area (.003 reduced pitch diameter) of 0.03537 square inches.
* Bolt grip length 1.0 inches.

TABLE III. 2. 10 (continued)

Part No. EWB 1615-4-16 — Material - 25% C. R. Waspaloy
FN 26-438 — Material - Waspaloy
Size - 1/4-28 (Rolled Threads After Age)

2. Stress Durability @ 70°F

Test No.	Seated Stress, lbs.	Seated Stress, psi(1)	Torque to Induce Stress, in. -lbs.	Length of Test, Hours	Remarks
1	6,840	193,300	150	48	Passed
2	6,840	193,300	160	48	Passed
3	6,840	193,300	150	48	Passed

3. Tension-Impact

Test No.	Test Temperature, °F	Energy Expended ft. -lbs.
1	-423	23.5
2	-423	21.0
3	-423	26.5
4	-320	23.0
5	-320	24.0
6	-320	25.0
7	70	34.0
8	70	35.5
9	70	33.5

(1) Stress Calculated at the Tensile Stress Area (.003 reduced pitch diameter) of 0.03537 square inches.

TABLE III. 2. 10 (continued)

Part No. - EWB 1615-4-16 Material - 25% C. R. Waspaloy
FN 26-428 Material - Waspaloy
Size - 1/4-28 (Rolled Threads After Age)

4. Double Shear

A. As-Received

Test No.	Test Temperature °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
1	-423	17,000	173,200
2	-423	16,400	167,100
3	-423	17,500	178,300
4	70	14,300	145,700
5	70	14,500	147,700
6	70	15,000	152,800
7	1400	9,350	95,200
8	1400	9,000	91,700
9	1400	9,500	96,800

B. As-Relaxed (50 Hours)

Test No.	Test Temperature °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
10	70	15,500	157,900
11	70	15,200	154,800
12	70	15,300	155,900

(2) Stress Calculated at Twice the Nominal Diameter Area, 0.09817 square inches.

TABLE III. 2. 10 (continued)

Part No. - EWB 1615-4-16 Material - 25% C. R. Waspaloy
FN 26-428 Material - Waspaloy
Size - 1/4-28 (Rolled Threads After Age)

5. Stress Rupture

Test No.	Test Temperature, °F	Load, lbs.	Stress, psi(1)	Hours to Failure	Location of Failure
1	1400	2,830	80,000	2.1	Thread
2	1400	2,830	80,000	1.7	Nut
3	1400	2,830	80,000	4.7	Nut
4	1400	2,300	65,000	18.8	Head
5	1400	2,300	65,000	21.2	Head
6	1400	2,300	65,000	24.2	Head
7	1400	1,415	40,000	145.0	Head
8	1400	1,415	40,000	146.0	Head
9	1400	1,415	40,000	87.9	Head

6. Stress Relaxation @1400°F

Initial Stress 100,000 psi

Test No.	Hours Run	Residual Stress lbs.	Residual Stress psi(1)
1	10	813	23,000
2	10	813	23,000
3	10	813	23,000
4	50	243	6,900
5	50	243	6,900
6	50	324	9,200

(1) Stress Calculated at the Tensile Stress Area (.003 reduced pitch diameter) of 0.03537 square inches.

TABLE III. 2. 10 (continued)

Part No. - EWB 1615-4-16 — Material - 25% C. R. Waspaloy
FN 26-428 Material - Waspaloy

Size - 1/4-28 (Rolled Threads After Age)

7. Nut Reuse and Galling Tendency @70°F

Seated Stress - 118,800 psi(1)

Test No.	Maximum Installation, inch-pounds	Torque to Induce Stress, inch-pounds	Torque, inch-pounds Breakaway	Removal
1st Application				
1	12	102	58	4.0
2	11	98	56	4.0
3	12	120	76	7.0
4	11	108	62	7.0
5	13	117	68	6.0
2nd Application				
1	4.5	110	64	3.5
2	4.0	107	62	3.5
3	6.0	118	67	5.0
4	6.0	106	62	5.5
5	6.0	115	67	5.0
3rd Application				
1	4.0	117	69	3.3
2	4.0	110	62	3.2
3	5.7	115	67	4.5
4	5.5	113	65	4.7
5	5.5	120	70	4.3
4th Application				
1	4.2	119	68	3.3
2	3.5	108	63	3.0
3	5.5	116	68	4.7
4	5.0	123	72	4.6
5	5.2	122	72	4.3
5th Application				
1	3.8	119	68	3.3
2	3.5	110	64	3.2
3	5.5	120	68	4.7
4	4.8	122	70	4.5
5	5.0	120	72	4.2

(1) Stress Calculated at Tensile Stress Area (.003 reduced pitch diameter) of 0.03537 square inches.

TABLE III. 2. 10 (continued)

Part No. EWB 1615-4-16 | Material - 25% C. R. Waspaloy
FN 26-428 | Material - Waspaloy

Size - 1/4-28 (Rolled Threads After Age)

8. Torque vs. Induced Load @ 70°F

Torque in.-lbs.	Test No. 1 Load, lbs.	Test No. 2 Load, lbs.	Test No. 3 Load, lbs.
DRY			
50	1,150	1,100	1,050
100	2,200	1,900	2,250
150	3,250	3,000	3,400
200	4,100	3,950	4,400
250	5,250	5,100	5,450
300	6,400	6,250	6,650
350	7,250	7,250	7,600
375	---	---	7,850
390	7,900 (B. F.)	---	---
450	---	8,100	---
SPS K3 Lube			
50	1,650	1,550	1,675
100	3,750	3,550	4,200
150	6,600	6,050	6,950
190	9,200 (N. S.)	9,000 (N. S.)	---
200			9,050 (B. F.)

(N. S.) Nut Stripped
(B. F.) Bolt Fractured

TABLE III. 2. 11

MECHANICAL PROPERTIES

Part No. Bolt - EWB 1615-3-28 Material - Rene 41
Part No. Nut - FN 1418-1032 Waspaloy
Size - #10-32 (Rolled Threads Before Age)

1. Tensile

A. Base Material Properties (As Received) 0.113 inch specimen

Test No.	Test Temperature, °F	Ultimate Stress, psi	0.2% Offset Yield Stress, psi	Elongation, Gage, .5 in. %	Reduction of Area, %
1	-423	208,100	142,800	14.0	12.3
2	-423	203,000	144,000	10.0	12.0
3	-423	201,000	140,000	14.0	12.0
4	70	165,800	101,000	20.0	18.8
5	70	174,000	105,000	20.0	18.5
6	70	174,000	104,200	22.0	16.0
7	1400	131,500	104,000	22.0	29.3
8	1400	129,500	96,900	20.0	32.5
9	1400	132,800	100,500	20.0	32.9

B. Axial Bolt Properties (As Received)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (1)	Johnson's 2/3 Approximation Yield Load, lbs.	Johnson's 2/3 Approximation Yield Stress, psi (1)
10	-423	4,000	207,800	3,400	176,600
11	-423	4,120	214,000	3,550	184,400
12	-423	4,070	211,400	3,525	183,100
13	-320	4,050	210,400	3,500	181,800
14	-320	4,000	207,800	3,350	174,000
15	-320	4,040	209,900	3,450	179,200
16	70	3,220	167,300	2,660	138,200
17	70	3,250	168,800	2,550	132,500
18	70	3,180	165,200	2,325	120,800
19	1400	2,925	151,900	2,380	123,600
20	1400	2,970	154,300	2,340	121,600
21	1400	2,725	141,600	2,315	120,300

(1) Stress calculated at Tensile Stress Area (.003 reduced pitch diameter) of 0.01925 square inches.

TABLE III. 2. 11 (continued)

Part No. EWB 1615-3-28 FN 1418-1032
Material - Rene 41 Waspaloy
Size - #10-32 (Rolled Threads Before Age)

1. Tensile (continued)

C. Angle Block Bolt Properties (3°@ Nut Bearing Face)*

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (1)
22	-423	4,000	207,800
23	-423	4,120	214,000
24	-423	4,070	211,400
25	-320	3,720	193,200
26	-320	3,880	201,600
27	-320	3,900	202,600
28	70	3,100	161,000
29	70	3,100	161,000
30	70	3,150	163,600

D. As Relaxed (50 Hours)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (1)	Yield Load, lbs.	Yield Stress, psi (1)
Preload A					
31	70	3,460	179,700	2,925	151,900
32	70	3,400	176,600	2,575	133,800
33	70	3,450	179,200	2,625	136,400
Preload B					
34	70	3,530	183,400	2,600	135,100
35	70	3,360	174,500	2,725	141,600
36	70	3,400	176,600	2,675	139,000

(1) Stress calculated at Tensile Stress Area (.003 reduced pitch diameter) of 0.01925 square inches.

* Bolt grip length 1.75 inches.

TABLE III.2.11 (continued)

Part No. EWB 1615-3-28 FN 1418-1032

Material - Rene 41 Waspaloy

Size - #10-32 (Rolled Threads Before Age)

2. Tension Impact

Test No.	Test Temperature, °F	Energy Expended, ft. - lbs.
1	-423	6.0
2	-423	4.5
3	-423	3.0
4	-320	6.0
5	-320	7.0
6	-320	6.5
7	70	9.0
8	70	11.5
9	70	11.0

3. Double Shear

A. As Received

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (2)
1	-423	8,400	148,100
2	-423	8,400	148,100
3	-423	8,350	147,200
4	70	6,900	121,700
5	70	6,900	126,700
6	70	7,200	126,900
7	1400	5,460	96,300
8	1400	6,000	105,800
9	1400	6,025	106,200

(2) Stress calculated at twice the Nominal Diameter Area, 0.05671 square inches.

TABLE III. 2. 11 (continued)

Part No. EWB 1615-3-28 FN 1418-1032 — Material - Rene 41 Waspaloy

Size - #10-32 (Rolled Threads Before Age)

3. Double Shear (continued)

B. As Relaxed (50 Hours)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (2)
Preload A			
10	70	7,000	123,400
11	70	7,080	124,800
12	70	7,060	124,500
Preload B			
13	70	7,000	123,400
14	70	7,100	125,200
15	70	7,200	126,900

4. Tension-Tension Fatigue @ 70°F

Test No.	Min. Load, lbs.	Min. Stress, psi (3)	Max. Load, lbs.	Max. Stress, psi (3)	Cycles to Failure	Location of Failure
1	137	7,800	1,370	78,000	103,000	Thread
2	137	7,800	1,370	78,000	79,000	Thread
3	137	7,800	1,370	78,000	43,000	Thread

(2) Stress calculated at twice the Nominal Diameter Area, 0.05671 square inches.

(3) Stress calculated at Basic Minor Diameter Area, 0.01753 square inches.

TABLE III.2.11 (continued)

Part No. EWB 1615-3-28
FN 1418-1032
Size - #10-32 (Rolled Threads Before Age)

Material - Rene 41
Waspaloy

5. Stress Relaxation @1400°F

Preload A - Initial Stress - 99,700 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi (1)
1	10	720	37,400
2	10	700	36,300
3	10	670	34,800
4	50	550	28,500
5	50	402	20,900
6	50	520	27,000

Preload B - Initial Stress - 62,300 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi (1)
7	10	520	27,000
8	10	462	24,000
9	10	379	19,700
10	50	520	27,000
11	50	320	16,600
12	50	210	10,900

6. Stress Rupture

Test No.	Test Temperature, °F	Load, lbs.	Stress, psi (1)	Hours to Failure	Location of Failure
1	1400	1,925	100,000	1.1	Thread
2	1400	1,925	100,000	1.4	Thread
3	1400	1,925	100,000	2.3	Thread
4	1400	1,540	80,000	6.7	Thread
5	1400	1,540	80,000	5.0	Thread
6	1400	1,348	70,000	100.2	No Failure
7	1400	1,348	70,000	100.9	No Failure
8	1400	1,348	70,000	108.6	No Failure

(1) Stress calculated at Tensile Stress Area (.003 reduced Pitch Diameter) of 0.01925 square inches.

TABLE III. 2. 11 (continued)

Part No. EWB 1615-3-28
FN 1418-1032
Size - #10-32 (Rolled Threads Before Age)

Material - Rene 41
Waspaloy

7. Nut Reuse and Galling Tendency @70°F

Seated Stress - 81,000 psi (1)

Test No.	Maximum Installation, inch-pounds	Torque to Induce Stress, inch-pounds	Torque, inch - pounds Breakaway	Removal
1st Application				
1	9	80	60	10
2	7	70	50	6
3	7	70	55	7
4	7	65	55	6
5	8	65	50	7
2nd Application				
1	6	65	50	10
2	5	55	40	5
3	5	67	55	5
4	5	60	45	4
5	5	62	45	5
3rd Application				
1	11	75	60	12
2	5	55	40	5
3	4	65	47	5
4	5	60	50	5
5	5	60	45	5
4th Application				
1	10	70	55	12
2	5	60	45	4
3	6	65	50	5
4	5	65	50	5
5	5	60	45	5
5th Application				
1	10	70	55	10
2	5	65	45	4
3	5	65	50	5
4	5	60	45	3
5	5	62	45	4

(1) Stress calculated at Tensile Stress Area (.003 reduced Pitch Diameter) of 0.01925 square inches.

TABLE III. 2. 11 (continued)

Part No. EWB 1615-3-28 Material - Rene 41
FN 1418-1032 Waspaloy
Size - #10-32 (Rolled Threads Before Age)

8. Vibration - ALMA #10

Test No.	Test Temperature, °F	Maximum Installation 1st	5th	Torque in.-lb.	No. of Cycles	Degrees Movement	10X Mag. Visual Insp.	Remarks
1	-320	11	9	30	30,000	0°	No cracks	Passed
2	-320	12	9	30	30,000	0°	No cracks	Passed
3	-320	10	8	30	30,000	0°	No cracks	Passed
4	-320	10	9	30	30,000	0°	No cracks	Passed
5	-320	10	8	30	30,000	0°	No cracks	Passed
6	70	10	6	30	30,000	15°	No cracks	Passed
7	70	12	7	30	30,000	15°	No cracks	Passed
8	70	9	5	30	30,000	90°	No cracks	Passed
9	70	12	6	30	30,000	15°	No cracks	Passed
10	70	10	7	30	30,000	60°	No cracks	Passed

9. Torque vs. Induced Load @ Room Temperature

Torque in.-lbs.	Test No. 1 Load, lbs.	Test No. 2 Load, lbs.	Test No. 3 Load, lbs.
25	500	550	600
50	1050	1050	1300
75	1750	1550	2400
100	2600	2100	2900
125	B.B.	B.B.	B.B.

B.B. - Bolt Broke

TABLE III. 2. 12

MECHANICAL PROPERTIES

Part No. Bolt - EWB 1615-4-28 Material - Rene 41
Part No. Nut -FN 1418-428 Waspaloy
Size - 1/4-28 (Rolled Threads Before Age)

1. Tensile

A. Base Material Properties (As Received) 0.113 inch specimen

Test No.	Test Temperature, °F	Ultimate Stress, psi	0.2% Offset Yield Stress, psi	Elongation, Gage, .5 in. %	Reduction of Area, %
1	-423	192,700	156,200	8.0	10.5
2	-423	196,800	158,800	8.0	9.0
3	-423	188,500	151,000	8.0	10.5
4	70	161,200	111,200	14.0	15.5
5	70	165,100	109,400	14.0	15.5
6	70	164,000	115,000	10.0	13.7
7	1400	134,700	125,000	18.0	20.5
8	1400	135,400	106,800	16.0	22.0
9	1400	144,800	96,400	20.0	26.8

B. Axial Bolt Properties (As Received)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (1)	Johnson's 2/3 Approximation Yield Load, lbs.	Johnson's 2/3 Approximation Yield Stress, psi (1)
10	-423	7,360	208,100	6,300	178,100
11	-423	7,440	210,300	6,300	178,100
12	-423	7,350	207,800	6,250	176,700
13	-320	7,200	203,600	6,000	169,600
14	-320	7,260	205,300	6,100	172,500
15	-320	7,250	205,000	6,150	174,900
16	70	5,800	164,000	4,500	127,200
17	70	5,860	165,700	4,650	131,500
18	70	5,700	161,200	4,600	130,100
19	1400	5,430	152,500	4,500	127,200
20	1400	5,410	153,000	4,640	131,200
21	1400	5,375	152,000	4,460	126,100

(1) Stress calculated at Tensile Stress Area (.003 reduced pitch diameter) of 0.03537 square inches.

TABLE III. 2. 12 (continued)

Part No. EWB 1615-4-28 — Material - Rene 41
FN 1418-428 — Waspaloy
Size - 1/4-28 (Rolled Threads Before Age)

1. Tensile (continued)

C. Angle Block Bolt Properties (3° @ Nut Bearing Face)*

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (1)
22	-423	6,990	197,600
23	-423	7,220	204,100
24	-423	7,360	208,100
25	-320	6,260	177,000
26	-320	6,710	189,700
27	-320	6,680	188,900
28	70	5,860	165,700
29	70	5,760	162,800
30	70	5,930	167,700

D. As Relaxed (50 Hours)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (1)	Yield Load, lbs.	Yield Stress, psi (1)
Preload A					
31	70	6,120	173,000	5,200	147,000
32	70	6,140	173,500	5,150	145,600
33	70	6,120	173,000	5,150	145,600
Preload B					
34	70	6,160	174,100	5,150	144,100
35	70	6,170	174,400	5,050	142,700
36	70	6,170	174,400	5,000	141,300

(1) Stress calculated at Tensile Stress Area (.003 reduced pitch diameter) of 0.03537 square inches.
* Bolt grip length 1.75 inches.

TABLE III. 2. 12 (continued)

Part No. EWB 1615-4-28
FN 1418-428
Size - 1/4-28 (Rolled Threads Before Age)

Material - Rene 41
Waspaloy

2. Tension Impact

Test No.	Test Temperature, °F	Energy Expended, ft. - lbs.
1	-423	14.0
2	-423	23.0
3	-423	17.0
4	-320	19.0
5	-320	22.0
6	-320	23.5
7	70	28.0
8	70	28.5
9	70	29.0

3. Double Shear

A. As Received

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (2)
1	-423	14,250	145,200
2	-423	13,600	138,500
3	-423	14,000	142,600
4	70	12,300	125,300
5	70	12,500	127,300
6	70	12,400	126,300
7	1400	9,650	98,300
8	1400	10,450	106,400
9	1400	10,350	105,400

(2) Stress calculated at twice the Nominal Diameter Area, 0.09817 square inches.

TABLE III. 2. 12 (continued)

Part No. EWB 1615-4-28 Material - Rene 41
FN 1418-428 Waspaloy
Size 1/4-28 (Rolled Threads Before Age)

3. Double Shear (continued)

B. As Relaxed (50 Hours)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (2)
Preload A			
10	70	13,000	132,400
11	70	13,100	133,400
12	70	13,000	132,400
Preload B			
13	70	12,100	123,300
14	70	12,800	130,400
15	70	12,900	131,400

4. Tension-Tension Fatigue @70° F

Test No.	Min. Load, lbs.	Min. Stress, psi (3)	Max. Load, lbs.	Max. Stress, psi (3)	Cycles to Failure	Location of Failure
1	254	7,800	2,540	78,000	133,000	Thread
2	254	7,800	2,540	78,000	55,000	Thread
3	254	7,800	2,540	78,000	61,000	Thread

(2) Stress calculated at twice the Nominal Diameter Area, 0.09817 square inches.
(3) Stress calculated at Basic Minor Diameter Area of 0.03256 square inches.

TABLE III.2.12 (continued)

Part No. EWB 1615-4-28 Material - Rene 41
FN 1418-428 Waspaloy
Size 1/4-28 (Rolled Threads Before Age)

5. Stress Relaxation @ 1400°F

Preload A - Initial Stress - 77,400 psi (1)

Test No.	Hours Run	Residual Stress Pounds	Residual Stress psi (1)
1	10	1,469	41,500
2	10	1,571	44,400
3	10	1,571	44,400
4	50	1,165	32,900
5	50	1,267	35,800
6	50	1,064	30,100

Preload B - Initial Stress - 48,300 psi

Test No.	Hours Run	Residual Stress Pounds	Residual Stress psi (1)
7	10	1,075	30,400
8	10	1,173	33,200
9	10	956	27,000
10	50	782	22,100
11	50	665	18,800
12	50	805	22,800

6. Stress Rupture

Test No.	Test Temperature, °F	Load lbs.	Stress psi (1)	Hours to Failure	Location of Failure
1	1400	4,244	120,000	4.8	Thread
2	1400	4,244	120,000	4.5	Thread
3	1400	4,244	120,000	2.3	Thread
4	1400	3,537	100,000	16.2	Thread
5	1400	3,537	100,000	15.0	Thread
6	1400	3,537	100,000	10.0	Thread
7	1400	2,820	80,000	101.5	Thread
8	1400	2,820	80,000	100.1	Thread
9	1400	2,820	80,000	100.3	Thread
10					

(1) Stress calculated at Tensile Stress Area (.003 reduced Pitch Diameter) of 0.03537 square inches

TABLE III. 2. 12 (continued)

Part No. EWB 1615-4-28 FN 1418-428
Material - Rene 41 Waspaloy
Size - 1/4-28 (Rolled Threads Before Age)

7. Nut Reuse and Galling Tendency @70° F

Seated Stress - 81,000 psi (1)

Test No.	Maximum Installation, inch-pounds	Torque to Induce Stress, inch - pounds	Torque, inch-pounds Breakaway	Removal
1st Application				
1	15	170	135	15
2	26	175	140	17
3	22	215	170	16
4	14	170	130	14
5	15	170	140	10
2nd Application				
1	12	165	120	12
2	12	160	130	11
3	16	200	160	12
4	11	165	140	11
5	9	175	140	7
3rd Application				
1	10	165	130	9
2	10	170	140	10
3	12	180	140	12
4	9	170	140	10
5	7	170	140	5
4th Application				
1	9	165	140	8
2	10	170	140	9
3	10	180	140	12
4	10	175	140	8
5	5	170	130	4
5th Application				
1	8	165	135	7
2	9	170	140	8
3	11	180	150	10
4	9	170	140	7
5	4	165	120	4

(1) Stress calculated at Tensile Stress Area (.003 reduced Pitch Diameter) of 0.03537 square inches.

TABLE III. 2. 12 (continued)

Part No. EWB 1615-4-28   Material - Rene 41
FN 1418-428   Waspaloy
Size - 1/4-28 (Rolled Threads Before Age)

8. Vibration - ALMA #10

Test No.	Test Temperature, °F	Maximum Installation, 1st	5th	Torque, in-lb.	No. of Cycles	Degree Movement	10X Mag. Visual Insp.	Remarks
1	-320	22	12	60	30,000	0°	No cracks	Passed
2	-320	17	15	60	30,000	0°	No cracks	Passed
3	-320	20	15	60	30,000	0°	No cracks	Passed
4	-320	25	18	60	30,000	0°	No cracks	Passed
5	-320	15	10	60	30,000	0°	No cracks	Passed
6	70	20	16	60	30,000	0°	No cracks	Passed
7	70	20	12	60	30,000	0°	No cracks	Passed
8	70	20	16	60	30,000	0°	No cracks	Passed
9	70	22	18	60	30,000	10°	No cracks	Passed
10	70	15	12	60	30,000	45°	No cracks	Passed

9. Torque vs. Induced Load @ Room Temperature

Torque, in. - lbs.	Test No. 1 Load, lbs.	Test No. 2 Load, lbs.	Test No. 3 Load, lbs.
50	600	650	650
100	1350	1500	1400
150	2050	2500	2200
200	3100	3350	2850
250	3800	4150	3500

TABLE III. 2. 13

MECHANICAL PROPERTIES

Part No. Bolt - EWB 1615-8-48 Material - Rene 41
Part No. Nut - FN 1418-820 Waspaloy
Size - 1/2-20 (Rolled Threads Before Age)

1. Tensile

A. Base Material Properties (As Received)

Test No.	Test Temperature, °F	Ultimate Stress, psi	0.2% Offset Yield Stress, psi	Elongation, Gage, .5 in. %	Reduction of Area, %
1	-423	192,000	153,000	6.4	8.6
2	-423	195,100	153,600	7.1	9.4
3	-423	204,000	157,500	5.7	9.4
4	70	173,000	120,000	13.5	14.6
5	70	181,900	122,600	17.1	16.6
6	70	178,800	119,500	16.4	17.2
7	1400	146,900	110,500	13.6	18.3
8	1400	146,700	112,500	16.4	20.7
9	1400	148,200	109,600	17.1	22.4

B. Axial Bolt Properties (As Received)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (1)	Johnson's 2/3 Approximation Yield Load, lbs.	Yield Stress, psi (1)
10	-423	31,250	198,000	25,000	158,400
11	-423	32,000	202,800	25,750	163,200
12	-423	31,550	199,900	-	-
13	-320	31,800	201,500	27,500	174,200
14	-320	31,200	197,700	26,600	168,500
15	-320	31,400	198,900	27,500	174,200
16	70	26,500	167,900	19,750	125,100
17	70	26,500	167,900	19,500	123,500
18	70	26,800	169,800	20,000	126,700
19	1400	27,200	172,300	19,000	120,400
20	1400	27,375	175,800	19,200	121,600
21	1400	27,300	173,000	19,700	124,800

(1) Stress calculated at Tensile Stress Area (.003 reduced pitch diameter) of 0.1578 square inches.

TABLE III.2.13 (continued)

Part No. EWB 1615-8-48 FN 1418-820 — Material - Rene 41 Waspaloy

Size - 1/2-20 (Rolled Threads Before Age)

1. Tensile (continued)

C. Angle Block Bolt Properties (3°∠@ Nut Bearing Face)*

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (1)
22	-423	30,950	196,100
23	-423	30,600	193,900
24	-423	31,150	197,400
25	-320	30,000	190,100
26	-320	30,400	192,600
27	-320	30,200	191,400
28	70	25,500	161,600
29	70	25,400	161,000
30	70	25,600	162,200

D. As Relaxed (50 Hours)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (1)	Yield Load, lbs.	Yield Stress, psi (1)
Preload A					
31	70	27,500	174,300	22,000	139,400
32	70	27,700	175,500	22,500	142,600
33	70	28,200	178,700	23,250	147,300
Preload B					
34	70	27,400	173,600	21,400	135,600
35	70	27,600	174,900	21,700	137,500
36	70	27,600	174,900	22,000	139,400

(1) Stress calculated at Tensile Stress Area (.003 reduced pitch diameter) of 0.1578 square inches.

* Bolt grip length 3.0 inches.

TABLE III. 2. 13 (continued)

Part No. EWB 1615-8-48 Material – Rene 41
FN 1418-820 Waspaloy
Size - 1/2-20 (Rolled Threads Before Age)

2. Double Shear

A. As Received

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (2)
1	-423	51, 400	130, 900
2	-423	53, 850	137, 100
3	-423	52, 000	132, 400
4	70	48, 900	124, 500
5	70	50, 200	[illegible], 900
6	70	49, 500	12[illegible]00
7	1400	40, 500	103, 100
8	1400	40, 300	102, 600
9	1400	38, 500	98, 000

B. As Relaxed (50 Hours)

Preload A

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (2)
10	70	52, 400	133, 400
11	70	53, 500	136, 200
12	70	54, 400	138, 500

Preload B

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (2)
13	70	52, 600	133, 900
14	70	52, 800	134, 500
15	70	52, 800	134, 500

(2) Stress calculated at twice the Nominal Diameter Area, 0.3927 square inches.

TABLE III. 2. 13 (continued)

Part No. EWB 1615-8-48 Material - Rene 41
FN 1418-820 Waspaloy
Size - 1/2-20 (Rolled Threads Before Age)

3. Tension-Tension Fatigue @70° F

Test No.	Min. Load lbs.	Min. Stress psi (3)	Max. Load lbs.	Max. Stress psi (3)	Cycles to Failure	Location of Failure
1	1,160	7,800	11,590	78,000	35,100	Thread
2	1,160	7,800	11,590	78,000	54,300	Thread
3	1,160	7,800	11,590	78,000	34,000	Thread

4. Stress Relaxation @ 1400° F

Preload A - Initial Stress - 73,000 psi

Test No.	Hours Run	Residual Pounds	Stress psi (1)
1	10	7,137	45,200
2	10	6,993	44,300
3	10	6,605	41,900
4	50	5,958	37,800
5	50	5,310	33,700
6	50	5,310	33,700

Preload B - Initial Stress - 46,400 psi

Test No.	Hours Run	Residual Pounds	Stress psi (1)
7	10	5,052	32,000
8	10	4,800	30,400
9	10	4,673	29,600
10	50	4,420	28,000
11	50	4,800	30,400
12	50	4,168	26,400

(1) Stress calculated at Tensile Stress Area (.003 reduced Pitch Diameter) of 0.1578 square inches.

TABLE III. 2. 13 (continued)

Part No. EWB 1615-8-48 FN 1418-820

Material - Rene 41 Waspaloy

Size - 1/2-20 (Rolled Threads Before Age)

5. Stress Rupture

Test No.	Test Temperature °F	Load, lbs.	Stress, psi (1)	Hours to Failure	Location of Failure
1	1400	18,936	120,000	1.6	Thread
2	1400	18,936	120,000	2.2	Thread
3	1400	18,936	120,000	.7	Thread
4	1400	15,780	100,000	7.0	Thread
5	1400	15,780	100,000	12.5	Thread
6	1400	15,780	100,000	17.5	Thread
7	1400	12,624	80,000	100.0	No Failure
8	1400	12,624	80,000	102.6	No Failure
9	1400	12,624	80,000	99.0	Thread
10					

TABLE III. 2. 13 (continued)

Part No. EWB 1615-8-48 Material - Rene 41
FN 1418-820 Waspaloy

Size - 1/2-20 (Rolled Threads Before Age)

6. Nut Reuse and Galling Tendency @70°F

Seated Stress - 81,000 psi (1)

Test No.	Maximum Installation in.-lbs.	Torque to Induce Stress, inch-pounds	Torque, inch-pounds Breakaway	Torque, inch-pounds Removal
1st Application				
1	85	1050	900	75
2	80	1000	800	60
3	70	1150	950	50
4	70	1000	850	55
5	75	1075	875	55
2nd Application				
1	65	1025	825	55
2	55	1025	750	45
3	60	1150	925	40
4	55	975	850	45
5	50	1050	850	50
3rd Application				
1	60	1050	875	55
2	60	1000	800	40
3	60	1125	900	40
4	55	1025	850	45
5	55	1050	850	45
4th Application				
1	50	1000	850	50
2	55	975	850	40
3	50	1075	850	40
4	50	1025	875	38
5	45	1025	800	48
5th Application				
1	60	1000	850	45
2	50	1025	850	40
3	55	1100	825	35
4	55	975	850	45
5	45	1075	850	45

(1) Stress calculated at Tensile Stress Area (.003 reduced Pitch Diameter) of 0.1578 square inches.

TABLE III. 2. 13 (continued)

Part No. EWB 1615-8-48 FN 1418-820

Material - Rene 41 Waspaloy

Size - 1/2-20 (Rolled Threads Before Age)

7. Vibration - ALMA #10

Test No.	Test Temperature, °F	Maximum Installation, 1st	5th	Seating Torque, in-lbs.	No. of Cycles	Degrees Movement	10X Mag. Visual Insp.	Remar
1	-320	100	40	300	30,000	0°	No Cracks	Passe
2	-320	110	60	300	30,000	0°	No Cracks	Passe
3	-320	60	40	300	30,000	0°	No Cracks	Passe
4	-320	110	60	300	30,000	0°	No Cracks	Passe
5	-320	120	60	300	30,000	0°	No Cracks	Passe
6	70	100	60	300	30,000	0°	No Cracks	Passe
7	70	110	40	300	30,000	0°	No Cracks	Passe
8	70	120	60	300	30,000	0°	No Cracks	Passe
9	70	130	60	300	30,000	0°	No Cracks	Passe
10	70	130	50	300	30,000	0°	No Cracks	Passe

8. Torque vs. Induced Load @ Room Temperature

Torque in-lbs.	Test No. 1 Load, lbs.	Test No. 2 Load, lbs.	Test No. 3 Load, lbs.
500	4,500	4,000	4,250
1000	11,500	10,000	10,000
1500	17,500	16,500	16,750
2000	21,000	20,500	20,500

TABLE III.2.14

MECHANICAL PROPERTIES

Part No. EWB 1615-4-28 Material AF 1753
Size - 1/4-28 x 2.250 (Rolled Threads Before Age)

1. Tensile

A. Base Material Properties (As Received) .113 inches specimen

Test No.	Test Temperature, °F	Ultimate Stress, psi	0.2% Offset Yield Stress, psi	Elongation Gage, .5 in. %	Reduction of Area, %
1	-423	266,000	147,500	22.0	21.9
2	-423	262,000	165,000	24.0	26.3
3	-423	258,000	145,000	24.0	23.2
4	70	183,000	117,500	26.0	32.3
5	70	188,700	130,600	24.0	32.4
6	70	186,700	128,500	26.0	31.0
7	1600	95,900	93,300	4.0	10.5
8	1600	90,800	88,700	4.0	7.0
9	1600	85,500	85,000	4.0	3.5

B. V-Notch Properties (K_t 8)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi	Notch to Smooth Tensile Ratio
10	-423	6,400	263,400	1.01
11	-423	6,340	259,800	.99
12	-423	6,350	259,200	.99
13	70	5,550	225,600	1.21
14	70	5,500	223,600	1.20
15	70	5,520	226,200	1.22
16	1600	1,735	70,200	0.77
17	1600	1,685	69,100	0.76
18	1600	1,625	66,100	0.73

TABLE III. 2. 14 (continued)

Part No. EWB 1615-4-28 Material AF 1753
Size - 1/4-28 x 2.250 (Rolled Threads Before Age)

1. Tensile (continued)

C. Axial Bolt Properties

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)	Johnson's 2/3 Approximation Yield Load, lbs.	Johnson's 2/3 Approximation Yield Stress, psi(1)
19	-423	8,060	227,900	6,350	179,500
20	-423	7,980	219,400	6,000	169,600
21	-423	8,040	227,300	6,200	175,300
22	-320	7,680	217,100	6,500	183,800
23	-320	7,680	217,100	6,050	171,000
24	-320	7,660	216,600	6,400	180,900
25	70	6,600	187,000	4,950	140,000
26	70	6,720	190,000	5,175	146,300
27	70	6,540	184,900	5,200	147,000
28	1600	3,115	88,000	1,950	55,100
29	1600	3,300	93,300	2,725	77,000
30	1600	3,735	105,600	3,425	96,800

D. Angle Block Bolt Properties (3°∠ @ Nut Bearing Face)*

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
31	-423	6,760	191,100
32	-423	7,580	214,300
33	-423	7,720	218,300
34	-320	6,800	192,300
35	-320	7,820	221,100
36	-320	7,630	215,700
37	70	6,480	183,200
38	70	6,440	182,100
39	70	6,390	180,700

(1) Stress calculated at Tensile Stress Area (.003 Reduced Pitch Diameter), 0.03537 square inches.
* Bolt grip length 1.75 inches.

TABLE III. 2. 14 (continued)

Part No. EWB 1615-4-28 Material AF 1753
Size - 1/4-28 x 2.250 (Rolled Threads Before Age)

1. Tensile (continued)

E. As Relaxed Bolt Properties (50 Hours)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)	Yield Load, lbs.	Yield Stress, psi(1)
40	70	5,660	160,000	4,000	113,100
41	70	4,380	123,800	3,980	112,500
42	Bolt failed when being disassembled after relaxation test.				

2. Tension Impact

Test No.	Test Temperature, °F	Energy Expended, ft.-lbs.
1	-423	27.0
2	-423	27.0
3	-423	30.5
4	-320	27.0
5	-320	28.0
6	-320	25.0
7	70	29.5
8	70	30.5
9	70	26.0

(1) Stress calculated at Tensile Stress Area (.003 Reduced Pitch Diameter), 0.03537 square inches..

TABLE III. 2. 14 (continued)

Part No. EWB 1615-4-28 Material AF 1753
Size - 1/4-28 x 2.250 (Rolled Threads Before Age)

3. Double Shear

A. As Received

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
1	-423	14,950	152,300
2	-423	15,350	156,400
3	-423	14,650	149,200
4	70	11,900	121,200
5	70	12,500	127,300
6	70	12,100	123,300
7	1600	5,475	55,800
8	1600	5,650	57,6[illegible]
9	1600	6,250	63,700

B. As Relaxed (50 Hours)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
10	70	12,200	124,300
11	70	12,300	125,300
12	Bolt failed when being disassembled after relaxation test.		

4. Tension-Tension Fatigue @70°F

Test No.	Min. Load, lbs.	Min. Stress, psi	Max. Load, lbs.	Max. Stress, psi(3)	Cycles to Failure	Location of Failure
1	312	9,300	3,115	93,000	29,000	Thread
2	312	9,300	3,115	93,000	20,000	Thread
3	312	9,300	3,115	93,000	33,000	Thread

(2) Stress calculated at twice the Nominal Diameter Area of 0.09817 square inches.
(3) Stress calculated at Basic Minor Diameter Area of 0.03256 square inches.

TABLE III. 2. 14 (continued)

Part No. EWB 1615-4-28 Material AF 1753
Size - 1/4-28 x 2.250 (Rolled Threads Before Age)

5. Stress Relaxation @ 1600° F

Initial Stress - 73,500 psi

Test No.	Hours Run	Residual Stress Pounds	Residual Stress psi(1)
1	1	1,450	41,000
	10	760	21,500
	50	Bolt Broke	
2	1	960	27,100
	10	800	22,600
	50	640	18,100
3	1	1,720	48,600
	10	760	20,900
	50	440	12,500

6. Stress Rupture

Test No.	Test Temperature, °F	Load, lbs.	Load Stress, psi(1)	Hours to Failure	Location of Failure
1	1600	2,500	70,000	1.2	Thread
2	1600	2,122	60,000	4.6	Thread
3	1600	2,122	60,000	3.3	Thread
4	1600	1,945	55,000	5.4	Thread
5	1600	1,768	50,000	11.1	Thread
6	1600	1,768	50,000	25.3	Thread
7	1600	1,768	50,000	33.9	Thread

7. Coefficient of Thermal Expansion(3)

Temperature	Inches/Inch/°F x 10^6
600	6.7
1000	7.3
1200	7.5
1400	7.8
1600	8.2

(1) Stress calculated at Tensile Stress Area (.003 Reduced Pitch Diameter), 0.03537 square inches.

(3) Universal Cyclops Steel Corp. - Technical Data on Unitemp AF 1753

TABLE III.2..15

MECHANICAL PROPERTIES

Part No. Bolt - EWB 1615-4-28 Material - AF 1753
Part No. Nut - FN 26-428 Material - AF 1753
Size - 1/4-28 (Rolled Threads After Age)

1. Tensile

A. Base Material Properties (As Received) 0.113 inch specimen

Test No.	Test Temperature °F	Ultimate Stress psi	0.2% Offset Yield Stress, psi	Elongation Gage, .5 in. %	Reduction of Area, %
1	-423	264,600	145,800	24.0	25.3
2	-423	267,300	165,800	24.0	26.6
3	-423	249,500	145,200	28.0	28.8
4	-320	263,000	161,500	22.0	23.5
5	-320	257,900	160,500	24.0	28.5
6	-320	256,300	153,600	26.0	30.0
7	70	199,000	132,500	22.0	40.8
8	70	205,600	145,400	20.0	36.8
9	70	199,400	138,700	20.0	31.0
10	1600	92,800	83,300	12.0	16.5
11	1600	95,300	88,500	8.0	11.2
12	1600	89,400	87,800	8.0	14.0

TABLE III. 2. 15 (continued)

Part No. EWB 1615-4-28 Material - AF 1753
FN 26-428 Material - AF 1753
Size - 1/4-28 (Rolled Threads After Age)

1. Tensile (continued)

B. Axial Bolt Properties (As Received)

Test No.	Test Temperature °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)	Johnson's 2/3 Approximation Yield Load, lbs.	Johnson's 2/3 Approximation Yield Stress, psi
13	-423	8,200	231,800	6,500	183,800
14	-423	8,550	241,700	6,900	195,100
15	-423	8,820	249,400	6,600	186,600
16	-320	8,500	240,300	5,000	141,300
17	-320	8,500	240,300	4,875	137,800
18	-320	8,500	240,300	4,750	134,300
19	70	7,090	200,400	4,700	132,800
20	70	6,950	196,400	4,500	127,200
21	70	7,200	203,500	4,700	132,800
22	1600	3,600	101,800	3,000	84,800
23	1600	3,550	100,300	3,250	91,900
24	1600	3,050	86,200	2,750	77,700
C. Angle-Block Bolt Properties (3° ∠ @ Nut Bearing Face)*					
25	-423	8,100	229,000		
26	-423	8,340	235,800		
27	-423	8,150	230,400		
28	-320	8,500	240,300		
29	-320	8,250	233,200		
30	-320	8,175	231,100		
31	70	7,360	208,100		
32	70	7,280	205,800		
33	70	7,000	197,900		
D. As-Relaxed Bolt Properties (50 Hours)					
34	70	5,750	162,600	4,450	125,800
35	70	5,550	156,900	4,300	121,600
36	70	5,650	159,700	4,350	123,000

(1) Stress Calculated at Tensile Stress Area (.003 reduced pitch diameter) of 0.03537 square inches.
* Bolt grip length 1.75 inches.

TABLE III. 2. 15 (continued)

Part No. EWB 1615-4-28 Material - AF 1753
FN 26-428 Material - AF 1753
Size 1/4-28 (Rolled Threads After Age)

2. Stress Durability @70°F

Test No.	Seated Stress, lbs.	psi(1)	Torque to Induce Stress, in. -lbs.	Length of Test, Hours	Remarks
1	4,200	118,700	80	44	Passed
2	4,200	118,700	80	44	Passed
3	4,200	118,700	80	44	Passed

3. Tension-Impact

Test No.	Test Temperature, °F	Energy Expended, ft. -lbs.
1	-423	30.0
2	-423	37.0
3	-423	25.0
4	-320	32.0
5	-320	47.0
6	-320	42.0
7	70	41.0
8	70	45.0
9	70	44.0

(1) Stress Calculated at the Tensile Stress Area (.003 reduced pitch diameter) of 0.03537 square inches.

TABLE III. 2. 15 (continued)

Part No. - EWB 1615-4-28 Material - AF 1753
FN 26-428 Material - AF 1753
Size - 1/4-28 (Rolled Threads After Age)

4. Double Shear

A. As-Received

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
1	-423	15,500	157,900
2	-423	15,900	162,000
3	-423	16,100	164,000
4	70	13,200	134,500
5	70	13,300	135,500
6	70	13,300	135,500
7	1600	6,050	61,600
8	1600	6,650	67,700
9	1600	6,400	65,200

B. As-Relaxed (50 Hours)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
10	70	13,000	132,400
11	70	12,600	128,400
12	70	12,400	126,300

(2) Stress Calculated at Twice the Nominal Diameter Area, 0.09817 square inches.

TABLE III. 2. 15 (continued)

Part No. - EWB 1615-4-28 Material - AF 1753
FN 26-428 Material - AF 1753
Size - 1/4-28 (Rolled Threads After Age)

5. Stress Rupture

Test No.	Test Temperature, °F	Load, lbs.	Stress, psi(1)	Hours to Failure	Location of Failure
1	1600	1,415	40,000	3.2	Thread
2	1600	1,415	40,000	2.8	Thread
3	1600	1,061	30,000	11.7	Thread
4	1600	1,061	30,000	26.5	Thread
5	1600	1,061	30,000	15.8	Thread
6	1600	707	20,000	164.1	No Failure
7	1600	707	20,000	164.1	No Failure
8	1600	707	20,000	77.4	Head
9	1600	707	20,000	62.7	Thread

6. Stress Relaxation @1600°F

Initial Stress - 76,000 psi

Test No.	Hours Run	Residual Stress lbs.	Residual Stress psi(1)
1	10	618	17,400
2	10	0	0
3	10	0	0
4	50	0	0
5	50	0	0
6	50	0	0

(a) Combination of initial preload and test temperature was too high.

(1) Stress Calculated at the Tensile Stress area (.003 reduced pitch diameter) of 0.03537 square inches.

TABLE III. 2. 15 (continued)

Part No. - EWB 1615-4-28 — Material - AF 1753
FN 26-428 — Material - AF 1753
Size - 1/4-28 (Rolled Threads After Age)

7. Nut Reuse and Galling Tendency @70°F

Seated Stress - 97,200 psi(1)

Test No.	Maximum Installation, inch-pounds	Torque to Induce Stress, inch-pounds	Torque, inch - pounds Breakaway	Removal
1st Application				
1	10.0	110	82	6.0
2	8.5	92	82	5.5
3	9.0	103	95	4.0
4	7.0	118	85	4.0
5	8.0	135	105	4.0
2nd Application				
1	5.5	113	88	6.0
2	4.0	98	72	4.0
3	3.5	105	75	3.3
4	3.0	120	85	2.8
5	4.0	137	105	3.5
3rd Application				
1	5.5	115	88	5.8
2	3.5	98	68	4.0
3	3.0	108	82	2.8
4	2.8	120	85	2.5
5	3.6	142	112	3.4
4th Application				
1	5.2	118	82	5.8
2	3.7	98	75	4.0
3	3.0	110	77	2.8
4	2.8	120	78	2.2
5	3.2	153	120	3.6
5th Application				
1	5.6	118	86	6.2
2	3.8	98	82	4.2
3	3.2	112	72	3.0
4	3.0	120	78	2.0
5	3.2	150	120	3.8

(1) Stress Calculated at Tensile Stress Area (.003 reduced pitch diameter) of 0.03537 square inches.

TABLE III. 2. 15 (continued)

Part No. EWB 1615-4-28 Material - AF 1753
FN 26-428 Material - AF 1753
Size - 1/4-28 (Rolled Threads After Age)

8. Torque vs. Induced Load @70°F

Torque in. -lbs.	Test No. 1 Load, lbs.	Test No. 2 Load, lbs.	Test No. 3 Load, lbs.
DRY			
50	1,050	1,200	1,100
100	2,200	2,450	2,250
150	3,400	3,700	3,500
200	4,400	4,850	4,500
250	5,375	5,900	5,550
300	6,200	6,600	6,450
330	---	---	6,750
340	6,700	6,900	
SPS K3 Lube			
50	1,400	1,500	1,400
100	3,000	3,200	2,950
150	6,350	6,150	6,050
160	7,100	7,050	7,000

TABLE III. 2. 16

MECHANICAL PROPERTIES

Part No. Bolt - EWB 1615-6-28 Material - AF 1753
Part No. Nut - FN 26-624 Material - AF 1753
Size - 3/8-24 (Rolled Threads After Age)

1. Tensile

A. Base Material Properties (As Received) 0. 252 inches specimen

Test No.	Test Temperature, °F	Ultimate Stress, psi	0. 2% Offset Yield Stress, psi	Elongation, Gage, . 5 in. %	Reduction of Area, %
1	-423	263, 100	183, 100	18. 0	15. 6
2	-423	242, 200	165, 600	12. 0	12. 5
3	-423	246, 900	158, 100	15. 0	13. 9
4	-320	254, 900	176, 700	16. 0	17. 4
5	-320	246, 900	162, 200	17. 0	16. 9
6	-320	246, 900	175, 100	15. 0	16. 0
7	70	204, 400	159, 900	14. 0	23. 9
8	70	204, 000	159, 600	15. 0	26. 0
9	70	202, 800	157, 800	15. 0	25. 4
10	1600	93, 600	91, 300	4. 0	8. 6
11	1600	95, 600	93, 800	8. 0	13. 9
12	1600	88, 200	83, 100	8. 0	16. 2

TABLE III. 2. 16 (continued)

Part No. EWB 1615-6-28 Material - AF 1753
FN 26-624 Material - AF 1753
Size - 3/8-24 (Rolled Threads After Age)

1. Tensile (continued)

B. Axial Bolt Properties (As Received)

Test No.	Test Temperature °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)	Johnson's 2/3 Approximation Yield Load, lbs.	Johnson's 2/3 Approximation Yield Stress, psi
13	-423	20,900	242,300	13,500	156,500
14	-423	21,500	249,300	17,400	201,800
15	-423	20,900	242,300	16,750	194,200
16	-320	20,100	233,100	13,625	158,000
17	-320	21,250	246,400	15,750	182,600
18	-320	21,200	245,800	17,250	200,000
19	70	16,500	191,300	10,600	122,900
20	70	18,000	208,700	12,500	144,900
21	70	16,300	189,000	9,700	112,400
22	1600	6,980	80,900	6,100	70,700
23	1600	8,360	96,900	7,200	83,500
24	1600	8,820	102,300	7,250	84,100
C. Angle-Block Bolt Properties (3°∠ @ Nut Bearing Face)*					
25	-423	19,300	223,800		
26	-423	20,300	235,400		
27	-423	19,700	228,400		
28	-320	21,300	247,000		
29	-320	20,800	241,200		
30	-320	21,100	244,700		
31	70	17,700	205,200		
32	70	17,200	199,400		
33	70	16,000	185,500		
D. As-Relaxed Bolt Properties (50 Hours)					
34	70	13,700	158,900	10,750	124,700
35	70	14,000	162,300	11,375	131,900
36	70	14,400	170,000	11,250	130,400

(1) Stress Calculated at Tensile Stress Area (.003 reduced pitch diameter) of 0.08624 square inches.

* Bolt grip length 1.75 inches.

TABLE III. 2. 16 (continued)

Part No. EWB 1615-6-28 Material - AF 1753
FN 26-624 Material - AF 1753

Size - 3/8-24 (Rolled Threads After Age)

2. Stress Durability @ 70°F

Test No.	Seated Stress, lbs.	Seated Stress, psi(1)	Torque to Induce Stress, in. -lbs.	Length of Test, Hours	Remarks
1	9,800	113,600	375	42	Passed
2	9,800	113,600	425	42	Passed
3	9,800	113,600	325	42	Passed

3. Double Shear

A. As-Received

Test No.	Test Temperature, °F	Ultimate, Load, lbs.	Ultimate, Stress, psi(2)
1	-423	32,800	148,600
2	-423	35,600	161,200
3	-423	35,500	160,800
4	70	27,700	125,500
5	70	29,500	133,600
6	70	28,900	130,900
7	1600	13,500	61,100
8	1600	13,450	60,900
9	1600	13,240	60,000
As-Relaxed (50 Hours)			
10	70	26,900	121,800
11	70	28,000	126,800
12	70	27,700	125,500

(1) Stress Calculated at the Tensile Stress Area (.003 reduced pitch diameter) of 0.08624 square inches.

(2) Stress Calculated at Twice the Nominal Diameter Area, 0.2208 square inches.

TABLE III. 2. 16 (continued)

Part No. - EWB 1615-6-28 Material - AF 1753
FN 26-624 Material - AF 1753
Size - 3/8-24 (Rolled Threads After Age)

4. Stress Rupture

Test No.	Test Temperature, °F	Load, lbs.	Stress, psi(1)	Hours to Failure	Location of Failure
1	1600	4,312	50,000	2.0	Thread
2	1600	4,312	50,000	0.9	Thread
3	1600	4,312	50,000	3.5	Thread
4	1600	3,450	40,000	5.4	Head
5	1600	3,450	40,000	16.6	Thread
6	1600	3,450	40,000	12.9	Head
7	1600	1,724	20,000	61.6	Head
8	1600	1,724	20,000	142.1	Thread
9	1600	1,724	20,000	100.0	No Failure

5. Stress Relaxation @1600°F

Initial Stress - 76,000 psi (1)

Test No.	Hours Run	Residual Stress lbs.	psi(1)
1	10	472	5,500
2	10	236	2,700
3	10	118	1,400
4	50	118	1,400
5	50	0	0
6	50	0	0

(a) Combination of initial preload and test temperature was too high.

(1) Stress Calculated at the Tensile Stress Area (.003 reduced pitch diameter) of 0.08624 square inches.

TABLE III. 2. 16 (continued)

Part No. EWB 1615-6-28 Material - AF 1753
FN 26-624 Material - AF 1753
Size 3/8-24 (Rolled Threads After Age)

6. Nut Reuse and Galling Tendency @ 70°F

Seated Stress - 97,200 psi(1)

Test No.	Maximum Installation, inch-pounds	Torque to Induce Stress, inch-pounds	Torque, inch - pounds Breakaway	Removal
1st Application				
1	30	470	340	14
2	24	470	350	11
3	28	510	380	11
4	33	475	350	13
5	21	470	340	8
2nd Application				
1	17	510	370	16
2	16	490	350	12
3	14	520	360	11
4	16	500	380	12
5	14	450	325	7
3rd Application				
1	18	510	320	15
2	15	465	340	11
3	13	485	360	10
4	14	525	390	11
5	8	425	315	6
4th Application				
1	19	500	380	15
2	13	460	350	11
3	12	490	360	10
4	13	540	410	9.5
5	7	425	300	6
5th Application				
1	16	500	370	12
2	12	485	365	12
3	11	500	360	10
4	12	540	410	11
5	7	435	310	6

(1) Stress Calculated at Tensile Stress Area (.003 reduced pitch diameter) of 0.08624 square inches.

TABLE III. 2. 16 (continued)

Part No. EWB 1615-6-28 Material - AF 1753
FN 26-624 Material - AF 1753
Size 3/8-24 (Rolled Threads After Age)

7. Torque vs. Induced Load @70°F

Torque in. -lbs	Test No. 1 Load, lbs.	Test No. 2 Load, lbs.	Test No. 3 Load, lbs.
DRY			
100	725	700	700
200	2,075	1,900	2,000
300	3,150	3,750	3,550
400	4,550	5,100	4,950
500	6,050	6,575	6,400
600	7,850	7,950	7,900
700	9,100	10,400	10,050
800	10,500	12,025	12,000
900	12,400	13,875	12,950
1000	13,650	14,750	14,300
1100	14,325	15,350	15,050
1150	15,200		
SPS K3 Lube			
100	1,150	1,200	1,300
200	3,700	3,050	3,625
300	8,100	5,550	6,825
400	10,650	9,600	10,250
500	12,950	13,000	15,650
525		15,600	
600	14,850		
625			
650	15,675 (B. F.)		

B. F. - Bolt Fractured

APPENDIX III. 3.

Titanium Base Fasteners

MATERIAL PROPERTIES

Titanium Base Alloys

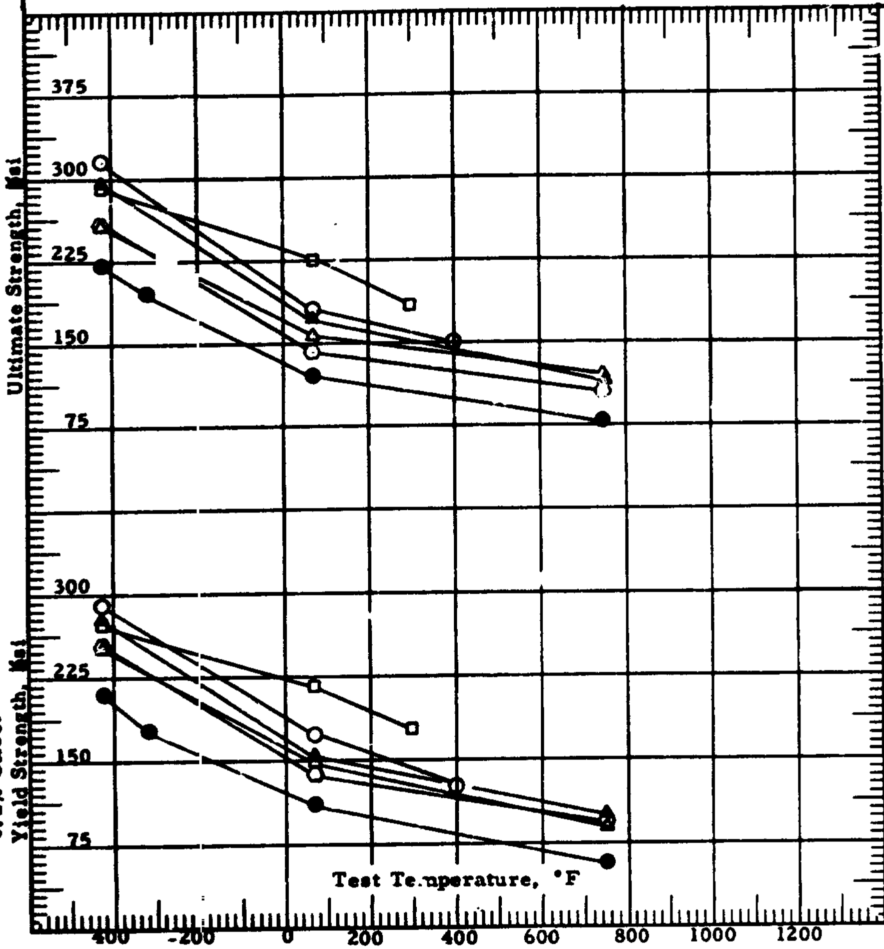
SPS LABORATORIES

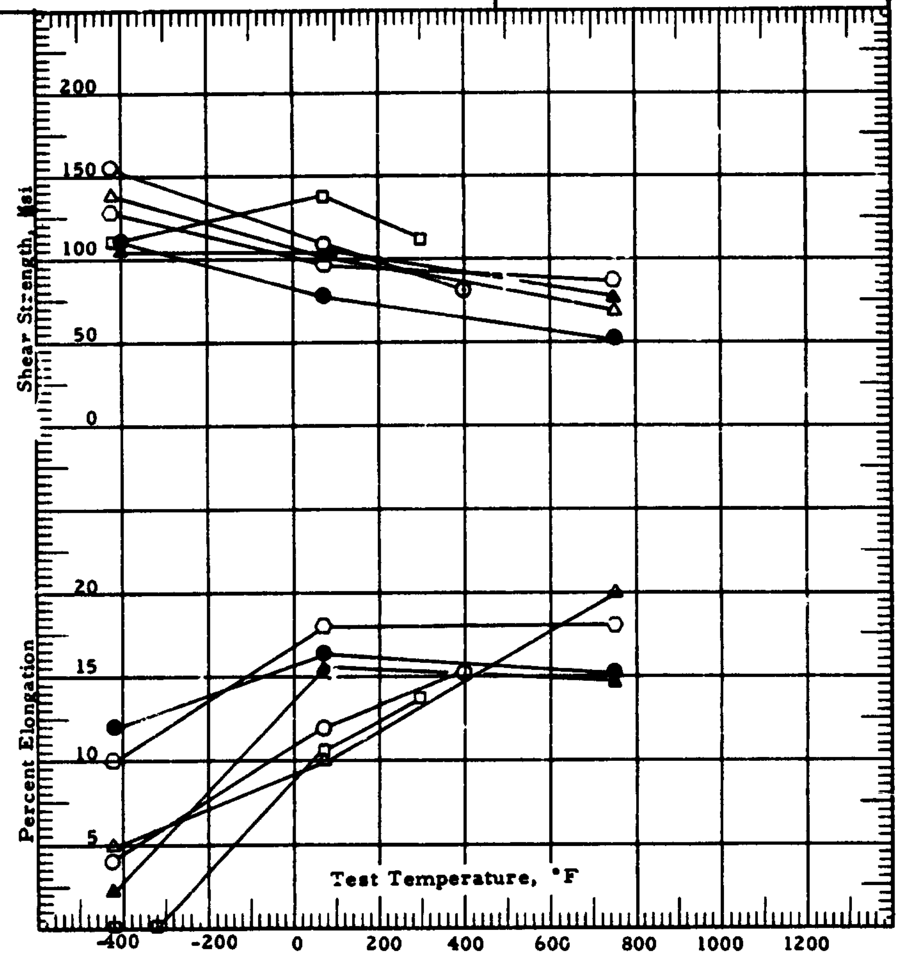
Chart No.: III. 3. 1

Date:

Legend

○ — Ti 6Al-4V
△ — Ti 7Al-12Zr
□ — Ti 1Al-8V-5Fe
⬡ — Ti 8Al-1Mo-1V
● — Ti 5Al-2.5Sn (ELI)
▲ — Ti 5Al-5Sn-5Zr





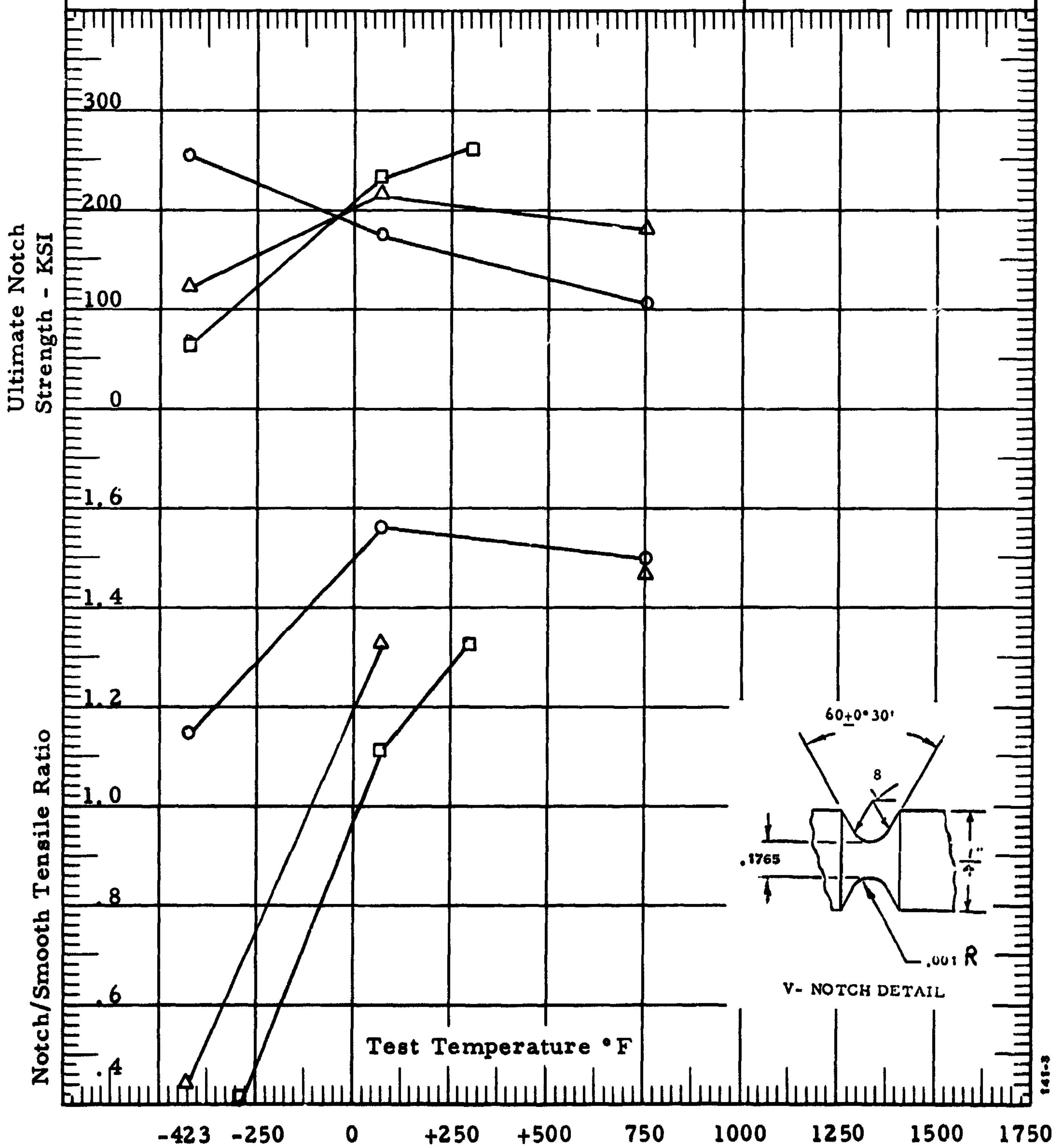
Material Notch Properties
Titanium Base Alloys
Stress Concentration Factor K_t - 8

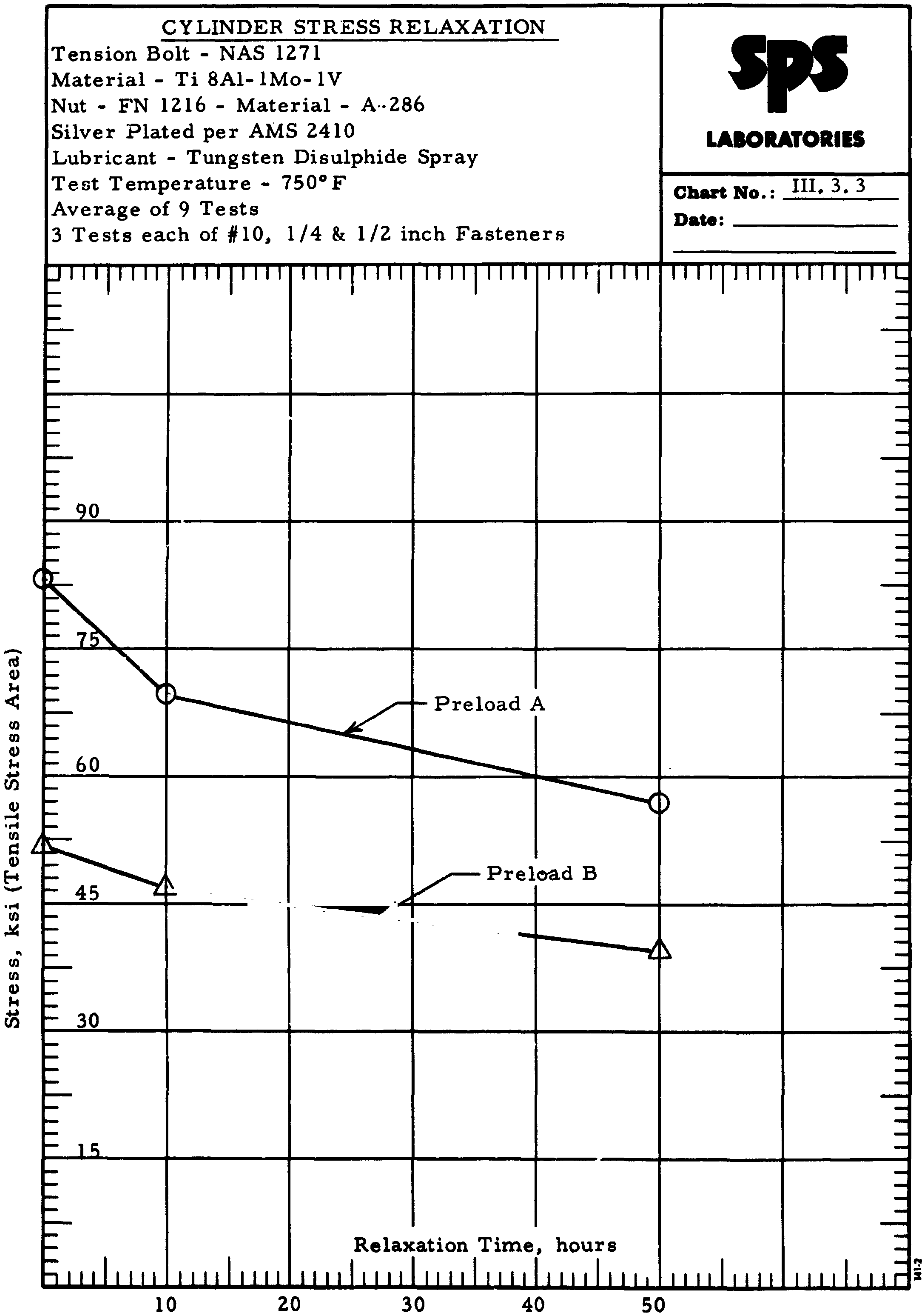
SPS
LABORATORIES

Chart No.: III. 3. 2
Date:

Legend

O Ti 5Al-2. 5Sn (ELI)
Δ Ti 5Al-5Sn-5Zr
□ Ti 1Al-8V-5Fe




CYLINDER STRESS RELAXATION
Tension Bolt - NAS 1271
Material - Ti 8Al-1Mo-1V
Nut - FN 1216 - Material - A-286
Silver Plated per AMS 2410
Lubricant - Tungsten Disulphide Spray
Test Temperature - 750° F
Average of 9 Tests
3 Tests each of #10, 1/4 & 1/2 inch Fasteners
SPS
LABORATORIES
Chart No.: III. 3. 3
Date:
90
75
60
45
30
15
Preload A
Preload B
Stress, ksi (Tensile Stress Area)
Relaxation Time, hours
10
20
30
40
50

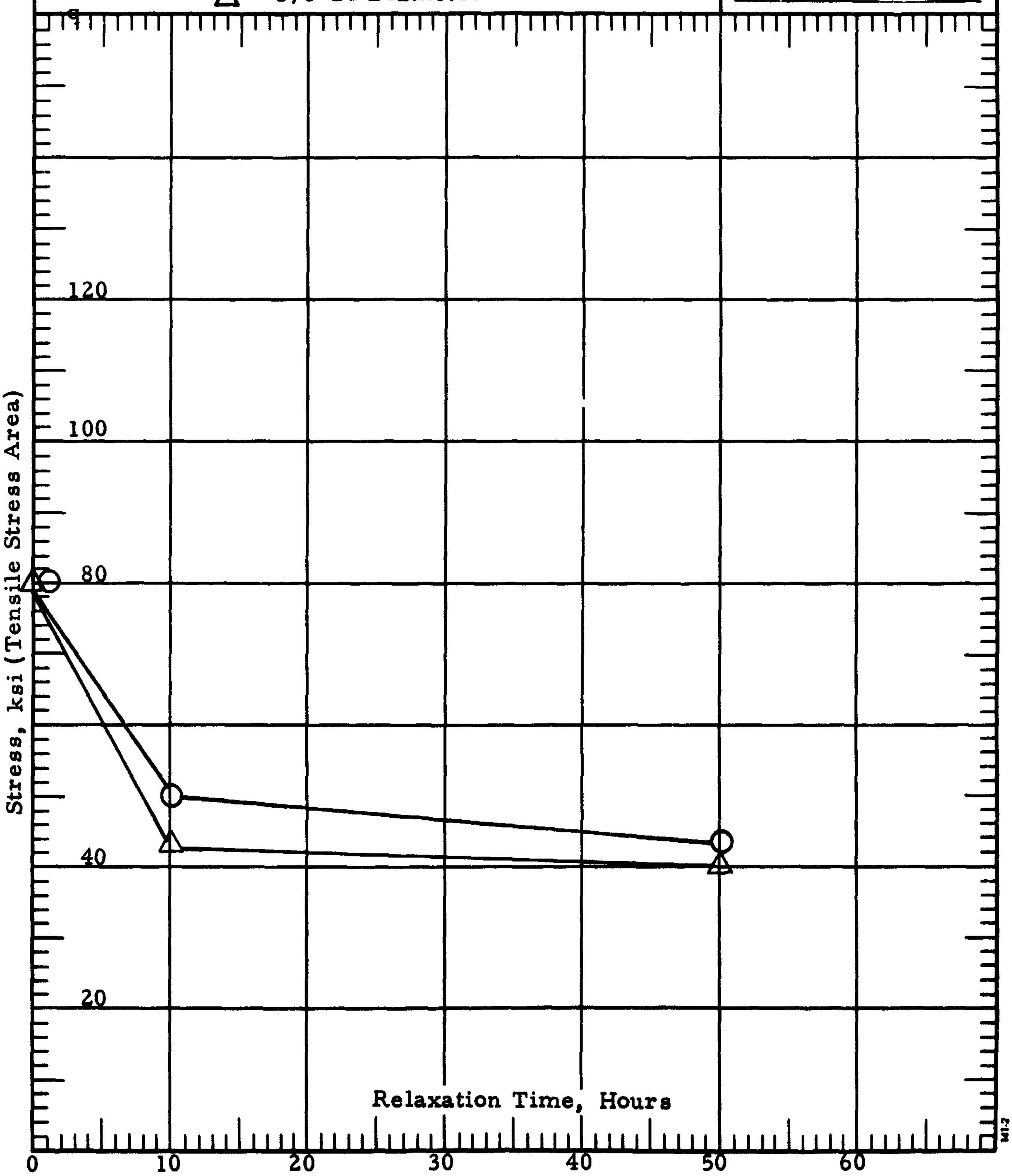
CYLINDER STRESS RELAXATION

Tension Bolt - EWBT 815
Material - Ti 5Al-2. 5Sn (ELI)
Nut - FN 1216 - Material A-286
Silver Plated per AMS 2410
Test Temperature - 750°F

Legend
○ - 1/4-28 Diameter
△ - 3/8-24 Diameter

SPS LABORATORIES

Chart No.: III. 3. 4
Date:

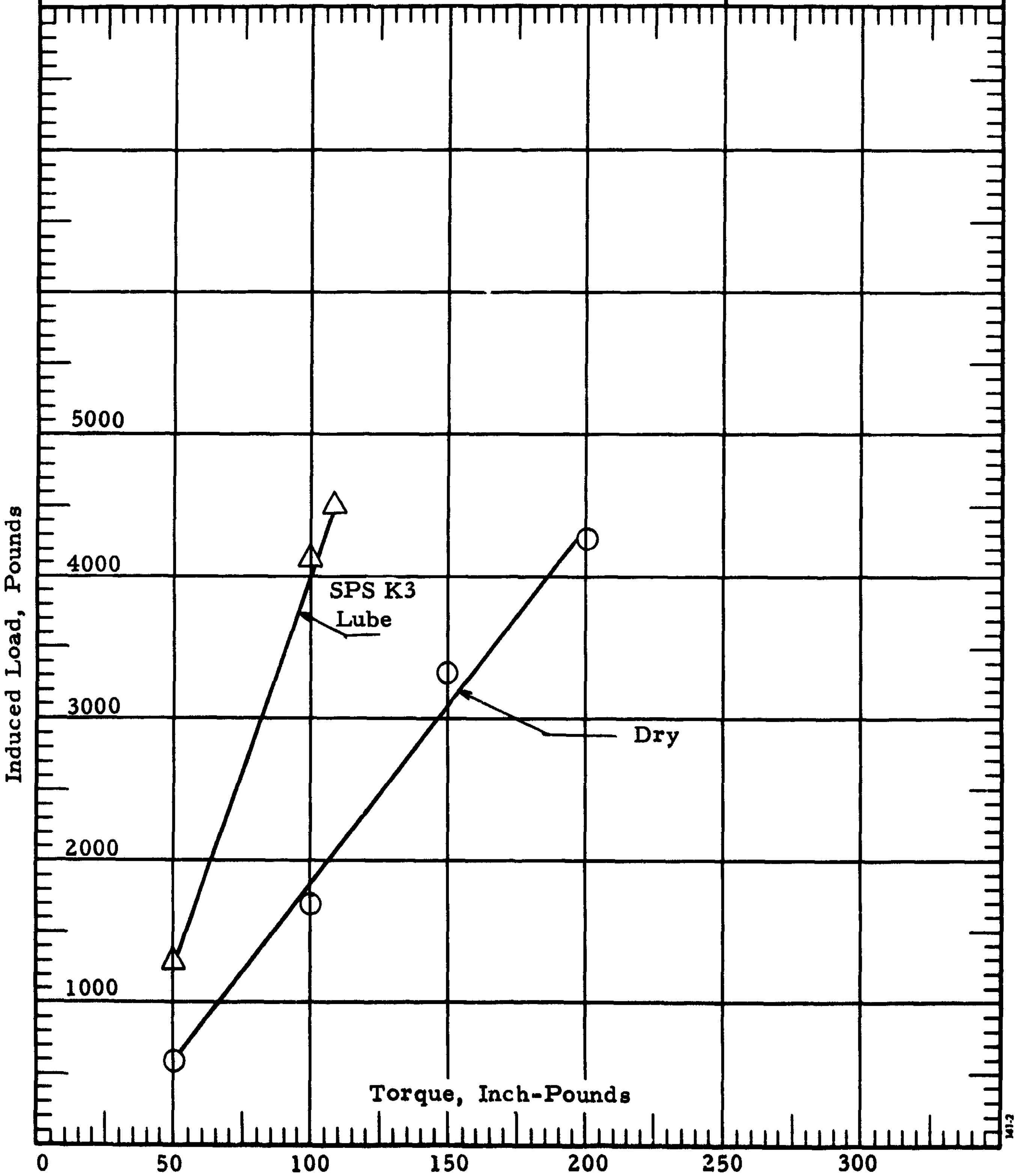


TORQUE VERSUS INDUCED LOAD

Tension Bolt - T815
Material Ti 5Al-2.5Sn (ELI)
Nut FN 1216 - Material A-286
Silver Plated per AMS 2410
Test Temperature - Room
Bolt Diameter 1/4-28
Average of 3 Tests

SPS LABORATORIES

Chart No.: III. 3. 5
Date:



TORQUE VERSUS INDUCED LOAD

Tension Bolt EWBT 815 - Material Ti5Al-2.5Sn(ELI)
Nut - FN 1216 - Material A-286
Silver Plated per AMS 2410
Test Temperature - Room
Bolt Diameter 3/8-24
Average 3 Tests

SPS LABORATORIES

Chart No.: III. 3. 6
Date:

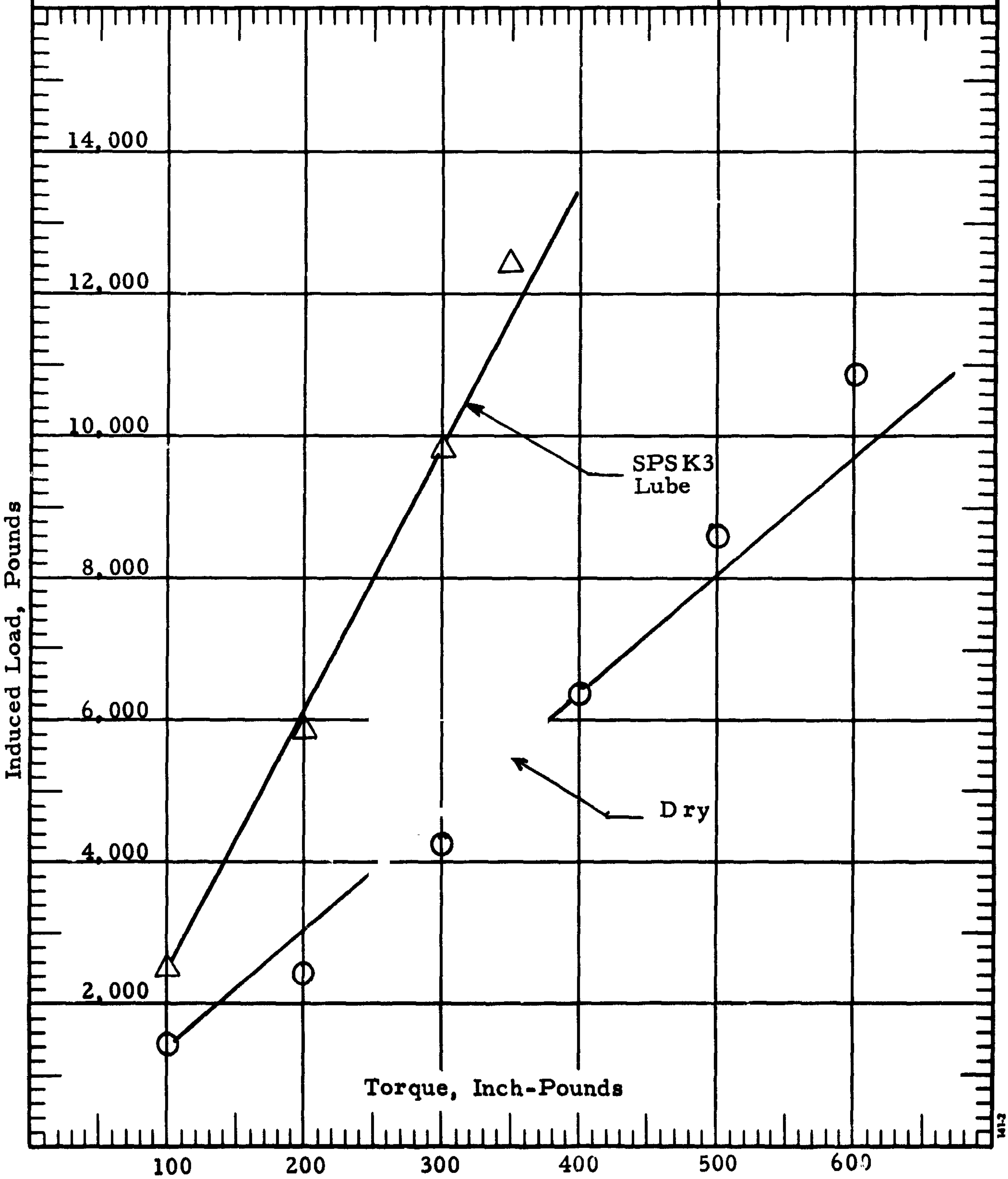


TABLE III. 3. 1

MECHANICAL PROPERTIES

Part No. Bolt - VS1134-3-48 — Material - Ti 6Al-4V (160 KSI)
Nut - FN 1216-1032 — Material - A-286 (160 KSI)
Size - #10-32

1. Tensile

A. Axial Bolt Properties

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
1	-423	5,020	251,100
2	-423	5,350	267,600
3	-423	4,830	241,600
4	-320	4,200	210,100
5	-320	4,780	239,100
6	-320	4,360	218,100
7	70	3,570	178,500
8	70	3,650	182,500
9	70	3,650	182,500

B. Angle Block Bolt Properties (3°∠ @ Nut Bearing Face)*

Test No.	Test Temperature, °F	Ultimate Load, °F	Ultimate Stress, psi(1)
10	-423	2,730	136,600
11	-423	3,700	185,100
12	-423	3,690	184,600
13	-320	2,700	135,100
14	-320	2,880	144,100
15	-320	3,800	190,100
16	70	2,940	147,100
17	70	3,260	163,100
18	70	3,400	170,100

(1) Stress calculated at Tensile Stress Area of 0.01999 square inches.
* Bolt grip length 3.0 inches.

TABLE III. 3. 1 (continued)

Part No. VS1134-3-48 Material - Ti 6Al-4V (160 KSI)
FN 1216-1032 Material - A-286 (160 KSI)
Size - #10-32

2. Tension Impact

Test No.	Test Temperature, °F	Energy Expended ft. -lbs.
1	-423	8.5
2	-423	10.0
3	-423	13.0
4	-320	7.0
5	-320	6.5
6	-320	7.0
7	70	10.0
8	70	10.0
9	70	10.5

3. Tension-Tension Fatigue @70°F

Test No.	Min. Load, lbs.	Min. Stress, psi	Max. Load, lbs.	Max. Stress, psi(2)	Cycles to Failure	Location of Failure
1	146	8,300	1,460	83,000	418,000	Thread
2	146	8,300	1,460	83,000	226,000	Thread
3	146	8,300	1,460	83,000	255,000	Thread

(2) Stress calculated at Basic Minor Diameter Area of 0.01753 square inches.

TABLE III. 3. 2

MECHANICAL PROPERTIES

Part No. Bolt - NAS 1271-38 Material - Ti 6Al-4V (160 KSI)
Nut - FN 1216-428 Material - A-286 (160 KSI)
Size - 1/4-28

1. Tensile

A. Axial Bolt Properties

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
1	-423	8,920	245,300
2	-423	9,700	266,700
3	-423	8,650	237,800
4	-320	9,000	247,500
5	-320	9,100	250,200
6	-320	8,600	236,500
7	70	6,750	135,500
8	70	6,475	178,000
9	70	6,500	178,700

B. Angle Block Bolt Properties (3°∠ @ Nut Bearing Face)*

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
10	-423	5,110	140,500
11	-423	4,140	113,800
12	-423	4,240	116,600
13	-320	4,100	112,700
14	-320	5,500	151,200
15	-320	3,000	82,500
16	70	6,420	176,500
17	70	6,600	181,500
18	70	6,480	178,200

(1) Stress calculated at Tensile Stress Area of 0.03637 square inches.
*** Bolt grip length 2.375 inches.**

TABLE III. 3. 2 (continued)

Part No. NAS 1271-38
FN 1216-428
Size - 1/4-28

Material - Ti 6Al-4V (160 ksi)
A-286 (160 ksi)

2. Tension Impact

Test No.	Test Temperature, °F	Energy Expended, ft. - lbs.
1	-423	24.5
2	-423	25.0
3	-423	20.0
4	-320	24.0
5	-320	27.0
6	-320	26.0
7	70	27.5
8	70	27.0
9	70	25.0

3. Tension-Tension Fatigue @70°F

Test No.	Min. Load, lbs.	Min. Stress, psi	Max. Load, lbs.	Max. Stress, psi (2)	Cycles to Failure	Location of Failure
1	271	8,300	2,710	83,000	50,000	Thread
2	271	8,300	2,710	83,000	39,000	Thread
3	271	8,300	2,710	83,000	41,000	Thread

4. Vibration - ALMA #10

Test No.	Test Temperature, °F	Maximum Installation, 1st	5th	Seating Torque, in. -lbs.	No. of Cycles	Degrees Movement	10X Mag. Visual Insp.	Remarks
1	-320	25	25	60	30,000	0°	No Cracks	Passed
2	-320	20	30	60	30,000	0°	No Cracks	Passed
3	-320	15	25	60	30,000	0°	No Cracks	Passed
4	-320	40	15	60	30,000	0°	No Cracks	Passed
5	-320	20	15	60	30,000	0°	No Cracks	Passed
6	70	15	10	60	30,000	0°	No Cracks	Passed
7	70	18	12	60	30,000	0°	No Cracks	Passed
8	70	12	8	60	30,000	60°	No Cracks	Passed
9	70	15	10	60	30,000	0°	No Cracks	Passed
10	70	13	10	60	30,000	0°	No Cracks	Passed

(2) Stress calculated at Basic Minor Diameter Area of 0.03256 square inches.

TABLE III. 3. 3

MECHANICAL PROPERTIES

Part No. Bolt - NAS 1275-48 — Material - Ti 6Al-4V (160 KSI)
Nut - FN 1216-820 — Material - A-286 (160 KSI)
Size - 1/2-20

1. Tensile

A. Axial Bolt Properties

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
1	-423	32,500	203,000
2	-423	37,800	236,000
3	-423	32,400	202,600
4	-320	32,400	202,600
5	-320	30,000	187,600
6	-320	33,900	212,600
7	70	29,500	184,400
8	70	29,700	185,700
9	70	29,600	185,100

B. Angle Block Bolt Properties (3°∠ @ Nut Bearing Face)*

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
10	-423	27,000	157,200
11	-423	26,600	155,000
12	-423	28,010	163,500
13	-320	19,000	118,800
14	-320	21,060	131,700
15	-320	20,300	127,000
16	70	25,800	161,400
17	70	22,000	137,600
18	70	21,000	131,300

(1) Stress calculated at the Tensile Stress Area of 0.1599 square inches.
* Bolt grip length 3.0 inches.

TABLE III. 3. 3 (continued)

Part No. NAS 1275-48 — Material - Ti 6Al-4V (160 KSI)
FN 1216-820 — Material - A-286 (160 KSI)
Size - 1/2-20

2. Double Shear

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
1	-423	47,800	121,800
2	-423	48,000	122,200
3	-423	51,200	130,400

3. Tension-Tension Fatigue @70°F

Test No.	Min. Load, lbs.	Min. Stress, psi	Max. Load, lbs.	Max. Stress, psi (3)	Cycles to Failure	Location of Failure
1	1,230	8,300	12,300	83,000	38,000	Thread
2	1,230	8,300	12,300	83,000	24,000	Thread
3	1,230	8,300	12,300	83,000	27,000	Thread

4. Vibration - ALMA #10 -

Test No.	Test Temperature °F	Maximum Installation 1st	5th	Seating Torque in.-lbs.	No. of Cycles	Degrees Mov't	10X Mag. Visual Insp.	Remarks
1	-320	70	60	300	30,000	0°	No cracks	Passed
2	-320	100	200	300	30,000	0°	No cracks	Passed
3	-320	60	100	300	30,000	0°	No cracks	Passed
4	-320	50	80	300	30,000	0°	No cracks	Passed
5	70	120	150	300	30,000	0°	No cracks	Passed
6	70	135	145	300	30,000	0°	No cracks	Passed
7	70	125	150	300	30,000	0°	No cracks	Passed
8	70	130	140	300	30,000	0°	No cracks	Passed
9	70	125	125	300	30,000	0°	No cracks	Passed

(2) Stress calculated at Twice Nominal Diameter area, 0.3927 square inches.
(3) Stress calculated at Basic Minor Diameter Area of 0.1486 square inches.

TABLE III.3.4

MECHANICAL PROPERTIES

Part No. EWB T815-4-28 Material Ti-5Al-2.5 Sn(ELI)
Size - 1/4-28 x 2.250

1. Tensile

A. Base Material Properties (As Received) .113 inches specimen

Test No.	Test Temperature, °F	Ultimate, Stress, psi	0.2% Offset Yield Stress, psi	Elongation, Gage, .5 in. %	Reduction of Area, %
1	-423	222,900	192.700	12.0	18.5
2	-423	226,500	188,800	12.0	17.0
3	-423	227,100	203,100	12.0	17.1
4	70	119,300	90,300	18.0	26.5
5	70	113,200	90,300	16.0	36.9
6	70	111,200	89,200	18.0	42.4
7	750	71,000	48,000	14.0	46.2
8	750	72,400	48,900	14.0	44.0
9	750	71,000	48,000	16.0	49.8

B. V-Notch Properties (K_t 8)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi	Notch to Smooth Tensile Ratio
10	-423	6,000	256,400	1.14
11	-423	5,900	252,100	1.12
12	-423	6,400	273,400	1.21
13	70	4,190	178,300	1.56
14	70	4,200	179,500	1.57
15	70	4,200	178,700	1.56
16	750	2,525	107,900	1.50
17	750	2,525	107,900	1.50
18	750	2,565	109,600	1.53

TABLE III. 3. 4 (continued)

Part No. EWB T815-4-28 Material Ti-5Al-2.5 Sn(ELI)
Size - 1/4-28 x 1.562

1. Tensile (continued)

C. Axial Bolt Properties

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)	Johnson's 2/3 Approximation Yield Load, lbs.	Johnson's 2/3 Approximation Yield Stress, psi(1)
19	-423	8,320	228,800	8,000	220,000
20	-423	8,280	227,700	8,100	222,700
21	-423	8,220	226,000	8,000	220,000
22	-320	7,400	203,500	7,400	195,200
23	-320	7,300	200,700	6,990	192,200
24	-320	7,350	202,100	7,000	192,500
25	70	4,660	128,100	3,890	107,000
26	70	4,850	133,400	3,600	99,000
27	70	4,670	128,400	3,600	99,000
28	750	3,150	86,600	2,350	64,600
29	750	3,125	85,900	2,300	63,200
30	750	3,125	85,900	2,350	64,600

D. Angle Block Bolt Properties (3°∠ @ Nut Bearing Face)*

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
31	-423	3,700	101,700
32	-423	6,160	169,400
33	-423	2,840	78,100
34	-320	7,260	199,600
35	-320	7,020	193,000
36	-320	7,360	202,400
37	70	4,740	130,300
38	70	4,700	129,200
39	70	4,780	131,400

(1) Stress calculated at Tensile Stress Area of 0.03637 square inches.
*** Bolt grip length 1.75 inches.**

TABLE III. 3.4 (continued)

Part No. EWB T815-4-28
Size - 1/4-28 x 1.562

Material Ti-5Al-2.5 Sn(ELI)

1. Tensile (continued)

E. As Relaxed Bolt Properties (50 Hours)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)	Yield Load, lbs.	Yield Stress, psi(1)
40	70	4,700	129,200	4,050	111,400
41	70	4,690	129,000	4,100	112,700
42	70	4,680	128,700	4,100	112,700

2. Tension Impact

Test No.	Test Temperature, °F	Energy Expended, ft.-lbs.
1	-423	17.0
2	-423	23.5
3	-423	20.5
4	-320	24.0
5	-320	22.0
6	-320	21.5
7	70	20.5
8	70	24.5
9	70	25.0

(1) Stress calculated at Tensile Stress Area of 0.03637 square inches.

TABLE III. 3. 4 (continued)

Part No. EWB T815-4-28 Material Ti-5Al-2.5 Sn(ELI)
Size - 1/4-28 x 2.250

3. Double Shear

A. As Received

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
1	-423	10,700	109,000
2	-423	10,950	111,500
3	-423	11,700	119,200
4	70	7,280	74,200
5	70	8,100	82,500
6	70	7,520	76,600
7	750	5,025	51,200
8	750	5,100	52,000
9	750	5,300	54,000

B. As Relaxed (50 Hours)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
10	70	6,680	68,000
11	70	7,190	73,200
12	70	7,460	76,000

4. Tension-Tension Fatigue @70° F

Test No.	Min. Load, lbs.	Min. Stress, psi	Max. Load, lbs.	Max. Stress, psi(3)	Cycles to Failure	Location of Failure
1	183	5,600	1,830	56,000	2,208,000	Thread
2	183	5,600	1,830	56,000	777,000	Thread
3	183	5,600	1,830	56,000	1,270,000	Thread

(2) Stress calculated at twice the Nominal Diameter Area of 0.09817 square inches.

(3) Stress calculated at Basic Minor Diameter Area of 0.03256 square inches.

TABLE III. 3. 4 (continued)

Part No. EWB T815-4-28 Material Ti-5Al-2.5 Sn(ELI)
Size - 1/4-28 x 2.250

5. Stress Relaxation @ 750° F

Initial Stress - 52,200 psi

Test No.	Hours Run	Residual Stress Pounds	Residual Stress psi(1)
1	1	1,800	49,400
	10	1,800	49,400
	50	1,800	49,400
2	1	1,800	49,400
	10	1,800	49,400
	50	1,800	49,400
3	1	1,050	28,800
	10	1,050	28,800
	50	1,050	28,800

6. Stress Rupture

Test No.	Test Temperature °F	Load, lbs.	Load Stress, psi(1)	Hours to Failure	Location of Failure
1	750	3,150	86,600	77.1	Thread
2	750	3,150	86,600	Failed Loading	
3	750	2,909	80,000	107.0	No Failure
4	750	2,909	80,000	196.4	No Failure
5	750	2,909	80,000	103.3	No Failure

7. Coefficient of Thermal Expansion(3)

Temperature	Inches/Inch/°Fx10^6
200	5.2
800	5.3
1200	5.5

(1) Stress calculated at Tensile Stress Area of 0.03637 square inches.

(3) Alloy Digest - Filing Code Ti 21

TABLE III. 3. 5

MECHANICAL PROPERTIES

Part No. Bolt - EWB T815-4-28
Part No. Nut - FN 1216-428
Size - 1/4-28 x 2.250

Material - Ti 5Al-2.5Sn (ELI)
Material - A-286

1. Tensile

A. Base Material Properties (As Received) 0.113 inches specimen

Test No.	Test Temperature, °F	Ultimate Stress, psi	0.2% Offset Yield Stress, psi	Elongation, Gage, .5 in. %	Reduction of Area, %
1	-423	222,900	192,700	12.0	18.5
2	-423	226,500	188,800	12.0	17.0
3	-423	227,100	203,100	12.0	17.1
4	-320	191,600	166,600	16.0	32.9
5	-320	187,700	163,200	18.0	32.3
6	-320	187,500	166,600	16.0	31.4
7	70	119,300	90,300	18.0	26.5
8	70	113,200	90,300	16.0	36.9
9	70	111,200	89,200	18.0	42.4
10	750	71,000	48,000	14.0	46.2
11	750	72,400	48,900	14.0	44.0
12	750	71,000	48,000	16.0	49.8

TABLE III. 3. 5 (continued)

Part No. EWB T815-4-28
FN 1216-428
Size - 1/4-28

Material - Ti 5Al-2.5 Sn (ELI)
A-286

1. Tensile (continued)

B. Axial Bolt Properties (As Received)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (1)	Johnson's 2/3 Approximation Yield Load, lbs.	Johnson's 2/3 Approximation Yield Stress, psi
13	-423	8,320	228,800	8,000	220,000
14	-423	8,280	227,700	8,100	222,700
15	-423	8,220	226,000	8,000	220,000
16	-320	7,150	196,500	6,500	173,900
17	-320	7,300	200,700	6,990	192,200
18	-320	7,350	202,100	7,000	192,500
19	70	4,640	127,500	3,575	98,200
20	70	4,660	128,100	3,890	107,000
21	70	4,670	128,400	3,600	99,000
22	750	3,100	85,200	2,150	59,100
23	750	3,150	86,600	2,350	64,600
24	750	3,125	85,900	2,300	63,200

C. Angle-Block Bolt Properties (3°∠ @Nut Bearing Face)*

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (1)
25	-423	5,100	140,200
26	-423	4,950	136,100
27	-423	5,800	159,500
28	-320	7,200	198,000
29	-320	7,100	195,200
30	-320	7,300	200,700
31	70	4,660	128,100
32	70	4,540	124,800
33	70	4,650	127,900

D. As-Relaxed Bolt Properties (50 Hours)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (1)	Yield Load, lbs.	Yield Stress, psi
34	70	4,650	127,900	4,000	110,000
35	70	4,650	127,900	4,075	112,000
36	70	4,670	128,400	4,150	114,100

(1) Stress Calculated at Tensile Stress Area of 0.03637 square inches.
* Bolt grip length 1.75 inches.

TABLE III. 3. 5 (continued)

Part No. EWB T815-4-28 FN 1216-428
Size - 1/4-28

Material - Ti 5Al-2. 5 Sn (ELI) A-286

2. Stress Durability @70°F

Test No.	Seated Stress lbs.	Seated Stress psi(1)	Torque To Induce Stress, in. -lbs	Length of Test, Hours	Remarks
1	3,330	91,400	170	24	Passed
2	3,330	91,400	170	24	Passed
3	3,330	91,400	170	24	Passed

3. Tension-Impact

Test No.	Test Temperature °F	Energy Expended ft. -lbs.
1	-423	17.0
2	-423	23.5
3	-423	20.5
4	-320	24.0
5	-320	22.0
6	-320	21.5
7	70	20.5
8	70	24.5
9	70	25.0

(1) Stress Calculated at the Tensile Stress Area of 0.03637 square inches.

TABLE III. 3. 5 (continued)

Part No. EWB T815-4-28
FN 1216-428
Size - 1/4-28

Material - Ti 5Al-2. 5 Sn (ELI)
A-286

4. Double Shear

A. As Received

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
1	-423	10, 700	109, 000
2	-423	10, 950	111, 500
3	-423	11, 700	119, 200
4	70	7, 280	74, 200
5	70	8, 100	82, 500
6	70	7, 520	76, 600
7	750	5, 025	51, 200
8	750	5, 100	52, 000
9	750	5, 300	54, 000

B. As-Relaxed (50 Hours)

10	70	7, 800	79, 500
11	70	7, 950	81, 000
12	70	7, 900	80, 500

(2) Stress Calculated at Twice the Nominal Diameter Area, 0. 09817 square inches.

TABLE III. 3. 5 (continued)

Part No. EWB T 815-4-28
FN 1216-428
Size - 1/4-28

Material - Ti 5Al-2.5 Sn(ELI)
A-286

5. Stress Rupture

Test No.	Test Temperature-°F	Load, lbs.	Stress, psi(1)	Hours to Failure	Location of Failure
1	750	3,273	90,000	Failed Loading	
2	750	3,273	90,000	Failed Loading	
3	750	3,090	85,000	147.5	No Failure
4	750	3,090	85,000	97.5	No Failure
5	750	3,090	85,000	149.4	No Failure

Testing was discontinued. Fastener assembly was not considered rupture sensitive at 750°F. The stress required for 100 hour life was 99% of the 750°F tensile strength.

6. Stress Relaxation @ 750°F

Initial Stress - 80,000 psi

Test No.	Hours Run	Residual Stress lbs.	Residual Stress psi(1)
1	10	1,856	51,000
2	10	1,856	51,000
3	10	1,740	47,800
4	50	1,590	43,700
5	50	1,480	40,700
6	50	1,650	45,400

(1) Stress Calculated at the Tensile Stress Area of 0.03637 square inches.

TABLE III. 3. 5 (continued)

Part No. EWB T815-4-28 Material - Ti 5Al-2.5Sn (ELI)
FN 1216-428-SPS K3 Lube Material - A-286
Size - 1/4-28

7. Nut Reuse and Galling Tendency @70°F

Seated Stress - 59,400 psi(1)

Test No.	Maximum Installation, inch-pounds	Torque to Induce Stress, inch-pounds	Torque, inch - pounds Breakaway	Removal
1st Application				
1	21	88	58	11
2	25	98	68	12
3	18	96	68	13
4	18	91	62	9
5	19	90	68	9
2nd Application				
1	15	94	64	11
2	17	105	70	13
3	13	100	71	13
4	11	93	62	6
5	14	96	70	8
3rd Application				
1	15	93	62	14
2	18	98	65	16
3	17	105	76	16
4	19	110	73	17
5	17	100	80	15
4th Application				
1	19	97	75	14
2	23	100	78	17
3	28	120	88	22
4	15	100	75	13
5	13	102	72	14
5th Application				
1	19	102	72	12
2	23	100	73	19
3	25	118	88	24
4	17	102	73	13
5	17	103	70	14

(1) Stress Calculated at Tensile Stress Area of 0.03637 square inches.

TABLE III. 3. 5 (continued)

Part No. EWB T815-4-28 Material - Ti 5Al-2. 5Sn (ELI)
FN 1216-428 Material - A-286
Size - 1/4-28

8. Torque vs. Induced Load @ 70°F

Torque in.-lbs	Test No. 1 Load, lbs.	Test No. 2 Load, lbs.	Test No. 3 Load, lbs.
DRY			
50	550	500	500
75	1,300	1,000	1,150
100	1,850	1,650	1,550
125	2,550	2,200	2,350
150	3,500	3,900	2,850
175	4,000	3,700	3,750
200	4,200 (B. F.)	4,150 (B. F.)	4,350 (B. F.)
SPS K3 Lube			
50	1,200	1,400	1,250
75	3,000	2,700	2,100
100	4,150	4,200	4,000
105	---	4,500 (B. F.)	---
110	4,550 (B. F.)		4,500 (B. F.)

B. F. - Bolt Fractured

TABLE III. 3. 6

MECHANICAL PROPERTIES

Part No. Bolt - EWB T815-6-28
Part No. Nut - FN 1216-624
Size - 3/8-24

Material - Ti 5Al-2. 5Sn (ELI)
Material - A-286

1. Tensile

A. Base Material Properties (As Received) 0. 252 inches specimen

Test No.	Test Temperature, °F	Ultimate Stress psi	0. 2% Offset Yield Stress, psi	Elongation Gage, . 5 in. %	Reduction of Area, %
1	-423	221, 100	215, 100	10. 0	31, 6
2	-423	224, 600	215, 500	8. 0	28. 9
3	-423	222, 600	214, 500	8. 0	27. 5
4	-320	198, 700	188, 200	14. 0	35. 0
5	-320	197, 700	185, 700	15, 0	33. 4
6	-320	195, 200	181, 700	13. 0	30. 3
7	70	125, 400	116, 500	16. 0	40. 5
8	70	125, 800	117, 500	17. 0	40. 8
9	70	124, 000	115, 400	17. 0	40. 6
10	750	83, 600	62, 200	21. 0	50. 1
11	750	83, 600	62, 200	19. 0	53. 1
12	750	85, 000	63, 700	20. 0	53. 5

TABLE III.3.6 (continued)

Part No. EWB T815-6-28 Material Ti 5Al-2.5Sn (ELI)
FN 1216-624 Material A-286
Size - 3/8-24

1. Tensile (continued)

B. Axial Bolt Properties (As Received)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)	Johnson's 2/3 Approximation Yield Load, lbs.	Johnson's 2/3 Approximation Yield Stress, psi
13	-423	19,300	219,800	16,750	190,800
14	-423	19,800	225,500	18,250	207,800
15	-423	19,900	226,600	17,000	193,600
16	-320	18,500	210,600	14,750	167,900
17	-320	18,700	212,900	13,800	157,100
18	-320	18,300	208,400	14,100	160,500
19	70	12,500	142,300	10,000	113,800
20	70	12,900	146,900	10,100	115,000
21	70	12,600	143,400	10,000	113,800
22	750	7,920	90,100	5,950	67,700
23	750	7,800	88,800	5,900	67,100
24	750	7,960	90,600	6,200	70,600

C. Angle-Block Bolt Properties (3° ∠ @ Nut Bearing Face)*

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
25	-423	18,300	208,400
26	-423	16,000	182,200
27	-423	17,500	199,300
28	-320	15,500	176,500
29	-320	14,750	168,000
30	-320	16,750	190,800
31	70	12,750	145,200
32	70	12,450	141,800
33	70	12,450	141,800

D. As-Relaxed Bolt Properties (50 hours)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)	Yield Load, lbs.	Yield Stress, psi
34	70	12,700	144,600	11,100	126,400
35	70	12,750	145,000	11,500	131,000
36	70	12,650	144,100	11,500	131,000

(1) Stress Calculated at Tensile Stress Area of 0.08781 square inches.
* Bolt grip length 1.75 inches.

TABLE III. 3.6 (continued)

Part No. EWB T815-6-28
FN 1216-624
Size - 3/8-24

Material - Ti 5Al-2.5Sn (ELI)
Material - A-286

2. Stress Durability @ 70°F

Test No.	Seated lbs.	Stress psi (1)	Torque to Induce Stress, in. - lbs.	Length of Test, Hours	Remarks
1	9,000	102,500	400	42	Passed
2	9,000	102,500	400	42	Passed
3	9,000	102,500	425	42	Passed

3. Double Shear

A. As-Received

Test No.	Test Temperature, °F	Ultimate, Load lbs.	Ultimate, Stress psi(2)
1	-423	29,850	135,200
2	-423	29,500	133,600
3	-423	24,880	112,700
4	70	17,700	80,200
5	70	18,700	84,700
6	70	18,400	83,300
7	750	13,500	61,100
8	750	12,600	57,100
9	750	14,300	64,800
As-Relaxed (50 Hours)			
10	70	20,250	91,700
11	70	19,000	86,100
12	70	17,850	80,800

(1) Stress Calculated at the Tensile Stress Area of 0.08781 square inches.

(2) Stress Calculated at Twice the Nominal Diameter Area, 0.2208 square inches.

TABLE III. 3. 6 (continued)

Part No. EWB T815-6-28
FN 1216-624
Size - 3/8-24

Material - Ti 5Al-2. 5Sn (ELI)
Material - A-286

4. Stress Rupture

Test No.	Test Temperature, °F	Load, lbs.	Stress, psi(1)	Hours to Failure	Location of Failure
1	750	8,342	95,000	Failed Loading	
2	750	7,903	90,000	121.0	No Failure
3	750	7,903	90,000	165.0	No Failure

Testing was discontinued. Fastener assembly was not considered rupture sensitive at 750°F
The stress required for 100 hour life was 99% of the 750°F tensile strength.

5. Stress Relaxation @ 750°F

Initial Stress - 80,000 psi (1)

Test No.	Hours Run	Residual Stress lbs.	Residual Stress psi(1)
1	10	4,106	46,800
2	10	4,320	49,200
3	10	3,786	43,100
4	50	3,260	37,100
5	50	3,570	41,000
6	50	3,890	44,300

(1) Stress Calculated at the Tensile Stress Area of 0.08781 square inches.

TABLE III. 3. 6 (continued)

Part No. - EWB T815-6-28 Material - Ti 5Al-2. 5Sn (ELI)
FN 1216-624-SPS K3 Lube Material - A-286
Size - 3/8-24

6. Nut Reuse and Galling Tendency @70°F

Seated Stress - 59, 400 psi(1)

Test No.	Maximum Installation, inch-pounds	Torque to Induce Stress, inch-pounds	Torque, inch - pounds Breakaway	Removal
1st Application				
1	28	165	135	18
2	37	175	135	27
3	50	160	125	37
4	27	175	140	17
5	45	160	130	33
2nd Application				
1	20	160	130	20
2	28	170	140	27
3	40	160	130	34
4	28	175	135	20
5	35	160	120	27
3rd Application				
1	18	160	125	17
2	25	170	130	25
3	25	160	125	27
4	20	170	130	13
5	33	160	120	25
4th Application				
1	22	160	125	17
2	32	175	125	35
3	30	160	125	27
4	22	170	130	15
5	33	165	130	28
5th Application				
1	17	170	125	17
2	45	170	125	40
3	35	160	125	30
4	22	170	130	18
5	37	165	125	37

(1) Stress Calculated at Tensile Stress Area (.003 reduced pitch diameter) of 0.08781 square inches.

TABLE III. 3. 6 (continued)

Part No. EWB T815-6-28 — Material - Ti 5Al-2. 5Sn (ELI)
FN 1216-624 — Material - A-286
Size - 3/8-24

7. Torque vs. Induced Load @ 70°F

Torque in. -lbs	Test No. 1 Load, Lbs.	Test No. 2 Load, lbs.	Test No. 3 Load, lbs.
DRY			
100	1,450	----	----
200	3,069	1,618	2,400
300	4,910	3,738	4,051
400	6,975	5,970	6,193
500	8,928	8,481	8,425
575		10,825	
600	10,936		10,657
SPS K3 Lube			
100	2,522	2,232	2,723
200	6,205	5,558	6,082
300	10,044	9,207	10,211
350	12,387	12,108	12,108

TABLE III. 3. 7

MECHANICAL PROPERTIES

Part No. Bolt - EWBT815-3-34 Material - Ti 7Al-12Zr (150 KSI)
Nut - FN1216-1032 Material - A-286 (160 KSI)
Size - #10-32

1. Tensile

A. Axial Bolt Properties

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
1	-423	4,480	224,100
2	-423	4,560	228,100
3	-423	4,600	230,100
4	-320	4,420	221,300
5	-320	4,230	211,700
6	-320	4,400	220,000
7	70	3,250	162,500
8	70	3,300	165,000
9	70	3,300	165,000

B. Angle Block Bolt Properties (3°∠ @ Nut Bearing Face)*

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
10	-423	2,800	140,100
11	-423	2,400	120,100
12	-320	2,660	133,000
13	-320	2,500	125,000
14	70	2,810	140,500
15	70	2,810	140,500

(1) Stress calculated at Tensile Stress Area of 0.01999 square inches.
* Bolt grip length 2.125 inches.

TABLE III. 3.7 (continued)

Part No. EWBT815-3-34 — Material - Ti 7Al-12Zr (150 KSI)
FN 1216-1032 — Material - A-286 (160 KSI).
Size - #10-32

2. Tension Impact

Test No.	Test Temperature, °F	Energy Expended ft. -lbs.
1	-423	4.0
2	-423	5.0
3	-320	7.0
4	-320	7.0
5	70	13.0
6	70	13.0

3. Tension-Tension Fatigue @70°F

Test No.	Min. Load, lbs.	Min. Stress, psi	Max. Load, lbs.	Max. Stress, psi(2)	Cycles to Failure	Location of Failure
1	137	7,800	1,367	78,000	23,000	Thread
2	137	7,800	1,367	78,000	37,900	Thread

4. Vibration - ALMA #10 - *

Test No.	Test Temperature °F	Maximum Installation 1st	Maximum Installation 5th	Seating Torque in. -lbs.	No. of Cycles	Degrees Mov't	10X Mag. Visual Insp.	Remarks
1	-320	16	16	60	30,000	0°	No cracks	Passed
2	-320	20	20	60	30,000	0°	No cracks	Passed
3	-320	20	18	60	30,000	0°	No cracks	Passed
4	-320	14	6	60	30,000	0°	No cracks	Passed
5	-320	18	12	60	30,000	0°	No cracks	Passed
6	70	35	20	60	30,000	0°	No cracks	Passed
7	70	30	15	60	30,000	0°	No cracks	Passed
8	70	25	15	60	30,000	0°	No cracks	Passed
9	70	28	20	60	30,000	0°	No cracks	Passed
10	70	25	13	60	30,000	0°	No cracks	Passed

* Test run with 1/4-28 EWB T 815-4 and FN 1216-428

(2) Stress calculated at Basic Minor Diameter Area of 0.01753 square inches.

TABLE III. 3. 8

MECHANICAL PROPERTIES

Part No. Bolt - EWBT815-8-46 — Material - Ti 7Al-12Zr (150 KSI)
Nut - FN 1216-820 — Material - A-286 (160 KSI)
Size - 1/2-20

1. Tensile

A. Axial Bolt Properties

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
1	-423	34,500	216,000
2	-423	28,800	180,000
3	-423	30,500	191,000
4	-320	25,600	160,100
5	-320	25,500	159,500
6	-320	29,000	181,400
7	70	25,000	156,300
8	70	25,200	157,500
9	70	25,200	157,500

B. Angle Block Bolt Properties (3°∠ @ Nut Bearing Face)*

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
10	-423	26,500	165,700
11	-423	29,100	182,900
12	-423	27,500	172,000
13	-320	23,500	147,000
14	-320	21,500	134,500
15	-320	20,000	125,100
16	70	18,800	117,600
17	70	18,600	116,300
18	70	17,500	109,400

(1) Stress calculated at Tensile Stress Area of .1599 square inches.
* Bolt grip length 2.875 inches.

TABLE III. 3. 8 (continued)

Part No. EWBT815-8-46 — Material - Ti 7Al-12Zr (150 KSI)
FN 1216-820 — Material - A-286 (160 KSI)
Size - 1/2-20

2. Tension-Tension Fatigue @70°F

Test No.	Min. Load, lbs.	Min. Stress, psi	Max. Load, lbs.	Max. Stress, psi(2)	Cycles to Failure	Location of Failure
1	1,159	7,800	11,591	78,000	22,000	Thread
2	1,159	7,800	11,591	78,000	25,200	Thread
3	1,159	7,800	11,591	78,000	94,000	Thread

3. Vibration - ALMA #10-

Test No.	Test Temperature °F	Maximum Installation 1st	5th	Seating Torque in.-lbs.	No. of Cycles	Degrees Mov't	10X Mag. Visual Insp.	Remarks
1	-320	110	185	300	30,000	0°	No cracks	Passed
2	-320	125	205	300	30,000	0°	No cracks	Passed
3	-320	140	125	300	30,000	0°	No cracks	Passed
4	-320	110	225	300	30,000	0°	No cracks	Passed
5	-320	75	120	300	30,000	0°	No cracks	Passed
6	70	120	150	300	30,000	0°	No cracks	Passed
7	70	185	150	300	30,000	0°	No cracks	Passed
8	70	100	130	300	30,000	0°	No cracks	Passed
9	70	135	145	300	30,000	0°	No cracks	Passed
10	70	135	150	300	30,000	9°	No cracks	Passed

(2) Stress calculated at Basic Minor Diameter of 0.1486 square inches.

TABLE III. 3. 9

MECHANICAL PROPERTIES

Part No. Bolt - EWB 22-3-28 Material - Ti-8Al-1Mo-1V
Part No. Nut - FN 1216-1032 A-286
Size - #10-32

1. Tensile

A. Base Material Properties (As Received) 0.113 inches specimen

Test No.	Test Temperature, °F	Ultimate Stress, psi	0.2% Offset Yield Stress, psi	Elongation, Gage, .5 in. %	Reduction of Area, %
1	-423	274,400	252,500	10.0	18.6
2	-423	271,400	250,000	10.0	31.0
3	-423	271,000	255,000	10.0	15.4
4	70	149,000	145,800	18.0	45.5
5	70	147,500	144,000	18.0	44.6
6	70	148,000	145,400	18.0	46.5
7	750	105,900	88,000	20.0	58.0
8	750	104,300	88,500	20.0	57.2
9	750	106,200	91,100	20.0	63.5

B. Axial Bolt Properties (As Received)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (1)	Johnson's 2/3 Approximation Yield Load, lbs.	Johnson's 2/3 Approximation Yield Stress, psi
10	-423	4,890	244,600	No Yield	
11	-423	4,250	212,600	No Yield	
12	-423	5,390	269,600	No Yield	
13	-320	4,300	215,100	No Yield	
14	-320	4,750	237,600	No Yield	
15	-320	4,750	237,600	No Yield	
16	70	3,280	164,100	2,750	137,600
17	70	3,300	165,100	2,925	146,300
18	70	3,320	166,100	2,800	140,100
19	750	2,335	116,800	1,900	95,000
20	750	1,935	96,800	1,550	77,500
21	750	2,340	117,100	2,050	102,600

(1) Stress calculated at Tensile Stress Area of 0.01999 square inches.

TABLE III. 3.9 (continued)

Part No. EWB 22-3-28
FN 1216-1032
Size - #10-32

Material - Ti-8Al-1Mo-1V
A-286

1. Tensile (continued)

C. Angle Block Bolt Properties (3°∠@ Nut Bearing Face)*

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (1)
22	-423	3,800	190,100
23	-423	4,390	219,600
24	-423	3,820	191,100
25	-320	3,600	180,100
26	-320	3,800	190,100
27	-320	3,350	167,600
28	70	2,970	148,600
29	70	2,930	146,600
30	70	3,180	159,100

D. As Relaxed Bolt Properties (50 Hours)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (1)	Yield Load, lbs.	Yield Stress, psi (1)
Preload A					
31	70	2,730	136,600	2,650	132,600
32	70	3,120	156,100	2,750	137,600
33	70	Bolt Failed during disassembly.			
Preload B					
34	70	3,100	155,100	2,850	142,600
35	70	2,960	148,100	2,700	135,100
36	70	3,050	152,600	2,800	140,100

(1) Stress calculated at Tensile Stress Area of 0.01999 square inches.
* Bolt grip length 1.75 inches.

TABLE III. 3. 9 (continued)

Part No. EWB 22-3-28
FN 1216-1032
Size - #10-32

Material - Ti-8Al-1Mo-1V
A-286

2. Tension Impact

Test No.	Test Temperature, °F	Energy Expended, ft. - lbs.
1	-423	5.0
2	-423	4.0
3	-423	3.5
4	-320	9.0
5	-320	8.5
6	-320	8.0
7	70	9.0
8	70	8.0
9	70	8.0

3. Double Shear

A. As Received

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (2)
1	-423	7,260	128,000
2	-423	7,800	137,500
3	-423	7,500	132,300
4	70	5,780	101,900
5	70	5,700	100,500
6	70	5,770	101,700
7	750	3,850	67,900
8	750	3,920	69,900
9	750	3,900	68,800

(2) Stress calculated at twice the Nominal Diameter Area, 0.05671 square inches.

TABLE III.3.9 (continued)

Part No. EWB 22-3-28
FN 1216-1032
Size - #10-32

Material - Ti-8Al-1Mo-1V
A-286

3. Double Shear (continued)

B. As Relaxed (50 Hours)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (2)
Preload A			
10	70	5,280	93,100
11	70	5,180	91,300
12	70	5,240	92,400
Preload B			
13	70	5,260	92,800
14	70	5,210	91,900
15	70	5,190	91,500

4. Tension-Tension Fatigue @70°F

Test No.	Min. Load, lbs.	Min. Stress, psi (3)	Max. Load, lbs.	Max. Stress, psi (3)	Cycles to Failure	Location of Failure
1	128	7,280	1,276	72,800	3,192,000	Thread
2	128	7,280	1,276	72,800	1,525,000	Thread
3	128	7,280	1,276	72,800	4,835,000	Thread

(2) Stress calculated at twice the Nominal Diameter Area, 0.05671 square inches.

(3) Stress calculated at Basic Minor Diameter Area of 0.01753 square inches.

TABLE III. 3. 9 (continued)

Part No. EWB 22-3-28 FN 1216-1032 — Material - Ti-8Al-1Mo-1V A-286

Size - #10-32

5. Stress Relaxation @750° F

Preload A - Initial Stress - 112,000 psi

Test No.	Hours Run	Residual Stress pounds	psi (1)
1	10	1,390	69,500
2	10	1,340	67,000
3	10	1,390	69,500
4	50	1,225	61,250
5	50	1,060	53,000
6	50	1,060	53,000

Preload B - Initial Stress - 70,000 psi

Test No.	Hours Run	Residual Stress pounds	psi (1)
7	10	965	48,250
8	10	930	46,500
9	10	1,005	50,250
10	50	796	39,800
11	50	796	39,800
12	50	832	41,600

6. Stress Rupture

Test No.	Test Temperature, °F	Load, lbs.	Stress, psi(1)	Hours to Failure	Location of Failure
1	750	2,199	110,000	0.7	Thread
2	750	2,199	110,000	2.1	Thread
3	750	2,199	110,000	1.3	Thread
4	750	2,099	105,000	4.4	Thread
5	750	2,099	105,000	4.1	Thread
6	750	2,099	105,000	4.7	Thread
7	750	2,000	100,000	142.0	No Failure
8	750	2,000	100,000	42.1	Thread
9	750	2,000	100,000	100.0	No Failure

(1) Stress calculated at Tensile Stress Area of 0.01999 square inches.

TABLE III. 3. 9 (continued)

Part No. EWB 22-3-28 — Material - Ti 8Al-1Mo-1V
FN 1216-1032 — A-286

Size - #10-32

7. Nut Reuse and Galling Tendency @ 70°F

Seated Stress - 75,600 psi (1)

Test No.	Maximum Installation, inch -pounds	Torque to Induce Stress, inch - pounds	Torque, inch - pounds Breakaway	Removal
1st Application				
1	13	70	60	9
2	23	90	75	18
3	15	80	65	11
4	13	70	60	8
5	15	85	70	8
2nd Application				
1	10	70	55	10
2	16	85	75	16
3	13	75	65	10
4	10	75	50	16
5	10	80	65	11
3rd Application				
1	10	65	55	10
2	17	85	75	17
3	13	85	65	13
4	12	60	60	15
5	9	80	70	12
4th Application				
1	10	70	55	9
2	17	90	70	17
3	11	80	70	13
4	13	65	55	14
5	9	75	70	10
5th Application				
1	10	75	55	8
2	15	85	75	18
3	11	80	65	12
4	12	65	60	14
5	7	85	70	12

(1) Stress calculated at Tensile Stress Area of 0.01999 square inches.

TABLE III.3.9 (continued)

Part No: EWB 22-3-28
FN 1216-1032

Material - Ti 8Al-1Mo-1V
A-286

Size - #10-32

8. Vibration - ALMA #10

Test No.	Test Temperature, °F	Maximum Installation, 1st	Maximum Installation, 5th	Seating Torque, in.-lbs.	No. of Cycles	Degrees Movement	10X Mag. Visual Insp.	Remarks
1	-320	18	16	30	30,000	0°	No cracks	Passed
2	-320	19	8	30	30,000	0°	No cracks	Passed
3	-320	16	9	30	30,000	0°	No cracks	Passed
4	70	12	14	30	30,000	0°	No cracks	Passed
5	70	11	15	30	30,000	0°	No cracks	Passed
6	70	11	18	30	30,000	0°	No cracks	Passed
7	70	11	17	30	30,000	0°	No cracks	Passed
8	70	10	18	30	30,000	0°	No cracks	Passed

9. Torque vs. Induced Load @ Room Temperature

Torque in.-lbs.	Test No. 1 Load, lbs.	Test No. 2 Load, lbs.	Test No. 3 Load, lbs.
25	450	500	400
50	1200	1350	1250
75	2050	2150	2250
100	2800	2900	2950
125	B.B.	B.B.	B.B.

B.B. - Bolt Broke

TABLE III. 3. 10

MECHANICAL PROPERTIES

Part No. Bolt - NAS 1271-28
Part No. Nut - FN 1216-428
Size - 1/4-28

Material - Ti 8Al-1Mo-1V
A-286

1. Tensile

A. Base Material Properties (As Received) 0.113 inch specimen

Test No.	Test Temperature, °F	Ultimate Stress, psi	0.2% Offset Yield Stress, psi	Elongation, Gage, .5 in. %	Reduction of Area, %
1	-423	277,000	250,000	14.0	29.9
2	-423	270,400	250,000	14.0	37.0
3	-423	273,900	250,000	14.0	29.9
4	70	147,900	143,300	20.0	45.0
5	70	145,500	139,000	20.0	47.5
6	70	148,900	143,200	16.0	34.2
7	750	101,500	87,000	18.0	63.8
8	750	102,000	87,500	18.0	62.8
9	750	104,000	86,700	10.0	58.7

B. Axial Bolt Properties (As Received)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (1)	Johnson's 2/3 Approximation Yield Load, lbs.	Johnson's 2/3 Approximation Yield Stress, psi (1)
10	-423	9,465	260,200	No Yield	
11	-423	9,060	249,100	No Yield	
12	-423	9,000	247,500	No Yield	
13	-320	8,800	242,000	No Yield	
14	-320	8,700	239,200	No Yield	
15	-320	8,800	242,000	No Yield	
16	70	6,240	171,600	5,050	138,900
17	70	5,990	164,700	5,100	140,200
18	70	5,930	163,000	4,950	136,100
19	750	4,240	116,600	3,625	99,700
20	750	4,250	116,900	3,640	100,100
21	750	4,310	118,500	3,650	100,400

(1) Stress calculated at Tensile Stress Area of 0.03637 square inches.

TABLE III. 3. 10 (continued)

Part No: NAS 1271-28
FN 1216-428
Size - 1/4-28

Material - Ti 8Al-1Mo-1V
A-286

1. Tensile (continued)

C. Angle Block Bolt Properties (3°∠@ Nut Bearing Face)*

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (1)
22	-423	5,700	156,700
23	-423	5,730	157,500
24	-423	4,380	120,400
25	-320	4,220	116,000
26	-320	4,350	119,600
27	-320	3,920	107,800
28	70	5,400	148,500
29	70	5,340	146,800
30	70	5,580	153,400

D. As Relaxed (50 Hours)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (1)	Yield Load, lbs.	Yield Stress, psi (1)
Preload A					
31	70	5,680	156,200	5,250	144,300
32	70	5,640	155,100	5,400	148,500
33	70	5,640	155,100	5,300	145,700
Preload B					
34	70	5,600	154,000	5,100	140,200
35	70	5,650	155,300	5,175	142,300
36	70	5,500	151,200	5,200	143,000

(1) Stress calculated at Tensile Stress Area of 0.03637 square inches.
* Bolt grip length 1.75 inches.

TABLE III. 3. 10 (continued)

Part No. NAS 1271-28
FN 1216-428
Size - 1/4-28

Material - Ti 8Al-1Mo-1V
A-286

2. Tension Impact

Test No.	Test Temperature, °F	Energy Expended, ft. - lbs.
1	-423	19.0
2	-423	20.5
3	-423	20.0
4	-320	20.5
5	-320	20.5
6	-320	23.5
7	70	23.0
8	70	20.5
9	70	21.5

3. Double Shear

A. As Received

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (2)
1	-423	13,000	132,400
2	-423	13,500	137,500
3	-423	12,700	129,300
4	70	10,020	102,100
5	70	9,940	101,300
6	70	9,540	97,200
7	750	7,000	71,300
8	750	6,970	71,000
9	750	7,125	72,600

(2) Stress calculated at Twice the Nominal Diameter area, 0.09817 square inches.

TABLE III. 3. 10 (continued)

Part No. NAS 1271-28
FN 1216-428
Size - 1/4-28

Material - Ti 8Al-1Mo-1V
A-286

3. Double Shear (continued)

B. As Relaxed (50 Hours)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (2)
Preload A			
10	70	10,170	103,600
11	70	10,400	105,900
12	70	9,900	100,800
Preload B			
13	70	9,370	95,400
14	70	9,500	96,800
15	70	9,500	96,800

4. Tension-Tension Fatigue @ 70°F

Test No.	Min. Load, lbs.	Min. Stress, psi (3)	Max. Load, lbs.	Max. Stress, psi (3)	Cycles to Failure	Location of Failure
1	237	7,280	2,370	72,800	480,000	Thread
2	237	7,280	2,370	72,800	346,000	Thread
3	237	7,280	2,370	72,800	8,147,000	No Failure

(2) Stress calculated at Twice the Nominal Diameter Area, 0.09817 square inches.
(3) Stress calculated at Basic Minor Diameter Area of 0.03256 square inches.

TABLE III. 3. 10 (continued)

Part No. NAS 1271-28
FN 1216-428

Material - Ti 8Al-1Mo-1V
A-286

Size - 1/4-28

5. Stress Relaxation @ 750° F

Preload A - Initial Stress - 112,000 psi

Test No.	Hours Run	Residual Stress Pounds	Residual Stress psi (1)
1	10	2,470	67,900
2	10	2,470	67,900
3	10	2,490	68,400
4	50	1,780	48,900
5	50	1,875	51,500
6	50	1,950	53,600

Preload B - Initial Stress - 70,000 psi

Test No.	Hours Run	Residual Stress Pounds	Residual Stress psi (1)
7	10	1,653	45,500
8	10	1,728	47,500
9	10	1,679	46,200
10	50	1,450	39,900
11	50	1,412	38,800
12	50	1,450	39,900

6. Stress Rupture

Test No.	Test Temperature, °F	Load, lbs.	Stress, psi (1)	Hours to Failure	Location of Failure
1	750	4,364	120,000	Failed Loading	
2	750	4,183	115,000	21.1	Thread
3	750	4,183	115,000	46.4	Thread
4	750	4,183	115,000	57.1	Thread
5	750	4,183	115,000	136.7	Thread
6	750	4,000	110,000	132.7	No Failure
7	750	4,000	110,000	100.0	No Failure
8	750	4,000	110,000	114.5	No Failure

(1) Stress calculated at Tensile Stress Area of 0.03637 square inches.

TABLE III. 3. 10 (continued)

Part No. - NAS 1271-28
FN 1216-428
Size - 1/4-28

Material - Ti 8Al-1Mo-1V
A-286

7. Nut Reuse and Galling Tendency @ 70°F

Seated Stress - 75,600 psi (1)

Test No.	Maximum Installation, inch - pounds	Torque to Induce Stress, inch - pounds	Torque, inch - pounds Breakaway	Removal
1st Application				
1	23	100	80	13
2	30	110	85	18
3	18	105	80	10
4	20	100	75	15
5	20	105	80	14
2nd Application				
1	23	100	80	15
2	33	120	95	25
3	20	110	80	12
4	18	100	75	14
5	18	95	75	11
3rd Application				
1	28	100	80	17
2	35	115	90	26
3	20	105	80	11
4	18	100	70	14
5	18	100	75	10
4th Application				
1	26	105	75	18
2	30	115	95	30
3	18	100	75	12
4	15	105	80	15
5	16	110	70	10
5th Application				
1	28	110	80	21
2	33	120	90	25
3	20	100	85	15
4	15	95	80	16
5	18	105	75	9

(1) Stress calculated at Tensile Stress Area of 0.03637

TABLE III. 3. 10 (continued)

Part No. NAS 1271-28
FN 1216-428
Size - 1/4-28

Material - Ti 8Al-1Mo-1V
A-286

8. Vibration - ALMA #1L

Test No.	Test Temperature, °F	Maximum Installation, 1st	5th	Seating Torque, in.-lbs.	No. of Cycles	Degree Movement	10X Mag. Visual Insp.	Remarks
1	-320	24	20	60	30,000	0°	No cracks	Passed
2	-320	22	28	60	30,000	0°	No cracks	Passed
3	-320	22	21	60	30,000	0°	No cracks	Passed
4	-320	22	32	60	30,000	0°	No cracks	Passed
5	-320	19	16	60	30,000	0°	No cracks	Passed
6	70	30	34	60	30,000	0°	No cracks	Passed
7	70	28	30	60	30,000	0°	No cracks	Passed
8	70	22	20	60	30,000	0°	No cracks	Passed
9	70	24	32	60	30,000	0°	No cracks	Passed
10	70	20	36	60	30,000	0°	No cracks	Passed

9. Torque vs. Induced Load @ Room Temperature

Torque, in.-lbs.	Test No. 1 Load, lbs.	Test No. 2 Load, lbs.	Test No. 3 Load, lbs.
50	400	500	650
75	1150	1250	1350
100	1550	1750	1900
125	2300	2550	2950
150	2900	3400	3550
175	3600	4200	4500
200	4150	5200	5100
225	5400	5500	5350

TABLE III. 3. 11

MECHANICAL PROPERTIES

Part No. Bolt - NAS 1275-48   Material - Ti 8Al-1Mo-1V
Nut - FN 1216-820   A-286
Size - 1/2-20

1. Tensile

A. Base Material Properties (As Received)

Test No.	Test Temperature, °F	Ultimate Stress, psi	0.2% Offset Yield Stress, psi	Elongation Gage, 1.4 in. %	Reduction of Area, %
1	-423	242,300	231,000	8.5	36.6
2	-423	246,800	234,300	4.2	18.0
3	-423	242,000	237,500	5.7	8.8
4	70	140,000	138,500	17.8	39.2
5	70	139,100	134,600	18.5	38.9
6	70	141,000	139,000	17.8	39.2
7	750	103,300	81,700	17.8	52.6
8	750	102,300	82,100	21.1	53.6
9	750	102,200	85,200	18.5	47.8

B. Bolt Properties (As Received)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (1)	Johnson's 2/3 Approximation Yield Load, lbs.	Johnson's 2/3 Approximation Yield Stress, psi
10	-423	32,400	202,600	No Yield	
11	-423	38,700	242,000	No Yield	
12	-423	34,000	212,600	No Yield	
13	-320	35,100	219,500	No Yield	
14	-320	34,500	215,700	No Yield	
15	-320	34,500	215,700	No Yield	
16	70	24,700	154,400	23,400	146,300
17	70	25,000	156,300	23,000	143,800
18	70	25,000	156,300	23,200	145,000
19	750	18,050	112,800	15,300	95,600
20	750	18,100	113,100	15,200	95,000
21	750	18,250	114,100	15,300	95,600

(1) Stress calculated at the Tensile Stress Area of 0.1599 square inches.

TABLE III. 3. 11 (continued)

Part No. NAS 1275-48
FN 1216-820
Size 1/2-20

Material Ti 8Al-1Mo-1V
A-286

1. Tensile (continued)

C. Angle-Block Bolt Properties (3°∠ @ Nut Bearing Face) *

Test No.	Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (1)
22	-423	28,900	181,000
23	-423	26,300	164,500
24	-423	25,100	157,000
25	-320	23,000	143,800
26	-320	26,000	162,600
27	-320	23,800	148,800
28	70	19,000	118,800
29	70	19,600	122,500
30	70	20,400	127,500

D. As Relaxed (50 Hours)

Test No.	Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (1)	Yield Load, lbs.	Yield Stress, psi (1)
Preload A					
31	70	23,700	148,200	23,000	143,800
32	70	23,800	148,800	22,600	141,300
33	70				
Preload B					
34	70	23,200	145,100	22,750	142,200
35	70	23,500	146,900	22,750	142,200
36	70	23,800	148,800	23,000	143,800

(1) Stress calculated at the Tensile Stress Area of 0.1599 square inches.
* Bolt grip length 3.0 inches.

TABLE III. 3. 11 (continued)

Part No. NAS 1275-48 Material-Ti 8Al-1Mo-1V
FN 1216-820 A-286
Size - 1/2-20

2. Double Shear

A. As Received

Test No.	Test Temperature °F	Ultimate Load, lbs.	Ultimate Stress, psi (2)
1	-423	46,400	118,200
2	-423	50,900	129,600
3	-423	43,800	111,500
4	70	36,000	91,500
5	70	38,600	98,000
6	70	40,900	104,000
7	750	26,800	68,200
8	750	25,900	66,000
9	750	25,500	64,900

B. As Relaxed

Preload A

10	70	38,800	98,800
11	70	39,800	101,300
12	70	37,300	95,000

Preload B

13	70	37,100	94,500
14	70	38,600	98,300
15	70	37,400	95,200

(2) Stress calculated at Twice Nominal Diameter Area, 0.3927 square inches.

TABLE III. 3. 11 (continued)

Part No. NAS 1275-48
FN 1216-820
Size - 1/2-20

Material - Ti 8Al-1Mo-1V
A-286

3. Tension-Tension-Fatigue @ 70° F

Test No.	Min. Load, lbs.	Min. Stress, psi (3)	Max. Load, lbs.	Max. Stress, psi (3)	Cycles to Failure	Location of Failure
1	1,080	7,280	10,800	72,800	96,800	Thread
2	1,080	7,280	10,800	72,800	241,700	Thread
3	1,080	7,280	10,800	72,800	68,200	Thread

4. Stress Relaxation @ 750° F

Preload A - Initial Stress - 83,200 psi

Test No.	Hours Run	Residual Stress Pounds	Residual Stress psi (1)
1	10	11,933	74,600
2	10	12,006	75,100
3	10	12,150	76,000
4	50	10,487	65,600
5	50	10,270	64,200
6	50	9,981	62,400

Preload B - Initial Stress - 52,000 psi

Test No.	Hours Run	Residual Stress Pounds	Residual Stress psi (1)
7	10	7,583	47,400
8	10	7,509	47,000
9	10	7,583	47,400
10	50	6,331	39,600
11	50	6,184	38,700
12	50	6,258	39,100

(1) Stress calculated at the Tensile Stress Area of 0.1599 square inches.
(3) Stress calculated at the Basic Minor Diameter Area of 0.1486 square inches.

TABLE III. 3. 11 (continued)

Part No. NAS 1275-48
FN 1216-820
Size - 1/2-20

Material - Ti 8Al-1Mo-1V
A-286

5. Stress Rupture

Test No.	Test Temperature, °F	Load, lbs.	Stress, psi (1)	Hours to Failure	Location of Failure
1	750	19,200	120,000	Failed Loading	
2	750	18,400	115,000	Failed Loading	
3	750	17,600	110,000	120.3	No Failure
4	750	17,600	110,000	49.0	Thread
5	750	17,600	110,000	105.9	No Failure

(1) Stress calculated at the Tensile Stress Area of 0.1599 square inches.

TABLE III. 3. 11 (continued)

Part No. NAS 1275-48
FN 1216-820
Size - 1/2-20

Material - Ti 8Al-1Mo-1V
A-286

6. Nut Reuse and Galling Tendency @70°F

Seated Stress - 75,600 psi (1)

Test No.	Maximum Installation, inch-pounds	Seated Stress psi (1)	Induce Stress inch-pounds	Torque After Soak Breakaway	Torque After Soak Removal
1st Application					
1	70		625	475	60
2	70		640	450	60
3	85		615	450	55
4	90		575	425	75
5	95		600	475	80
2nd Application					
1	65		620	475	55
2	55		630	500	60
3	60		600	475	55
4	65		600	475	70
5	70		575	450	75
3rd Application					
1	65		625	450	60
2	50		625	450	58
3	60		600	475	55
4	60		590	450	60
5	65		610	500	75
4th Application					
1	65		600	450	55
2	50		620	450	55
3	60		600	450	60
4	50		575	450	55
5	60		585	475	70
5th Application					
1	70		600	475	65
2	50		615	500	55
3	65		590	475	60
4	60		575	450	60
5	55		585	450	60

(1) Stress calculated at the Tensile Stress Area of 0.1599 square inches.

TABLE III. 3. 11 (continued)

Part No. NAS 1275-48 Material - Ti 8Al-1Mo-1V
FN 1216-820 A-286
Size - 1/2-20

7. Torque vs. Induced Load @ Room Temperature

Torque, in. - lbs.	Test No. 1 Load, lbs.	Test No. 2 Load, lbs.	Test No. 3 Load, lbs.
500	3,250	3,500	3,250
1000	9,500	9,500	9,500
1500	14,000	15,000	15,000
2000	19,500	20,500	20,000

TABLE III. 3. 12

MECHANICAL PROPERTIES

Part No. EWB T815-4-28
Size - 1/4-28 x 2.250

Material Ti 5Al-5Sn-5Zr

1. Tensile

A. Base Material Properties (As Received) .113 inches specimen

Test No.	Test Temperature, °F	Ultimate Stress, psi	0.2% Offset Yield Stress, psi	Elongation Gage, .5 in. %	Reduction of Area, %
1	-423	292,200	268,600	6.0	15.5
2	-423	298,000	275,500	2.0	3.5
3	-423	298,000	270,400	2.0	5.1
4	70	176,000	150,000	16.0	36.9
5	70	171,000	144,000	18.0	36.5
6	70	158,900	144,800	18.0	44.0
7	750	112,400	91,800	14.0	56.4
8	750	121,000	97,000	14.0	58.3
9	750	118,500	95,000	14.0	57.0

B. V-Notch Properties (K_t 8)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi	Notch to Smooth Tensile Ratio
10	-423	3,140	127,600	0.43
11	-423	3,360	136,600	0.46
12	-423	2,950	120,400	0.41
13	70	5,440	220,200	1.31
14	70	5,390	218,200	1.29
15	70	5,400	219,500	1.30
16	750	4,320	174,900	1.49
17	750	4,325	175,100	1.49
18	750	4,210	172,500	1.47

TABLE III. 3. 12 (continued)

Part No. EWB T815-4-28 Material Ti 5Al-5Sn-5Zr
Size - 1/4-28 x 2.250

1. Tensile (continued)

C. Axial Bolt Properties

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)	Johnson's 2/3 Yield Load, lbs.	Approximation Yield Stress, psi(1)
19	-423	9,520	261,800	No Yield	
20	-423	7,660	210,600	No Yield	
21	-423	9,140	251,300	No Yield	
22	-423	5,280	145,200	No Yield	
23	-320	9,350	257,100	No Yield	
24	-320	9,300	255,700	No Yield	
25	-320	9,200	253,000	No Yield	
26	70	6,540	180,000	5,500	151,200
27	70	6,690	183,900	5,600	154,000
28	70	6,720	184,800	5,700	156,700
29	750	4,680	128,700	3,775	103,800
30	750	4,610	126,800	3,860	106,100
31	750	4,775	131,300	3,500	96,200

D. Angle Block Bolt Properties (3°∠ @ Nut Bearing Face)*

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
32	-423	4,580	125,900
33	-423	4,300	118,200
34	-423	2,620	72,000
35	-320	4,100	112,700
36	-320	6,100	167,700
37	-320	5,600	154,000
38	70	6,260	172,100
39	70	5,860	161,100
40	70	6,650	182,800

(1) Stress calculated at Tensile Stress Area of 0.03637 square inches.
* Bolt grip length 1.75 inches.

TABLE III. 3. 12 (continued)

Part No. EWB T815-4
Size - 1/4-28 x 2.250

Material Ti 5Al-5Sn-5Zr

1. Tensile (continued)

E. As Relaxed Bolt Properties (50 Hours)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)	Yield Load, lbs.	Yield Stress, psi(1)
41	70	5,900	162,200	No Yield	
42	70	5,820	160,000	No Yield	
43	70	5,600	154,000	No Yield	

2. Tension Impact

Test No.	Test Temperature, °F	Energy Expended, ft.-lbs.
1	-423	26.5
2	-423	24.0
3	-423	26.0
4	-320	24.0
5	-320	25.0
6	-320	24.0
7	70	23.5
8	70	22.5
9	70	24.0

(1) Stress calculated at Tensile Stress Area of 0.03637 square inches.

TABLE III. 3. 12 (continued)

Part No. EWB T815-4
Size - 1/4-28 x 2.250

Material Ti 5Al-5Sn-5Zr

3. Double Shear

A. As Received

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
1	-423	10,800	110,000
2	-423	10,800	110,000
3	-423	10,150	103,400
4	70	11,500	117,100
5	70	10,500	107,000
6	70	9,900	100,800
7	750	7,425	75,600
8	750	7,450	75,900
9	750	7,440	75,800

B. As Relaxed (50 Hours)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi (2)	Yield Load, lbs.	Yield Stress, psi(1)
10	70	5,900	162,200	No Yield	
11	70	5,820	160,000	No Yield	
12	70	5,600	154,000	No Yield	

4. Tension-Tension Fatigue @70°F

Test No.	Min. Load, lbs.	Min. Stress, psi	Max. Load, lbs.	Max. Stress, psi(3)	Cycles to Failure	Location of Failure
1	236	6,500	2,360	65,000	169,000	Thread
2	236	6,500	2,360	65,000	147,000	Thread
3	236	6,500	2,360	65,000	106,000	Thread

(2) Stress calculated at twice the Nominal Diameter Area of 0.09817 square inches.

(3) Stress calculated at the Basic Minor Diameter Area of 0.03256 square inches.

TABLE III. 3. 12 (continued)

Part No. EWB T815-4
Size - 1/4-28 x 2.250

Material Ti 5Al-5Sn-5Zr

5. Stress Relaxation @ 750°F

Initial Stress - 88,000 psi

Test No.	Hours Run	Residual Stress Pounds	Residual Stress psi(1)
1	1	2,700	74,200
	10	2,250	61,800
	50	1,820	50,000
2	1	2,650	89,300
	10	2,380	65,400
	50	1,850	50,800
3	1	2,720	74,700
	10	2,100	57,700
	50	1,700	46,700

6. Stress Rupture

Test No.	Test Temperature, °F	Load, lbs.	Load Stress, psi(1)	Hours to Failure	Location of Failure
1	750	4,700	129,200	0.4	Thread
2	750	4,546	125,000	31.7	Thread
3	750	4,546	125,000	141.7	No Failure
4	750	4,546	125,000	102.2	No Failure
5	750	4,546	125,000	102.3	No Failure

7. Coefficient of Thermal Expansion

Temperature Inches/Inch/°F$\times 10^6$

Data is not available at the present time.

(1) Stress calculated at Tensile Stress Area of 0.03637 square inches.

APPENDIX III.4

Cobalt Base Fasteners

TABLE III.4.1

MECHANICAL PROPERTIES

Part No. EWB 22-4
Size - 1/4-28 x 1.562

Material 30% Cold Reduced L605
(Unaged)

1. Tensile

A. Base Material Properties (As Received) .113 inches specimens

Test No.	Test Temperature, °F	Ultimate Stress, psi	0.2% Offset Yield Stress, psi	Elongation Gage, .5 in. %	Reduction of Area, %
1	-423	356,000	210,000	10.0	13.5
2	-423	356,200	226,500	10.0	14.0
3	-423	354,100	229,100	8.0	14.0
4	70	235,000	127,500	8.0	10.5
5	70	233,000	140,000	8.0	14.5
6	70	235,000	150,000	8.0	10.5
7	1400	105,000	87,500	6.0	7.0
8	1400	122,400	106,800	6.0	5.5
9	1400	122,900	101,500	6.0	5.5

B. V-Notch Properties (K_t 8)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi	Notch to Smooth Tensile Ratio
10	-423	4,600	189,300	0.53
11	-423	4,380	178,000	0.50
12	-423	5,320	217,100	0.61
13	70	4,280	174,000	0.74
14	70	3,840	155,500	0.66
15	70	3,960	160,300	0.68
16	1400	2,350	95,100	0.81
17	1400	1,950	78,900	0.71
18	1400	2,175	88,400	0.76

TABLE III. 4. 1 (continued)

Part No. EWB 22-4
Size - 1/4-28 x 1.562

Material 30% Cold Reduced L605
(Unaged)

1. Tensile (continued)

C. Axial Bolt Properties

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)	Johnson's 2/3 Approximation Yield Load, lbs.	Yield Stress, psi(1)
19	-423	13,100	370,400	10,250	289,800
20	-423	13,600	384,500	10,750	303,900
21	-423	13,000	367,500	11,000	311,000
22	-320	12,700	359,100	11,000	311,000
23	-320	12,500	353,400	10,800	305,300
24	70	10,250	289,800	6,300	178,100
25	70	10,100	285,600	5,400	152,700
26	70	9,900	280,000	4,850	137,000
27	1400	4,300	121,500	3,750	106,000
28	1400	3,665	103,600	2,700	76,300
29	1400	4,350	122,900	3,650	103,100

D. Angle Block Bolt Properties (3°∠ @ Nut Bearing Face) *

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)
30	-423	12,500	353,400
31	-423	11,800	333,600
32	-423	12,100	342,100
33	-320	12,680	358,500
34	-320	12,400	350,600
35	70	9,540	269,700
36	70	9,520	269,200

(1) Stress calculated at Tensile Stress Area (.003 Reduced Pitch Diameter), 0.03537 square inches.

* Bolt grip length 1.062 inches.

TABLE III. 4. 1 (continued)

Part No. EWB 22-4
Size - 1/4-28 x 1.562

Material 30% Cold Reduced L605
(Unaged)

1. Tensile (continued)

E. As Relaxed Bolt Properties (50 Hours)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)	Yield Load, lbs.	Yield Stress, psi(1)
37	70	8,670	245,100	6,500	183,800
38	Initial preload exceeded during loading and bolt failed.				
39	Initial preload exceeded during loading and bolt failed.				

2. Tension Impact

Test No.	Test Temperature, °F	Energy Expended, ft.-lbs.
1	-423	43.0
2	-423	46.0
3	-423	46.0
4	-320	41.0
5	-320	46.0
6	-320	43.0
7	70	39.0
8	70	38.0
9	70	37.5

(1) Stress calculated at Tensile Stress Area (.003 Reduced Pitch Diameter), 0.03537 square inches.

TABLE III. 4. 1 (continued)

Part No. EWB 22-4
Size - 1/4-28 x 1.562

Material 30% Cold Reduced L605

3. Double Shear

A. As Received

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
1	-423	18,750	191,000
2	-423	18,350	186,900
3	-423	17,100	174,200
4	70	14,600	148,700
5	70	14,800	150,700
6	70	15,000	152,800
7	1400	8,125	82,800
8	1400	8,250	84,000
9	1400	8,275	84,300

B. As Relaxed (50 Hours)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
10	70	13,700	139,600
11	Initial preload exceeded during loading and bolt failed.		
12	Initial preload exceeded during loading and bolt failed.		

4. Tension-Tension Fatigue @70° F

Test No.	Min. Load, lbs.	Min. Stress, psi(3)	Max. Load, lbs.	Max. Stress, psi(3)	Cycles to Failure	Location of Failure
1	440	13,500	4,400	135,000	96,000	Thread
2	440	13,500	4,400	135,000	103,000	Thread
3	440	13,500	4,400	135,000	7,000	Thread

(2) Stress calculated at twice Nominal Diameter Area of 0.09817 square inches.

(3) Stress calculated at Basic Minor Diameter Area of 0.03256 square inches.

TABLE III. 4. 1 (continued)

Part No. EWB 22-4
Size - 1/4-28 x 1.562

Material 30% Cold Reduced L605

5. Stress Relaxation @ 1400°F

Initial Stress - 80, 300 psi

Test No.	Hours Run	Residual Stress Pounds	Residual Stress psi[1]
1	1	1, 150	32, 500
	10	840	23, 700
	50	490	13, 900
2	1	Initial Preload exceeded during loading and bolt failed.	
	10		
	50		
3	1	Initial Preload exceeded during loading and bolt failed.	
	10		
	50		

6. Stress Rupture

Test No.	Test Temperature, °F	Load, lbs.	Stress, psi[1]	Hours to Failure	Location of Failure
1	1400	2, 500	70, 000	0. 1	Thread
2	1400	2, 120	60, 000	0. 1	Thread
3	1400	1, 769	50, 000	7. 6	Thread
4	1400	1, 7'9	50, 000	6. 4	Thread

7. Coefficient of Thermal Expansion[3]

Temperature	Inches/Inch/°Fx10^6
600	7. 61
1000	8. 30
1400	8. 92
1800	9. 70

(1) Stress calculated at Tensile Stress Area (. 003 Reduced Pitch Diameter), 0. 03537 square inches.

(3) Alloy Digest - Filing Code Co-5

TABLE III. 4. 2

MECHANICAL PROPERTIES

Part No. Bolt - EWB 1615-4-16 Material - 30% C. R. L605
Part No. Nut - Nut Slug Material - L605
Size - 1/4-28 (Rolled Threads After Age)

1. Tensile

A. Base Material Properties (As Received) 0. 113 inch specimen

Test No.	Test Temperature, °F	Ultimate Stress, psi	0. 2% Offset Yield Stress, psi	Elongation, Gage, . 5 in. %	Reduction of Area, %
1	-423	323,000	235,000	4.0	8.6
2	-423	341,000	242,900	4.0	5.5
3	-423	330,000	290,000	4.0	5.4
4	-320	323,500	262,200	4.0	5.5
5	-320	325,500	260,400	4.0	5.5
6	-320	Test Not Conducted			
7	70	277,400	215,300	4.0	17.8
8	70	245,900	204,000	6.0	13.6
9	70	245,800	218,700	6.0	12.1
10	1600	73,400	65,300	18.0	25.0
11	1600	68,400	55,200	18.0	25.5
12	1600	66,600	49,000	18.0	23.0

TABLE III. 4. 2 (continued)

Part No. EWB 1615-4-16 Material - 30% C. R. L605
Nut Slug Material - L605
Size - 1/4-28 (Rolled Threads After Age)

1. Tensile (continued)

B. Axial Bolt Properties (As Received)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)	Johnson's 2/3 Approximation Yield Load, lbs.	Johnson's 2/3 Approximation Yield Stress, psi
13	-423	12,150	343,500	11,500	325,100
14	-423	11,900	336,400	11,400	322,300
15	-423	12,200	344,900	11,500	325,100
16	-320	12,000	339,300	11,375	321,600
17	-320	11,400	322,300	10,000	282,700
18	-320	12,600	356,200	10,875	307,500
19	70	9,800	277,100	7,100	200,700
20	70	10,300	291,200	8,000	226,200
21	70	10,100	285,600	7,400	209,200
22	1600	2,100	59,300	1,625	45,900
23	1600	2,000	56,300	1,250	35,300
24	1600	2,250	63,600	1,510	42,600

C. Angle-Block Bolt Properties (3°∠ @ Nut Bearing Face) *

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)	Yield Load, lbs.	Yield Stress, psi
25	-423	10,100	285,600		
26	-423	11,200	316,700		
27	-320	12,700	359,100		
28	-320	9,000	254,500		
29	70	9,400	265,800		
30	70	9,200	260,100		

D. As-Relaxed Bolt Properties (50 Hours)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(1)	Yield Load, lbs.	Yield Stress, psi
31	70	7,200	203,600	4,900	138,500
32	70	6,900	195,100	4,250	120,200
33	70	7,050	199,300	4,500	127,200

(1) Stress Calculated at Tensile Stress Area (.003 reduced pitch diameter) of 0.03537 square inches.
* Bolt grip length 1.0 inches.

TABLE III. 4. 2 (continued)

Part No. EWB 1615-4-16
Nut Slug
Size - 1/4-28 (Rolled Threads After Age)

Material - 30% C. R. L605
Material - L605

2. Stress Durability @70°F

Test No.	Seated Stress, lbs.	Seated Stress, psi[1]	Torque to Induce Stress, in. -lbs.	Length of Test, Hours	Remarks
1	6,700	189,400	175	42	Passed
2	6,700	189,400	175	42	Passed
3	6,700	189,400	175	42	Passed

3. Tension-Impact

Test No.	Test Temperature °F	Energy Expended, ft. -lbs.
1	-423	19.0
2	-423	20.5
3	-320	23.0
4	-320	22.0
5	70	20.5
6	70	18.5

(1) Stress Calculated at the Tensile Stress Area (.003 reduced pitch diameter) of 0.03537 square inches.

TABLE III.4.2 (continued)

Part No. - EWB 1615-4-16 Nut Slug
Size - 1/4-28 (Rolled Threads After Age)

Material - 30% C. R. L605
Material - L605

4. Double Shear

A. As-Received

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
1	-423	14,860	151,400
2	-423	14,500	147,700
3	-423	15,500	157,900
4	70	13,300	135,500
5	70	13,400	136,500
6	70	12,900	131,400
7	1600	3,600	36,700
8	1600	4,300	43,800

B. As-Relaxed (50 Hours)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
9	70	14,200	144,600
10	70	13,750	140,100
11	70	14,000	142,600

(2) Stress Calculated at Twice the Nominal Diameter Area, 0.09817 square inches.

TABLE III. 4. 2 (continued)

Part No. - EWB 1615-4-16 Nut Slug
Material - 30% C. R. L605
Material - L605
Size - 1/4-28 (Rolled Threads After Age)

5. Stress Rupture

Test No.	Test Temperature, °F	Load, lbs.	Stress, psi(1)	Hours to Failure	Location of Failure
1	1600	707	20,000	4.4	Thread
2	1600	707	20,000	2.3	Thread
3	1600	531	15,000	32.0	Thread
4	1600	531	15,000	23.1	Thread
5	1600	354	10,000	76.4	Thread
6	1600	354	10,000	148.4	Thread

6. Stress Relaxation @1600°F

Initial Stress - 33,000 psi

Test No.	Hours Run	Residual Stress lbs.	Residual Stress psi(1)
1	10	The residual stress for all specimens was zero in less than 10 hours.	
2	10		
3	10		
4	50		
5	50		
6	50		

(1) Stress Calculated at the Tensile Stress Area (.003 reduced pitch diameter) of 0.03537 square inches.

APPENDIX IV

TABLES OF RESULTS

POINT DRIVE FASTENERS

APPENDIX IV - 1

NICKEL BASE FASTENERS

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TABLE IV. 1. 1

MECHANICAL PROPERTIES

Part No. Bolt - 63439-8-24
Twist-Off Nut - TN 12-8
Size - 1/4-28 (Rolled Threads After Age)

Material - Inconel 718
Material - Waspaloy

1. Tensile

A. As Received

Test No.	Test Temperature, °F	Preload, lbs.	Preload, psi(1)	Ultimate Load, pounds	Ultimate Stress psi(1)
1	-423			8, 300	228, 200
2	-423			7, 800	214, 500
3	-423			8, 500	233, 700
4	70	4, 150	114, 100	6, 800	187, 000
5	70	3, 800	104, 500	6, 800	187, 000
6	70	4, 150	114, 100	6, 780	186, 400
7	1200			5, 200	142, 900
8	1200			4, 800	131, 900
9	1200			4, 850	133, 300

B. As-Relaxed (50 Hours)

10	70			5, 710	157, 000
11	70			5, 480	150, 700
12	70			5, 640	155, 100

(1) Stress Calculated at the Tensile Stress Area of 0. 03637 square inches.

TABLE IV. 1. 1 (continued)

Part No. - 63439-8-24 Material - Inconel 718
TN 12-8 Material - Waspaloy
Size - 1/4-28 (Rolled Threads After Age)

2. Double Shear

A. As-Received

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
1	-423	15,150	154,300
2	-423	15,650	159,400
3	-423	16,100	164,000
4	70	12,150	123,800
5	70	12,800	130,400
6	70	13,000	132,400
7	1200	10,000	101,900
8	1200	9,800	99,800
9	1200	10,200	103,900

B. As-Relaxed (50 Hours)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
10	70	13,300	135,500
11	70	13,600	138,500
12	70	13,700	139,600

3. Stress Relaxation @1200°F

Initial Stress - 88,800 psi (1)

Test No.	Hours Run	Residual Stress lbs.	Residual Stress psi(1)
1	10	2,625	72,200
2	10	2,820	77,500
3	10	2,775	76,300
4	50	2,100	57,700
5	50	1,950	53,600
6	50	2,200	60,500

(1) Stress Calculated at the Tensile Stress Area of 0.03637 square inches.
(2) Stress Calculated at Twice the Nominal Diameter Area, 0.09817 square inches.

TABLE IV. 1. 2

MECHANICAL PROPERTIES

Part No. Bolt - 63439-12-21 — Material - Inconel 718
Twist-Off Nut - TN 12-12 — Material - Waspaloy
Size - 3/8-24 (Rolled Threads After Age)

1. Tensile

A. As Received

Test No.	Test Temperature, °F	Preload, lbs.	Preload, psi(1)	Ultimate Load, pounds	Ultimate Stress psi(1)
1	-423			20,500	233,500
2	-423			24,500	279,000
3	-423			24,800	282,400
4	70	10,400	118,400	17,700	201,600
5	70	10,250	116,700	18,300	208,400
6	70	8,300	94,500	17,200	195,900
7	1200			16,900	192,400
8	1200			16,600	189,000
9	1200			17,100	194,700

B. As-Relaxed (50 Hours)

Test No.	Test Temperature, °F	Preload, lbs.	Preload, psi(1)	Ultimate Load, pounds	Ultimate Stress psi(1)
10	70			12,600	143,500
11	70			9,800	111,600
12	70			13,800	157,200

(1) Stress Calculated at the Tensile Stress Area of 0.08781 square inches.

TABLE IV. 1. 2 (continued)

Part No. - 63439-12-21 Material - Inconel 718
TN 12-12 Material - Waspaloy
Size - 3/8-24 (Rolled Threads After Age

2. Double Shear

A. As-Received

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
1	-423	33,100	150,000
2	-423	32,250	146,100
3	-423	31,700	143,600
4	70	29,500	133,600
5	70	29,100	131,800
6	70	29,200	132,200
7	1200	21,500	97,400
8	1200	24,000	108,700
9	1200	20,000	90,600

B. As-Relaxed (50 Hours)

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
10	70	31,500	142,700
11	70	32,200	145,800
12	70	32,600	147,600

3. Stress Relaxation @1200°F

Initial Stress - 88,800 psi (1)

Test No.	Hours Run	Residual Stress lbs.	Residual Stress psi(1)
1	10	5,030	57,300
2	10	5,270	60,000
3	10	5,180	64,760
4	50	4,250	48,400
5	50	4,400	50,100
6	50	5,200	59,200

(1) Stress Calculated at the Tensile Stress area of 0.08781 square inches.
(2) Stress Calculated at Twice the Nominal Diameter Area, 0.2208 square inches.

TABLE IV. 1. 3

MECHANICAL PROPERTIES

Part No. Bolt - PDP 16-6-20 — Material - Waspaloy
Twist-off Nut - TN 12-6 — Material - Waspaloy
Size - #10-32

1. Tensile

A. As Received

Test No.	Test Temperature, °F	Preload, pounds	Preload, psi(1)	Ultimate Load, pounds	Ultimate Stress, psi(1)
1	-423			3,720 (H)	186,100
2	-423			3,280 (H)	164,100
3	-423			3,470 (H)	173,600
4	70	2,000	100,100	3,400	170,100
5	70	1,990	99,500	3,300	165,100
6	70	2,020	101,100	3,330	166,600
7	1400			2,570 (H)	128,600
8	1400			2,650 (H)	132,600
9	1400			2,480 (H)	124,100

H - Head Failure
(1) Stress calculated at Tensile Stress Area of 0.01999 square inches.

TABLE IV. 1. 3 (continued)

Part No. Bolt - PDP 16-6-20 Material - Waspaloy
Twist-off Nut - TN 12-6 Material - Waspaloy
Size - #10-32

2. Double Shear

A. As Received

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
1	-423	8,940	157,600
2	-423	8,700	153,400
3	-423	8,880	156,600
4	70	6,450	113,700
5	70	6,520	115,000
6	70	6,540	115,300
7	1400	5,475	96,500
8	1400	5,530	97,500
9	1400	5,400	95,200

3. Vibration - ALMA #10

Test No.	Test Temperature, °F	Installation Torque, in.-lbs.	Breakoff Torque, in.-lbs.	No. of Cycles	Degrees Movement	10X Mag. Visual Insp.	Remarks
1	-320	10	68	30,000	0°	No Cracks	Passed
2	-320	11	60	30,000	0°	No Cracks	Passed
3	-320	16	55	30,000	0°	No Cracks	Passed
4	-320	7	60	30,000	0°	No Cracks	Passed
5	-320	11	62	30,000	0°	No Cracks	Passed
6	70	18	75	30,000	0°	No Cracks	Passed
7	70	13	65	30,000	0°	No Cracks	Passed
8	70	13	70	30,000	0°	No Cracks	Passed
9	70	13	68	30,000	0°	No Cracks	Passed
10	70	11	55	30,000	0°	No Cracks	Passed

(2) Stress calculated at Twice Nominal Diameter Area, 0.05671 square inches.

TABLE IV. 1.4

MECHANICAL PROPERTIES

Part No. Bolt - PDP 16-8-21 Material - Waspaloy
Twist-off Nut - TN 12-8 Material - Waspaloy
Size - 1/4-28

1. Tensile

A. As Received

Test No.	Test Temperature, °F	Preload, pounds	Preload, psi(1)	Ultimate Load, pounds	Ultimate Stress, psi(1)
1	-423			6,830 (H)	187,800
2	-423			6,830 (H)	187,800
3	-423			6,750 (H)	185,600
4	70	3,850	105,900	5,740 (H)	157,800
5	70	3,870	106,400	5,680 (H)	156,200
6	70	4,200	115,500	5,880 (H)	161,700
7	1400			4,400 (H)	121,000
8	1400			4,250 (H)	116,900
9	1400			4,050 (H)	111,400

B. As Relaxed (50 Hours)

10	70			3,000 (H)	82,500
11	70			2,900 (H)	80,000
12	70			4,680 (H)	122,000

H - Head Failure
(1) Stress calculated at Tensile Stress Area of 0.03637 square inches.

TABLE IV. 1. 4 (continued)

Part No. Bolt - PDP 16-8-21 Material - Waspaloy
Twist-off Nut - TN 12-8 Material - Waspaloy
Size - 1/4-28

2. Double Shear

A. As Received

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
1	-423	15,000	152,800
2	-423	15,900	162,000
3	-423	15,500	157,900
4	70	11,250	114,600
5	70	11,450	116,600
6	70	11,450	116,600
7	1400	9,400	95,800
8	1400	9,150	93,200
9	1400	9,125	93,000

B. As Relaxed (50 Hours)

10	70	12,000	122,500
11	70	12,600	128,500
12	70	12,800	130,500

(2) Stress calculated at Twice Nominal Diameter Area, 0.09817 square inches.

TABLE IV. 1.4 (continued)

Part No. Bolt- PDP 16-8-21 Material - Waspaloy
Twist-off Nut - TN 12-8 Waspaloy
Size - 1/4-28

3. Vibration - ALMA #10

Test No.	Test Temperature, °F	Installation Torque, in. -lbs.	Breakoff Torque, in. -lbs.	No. of Cycles	Degrees Movement	10X Mag. Visual Insp.	Remarks
1	-320	20	135	30,000	0°	No Cracks	Passed
2	-320	16	145	30,000	0°	No Cracks	Passed
3	-320	22	130	30,000	0°	No Cracks	Passed
4	-320	17	150	30,000	0°	No Cracks	Passed
5	-320	12	130	30,000	0°	No Cracks	Passed
6	70	25	140	30,000	0°	No Cracks	Passed
7	70	20	135	30,000	0°	No Cracks	Passed
8	70	20	135	30,000	0°	No Cracks	Passed
9	70	16	140	30,000	180°	No Cracks	Passed
10	70	16	125	30,000	60°	No Cracks	Passed

4. Relaxation @ 1400°F

Initial Preload - 60,000 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi (1)
1	10	1,250	34,400
2	10	1,420	39,000
3	10	1,070	29,400
4	50	800	22,000
5	50	650	17,900
6	50	1,040	28,600

(1) Stress calculated at the Tensile Stress Area of 0.03637 square inches.

TABLE IV.1.5

MECHANICAL PROPERTIES

Part No. Bolt - PDP 16-12-21 Material - Waspaloy
Twist-Off Nut - TN 12-12 Material - Waspaloy
Size - 3/8-24

1. Tensile

A. As Received

Test No.	Test Temperature, °F	Preload, pounds	Preload, psi	Ultimate Load, pounds	Ultimate Stress, psi
1	-423			10,500 (H)	119,600
2	-423			12,700 (H)	144,600
3	-423			13,800 (H)	157,200
4	70	7,750	88,300	10,150 (H)	115,600
5	70	7,750	88,300	9,950 (H)	112,700
6	70	8,100	92,200	10,000 (H)	113,900
7	1400			7,400 (H)	84,300
8	1400			7,450 (H)	84,800
9	1400			7,600 (H)	86,600

B. As Relaxed (50 hours)

10	70			10,500 (H)	119,600
11	70			10,500 (H)	119,600
12	70			10,000 (H)	113,900

(1) Stress calculated at the Tensile Stress Area of 0.08781 square inches.
(H) Head Failure

TABLE IV. 1. 5(continued)

Part No. Bolt - PDP 16-12-21 — Material - Waspaloy
Twist-off Nut - TN 12-12 — Material - Waspaloy
Size - 3/8-24

2. Double Shear

A. As Received

Test No.	Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
1	-423	32,000	144,900
2	-423	30,000	135,900
3	-423	32,300	146,300
4	70	28,700	130,000
5	70	28,200	127,700
6	70	28,300	128,200
7	1400	20,900	94,700
8	1400	21,700	98,300
9	1400	21,700	98,300

B. As Relaxed (50 Hours)

Test No.	Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
10	70	27,000	122,300
11	70	27,300	123,600
12	70	27,200	123,200

(2) Stress calculated at Twice Nominal Diameter Area, 0.2208 square inches.

TABLE IV. 1.5(continued)

Part No. Bolt-PDP 16-12-21 — Material - Waspaloy
Twist-Off Nut - TN 12-12 — Waspaloy
Size - 3/8-24

3. Vibration - Alma #10

Test No.	Temperature, °F	Installation Torque, in.-lbs.	Breakoff Torque in.-lbs.	No. of Cycles	Degrees Movement	10X Mag. Visual Insp.	Remarks
1	-320	50	500	30,000	0°	No cracks	Passed
2	-320	60	500	30,000	0°	No cracks	Passed
3	-320	50	475	30,000	0°	No cracks	Passed
4	-320	50	525	30,000	0°	No cracks	Passed
5	-320	60	575	30,000	0°	No cracks	Passed
6	70	40	500	30,000	0°	No cracks	Passed
7	70	50	500	30,000	0°	No cracks	Passed
8	70	50	500	30,000	0°	No cracks	Passed
9	70	50	525	30,000	0°	No cracks	Passed
10	70	40	475	30,000	0°	No cracks	Passed

4. Relaxation @ 1400°F

Initial Preload - 60,000 psi

Test No.	Hours Run	Residual Stress pounds	Residual Stress psi
1	10	1,920	21,900
2	10	2,850	32,500
3	10	3,350	38,200
4	50	1,600	18,200
5	50	2,400	27,300
6	50	2,620	29,800

TABLE IV. 1. 6

MECHANICAL PROPERTIES

Part No. Bolt - 63439-8-24 Material - 25% C. R. Waspaloy
Nut - TN 12-8 Material - Waspaloy
Size - 1/4-28 (Rolled Threads After Age)

1. Tensile

A. As Received

Test No.	Test Temperature °F	Preload, lbs.	Preload, psi(1)	Ultimate Load, pounds	Ultimate Stress psi(1)
1	-423			11, 300	310, 700
2	-423			11, 620 (N. S.)	319, 500
3	-423			11, 060	304, 100
4	70	3, 450	94, 900	7, 900	217, 200
5	70	3, 450	94, 900	7, 780	213, 900
6	70	4, 050	1 11, 400	7, 700	211, 700
7	1400			4, 300	118, 200
8	1400			4, 580 (N. S.)	125, 900
9	1400			4, 600	126, 400

B. As-Relaxed (50 Hours)

Test No.	Test Temperature °F	Preload, lbs.	Preload, psi(1)	Ultimate Load, pounds	Ultimate Stress psi(1)
10	70			6, 650	182, 800
11	70			7, 125	195, 900
12	70			6, 450	177, 300

N. S. - Nut Stripped

(1) Stress Calculated at the Tensile Stress Area of 0. 03637 square inches.

TABLE IV. 1.6(continued)

Part No. 63439-8-21 — Material - 25% C. R. Waspaloy
TN 12-8 — Material - Waspaloy
Size - 1/4-28 (Rolled Threads After Age)

2. Double Shear

A. As-Received

Test No.	Test Temperature °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
1	-423	17,000	173,200
2	-423	16,400	167,100
3	-423	17,500	178,300
4	70	14,300	145,700
5	70	14,500	147,700
6	70	12,000	122,200
7	1400	9,350	95,200
8	1400	9,000	91,700
9	1400	9,500	96,800
B. As-Relaxed (50 Hours)			
10	70	14,500	147,700
11	70	14,500	147,700
12	70	14,700	149,700

3. Stress Relaxation @1400°F

Initial Stress - 74,200 psi

Test No.	Hours Run	Residual Stress lbs.	Residual Stress psi(1)
1	10	920	25,300
2	10	790	21,700
3	10	625	17,200
4	50	520	14,300
5	50	500	13,700
6	50	450	12,400

(1) Stress Calculated at the Tensile Stress Area of 0.03637 square inches.
(2) Stress Calculated at Twice the Nominal Diameter Area, 0.09817 square inches.

TABLE IV. 1. 7

MECHANICAL PROPERTIES

Part No. Bolt - 63439-8-21 — Material - AF 1753
Twist-Off Nut - TN 12-8 — Material - Waspaloy
Size - 1/4-28 (Rolled Threads Before Age)

1. Tensile

A. As Received

Test No.	Test Temperature, °F	Preload, lbs.	Preload psi(1)	Ultimate Load, pounds	Ultimate Stress psi(1)
1	-423			7,920	217,800
2	-423			7,800	214,500
3	-423			8,050	221,300
4	70	2,800	77,000	5,560	152,900
5	70	2,670	72,200	5,320	146,300
6	70	2,280	62,700	5,660	155,600
7	1600			3,210	88,300
8	1600			3,300	90,700
9	1600			3,175	87,300

B. As Relaxed (50 Hours)

Test No.	Test Temperature, °F	Preload, lbs.	Preload psi(1)	Ultimate Load, pounds	Ultimate Stress psi(1)
10	70			5,940	162,200
11	70			4,300	118,200
12	70	Fastener assembly damaged when disassembled			

(1) Stress Calculated at the Tensile Stress Area of 0.03637 square inches.

TABLE IV. 1. 7 (continued)

Part No. - 63439-8-21 TN 12-8

Material - AF 1753

Material - Waspaloy

Size - 1/4-28 (Rolled Threads Before Age)

2. Double Shear

A. As-Received

Test No.	Test Temperature °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
1	-423	15,500	157,900
2	-423	15,900	162,000
3	-423	16,100	164,000
4	70	13,200	134,500
5	70	13,300	135,500
6	70	13,300	135,500
7	1600	6,050	61,600
8	1600	6,650	67,700
9	1600	6,400	65,200

B. As-Relaxed (50 Hours)

10	70	13,400	136,500
11	70	13,800	140,600
12	70	13,900	141,600

3. Stress Relaxation @1600°F

Initial Stress - 52,200 psi

Test No.	Hours Run	Residual Stress lbs.	Residual Stress psi(1)
1	10	400	11,000
2	10	650	17,900
3	10	310	8,500
4	50	350	9,600
5	50	300	8,200
6	50	310	8,500

(1) Stress Calculated at the Tensile Stress Area of 0.03637 square inches.

(2) Stress Calculated at Twice the Nominal Diameter Area, 0.09817 square inches.

TABLE IV. 1. 8

MECHANICAL PROPERTIES

Part No. Bolt - 63439-12-21
Twist-Off Nut - TN 12-12
Size - 3/8-24 (Rolled Threads Before Age)

Material - AF 1753
Material - Waspaloy

1. Tensile

A. As Received

Test No.	Test Temperature, °F	Preload, lbs.	Preload psi(1)	Ultimate Load, pounds	Ultimate Stress psi(1)
1	-423			13,000	148,000
2	-423			13,900	158,300
3	-423			14,300	162,900
4	70	4,750	54,100	12,500	142,400
5	70	4,400	50,100	12,000	136,700
6	70	5,000	57,000	11,500	131,000
7	1600			6,800	77,400
8	1600			6,600	75,200
9	1600			7,350	83,700
B. As-Relaxed (50 Hours)					
10	70			9,400	107,000
11	70			10,360	118,000
12	70			12,000	136,700

(1) Stress Calculated at the Tensile Stress Area of 0.08781 square inches.

TABLE IV.1.8 (continued)

Part No. - 63439-12-21 Material - AF 1753
TN 12012 Material - Waspaloy
Size - 3/8-24 (Rolled Threads Before Age)

2. Double Shear

A. As-Received

Test No.	Test Temperature °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
1	-423	32,800	148,600
2	-423	35,600	161,200
3	-423	35,500	160,800
4	70	27,700	125,500
5	70	29,500	133,600
6	70	28,900	130,900
7	1600	13,500	61,100
8	1600	13,450	60,900
9	1600	13,240	60,000

B. As-Relaxed (50 Hours)

Test No.	Test Temperature °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
10	70	29,400	133,200
11	70	29,600	134,100
12	70	27,100	122,700

3. Stress Relaxation @1600°F

Initial Stress- 39,400 psi (1)

Test No.	Hours Run	Residual Stress lbs.	Residual Stress psi(1)
1	10	580	6,600
2	10	640	7,300
3	10	600	6,800
4	50	400	4,600
5	50	400	4,600
6	50	100	1,130

(1) Stress Calculated at the Tensile Stress Area of 0.08781 square inches.
(2) Stress Calculated at Twice the Nominal Diameter Area, 0.2208 square inches.

APPENDIX IV - ?

TITANIUM BASE FASTENERS

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TABLE IV. 2. 1

MECHANICAL PROPERTIES

Part No. Bolt - PDP 16-6-20 Material - Ti-5Al-2.5 Sn
Twist-off Nut - HL 70W-6 Material - Al 2024-T4
Size - #10-32

1. Tensile

Test No.	Test Temperature, °F	Preload, pounds	Preload, psi(1)	Ultimate Load, pounds	Ultimate Stress, psi(1)
1	-423			2,870(N.S.)	143,600
2	-423			2,830(N.S.)	141,600
3	-423			3,000(N.S.)	150,100
4	70	1100	55,000	2,015(N.S.)	100,800
5	70	950	47,500	2,095(N.S.)	104,800
6	70	950	47,500	2,090(N.S.)	104,600
7	250			1,880(N.S.)	94,000
8	250			1,890(N.S.)	94,500
9	250			1,900(N.S.)	95,000

2. Double Shear

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress psi(2)
1	-423	7,200	127,000
2	-423	6,720	118,500
3	-423	6,820	120,300
4	70	4,120	72,700
5	70	4,100	72,300
6	70	4,000	70,500
7	250	3,950	69,700
8	250	3,990	70,400
9	250	4,350	76,700

(1) Stress calculated at Tensile Stress Area of 0.01999 square inches.

(2) Stress calculated at Twice Nominal Diameter Area, 0.05671 square inches.
N. S. - Nut Stripped

TABLE IV. 2. 1 (continued)

Part No. Bolt - PDP 16-6-20
Twist-off Nut - HL 70W-6
Size - #10-32

Material - Ti-5Al-2.5Sn
Al 2024-T4

3. Vibration - ALMA #10

Test No.	Test Temperature, °F	Installation Torque, in. - lbs.	Breakoff Torque, in. -lbs.	No. of Cycles	Degrees Movement	10X Mag. Visual Insp.	Remarks
1	-320	15	26	30,000	0°	No Cracks	Passed
2	-320	16	35	30,000	0°	No Cracks	Passed
3	-320	18	34	30,000	0°	No Cracks	Passed
4	-320	15	30	30,000	0°	No Cracks	Passed
5	-320	18	26	30,000	0°	No Cracks	Passed
6	70	12	28	30,000	0°	No Cracks	Passed
7	70	16	28	30,000	0°	No Cracks	Passed
8	70	14	32	30,000	0°	No Cracks	Passed
9	70	14	29	30,000	0°	No Cracks	Passed
10	70	16	31	30,000	0°	No Cracks	Passed

TABLE IV.2.2

MECHANICAL PROPERTIES

Part No. Bolt - PDP 16-8-21 — Material - Ti-5Al-2.5 Sn
Twist-off Nut - HL 70W-8 — Material - Al 2024-T4
Size - 1/4-28

1. Tensile

Test No.	Test Temperature, °F	Preload, pounds	Preload, psi(1)	Ultimate Load, pounds	Ultimate Stress, psi(1)
1	-423			4,930 (N.S.)	135,600
2	-423			5,220 (N.S.)	143,500
3	-423			5,350 (N.S.)	147,100
4	70	2,600	71,500	3,400 (N.S.)	93,500
5	70	1,660	45,600	3,825 (N.S.)	105,200
6	70	2,900	79,700	3,520 (N.S.)	96,800
7	250			3,465 (N.S.)	95,300
8	250			3,300 (N.S.)	90,700
9	250			3,325 (N.S.)	91,400

2. Double Shear

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
1	-423	11,200	114,100
2	-423	11,200	114,100
3	-423	11,950	121,700
4	70	6,720	68,500
5	70	7,600	77,400
6	70	7,200	73,300
7	250	7,000	71,300
8	250	6,900	70,300
9	250	6,500	66,200

(1) Stress calculated at Tensile Stress Area of 0.03637 square inches.
(2) Stress calculated at Twice Nominal Diameter Area, 0.09817 square inches.
N.S. - Nut Stripped

TABLE IV. 2. 2 (continued)

Part No. Bolt - PDP 16-8-21 | Material - Ti-5Al-2. 5Sn
Twist-off Nut - HL 70W-8 | Al 2024-T4
Size - 1/4-28

3. Vibration - ALMA #10

Test No.	Test Temperature, °F	Installation Torque, in. - lbs.	Breakoff Torque, in. -lbs.	No. of Cycles	Degrees Movement	10X Mag. Visual Insp.	Remarks
1	-320	12	62	30,000	0°	No Cracks	Passed
2	-320	10	60	30,000	0°	No Cracks	Passed
3	-320	14	65	30,000	0°	No Cracks	Passed
4	-320	14	68	30,000	0°	No Cracks	Passed
5	-320	12	70	30,000	0°	No Cracks	Passed
6	70	13	70	8,000	Complete Motion		Failure
7	70	16	68	6,000	Complete Motion		Failure
8	70	14	75	30,000	0°	No Cracks	Passed
9	70	20	70	30,000	0°	No Cracks	Passed
10	70	14	70	8,000	Complete Motion		Failure

TABLE IV. 2. 3

MECHANICAL PROPERTIES

Part No. Bolt - PDP 16-12-21 — Material - Ti5Al-2.5 Sn
Twist-off Nut - HL 70W-12 — Material - Al 2024-T4
Size - 3/8-24

1. Tensile

Test No.	Test Temperature, °F	Preload, pounds	Preload, psi(1)	Ultimate Load, pounds	Ultimate Stress, psi(1)
1	-423			10,700 (H)	121,900
2	-423			12,500 (H)	142,400
3	-423			11,900 (H)	135,500
4	70	6,000	68,300	8,500 (H)	96,800
5	70	5,450	62,100	8,630 (H)	98,300
6	70	5,950	67,800	8,440 (H)	96,100
7	250			6,950 (H)	79,100
8	250			6,800 (H)	77,400
9	250			6,925 (H)	78,900

2. Double Shear

Test No.	Test Temperature, °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
1	-423	30,300	137,500
2	-423	29,000	131,300
3	-423	28,500	129,100
4	70	19,700	89,500
5	70	22,300	101,000
6	70	20,500	94,500
7	250	19,200	87,000
8	250	20,000	90,600
9	250	20,900	94,700

H - Head Failure

(1) Stress calculated at Tensile Stress Area of 0.08781 square inches.
(2) Stress calculated at Twice Nominal Diameter Area, 0.2208 square inches.

TABLE IV. 2. 3(continued)

Part No. Bolt - PDP 16-12-21
Twist-off Nut - HL 70W-12
Size - 3/8-24

Material - Ti-5Al-2.5Sn
Al 2024-T4

3. Vibration - ALMA #10

Test No.	Test Temperature, °F	Installation Torque, in.-lbs.	Breakoff Torque, in.-lbs.	No. of Cycles	Degrees Movement	10X Mag. Visual Insp.	Remarks
1	-320	60	210	30,000	0°	No Cracks	Passed
2	-320	60	215	30,000	0°	No Cracks	Passed
3	-320	60	195	30,000	0°	No Cracks	Passed
4	-320	55	200	30,000	0°	No Cracks	Passed
5	-320	60	210	30,000	0°	No Cracks	Passed
6	70	60	200	30,000	0°	No Cracks	Passed
7	70	45	200	30,000	0°	No Cracks	Passed
8	70	50	210	30,000	0°	No Cracks	Passed
9	70	50	220	30,000	0°	No Cracks	Passed
10	70	52	200	30,000	0°	No Cracks	Passed

TABLE IV. 2. 4

MECHANICAL PROPERTIES

Part No. Bolt - PTF 16-4-21
Nut - HL 70W-8
Size - 1/4-28

Material - Ti 5Al-2. 5Sn (ELI)
Material - AL 2024-T4

1. Tensile

A. As Received

Test No.	Test Temperature °F	Preload, lbs.	Preload, psi(1)	Ultimate Load, pounds	Ultimate Stress psi(1)
1	-423			4,800 (N. S.)	132,000
2	-423			4,470 (N. S.)	122,900
3	-423			4,950 (N. S.)	136,100
4	70	2,900	79,700	3,400 (N. S.)	93,500
5	70	2,850	78,300	3,280 (N. S.)	90,200
6	70	1,900	52,200	3,240 (N. S.)	89,100
7	250			3,280 (N. S.)	90,200
8	250			3,200 (N. S.)	88,000
9	250			3,100 (N. S.)	85,200

N. S. - Nut Stripped

(1) Stress Calculated at the Tensile Stress Area of 0. 03637 square inches.

TABLE IV. 2. 4 (continued)

Part No. - PTF 16-4-21
HL 70W-8
Size - 1/4-28

Material - Ti 5Al-2. 5Sn (ELI)
Material - AL 2024-T4

2. Double Shear

A. As-Received

Test No.	Test Temperature °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
1	-423	12,550	127,800
2	-423	12,000	122,200
3	-423	13,300	135,500
4	70	9,100	92,700
5	70	9,700	98,800
6	70	8,200	83,500
7	250	8,000	81,500
8	250	7,900	80,500
9	250	8,450	86,100

(2) Stress Calculated at Twice the Nominal Diameter Area, 0.09817 square inches.

TABLE IV. 2. 5

MECHANICAL PROPERTIES

Part No. Bolt - PTF 16-6-21 Material - Ti 5Al-2.5Sn (ELI)
Nut - HL 70W-12 Material - Al 2024-T4
Size - 3/8-24

1. Tensile

A. As Received

Test No.	Test Temperature °F	Preload, lbs.	Preload, psi[1]	Ultimate Load, pounds	Ultimate Stress, psi[1]
1	-423			13,200 (N.S.)	150,300
2	-423			13,600 (N.S.)	154,900
3	-423			12,800 (N.S.)	145,800
4	70	4,930	56,400	9,220 (N.S.)	105,000
5	70	5,400	61,500	8,900 (N.S.)	101,400
6	70	4,970	56,600	9,100 (N.S.)	103,600
7	250			8,400	95,700
8	250			8,600	97,900
9	250			8,650	98,500

(1) Stress Calculated at the Tensile Stress Area of 0.08781 square inches.

TABLE IV. 2. 5 (continued)

Part No. - PTF 16-6-21
HL 70W-6
Size - 3/8-24

Material - Ti 5Al-2. 5Sn (ELI)
Material - AL 2024-T4

2. Double Shear

A. As-Received

Test No.	Test Temperature °F	Ultimate Load, lbs.	Ultimate Stress, psi[(2)]
1	-423	29,850	135,200
2	-423	29,500	133,600
3	-423	24,880	112,700
4	70	17,700	80,200
5	70	18,700	84,700
6	70	18,400	83,300
7	250	17,000	77,000
8	250	18,600	84,200
9	250	17,500	79,300

(2) Stress Calculated at Twice the Nominal Diameter Area, 0. 2208 square inches.

APPENDIX IV - 3

COBALT BASE FASTENERS

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TABLE IV. 3. 1

MECHANICAL PROPERTIES

Part No. Bolt - 63439-8-21
Twist-Off Nut - TN-12-8
Size - 1/4-28 (Rolled Threads Before Age)

Material - 30% C. R. L605
Material - Waspaloy

1. Tensile

A. As Received

Test No.	Test Temperature, °F	Preload, lbs.	Preload, psi(1)	Ultimate Load, pounds	Ultimate Stress, psi(1)
1	-423			6,740	184,200
2	-423			6,190	170,200
3	-423			5,980	164,400
4	70	4,650	127,900	7,500	206,200
5	70	4,350	119,600	7,350	202,100
6	70	3,750	103,100	8,700	239,200
7	1600			2,625 (H)	72,200
8	1600			2,490 (N. S.)	68,500
9	1600			2,800	77,000
B. As-Relaxed (50 Hours)					
10	70			7,000	192,500
11*	70			8,250	226,800
12	70			Not Tested	

H - Head Failure
N. S. - Nut Stripped
*As Relaxed at 1400°F

(1) Stress Calculated at the Tensile Stress Area of 0.03637 Square Inches.

TABLE IV. 3. 1 (continued)

Part No. - 63439-8-21 Material - 30% C. R. L605
TN 12-8 Material - Waspaloy
Size - 1/4-28 (Rolled Threads Before Age)

2. Double Shear

A. As-Received

Test No.	Test Temperature °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
1	-423	16,100	164,000
2	-423	17,300	176,200
3	-423	15,700	159,900
4	70	11,900	121,200
5	70	10,000	101,900
6	70	9,500	96,800
7	1600	4,800	48,900
8	1600	4,950	50,400
9	1600	4,800	48,900

B. As-Relaxed (50 Hours)

Test No.	Test Temperature °F	Ultimate Load, lbs.	Ultimate Stress, psi(2)
10	70	12,600	128,300
*11	70	13,100	133,400
12	70	Not Tested	

3. Stress Relaxation @1400°F

Initial Stress - 52,200 psi (1)

Test No.	Hours Run	Residual Stress lbs.	Residual Stress psi(1)
1*	10	-	-
2*	10	-	-
3	10	400	11,000
4	50	-	-
5	50	-	-
6	50	250	6,900

(1) Stress Calculated at the Tensile Stress Area of 0.03637 square inches.
(2) Stress Calculated at Twice the Nominal Diameter Area, 0.09817 square inches.
*Specimens #1 & 2 were tested at 1600°F. Residual stresses for these parts was zero in less than 10 hours. The test temperature for #3 specimen was subsequently dropped to 1400°F.