Westinghouse Electric Company

Plant Apparatus Division
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WPAD-PHT-ENG-11419
May 26, 1998

Assistant Naval Sea Systems Command
Technical Representative - Pittsburgh
500 Penn Center Boulevard
Pittsburgh, Pennsylvania 15235-5713

Subject: FINAL DISTRIBUTION AND SUBMITTAL FOR PUBLICATION OF WPAD-QES-ME-1206 "EVALUATION OF REPLACEMENT THREAD LUBRICANTS FOR RED LEAD AND GRAPHITE IN MINERAL OIL", FOR NAVSEA INFORMATION

References:
(a) NAVSEA letter Ser 08L/95-06480 dated July 25, 1995
(b) WPAD letter WPAD-ES-ME-1737 dated May 12, 1995
(c) WPAD letter WPAD-ES-ME-2091, dated August 14, 1996
(d) NAVSEA letter Ser 08S/96-12004, dated September 20, 1996
(e) WPAD draft report WPAD-QES-ME-1206 dated June 30, 1997
(f) WPAD letter WPAD-RE-PCR-6514, dated July 3, 1997
(g) NAVSEA memo 97371, dated August 19, 1997

Keywords: LUBRICANT + FASTENER + RED LEAD + MOLYKOTE P37

Dear Sir:

PURPOSE

This letter transmits the subject report for NAVSEA information, for program use and for publication by the Defense Technical Information Center and the Department of Energy's Office of Scientific and Technical Information.

BACKGROUND

NAVSEA, in reference (a), approved with comments the WPAD recommendation (reference (b)) to replace Red Lead and Graphite in Mineral Oil (RLGMO) per MIL-L-24479 with anti-galling compound per A-A-59004 (Dow Corning Molykote P37). Reference (a) requested WPAD to prepare a report suitable for unrestricted public release documenting the test results. Reference (a) also requested WPAD to consider whether further confirmatory coefficient of friction and corrosion testing of Molykote P37 is necessary. WPAD subsequently submitted (reference (c)) and NAVSEA approved with comment (reference (d)) test specifications for additional coefficient of friction and corrosion testing.

After completing the additional coefficient of friction testing approved by reference (d), WPAD prepared the draft report WPAD-QES-ME-1206 (reference (e)) discussing the RLGMO replacement evaluation for unrestricted public release. Reference (e) was submitted to NAVSEA via ANSTR-Pittsburgh in reference (f) for review for release to the public. Reference (g) approved the release of WPAD-QES-ME-1206 for unlimited distribution subject to the following comments:

- Delete reference to future (corrosion) work.
- Perform a review by a technical publications group to ensure proper formatting.

A mark up copy of the report was provided with additional editorial comments.

DISCUSSION

In order to comply with the NAVSEA request for a review by a technical publications group, the WPAD Technical Manuals Section performed an editorial review of reference (e). Comments generated by this review along with the mark up comments provided by NAVSEA in reference (g) have been incorporated. In addition the section discussing the future corrosion efforts has been deleted from the final report. The final version of WPAD-QES-ME-1206 is provided as Enclosure (1).

As originally requested in reference (a), WPAD has contacted both the Defense Technical Information Center and the Department of Energy's Office of Scientific and Technical Information and has prepared the necessary forms for submittal and publication. These completed forms are included on a limited distribution as Enclosures (2) and (3). Submittal to these organizations is made via this letter.

CONCLUSION

This letter provides for program use and NAVSEA information, the final report of the coefficient of friction testing generated during the RLGMO replacement evaluation. Furthermore, this letter provides the subject report to the Defense Technical Information Center and the Department of Energy's Office of Scientific and Technical Information for unrestricted public release.

PRIME CONTRACTOR AND SHIPYARD ACTION

None. This letter provides the final copy of the subject report for use.

NAVSEA ACTION

None. This letter is for information and transmits the final copy of the subject report.

Very truly yours,

Thomas L. Jungling

T.L. Jungling, Senior Engineer
Steam Generator Engineering Section
Pump & Heat Transfer Activity

Approved by:

W.J. Bohenick, Manager
Steam Generator Engineering Section
Pump & Heat Transfer Activity

Enclosures:

1) WPAD-QES-ME-1206, "Evaluation of Replacement Thread Lubricants for Red Lead and Graphite in Mineral Oil," dated April 30, 1998
2) Standard Form 298, "Report Documentation Page" (For DTIC)
3) DOE Form 1332.15, "Announcement and Distribution of Department of Energy Scientific and Technical Information" (For DOE OSTI)

ENCLOSURE 2 to
WPAD-PHT-ENG-11419

Standard Form 298

REPORT DOCUMENTATION PAGE

DEFENSE TECHNICAL INFORMATION CENTER

(DOD DTIC)

Westinghouse Electric Company
Plant Apparatus Division
500 Penn Center Boulevard
Pittsburgh, PA 15235-5713

REPORT DOCUMENTATION PAGE

Form Approved
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12a. DISTRIBUTION / AVAILABILITY STATEMENT
Statement A applies

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
Eight commercially available thread lubricants were evaluated to determine the best replacement for Red Lead and Graphite in Mineral Oil (RLGMO). The evaluation included coefficient of friction testing, high temperature anti-seizing testing, room temperature anti-galling testing, chemical analysis for detrimental impurities, corrosion testing, off-gas testing, and a review of health and environmental factors. The coefficient of friction testing covered a wide variety of factors including stud, nut, and washer materials, sizes, manufacturing methods, surface coatings, surface finishes, applied loads, run-in cycles, and relubrication. Only one lubricant, Dow Corning Molykote P37, met all the criteria established for a replacement lubricant. It has a coefficient of friction range similar to RLGMO. Therefore, it can be substituted directly for RLGMO without changing the currently specified fastener torque values for the sizes, materials and conditions evaluated. Other lubricants did not perform as well as Molykote P37 in one or more test or evaluation categories.

14. SUBJECT TERMS
Lubricant, Fastener, Red Lead, Molykote P37

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17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	NONE

ENCLOSURE 3 to
WPAD-PHT-ENG-11419

DOE Form 1332.15

ANNOUNCEMENT AND DISTRIBUTION OF DEPARTMENT OF ENERGY SCIENTIFIC AND TECHNICAL INFORMATION

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2

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PART I Information Product Identification

A. Identifiers

1. Product/Report Nos. WPAD-QES-ME-1206

2. Award/Contract Nos. N00024-89-C-4003

3. Title Evaluation of Replacement Thread Lubricants for Red Lead and Graphite in Mineral Oil

(Grantees and Awardees skip to Part 1.B.)

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6. Project ID(s) ______

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9. Information Product Filename ______

B. Information Product Description

X 1. Report

a. Type ___ Quarterly ___ Semiannual ___ Annual X Final ___ Topical

___ Other *(Specify)* ______

b. Dates covered *(mm/dd/yyyy)* ___/___/___ thru ___/___/___

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a. Type ___ Conference paper ___ Published proceedings ___ Other *(Specify)* ______

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___ 3. **Additional instructions/explanations** ___

D. Contact *(Person knowledgeable about the information product and its submission)*

Name Thomas Jungling Position Senior Engineer Phone 412-829-8787

Organization Westinghouse Plant Apparatus Division E-Mail ___

PART III Bibliographic Information

(Note: Providing the following information is optional. For information products that are to be included in the OpenNet Database, the following information will be used for the OpenNet Database records. For all information products, it will be used in announcing those products, as appropriate, to other parts of the DOE community.)

A. Personal Author/Affiliation Thomas L. Jungling, David R. Rauth, Daniel Goldberg

B. Performing Organization Westinghouse Electric Company, Plant Apparatus Division

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E. Abstract Eight commercially available thread lubricants were evaluated to determine the best replacement for Red Lead and Graphite in Mineral Oil (RLGMO). The evaluation included coefficient of friction testing, high temperature anti-seizing testing, room temperature anti-galling testing, chemical analysis for detrimental impurities, corrosion testing, off-gas testing, and a review of health and environmental factors. The coefficient of friction testing covered a wide variety of factors including stud, nut, and washer materials, sizes, manufacturing methods, surface coatings, surface finishes, applied loads, run-in cycles, and relubrication. Only one lubricant, Dow Corning Molykote P37, met all the criteria established for a replacement lubricant. It has a coefficient of friction range similar to RLGMO. Therefore, it can be substituted directly for RLGMO without changing the currently specified fastener torque values for the sizes, materials and conditions evaluated. Other lubricants did not perform as well as Molykote P37 in one or more test or evaluation categories.

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EVALUATION OF REPLACEMENT THREAD LUBRICANTS FOR RED LEAD AND GRAPHITE IN MINERAL OIL

WPAD-QES-ME-1206

T.L. Jungling, D.R. Rauth and D. Goldberg

April 30, 1998

NOTE

NOTICE

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DISCLAIMER

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ABSTRACT

Eight commercially available thread lubricants were evaluated to determine the best replacement for Red Lead and Graphite in Mineral Oil (RLGMO). The evaluation included coefficient of friction testing, high temperature anti-seizing testing, room temperature anti-galling testing, chemical analysis for detrimental impurities, corrosion testing, off-gas testing, and a review of health and environmental factors. The coefficient of friction testing covered a wide variety of factors including stud, nut, and washer materials, sizes, manufacturing methods, surface coatings, surface finishes, applied loads, run-in cycles, and relubrication. Only one lubricant, Dow Corning Molykote P37, met all the criteria established for a replacement lubricant. It has a coefficient of friction range similar to RLGMO. Therefore, it can be substituted directly for RLGMO without changing the currently specified fastener torque values for the sizes, materials and conditions evaluated. Other lubricants did not perform as well as Molykote P37 in one or more test or evaluation categories.

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Evaluation of Replacement Thread Lubricants For Red Lead And Graphite in Mineral Oil

I. Introduction

Westinghouse uses hundreds of bolted closures on power plants, employing fastener materials including high-strength alloy steels, nickel-based alloys, copper-nickel, austenitic stainless steels and aluminum alloys. Since many of these fasteners rely on torque to establish precise preload stresses in the bolted closure, the thread lubricant must be well characterized with a predictable and narrow coefficient of friction range. For closures in some high temperature systems the purity of the lubricant is essential. The lubricant must contain very low levels of detrimental materials, such as mercury, sulfur, phosphorus, halogens and low melting points metals. Also, in high-temperature systems the lubricant must possess adequate anti-seizing properties to permit disassembly and maintenance of the hardware.

Other characteristics of concern relate to the health and environmental aspects of the lubricant. Lubricants are used in confined spaces; therefore, they must have minimal toxicity to the workers both during initial application and at elevated temperatures where volatile toxic gases may be produced. Lubricants that are considered environmentally hazardous will result in additional disposal cost at the end of life.

II. Background

For more than 20 years Westinghouse has specified the use of Red Lead and Graphite in Mineral Oil (RLGMO) per the Military Specification MIL-L-24479 as a thread lubricant for fastener applications, including closure fasteners on high-pressure and high-temperature components. Many of these fasteners rely on torque to establish precise preload stresses. RLGMO has provided a predictable and narrow coefficient of friction range, resulting in excellent performance. Based on testing with a limited number of fastener alloys, the design coefficient of friction range of RLGMO was established to be from 0.05 to 0.11. This range has proven to be narrow enough so that a single torque value can be assigned to a fastener design. Based on analysis, a single torque value can produce an installation load will not exceed the design stress limits on the fastener while achieving the necessary preload for operation.

However, concerns regarding the hazardous nature of lead both to the worker and for eventual disposal of hardware, as well as more restrictive environmental regulations regarding the use of lead, prompted Westinghouse to evaluate, qualify, and prepare a specification for the procurement of a non-hazardous commercial lubricant as a replacement for RLGMO. As a secondary objective, Westinghouse evaluated if the replacement lubricant could also replace a second widely used thread lubricant, Molybdenum DiSulfide in Isopropanol (MDSI). MDSI is used interchangeably with RLGMO on many alloy steel fasteners as well as in high temperature applications on nickel-based alloys.

Objectives

The objective of the original phase of testing was to evaluate and identify a non-hazardous commercial lubricant to replace RLGMO, possessing a coefficient of friction range which duplicates that of RLGMO. The objective of the second phase of testing was to expand the coefficient of friction database for the selected lubricant with additional alloy combinations, fastener sizes and manufacturing methods. This report summarizes the process used to select the replacement lubricant and provides the coefficient of friction data for use with this lubricant.

Overall Approach

Based on a review of product literature and material safety data sheets (MSDS) for 14 commercially available anti-seizing lubricants, eight candidate lubricants that did not contain obvious detrimental materials were selected for testing as potential replacements. These lubricants fell into three broad categories based on their anti-seize additives: nickel-based, copper-based or metallic-free. In addition to the eight candidate lubricants, both RLGMO and MDSI were included in the test plan to act as controls and provide comparisons to current experience.

In order to select a suitable replacement for RLGMO and MDSI, the following characteristics (acceptance criteria) were evaluated:

- Coefficient of friction range (similar to the established range for RLGMO, that is, 0.05 to 0.11).
- Anti-seizing capability (preclude seizing after service at temperatures up to 650°F).
- Anti-galling capability (preclude galling of fasteners at ambient temperature during initial torquing).
- Detrimental material content (less than 250 parts per million (ppm) of low melting point metals, halides, sulfur, and phosphorus and less than 10 ppm of mercury).
- Health related concerns (minimal worker safety precautions required and no release of toxic gases during heating).
- Environmental concerns (that is, it is not a hazardous material relative to disposal).
- Corrosivity (that is, it will not cause general or localized corrosion or exacerbate stress induced corrosion of the fastener or adjacent materials).

After this evaluation had been completed and the replacement lubricant determined, additional coefficient of friction testing was conducted to expand the database to a number of prototypic fastener combinations.

III. Experimental Procedures

Candidate Lubricants

A compositional summary of the 10 lubricants evaluated is given in Table 1. The compositions listed were based on manufacturer's literature as well as the corresponding MSDS.

Table 1 Test Lubricants and Qualitative Composition

LUBRICANT		COMPOSITION, PERCENT			
No.	Manufacturer, Name	Copper	Nickel	Graphite	Other
1	**Fel Pro**, N5000, High Performance		20	25	
2	**Fel Pro**, N1000	20		25	
3	**Huron**, Neolube No. 650			40-60	25-50 Mineral Oil 2-25 Petrolatum
4	**Jet Lube**, NIKAL, Nuclear Grade		30		Polyisobutene
5	**Fel Pro**, N2000, High Purity	25		20	25 Petroleum Distillates
6	**Bostik**, Never Seez - Ni/Nuclear Grade		18		Talc Bentone Grease
7	**Lub-O-Seal**, NM-91 Anti-Seize, Nuclear Grade			unknown	
8	**Dow Corning**, Molykote P37 Paste			21	50 Mineral Oil 14 Calcium Hydroxide 9 Zirconium Oxide 1 Silica
9	Molybdenum Disulfide in Isopropanol (MDSI) MIL-L-24478				60 Molybdenum Disulfide 40 Isopropanol
10	Red Lead and Graphite in Mineral Oil (RLGMO) MIL-L-24479			16	60 Lead Oxide 24 Mineral Oil
	Fel Pro, N7000 (Phase II testing only)			20	25 Calcium Oxide

Functional Testing

A test program was developed to evaluate each lubricant's coefficient of friction, anti-seizing, and anti-galling capability. This testing was designed to provide a statistically significant database on all ten lubricants so that comparisons could be made between the candidate lubricants, RLGMO and MDSI. These comparisons of performance would form the basis for the best replacement for RLGMO and possibly MDSI. For the evaluation of anti-galling and anti-seizing resistance three material combinations were used: Type 304 (Unified Numbering System (UNS) S30400) stainless steel studs and nuts, alloy steel (AISI 4140 - Grade B7 (UNS G41400)) studs and carbon steel (UNS K04002) nuts and Monel K-500 (UNS N05500) studs with Monel 400 (UNS N04400) nuts. The stainless steel combination was judged most likely to result in galling for a poor or marginal lubricant. These combinations allow the evaluation of actual fastener materials as well as assuring test "failures", so that the candidate lubricants can be ranked. Due to the relatively low usage of stainless steel fasteners in actual hardware, Alloy 625 (Inconel 625 - UNS N06625) studs and nuts replaced the stainless steel combination in the coefficient of friction testing. This phase of testing also included the K-500/Monel 400 combination as well as both bare and phosphate coated alloy steel studs. The studs were 3/4-10UNC-2A with rolled threads. For the above combinations, hardened carbon steel washers were used to represent a prototypical bearing surface. The washers were fixed so they could not rotate during the test which could have resulted in erroneous coefficient of friction values. For each test a new (previously unused) stud, nut, and washer were employed.

Prior to testing, the studs, nuts, and washers were cleaned in sequential baths of trichloroethane and acetone and dried. Studs were visually inspected for burrs and defects which could lead to premature galling during the tests. Studs and nuts were assembled by hand to ensure that there was no interference or binding prior to testing. Each test assembly and its individual components were engraved with a unique identification number representing the alloy, the lubricant, and the test set number.

Coefficient of Friction Testing

Phase I Testing

Two Skidmore-Wilhelm Torque Tension units equipped with calibrated load cells, shown in Figure 1, were utilized for measuring the load on the test assembly. Typical test assemblies are shown in Figure 2. For each material/lubricant combination, five duplicate test assemblies were loaded in five equal increments up to a load value equivalent to 2/3 of the stud material minimum yield strength. At each increment the torque value was recorded. Each loading cycle was repeated four times. The four loading cycles were defined as follows:

Cycle A (Run-In)	Representing a new, unused fastener torqued for the first time.
Cycle B (Design)	Representing a fastener having been subjected to a previous torquing cycle, disassembled, additional lubricant applied and retorqued. This generally represents actual fastener installation practice, and is considered most prototypical.
Cycle C (Used Stud Run-In)	Representing a used fastener that has been removed from the original hardware, cleaned, relubricated and retorqued.
Cycle D (Used Stud Design)	Representing a used fastener that has been removed from the original hardware, cleaned, relubricated, retorqued once, disassembled additional lubricant applied and retorqued again, that is, a used fastener subjected to Cycle B conditions.

Between Cycles A and B, and Cycles C and D, the nuts were run back far enough to add additional lubricant, and the assembly was retorqued in the same five-step sequence as the previous cycle. This was done to simulate the installation procedure currently in use. A complete cleaning of the assembly was performed between Cycles B and C to simulate a maintenance event during the life of the component. During the maintenance event the stud is removed, cleaned and reinstalled. Therefore, Cycle D represents the typical coefficients of friction seen during the installation of a "used stud."

The torque wrenches and the Skidmore-Wilhelm torque-tension test units were calibrated prior to and at the completion of testing. The calibrations were factored directly into the equation used to calculate the coefficient of friction values. In addition to the initial calibration, the torque wrenches also received a daily calibration at the highest torque value expected during that day's tests. The accuracy of the torque wrenches was $\pm$ 2 percent.

Phase II Testing

After the completion of the initial program described above and selection of Molykote P37 as the replacement lubricant, a follow-up program was designed to establish coefficient of friction ranges for additional fastener parameters. The test sequence was a simplified version of the Phase I testing and was defined as:

Cycle 1 (Run-In) — Representing a new, unused fastener torqued for the first time.

Cycle 2 (Design) — Representing a fastener having been subjected to a previous torquing cycle, disassembled, additional lubricant applied and retorqued. This generally represents actual fastener installation practice, and is considered most prototypical.

Cycle 3 (Design) — Representing a duplicate of the Cycle 2 loading step to increase the available data.

This simplified sequence was selected since the data from Cycles B and D in the initial phase were unaffected by Cycle C. This testing was designed to evaluate:

- additional fastener (stud and nut) material combinations
- different size fasteners - 3/4 to 2 inches in diameter
- different bearing (washer) materials
- different manufacturing methods - machined and rolled threads
- a new metallic-free lubricant as a potential alternate to Molykote P37

The additional fastener materials included K-500 studs with K-500 nuts, titanium (UNS R56401) studs with Alloy 625 nuts, Type 17-4PH (UNS S17400) studs with Type 316 (UNS S31600) stainless steel nuts. The detailed listing of materials, sizes and surface treatments are listed in Table 7. Except as noted in the following list, five duplicate assemblies were used for each lubricant tested. The following exceptions to the five assemblies were:

- Due to cost considerations, only one assembly was provided for testing of RLGMO, for the four machined Alloy 625 sets which ranged in size from 0.75, 1.75 and 2.0 inches in diameter.
- Four Type 17-4PH/Type 316 test assemblies used a Type 316 washer, while the fifth set was tested with a carbon steel washer to investigate the effect of the bearing material.
- Two K-500/K-500 assemblies were tested with each of the following washer materials for comparison to those tested with carbon steel washers: HY-80 (UNS J42015), Type 430 (UNS S43000) stainless steel, and Alloy 625.

Anti-Seizing Testing

The high temperature anti-seizing test required exposing test assemblies, consisting of a stud with two nuts torqued to a load representing 2/3 of the yield strength of the stud material, to a temperature of 650°F. For each lubricant/material combination, one test assembly was removed from the test oven at time intervals of one, three and six weeks. The final two test assemblies were removed after ten weeks. After each test assembly was removed from the oven, it was disassembled, inspected for the condition of the residual lubricant, cleaned and inspected for signs of material degradation, such as pitting or general corrosion. The installation and breakaway torque values were recorded for each cycle.

Anti-Galling Testing

For each material and lubricant combination, two test assemblies were subjected to up to twelve torquing and untorquing cycles. For each new test assembly, lubricant was applied to the stud and nut threads as well as the nut and washer bearing surfaces. After the fourth and eighth cycle the assembly was removed and cleaned of residual lubricant, reassembled and fresh lubricant was applied. For the first eight cycles, the assemblies were loaded to 2/3 of the minimum yield strength of the stud material. For the final four cycles, the assemblies were loaded to the minimum yield strength value. The installation and breakaway torque values were recorded for each cycle and any occurrence of galling was recorded. Because the assemblies were only relubricated after the fourth and eighth cycles, the probability of galling was enhanced. After the completion of the testing, each assembly was visually inspected at 15 to 20X magnification for evidence of galling. For each of the three alloy combinations, an initial test assembly was tested without lubricant to demonstrate that galling would occur.

Detrimental Material Evaluation

A sample of each candidate lubricant in its original container was evaluated for the following detrimental materials: mercury, antimony, bismuth, cadmium, lead, tin, zinc, sulfur, and phosphorus, and the following halides: chloride, bromide, and fluoride.

Health and Environmental Testing

Although details are beyond the scope of this paper, the following actions were taken for each candidate lubricant in order to assess the health and environmental issues:

- Off-gas testing was performed to determine if toxic gases would be released at 650°F.
- A hazardous material review was conducted in accordance with 40 CFR Part 261.
- A toxicological evaluation in accordance with the guidelines established by the International Agency for Research on Cancer (IARC), the American Conference of Governmental Industrial Hygienists (ACGIH) and the Environmental Protection Agency (EPA) was performed.

Corrosion Testing

The eight candidate replacement lubricants, MDSI, and RLGMO were applied to seven groups of representative fastener alloys, as listed in Table 2. The fastener assemblies were 3/4-10UNC studs and nuts.

Table 2 Corrosion Test Alloy Combinations

STUD MATERIAL	NUT MATERIAL
Steel, AISI 4140 Grade B7 (UNS G41400)	Steel ASTM A194, Grade 4
Type 304 Stainless steel (UNS S30400)	Type 304 Stainless steel
70/30 Copper Nickel (UNS C71500)	70/30 Copper Nickel (UNS C71500)
Nickel Aluminum Bronze (UNS C63200)	Nickel Aluminum Bronze (UNS C63200)
Monel K-500 (UNS N05500) QQ-N-286, Class A	Monel 400 (UNS N04400) QQ-N-281, Class A
Alloy 625 (UNS N06625) ASTM B446, Grade 1	Alloy 625 ASTM B446, Grade 1
Titanium (UNS R50400) ASTM B348, Grade 2	Titanium ASTM B348, Grade 2

The corrosion test program consisted of four categories of tests, which are summarized as follows:

Test 1 - Localized Fastener Corrosion Due To Lubricant In Air

In this test, studs and nuts of each fastener alloy were lubricated with one of the ten original lubricants. Four nuts of the corresponding alloy were assembled on each lubricated stud to provide the test specimen. Some nut faces were coated with lubricant and some were cleaned of lubricant. The test specimen therefore contained lubricant filled crevices, lubricant covered noncreviced surfaces and clean noncreviced surfaces. The test specimens were placed in an oven with an air atmosphere at a temperature of 250°F ± 10°F and held for 750 hours. The test specimens were then cleaned and visually examined to establish whether any surfaces covered by the lubricant were more heavily corroded than surfaces cleaned of lubricant.

Test 2 - Localized Fastener Corrosion Due To Lubricant In Salt Water

In this test, studs and nuts of each fastener alloy were lubricated with each of the ten original lubricants. Four nuts of the corresponding alloy were assembled on each lubricated stud to provide the test specimen. Some nut faces were coated with lubricant and some were cleaned of lubricant. The test specimen therefore contained lubricant filled crevices, lubricant covered noncreviced surfaces and clean noncreviced surfaces. Unlubricated control test specimens of each fastener alloy were also prepared. The test specimens were placed in a synthetic salt water test solution, heated to a temperature of 175°F ± 5°F and held for 750 hours. A separate test solution was used for each test specimen. The test specimens were then cleaned and visually examined to establish whether any lubricated test specimen was more heavily corroded than the unlubricated control specimen of the same fastener alloy.

Test 3 - Environmentally Induced Corrosion Due To Lubricant In Salt Water Or In Distilled Water

In this test, studs and nuts of each fastener alloy were lubricated with each of the ten original lubricants. Some of the lubricated studs and nuts were placed in an oven at approximately 650°F for several hours to volatilize the lubricant. Two nuts of the corresponding alloy were assembled on each stud. A spacer, fabricated from a nut of the corresponding alloy, was installed between the two nuts. The stud was then placed in a tensile test machine and loaded to 90 percent of the stud yield strength reported in the certified material test report. The two nuts were hand tightened against the spacer and the applied load was then released to provide the test specimen. Unlubricated control test specimens of each fastener alloy were also prepared.

For each lubricant and for each fastener alloy, sets of three test specimens were prepared consisting of one lubricated test specimen (as-lubricated), one test specimen made with lubricated and volatilized studs and nuts (volatilized), and one unlubricated test specimen (unlubricated). One set of test specimens was placed in a common synthetic salt water test solution, and one set of test specimens was placed in a common distilled water test solution. One unlubricated control test specimen for each fastener alloy was also tested in a separate salt water test solution and one in a separate distilled water test solution. The test solutions were heated to a minimum of 170°F and allowed to evaporate off water vapor so that the test solutions evaporated in approximately 150 hours.

The test specimens were then cleaned and examined visually and by fluorescent penetrant inspection to establish whether a test specimen in the set for any lubricant showed defects that were not found in the unlubricated control specimen of the same fastener alloy tested in the same medium. Studs were fluorescent-penetrant inspected prior to testing to identify defects that could interfere with the post-test inspection. Studs with defects were excluded from testing where possible.

<u>Test 4</u> - Galvanically Assisted Localized Corrosion

In this test 3/4-10UNC studs of titanium alloy Grade 2 and carbon steel nuts were lubricated with each of the 10 original lubricants. Some of the lubricated studs and nuts were placed in an oven at approximately 650°F for several hours to volatilize the lubricant. One nut was assembled on each stud to provide the test specimen. Unlubricated control test specimens were also prepared.

In one series of tests, one test specimen for each lubricant and one unlubricated control test specimen was placed in an oven with an air atmosphere at a temperature of 250°F ± 10°F and held for 750 hours. The test specimens were then cleaned and visually examined to establish whether any surfaces covered by the lubricant were more heavily corroded than the unlubricated control specimens.

In a second series of tests, one lubricated test specimen and one test specimen made with lubricated and baked studs and nuts were placed in a distilled water test solution. One unlubricated control test specimen was also tested. A separate test solution was used for each test specimen.

The test solutions were heated to a temperature of 175°F ± 5°F and held for 750 hours. The test specimens were then cleaned and visually examined to establish whether any lubricated test specimen was more heavily corroded than the unlubricated control specimen.

IV. Results And Discussion

Coefficient of Friction Results

The coefficients of friction for each torque increment was calculated using the relationship shown in Appendix A. Various summary statistics were performed on the coefficient of friction data. A discussion of the statistics and the coefficient of friction results are included in Appendix B. These statistics were focused in five basic categories; the tolerance range of the data, form of the distribution of individual values, stud-to-stud variations, significant differences between run-in and design values and the significant differences between the design value and the used stud design value. The importance of the coefficient of friction on design is mainly the ability to accurately predict the stress in a loaded stud/fastener. A small range of the coefficient of friction is essential and is considered to be the best measure of the relative merit (from a coefficient of friction viewpoint) of lubricant candidates. A 90/95 tolerance interval (90 percent confidence that 95 percent of the data falls within the interval) was chosen to rank the lubricant candidates and the control lubricants.

The tolerance ranges for each lubricant/material combination have been calculated and are provided in Attachments I-IV of Appendix B. These are 90/95 tolerance ranges and the relative merit of each lubricant is shown in Figure 3 for the design and used stud design values of measured coefficient of friction. These results demonstrate that Molykote P37 is very similar in performance to RLGMO based on the mean coefficient of friction and the tolerance range.

Phase I Test Results

The individual ranges for each lubricant are graphically presented in Figures 2 and 3 of Appendix B. Based on the evaluation of the test data, Molykote P37 can be used in place of RLGMO or MDSI with no adjustment to the specified torque values determined for RLGMO and MDSI, because of the similarity in coefficient of friction range. The overall 90/95 tolerance ranges of coefficient of friction, inclusive of the four material combinations tested, for the replacement and the control lubricants are listed in Table 3.

Table 3 Coefficient of Friction Ranges (90/95 Tolerance Interval)

LUBRICANT	COEFFICIENT OF FRICTION RANGE	
	Westinghouse Testing	Established Range
Dow Corning Molykote P37 Paste	0.06 - 0.16	----
RLGMO	0.06 - 0.15	0.05 - 0.11
MDSI	0.05 - 0.26	0.05 - 0.14

Although the ranges for the replacement lubricants appear to be significantly larger than the established range listed for RLGMO, the results of the Westinghouse testing actually produced a RLGMO range of 0.06 to 0.15 which is comparable to the range for Molykote P37. The range for MDSI is significantly wider than the replacement. The basis for the difference between the Westinghouse results and the established range is that Westinghouse data have been skewed to the high end by the inclusion of unplated Alloy 625 fasteners in the testing. The previously established ranges for coefficient of friction were based on test data from a limited number of alloys, primarily alloy steels. Nickel-chromium-iron based alloy fasteners were not included in previous testing. Using the data of Tables XI and XIII of Appendix B, the ranges listed in Table 4 have been calculated without Alloy 625 data included.

Table 4 Coefficient of Friction Range (excluding Alloy 625)

LUBRICANT	COEFFICIENT OF FRICTION RANGE (excluding Alloy 625)	
	Westinghouse Testing	Established Range
Dow Corning Molykote P37 Paste	0.07 - 0.12	----
RLGMO	0.06 - 0.13	0.05 - 0.11
MDSI	0.05 - 0.13	0.05 - 0.14

Several conclusions can be drawn from these data. First, the coefficient of friction ranges for RLGMO and Molykote P37 continue to be consistent with each other, having the same arithmetic average, and the Molykote P37 range is within the MDSI range. Second, the RLGMO and MDSI ranges found in the Westinghouse testing match well with the established ranges when unplated Alloy 625 fasteners are excluded. Finally, it is technically feasible to develop separate coefficient of friction ranges for unplated Alloy 625, which can allow for tighter control on design torques. Based on the test results and the comparison to the currently acceptable ranges, two coefficient of friction ranges for Molykote P37 were established. The standard range, 0.07 - 0.12, will be that which excludes the Alloy 625 results, since this range is directly comparable to the current ranges used for RLGMO and MDSI. It should be noted that this range has been developed using 3/4-inch fasteners of uncoated and phosphate coated alloy steel, alloy steel nuts, and steel washers, as well as Monel K-500 studs with Monel 400 nuts and steel washers. The vast majority of fasteners in service are either alloy steel or Monel K-500, both of which have been included in the Westinghouse testing. The Phase II testing was initiated to evaluate other fastener materials against these ranges. In addition, a second range was established that is specific to unplated nickel-chromium-iron-based alloy fasteners based on the Alloy 625 test data. This range of coefficient of friction is 0.06 - 0.16 for Molykote P37.

Phase II Test Results

As with the coefficient of friction data generated in the original (Phase I) program, various summary statistics were performed on the data. These statistics included the tolerance range of the data, significant differences between run-in (Cycle 1) and design values (Cycle 2) and the significant differences between the design value and the used stud design value (Cycle 3). The actual coefficient of friction results for all Phase II tests are provided in Appendix C. A summary of the mean, standard deviation and 90/95 tolerance range of the coefficient of friction results for Molykote P37 and RLGMO is provided in Table 5 for the run-in cycle and Table 6 for the design cycles, that is, combined coefficient of friction values for Cycles B and D for Phase I and Cycles 2 and 3 for Phase II. For alloy combinations that included less than four test assemblies, only the mean and standard deviation is reported. The data in Tables 5 and 6 are grouped by the composition of the test stud. The results reported in Tables 5 and 6 are considered worst case, that is, skewed to the high side of the coefficient of friction range, since the fasteners have been procured as off-the-shelf items. The only exception to this are the four sets of Alloy 625 assemblies, beginning with the label 'IM' and the alloy steel assemblies labeled 'AS', which are actual production hardware.

Comparison of the design (Cycle 2) coefficient of friction values from the Phase II tests supports the substitution of Molykote P37 for RLGMO. This is especially true for the alloy steel and Alloy 625 materials. The most significant difference between Molykote P37 and RLGMO is observed for the largest diameter fasteners. For sizes up to 1.75 inches in diameter the difference between the Molykote P37 and RLGMO coefficients of friction is less than or equal to 0.02; however, for the 2.0 inch Alloy 625 fastener combination the mean coefficient of friction for Molykote P37 exceeds that of RLGMO by more than 0.05 for the run-in cycle and 0.02 for the subsequent cycles. For fastener sizes larger than 1.5 inches, which rely on torque to establish the preload, the use of a run-in cycle and prototypic testing should be strongly considered.

The other instance in which a significant difference between lubricants was observed occurred for the Type 17-4PH stud with a Type 316 nut bearing on a Type 316 stainless steel washer. For this material combination the coefficient of friction range more closely matched that originally established for Alloy 625 fasteners. When a carbon steel washer was substituted for the stainless steel washer the coefficient of friction values began to converge.

The following summarizes the results observed for each alloy family tested and for the various fastener parameters evaluated:

Alloy Steel The coefficient of friction data for all alloy steel combinations were essentially the same and within the range of the previous testing. The only exception is for Molykote P37 on the larger, 1.5-inch diameter fasteners, which exhibited a Cycle 2 mean coefficient of friction of 0.12 and a tolerance range of 0.10 to 0.14. This is compared to an equivalent range of 0.10 to 0.12 for the RLGMO. It should be noted that for the run-in cycle the mean and tolerance range for both lubricants are essentially the same. Examination of the data indicates that for Cycles 1 through 3 as well as for each load increment, the coefficients of friction for RLGMO are essentially the same while for Molykote P37 the values for Cycles 2 and 3 increase slightly. This observation is contrary to the general trend that the coefficient of friction tends to decrease with subsequent cycles.

Monel K-500 As observed in the original testing, Molykote P37 consistently exhibits a mean coefficient of friction as well as a tolerance range which was approximately 0.01 to 0.02 higher than that of RLGMO. However, in the Phase II testing the absolute value of the coefficient of friction results for both lubricants is shifted slightly higher than in the original testing, producing 90/95 confidence range up to 0.134 (K-500/K-500/Carbon Steel) for Molykote P37 on the 0.75-inch fasteners and a range up to 0.144 (K-500/Monel 400/Carbon Steel) on the larger 1.5-inch fastener. Although close examination of the large diameter fastener results (see Appendix C, Data Sets 61-65 and 156-160) indicate that the ranges for both lubricants are skewed higher due to the final torque increment which exhibits a large non-linear increase in coefficient of friction possibly due to the lower strength of the Monel 400 nut. Reanalyzing the data excluding the highest load increment reduces the maximum of the Molykote P37 range to 0.135, which is consistent with the other K-500 data.

Type 17-4PH As mentioned above, a significant difference was observed between the lubricants when a Type 316 stainless steel washer was employed. The Molykote P37 exhibited a significant decrease in coefficient of friction from the high Cycle 1 results to Cycle 2 results for the four assemblies using the Type

316 washer, but no difference on the one assembly which used a carbon steel washer, since the coefficient of friction for Cycle 1 and Cycle 2 were low. Therefore, it appears that the interaction between the Type 316 nut and washer results in a significant increase in the initial coefficient of friction for the Molykote P37 while the RLGMO was better at mitigating this effect. Since austenitic stainless alloys are known to be prone to galling, the higher coefficient of friction was not surprising. These types of material combinations should be evaluated using ranges similar to that previously discussed for unplated Alloy 625.

Alloy 625

The Alloy 625 assemblies produced mixed results. The additional set of commercially procured fasteners with Alloy 625 washers (Alloy Code II) duplicates the results of the original test program producing coefficients of friction consistent with the previous range. The use of chromium plating, as expected provides a significant reduction in the coefficient of friction. However, the two 0.75-inch fasteners, IMC2 and IMC3, which are actual production hardware, result in a low coefficient of friction range comparable to any of the alloy steel assemblies. As the fastener size increases to 1.75 inches and ultimately 2.0 inches, the Molykote P37 coefficient of friction diverges from that of the RLGMO. Also, eventually in the 2.0-inch size, the Molykote P37 friction exceeds the previous range recommended for Alloy 625. A possible explanation for the lower coefficient of friction for the 0.75-inch fasteners is the use of the heavy hex nuts with the larger diameter bearing face. Examination of the 'IM' nuts and washers indicated that the actual bearing area was significantly larger with the heavy hex nuts than with the smaller commercial nuts. For the same load, this would have resulted in a lower bearing stress and lower tendency for galling. However, as the fastener size increased, even the larger nuts and bearing area did not help maintain a reasonable coefficient of friction range for the Molykote P37. As discussed in the **Surface Coating** paragraph below, the use of coating such a chromium plating may reduce the coefficient of friction on the larger fastener sizes.

Titanium

For the titanium combination tested, both Molykote P37 and RLGMO exhibited essentially identical coefficient of friction ranges. The tolerance ranges for both lubricants extend up to coefficients of 0.14. Although neither lubricant exhibits any significant difference from Cycles 1 through 3, they both exhibit increasing coefficients of friction at the higher load increments, suggesting that an additional interaction is occurring between the materials at higher loads.

Size Effects

The Molykote P37 appears to be more sensitive to size effects above 1.5 inches in diameter than RLGMO. Up to this size both lubricants exhibited a slight increase in the coefficient of friction values at approximately the same rate; however, for the 2.0-inch Alloy 625 fasteners the Molykote P37 coefficient of friction significantly exceeds that of RLGMO, resulting a Cycle 1 mean value as high as 0.176 compared to 0.117 for RLGMO. For this size fastener the required load may be resulting in a breakdown of the Molykote P37's ability to properly perform, although it is noted that an improvement was observed for Cycles 2 and 3.

Run-in Cycles

For most alloy combinations tested a significant decrease in the coefficient of friction values was observed between Cycle 1 and Cycle 2, indicating that a run-in cycle or pretorquing step is valuable in controlling the final coefficient of friction value. This difference was least noticeable for the alloy steel combinations, the chromium plated Alloy 625 assemblies and for the 0.75-inch unplated Alloy 625 fasteners with the heavy hex nuts. The plating helps to reduce the tendency to gall for susceptible materials during the first torque cycle.

Washer Materials The effect of washer (bearing) material was most significant when materials which are known to be prone to galling were used, such as previously discussed for the Type 17-4 PH assemblies. Higher coefficients of friction were noted for the alloy steel assemblies which used a Type 430 stainless steel lock plate. Changing washer materials in conjunction with the K-500 studs did not produce any significant differences or trends. Likewise, no significant difference was observed by changing from carbon steel washers to Alloy 625 washers for the Alloy 625 assemblies.

Surface Coating Surface coating provides a significant benefit in both decreasing the coefficient of friction range as well as narrowing the standard deviation of the data compared to the equivalent materials in the uncoated condition. The three types of surface treatments tested were: manganese phosphate coating and zinc plating on alloy steel, and chromium plating on Alloy 625.

Class of Fastener Fit No significant difference was observed between Class 2 (Alloy Code IMC2) and Class 3 (IMC3) Alloy 625 fasteners tested, implying that the tighter thread tolerances for the Class 3 fit does not have an influence on the coefficient of friction value.

Manufacturing Method No significant difference was observed between machine and rolled threads.

Potential Alternate Lubricant Limited testing (six different fastener assemblies) was performed with the new metallic-free lubricant, labeled as N7000. The results of the testing with N7000 are provided at the end of Appendix C. In general, this lubricant produced coefficient of friction values which exceed those of Molykote P37 by approximately 0.01 for all three torque cycles.

One obvious exception was the original Alloy 625 combination (Alloy Code I) in which the N7000 values were significantly less than either Molykote P37 or RLGMO. This result was so far out of line with the other data that the test laboratory was requested to repeat the test with a single spare Alloy 625 fastener assembly. This repeat test produced a result which was more expected. Although no explanation as to the source of the low values is offered, the retest values are considered more representative based on the other assemblies tested.

Based on the results of the limited screening testing, N7000 would not have been selected over Molykote P37 if it had been included in the original test matrix.

Use of the Coefficient of Friction Data

The tolerance ranges provided in Appendices B and C include data over a wide range of loading conditions, that is, up to 2/3 of the yield strength of the stud material. In many applications, applied loads will be significantly less than this limit. For some of the alloys tested the coefficient of friction increases with increasing load; therefore, the raw data should be consulted to get a more representative indication of coefficient of friction for the range of load in question.

Table 5 Run-in Coefficient of Friction Values

STUD MATERIAL	ALLOY CODE (Note 1)	LUBRICANT					
		Molykote P37			RLGMO		
		Mean	Std. Dev.	90/95 Tolerance	Mean	Std. Dev.	90/95 Tolerance
Alloy Steel	A	0.097	0.007	0.076 - 0.118	0.092	0.003	0.083 - 0.101
	AM	0.099	0.010	0.075 - 0.122	0.097	0.005	0.084 - 0.110
	P	0.088	0.004	0.078 - 0.098	0.089	0.008	0.069 - 0.109
	AR1	0.111	0.010	0.086 - 0.135	0.117	0.005	0.103 - 0.130
	AZ	0.086	0.005	0.074 - 0.098	0.097	0.009	0.074 - 0.119
	AS	0.095	0.016	0.053 - 0.137	0.091	0.024	0.027 - 0.155
K-500	M	0.102	0.008	0.082 - 0.122	0.088	0.009	0.066 - 0.110
	MK	0.125	0.009	0.101 - 0.147	0.105	0.007	0.087 - 0.123
	MCU	0.131	0.014	0.090 - 0.171	0.126	0.009	
	MH	0.147	0.006		0.139	0.006	
	MS	0.141	0.011		0.124	0.009	
	MI	0.141	0.010		0.122	0.007	
	MA	0.140	0.014	0.105 - 0.175	0.108	0.013	0.075 - 0.140
	MA (Note 2)	0.135	0.010	0.110 - 0.160	0.103	0.009	0.079 - 0.127
Alloy 625	I	0.164	0.021	0.112 - 0.216	0.164	0.025	0.102 - 0.226
	ICR	0.105	0.011	0.079 - 0.131	0.104	0.007	0.088 - 0.121
	II	0.149	0.015	0.113 - 0.185	0.160	0.015	0.122 - 0.197
	IMC2	0.111	0.010	0.087 - 0.135	0.102	0.015	
	IMC3	0.101	0.008	0.082 - 0.120	0.109	0.006	
	IMA	0.122	0.020	0.070 - 0.174	0.093	0.016	
	IMB	0.176	0.040	0.066 - 0.285	0.117	0.014	
Titanium	T	0.117	0.009	0.094 - 0.139	0.115	0.010	0.091 - 0.139
Type 17-4PH	SS	0.163	0.015	0.125 - 0.202	0.130	0.010	0.103 - 0.156
	SSC	0.112	0.010		0.115	0.002	

Notes:

(1) See the Key to the Alloy Codes located in Table 7.
(2) Same as MA, excluding the highest torque increment.

Table 6 Design Coefficient of Friction Values

STUD MATERIAL	ALLOY CODE (Note 1)	LUBRICANT					
		Molykote P37			RLGMO		
		Mean	Std. Dev.	90/95 Tolerance	Mean	Std. Dev.	90/95 Tolerance
Alloy Steel	A	0.097	0.005	0.082 - 0.112	0.088	0.004	0.076 - 0.100
	AM	0.103	0.009	0.081 - 0.125	0.090	0.007	0.072 - 0.108
	P	0.090	0.005	0.078 - 0.102	0.083	0.005	0.071 - 0.095
	AR1	0.121	0.011	0.094 - 0.149	0.111	0.005	0.099 - 0.123
	AZ	0.081	0.007	0.063 - 0.100	0.082	0.010	0.058 - 0.106
	AS	0.080	0.015	0.041 - 0.120	0.079	0.014	0.041 - 0.116
K-500	M	0.094	0.008	0.074 - 0.114	0.075	0.006	0.060 - 0.090
	MK	0.115	0.008	0.096 - 0.134	0.095	0.008	0.077 - 0.114
	MCU	0.097	0.011	0.069 - 0.125	0.100	0.011	
	MH	0.119	0.009		0.105	0.010	
	MS	0.105	0.014		0.097	0.007	
	MI	0.112	0.007		0.112	0.007	
	MA	0.120	0.010	0.095 - 0.144	0.106	0.009	0.085 - 0.127
	MA (Note 2)	0.117	0.007	0.098 - 0.135	0.102	0.008	0.080 - 0.123
Alloy 625	I	0.108	0.010	0.083 - 0.133	0.113	0.014	0.078 - 0.148
	ICR	0.100	0.012	0.070 - 0.130	0.094	0.013	0.062 - 0.126
	II	0.111	0.009	0.088 - 0.134	0.118	0.012	0.089 - 0.148
	IMC2	0.089	0.010	0.065 - 0.113	0.101	0.006	
	IMC3	0.087	0.008	0.067 - 0.106	0.104	0.006	
	IMA	0.108	0.017	0.063 - 0.152	0.099	0.012	
	IMB	0.129	0.028	0.051 - 0.207	0.106	0.014	
Titanium	T	0.113	0.014	0.078 - 0.149	0.107	0.014	0.073 - 0.141
Type 17-4PH	SS	0.121	0.015	0.082 - 0.160	0.098	0.012	0.066 - 0.130
	SSC	0.110	0.006		0.083	0.007	

Notes:

(1) See the Key to the Alloy Codes located in Table 7.
(2) Same as MA, excluding the highest torque increment.

Table 7 Key to Tables 5 and 6

ALLOY CODE	ALLOY COMBINATION			COMMENTS
	Stud	Nut	Washer	
A	AISI 4140	Carbon Steel, Gr 2H	Carbon Steel	Rolled threads
AM	AISI 4140	Carbon Steel, Gr 2H	Carbon Steel	Machined threads
P	AISI 4140, Mn Phosphate Coated	Carbon Steel, Gr 2H	Carbon Steel	Rolled threads
AR1	AISI 4140	Carbon Steel, Gr 2H	Carbon Steel	1.5 inches
AZ	Steel, Grade 5, Zinc plated	Carbon Steel, Grade 5	Carbon Steel	Rolled threads
AS	AISI 4340	AISI 4340	Type 430 Stainless Nutlock	Machined threads 1.0 inches
M	K-500	Monel 400	Carbon Steel	Rolled threads
MK	K-500	K-500	Carbon Steel	Rolled threads
MCU	K-500	K-500	70-30 Cu-Ni	Rolled threads
MH	K-500	K-500	HY 80	Rolled threads
MS	K-500	K-500	Type 430	Rolled threads
MI	K-500	K-500	Alloy 625	Rolled threads
MA	K-500	Monel 400	Carbon Steel	Rolled threads 1.5 inches
I	Alloy 625	Alloy 625	Carbon Steel	Rolled threads
ICR	Alloy 625, Chromium plated	Alloy 625	Carbon Steel	Rolled threads
II	Alloy 625	Alloy 625	Alloy 625	Rolled threads
IMC2	Alloy 625	Alloy 625	Alloy 625	Military Specification Machined threads Class 2
IMC3	Alloy 625	Alloy 625	Alloy 625	Military Specification Machined threads Class 3
IMA	Alloy 625	Alloy 625	Alloy 625	Military Specification Machined threads 1.75 inches
IMB	Alloy 625	Alloy 625	Alloy 625	Military Specification Machined threads 2.00 inches
T	Titanium, Gr 5	Alloy 625	Carbon Steel	Rolled threads
SS	Type 17-4PH Stainless Steel	Type 316 stainless	Type 316 stainless	Rolled threads
SSC	Type 17-4PH Stainless Steel	Type 316 stainless	Carbon Steel	Rolled threads

Anti-Seizing Test Results

To begin this test a coefficient of friction value of 0.10 was assumed in order to develop torque values with which to load the test assemblies. Each test assembly was given one run-in cycle to the calculated torque value, disassembled, cleaned, relubricated and retorqued prior to placing in an oven at 650°F. Based on the coefficient of friction testing results, the assumed coefficient of friction of 0.10 was within the range for all lubricants except NIKAL , Neolube No. 650 and NM-91. For NIKAL and NM-91, the coefficient of friction of 0.10 is below the determined coefficient of friction range, resulting in lower loads on these studs than the test assemblies for the other lubricants. However, both of these lubricants required high breakaway torques, indicating that their actual performance would have been even worse had higher loads (torques) been used. For Neolube No. 650 a coefficient of friction of 0.10 was actually above the determined range, indicating higher loads were applied to these assemblies than to the others.

The tabulated breakaway torque results for the anti-galling test are shown in Tables 1 through 3 in Appendix D. After one week of exposure approximately half of the 30 test assemblies still exhibited evidence of moisture after the assembly was untorqued and examined. Except for one test assembly, after three weeks of exposure, the lubricant on test assemblies had completely dried. That is, the oil constituent had oxidized, leaving only the solid anti-seizing additives. After six weeks of exposure the test assemblies had completely dried lubricant. Once dried, all of the candidate lubricants were easily removed with a nylon brush as they formed a dry powder or dust. The fasteners which had moist lubricant present could be cleaned with a cloth, but it took more time because residual lubricant smeared. Only those assemblies coated with RLGMO or MDSI required wire brushing to remove the dried baked on lubricant. Even after wire brushing, visual evidence of RLGMO was still present on the six-week assemblies.

Based on the 6- and 10-week anti-seize test results, Molykote P37 exhibited the best performance of any candidate lubricant. For both the alloy steel and K-500/Monel 400 fastener combinations, the breakaway torques for Molykote P37 were less than 40 percent higher than the installation value. For the stainless steel fasteners the breakaway torque is approximately 2.5 times the installation value. This material combination, that is, unplated stainless steel studs and nuts, is considered a worst case. For RLGMO the breakaway torques on alloy steel and K-500/Monel 400 were the same as for Molykote P37. On the unplated stainless steel fasteners, the RLGMO breakaway torques were only 60 percent higher than installation values, indicating a noticeable difference between the two lubricants. Breakaway torques for MDSI were lower than either the Molykote P37 or RLGMO, although during the untorquing audible clicking accompanied by jumping of the torque wrench follower occurred in all of the MDSI assemblies raising a question as to the precise torque values reported. Somewhat higher breakaway torque values are, therefore, expected if MDSI is replaced with Molykote P37.

Anti-Galling Test Results

Tables 1 through 6 of Appendix E provide the raw data for the anti-galling test. For each alloy an initial test assembly was tested without lubricant and in each case galling or seizing occurred within the first four cycles, confirming that the material combinations without lubrication will gall. In general, all lubricant/material combinations, except Never Seez and MDSI, completed the first eight cycles with no signs of galling. On the K-500/Monel 400 and stainless steel assemblies, the Never Seez showed signs of galling by the second cycle via audible clicking accompanying erratic jumps on the load cell gage. The clicking and uneven loading increased in frequency on each subsequent cycle until the testing was stopped after four cycles on the K-500/Monel 400 assemblies and six and seven cycles on the two stainless steel assemblies. The MDSI lubricated K-500/Monel 400 and alloy steel assemblies showed erratic increases in the installation torque values during the first eight cycles. Galling was visually observed on the threads during the cleaning step between Cycles 8 and 9.

In general, all lubricants required the highest torque value on Cycle 1, which then decreased to a relatively stable value through Cycle 8. For some lubricants, primarily NM-91 and N2000, a small increase in torque was seen on Cycle 5, which represented the reapplication of fresh lubricant on a cleaned, although previously used assembly. The higher values observed on Cycle 1 and occasionally at Cycle 5 represent the run-in cycle for the lubricant on a clean surface. It has been established by previous testing that during the initial loading of a new fastener a higher coefficient of friction exists compared to subsequent loading cycles for the same fastener assembly. This is seen clearly in the coefficient of friction results. As long as the torque values remained relatively constant or decreased between Cycles 2 and 8 galling was not suspected. With the exception of the small increase on Cycle 5 mentioned above, except NIKAL and MDSI, the lubricants completed eight cycles without galling.

To provide a more severe test of the lubricants ability to prevent galling, the load was increased to the stud material's yield strength during the last four cycles. As seen in the data of Appendix E, when the load was increased to the yield strength, most fasteners required a higher torque value on Cycle 9, which generally decreased during the final three cycles. Again this represents a run-in cycle for the higher loading. During Cycle 9 audible clicking and exceptionally high torques were noted for one of the two stainless steel test assemblies lubricated with each of the following lubricants: N5000, Neolube No. 650, Never Seez, Molykote P37 and MDSI. (Note: Testing of the assemblies lubricated with NIKAL had been discontinued prior to Cycle 9 due to severe galling.) On Cycle 10 the torque values for all of these assemblies decreased and remained stable through Cycle 12. These lubricants exhibited slightly more visible evidence of galling on the stainless steel assemblies than the remaining four lubricants: N1000, N2000, NM-91 and RLGMO. Since this event was only seen on the stainless steel assemblies at the load equal to the yield strength and torques for subsequent cycles returned to more expected values, these results are not considered significant because of the limited usage of austenitic stainless steel fasteners. In addition, Cycles 9 through 12 represent a severe over-test because fasteners in service are not intentionally preloaded to yield strength.

<u>Detrimental Material Evaluation</u>

Five of the eight candidates completely met the detrimental material limits, while two of the remaining three exceeded the limit for one element by less than 10 ppm. The final lubricant (NM-91) contained almost 700 ppm of sulfur.

<u>Health and Environmental Evaluation</u>

The MSDS for the eight candidate lubricants were reviewed for potential generation of hazardous wastes. The review indicated that none of the candidate lubricants contain hazardous substances per the Code of Federal Regulations, Title 40, Part 261; therefore, the use of any of these lubricants would not lead to the generation of a hazardous wastes based on their composition or physical/chemical characteristics and all are equally acceptable from a disposal standpoint.

Off-gas testing of each candidate lubricant was performed to determine the composition of volatile products produced during a 48 hour exposure at 650°F. Molykote P37, Neolube No. 650 and NM-91 off gassed formaldehyde, which is a suspected human carcinogen as classified by ACGIH. The sources of formaldehyde in Molykote P37 are mineral oil and polyisobutylene, which are essential ingredients in the formulation. It would not be feasible to eliminate the sources of formaldehyde. However, formaldehyde would not be released at temperatures below about 600°F. For all candidate lubricants, the organic constituents off-gas during the first 24 hours of heating indicating that the first 24 hours is the period of greatest concern. The recommended safety practices to be followed when using Molykote P37 are as follows:

- use chemical worker goggles
- use neoprene or equivalent gloves
- avoid of extreme heat, such as during welding, and motorized methods to remove the residual lubricant, such as wire brushing
- use adequate ventilation during the first 24 hours of high temperature operations
- wipe off excess lubricant before hot operations

Independently, a certified industrial hygienist reviewed the MSDS for the candidate lubricants for human toxicological concerns. The results are summarized as follows:

- nickel and nickel compounds are known human carcinogens (Group 1 Carcinogens by the IARC)
- copper and nickel produce chronic toxic metal effects in humans, although copper is less of a human toxicological problem than nickel

Molykote P37 does not contain nickel or copper, and thus is not a human toxicological concern.

<u>Corrosion Testing Results</u>

No corrosion effects were observed in any fastener specimen lubricated with Molykote P37. Corrosion effects were observed with several of the other candidate replacement lubricants. The following summarizes the results of the corrosion testing:

- None of the eight candidate replacement lubricants, including Molykote P37, caused any corrosion effects in air which are different from or more apparent than that caused by RLGMO, MDSI or from corrosion effects under similar conditions of exposure to unlubricated fasteners in any of the tested materials.

- N1000, Never Seez and NM-91 caused localized corrosion, that is, pitting and crevice corrosion, of K-500 fasteners which was more apparent than that occurring in unlubricated K-500 fasteners under similar conditions of salt water exposure.

- N1000 intergranularly attacked Type 304 stainless steel fasteners in salt water exposure.

- None of the eight candidate replacement lubricants for RLGMO caused any galvanically assisted localized corrosion effects in air or distilled water. These corrosion effects which are different from or more apparent than that caused by RLGMO, MDSI or from corrosion effects under similar conditions of exposure to unlubricated fasteners in any of the tested materials.

V. Conclusions

Based on the results of the initial testing, Westinghouse concluded that Dow Corning Molykote P37 is the best replacement for RLGMO in that it best simulates the coefficient of friction range, the anti-galling and anti-seizing properties of the RLGMO, is non-hazardous, poses minimal health risks and is non-corrosive to the fastener alloys evaluated. Initial testing also indicated that Molykote P37 could be used as a replacement for MDSI based on the improved coefficient of friction range. However, because MDSI is not hazardous and does possess the best anti-seizing resistance of any lubricant tested, an across the board replacement was not undertaken.

Additional testing performed in a Phase II program confirmed the choice of Molykote P37 and greatly expanded the coefficient of friction database to additional fastener alloy combinations. Dow Corning Molykote P37 Paste meets the requirements of Commercial Item Description, A-A-59004, "Anti-Galling Compound, Thread Lubricating, Seizing Resistant, and Calcium Hydroxide Containing".

The selection of Molykote P37 by Westinghouse does not reflect functional deficiencies with the other candidate lubricants in this evaluation but rather that Molykote P37 was the best match for RLGMO based on the Westinghouse criteria. Readers should compare the results discussed herein against the specific application requirements prior to selection of a lubricant.

VI. Acknowledgments

The authors wish to acknowledge N.P. Grado for designing and coordinating the corrosion testing, L.N. Eaton for assisting in the evaluation of the coefficients of friction, K.M. Goellner and R.D. Hays of the Westinghouse Bettis Laboratory for performing the toxicological evaluations, R. Hagar of the Naval Sea Systems Command for coordinating the environmental off gas testing and E.E. Toomey for assistance in procuring the test material and expediting the placement of the testing contracts. The authors also acknowledge the contributions of S.W. Bodner of the Naval Sea Systems Command for his sponsorship and continued interest in this work.

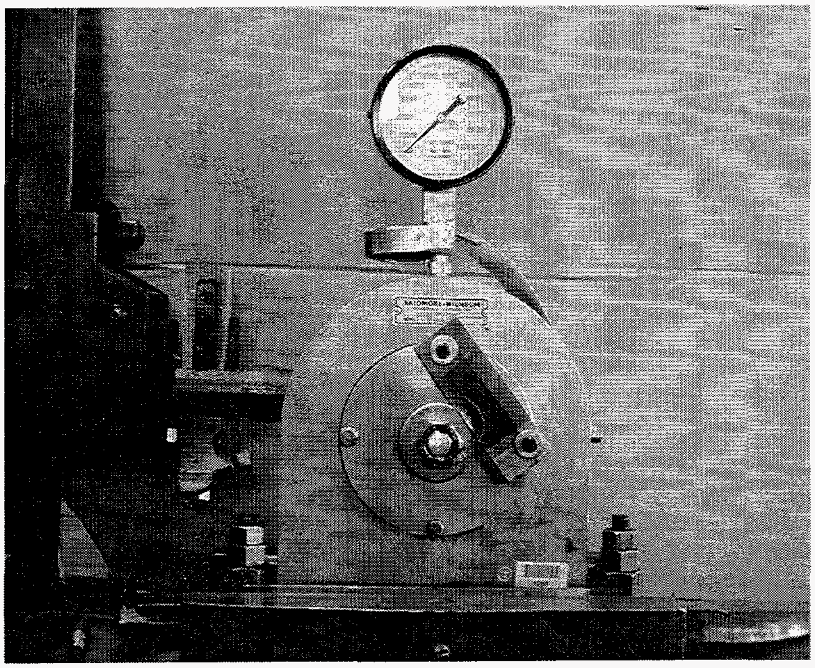

Figure 1. Skidmore-Wilhelm Torque Tension Unit, Model RL

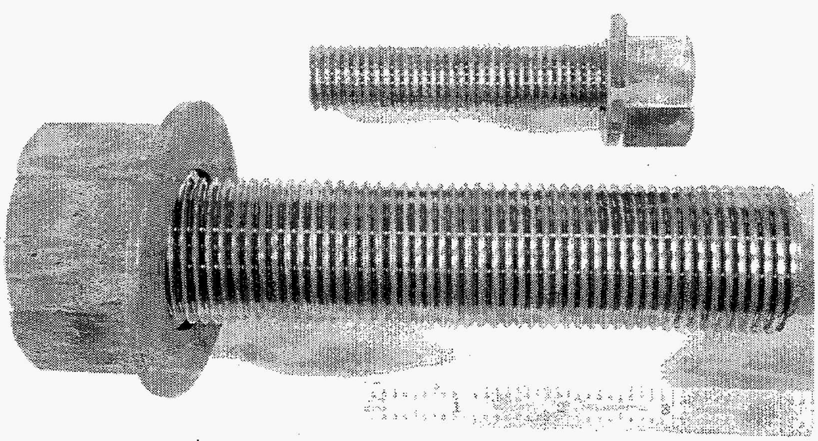

Figure 2. Typical Fastener Assemblies: 1.5-8UNC-2A Monel K-500 (Alloy Code MA) and 0.75-10UNC-3A Alloy 625 (Alloy Code IMC3)

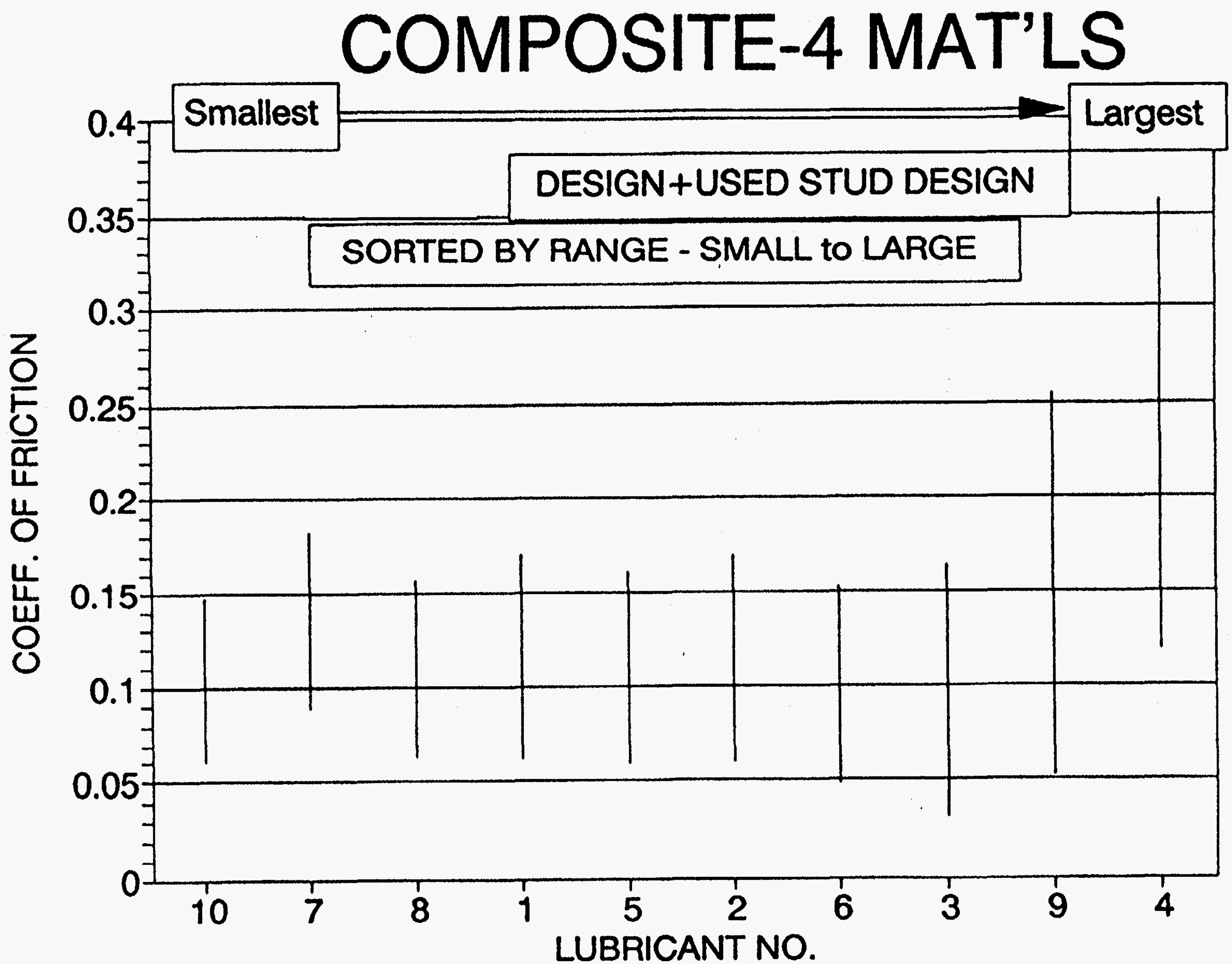

Figure 3. Coefficient of Friction Ranges of the Phase I Lubricants

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Appendix A

EQUATION FOR CALCULATING THE COEFFICIENT OF FRICTION (μ)

$$\mu = -\left[\frac{C + \sqrt{C^2 - 4D_b A \sin\lambda}}{2 D_b \sin\lambda}\right]$$

where:

$$C = -\left[D_b \cos\alpha_n \cos\lambda + \frac{24T}{P}\sin\lambda + E\cos\lambda\right]$$

$$A = \left[\frac{24T}{P}\cos\alpha_n \cos\lambda - E\cos\alpha_n \sin\lambda\right]$$

T = Torque, ft-lb.

P = Axial load, lb.

E = Minimum pitch diameter, in.

D_h = Flats diameter of nuts, in.

B = Diameter of hole in washer, in.

$$D_b = \frac{2}{3}\frac{D_h^3 - B^3}{D_h^2 - B^2}$$

N = Number of threads per inch

α = One-half the thread profile angle

λ = Helix angle = arc tan $\dfrac{1}{N E \pi}$

α_n = Arc tan (tan α cos λ)

Appendix B

SUMMARY STATISTICS OF COEFFICIENT OF FRICTION DATABASE OF REPLACEMENT CANDIDATES FOR RED LEAD AND GRAPHITE IN MINERAL OIL (RLGMO)

This appendix includes the calculated coefficient of friction data, based on the equation of Appendix A. The actual test information, i.e, the individual loads and corresponding torque values, and the detailed statistical analysis can be obtained by requesting from the authors at:

Westinghouse Electric Company
Plant Apparatus Division
500 Penn Center Boulevard
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SUMMARY STATISTICS OF COEFFICIENT OF FRICTION DATABASE OF REPLACEMENT CANDIDATES FOR RED LEAD AND GRAPHITE IN MINERAL OIL (RLGMO)

I. PURPOSE

The purpose of this enclosure is to provide the analysis (summary statistics) of the torque-tension test results of coefficient of friction data of lubricant replacement candidates for red lead and graphite in mineral oil (RLGMO).

II. BACKGROUND

The final approved coefficient of friction testing matrix for RLGMO replacement lubricant candidates includes ten lubricants and four (4) material combinations. This is an incomplete blocked experiment with only minor perturbations* from a complete blocked experiment. Forty sets of torque-tension tests were performed. The data from these tests are used to establish the coefficient of friction for each lubricant/material combination. There are five (5) studs per combination* and four loading sequences. Each loading sequence contains six (6) values of coefficient of friction; five (5) on the loading portion with the highest load equal to 2/3 yield strength and one (1) break-away value**.

* For the Alloy Steel (B7) Stud/Nut fasteners, only two (2) studs were tested.

** Breakaway coefficient of friction not provided in this enclosure.

III. DESCRIPTION OF SUMMARY ANALYSIS

A. Summary Statistics

The analysis of the torque-tension coefficient of friction testing focused on summary statistics for each of the 40 dataset combinations. Main features include an overall assessment of the variation of the coefficient of friction, mean values, standard deviations and the range of the data.

Most of the coefficient of friction distributions can be characterized by a normal distribution with a smaller standard deviation for the lower half than the upper half of the distribution.

B. Stud and Load Sequence Subgrouping

The data are grouped by material and provided in tables of the attachments (one material combination in each attachment) to this enclosure. A mean value and standard deviation were calculated for each stud loading portion of the test. In addition, mean values and standard deviations were calculated for each of the four (4) loading sequences which include all five (5) studs.

The categories of the 4-step loading sequences are defined as:

1. run-in,
2. design,
3. used stud run-in, and
4. used stud design.

The initial run-in represents a new stud cleaned and lubricated, and then torqued. The stud is unloaded, lubricated and loaded again as in the field application. This represents the design values of coefficient of friction. The stud is unloaded, cleaned and lubricated and loaded again. This represents a used stud run-in. The stud is unloaded, lubricated, and loaded again, representing the design case for a used stud. A test of significant differences of the mean values and variances for the each material/lubricant combination are calculated and provided for the coefficient of friction data for (a) the design vs the run-in and (b) the used stud design vs the design categories. Significant difference here is calculated at the 95 percent confidence level.

C. Analysis of Variance (ANOVA) to Measure Stud-to-Stud Variations

An ANOVA is carried out for every lubricant/material combination to measure the significance of the stud-to-stud variation compared to the within stud variation of coefficient of friction. The application here is to establish whether the variations of the mean values for each stud are significantly different from the overall mean value. The inference here is, if there is no significant difference of mean values, the testing of five (5) can represent the coefficient of friction for all studs. A significant variation from stud-to-stud suggests that a tolerance interval, based on degrees of freedom of the testing, should be factored into the application of coefficient of friction values for all studs.

D. Ranking Criteria for All Stud/Lubricant Combinations.

The results of the lubricant coefficient of friction analyses described above were used to establish a relative ranking of lubricant candidates for each of the material combinations. See, for example, Tables I - VIII which list the summary statistics for each lubricant/material combination. A sort (ranking of lubricants) by features (e.g., range of coefficient of friction) was provided for consideration to choose potential lubricants for final recommendation of replacement for RLGMO. A small range is desirable since this would allow better predictable values of loading stresses for design calculations. A stud-to-stud variation would not be a desirable characteristic, since some adjustment must be made for use in design values provided.

IV. RESULTS

As one criteria for ranking the lubricant coefficient of friction values, a tolerance interval (90 percent/95 percent from reference (a)) was calculated for each range of the design values of coefficient of friction for each lubricant/material combination and an overall composite ranking. This analysis was extended to used-stud design tolerance ranges and to the initial run-in tolerance ranges. The maximum and minimum values of the tolerance range were then obtained for each lubricant for all material combinations used. These values are listed in Tables IX through XIV. A composite plot of these ranges of coefficient of friction were developed for each of the three categories; run-in (Figure 1), design (Figure 2), and used-stud design (Figure 3). In addition, an individual plot of the relative ranking of the design coefficient of friction tolerance ranges for each material combination are provided in Figures 4 through 7. The data used for Tables I through XIV and Figures 1 through 7 are from the detailed datasets of coefficient of friction values in Attachments I through IV.

V. REFERENCES

(a) Experimental Statistics, National Bureau of Standards Handbook 91, August 1, 1963

Attachments: I - Phase I - Coefficient of Friction Dataset: Alloy 625
II - Phase I - Coefficient of Friction Dataset: Monel K-500 (K-Monel)/Monel 400
III - Phase I - Coefficient of Friction Dataset: AISI 4140 Phosphate Coated
IV - Phase I - Coefficient of Friction Dataset: AISI 4140 Alloy Steel (B7)

TABLE I

SUMMARY STATISTICS FOR LUBRICANT CANDIDATES

Material Combination: Inconel 625 Stud/Nut

LUBRICANT NUMBER	COEFFICIENT OF FRICTION OVERALL 5 STUDS, 4 LOADING LOADING VALUES UP TO 2/3 Yield				Stud-to Stud Change Mean	Run-in vs Design Mean	Design vs Used Stud Design Mean
	Mean	Std Dev	Range	Normal Distr. Y/N	Signif Diff. Y/N*	Signif Diff. Y/N*	Signif Diff. Y/N*
1	0.152	0.037	0.180	Yes	Yes	Yes	No
2	0.137	0.038	0.231	Yes	Yes	Yes	Yes
3	0.126	0.042	0.173	Yes	Yes	Yes	Yes
4	0.263	0.050	0.260	Yes	Yes	Yes	N/A **
5	0.139	0.043	0.195	Yes	Yes	Yes	Yes
6	0.143	0.032	0.122	No	No	Yes	No
7	0.174	0.037	0.164	Yes	No	Yes	No
8	0.127	0.029	0.125	Yes	Yes	Yes	No
9	0.179	0.048	0.234	Yes	Yes	Yes	Yes
10	0.127	0.028	0.129	Yes	No	Yes	Yes

* Significance is at the 95% confidence level; i.e., a significant difference for the stud mean value outside of the 95% confidence interval of the overall mean value, or there is a significant difference between the design and run-in mean values at the 95% confidence level.

** For Lubricant 4 only 50 values are provided. Testing was difficult and completion of the used stud testing is pending.

TABLE II

COEFFICIENT OF FRICTION RUN-IN AND DESIGN VALUES

Material Combination: Inconel 625 Stud/Nut

LUBRICANT NUMBER	COEFFICIENT OF FRICTION					
	RUN - IN LOADING			DESIGN LOADING		
	MEAN	STD DEV	RANGE	MEAN	STD DEV	RANGE
1	0.200	0.030	0.068	0.126	0.018	0.047
2	0.189	0.035	0.168	0.120	0.020	0.105
3	0.185	0.025	0.086	0.108	0.023	0.058
4	0.287	0.040	0.200	0.239	0.048	0.183
5	0.197	0.032	0.113	0.117	0.018	0.074
6	0.185	0.018	0.067	0.118	0.014	0.042
7	0.231	0.025	0.098	0.150	0.013	0.038
8	0.164	0.021	0.066	0.108	0.010	0.046
9	0.222	0.053	0.171	0.166	0.036	0.131
10	0.164	0.025	0.086	0.113	0.014	0.046

TABLE III

SUMMARY STATISTICS FOR LUBRICANT CANDIDATES

Material Combination: Monel K500/Monel 400 Stud/Nut

LUBRICANT NUMBER	COEFFICIENT OF FRICTION OVERALL 5 STUDS, 4 LOADING LOADING VALUES UP TO 2/3 Yield				Stud-to Stud Change Mean	Run-in vs Design Mean	Design vs Used Stud Design Mean
	Mean	Std Dev	Range	Normal Distr. Y/N	Signif Diff. Y/N*	Signif Diff. Y/N*	Signif Diff. Y/N*
1	0.102	0.013	0.067	Yes	Yes	Yes	No
2	0.102	0.011	0.051	Yes	Yes	Yes	No
3	0.065	0.010	0.053	Yes	No	Yes	Yes
4	0.161	0.016	0.077	Yes	Yes	No	Yes
5	0.090	0.013	0.059	Yes	Yes	Yes	Yes
6	0.086	0.015	0.074	Yes	Yes	Yes	Yes
7	0.156	0.009	0.048	No	Yes	Yes	Yes
8	0.097	0.009	0.042	Yes	Yes	Yes	No
9	0.087	0.013	0.065	Yes	Yes	No	No
10	0.077	0.010	0.054	Yes	Yes	Yes	Yes

* Significance is at the 95% confidence level; i.e., a significant difference for the stud mean value outside of the 95% confidence interval of the overall mean value, or there is a significant difference between the design and run-in mean values at the 95% confidence level.

TABLE IV

COEFFICIENT OF FRICTION RUN-IN AND DESIGN VALUES

Material Combination: K-Monel/Monel Stud/Nut

LUBRICANT NUMBER	COEFFICIENT OF FRICTION					
	RUN - IN LOADING			DESIGN LOADING		
	MEAN	STD DEV	RANGE	MEAN	STD DEV	RANGE
1	0.114	0.013	0.041	0.099	0.010	0.035
2	0.108	0.009	0.031	0.101	0.009	0.031
3	0.074	0.012	0.042	0.065	0.008	0.032
4	0.150	0.010	0.034	0.153	0.014	0.053
5	0.103	0.010	0.040	0.088	0.010	0.036
6	0.097	0.015	0.056	0.085	0.015	0.058
7	0.154	0.011	0.048	0.160	0.009	0.030
8	0.102	0.008	0.026	0.094	0.008	0.026
9	0.087	0.009	0.030	0.087	0.014	0.037
10	0.088	0.009	0.027	0.075	0.006	0.020

TABLE V

SUMMARY STATISTICS FOR LUBRICANT CANDIDATES

Material Combination: AISI 4140 Phosphate Coat/AISI 4140 Stud/Nut

LUBRICANT NUMBER	COEFFICIENT OF FRICTION OVERALL 5 STUDS, 4 LOADING LOADING VALUES UP TO 2/3 Yield				Stud-to Stud Change Mean	Run-in vs Design Mean	Design vs Used Stud Design Mean
	Mean	Std Dev	Range	Normal Distr. Y/N	Signif Diff. Y/N*	Signif Diff. Y/N*	Signif Diff. Y/N*
1	0.091	0.009	0.042	Yes	Yes	Yes	Yes
2	0.088	0.008	0.044	No	Yes	Yes	No
3	0.052	0.008	0.048	Yes	Yes	Yes	No
4	0.143	0.009	0.045	Yes	Yes	Yes	Yes
5	0.079	0.008	0.036	Yes	Yes	Yes	No
6	0.083	0.006	0.034	Yes	Yes	Yes	No
7	0.110	0.006	0.034	Yes	Yes	No	Yes
8	0.090	0.005	0.028	Yes	Yes	No	No
9	0.098	0.018	0.072	Yes	Yes	No	No
10	0.082	0.007	0.050	Yes	Yes	Yes	Yes

* Significance is at the 95% confidence level; i.e., a significant difference for the stud mean value outside of the 95% confidence interval of the overall mean value, or there is a significant difference between the design and run-in mean values at the 95% confidence level.

TABLE VI

COEFFICIENT OF FRICTION RUN-IN AND DESIGN VALUES

Material Combination: AISI 4140 Phosphate Coat/AISI 4140 Stud/Nut

LUBRICANT NUMBER	COEFFICIENT OF FRICTION					
	RUN - IN LOADING			DESIGN LOADING		
	MEAN	STD DEV	RANGE	MEAN	STD DEV	RANGE
1	0.099	0.004	0.016	0.092	0.008	0.026
2	0.095	0.005	0.016	0.085	0.007	0.024
3	0.061	0.007	0.023	0.048	0.005	0.024
4	0.148	0.008	0.034	0.136	0.006	0.023
5	0.087	0.005	0016	0.0757	0.006	0.023
6	0.089	0.005	0.019	0.080	0.005	0.016
7	0.109	0.007	0.034	0.107	0.005	0.014
8	0.088	0.004	0.013	0.090	0.005	0.015
9	0.106	0.018	0.051	0.102	0.020	0.061
10	0.089	0.008	0.040	0.083	0.005	0.022

TABLE VII

SUMMARY STATISTICS FOR LUBRICANT CANDIDATES

Material Combination: Alloy Steel (B7) Stud/Nut

LUBRICANT NUMBER	COEFFICIENT OF FRICTION OVERALL 5 STUDS, 4 LOADING LOADING VALUES UP TO 2/3 Yield				Stud-to Stud Change Mean	Run-in vs Design Mean	Design vs Used Stud Design Mean
	Mean	Std Dev	Range	Normal Distr. Y/N	Signif Diff. Y/N	Signif Diff. Y/N*	Signif Diff. Y/N*
1	0.105	0.009	0.032	Yes	N/A**	Yes	No
2	0.095	0.009	0.036	Yes	N/A	No	Yes
3	0.059	0.010	0.039	Yes	N/A	Yes	Yes
4	0.148	0.007	0.029	Yes	N/A	Yes	Yes
5	0.095	0.009	0.030	Yes	N/A	Yes	Yes
6	0.105	0.008	0.036	Yes	N/A	Yes	No
7	0.123	0.007	0.030	Yes	N/A	Yes	No
8	0.099	0.005	0.025	Yes	N/A	No	No
9	0.102	0.017	0.062	Yes	N/A	Yes	Yes
10	0.088	0.004	0.018	Yes	N/A	Yes	Yes

* Significance is at the 95% confidence level; i.e., a significant difference for the stud mean value outside of the 95% confidence interval of the overall mean value, or there is a significant difference between the design and run-in mean values at the 95% confidence level.

** This material had only 2 studs tested, not 5 as with the other material combinations.

TABLE VIII

COEFFICIENT OF FRICTION RUN-IN AND DESIGN VALUES

Material Combination: Alloy Steel (B7) Stud/Nut

LUBRICANT NUMBER	COEFFICIENT OF FRICTION					
	RUN - IN LOADING			DESIGN LOADING		
	MEAN	STD DEV	RANGE	MEAN	STD DEV	RANGE
1	0.117	0.004	0.012	0.100	0.007	0.022
2	0.101	0.005	0.015	0.096	0.010	0.033
3	0.071	0.008	0.025	0.057	0.006	0.013
4	0.152	0.006	0.020	0.141	0.006	0.020
5	0.101	0.003	0.009	0.095	0.006	0.015
6	0.111	0.004	0.016	0.104	0.008	0.026
7	0.125	0.009	0.027	0.119	0.004	0.013
8	0.097	0.007	0.026	0.097	0.005	0.016
9	0.123	0.009	0.026	0.107	0.006	0.017
10	0.092	0.003	0.012	0.088	0.004	0.010

Table IX. Initial Run-in Values; Tolerance Ranges

90%/95% TOLERANCE BANDS FOR COEFFICIENT OF FRICTION   SORT ON RANGE

INITIAL RUN-IN VALUES

LUBR.	MEAN INCONEL	STD DEV	90/95 TOL LOW	90/95 TOL HIGH	RANKED RANGE	RANGE/ MEAN	4140 PHO MEAN	STD DEV	90/95 TOL LOW	90/95 TOL HIGH	RANKED RANGE	LUBRICANT	RANGE/ MEAN
6	0.185	0.018	0.140468	0.229532	0.089064	0.481427	0.088	0.004	0.078104	0.097896	0.019792	8	0.224909
8	0.164	0.021	0.112046	0.215954	0.103908	0.633585	0.099	0.004	0.089104	0.108896	0.019792	1	0.199919
7	0.231	0.025	0.16915	0.29285	0.1237	0.535498	0.095	0.005	0.08263	0.10737	0.02474	2	0.260421
10	0.164	0.025	0.10215	0.22585	0.1237	0.754268	0.089	0.005	0.07663	0.10137	0.02474	6	0.277978
3	0.185	0.025	0.12315	0.24685	0.1237	0.668649	0.087	0.005	0.07463	0.09937	0.02474	5	0.284368
1	0.2	0.03	0.12578	0.27422	0.14844	0.7422	0.061	0.007	0.043682	0.078318	0.034636	3	0.567803
5	0.197	0.032	0.117832	0.276168	0.158336	0.803736	0.109	0.007	0.091682	0.126318	0.034636	7	0.317761
2	0.189	0.035	0.10241	0.27559	0.17318	0.916296	0.089	0.008	0.069208	0.108792	0.039584	10	0.444764
4	0.287	0.04	0.18804	0.38596	0.19792	0.689617	0.148	0.008	0.128208	0.167792	0.039584	4	0.267459
9	0.222	0.053	0.090878	0.353122	0.262244	1.181279	0.106	0.018	0.061468	0.150532	0.089064	9	0.840226

MAT'L>> LUBR.	K MONEL/MONEL MEAN	STD DEV	90/95 TOL LOW	90/95 TOL HIGH	RANKED RANGE	RANGE/ MEAN	B7 ALLOY MEAN	STD DEV	90/95 TOL LOW	90/95 TOL HIGH	RANKED RANGE	LUBRICANT	RANGE/ MEAN
8	0.102	0.008	0.082208	0.121792	0.039584	0.388078	0.092	0.003	0.082946	0.101054	0.018108	10	0.196826
9	0.087	0.009	0.064734	0.109266	0.044532	0.511862	0.101	0.003	0.091946	0.110054	0.018108	5	0.179287
10	0.088	0.009	0.065734	0.110266	0.044532	0.506045	0.111	0.004	0.098928	0.123072	0.024144	6	0.217514
2	0.108	0.009	0.085734	0.130266	0.044532	0.412333	0.117	0.004	0.104928	0.129072	0.024144	1	0.206359
5	0.103	0.01	0.07826	0.12774	0.04948	0.480388	0.101	0.005	0.08591	0.11609	0.03018	2	0.298812
4	0.15	0.01	0.12526	0.17474	0.04948	0.329867	0.152	0.006	0.133892	0.170108	0.036216	4	0.238263
7	0.154	0.011	0.126786	0.181214	0.054428	0.353429	0.097	0.007	0.075874	0.118126	0.042252	8	0.435588
3	0.074	0.012	0.044312	0.103688	0.059376	0.802378	0.071	0.008	0.046856	0.095144	0.048288	3	0.680113
1	0.144	0.013	0.111838	0.176162	0.064324	0.446694	0.125	0.009	0.097838	0.152162	0.054324	7	0.434592
6	0.097	0.015	0.05989	0.13411	0.07422	0.765155	0.123	0.009	0.095838	0.150162	0.054324	9	0.441659

Table X. Initial Run-in Values; Tolerance Ranges

COMPOSITE MATERIALS - MIN/MAX 90/95 TOLERANCE - ALL FOUR MATERIALS
SORT ON RANGE

LUBRICANT	MIN	MAX	RANGE
8	0.075874	0.215954	0.14008
10	0.065734	0.22585	0.160116
6	0.05989	0.229532	0.169642
1	0.089104	0.27422	0.185116
2	0.08263	0.27559	0.19296
7	0.091682	0.29285	0.201168
5	0.07463	0.276168	0.201538
3	0.043682	0.24685	0.203168
4	0.12526	0.38596	0.2607
9	0.061468	0.353122	0.291654

Table XI. Initial Design Values; Tolerance Ranges

90%/95% TOLERANCE BANDS FOR COEFFICIENT OF FRICTION   SORT ON RANGE

DESIGN VALUES

LUBR.	INCONEL MEAN	STD DEV	90/95 TOL LOW	90/95 TOL HIGH	RANKED RANGE	RANGE/ MEAN	4140 PHO MEAN	STD DEV	90/95 TOL LOW	90/95 TOL HIGH	RANKED RANGE	LUBRICANT	RANGE/ MEAN
8	0.108	0.01	0.08326	0.13274	0.04948	0.458148	0.107	0.005	0.09463	0.11937	0.02474	7	0.231215
7	0.15	0.013	0.117838	0.182162	0.064324	0.428827	0.083	0.005	0.07063	0.09537	0.02474	10	0.298072
6	0.118	0.014	0.083364	0.152636	0.069272	0.587051	0.08	0.005	0.06763	0.09237	0.02474	6	0.30925
10	0.113	0.014	0.078364	0.147636	0.069272	0.613027	0.048	0.005	0.03563	0.06037	0.02474	3	0.515417
1	0.126	0.018	0.081468	0.170532	0.089064	0.706857	0.09	0.005	0.07763	0.10237	0.02474	8	0.274889
5	0.117	0.018	0.072468	0.161532	0.089064	0.761231	0.136	0.006	0.121156	0.150844	0.029688	4	0.216294
2	0.12	0.02	0.07052	0.16948	0.09896	0.824667	0.076	0.006	0.061156	0.090844	0.029688	5	0.390632
3	0.108	0.023	0.051098	0.164902	0.113804	1.053741	0.085	0.007	0.067682	0.102318	0.034636	2	0.407482
9	0.166	0.036	0.076936	0.255064	0.178128	1.07306	0.092	0.008	0.072208	0.111792	0.039584	1	0.430261
4	0.239	0.048	0.120248	0.357752	0.237504	0.993741	0.102	0.02	0.05252	0.15148	0.09896	9	0.970196

MAT'L>> LUBR.	K MONEL/MONEL MEAN	STD DEV	90/95 TOL LOW	90/95 TOL HIGH	RANKED RANGE	RANGE/ MEAN	B7 ALLOY MEAN	STD DEV	90/95 TOL LOW	90/95 TOL HIGH	RANKED RANGE	LUBRICANT	RANGE/ MEAN
10	0.075	0.006	0.060156	0.089844	0.029688	0.39584	0.119	0.004	0.106928	0.131072	0.024144	7	0.202891
8	0.094	0.008	0.074208	0.113792	0.039584	0.421106	0.088	0.004	0.075928	0.100072	0.024144	10	0.274364
3	0.065	0.008	0.045208	0.084792	0.039584	0.608985	0.097	0.005	0.08191	0.11209	0.03018	8	0.311134
2	0.101	0.009	0.078734	0.123266	0.044532	0.440911	0.095	0.006	0.076892	0.113108	0.036216	5	0.381221
7	0.16	0.009	0.137734	0.182266	0.044532	0.278325	0.141	0.006	0.122892	0.159108	0.036216	4	0.256851
5	0.088	0.01	0.06326	0.11274	0.04948	0.562273	0.057	0.006	0.038892	0.075108	0.036216	3	0.635368
1	0.099	0.01	0.07426	0.12374	0.04948	0.499798	0.107	0.006	0.088892	0.125108	0.036216	9	0.338467
4	0.153	0.014	0.118364	0.187636	0.069272	0.452758	0.1	0.007	0.078874	0.121126	0.042252	1	0.42252
9	0.087	0.014	0.052364	0.121636	0.069272	0.79623	0.104	0.008	0.079856	0.128144	0.048288	6	0.464308
6	0.085	0.015	0.04789	0.12211	0.07422	0.873176	0.096	0.01	0.06582	0.12618	0.06036	2	0.62875

Table XII. Initial Design Values; Tolerance Ranges

COMPOSITE MATERIALS - MIN/MAX 90/95 TOLERANCE - ALL FOUR MATE

SORT ON RANGE

LUBRICANT	MIN	MAX	RANGE
8	0.074208	0.13274	0.058532
10	0.060156	0.147636	0.08748
7	0.09463	0.182266	0.087636
1	0.072208	0.170532	0.098324
5	0.061156	0.161532	0.100376
2	0.06582	0.16948	0.10366
6	0.04789	0.152636	0.104746
3	0.03563	0.164902	0.129318
9	0.052364	0.255064	0.2027
4	0.118364	0.357752	0.023939

Table XIII. Used Stud Design Values; Tolerance Ranges

90%/95% TOLERANCE BANDS FOR COEFFICIENT OF FRICTION SORT ON RANGE

USED STUD DESIGN VALUES

LUBR.	INCONEL MEAN	STD DEV	90/95 TOL LOW	90/95 TOL HIGH	RANGE	RANGE/ MEAN	4140 PHO MEAN	STD DEV	90/95 TOL LOW	90/95 TOL HIGH	RANGE	LUBRICANT	RANGE/ MEAN
1	0.122	0.011	0.094786	0.149214	0.054428	0.446131	0.084	0.009	0.061734	0.106266	0.044532	1	0.530143
2	0.105	0.011	0.077786	0.132214	0.054428	0.518362	0.082	0.009	0.059734	0.104266	0.044532	2	0.543073
3	0.091	0.018	0.046468	0.135532	0.089064	0.978725	0.049	0.007	0.031682	0.066318	0.034636	3	0.706857
4	N/A	N/A	0	0			0.148	0.011	0.120786	0.175214	0.054428	4	0.367757
5	0.105	0.014	0.070364	0.139636	0.069272	0.659733	0.076	0.007	0.058682	0.093318	0.034636	5	0.455737
6	0.116	0.012	0.086312	0.145688	0.059376	0.511862	0.079	0.005	0.06663	0.09137	0.02474	6	0.313165
7	0.15	0.012	0.120312	0.179688	0.059376	0.39584	0.112	0.006	0.097156	0.126844	0.029688	7	0.265071
8	0.11	0.019	0.062994	0.157006	0.094012	0.854655	0.09	0.007	0.072682	0.107318	0.034636	8	0.384844
9	0.137	0.02	0.08752	0.18648	0.09896	0.722336	0.094	0.011	0.066786	0.121214	0.054428	9	0.579021
10	0.104	0.009	0.081734	0.126266	0.044532	0.428192	0.079	0.004	0.069104	0.088896	0.019792	10	0.250532

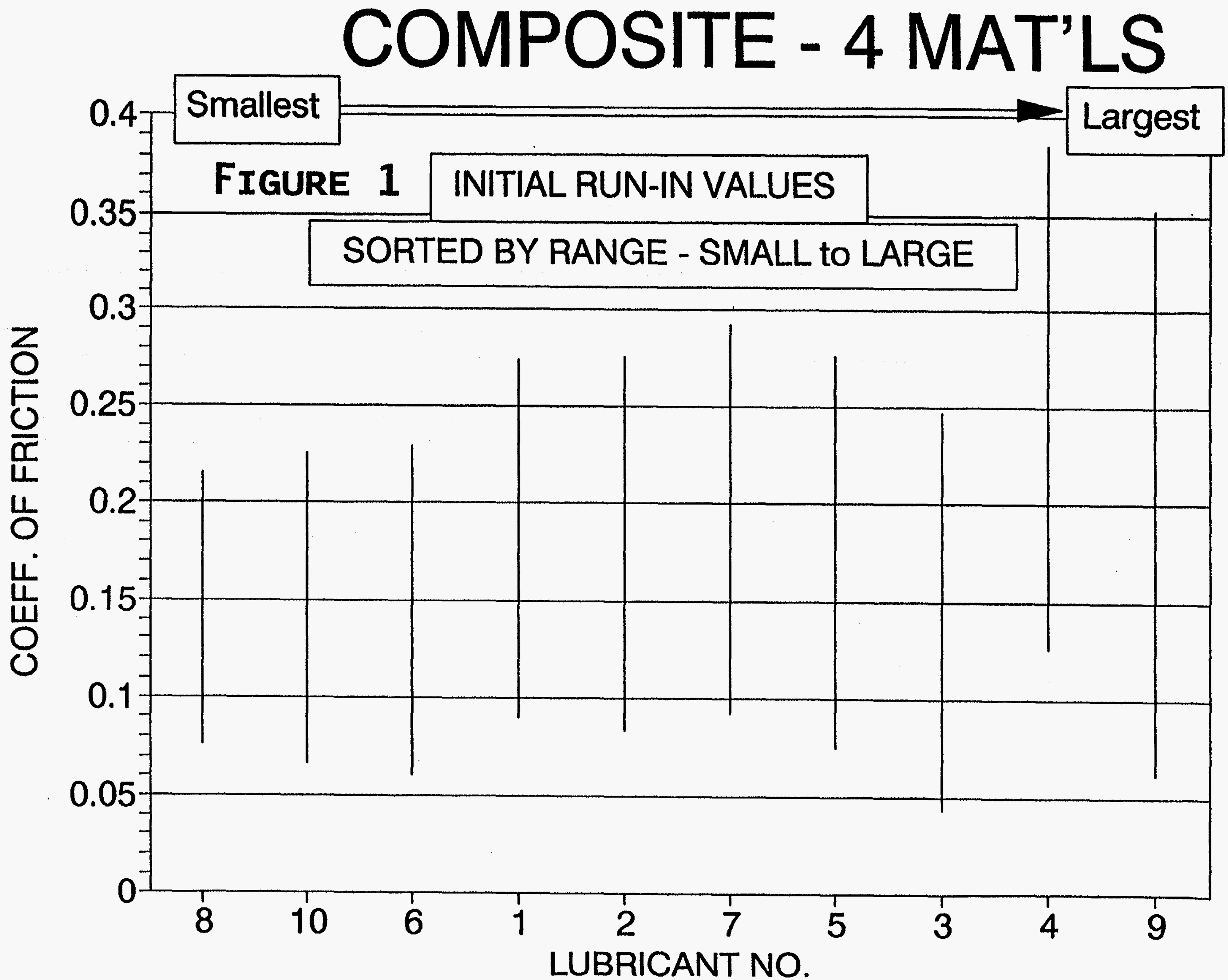
MAT'L>> LUBR.	K MONEL/MONEL MEAN	STD DEV	90/95 TOL LOW	90/95 TOL HIGH	RANGE	RANGE/ MEAN	B7 ALLOY MEAN	STD DEV	90/95 TOL LOW	90/95 TOL HIGH	RANGE	LUBRICANT	RANGE/ MEAN
1	0.095	0.011	0.067786	0.122214	0.054428	0.572926	0.096	0.004	0.083928	0.108072	0.024144	1	0.2515
2	0.098	0.012	0.068312	0.127688	0.059376	0.605878	0.088	0.009	0.060838	0.115162	0.054324	2	0.617318
3	0.057	0.006	0.042156	0.071844	0.029688	0.520842	0.052	0.005	0.03691	0.06709	0.03018	3	0.580385
4	0.176	0.013	0.143838	0.208162	0.064324	0.365477	0.149	0.005	0.13391	0.16409	0.03018	4	0.20255
5	0.083	0.007	0.065682	0.100318	0.034636	0.417301	0.087	0.007	0.065874	0.108126	0.042252	5	0.485655
6	0.077	0.009	0.054734	0.099266	0.044532	0.578338	0.103	0.011	0.069802	0.136198	0.066396	6	0.644621
7	0.153	0.006	0.138156	0.167844	0.029688	0.194039	0.121	0.004	0.108928	0.133072	0.024144	7	0.199537
8	0.094	0.01	0.06926	0.11874	0.04948	0.526383	0.1	0.004	0.087928	0.112072	0.024144	8	0.24144
9	0.085	0.013	0.052838	0.117162	0.064324	0.756753	0.086	0.011	0.052802	0.119198	0.066396	9	0.772047
10	0.075	0.006	0.060156	0.089844	0.029688	0.39584	0.084	0.003	0.074946	0.093054	0.018108	10	0.215571

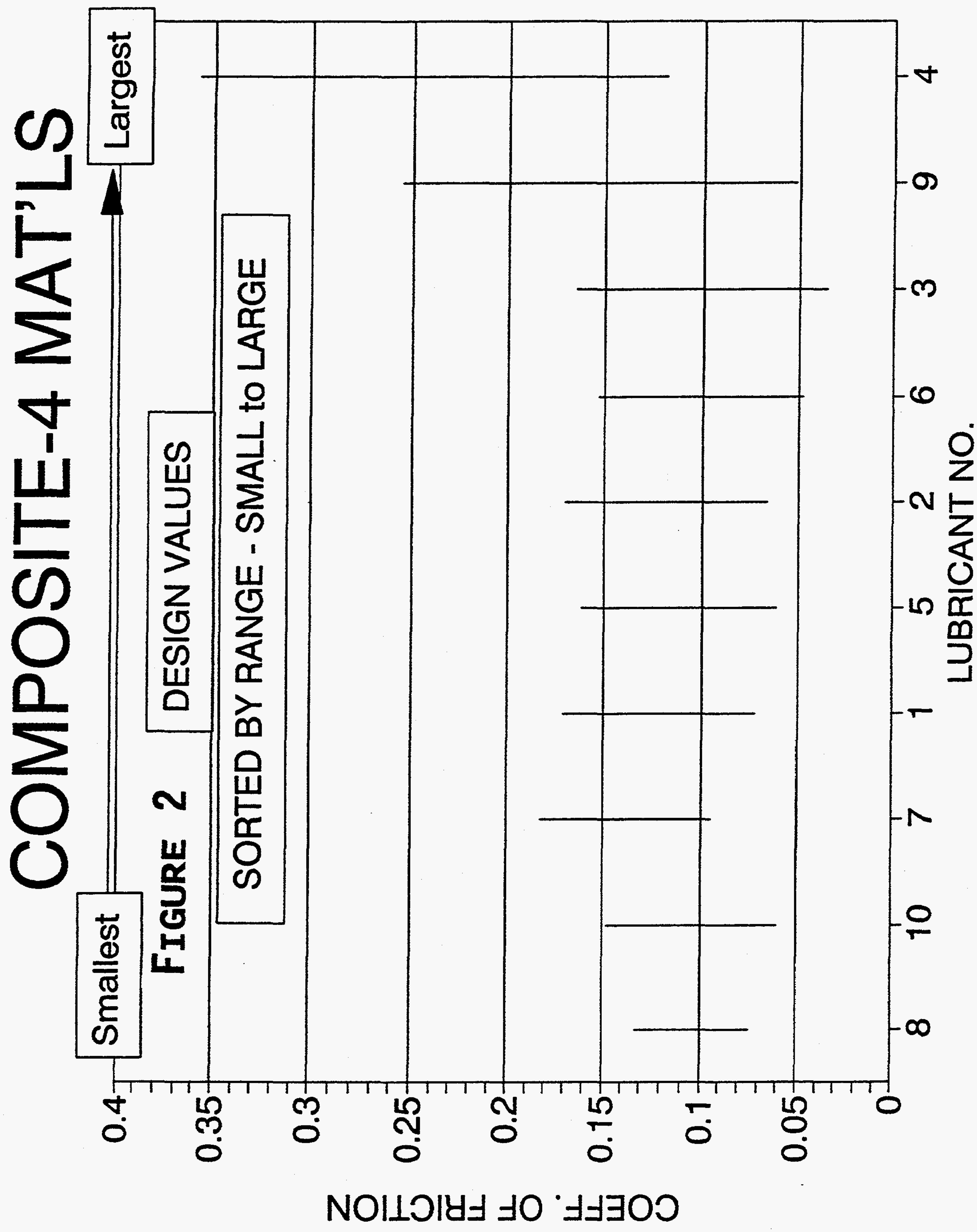
Table XIV. Used Stud Design Values; Tolerance Ranges

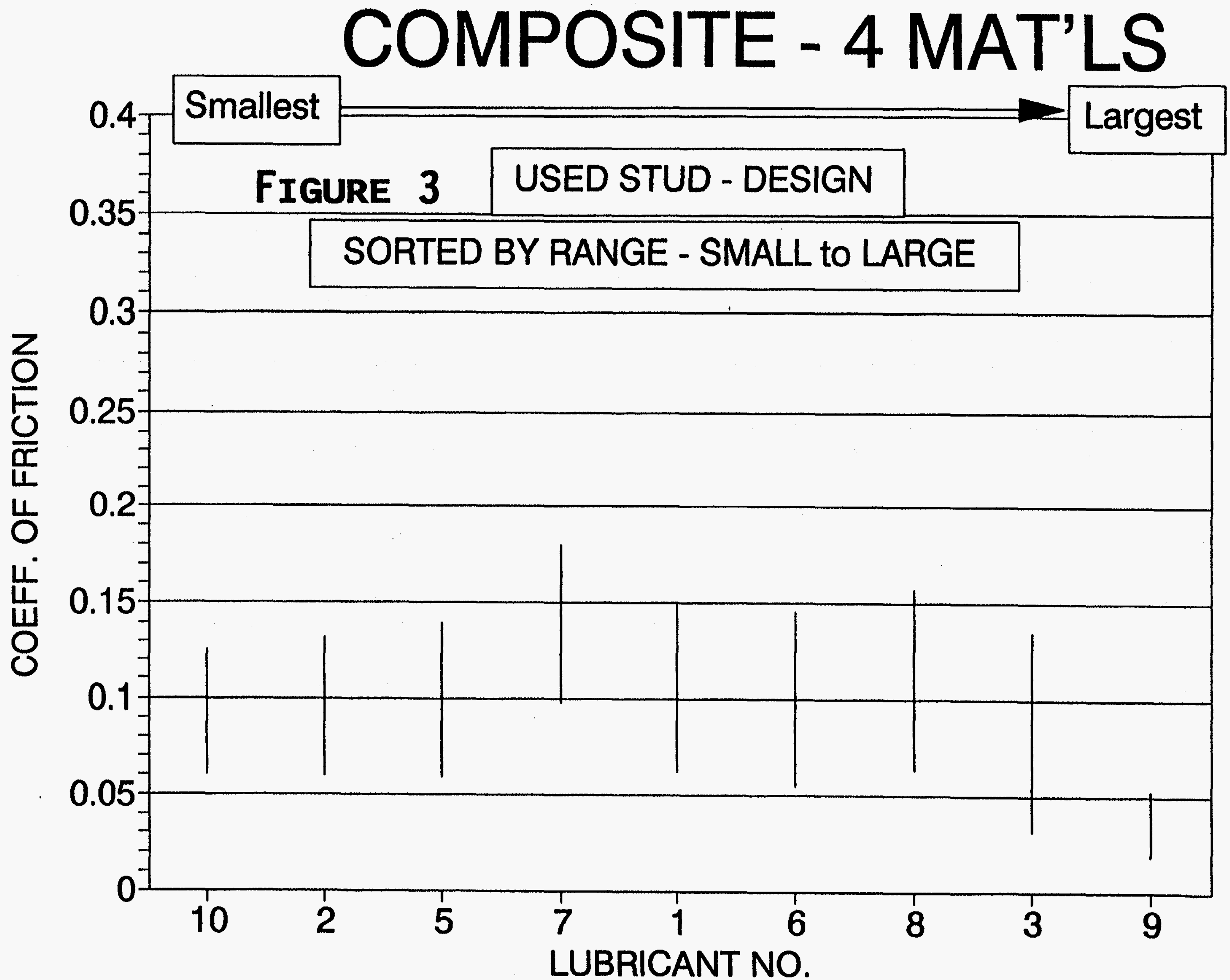
COMPOSITE MATERIALS - MIN/MAX 90/95 TOLERANCE - ALL FOUR MATERIALS

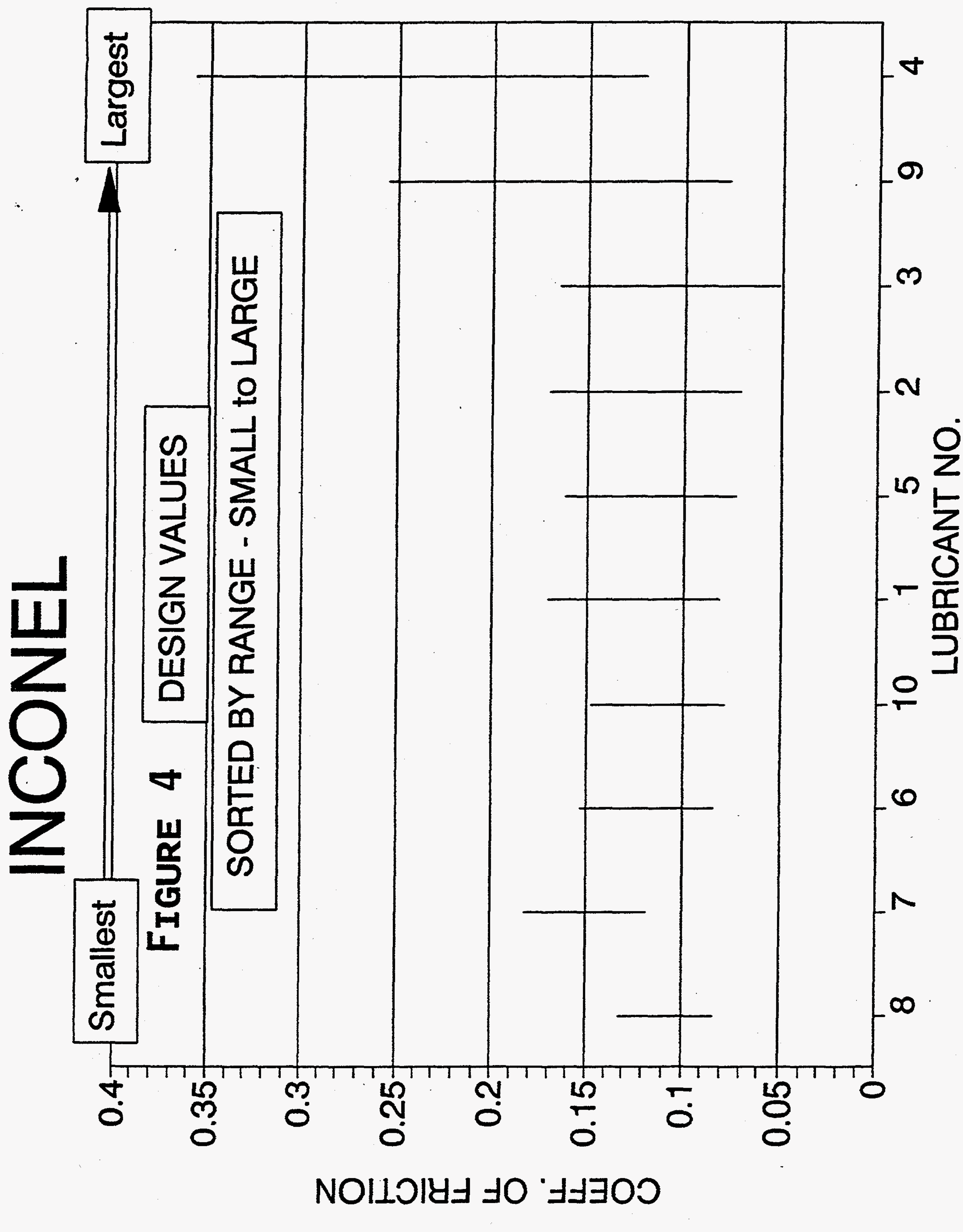
SORT ON RANGE

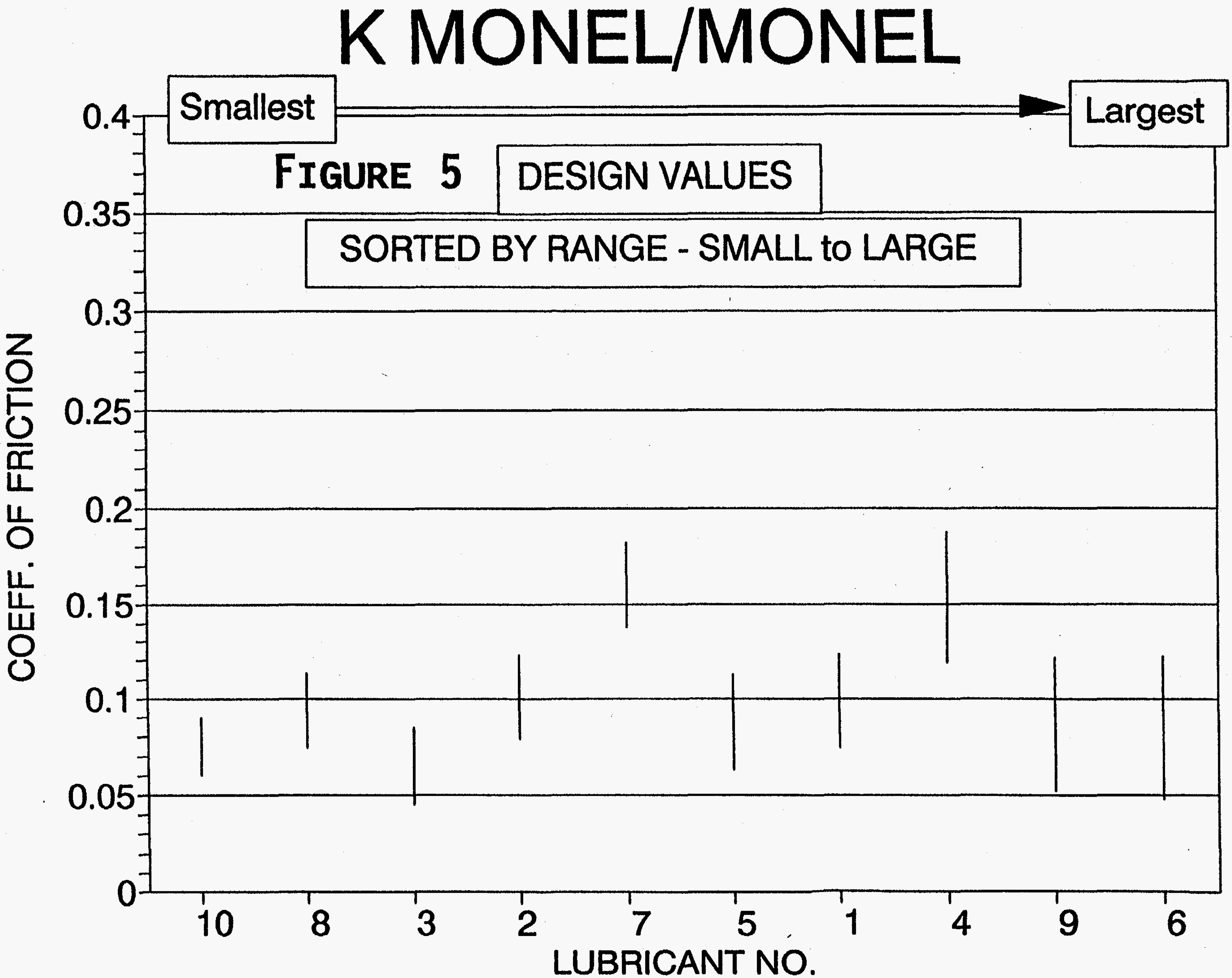
LUBRICANT	MIN	MAX	RANGE
4	n/a	n/a	n/a
10	0.060156	0.126266	0.06611
2	0.059734	0.132214	0.07248
5	0.058682	0.139636	0.080954
7	0.097156	0.179688	0.082532
1	0.061734	0.149214	0.08748
6	0.054734	0.145688	0.090954
8	0.062994	0.157006	0.094012
3	0.031682	0.135532	0.10385
9	0.052802	0.018648	0.133678


COMPOSITE - 4 MAT'LS
Smallest
Largest
FIGURE 1
INITIAL RUN-IN VALUES
SORTED BY RANGE - SMALL to LARGE
COEFF. OF FRICTION
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
8
10
6
1
2
7
5
3
4
9
LUBRICANT NO.

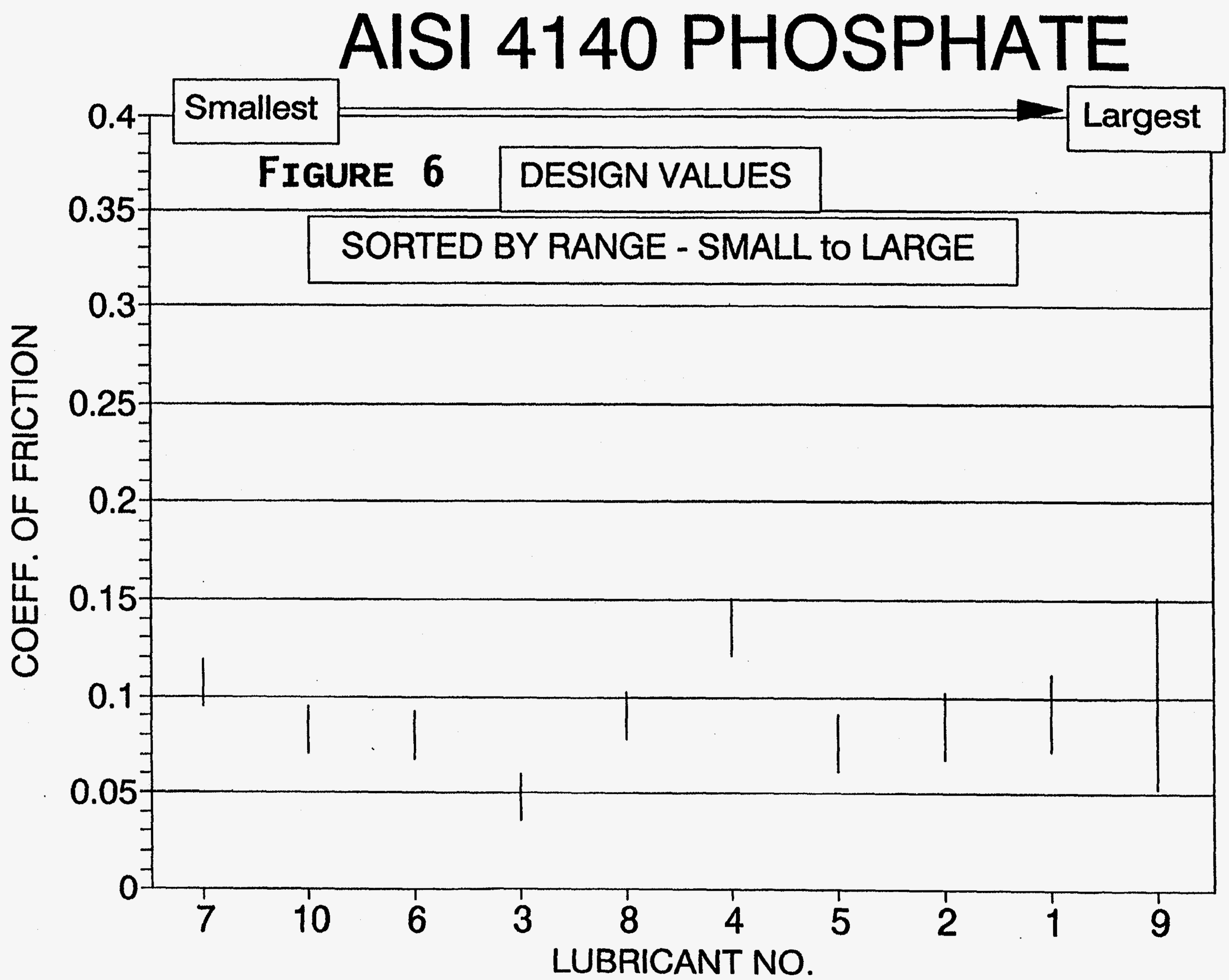

COMPOSITE-4 MAT'LS
FIGURE 2
Smallest
Largest
DESIGN VALUES
SORTED BY RANGE - SMALL to LARGE
COEFF. OF FRICTION
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
LUBRICANT NO.
8
10
7
1
5
2
6
3
9
4


COMPOSITE - 4 MAT'LS
Smallest
Largest
FIGURE 3
USED STUD - DESIGN
SORTED BY RANGE - SMALL to LARGE
COEFF. OF FRICTION
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
10
2
5
7
1
6
8
3
9
LUBRICANT NO.


INCONEL
Smallest
Largest
FIGURE 4
DESIGN VALUES
SORTED BY RANGE - SMALL to LARGE
COEFF. OF FRICTION
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
8
7
6
10
1
5
2
3
9
4
LUBRICANT NO.



K MONEL/MONEL
Smallest
Largest
FIGURE 5
DESIGN VALUES
SORTED BY RANGE - SMALL to LARGE
COEFF. OF FRICTION
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
10
8
3
2
7
5
1
4
9
6
LUBRICANT NO.



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Appendix B
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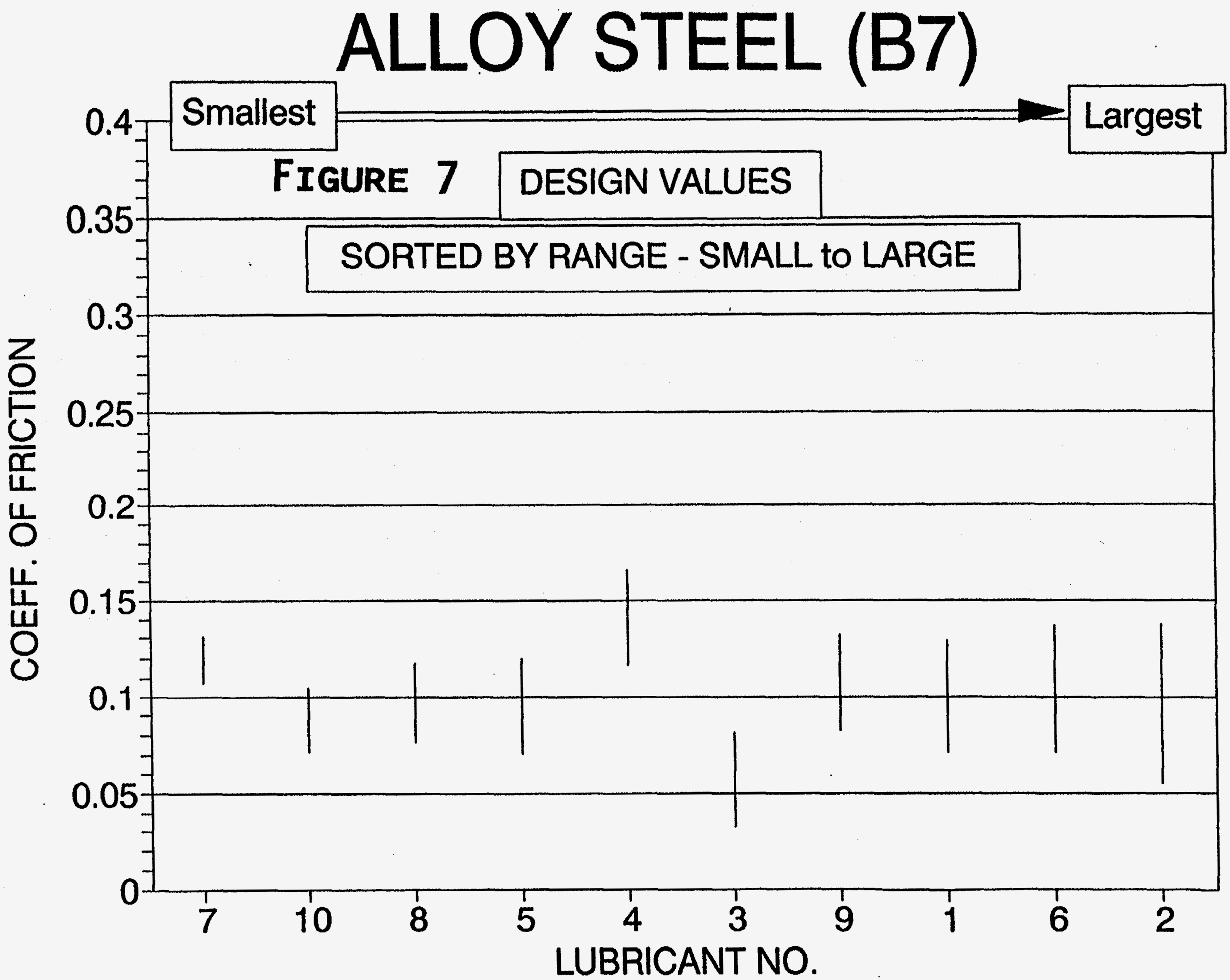
ALLOY STEEL (B7)
Smallest
Largest
FIGURE 7
DESIGN VALUES
SORTED BY RANGE - SMALL to LARGE
COEFF. OF FRICTION
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
7
10
8
5
4
3
9
1
6
2
LUBRICANT NO.

ATTACHMENT I

Phase I - Coefficient of Friction Dataset

Alloy 625

The main body of the following tables list each individual calculated coefficient of friction value, based on the equation of Appendix A, for every Alloy 625 stud tested. The mean coefficient of friction and standard deviations for each individual stud is provided at the bottom of the table, while the mean coefficient of friction, standard deviation and the results of the statistical tests performed for all studs tested under the same loading sequence are provided to the right of the individual values.

Table 1 Summary Statistics for I1

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	
	0.206176	0.256768	0.276194	0.178885	0.182786				t-TEST	F-TEST	
	0.18079	0.226041	0.249612	0.159115	0.184729				t*=1.68	F*=1.98	95% Confi
	0.176099	0.215795	0.225959	0.157524	0.201812	RUN-IN	0.199613	0.029919			
	0.174479	0.193363	0.197991	0.190586	0.222039						
	0.171377	0.185481	0.19643	0.175111	0.205186	XXXXXXXXXXXXXXXXXXXXXX					
	0.12811	0.163275	0.171081	0.10072	0.139838				DESIGN VS RUN-IN		
	0.109772	0.123599	0.139391	0.095936	0.125574				t	F	
	0.112347	0.118997	0.133619	0.105696	0.121656	DESIGN	0.126179	0.017637	10.57199	2.877566	
	0.118657	0.110578	0.141584	0.119667	0.127742				YES	YES	
	0.128863	0.11324	0.142914	0.125739	0.135889	XXXXXXXXXXXXXXXXXXXXXX					
	0.167178	0.171081	0.182786	0.12811	0.151559						
	0.141365	0.159115	0.166999	0.133471	0.155172	USED STUD RUN-IN					
	0.145575	0.162833	0.169467	0.137605	0.173446		0.154424	0.014373			
	0.14352	0.154167	0.159973	0.145457	0.175446						
	0.13745	0.14597	0.148213	0.144474	0.160172	XXXXXXXXXXXXXXXXXXXXXX					
	0.108549	0.147653	ERR	0.116375	0.143746				DESIGN VS USED STUD DESIGN		
	0.101867	0.127549	ERR	0.111748	0.129523	USED STUD DESIGN			t	F	
	0.109687	0.118997	ERR	0.117667	0.130961		0.121656	0.010741	1.059955	2.696523	
	0.118657	0.117647	ERR	0.117647	0.126733				NO	YES	
	0.124958	0.121834	ERR	0.117147	0.124177	XXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.140274	0.156699	0.180147	0.133934	0.155909		0.152	0.037			
STD DEV	0.029693	0.041377	0.042456	0.026789	0.03083						

TABLE 2: A TABLE2; ALLOY TYPE I, LUBRICANT NO.2

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARAIANCE	
	0.31901	0.186768	0.171157	0.256881	0.217958				t-TEST	F-TEST	
	0.222208	0.172987	0.16313	0.208437	0.18284				t*=1.68	F*=1.98	95% Confi
	0.198084	0.17485	0.17485	0.190448	0.176177	RUN-IN	0.188693	0.035414			
	0.183259	0.177457	0.173589	0.179392	0.161979						
	0.172947	0.167717	0.165475	0.168464	0.15127	XXXXXXXXXXXXXXXXXXXXXXX					
	0.19847	0.108597	0.116427	0.104681	0.120341				DESIGN VS RUN-IN		
	0.135504	0.094	0.105867	0.101912	0.101912				t	F	
	0.116389	0.109735	0.112397	0.12171	0.112397	DESIGN	0.119887	0.01962	8.497643	3.258124	
	0.110627	0.12073	0.11871	0.133856	0.117699				YES	YES	
	0.123451	0.125014	0.132826	0.134388	0.119544	XXXXXXXXXXXXXXXXXXXXXXX					
	0.186768	0.1399	0.128166	0.159441	0.124254						
	0.141427	0.121679	0.12563	0.137479	0.10389	USED STUD RUN-IN					
	0.14431	0.12171	0.132348	0.142982	0.108405		0.132688	0.017871			
	0.134865	0.124769	0.134865	0.148426	0.107596						
	0.130482	0.127358	0.132826	0.149026	0.1086	XXXXXXXXXXXXXXXXXXXXXXX					
	0.128166	0.092929	0.092929	0.108597	0.104681				DESIGN VS USED STUD DESIGN		
	0.105867	0.092022	0.094	0.101912	0.088065	USED STUD DESIGN			t	F	
	0.113728	0.097754	0.097754	0.108405	0.092427		0.105054	0.01073	3.316556	3.343545	
	0.12073	0.104564	0.102542	0.11871	0.096476				YES	YES	
	0.116417	0.110945	0.105472	0.121888	0.109381	XXXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.155136	0.128574	0.139217	0.144852	0.125295		0.136581	0.038906			
STD DEV	0.051775	0.030889	0.023843	0.040161	0.034525						

TABLE 3: ALLOY TYPE I, LUBRICANT NO. 3

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARAIANCE	
	0.237428	0.175061	0.19847	0.229642	0.167252				t-TEST	F-TEST	
	0.220241	0.159185	0.202533	0.208437	0.151295				t*=1.68	F*=1.98	95% Confi
	0.203173	0.158922	0.208261	0.190448	0.168215	RUN-IN	0.184714	0.025132			
	0.174556	0.173589	0.205484	0.163914	0.171654						
	0.155757	0.178176	0.200167	0.148278	0.167717	XXXXXXXXXXXXXXXXXXXXXXX					
	0.120341	0.100764	0.159441	0.08509	0.08117				DESIGN VS RUN-IN		
	0.101912	0.080148	0.139453	0.082128	0.080148				t	F	
	0.113728	0.087099	0.140324	0.084434	0.087099	DESIGN	0.107506	0.023478	11.22467	1.14594	
	0.110627	0.116689	0.144553	0.089397	0.093443				YES	NO	
	0.109381	0.127358	0.138292	0.099769	0.114854	XXXXXXXXXXXXXXXXXXXXXXX					
	0.108597	0.08117	0.175061	0.092929	0.124254						
	0.113774	0.086086	0.159185	0.084107	0.13353	USED STUD RUN-IN					
	0.129689	0.105742	0.152281	0.081769	0.145639		0.119836	0.027632			
	0.128808	0.113659	0.139709	0.080292	0.150363						
	0.121107	0.109381	0.13595	0.090804	0.152018	XXXXXXXXXXXXXXXXXXXXXXX					
	0.073328	0.069405	0.132078	0.073328	0.08117				DESIGN VS USED STUD DESIGN		
	0.066287	0.070248	0.105867	0.064306	0.076189	USED STUD DESIGN			t	F	
	0.088431	0.079104	0.100417	0.077771	0.084434		0.091014	0.018451	2.761431	1.619091	
	0.094454	0.086363	0.114669	0.103553	0.095465				YES	NO	
	0.109381	0.092434	0.12267	0.110163	0.103842	XXXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.12905	0.112529	0.166611	0.112028	0.121488		0.125768	0.042778			
STD DEV	0.046513	0.03695	0.028587	0.048595	0.035324						

TABLE 4: ALLOY I, LUBRICANT NO. 4

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	
	0.307375	0.276316	0.249102	0.276316	0.419584				t-TEST	F-TEST	
	0.282927	0.279162	0.257576	0.257576	0.346837				t*=1.68	F*=1.98	95% Confi
	0.260976	0.276776	0.279206	0.241303	0.340332	RUN-IN	0.287076	0.040144			
	0.284333	0.308375	0.316063	0.257553	0.315102						
	0.288956	0.288956	0.273911	0.219964	0.272327	XXXXXXXXXXXXXXXXXXXXXXX					
	0.225748	0.252992	0.342262	0.167252	0.24132				DESIGN VS RUN-IN		
	0.202533	0.234004	0.307386	0.159185	0.239899				t	F	
	0.21589	0.2286	0.313061	0.172196	0.250031	DESIGN	0.238642	0.048284	3.856715	1.446634	
	0.250326	0.263875	0.287219	0.175523	0.25936				YES	NO	
	0.218408	0.233962	0.29934	0.169959	0.255717	XXXXXXXXXXXXXXXXXXXXXXX					
						USED STUD RUN-IN					
							0	0			
						XXXXXXXXXXXXXXXXXXXXXXX					
									DESIGN VS USED STUD DESIGN		
						USED STUD DESIGN			t	F	
							0	0			
						XXXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.126874	0.132151	0.195008	0.104841	0.147026		0.262859	0.050295			
STD DEV	0.132584	0.136804	0.144565	0.11203	0.156315						

TABLE 5: ALLOY I, LUBRICANT NO. 5

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARAIANCE	
	0.163347	0.276316	0.19457	0.225748	0.252992				t-TEST	F-TEST	
	0.153268	0.251686	0.172987	0.208437	0.210405				t*=1.68	F*=1.98	95% Confi
	0.169542	0.236223	0.172196	0.203173	0.206989	RUN-IN	0.196735	0.032197			
	0.163914	0.206409	0.175523	0.193448	0.201781						
	0.155757	0.187024	0.167717	0.183372	0.185563	XXXXXXXXXXXXXXXXXXXXXXX					
	0.120341	0.159441	0.08509	0.128166	0.120341				DESIGN VS RUN-IN		
	0.101912	0.12563	0.092022	0.13353	0.10389				t	F	
	0.105742	0.116389	0.096423	0.146968	0.105742	DESIGN	0.117324	0.018045	10,75773	3.183422	
	0.107596	0.110627	0.103553	0.143584	0.116689				YES	YES	
	0.107036	0.119544	0.116417	0.144538	0.121888	XXXXXXXXXXXXXXXXXXXXXXX					
	0.096847	0.214062	0.100764	0.120341	0.178964						
	0.105867	0.161158	0.095979	0.117727	0.159185	USED STUD RUN-IN					
	0.12171	0.156266	0.10308	0.129689	0.160249		0.134621	0.028662			
	0.132846	0.153268	0.103553	0.129818	0.153268						
	0.133607	0.150522	0.114072	0.130482	0.142196	XXXXXXXXXXXXXXXXXXXXXXX					
	0.08117	0.1399	0.08901	0.100764	0.1399				DESIGN VS USED STUD DESIGN		
	0.086086	0.111798	0.088065	0.105867	0.113774	USED STUD DESIGN			t	F	
	0.089763	0.113728	0.095091	0.105742	0.111066		0.10534	0.014429	-2.5935	1.564176	
	0.095465	0.112648	0.096476	0.112648	0.106585				YES	NO	
	0.103028	0.113291	0.098954	0.115636	0.107036	XXXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.119742	0.160796	0.126263	0.143984	0.149925		0.138505	0.04279			
STD DEV	0.028144	0.051371	0.038026	0.037777	0.043574						

TABLE 6: ALLOY I, LUBRICANT NO. 6

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARAIANCE	
	0.217958	0.19457	0.210165	0.210165	0.182867				t-TEST	F-TEST	
	0.204501	0.1789	0.172987	0.202533	0.157213				t*=1.68	F*=1.98	95% Confi
	0.200629	0.187902	0.18281	0.187902	0.158922	RUN-IN	0.184678	0.017745			
	0.192522	0.185112	0.192522	0.178425	0.155204						
	0.181911	0.173694	0.185563	0.170706	0.15127	XXXXXXXXXXXXXXXXXXXXXXX					
	0.112512	0.120341	0.120341	0.135989	0.128166				DESIGN VS RUN-IN		
	0.097957	0.10389	0.10389	0.121679	0.105867				t	F	
	0.099086	0.111066	0.111066	0.12836	0.116389	DESIGN	0.116394	0.013559	14.8402	1.71283	
	0.103553	0.107596	0.139709	0.133856	0.11972				YES	NO	
	0.116417	0.113291	0.15127	0.131263	0.126576	XXXXXXXXXXXXXXXXXXXXXXX					
	0.19457	0.155534	0.182867	0.147718	0.19457						
	0.167073	0.141427	0.143401	0.151295	0.165102	USED STUD RUN-IN					
	0.162905	0.146968	0.136336	0.152281	0.156266		0.152594	0.017024			
	0.151331	0.147458	0.137772	0.144553	0.145521						
	0.144538	0.134388	0.13673	0.13673	0.137511	XXXXXXXXXXXXXXXXXXXXXXX					
	0.1399	0.100764	0.147718	0.104681	0.124254				DESIGN VS USED STUD DESIGN		
	0.117727	0.095979	0.115751	0.097957	0.111798	USED STUD DESIGN			t	F	
	0.116389	0.115058	0.111066	0.10308	0.117719		0.116017	0.012363	-0.64757	1.202809	
	0.109617	0.129818	0.11871	0.107596	0.11871				NO	NO	
	0.110945	0.133607	0.121888	0.110945	0.118762	XXXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.147102	0.138868	0.153829	0.142886	0.13962		0.142921	0.032045			
STD DEV	0.040202	0.031493	0.032008	0.032946	0.024767						

TABLE 7: ALLOY I, LUBRICANT NO.7

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARAIANCE	
	0.237428	0.202369	0.276316	0.276316	0.295733				t-TEST	F-TEST	
	0.220241	0.230072	0.251686	0.255613	0.234004				t*=1.68	F*=1.98	95% Confi
	0.22733	0.222246	0.246381	0.238763	0.219704	RUN-IN	0.231141	0.025372			
	0.220288	0.215663	0.231344	0.211962	0.210111						
	0.211114	0.200897	0.244065	0.197977	0.200897	XXXXXXXXXXXXXXXXXXXXXXX					
	0.1399	0.186768	0.171157	0.171157	0.171157				DESIGN VS RUN-IN		
	0.143401	0.149321	0.143401	0.13353	0.141427				t	F	
	0.140324	0.15361	0.138995	0.138995	0.140324	DESIGN	0.1503	0.013272	14.11643	3.654582	
	0.154236	0.158108	0.141647	0.144553	0.137772				YES	YES	
	0.155757	0.159495	0.146782	0.154261	0.141415	XXXXXXXXXXXXXXXXXXXXXXX					
	0.167252	0.182867	0.178964	0.163347	0.182867						
	0.161158	0.15524	0.159185	0.161158	0.16313	USED STUD RUN-IN					
	0.172196	0.156266	0.162905	0.164232	0.161577		0.165445	0.007008			
	0.166817	0.162947	0.164882	0.167785	0.162947						
	0.16398	0.16398	0.165475	0.163232	0.161738	XXXXXXXXXXXXXXXXXXXXXXX					
	0.1399	0.151626	0.151626	0.143809	0.178964				DESIGN VS USED STUD DESIGN		
	0.131555	0.131555	0.139453	0.153268	0.157213	USED STUD DESIGN			t	F	
	0.136336	0.146968	0.140324	0.160249	0.152281		0.14973	0.011606	-0.16146	1.307768	
	0.140678	0.154236	0.140678	0.16585	0.156172				NO	NO	
	0.143757	0.163232	0.144538	0.166222	0.152766	XXXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.168682	0.172373	0.188212	0.176614	0.17611		0.174154	0.037106			
STD DEV	0.034557	0.027948	0.047352	0.039414	0.039199						

TABLE 8:ALLOY I,LUBRICANT NO. 8

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARAIANCE	
	0.19067	0.151626	0.206267	0.1399	0.175061				t-TEST	F-TEST	
	0.192689	0.151295	0.18284	0.127605	0.153268				t*=1.68	F*=1.98	95% Confi
	0.196812	0.177503	0.172196	0.136336	0.150953	RUN-IN	0.163804	0.02143			
	0.184186	0.173589	0.166817	0.141647	0.144553						
	0.178176	0.159495	0.158	0.142196	0.141415	XXXXXXXXXXXXXXXXXXXXXX					
	0.108597	0.096847	0.120341	0.096847	0.100764				DESIGN VS RUN-IN		
	0.101912	0.105867	0.10389	0.092022	0.084107				t	F	
	0.109735	0.112397	0.112397	0.101749	0.096423	DESIGN	0.107545	0.010072	11.87954	4.527052	
	0.11972	0.114669	0.110627	0.108606	0.103553				YES	YES	
	0.130482	0.115636	0.115636	0.114854	0.110945	XXXXXXXXXXXXXXXXXXXXXX					
	0.167252	0.151626	0.151626	0.092929	0.096847						
	0.13353	0.135504	0.13353	0.088065	0.095979	USED STUD RUN-IN					
	0.138995	0.142982	0.137666	0.100417	0.107074		0.126673	0.022385			
	0.140678	0.147458	0.142615	0.102542	0.112648						
	0.146034	0.139073	0.139854	0.107036	0.114854	XXXXXXXXXXXXXXXXXXXXXX					
	0.147718	0.112512	0.132078	0.08509	0.08117				DESIGN VS USED STUD DESIGN		
	0.131555	0.094	0.109821	0.105867	0.082128	USED STUD DESIGN			t	F	
	0.135007	0.105742	0.113728	0.096423	0.089763		0.110464	0.018756	0.685551	3.46767	
	0.138741	0.111638	0.115679	0.098498	0.096476				NO	YES	
	0.141415	0.114072	0.115636	0.106254	0.100583	XXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.146695	0.130677	0.14362	0.109244	0.111928		0.127121	0.029144			
STD DEV	0.028947	0.025346	0.029529	0.016369	0.026724						

TABLE 9: ALLOY I, LUBRICANT NO. 9

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARAIANCE	
	0.167252	0.19847	0.178964	0.326764	0.217958				t-TEST	F-TEST	
	0.149321	0.192689	0.18284	0.265428	0.230072				t*=1.68	F*=1.98	95% Confi
	0.156266	0.201901	0.203173	0.26827	0.25368	RUN-IN	0.222099	0.05263			
	0.154236	0.197152	0.220288	0.293953	0.263875						
	0.152766	0.212573	0.255717	0.319916	0.268956	XXXXXXXXXXXXXXXXXXXXXXX					
	0.092929	0.19847	0.171157	0.178964	0.147718				DESIGN VS RUN-IN		
	0.095979	0.200564	0.161158	0.171016	0.141427				t	F	
	0.104411	0.194266	0.177503	0.181483	0.150953	DESIGN	0.166164	0.036231	4.377079	2.110071	
	0.114669	0.215663	0.197152	0.174556	0.172622				YES	YES	
	0.12892	0.223853	0.203817	0.172947	0.181911	XXXXXXXXXXXXXXXXXXXXXXX					
	0.19067	0.182867	0.167252	0.163347	0.147718						
	0.18087	0.16678	0.174958	0.15524	0.147348	USED STUD RUN-IN					
	0.191721	0.198084	0.214619	0.162905	0.177503		0.190711	0.029152			
	0.211036	0.213812	0.237673	0.168752	0.204558						
	0.24018	0.212573	0.252611	0.164727	0.219964	XXXXXXXXXXXXXXXXXXXXXXX					
	0.155534	0.128166	0.128166	0.167252	0.108597				DESIGN VS USED STUD DESIGN		
	0.147348	0.12563	0.127605	0.141427	0.101912	USED STUD DESIGN			t	F	
	0.158922	0.132348	0.136336	0.140324	0.107074		0.137453	0.020245	-3.45891	3.202715	
	0.170687	0.141647	0.140678	0.141647	0.109617				YES	YES	
	0.178176	0.142977	0.155009	0.137511	0.111727	XXXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.157095	0.185024	0.199925	0.194822	0.17426		0.179107	0.047711			
STD DEV	0.03759	0.031901	0.030744	0.061986	0.056893						

TABLE 10: ALLOY TYPE I , LUBRICANT NO.10

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARAIANCE	
	0.217958	0.186768	0.217958	0.128166	0.1399				t-TEST	F-TEST	
	0.18087	0.171016	0.204501	0.137479	0.13353				t*=1.68	F*=1.98	95% Confi
	0.164232	0.170869	0.189175	0.156266	0.132348	RUN-IN	0.164031	0.025156			
	0.154236	0.172622	0.166817	0.159076	0.139709						
	0.144538	0.165475	0.152018	0.168464	0.146782	XXXXXXXXXXXXXXXXXXXXXX					
	0.100764	0.120341	0.100764	0.120341	0.092929				DESIGN VS RUN-IN		
	0.094	0.111798	0.101912	0.109821	0.095979				t	F	
	0.093759	0.131019	0.109735	0.116389	0.107074	DESIGN	0.113401	0.013923	8.804803	3.264683	
	0.101531	0.139709	0.128808	0.12174	0.114669				YES	YES	
	0.109381	0.139073	0.129701	0.123451	0.120325	XXXXXXXXXXXXXXXXXXXXXX					
	0.116427	0.120341	0.128166	0.120341	0.128166						
	0.115751	0.109821	0.123654	0.12958	0.127605	USED STUD RUN-IN					
	0.12304	0.117719	0.137666	0.133678	0.132348		0.126361	0.008017			
	0.12073	0.124769	0.131837	0.136803	0.140678						
	0.117199	0.125795	0.127358	0.129701	0.139854	XXXXXXXXXXXXXXXXXXXXXX					
	0.100764	0.08901	0.104681	0.092929	0.108597				DESIGN VS USED STUD DESIGN		
	0.101912	0.088065	0.101912	0.094	0.095979	USED STUD DESIGN			t	F	
	0.104411	0.093759	0.108405	0.105742	0.108405		0.104191	0.009164	2.762597	2.308292	
	0.103553	0.098498	0.115679	0.107596	0.114669				YES	YES	
	0.099769	0.113291	0.124232	0.110163	0.116762	XXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.123241	0.129488	0.143338	0.125086	0.121915		0.126996	0.027583			
STD DEV	0.03299	0.029883	0.035985	0.020125	0.016606		R=O.1289				

ATTACHMENT II

Phase I - Coefficient of Friction Dataset

Monel K-500 (K-Monel)/Monel 400

The main body of the following tables list each individual calculated coefficient of friction value, based on the equation of Appendix A, for every Monel K-500 stud tested. The mean coefficient of friction and standard deviations for each individual stud is provided at the bottom of the table, while the mean coefficient of friction, standard deviation and the results of the statistical tests performed for all studs tested under the same loading sequence are provided to the right of the individual values.

TABLE 1: ALLOY M, LUBRICANT NO. 1

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARAIANCE	
	0.106455	0.097655	0.094721	0.121113	0.097655				t-TEST	F-TEST	
	0.113046	0.096638	0.102606	0.130931	0.09813				t*=1.68	F*=1.98	95% Confi
	0.125574	0.115489	0.108426	0.138517	0.111453	RUN-IN	0.114448	0.012956			
	0.117683	0.118416	0.106684	0.138748	0.114017						
	0.11954	0.126285	0.108293	0.131343	0.121789	XXXXXXXXXXXXXXXXXXXXXXX					
	0.088852	0.100589	0.082981	0.082981	0.091787				DESIGN VS RUN-IN		
	0.089176	0.102606	0.08619	0.087683	0.095146				t	F	
	0.098332	0.107417	0.092274	0.099342	0.10338	DESIGN	0.099245	0.010327	4.588031	1.57393	
	0.100082	0.110351	0.092531	0.103017	0.108884				YES	NO	
	0.108855	0.117853	0.098483	0.113917	0.118415	XXXXXXXXXXXXXXXXXXXXXXX					
	0.088852	0.091787	0.088852	0.100589	0.091787						
	0.095146	0.09813	0.087683	0.095146	0.093653	USED STUD RUN-IN					
	0.10237	0.108426	0.101361	0.098332	0.101361		0.100329	0.007526			
	0.10375	0.109618	0.105217	0.098615	0.102283						
	0.109418	0.115604	0.109418	0.101419	0.109418	XXXXXXXXXXXXXXXXXXXXXXX					
	0.085917	0.088852	0.071235	0.088852	0.085917				DESIGN VS USED STUD DESIGN		
	0.090668	0.095146	0.081711	0.08619	0.083204	USED STUD DESIGN			t	F	
	0.10237	0.106408	0.100352	0.087224	0.097323		0.095353	0.01084	-1.29975	1.101752	
	0.104484	0.105951	0.103017	0.087179	0.099349				NO	NO	
	0.110543	0.113355	0.111105	0.091435	0.106043	XXXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.103056	0.106329	0.097715	0.104129	0.10155		0.102344	0.01271			
STD DEV	0.01118	0.009879	0.008995	0.018382	0.01029						

TABLE 2: ALLOY M, LUBRICANT NO. 2

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARAIANCE	
	0.106455	0.100589	0.088852	0.091787	0.106455				t-TEST	F-TEST	
	0.110064	0.110064	0.095146	0.095146	0.110064				t*=1.68	F*=1.98	95% Confl
	0.116515	0.115489	0.10237	0.10237	0.113471	RUN-IN	0.107763	0.008769			
	0.115483	0.11475	0.10155	0.105217	0.113284						
	0.120102	0.116166	0.107168	0.115042	0.118978	XXXXXXXXXXXXXXXXXXXXXXX					
	0.103522	0.088852	0.077109	0.088852	0.100589				DESIGN VS RUN-IN		
	0.099622	0.095146	0.083204	0.096638	0.095146				t	F	
	0.106408	0.10237	0.095304	0.107417	0.109435	DESIGN	0.100858	0.009339	2.699949	1.128956	
	0.105951	0.105217	0.096353	0.108151	0.110351				YES	NO	
	0.108855	0.111105	0.100832	0.110543	0.114479	XXXXXXXXXXXXXXXXXXXXXXX					
	0.091787	0.103522	0.094721	0.097655	0.094721						
	0.08619	0.107081	0.105589	0.096638	0.101114	USED STUD RUN-IN					
	0.093284	0.116497	0.110444	0.098332	0.106408		0.103424	0.009775			
	0.091766	0.120615	0.110351	0.100082	0.105217						
	0.098483	0.127971	0.111105	0.104355	0.111667	XXXXXXXXXXXXXXXXXXXXXXX					
	0.082981	0.094721	0.077109	0.088852	0.094721				DESIGN VS USED STUD DESIGN		
	0.081711	0.104098	0.084697	0.092161	0.095146	USED STUD DESIGN			t	F	
	0.088234	0.117506	0.096313	0.100352	0.10338		0.097596	0.012015	-1.07192	1.655253	
	0.086414	0.119882	0.097117	0.098615	0.103017				NO	NO	
	0.090848	0.125723	0.100832	0.10548	0.10998	XXXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.099334	0.109868	0.098673	0.100184	0.105881		0.102415	0.010585			
STD DEV	0.011904	0.01058	0.010077	0.00716	0.00727						

TABLE 3: ALLOY M, LUBRICANT NO. 3

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARAIANCE	
	0.065359	0.062421	0.062421	0.059482	0.065359				t-TEST	F-TEST	
	0.07275	0.059301	0.06229	0.063785	0.068268				t*=1.68	F*=1.98	95% Confi
	0.082173	0.061957	0.071057	0.074089	0.074089	RUN-IN	0.073697	0.011796			
	0.086414	0.064226	0.083355	0.078766	0.079531						
	0.100832	0.073145	0.096134	0.091435	0.083798	XXXXXXXXXXXXXXXXXXXXXX					
	0.059482	0.053603	0.062421	0.056543	0.053603				DESIGN VS RUN-IN		
	0.063785	0.054816	0.065279	0.059301	0.059301				t	F	
	0.066002	0.059934	0.071057	0.059934	0.069035	DESIGN	0.064796	0.008257	3.091006	2.041021	
	0.06193	0.062695	0.07188	0.059633	0.07494				YES	YES	
	0.066407	0.070695	0.085561	0.068857	0.08321	XXXXXXXXXXXXXXXXXXXXXX					
	0.056543	0.056543	0.068297	0.059482	0.065359						
	0.060796	0.060796	0.063785	0.057806	0.06229	USED STUD RUN-IN					
	0.064991	0.066002	0.068024	0.057912	0.066002		0.064968	0.006282			
	0.064992	0.064992	0.071115	0.057336	0.065757						
	0.079096	0.071307	0.079096	0.062731	0.073145	XXXXXXXXXXXXXXXXXXXXXX					
	0.050663	0.047723	0.050663	0.056543	0.056543				DESIGN VS USED STUD DESIGN		
	0.057806	0.050331	0.053321	0.051626	0.057806	USED STUD DESIGN			t	F	
	0.066002	0.055889	0.057912	0.05083	0.055889		0.057177	0.006389	-3.64925	1.670316	
	0.064226	0.057336	0.06193	0.051975	0.051975				YES	NO	
	0.071307	0.063957	0.071307	0.054765	0.060893	XXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.068078	0.060883	0.072118	0.061652	0.06634		0.065159	0.010211			
STD DEV	0.01156	0.006727	0.009885	0.009917	0.009457						

TABLE 4: ALLOY M, LUBRICANT NO. 4

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARAIANCE	
	0.1504	0.144545	0.1504	0.1504	0.156252				t-TEST	F-TEST	
	0.139869	0.147314	0.144336	0.141358	0.154756				t*=1.68	F*=1.98	95% Confi
	0.143354	0.150123	0.152057	0.147222	0.15979	RUN-IN	0.150475	0.009905			
	0.136642	0.145765	0.144362	0.140853	0.157689						
	0.137963	0.171055	0.154442	0.164031	0.176907	XXXXXXXXXXXXXXXXXXXXXXX					
	0.132832	0.141618	0.159178	0.162103	0.1738				DESIGN VS RUN-IN		
	0.124971	0.133911	0.145625	0.153268	0.154756				t	F	
	0.13755	0.148189	0.153023	0.15689	0.162689	DESIGN	0.152599	0.014072	-0.61705	2.018427	
	0.137344	0.145063	0.156987	0.156286	0.156987				NO	YES	
	0.137963	0.158285	0.177492	0.175737	0.172226	XXXXXXXXXXXXXXXXXXXXXXX					
	0.1504	0.156252	0.162103	0.153326	0.182569						
	0.141358	0.153268	0.160708	0.168145	0.168145	USED STUD RUN-IN					
	0.152057	0.161722	0.166554	0.177179	0.171384		0.16323	0.011214			
	0.145063	0.155585	0.161896	0.170292	0.166102						
	0.163445	0.172811	0.156638	0.178662	0.185097	XXXXXXXXXXXXXXXXXXXXXXX					
	0.153326	0.165028	0.1738	0.194255	0.176724				DESIGN VS USED STUD DESIGN		
	0.154756	0.165171	0.169633	0.185985	0.177067	USED STUD DESIGN			t	F	
	0.161722	0.177179	0.17235	0.178144	0.190372		0.176333	0.013195	6.151762	1.137418	
	0.156987	0.168204	0.168905	0.173719	0.183998				YES	NO	
	0.183342	0.190384	0.188606	0.202319	0.196353	XXXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.147067	0.157574	0.1564	0.166509	0.171183		0.160659	0.015836			
STD DEV	0.01317	0.013902	0.008903	0.016978	0.012521						

TABLE 5: ALLOY M, LUBRICANT NO. 5

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARAIANCE	
	0.085917	0.085917	0.091787	0.118182	0.100589				t-TEST	F-TEST	
	0.093653	0.092161	0.093653	0.114537	0.095146				t*=1.68	F*=1.98	95% Confi
	0.105398	0.101361	0.101361	0.118515	0.098332	RUN-IN	0.102636	0.010448			
	0.105951	0.096353	0.102283	0.11695	0.099349						
	0.113917	0.101419	0.106605	0.125723	0.100832	XXXXXXXXXXXXXXXXXXXXXXX					
	0.085917	0.077109	0.071235	0.100589	0.074172				DESIGN VS RUN-IN		
	0.087683	0.078724	0.078724	0.093653	0.077231				t	F	
	0.099342	0.082173	0.084194	0.099342	0.085204	DESIGN	0.08758	0.009691	5.282535	1.162519	
	0.097881	0.081825	0.081825	0.099349	0.083355				YES	NO	
	0.100832	0.088498	0.084385	0.107168	0.089086	XXXXXXXXXXXXXXXXXXXXXXX					
	0.080045	0.080045	0.071235	0.109387	0.080045						
	0.078724	0.084697	0.066774	0.102606	0.080218	USED STUD RUN-IN					
	0.084194	0.086214	0.068024	0.107417	0.086214		0.085517	0.013619			
	0.084884	0.083355	0.067288	0.108884	0.081825						
	0.089086	0.089086	0.067632	0.114479	0.085561	XXXXXXXXXXXXXXXXXXXXXXX					
	0.082981	0.080045	0.074172	0.097655	0.080045				DESIGN VS USED STUD DESIGN		
	0.078724	0.077231	0.07275	0.093653	0.077231	USED STUD DESIGN			t	F	
	0.089244	0.082173	0.077121	0.092274	0.082173		0.083096	0.006668	-1.90588	2.111934	
	0.088708	0.08412	0.074175	0.086414	0.08106				YES	YES	
	0.090848	0.088498	0.076745	0.088498	0.080659	XXXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.091196	0.08605	0.082467	0.104764	0.085926		0.089707	0.012798			
STD DEV	0.009787	0.00718	0.013947	0.011082	0.008414						

TABLE 6; ALLOY M, LUBRICANT NO.6

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARAIANCE	
	0.077109	0.091787	0.077109	0.085917	0.094721				t-TEST	F-TEST	
	0.075737	0.093653	0.08619	0.105589	0.09813				t*=1.68	F*=1.98	95% Confi
	0.079142	0.10237	0.093284	0.121541	0.105398	RUN-IN	0.097201	0.014951			
	0.08259	0.100082	0.094059	0.125745	0.106684						
	0.086148	0.104355	0.100245	0.131905	0.110543	XXXXXXXXXXXXXXXXXXXXXX					
	0.065359	0.091787	0.085917	0.100589	0.088852				DESIGN VS RUN-IN		
	0.06229	0.084697	0.083204	0.099622	0.075737				t	F	
	0.060946	0.088234	0.087224	0.10338	0.079142	DESIGN	0.084523	0.014977	2.995564	1.003423	
	0.058102	0.084884	0.086414	0.108151	0.079531				YES	NO	
	0.059667	0.089673	0.089673	0.115604	0.084385	XXXXXXXXXXXXXXXXXXXXXX					
	0.068297	0.100589	0.085917	0.097655	0.082981						
	0.065279	0.095146	0.080218	0.09813	0.077231	USED STUD RUN-IN					
	0.068024	0.092274	0.089244	0.098332	0.082173		0.086762	0.011624			
	0.068819	0.090237	0.093295	0.096353	0.078766						
	0.076745	0.091435	0.104355	0.103181	0.084385	XXXXXXXXXXXXXXXXXXXXXX					
	0.074172	0.080045	0.077109	0.085917	0.085917				DESIGN VS USED STUD DESIGN		
	0.063785	0.080218	0.07275	0.081711	0.077231	USED STUD DESIGN			t	F	
	0.062968	0.078131	0.0751	0.092274	0.073078		0.077353	0.009314	-2.03246	2.585455	
	0.061164	0.072645	0.078001	0.091766	0.069584				YES	YES	
	0.063957	0.077921	0.087911	0.096722	0.073757	XXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.069015	0.089508	0.08909	0.102004	0.085411		0.08646	0.014608			
STD DEV	0.008189	0.008771	0.007141	0.013223	0.011802						

TABLE 7:ALLOY M, LUBRICANT NO. 7

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARAIANCE	
	0.153326	0.135761	0.147473	0.147473	0.153326				t-TEST	F-TEST	
	0.150291	0.144336	0.154756	0.138379	0.145825				t*=1.68	F*=1.98	95% Confi
	0.163655	0.15689	0.16752	0.147222	0.15109	RUN-IN	0.153698	0.0109			
	0.161896	0.161194	0.147168	0.147168	0.150675						
	0.183342	0.177492	0.156638	0.148401	0.151147	XXXXXXXXXXXXXXXXXXXXXX					
	0.170877	0.159178	0.162103	0.159178	0.1504				DESIGN VS RUN-IN		
	0.154756	0.15922	0.157732	0.147314	0.150291				t	F	
	0.165588	0.168486	0.160756	0.153023	0.15109	DESIGN	0.159773	0.008808	-2.16742	1.531555	
	0.159091	0.170292	0.155585	0.155585	0.147168				YES	YES	
	0.172811	0.177492	0.176322	0.158834	0.151147	XXXXXXXXXXXXXXXXXXXXXX					
	0.1738	0.167953	0.162103	0.1504	0.156252						
	0.153268	0.157732	0.157732	0.148802	0.154756	USED STUD RUN-IN					
	0.155923	0.165588	0.160756	0.154957	0.158823		0.156882	0.006711			
	0.154182	0.163999	0.15278	0.147168	0.151377						
	0.154442	0.166373	0.1495	0.14895	0.154442	XXXXXXXXXXXXXXXXXXXXXX					
	0.159178	0.165028	0.156252	0.147473	0.1504				DESIGN VS USED STUD DESIGN		
	0.148802	0.157732	0.150291	0.150291	0.145825	USED STUD DESIGN			t	F	
	0.15399	0.15979	0.150123	0.153023	0.154957		0.153145	0.005955	-3.11687	2.187584	
	0.150675	0.159792	0.145765	0.145765	0.151377				YES	YES	
	0.166958	0.159383	0.14895	0.147303	0.1495	XXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.160343	0.161685	0.157928	0.149835	0.151493		0.155874	0.00862			
STD DEV	0.009333	0.009639	0.007658	0.00484	0.00327						

TABLE 8; ALLOY M, LUBRICANT NO. 8

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	
	0.094721	0.094721	0.091787	0.106455	0.088852				t-TEST	F-TEST	
	0.099622	0.095146	0.092161	0.104098	0.092161				t*=1.68	F*=1.98	95% Confl
	0.106408	0.104389	0.098332	0.110444	0.097323	RUN-IN	0.102214	0.00766			
	0.108151	0.106684	0.100816	0.108151	0.100082						
	0.114479	0.114479	0.11223	0.11223	0.101419	XXXXXXXXXXXXXXXXXXXXXXXX					
	0.088852	0.091787	0.085917	0.085917	0.077109				DESIGN VS RUN-IN		
	0.089176	0.093653	0.092161	0.092161	0.083204				t	F	
	0.095304	0.10237	0.101361	0.096313	0.090254	DESIGN	0.094276	0.008149	3.548844	1.131799	
	0.092531	0.105951	0.105217	0.092531	0.087943				YES	NO	
	0.097309	0.111667	0.108293	0.097896	0.092023	XXXXXXXXXXXXXXXXXXXXXXXX					
	0.091787	0.091787	0.088852	0.091787	0.080045						
	0.089176	0.087683	0.093653	0.093653	0.087683	USED STUD RUN-IN					
	0.096313	0.104389	0.107417	0.096313	0.097323		0.097466	0.008699			
	0.096353	0.105951	0.111084	0.097117	0.098615						
	0.102006	0.112792	0.116729	0.096722	0.101419	XXXXXXXXXXXXXXXXXXXXXXXX					
	0.074172	0.080045	0.077109	0.085917	0.077109				DESIGN VS USED STUD DESIGN		
	0.081711	0.087683	0.084697	0.089176	0.08619	USED STUD DESIGN			t	F	
	0.097323	0.10237	0.093284	0.101361	0.098332		0.093844	0.010497	-0.16255	1.659295	
	0.100082	0.103017	0.099349	0.10155	0.100082				NO	NO	
	0.102594	0.110543	0.106043	0.104355	0.102006	XXXXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.095903	0.100355	0.100401	0.098207	0.091959		0.09695	0.00931			
STD DEV	0.009082	0.009516	0.009485	0.007719	0.008254						

TABLE 9; ALLOY M, LUBRICANT NO. 9

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	
	0.077109	0.071235	0.085917	0.085917	0.082981				t-TEST	F-TEST	
	0.081711	0.069762	0.083204	0.08619	0.08619				t*=1.68	F*=1.98	95% Confi
	0.097323	0.078131	0.091264	0.094294	0.096313	RUN-IN	0.08731	0.008625			
	0.096353	0.077236	0.088708	0.092531	0.095588						
	0.100832	0.079684	0.090848	0.096722	0.096722	XXXXXXXXXXXXXXXXXXXXXX					
	0.088852	0.071235	0.074172	0.077109	0.088852				DESIGN VS RUN-IN		
	0.089176	0.063785	0.071256	0.084697	0.090668				t	F	
	0.101361	0.069035	0.078131	0.091264	0.108426	DESIGN	0.087062	0.013904	0.076033	2.598535	
	0.103017	0.065757	0.08259	0.093295	0.105217				NO	YES	
	0.108293	0.074982	0.089673	0.099658	0.106043	XXXXXXXXXXXXXXXXXXXXXX					
	0.074172	0.082981	0.068297	0.085917	0.074172						
	0.07275	0.065279	0.075737	0.084697	0.093653	USED STUD RUN-IN					
	0.080152	0.069035	0.081163	0.10338	0.116497		0.087158	0.016867			
	0.078766	0.074175	0.08259	0.115483	0.108884						
	0.081447	0.082622	0.090848	0.127971	0.108293	XXXXXXXXXXXXXXXXXXXXXX					
	0.077109	0.082981	0.071235	0.091787	0.085917				DESIGN VS USED STUD DESIGN		
	0.078724	0.075737	0.071256	0.089176	0.08619	USED STUD DESIGN			t	F	
	0.086214	0.084194	0.069035	0.107417	0.091264		0.085095	0.013215	-0.5127	1.106859	
	0.084884	0.079531	0.063461	0.111084	0.088708				NO	NO	
	0.090848	0.084385	0.065794	0.118415	0.092023	XXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.087455	0.075088	0.082293	0.09685	0.09513		0.086656	0.013305			
STD DEV	0.01059	0.006685	0.007473	0.013253	0.010711						

TABLE 10; ALLOY M, LUBRICANT 10

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	
	0.097655	0.080045	0.082981	0.091767	0.085917				t-TEST	F-TEST	
	0.090668	0.083204	0.083204	0.092161	0.081711				t*=1.68	F*=1.98	95% Confi
	0.088234	0.086214	0.085204	0.106408	0.083183	RUN-IN	0.088	0.008626			
	0.084884	0.08412	0.080295	0.106684	0.080295						
	0.086736	0.085561	0.081447	0.110543	0.080859	XXXXXXXXXXXXXXXXXXXXXXX					
	0.085917	0.085917	0.074172	0.080045	0.074172				DESIGN VS RUN-IN		
	0.077231	0.075737	0.080218	0.080218	0.074243				t	F	
	0.078131	0.071057	0.077121	0.083183	0.078131	DESIGN	0.075242	0.006183	6.010642	1.946174	
	0.071115	0.065757	0.068053	0.080295	0.069584				YES	NO	
	0.068857	0.06702	0.066407	0.081447	0.06702	XXXXXXXXXXXXXXXXXXXXXXX					
	0.088852	0.077109	0.074172	0.080045	0.077109						
	0.069762	0.07275	0.075737	0.077231	0.075737	USED STUD RUN-IN					
	0.066002	0.072067	0.07611	0.077121	0.072067		0.071922	0.006786			
	0.059633	0.069584	0.069584	0.07188	0.063461						
	0.056603	0.06947	0.070082	0.072532	0.063344	XXXXXXXXXXXXXXXXXXXXXXX					
	0.074172	0.071235	0.074172	0.077109	0.077109				DESIGN VS USED STUD DESIGN		
	0.07275	0.07275	0.075737	0.077231	0.074243	USED STUD DESIGN			t	F	
	0.069035	0.07611	0.0751	0.079142	0.071057		0.071423	0.005077	-2.38675	1.483318	
	0.060399	0.069584	0.068819	0.069584	0.068819				YES	NO	
	0.058442	0.068857	0.068245	0.071307	0.064569	XXXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.075254	0.075207	0.076319	0.083298	0.074132		0.076647	0.009502			
STD DEV	0.012049	0.006737	0.005911	0.012058	0.00662						

ATTACHMENT III

Phase I - Coefficient of Friction Dataset

AISI 4140 Phosphate Coated

The main body of the following tables list each individual calculated coefficient of friction value, based on the equation of Appendix A, for every AISI 4140 stud tested. The mean coefficient of friction and standard deviations for each individual stud is provided at the bottom of the table, while the mean coefficient of friction, standard deviation and the results of the statistical tests performed for all studs tested under the same loading sequence are provided to the right of the individual values.

TABLE 1; ALLOY P, LUBRICANT NO. 1

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	
	0.109049	0.100664	0.100664	0.095072	0.095072				t-TEST	F-TEST	
	0.105652	0.099959	0.101383	0.097112	0.092842				t*=1.68	F*=1.98	95% Confi
	0.103715	0.097933	0.105642	0.097933	0.096005	RUN-IN	0.099195	0.00435			
	0.101038	0.094737	0.103838	0.096837	0.094036						
	0.100683	0.094627	0.103897	0.097422	0.094068	XXXXXXXXXXXXXXXXXXXXXXX					
	0.083884	0.081086	0.083884	0.081086	0.07549				DESIGN VS RUN-IN		
	0.094265	0.089994	0.099959	0.091418	0.082873				t	F	
	0.101788	0.091165	0.105642	0.094077	0.086364	DESIGN	0.092392	0.008488	3.566561	3.807644	
	0.101038	0.091906	0.106638	0.096837	0.087529				YES	YES	
	0.100147	0.091831	0.104968	0.097422	0.088475	XXXXXXXXXXXXXXXXXXXXXXX					
	0.083884	0.081086	0.083884	0.086682	0.083884						
	0.087146	0.089994	0.097112	0.091418	0.084297	USED STUD RUN-IN					
	0.088292	0.089257	0.101788	0.090221	0.086364		0.089372	0.00594			
	0.086988	0.088258	0.103138	0.089718	0.086069						
	0.089035	0.087916	0.102826	0.089594	0.083441	XXXXXXXXXXXXXXXXXXXXXXX					
	0.072691	0.069891	0.081086	0.07549	0.067092				DESIGN VS USED STUD DESIGN		
	0.078599	0.081448	0.089994	0.081448	0.080024	USED STUD DESIGN			t	F	
	0.083471	0.084435	0.098897	0.087328	0.080577		0.084251	0.008641	-3.36034	0.965026	
	0.087529	0.086069	0.099638	0.090447	0.079501				YES	NO	
	0.089035	0.087357	0.101754	0.09239	0.080085	XXXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.092496	0.088982	0.100351	0.090998	0.085204		0.091302	0.008845			
STD DEV	0.009884	0.007273	0.00713	0.006203	0.007215						

TABLE 2; ALLOY P, LUBRICANT NO.2

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	
	0.095072	0.097866	0.086682	0.097866	0.095072				t-TEST	F-TEST	
	0.099959	0.097112	0.089994	0.098536	0.094265				t*=1.68	F*=1.98	95% Confl
	0.101788	0.096005	0.091165	0.102751	0.094077	RUN-IN	0.095334	0.004539			
	0.098938	0.094036	0.089718	0.101036	0.091177						
	0.100147	0.09239	0.089594	0.099612	0.088475	XXXXXXXXXXXXXXXXXXXXXXX					
	0.072691	0.076266	0.076266	0.083884	0.072691				DESIGN VS RUN-IN		
	0.080024	0.081446	0.082873	0.091418	0.078599				t	F	
	0.089257	0.085399	0.086364	0.096969	0.083471	DESIGN	0.085346	0.006873	6.063918	2.293197	
	0.091177	0.08534	0.087529	0.096837	0.08315				YES	YES	
	0.092949	0.085679	0.086238	0.099076	0.084001	XXXXXXXXXXXXXXXXXXXXXXX					
	0.081066	0.083884	0.07549	0.086682	0.086682						
	0.085722	0.085722	0.084297	0.089994	0.089994	USED STUD RUN-IN					
	0.094077	0.089257	0.086364	0.096897	0.091165		0.089109	0.005368			
	0.095437	0.088256	0.089718	0.096137	0.089718						
	0.099076	0.089035	0.088475	0.094627	0.087916	XXXXXXXXXXXXXXXXXXXXXXX					
	0.058691	0.07549	0.064292	0.081066	0.072691				DESIGN VS USED STUD DESIGN		
	0.0729	0.078599	0.078599	0.091418	0.080024	USED STUD DESIGN			t	F	
	0.081542	0.083471	0.081542	0.096005	0.084435		0.081834	0.006563	-1.59912	1.552179	
	0.08386	0.08534	0.08386	0.095437	0.08534				NO	NO	
	0.08512	0.082882	0.084001	0.093606	0.085679	XXXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.087977	0.086775	0.086187	0.094589	0.085932		0.087906	0.008153			
STD DEV	0.011254	0.006284	0.00443	0.005695	0.00639						

TABLE 3; ALLOY P, LUBRICANT NO. 3

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	
	0.07549	0.072691	0.072691	0.061491	0.058691				t-TEST	F-TEST	
	0.067199	0.070049	0.067199	0.058644	0.057218				t*=1.68	F*=1.98	95% Confi
	0.063207	0.065136	0.062242	0.057414	0.054517	RUN-IN	0.060968	0.006602			
	0.059053	0.060514	0.059053	0.053938	0.052476						
	0.05774	0.05949	0.055406	0.052488	0.050154	XXXXXXXXXXXXXXXXXXXXXX					
	0.044682	0.053068	0.041879	0.047484	0.039075				DESIGN VS RUN-IN		
	0.050087	0.057218	0.050087	0.045806	0.032961				t	F	
	0.049666	0.055463	0.045824	0.04679	0.045624	DESIGN	0.047636	0.005093	7.727028	1.784087	
	0.051014	0.053207	0.04736	0.046091	0.045697				YES	NO	
	0.050736	0.051906	0.048987	0.047819	0.044901	XXXXXXXXXXXXXXXXXXXXXX					
	0.050286	0.061491	0.050286	0.050286	0.081066						
	0.051513	0.058644	0.04866	0.054366	0.035816	USED STUD RUN-IN					
	0.052586	0.05838	0.048722	0.050654	0.048722		0.051926	0.007728			
	0.050283	0.054669	0.048822	0.048822	0.04736						
	0.048987	0.051905	0.04957	0.04957	0.046652	XXXXXXXXXXXXXXXXXXXXXX					
	0.044682	0.047484	0.061491	0.036272	0.039075				DESIGN VS USED STUD DESIGN		
	0.047233	0.054366	0.061496	0.04438	0.042953	USED STUD DESIGN			t	F	
	0.04679	0.05162	0.060311	0.04679	0.042925		0.046653	0.006726	0.48423	1.744466	
	0.045897	0.050283	0.057591	0.04736	0.042973				NO	NO	
	0.046652	0.050154	0.056573	0.047819	0.043149	XXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.05269	0.056689	0.053119	0.049814	0.047621		0.052345	0.008387			
STD DEV	0.008051	0.006624	0.008545	0.005566	0.010296						

TABLE 4; ALLOY P, LUBRICANT NO. 4

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	
	0.164666	0.150925	0.150925	0.153714	0.150925				t-TEST	F-TEST	
	0.159656	0.152558	0.153977	0.149718	0.155397				t*=1.68	F*=1.96	95% Confl
	0.156416	0.148109	0.149955	0.14257	0.150678	RUN-IN	0.147938	0.007672			
	0.146377	0.144369	0.14303	0.137003	0.14303						
	0.141531	0.144146	0.137346	0.131068	0.139962	XXXXXXXXXXXXXXXXXXXXXXXX					
	0.142556	0.131393	0.136975	0.134184	0.142556				DESIGN VS RUN-IN		
	0.142616	0.132671	0.141196	0.129628	0.139775				t	F	
	0.14257	0.133334	0.138876	0.127791	0.139799	DESIGN	0.135713	0.005858	6.332499	1.715613	
	0.138342	0.132314	0.137003	0.124128	0.134993				YES	NO	
	0.135254	0.134207	0.133684	0.1221	0.144669	XXXXXXXXXXXXXXXXXXXXXXXX					
	0.142556	0.131393	0.136975	0.131393	0.136975						
	0.149718	0.138354	0.146877	0.132671	0.142616	USED STUD RUN-IN					
	0.150878	0.138876	0.143493	0.13241	0.148109		0.139976	0.006696			
	0.147716	0.139682	0.137672	0.130974	0.14236						
	0.149375	0.137346	0.13787	0.127404	0.145715	XXXXXXXXXXXXXXXXXXXXXXXX					
	0.142556	0.136975	0.139766	0.131393	0.134184				DESIGN VS USED STUD DESIGN		
	0.161075	0.149718	0.152558	0.135513	0.148298	USED STUD DESIGN			t	F	
	0.166564	0.147186	0.156416	0.134258	0.150678		0.147925	0.01082	4.962935	3.411694	
	0.160432	0.147047	0.15374	0.132314	0.153071				YES	YES	
	0.16206	0.146761	0.151467	0.136623	0.167076	XXXXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.150156	0.140868	0.141724	0.133663	0.145563		0.142888	0.009478			
STD DEV	0.009533	0.007125	0.006123	0.007627	0.007626						

TABLE 5; ALLOY P, LUBRICANT NO. 5

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	
	0.095072	0.089479	0.095072	0.081066	0.089479				t-TEST	F-TEST	
	0.092842	0.089994	0.085722	0.081448	0.089994				t*=1.68	F*=1.98	95% Confi
	0.092149	0.089257	0.082506	0.081542	0.088292	RUN-IN	0.086966	0.004936			
	0.091177	0.086968	0.080231	0.078771	0.088258						
	0.089594	0.086798	0.080065	0.080065	0.086238	XXXXXXXXXXXXXXXXXXXXXXX					
	0.061491	0.067092	0.061491	0.064292	0.072691				DESIGN VS RUN-IN		
	0.074325	0.077174	0.0729	0.070049	0.077174				t	F	
	0.077683	0.082506	0.077683	0.075753	0.077683	DESIGN	0.075651	0.0064	6.999849	1.680901	
	0.081691	0.081691	0.078771	0.075851	0.079501				YES	NO	
	0.08456	0.083441	0.079525	0.078966	0.077267	XXXXXXXXXXXXXXXXXXXXXXX					
	0.07549	0.067092	0.067092	0.067092	0.072691						
	0.07575	0.080024	0.078599	0.071475	0.080024	USED STUD RUN-IN					
	0.080577	0.086364	0.081542	0.076718	0.080577		0.078041	0.005599			
	0.08315	0.08388	0.08242	0.075851	0.078041						
	0.085679	0.084001	0.082662	0.076166	0.077646	XXXXXXXXXXXXXXXXXXXXXXX					
	0.069891	0.067092	0.061491	0.056691	0.067092				DESIGN VS USED STUD DESIGN		
	0.07575	0.07575	0.066624	0.066624	0.078599	USED STUD DESIGN			t	F	
	0.079612	0.081542	0.076718	0.073824	0.080577		0.075601	0.007141	-0.02603	1.244782	
	0.081691	0.08388	0.076561	0.07366	0.080961				NO	NO	
	0.082322	0.086798	0.080644	0.078406	0.081204	XXXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.081525	0.081642	0.079101	0.074416	0.08021		0.079065	0.007603			
STD DEV	0.008346	0.007365	0.007743	0.006123	0.00595						

TABLE 6; ALLOY P, LUBRICANT NO. 6

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	
	0.081066	0.100664	0.095072	0.095072	0.095072				t-TEST	F-TEST	
	0.085722	0.092842	0.091418	0.092842	0.092842				t*=1.68	F*=1.98	95% Confi
	0.084435	0.090221	0.088292	0.092149	0.088292	RUN-IN	0.08919	0.004788			
	0.080231	0.089718	0.087529	0.087529	0.087529						
	0.081763	0.087357	0.086798	0.087916	0.087357	XXXXXXXXXXXXXXXXXXXXXX					
	0.067092	0.078288	0.081066	0.081066	0.07549				DESIGN VS	RUN-IN	
	0.0729	0.081448	0.082873	0.082873	0.077174				t	F	
	0.071694	0.081542	0.085399	0.085399	0.081542	DESIGN	0.079596	0.005128	6.837252	1.147139	
	0.07074	0.080231	0.08315	0.08461	0.08242				YES	NO	
	0.07169	0.080065	0.084001	0.08512	0.081763	XXXXXXXXXXXXXXXXXXXXXX					
	0.078288	0.083884	0.083884	0.069691	0.095072						
	0.077174	0.087146	0.087146	0.077174	0.089994	USED STUD RUN-IN					
	0.079612	0.085399	0.086364	0.076718	0.085399		0.082336	0.005356			
	0.077311	0.08242	0.08534	0.077311	0.08461						
	0.077846	0.082882	0.08456	0.077846	0.08512	XXXXXXXXXXXXXXXXXXXXXX					
	0.072691	0.07549	0.078288	0.072691	0.072691				DESIGN VS	USED STUD DESIGN	
	0.071475	0.081448	0.085722	0.078599	0.077174	USED STUD DESIGN			t	F	
	0.074789	0.082506	0.086364	0.078648	0.083471		0.07922	0.005013	-0.26202	1.046526	
	0.07293	0.08242	0.08534	0.076581	0.08461				NO	NO	
	0.074469	0.08512	0.085679	0.077287	0.084001	XXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.076208	0.084556	0.086194	0.081867	0.084581		0.082585	0.006413			
STD DEV	0.004938	0.005655	0.003527	0.006823	0.006096						

TABLE 7; ALLOY P, LUBRICANT NO. 7

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	
	0.114637	0.131393	0.117431	0.114637	0.109049				t-TEST	F-TEST	
	0.111343	0.121298	0.108497	0.112765	0.111343				t*=1.68	F*=1.98	95% Confi
	0.108532	0.110459	0.104678	0.109496	0.108532	RUN-IN	0.108794	0.0074			
	0.105238	0.106638	0.099638	0.103138	0.104538						
	0.10229	0.103697	0.097422	0.100683	0.10229	XXXXXXXXXXXXXXXXXXXXXXX					
	0.100664	0.114637	0.103459	0.111843	0.106254				DESIGN VS RUN-IN		
	0.102806	0.114188	0.104229	0.107075	0.108497				t	F	
	0.105642	0.119127	0.103715	0.109496	0.109496	DESIGN	0.10726	0.00478	0.870926	2.398463	
	0.108037	0.113635	0.101038	0.101038	0.108037				NO	YES	
	0.104433	0.110323	0.10229	0.104433	0.10711	XXXXXXXXXXXXXXXXXXXXXXX					
	0.111843	0.128601	0.123017	0.111843	0.111843						
	0.111343	0.124142	0.114188	0.107075	0.111343	USED STUD RUN-IN					
	0.115275	0.122015	0.109496	0.103715	0.112365		0.111957	0.006686			
	0.110837	0.115734	0.106638	0.103638	0.108737						
	0.108181	0.11193	0.106575	0.100683	0.107646	XXXXXXXXXXXXXXXXXXXXXXX					
	0.114637	0.114637	0.128601	0.100664	0.111843				DESIGN VS USED STUD DESIGN		
	0.111343	0.11561	0.111343	0.102806	0.111343	USED STUD DESIGN			t	F	
	0.113348	0.117201	0.110459	0.108605	0.110459		0.111977	0.005568	3.213669	1.356919	
	0.115734	0.117833	0.110137	0.108638	0.110137				YES	NO	
	0.11193	0.118353	0.108717	0.108575	0.112465	XXXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.109405	0.116583	0.106821	0.106252	0.109167		0.109997	0.006433			
STD DEV	0.004596	0.006751	0.006894	0.004326	0.0027						

TABLE 8; ALLOY P, LUBRICANT NO.8

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	
	0.092276	0.086682	0.089479	0.083884	0.095072				t-TEST	F-TEST	
	0.084297	0.084297	0.089994	0.084297	0.095689				t*=1.68	F*=1.98	95% Confi
	0.083471	0.084435	0.088292	0.087328	0.096005	RUN-IN	0.087756	0.004307			
	0.08388	0.08388	0.087529	0.086069	0.094737						
	0.082882	0.08456	0.08512	0.086796	0.092949	XXXXXXXXXXXXXXXXXXXXXXX					
	0.081086	0.078288	0.083884	0.081086	0.081086				DESIGN VS RUN-IN		
	0.08857	0.082873	0.085722	0.089994	0.08857				t	F	
	0.087328	0.088292	0.089257	0.095041	0.096005	DESIGN	0.088989	0.005334	-0.89931	1.533241	
	0.089718	0.090447	0.087529	0.094036	0.096137				NO	NO	
	0.09239	0.092949	0.092949	0.095186	0.096304	XXXXXXXXXXXXXXXXXXXXXXX					
	0.097666	0.089479	0.089479	0.083884	0.083884						
	0.094265	0.089994	0.087146	0.087146	0.092842	USED STUD RUN-IN					
	0.091185	0.090221	0.090221	0.089257	0.096897		0.091276	0.004388			
	0.089718	0.091177	0.089718	0.088258	0.100338						
	0.091272	0.094627	0.091831	0.089035	0.100147	XXXXXXXXXXXXXXXXXXXXXXX					
	0.100664	0.081086	0.081086	0.081066	0.072691				DESIGN VS USED STUD DESIGN		
	0.094265	0.08857	0.082873	0.081446	0.087146	USED STUD DESIGN			t	F	
	0.093113	0.090221	0.084435	0.090221	0.093113		0.090087	0.006979	0.625202	1.71194	
	0.093336	0.094036	0.090447	0.095437	0.095437				NO	NO	
	0.097981	0.095745	0.09239	0.095746	0.099612	XXXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.090478	0.088093	0.088543	0.088262	0.092833		0.089527	0.005439			
STD DEV	0.005419	0.004716	0.002453	0.004697	0.00701						

TABLE 9; ALLOY P, LUBRICANT NO. 9

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	
	0.097868	0.100664	0.083884	0.109049	0.069479				t-TEST	F-TEST	
	0.108497	0.108497	0.076599	0.124142	0.069994				t*=1.68	F*=1.98	95% Confi
	0.113346	0.113348	0.080577	0.131486	0.097933	RUN-IN	0.105612	0.016166			
	0.117133	0.115734	0.079501	0.134993	0.096837						
	0.12317	0.124775	0.080644	0.136916	0.101219	XXXXXXXXXXXXXXXXXXXXXXX					
	0.109049	0.089479	0.081066	0.117431	0.086682				DESIGN VS RUN-IN		
	0.11561	0.092842	0.07575	0.126965	0.08857				t	F	
	0.122978	0.098897	0.074789	0.124903	0.090221	DESIGN	0.102122	0.020334	0.639843	1.252716	
	0.131644	0.105236	0.07366	0.124627	0.087529				NO	NO	
	0.135777	0.109768	0.07337	0.126357	0.089594	XXXXXXXXXXXXXXXXXXXXXXX					
	0.095072	0.072691	0.072691	0.083884	0.069691						
	0.111343	0.084297	0.068624	0.097112	0.07575	USED STUD RUN-IN					
	0.116236	0.094077	0.067068	0.098897	0.079612		0.08699	0.017279			
	0.112936	0.096137	0.067088	0.093336	0.081691						
	0.127928	0.096863	0.066239	0.106717	0.08456	XXXXXXXXXXXXXXXXXXXXXXX					
	0.103459	0.092276	0.076266	0.086662	0.081066				DESIGN VS USED STUD DESIGN		
	0.105652	0.098536	0.082873	0.097112	0.085722	USED STUD DESIGN			t	F	
	0.107569	0.098897	0.079612	0.102751	0.084435		0.094436	0.011151	-1.65705	3.325182	
	0.108037	0.097538	0.081691	0.108037	0.089718				NO	YES	
	0.110859	0.095186	0.078406	0.113536	0.092949	XXXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.113708	0.099266	0.075036	0.112456	0.087174		0.09779	0.016036			
STD DEV	0.010537	0.011546	0.00557	0.01636	0.007423						

TABLE 10; ALLOY P, LUBRICANT 10

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	
	0.092276	0.086682	0.086682	0.117431	0.089479				t-TEST	F-TEST	
	0.091418	0.081448	0.089994	0.101383	0.089994				t*=1.68	F*=1.98	95% Confi
	0.090221	0.079612	0.086364	0.092149	0.091165	RUN-IN	0.089188	0.007906			
	0.090447	0.078041	0.08534	0.086799	0.090447						
	0.094627	0.077846	0.08512	0.084001	0.090713	XXXXXXXXXXXXXXXXXXXXXXX					
	0.081086	0.072691	0.083884	0.095072	0.081086				DESIGN VS RUN-IN		
	0.084297	0.081448	0.078599	0.085722	0.084297				t	F	
	0.084435	0.082506	0.081542	0.083471	0.087328	DESIGN	0.083461	0.004521	3.144089	3.058247	
	0.086799	0.080231	0.08242	0.079601	0.086986				YES	YES	
	0.086238	0.080085	0.083441	0.079525	0.091831	XXXXXXXXXXXXXXXXXXXXXXX					
	0.078288	0.069891	0.07549	0.081086	0.081086						
	0.080024	0.074325	0.077174	0.078599	0.080024	USED STUD RUN-IN					
	0.079612	0.077683	0.080577	0.076646	0.084435		0.077648	0.003413			
	0.075851	0.075121	0.075851	0.075121	0.08316						
	0.075606	0.073929	0.075606	0.07281	0.081204	XXXXXXXXXXXXXXXXXXXXXXX					
	0.072691	0.067092	0.072691	0.07549	0.069891				DESIGN VS USED STUD DESIGN		
	0.080024	0.078599	0.07575	0.080024	0.081448	USED STUD DESIGN			t	F	
	0.079612	0.080577	0.079612	0.083471	0.086364		0.078505	0.004577	-3.8519	1.024934	
	0.080231	0.078771	0.078041	0.080961	0.08534				YES	NO	
	0.076727	0.076727	0.079525	0.077846	0.08512	XXXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.083026	0.077665	0.081872	0.084455	0.085171		0.0822	0.00703			
STD DEV	0.006299	0.004529	0.004547	0.010417	0.005281						

ATTACHMENT IV

Phase I - Coefficient of Friction Dataset

AISI 4140 Alloy Steel (B7)

The main body of the following tables list each individual calculated coefficient of friction value, based on the equation of Appendix A, for every AISI 4140 stud tested. The mean coefficient of friction and standard deviations for each individual stud is provided at the bottom of the table, while the mean coefficient of friction, standard deviation and the results of the statistical tests performed for all studs tested under the same loading sequence are provided to the right of the individual values.

TABLE 1; ALLOY A, LUBRICANT NO.1

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	
	0.114637	0.114637	ERR	ERR	ERR				t-TEST	F-TEST	
	0.118454	0.118454	ERR	ERR	ERR				t*=1.734	F*=3.18	95% Confidence
	0.115275	0.121052	ERR	ERR	ERR	RUN-IN	0.116372	0.00414			
	0.110837	0.120631	ERR	ERR	ERR						
	0.109252	0.120494	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXX					
	0.089479	0.089479	ERR	ERR	ERR				DESIGN VS RUN-IN		
	0.101383	0.095689	ERR	ERR	ERR				t	F	
	0.100824	0.103715	ERR	ERR	ERR	DESIGN	0.100011	0.007379	6.115088	3.176385	
	0.099638	0.109437	ERR	ERR	ERR				Yes	No	
	0.09854	0.11193	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXX					
	0.109049	0.109049	ERR	ERR	ERR						
	0.108497	0.10992	ERR	ERR	ERR	USED STUD RUN-IN					
	0.110459	0.106605	ERR	ERR	ERR		0.107416	0.002308			
	0.105938	0.105238	ERR	ERR	ERR						
	0.103361	0.106039	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXX					
	0.089479	0.089479	ERR	ERR	ERR				DESIGN VS USED STUD DESIGN		
	0.092842	0.097112	ERR	ERR	ERR	USED STUD DESIGN			t	F	
	0.095041	0.098897	ERR	ERR	ERR		0.095808	0.004266	-1.55939	2.991219	
	0.096137	0.101038	ERR	ERR	ERR				No	No	
	0.096304	0.101754	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.103271	0.106533	ERR	ERR	ERR		0.104902	0.0092			
STD DEV	0.008638	0.009671	ERR	ERR	ERR						

TABLE 2; ALLOY A, LUBRICANT NO. 2

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	
	0.103459	0.089479	ERR	ERR	ERR				t-TEST	F-TEST	
	0.104229	0.101383	ERR	ERR	ERR				t*=1.734	F*=3.18	95% Confidence
	0.105642	0.098897	ERR	ERR	ERR	RUN-IN	0.101114	0.004544			
	0.103138	0.100338	ERR	ERR	ERR						
	0.103361	0.101219	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXX					
	0.089479	0.072691	ERR	ERR	ERR				DESIGN VS RUN-IN		
	0.092842	0.089994	ERR	ERR	ERR				t	F	
	0.09986	0.098897	ERR	ERR	ERR	DESIGN	0.095944	0.010072	1.479751	4.913217	
	0.103838	0.102438	ERR	ERR	ERR				No	Yes	
	0.106039	0.103361	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXX					
	0.095072	0.072691	ERR	ERR	ERR						
	0.099959	0.082873	ERR	ERR	ERR	USED STUD RUN-IN					
	0.104678	0.089257	ERR	ERR	ERR		0.093906	0.009931			
	0.102438	0.094036	ERR	ERR	ERR						
	0.101754	0.096304	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXX					
	0.081086	0.069891	ERR	ERR	ERR				DESIGN VS USED STUD DESIGN		
	0.089994	0.082873	ERR	ERR	ERR	USED STUD DESIGN			t	F	
	0.093113	0.087328	ERR	ERR	ERR		0.088497	0.00853	-1.78429	1.394303	
	0.095437	0.092636	ERR	ERR	ERR				Yes	No	
	0.09854	0.094068	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.098698	0.091033	ERR	ERR	ERR		0.094865	0.009417			
STD DEV	0.006671	0.010324	ERR	ERR	ERR						

TABLE 3; ALLOY A, LUBRICANT NO. 3

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	
	0.086682	0.067092	ERR	ERR	ERR				t-TEST	F-TEST	
	0.080024	0.065773	ERR	ERR	ERR				t*=1.734	F*=3.18	95% Confidence
	0.075753	0.065138	ERR	ERR	ERR	RUN-IN	0.070654	0.008133			
	0.07074	0.061245	ERR	ERR	ERR						
	0.07169	0.062406	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXX					
	0.061491	0.050286	ERR	ERR	ERR				DESIGN VS RUN-IN		
	0.064348	0.051513	ERR	ERR	ERR				t	F	
	0.062242	0.05162	ERR	ERR	ERR	DESIGN	0.056909	0.005939	4.316342	1.875367	
	0.060514	0.051014	ERR	ERR	ERR				Yes	No	
	0.063573	0.052468	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXX					
	0.058691	0.050286	ERR	ERR	ERR						
	0.061496	0.051513	ERR	ERR	ERR	USED STUD RUN-IN					
	0.065138	0.048722	ERR	ERR	ERR		0.056942	0.008226			
	0.067088	0.048091	ERR	ERR	ERR						
	0.068822	0.04957	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXX					
	0.050286	0.047484	ERR	ERR	ERR				DESIGN VS USED STUD DESIGN		
	0.054366	0.047233	ERR	ERR	ERR	USED STUD DESIGN			t	F	
	0.056449	0.047756	ERR	ERR	ERR		0.052021	0.005314	-1.93953	1.249019	
	0.058322	0.048091	ERR	ERR	ERR				Yes	No	
	0.061823	0.048403	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.064977	0.053286	ERR	ERR	ERR		0.059132	0.009749			
STD DEV	0.008766	0.006804	ERR	ERR	ERR						

TABLE 4; ALLOY A, LUBRICANT NO. 4

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	
	0.15929	0.156502	ERR	ERR	ERR				t-TEST	F-TEST	
	0.161075	0.152558	ERR	ERR	ERR				t*=1.734	F*=3.18	95% Confidence
	0.157339	0.151801	ERR	ERR	ERR	RUN-IN	0.152273	0.00647			
	0.151063	0.146377	ERR	ERR	ERR						
	0.145715	0.141008	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXX					
	0.145346	0.142556	ERR	ERR	ERR				DESIGN VS RUN-IN		
	0.151138	0.146877	ERR	ERR	ERR				t	F	
	0.140723	0.141646	ERR	ERR	ERR	DESIGN	0.141301	0.005645	4.040898	1.313249	
	0.139682	0.137672	ERR	ERR	ERR				Yes	No	
	0.135777	0.131591	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXX					
	0.150925	0.150925	ERR	ERR	ERR						
	0.151138	0.156817	ERR	ERR	ERR	USED STUD RUN-IN					
	0.150878	0.150878	ERR	ERR	ERR		0.148261	0.005288			
	0.145038	0.145038	ERR	ERR	ERR						
	0.141008	0.139962	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXX					
	0.142556	0.156502	ERR	ERR	ERR				DESIGN VS USED STUD DESIGN		
	0.148298	0.151138	ERR	ERR	ERR	USED STUD DESIGN			t	F	
	0.149032	0.15457	ERR	ERR	ERR		0.148768	0.004683	3.219517	1.453573	
	0.145708	0.151063	ERR	ERR	ERR				Yes	No	
	0.142577	0.146238	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.147715	0.147586	ERR	ERR	ERR		0.147651	0.00669			
STD DEV	0.006637	0.006915	ERR	ERR	ERR						

TABLE 5; ALLOY A, LUBRICANT NO.5

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	
	0.100664	0.106254	ERR	ERR	ERR				t-TEST	F-TEST	
	0.097112	0.104229	ERR	ERR	ERR				t*=1.734	F*=3.18	95% Confidence
	0.097933	0.102751	ERR	ERR	ERR	RUN-IN	0.101049	0.002971			
	0.097538	0.101038	ERR	ERR	ERR						
	0.100683	0.10229	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXX					
	0.089479	0.092276	ERR	ERR	ERR				DESIGN VS RUN-IN		
	0.08857	0.099959	ERR	ERR	ERR				t	F	
	0.091185	0.103715	ERR	ERR	ERR	DESIGN	0.095351	0.006133	2.644028	4.260592	
	0.089718	0.101738	ERR	ERR	ERR				Yes	Yes	
	0.093508	0.103361	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXX					
	0.083884	0.103459	ERR	ERR	ERR						
	0.087146	0.104229	ERR	ERR	ERR	USED STUD RUN-IN					
	0.088292	0.110459	ERR	ERR	ERR		0.096964	0.010005			
	0.088988	0.108037	ERR	ERR	ERR						
	0.090713	0.104433	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXX					
	0.081086	0.081086	ERR	ERR	ERR				DESIGN VS USED STUD DESIGN		
	0.080024	0.089994	ERR	ERR	ERR	USED STUD DESIGN			t	F	
	0.081542	0.094077	ERR	ERR	ERR		0.086706	0.007214	-2.88709	1.383502	
	0.081691	0.096137	ERR	ERR	ERR				Yes	No	
	0.082882	0.09854	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.089632	0.100403	ERR	ERR	ERR		0.095018	0.008595			
STD DEV	0.006617	0.00684	ERR	ERR	ERR						

TABLE 6; ALLOY A6, LUBRICANT NO. 6

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	
	0.100664	0.111843	ERR	ERR	ERR				t-TEST	F-TEST	
	0.107075	0.114188	ERR	ERR	ERR				t*=1.734	F*=3.18	95% Confidence
	0.113348	0.116238	ERR	ERR	ERR	RUN-IN	0.110633	0.004473			
	0.110837	0.113635	ERR	ERR	ERR						
	0.108181	0.110323	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXX					
	0.089479	0.100664	ERR	ERR	ERR				DESIGN VS RUN-IN		
	0.094265	0.105652	ERR	ERR	ERR				t	F	
	0.100824	0.110459	ERR	ERR	ERR	DESIGN	0.103623	0.008319	2.280067	3.456908	
	0.101738	0.115035	ERR	ERR	ERR				Yes	Yes	
	0.104968	0.115142	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXX					
	0.089479	0.103459	ERR	ERR	ERR						
	0.095689	0.111343	ERR	ERR	ERR	USED STUD RUN-IN					
	0.097933	0.110459	ERR	ERR	ERR		0.103042	0.007688			
	0.098238	0.110137	ERR	ERR	ERR						
	0.10229	0.111394	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXX					
	0.083884	0.100664	ERR	ERR	ERR				DESIGN VS USED STUD DESIGN		
	0.094265	0.104229	ERR	ERR	ERR	USED STUD DESIGN			t	F	
	0.097933	0.113348	ERR	ERR	ERR		0.103285	0.010965	-0.12348	1.736985	
	0.097538	0.117133	ERR	ERR	ERR				No	No	
	0.104433	0.119424	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.099653	0.110738	ERR	ERR	ERR		0.105196	0.008495			
STD DEV	0.007424	0.005324	ERR	ERR	ERR						

TABLE 7; ALLOY A, LUBRICANT NO. 7

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	
	0.134184	0.136975	ERR	ERR	ERR				t-TEST	F-TEST	
	0.131249	0.134092	ERR	ERR	ERR				t*=1.734	F*=3.18	95% Confidence
	0.125866	0.126828	ERR	ERR	ERR	RUN-IN	0.124958	0.009434			
	0.119232	0.117633	ERR	ERR	ERR						
	0.113536	0.109788	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXX					
	0.128601	0.123017	ERR	ERR	ERR				DESIGN VS RUN-IN		
	0.118454	0.119876	ERR	ERR	ERR				t	F	
	0.118164	0.118164	ERR	ERR	ERR	DESIGN	0.11935	0.003855	1.740091	5.987533	
	0.117633	0.116434	ERR	ERR	ERR				YES	Yes	
	0.115142	0.117818	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXX					
	0.139766	0.128601	ERR	ERR	ERR						
	0.132671	0.126985	ERR	ERR	ERR	USED STUD RUN-IN					
	0.12394	0.128715	ERR	ERR	ERR		0.127099	0.005836			
	0.122029	0.126225	ERR	ERR	ERR						
	0.12103	0.12103	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXX					
	0.128601	0.123017	ERR	ERR	ERR				DESIGN VS USED STUD DESIGN		
	0.121298	0.118454	ERR	ERR	ERR	USED STUD DESIGN			t	F	
	0.122978	0.118164	ERR	ERR	ERR		0.12148	0.003751	1.252214	1.056363	
	0.123428	0.115734	ERR	ERR	ERR				No	No	
	0.12424	0.118889	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.124112	0.122332	ERR	ERR	ERR		0.123222	0.006658			
STD DEV	0.00673	0.006635	ERR	ERR	ERR						

TABLE 8; ALLOY A, LUBRICANT NO. 8

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	
	0.114637	0.089479	ERR	ERR	ERR				t-TEST	F-TEST	
	0.095689	0.092842	ERR	ERR	ERR				t*=1.734	F*=3.18	95% Confidence
	0.096005	0.094077	ERR	ERR	ERR	RUN-IN	0.096523	0.006683			
	0.096137	0.095437	ERR	ERR	ERR						
	0.095186	0.095745	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXX					
	0.089479	0.092276	ERR	ERR	ERR				DESIGN VS RUN-IN		
	0.094265	0.092842	ERR	ERR	ERR				t	F	
	0.096969	0.101788	ERR	ERR	ERR	DESIGN	0.097136	0.005142	-0.2298	1.689354	
	0.098238	0.103138	ERR	ERR	ERR				No	No	
	0.096863	0.105504	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXX					
	0.100664	0.095072	ERR	ERR	ERR						
	0.097112	0.101383	ERR	ERR	ERR	USED STUD RUN-IN					
	0.098897	0.101788	ERR	ERR	ERR		0.100453	0.00395			
	0.097538	0.108037	ERR	ERR	ERR						
	0.09854	0.105504	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXX					
	0.095072	0.095072	ERR	ERR	ERR				DESIGN VS USED STUD DESIGN		
	0.095689	0.097112	ERR	ERR	ERR	USED STUD DESIGN			t	F	
	0.101788	0.098897	ERR	ERR	ERR		0.099898	0.004097	1.328358	1.574854	
	0.103138	0.101738	ERR	ERR	ERR				No	No	
	0.103897	0.106575	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.09829	0.098715	ERR	ERR	ERR		0.098503	0.005181			
STD DEV	0.005044	0.005436	ERR	ERR	ERR						

TABLE 9; ALLOY A, LUBRICANT NO. 9

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	
	0.106254	0.109049	ERR	ERR	ERR				t-TEST	F-TEST	
	0.118454	0.118454	ERR	ERR	ERR				t*=1.734	F*=3.18	95% Confidence
	0.12394	0.124903	ERR	ERR	ERR	RUN-IN	0.122633	0.009415			
	0.131644	0.130974	ERR	ERR	ERR						
	0.132114	0.130544	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXX					
	0.106254	0.111843	ERR	ERR	ERR				DESIGN VS RUN-IN		
	0.104229	0.112765	ERR	ERR	ERR				t	F	
	0.098897	0.114312	ERR	ERR	ERR	DESIGN	0.106845	0.00643	4.378945	2.144374	
	0.099638	0.112236	ERR	ERR	ERR				Yes	No	
	0.097422	0.110859	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXX					
	0.089479	0.103459	ERR	ERR	ERR						
	0.082873	0.104229	ERR	ERR	ERR	USED STUD RUN-IN					
	0.079612	0.100824	ERR	ERR	ERR		0.091473	0.012043			
	0.075851	0.101038	ERR	ERR	ERR						
	0.075608	0.101754	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXX					
	0.083884	0.089479	ERR	ERR	ERR				DESIGN VS USED STUD DESIGN		
	0.080024	0.091418	ERR	ERR	ERR	USED STUD DESIGN			t	F	
	0.077683	0.094077	ERR	ERR	ERR		0.086116	0.010659	-5.26619	2.748152	
	0.07366	0.097538	ERR	ERR	ERR				Yes	No	
	0.070571	0.102826	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.095405	0.108129	ERR	ERR	ERR		0.101767	0.01726			
STD DEV	0.019658	0.011826	ERR	ERR	ERR						

TABLE 10; ALLOY A, LUBRICANT NO. 10

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	
	0.097868	0.092276	ERR	ERR	ERR				t-TEST	F-TEST	
	0.091418	0.089994	ERR	ERR	ERR				t*=1.734	F*=3.18	95% Confidence
	0.094077	0.090221	ERR	ERR	ERR	RUN-IN	0.091591	0.003475			
	0.093336	0.087529	ERR	ERR	ERR						
	0.093508	0.085679	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXX					
	0.089479	0.083884	ERR	ERR	ERR				DESIGN VS RUN-IN		
	0.091418	0.085722	ERR	ERR	ERR				t	F	
	0.094077	0.089257	ERR	ERR	ERR	DESIGN	0.088193	0.003625	2.139611	1.088131	
	0.091177	0.08388	ERR	ERR	ERR				Yes	No	
	0.089035	0.084001	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXX					
	0.083884	0.083884	ERR	ERR	ERR						
	0.084297	0.089994	ERR	ERR	ERR	USED STUD RUN-IN					
	0.084435	0.093113	ERR	ERR	ERR		0.0864	0.003753			
	0.08315	0.090447	ERR	ERR	ERR						
	0.082322	0.088475	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXX					
	0.083884	0.081086	ERR	ERR	ERR				DESIGN VS USED STUD DESIGN		
	0.087146	0.082873	ERR	ERR	ERR	USED STUD DESIGN			t	F	
	0.085399	0.087328	ERR	ERR	ERR		0.084197	0.002533	-2.85739	2.048436	
	0.08388	0.08461	ERR	ERR	ERR				Yes	No	
	0.079525	0.086238	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXX					
							OVERALL				
MEAN	0.088166	0.087025	ERR	ERR	ERR		0.087595	0.00425			
STD DEV	0.005019	0.003347	ERR	ERR	ERR						

Appendix C

COEFFICIENT OF FRICTION DATA FOR THE PHASE II TEST ASSEMBLIES

This appendix includes the calculated coefficient of friction data, based on the equation of Appendix A. The actual test information, i.e, the individual loads and corresponding torque values, can be obtained by requesting from the authors at:

Westinghouse Electric Company
Plant Apparatus Division
500 Penn Center Boulevard
Pittsburgh, PA 15235-5713

KEY TO APPENDIX C

Alloy Code	Page Number	Alloy Combination			Comments
		Stud	Nut	Washer	
A	App. B, 42	AISI 4140	Carbon Steel, Gr 2H	Carbon Steel	Rolled threads
AM	15, 33	AISI 4140	Carbon Steel, Gr 2H	Carbon Steel	Machined threads
P	App. B	AISI 4140, Mn Phosphate Coated	Carbon Steel, Gr 2H	Carbon Steel	Rolled threads
AR1	13, 31	AISI 4140	Carbon Steel, Gr 2H	Carbon Steel	1.5 inches
AZ	12, 30, 44	Steel, Grade 5, Zinc plated	Carbon Steel, Grade 5	Carbon Steel	Rolled threads
AS	16, 34	AISI 4340	AISI 4340	Type 430 Stainless Nutlock	Machined threads 1.0 inches
M	App. B	K-500	Monel 400	Carbon Steel	Rolled threads
MK	3, 21, 39	K-500	K-500	Carbon Steel	Rolled threads
MCU	6, 24	K-500	K-500	70-30 Cu-Ni	Rolled threads
MH	7, 25	K-500	K-500	HY 80	Rolled threads
MS	4, 22	K-500	K-500	Type 430	Rolled threads
MI	5, 23	K-500	K-500	Alloy 625	Rolled threads
MA	14, 32	K-500	Monel 400	Carbon Steel	Rolled threads 1.5 inches
I	App. B, 40	Alloy 625	Alloy 625	Carbon Steel	Rolled threads
ICR	8, 26, 41	Alloy 625, Chromium plated	Alloy 625	Carbon Steel	Rolled threads
II	9, 27	Alloy 625	Alloy 625	Alloy 625	Rolled threads
IMC2	18, 35	Alloy 625	Alloy 625	Alloy 625	Military Specification Machined threads Class 2
IMC3	17, 36	Alloy 625	Alloy 625	Alloy 625	Military Specification Machined threads Class 3
IMA	19, 37	Alloy 625	Alloy 625	Alloy 625	Military Specification Machined threads 1.75 inches
IMB	20, 38	Alloy 625	Alloy 625	Alloy 625	Military Specification Machined threads 2.00 inches
T	11, 29, 43	Titanium, Gr 5	Alloy 625	Carbon Steel	Rolled threads
SS	10, 28	Type 17-4PH Stainless Steel	Type 316 stainless	Type 316 stainless	Rolled threads
SSC	10, 28	Type 17-4PH Stainless Steel	Type 316 stainless	Carbon Steel	Rolled threads

Lubricant Key

Data Set Number	Page Number	Lubricant Used
1 through 95	3 through 20	Molykote P37
96 through 190	21 through 38	RLGMO
191 through 220	39 through 44	Fel Pro N7000
Note: There were no Data Sets corresponding to Numbers 31 through 35 or 126 through 130.		

The main body of the following tables list each individual calculated coefficient of friction value, based on the equation of Appendix A, for every stud tested. The mean coefficient of friction and standard deviations for each individual stud is provided at the bottom of the table, while for alloy combinations that had at least four duplicate assemblies the mean coefficient of friction, standard deviation and the results of the statistical tests performed for all studs tested under the same loading sequence are provided to the right of the individual values.

Authors Note:

On the following pages, data columns which are marked as 'ERR' or '0.0000' signify that those assemblies were not tested. Markings of "ERR' or a blank entry within a column of data indicates that fewer than five load increments were used since higher loads would have exceeded the yield strength of at least one of the fastener assembly components, generally the washer or nut.

	SET 1-5	Alloy Code MK					MEAN	STD	TEST for	TEST for	90/95 Tolerance	
	STUD1	STUD2	STUD3	STUD4	STUD5		VALUE	DEVIATION	Mean	Variance		
	0.1445	0.1283	0.1445	0.1413	0.1186				95% Confidence			
	0.1305	0.1223	0.1256	0.1191	0.1256				t*= 1.68	F*=1.98		
	0.1341	0.1242	0.1220	0.1165	0.1132	RUN-IN	0.1246	0.0092		= 0.505	0.1474	0.1017
	0.1266	0.1306	0.1185	0.1129	0.1137							
	0.1229	0.1291	0.1166	0.1140	0.1185	XXXXXXXXXXXXXXXXXXXX						
	0.1121	0.1089	0.1218	0.1186	0.1121				DESIGN vs RUN-IN			
	0.1028	0.1126	0.1256	0.1207	0.1256				t	F		
	0.1121	0.1242	0.1165	0.1231	0.1176	DESIGN	0.1184	0.0059	0.2046	2.4695	0.1329	0.1038
	0.1145	0.1242	0.1193	0.1210	0.1226				No	Yes		
	0.1160	0.1260	0.1179	0.1197	0.1235	XXXXXXXXXXXXXXXXXXXX						
	0.0894	0.1056	0.1089	0.1154	0.1089				DESIGN vs CYCLE 3			
	0.1012	0.1093	0.1110	0.1093	0.1028				t	F		
	0.1033	0.1143	0.1110	0.1099	0.1099	CYCLE3	0.1114	0.0079	0.2534	0.5617	0.1308	0.0920
	0.1097	0.1234	0.1202	0.1089	0.1185				No	No		
	0.1114	0.1254	0.1216	0.1160	0.1197							
MEAN	0.1154	0.1206	0.1201	0.1178	0.1167							
STD DEV	0.0143	0.0081	0.0084	0.0079	0.0065							

DATA SET 6,7 Alloy Code MS

	STUD1	STUD2	STUD3	STUD4	STUD5	
	0.1380	0.1380	ERR	ERR	ERR	
	0.1419	0.1337	ERR	ERR	ERR	
	0.1462	0.1275	ERR	ERR	ERR	RUN-IN
	0.1513	0.1258	ERR	ERR	ERR	
	0.1660	0.1372	ERR	ERR	ERR	XXXXXXXXXXXX
	0.0959	0.0797	ERR	ERR	ERR	
	0.1044	0.0800	ERR	ERR	ERR	
	0.1143	0.0912	ERR	ERR	ERR	DESIGN
	0.1266	0.1047	ERR	ERR	ERR	
	0.1310	0.1134	ERR	ERR	ERR	XXXXXXXXXXXX
	0.1056	0.0894	ERR	ERR	ERR	
	0.0931	0.0996	ERR	ERR	ERR	
	0.1055	0.1011	ERR	ERR	ERR	CYCLE3
	0.1145	0.1121	ERR	ERR	ERR	
	0.1222	0.1191	ERR	ERR	ERR	
Mean	0.1238	0.1102	ERR	ERR	ERR	
Std Dev	0.0217	0.0199	ERR	ERR	ERR	

DATA SET 11,12 Alloy Code MI

	STUD1	STUD2	STUD3	STUD4	STUD5	
	0.1413	0.1348	ERR	ERR	ERR	
	0.1305	0.1402	ERR	ERR	ERR	
	0.1363	0.1610	ERR	ERR	ERR	RUN-IN
	ERR	ERR	ERR	ERR	ERR	
	ERR	ERR	ERR	ERR	ERR	XXXXXXXXXXXX
	0.1121	0.1056	ERR	ERR	ERR	
	0.1110	0.1093	ERR	ERR	ERR	
	0.1220	0.1286	ERR	ERR	ERR	DESIGN
	ERR	ERR	ERR	ERR	ERR	
	ERR	ERR	ERR	ERR	ERR	XXXXXXXXXXXX
	0.1121	0.1024	ERR	ERR	ERR	
	0.1093	0.1028	ERR	ERR	ERR	
	0.1176	0.1154	ERR	ERR	ERR	CYCLE3
	ERR	ERR	ERR	ERR	ERR	
	ERR	ERR	ERR	ERR	ERR	
Mean	0.1214	0.1222	ERR	ERR	ERR	
Std Dev	0.0119	0.0203	ERR	ERR	ERR	

DATA SET 16-20 Alloy Code MCU

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST for Mean	TEST for Variance	90/95 Tolerance	
	0.1218	0.1234	0.1684	0.1459	0.1234				95% Confidence			
	0.1256	0.1186	0.1380	0.1186	0.1154				t*= 1.68	F*=1.98		
	0.1418	0.1210	0.1340	0.1167	0.1145	RUN-IN	0.1310	0.0137			0.1649	0.0970
	0.1575	0.1288	0.1402	0.1256	0.1223							
	0.1782	0.1453	0.1440	0.1375	0.1375	XXXXXXXXXXXXXXXXXXXX						
	ERR	0.1065	0.1121	0.1008	0.1178				DESIGN vs RUN-IN			
	ERR	0.0927	0.1024	0.0829	0.1056				t	F		
	ERR	0.0863	0.0972	0.0820	0.0972	DESIGN	0.1009	0.0103	0.6263	1.7914	0.1272	0.0746
	ERR	0.0963	0.1061	0.0931	0.1028				No	Yes		
	ERR	0.1088	0.1193	0.1023	0.1062	XXXXXXXXXXXXXXXXXXXX						
	ERR	0.1065	0.1065	0.0952	0.1121				DESIGN vs CYCLE 3			
	ERR	0.0862	0.0862	0.0829	0.0959				t	F		
	ERR	0.0820	0.0798	0.0755	0.0972	CYCLE3	0.0925	0.0102	0.2062	1.0164	0.1186	0.0664
	ERR	0.0931	0.0865	0.0800	0.0947				No	No		
	ERR	0.1049	0.0971	0.0893	0.0984							
MEAN	0.1450	0.1067	0.1145	0.1019	0.1094							
STD DEV	0.0234	0.0180	0.0255	0.0221	0.0125							

DATA SET 21,22 Alloy Code MH

	STUD1	STUD2	STUD3	STUD4	STUD5	
	0.1445	0.1413	ERR	ERR	ERR	
	0.1386	0.1402	ERR	ERR	ERR	
	0.1494	0.1473	ERR	ERR	ERR	RUN-IN
	0.1529	0.1498	ERR	ERR	ERR	
	0.1569	0.1539	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX
	0.1121	0.1154	ERR	ERR	ERR	
	0.1175	0.1175	ERR	ERR	ERR	
	0.1209	0.1275	ERR	ERR	ERR	DESIGN
	0.1234	0.1330	ERR	ERR	ERR	
	0.1297	0.1378	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX
	0.1121	0.1089	ERR	ERR	ERR	
	0.1028	0.1044	ERR	ERR	ERR	
	0.1110	0.1121	ERR	ERR	ERR	CYCLE3
	0.1226	0.1226	ERR	ERR	ERR	
	0.1235	0.1247	ERR	ERR	ERR	
Mean	0.1279	0.1291	ERR	ERR	ERR	
Std Dev	0.0168	0.0157	ERR	ERR	ERR	

DATA SET 26-30 Alloy Code ICR

	STUD1	STUD2	STUD3	STUD4	STUD5
	0.1276	0.1276	0.1034	0.1082	0.1034
	0.1083	0.1107	0.0889	0.0962	0.1011
	0.1119	0.1071	0.0876	0.0909	0.1006
	0.1131	0.1070	0.0936	0.0948	0.1070
	0.1182	0.1112	0.1003	0.0973	0.1132
	0.1131	0.1034	0.0986	0.0937	0.1034
	0.1083	0.0962	0.0889	0.0768	0.0962
	0.1055	0.0925	0.0909	0.0763	0.0974
	0.1119	0.0985	0.0972	0.0813	0.1034
	0.1231	0.1053	0.1073	0.0894	0.1142
	0.1131	0.1179	0.1034	0.0840	0.1082
	0.1107	0.1035	0.0986	0.0720	0.0986
	0.0990	0.0974	0.1022	0.0714	0.1006
	0.1107	0.1046	0.1021	0.0826	0.1046
	0.1211	0.1092	0.1142	0.0934	0.1112
Mean	0.1130	0.1061	0.0985	0.0872	0.1042
Std Dev	0.0072	0.0088	0.0075	0.0105	0.0056

	MEAN VALUE	STD DEVIATION	TEST for Mean	TEST for Variance	90/95 Tolerance	
			95% Confidence			
			t*= 1.68	F*=1.98		
RUN-IN	0.1052	0.0106			0.1313	0.0791
XXXXXXXXXXXXXXXXXXXX						
			DESIGN vs RUN-IN			
			t	F		
DESIGN	0.0989	0.0114	0.1425	0.8505	0.1272	0.0706
			No	No		
XXXXXXXXXXXXXXXXXXXX						
			DESIGN vs CYCLE 3			
			t	F		
CYCLE3	0.1014	0.0127	-0.0510	0.8067	0.1329	0.0699
			No	No		

DATA SET 36-40		Alloy Code II									
STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST for Mean	TEST for Variance	90/95 Tolerance	
0.1469	0.1373	0.1373	0.1276	0.1179				95% Confidence			
0.1519	0.1470	0.1374	0.1422	0.1325				t*= 1.68	F*=1.98		
0.1572	0.1556	0.1346	0.1556	0.1362	RUN-IN	0.1492	0.0145			0.1850	0.1134
0.1632	0.1679	0.1498	0.1607	0.1449							
0.1700	0.1756	0.1567	0.1681	0.1557	XXXXXXXXXXXXXXXXXXXX						
0.1131	0.1179	0.1373	0.1082	0.1179				DESIGN vs RUN-IN			
0.1059	0.1035	0.1204	0.1083	0.1107				t	F		
0.1087	0.1071	0.1330	0.1168	0.1071	DESIGN	0.1156	0.0089	0.7176	2.6137	0.1377	0.0934
0.1119	0.1095	0.1144	0.1217	0.1107				No	Yes		
0.1221	0.1191	0.1132	0.1348	0.1162	XXXXXXXXXXXXXXXXXXXX						
0.1082	0.1179	0.1082	0.1179	0.1082				DESIGN vs CYCLE 3			
0.0986	0.0962	0.1011	0.0986	0.0962				t	F		
0.0974	0.1022	0.1071	0.1038	0.1006	CYCLE3	0.1067	0.0072	0.2760	1.5655	0.1244	0.0890
0.1034	0.1021	0.1119	0.1119	0.1046				No	No		
0.1152	0.1132	0.1132	0.1201	0.1092							

	STUD1	STUD2	STUD3	STUD4	STUD5
Mean	0.1249	0.1248	0.1250	0.1264	0.1179
Std Dev	0.0253	0.0256	0.0169	0.0215	0.0170

	DATA SET 41-45		Code SS	Studs 41-44 only			MEAN	STD	TEST for	TEST for	90/95 Tolerance	
	STUD1	STUD2	STUD3	STUD4	STUD5		VALUE	DEVIATION	Mean	Variance		
	0.1455	0.1455	0.1642	0.1525	0.1223				95% Confidence			
	0.1521	0.1603	0.1851	0.1603	0.1215				t*= 1.70	F*=2.47		
	0.1475	0.1638	0.1814	0.1711	0.1115	RUN-IN	0.1633	0.0150			0.2040	0.1226
	0.1565	0.1674	0.1961		0.1034							
					0.1006	XXXXXXXXXXXXXXXXXXXX						
	0.1432	0.1316	0.1269	0.0990	0.1153				DESIGN vs RUN-IN			
	0.1262	0.1297	0.1227	0.1156	0.1180				t	F		
	0.1208	0.1324	0.1339	0.1339	0.1123	DESIGN	0.1291	0.0122	0.6278	1.5004	0.1623	0.0959
	0.1313	0.1368	0.1527		0.1084				No	No		
					0.1067	XXXXXXXXXXXXXXXXXXXX						
	0.0990	0.1083	0.1083	0.0943	0.0990				DESIGN vs CYCLE 3			
	0.0956	0.1074	0.1121	0.1074	0.1132				t	F		
	0.1030	0.1169	0.1231	0.1300	0.1138	CYCLE3	0.1142	0.0145	0.2782	0.7147	0.1535	0.0750
	0.1179	0.1230	0.1379	0.1439	0.1062				No	No		
					0.1045							
Mean	0.1282	0.1353	0.1454	0.1308	0.1104							
Std Dev	0.0564	0.0589	0.0658	0.0672	0.0072							

DATA SET 46-50		Alloy Code T										
	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST for Mean	TEST for Variance	90/95 Tolerance	
	0.1039	0.1039	0.1112	0.1088	0.1015				95% Confidence			
	0.1124	0.1062	0.1148	0.1087	0.1087				t*= 1.68	F*=1.98		
	0.1184	0.1168	0.1160	0.1120	0.1160	RUN-IN	0.1166	0.0092		= 0.505	0.1392	0.0939
	0.1273	0.1255	0.1185	0.1168	0.1215							
	0.1324	0.1358	0.1253	0.1253	0.1267	XXXXXXXXXXXXXXXXXXX						
	0.1088	0.0893	0.0966	0.1088	0.0869				DESIGN vs RUN-IN			
	0.1111	0.0952	0.0989	0.1209	0.0940				t	F		
	0.1152	0.1012	0.1063	0.1256	0.1029	DESIGN	0.1123	0.0142	0.0908	0.4152	0.1475	0.0772
	0.1168	0.1145	0.1168	0.1308	0.1180				No	Yes		
	0.1329	0.1226	0.1338	0.1338	0.1267	XXXXXXXXXXXXXXXXXXX						
	0.1137	0.0966	0.1015	0.1088	0.0942				DESIGN vs CYCLE 3			
	0.1185	0.0989	0.0927	0.1099	0.0964				t	F		
	0.1232	0.1071	0.1021	0.1176	0.1087	CYCLE3	0.1145	0.0146	-0.0378	0.9397	0.1508	0.0783
	0.1279	0.1133	0.1156	0.1250	0.1145				No	No		
	0.1387	0.1239	0.1474	0.1382	0.1285							
Mean	0.1201	0.1101	0.1132	0.1194	0.1097							
Std Dev	0.0100	0.0131	0.0147	0.0100	0.0134							

DATA SET 51-55 Alloy Code AZ

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST for Mean	TEST for Variance	90/95 Tolerance	
	0.0963	0.0868	0.0805	0.0900	0.0868				95% Confidence			
	0.0951	0.0872	0.0920	0.0824	0.0856				t*= 1.68	F*=1.98		
	0.0909	0.0844	0.0791	0.0844	0.0877	RUN-IN	0.0864	0.0049		= 0.505	0.0984	0.0743
	0.0904	0.0847	0.0782	0.0831	0.0896							
	0.0892	0.0835	0.0769	0.0873	0.0873	XXXXXXXXXXXXXXXXXXXX						
	0.0805	0.0741	0.0741	0.0773	0.1026				DESIGN vs RUN-IN			
	0.0776	0.0888	0.0745	0.0776	0.0681				t	F		
	0.0834	0.0791	0.0758	0.0877	0.0791	DESIGN	0.0813	0.0072	0.2089	0.4601	0.0991	0.0636
	0.0814	0.0806	0.0749	0.0872	0.0855				No	Yes		
	0.0867	0.0841	0.0756	0.0867	0.0905	XXXXXXXXXXXXXXXXXXXX						
	0.0709	0.0805	0.0741	0.0773	0.0741				DESIGN vs CYCLE 3			
	0.0745	0.0808	0.0633	0.0776	0.0713				t	F		
	0.0834	0.0898	0.0726	0.0887	0.0801	CYCLE3	0.0812	0.0079	0.0033	0.8187	0.1009	0.0616
	0.0847	0.0888	0.0773	0.0896	0.0904				No	No		
	0.0886	0.0886	0.0789	0.0924	0.0924							
Mean	0.0849	0.0841	0.0765	0.0846	0.0847							
Std Dev	0.0072	0.0044	0.0058	0.0051	0.0089							

DATA SET 56-60 Alloy Code AR1

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST for Mean	TEST for Variance	90/95 Tolerance	
	0.1195	0.1289	0.1195	0.0934	0.1108				95% Confidence			
	0.1243	0.1180	0.1095	0.0905	0.1117				t*= 1.68	F*=1.98		
	0.1206	0.1132	0.0987	0.0987	0.1073	RUN-IN	0.1106	0.0099		= 0.505	0.1352	0.0860
	0.1199	0.1144	0.1045	0.0979	0.1056							
	0.1186	0.1195	0.1072	0.1037	0.1090	XXXXXXXXXXXXXXXXXXX						
	0.1195	0.1289	0.1242	0.0934	0.1289				DESIGN vs RUN-IN			
	0.1222	0.1272	0.1159	0.1117	0.1222				t	F		
!	0.1251	0.1251	0.1221	0.1103	0.1177	DESIGN	0.1211	0.0077	-0.2978	1.6625	0.1402	0.1021
	0.1254	0.1243	0.1199	0.1199	0.1265				No	No		
	0.1291	0.1274	0.1169	0.1186	0.1256	XXXXXXXXXXXXXXXXXXX						
	0.1152	0.1382	0.1195	0.0804	0.1242				DESIGN vs CYCLE 3			
	0.1159	0.1488	0.1138	0.1026	0.1272				t	F		
	0.1221	0.1398	0.1118	0.1118	0.1206	CYCLE3	0.1214	0.0138	-0.0074	0.3129	0.1555	0.0874
	0.1166	0.1342	0.1177	0.1177	0.1254				No	Yes		
	0.1230	0.1414	0.1186	0.1169	0.1326							
Mean	0.1212	0.1286	0.1147	0.1045	0.1197							
Std Dev	0.0039	0.0103	0.0071	0.0120	0.0087							

DATA SET 61-65		Alloy Code MA				MEAN	STD	TEST for	TEST for	90/95 Tolerance	
STUD1	STUD2	STUD3	STUD4	STUD5		VALUE	DEVIATION	Mean	Variance		
0.1253	0.1354	0.1404	0.1458	0.1253				95% Confidence			
0.1230	0.1259	0.1412	0.1337	0.1312				t*= 1.68	F*=1.98		
0.1265	0.1195	0.1369	0.1352	0.1456	RUN-IN	0.1398	0.0143			0.1751	0.1046
0.1351	0.1273	0.1454	0.1454	0.1570							
0.1524	0.1391	0.1658	0.1617	0.1761	XXXXXXXXXXXXXXXXXXXX						
0.1253	0.1051	0.1253	0.1203	0.1203				DESIGN vs RUN-IN			
0.1145	0.1173	0.1230	0.1173	0.1116				t	F		
0.1137	0.1152	0.1213	0.1213	0.1079	DESIGN	0.1226	0.0098	0.3580	2.1331	0.1468	0.0985
0.1221	0.1208	0.1234	0.1299	0.1273				No	Yes		
0.1309	0.1370	0.1268	0.1494	0.1391	XXXXXXXXXXXXXXXXXXXX						
0.1152	0.1051	0.1253	0.1203	0.1152				DESIGN vs CYCLE 3			
0.1063	0.1013	0.1173	0.1230	0.1063				t	F		
0.1021	0.1065	0.1213	0.1166	0.1123	CYCLE3	0.1172	0.0095	0.1417	1.0604	0.1407	0.0937
0.1183	0.1118	0.1196	0.1247	0.1183				No	No		
0.1247	0.1257	0.1227	0.1432	0.1268							

	STUD1	STUD2	STUD3	STUD4	STUD5
Mean	0.1224	0.1195	0.1304	0.1325	0.1280
Std Dev	0.0121	0.0122	0.0131	0.0138	0.0195

DATA SET 61-65		Alloy Code MA				MEAN	STD	TEST for	TEST for	90/95 Tolerance	
STUD1	STUD2	STUD3	STUD4	STUD5		VALUE	DEVIATION	Mean	Variance		
0.1253	0.1354	0.1404	0.1458	0.1253				95% Confidence			
0.1230	0.1259	0.1412	0.1337	0.1312				t*= 1.74	F*=2.27		
0.1265	0.1195	0.1369	0.1352	0.1456	RUN-IN	0.1351	0.0097			0.1600	0.1101
0.1351	0.1273	0.1454	0.1454	0.1570							
*					XXXXXXXXXXXXXXXXXXXX						
0.1253	0.1051	0.1253	0.1203	0.1203				DESIGN vs RUN-IN			
0.1145	0.1173	0.1230	0.1173	0.1116				t	F		
0.1137	0.1152	0.1213	0.1213	0.1079	DESIGN	0.1192	0.0064	0.4942	2.3496	0.1354	0.1029
0.1221	0.1208	0.1234	0.1299	0.1273				No	Yes		
					XXXXXXXXXXXXXXXXXXXX						
0.1152	0.1051	0.1253	0.1203	0.1152				DESIGN vs CYCLE 3			
0.1063	0.1013	0.1173	0.1230	0.1063				t	F		
0.1021	0.1065	0.1213	0.1166	0.1123	CYCLE3	0.1143	0.0075	0.1739	0.7192	0.1335	0.0951
0.1183	0.1118	0.1196	0.1247	0.1183				No	No		

	STUD1	STUD2	STUD3	STUD4	STUD5
Mean	0.1190	0.1159	0.1284	0.1278	0.1232
Std Dev	0.0092	0.0105	0.0097	0.0102	0.0154

* Excludes the highest torque increment, see discussion under the Monel K-500 section of Phase II Test Results.

	DATA SET 66-70		Alloy Code AM				MEAN	STD	TEST for	TEST for	90/95 Tolerance	
	STUD1	STUD2	STUD3	STUD4	STUD5		VALUE	DEVIATION	Mean	Variance		
	0.0905	0.0933	0.0988	0.0960	0.0738				95% Confidence			
	0.0965	0.1063	0.1021	0.1035	0.0854				t*= 1.68	F*=1.98		
	0.1057	0.1047	0.1094	0.1132	0.0867	RUN-IN	0.0987	0.0095		= 0.505	0.1222	0.0752
	0.0990	0.1060	0.1011	0.1108	0.0849							
	0.1029	0.1013	0.1013	0.1066	0.0876	XXXXXXXXXXXXXXXXXXXX						
	0.0960	0.0933	0.0933	0.0905	0.0905				DESIGN vs RUN-IN			
	0.1063	0.0924	0.1035	0.0965	0.0965				t	F		
	0.1085	0.1057	0.1123	0.1085	0.0952	DESIGN	0.1028	0.0081	-0.1156	1.3622	0.1229	0.0826
	0.1101	0.1108	0.1094	0.1087	0.0956				No	Yes		
	0.1120	0.1120	0.1130	0.1120	0.0970	XXXXXXXXXXXXXXXXXXXX						
	0.0933	0.0905	0.0849	0.0877	0.0905				DESIGN vs CYCLE 3			
	0.1063	0.0993	0.0965	0.0938	0.0910				t	F		
	0.1057	0.1132	0.1057	0.1142	0.1009	CYCLE3	0.1027	0.0097	0.0035	0.7070	0.1266	0.0787
	0.1108	0.1143	0.1046	0.1129	0.0997				No	No		
	0.1146	0.1136	0.1093	0.1146	0.0986							
Mean	0.1039	0.1038	0.0993	0.1046	0.0916							
Std Dev	0.0073	0.0084	0.0169	0.0093	0.0072							

	DATA SET 71-75		Alloy Code AS				MEAN	STD	TEST for	TEST for	90/95 Tolerance	
	STUD1	STUD2	STUD3	STUD4	STUD5		VALUE	DEVIATION	Mean	Variance		
	0.0987	0.0987	0.0587	0.0855	0.0865				95% Confidence			
	0.1019	0.1182	0.0703	0.0910	0.0901				t*= 1.70	F*=2.35		
	0.1154	0.1134	0.0933	0.1019	0.0999	RUN-IN	0.0949	0.0160		= 0.426	0.1371	0.0527
	ERR	ERR	ERR	ERR	ERR							
	ERR	ERR	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXX						
	0.0987	0.0977	0.0669	0.0660	0.0734				DESIGN vs RUN-IN			
	0.0953	0.0859	0.0655	0.0726	0.0812				t	F		
	0.1104	0.1043	0.0860	0.0834	0.0887	DESIGN	0.0851	0.0143	0.1624	1.2516	0.1228	0.0473
	ERR	ERR	ERR	ERR	ERR				No	No		
	ERR	ERR	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXX						
	0.1118	0.0587	0.0651	0.0559	0.0651				DESIGN vs CYCLE 3			
	0.0981	0.0531	0.0684	0.0631	0.0731				t	F		
	0.1060	0.0699	0.0790	0.0804	0.0890	CYCLE3	0.0758	0.0181	0.1432	0.6211	0.1237	0.0279
	ERR	ERR	ERR	ERR	ERR				No	No		
	ERR	ERR	ERR	ERR	ERR							
Mean	0.1040	0.0889	0.0726	0.0778	0.0830							
Std Dev	0.0071	0.0235	0.0112	0.0146	0.0108							

	DATA SET 76-80		Alloy Code IMC3				MEAN	STD	TEST for	TEST for	90/95 Tolerance	
	STUD1	STUD2	STUD3	STUD4	STUD5		VALUE	DEVIATION	Mean	Variance		
	0.1082	0.1034	0.1082	0.1034	0.0986				95% Confidence			
	0.0962	0.0986	0.0962	0.0962	0.0841				t*= 1.68	F*=1.98		
	0.0990	0.0974	0.0974	0.1022	0.0860	RUN-IN	0.1008	0.0076			0.1197	0.0820
	0.0985	0.1070	0.1021	0.1021	0.0936							
	0.1053	0.1182	0.1132	0.1092	0.0964	XXXXXXXXXXXXXXXXXXX						
	0.0986	0.0937	0.1082	0.0889	0.0889				DESIGN vs RUN-IN			
	0.0865	0.0841	0.0889	0.0792	0.0744				t	F		
	0.0795	0.0893	0.0795	0.0763	0.0747	DESIGN	0.0884	0.0088	0.3777	0.7405	0.1103	0.0665
	0.0887	0.0936	0.0899	0.0875	0.0789				No	No		
	0.0924	0.1033	0.0983	0.0983	0.0884	XXXXXXXXXXXXXXXXXXX						
	0.0889	0.0889	0.0889	0.0937	0.0937				DESIGN vs CYCLE 3			
	0.0841	0.0841	0.0744	0.0841	0.0792				t	F		
	0.0763	0.0779	0.0779	0.0763	0.0747	CYCLE3	0.0850	0.0067	0.1087	1.7248	0.1017	0.0684
	0.0838	0.0838	0.0875	0.0875	0.0789				No	No		
	0.0864	0.0934	0.0944	0.0973	0.0894							
Mean	0.0915	0.0944	0.0937	0.0922	0.0853							
Std Dev	0.0093	0.0106	0.0115	0.0103	0.0082							

DATA SET 81-85 Alloy Code IMC2

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST for Mean	TEST for Variance	90/95 Tolerance	
	0.1179	0.1228	0.1179	0.1324	0.1373				95% Confidence			
	0.1107	0.1035	0.0986	0.1011	0.1107				t*= 1.68	F*=1.98		
	0.1103	0.0974	0.0990	0.1038	0.1103	RUN-IN	0.1109	0.0098		= 0.505	0.1352	0.0866
	0.1119	0.1070	0.1009	0.1095	0.1095							
	0.1201	0.1082	0.1063	0.1112	0.1132	XXXXXXXXXXXXXXXXXXXX						
	0.0840	0.0986	0.0937	0.0986	0.0889				DESIGN vs RUN-IN			
	0.0744	0.0792	0.0841	0.0865	0.0841				t	F		
	0.0860	0.0828	0.0876	0.0941	0.0909	DESIGN	0.0912	0.0077	0.5616	1.6137	0.1103	0.0720
	0.0838	0.0924	0.0972	0.0960	0.0972				No	No		
	0.0934	0.0993	0.0983	0.1053	0.1023	XXXXXXXXXXXXXXXXXXXX						
	0.0695	0.0840	0.0840	0.0986	0.0889				DESIGN vs CYCLE 3			
	0.0647	0.0720	0.0768	0.0841	0.0841				t	F		
	0.0698	0.0795	0.0828	0.0925	0.0925	CYCLE3	0.0872	0.0113	0.1031	0.4675	0.1152	0.0592
	0.0801	0.0911	0.0924	0.1009	0.0997				No	Yes		
	0.0874	0.0983	0.0964	0.1043	0.1063							
Mean	0.0909	0.0944	0.0944	0.1013	0.1011							
Std Dev	0.0187	0.0134	0.0104	0.0115	0.0142							

	DATA SET 86-90		Alloy Code IMA				MEAN	STD	TEST for	TEST for	90/95 Tolerance	
	STUD1	STUD2	STUD3	STUD4	STUD5		VALUE	DEVIATION	Mean	Variance		
	0.1683	0.0923	0.1154	0.1016	0.0969				95% Confidence			
	0.1376	0.0962	0.1139	0.1087	0.1166				t*= 1.734	F*=2.17		
	0.1345	0.1039	0.1281	0.1217	0.1377	RUN-IN	0.1223	0.0203		= 0.461	0.1744	0.0701
	0.1330	0.1093	0.1354	0.1413	0.1532							
	ERR	ERR	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX						
	0.1154	0.0784	0.0969	0.1016	0.1016				DESIGN vs RUN-IN			
	0.1192	0.0824	0.0985	0.1061	0.1061				t	F		
	0.1185	0.0999	0.1039	0.1065	0.1233	DESIGN	0.1078	0.0140	0.2098	2.0965	0.1439	0.0718
	0.1259	0.1033	0.1140	0.1188	0.1366				No	No		
	ERR	ERR	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX						
	0.1108	0.0599	0.0877	0.1201	0.0831				DESIGN vs CYCLE 3			
	0.1061	0.0719	0.0893	0.1087	0.0962				t	F		
	0.1137	0.0885	0.0965	0.1265	0.1121	CYCLE3	0.1075	0.0199	0.0044	0.4990	0.1585	0.0566
	0.1093	0.1057	0.1093	0.1330	0.1259				No	No		
	0.1246	0.1152	0.1161	0.1368	0.1416							
Mean	0.1244	0.0929	0.1081	0.1178	0.1177							
Std Dev	0.0165	0.0160	0.0143	0.0135	0.0208							

	DATA SET 91-95		Alloy Code IMB				MEAN	STD	TEST for	TEST for	90/95 Tolerance	
	STUD1	STUD2	STUD3	STUD4	STUD5		VALUE	DEVIATION	Mean	Variance		
	0.1769	0.1373	0.2103	0.1505	0.2385				95% Confidence			
	0.1749	0.1575	0.1906	0.1339	0.2657				t*= 1.70	F*=2.29		
	0.1820	0.1594	0.1935	0.1317	ERR	RUN-IN	0.1756	0.0399			0.2854	0.0657
	ERR	ERR	ERR	0.1307	ERR							
	ERR	ERR	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX						
	0.1307	0.1009	0.1249	0.1009	0.1808				DESIGN vs RUN-IN			
	0.1433	0.1134	0.1149	0.0964	0.2032				t	F		
	0.1451	0.1348	0.1286	0.1047	0.2047	DESIGN	0.1335	0.0314	0.2952	1.6129	0.2200	0.0470
	0.1472	0.1357	0.1357	0.1121	ERR				No	No		
	ERR	ERR	ERR	0.1117	ERR	XXXXXXXXXXXXXXXXXXXX						
	0.1249	0.1042	0.1009	0.0782	0.1472				DESIGN vs CYCLE 3			
	0.1323	0.1244	0.1049	0.0905	0.1591				t	F		
	0.1389	0.1379	0.1203	0.0985	0.1671	CYCLE3	0.1222	0.0238	0.1021	1.7407	0.1878	0.0567
	0.1468	0.1344	0.1282	0.1028	ERR				No	No		
	ERR	ERR	ERR	0.1030	ERR							
Mean	0.1494	0.1309	0.1412	0.1104	0.1958							
Std Dev	0.0197	0.0190	0.0383	0.0197	0.0407							

	DATA SET 96-100		Alloy Code MK				MEAN	STD	TEST for	TEST for	90/95 Tolerance	
	STUD1	STUD2	STUD3	STUD4	STUD5		VALUE	DEVIATION	Mean	Variance		
	0.1056	0.1186	0.1089	0.1154	0.1056				95% Confidence			
	0.1012	0.1142	0.0931	0.1093	0.0979				t*= 1.68	F*=1.98		
	0.1011	0.1165	0.0934	0.1055	0.1011	RUN-IN	0.1046	0.0073			0.1227	0.0866
	0.1014	0.1145	0.0972	0.1047	0.0997							
	0.1017	0.1108	0.0958	0.1036	0.0984	XXXXXXXXXXXXXXXXXXXX						
	0.0959	0.1154	0.1056	0.1056	0.1089				DESIGN vs RUN-IN			
	0.0963	0.1142	0.1028	0.0931	0.0963				t	F		
	0.0956	0.1077	0.1000	0.0901	0.1022	DESIGN	0.0994	0.0070	0.1816	1.0884	0.1167	0.0821
	0.0980	0.1014	0.0980	0.0896	0.0980				No	No		
	0.0932	0.0977	0.0951	0.0906	0.0938	XXXXXXXXXXXXXXXXXXXX						
	0.0894	0.1024	0.0927	0.0894	0.0991				DESIGN vs CYCLE 3			
	0.0963	0.0931	0.0914	0.0898	0.0931				t	F		
	0.1000	0.0912	0.0868	0.0868	0.0934	CYCLE3	0.0913	0.0059	0.3156	1.4133	0.1059	0.0767
	0.0997	0.0880	0.0829	0.0838	0.0905				No	No		
	0.1004	0.0880	0.0800	0.0841	0.0899							
Mean	0.0984	0.1049	0.0949	0.0961	0.0979							
Std Dev	0.0040	0.0111	0.0079	0.0101	0.0053							

DATA SET 101, 102		Alloy Code MS			
STUD1	STUD2	STUD3	STUD4	STUD5	
0.1121	0.1186	0.0000	0.0000	0.0000	
0.1175	0.1110	0.0000	0.0000	0.0000	
0.1275	0.1187	0.0000	0.0000	0.0000	RUN-IN
0.1330	0.1242	0.0000	0.0000	0.0000	
0.1397	0.1335	0.0000	0.0000	0.0000	XXXXXXXX
0.0862	0.0829	0.0000	0.0000	0.0000	
0.0979	0.0947	0.0000	0.0000	0.0000	
0.1033	0.0934	0.0000	0.0000	0.0000	DESIGN
0.1081	0.1014	0.0000	0.0000	0.0000	
0.1088	0.1049	0.0000	0.0000	0.0000	XXXXXXXX
0.0894	0.0862	0.0000	0.0000	0.0000	
0.0947	0.0963	0.0000	0.0000	0.0000	
0.0956	0.0978	0.0000	0.0000	0.0000	CYCLE3
0.0989	0.0997	0.0000	0.0000	0.0000	
0.1023	0.1023	0.0000	0.0000	0.0000	

	STUD1	STUD2	STUD3	STUD4	STUD5
Mean	0.1077	0.1044	0.0000	0.0000	0.0000
Std Dev	0.0158	0.0142	0.0000	0.0000	0.0000

DATA SET 106,107 Alloy Code MI

	STUD1	STUD2	STUD3	STUD4	STUD5	
	0.1186	0.1186	ERR	ERR	ERR	
	0.1175	0.1158	ERR	ERR	ERR	
	0.1308	0.1319	ERR	ERR	ERR	RUN-IN
	ERR	ERR	ERR	ERR	ERR	
	ERR	ERR	ERR	ERR	ERR	XXXXXXXXXXXX
	0.1154	0.1121	ERR	ERR	ERR	
	0.1093	0.1093	ERR	ERR	ERR	
	0.1220	0.1231	ERR	ERR	ERR	DESIGN
	ERR	ERR	ERR	ERR	ERR	
	ERR	ERR	ERR	ERR	ERR	XXXXXXXXXXXX
	0.0927	0.1218	ERR	ERR	ERR	
	0.0947	0.1126	ERR	ERR	ERR	
	0.1099	0.1220	ERR	ERR	ERR	CYCLE3
	ERR	ERR	ERR	ERR	ERR	
	ERR	ERR	ERR	ERR	ERR	
Mean	0.1123	0.1186	ERR	ERR	ERR	
Std Dev	0.0124	0.0070	ERR	ERR	ERR	

DATA SET 111,112 Alloy Code MCU

	STUD1	STUD2	STUD3	STUD4	STUD5	
	0.1347	0.1403	ERR	ERR	ERR	
	0.1154	0.1186	ERR	ERR	ERR	
	0.1167	0.1231	ERR	ERR	ERR	RUN-IN
	0.1175	0.1288	ERR	ERR	ERR	
	0.1232	0.1375	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX
	0.1065	0.1234	ERR	ERR	ERR	
	0.0894	0.1056	ERR	ERR	ERR	
	0.0820	0.1058	ERR	ERR	ERR	DESIGN
	0.0865	0.1093	ERR	ERR	ERR	
	0.0932	0.1153	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX
	0.0895	0.1178	ERR	ERR	ERR	
	0.0959	0.1024	ERR	ERR	ERR	
	0.0907	0.0972	ERR	ERR	ERR	CYCLE3
	0.0914	0.1028	ERR	ERR	ERR	
	0.0906	0.1036	ERR	ERR	ERR	
Mean	0.1015	0.1154	ERR	ERR	ERR	
Std Dev	0.0160	0.0132	ERR	ERR	ERR	

DATA SET 116, 117 Alloy Code MH

	STUD1	STUD2	STUD3	STUD4	STUD5	
	0.1478	0.1348	ERR	ERR	ERR	
	0.1337	0.1337	ERR	ERR	ERR	
	0.1385	0.1440	ERR	ERR	ERR	RUN-IN
	0.1338	0.1451	ERR	ERR	ERR	
	0.1310	0.1496	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX
	0.1024	0.1121	ERR	ERR	ERR	
	0.0931	0.1044	ERR	ERR	ERR	
	0.0989	0.1132	ERR	ERR	ERR	DESIGN
	0.1039	0.1177	ERR	ERR	ERR	
	0.1114	0.1222	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX
	0.0862	0.1024	ERR	ERR	ERR	
	0.0865	0.1012	ERR	ERR	ERR	
	0.0945	0.1088	ERR	ERR	ERR	CYCLE3
	0.1056	0.1121	ERR	ERR	ERR	
	0.1095	0.1160	ERR	ERR	ERR	
Mean	0.1118	0.1212	ERR	ERR	ERR	
Std Dev	0.0201	0.0162	ERR	ERR	ERR	

	DATA SET 121-125		Alloy Code ICR				MEAN	STD	TEST for	TEST for	90/95 Tolerance	
	STUD1	STUD2	STUD3	STUD4	STUD5		VALUE	DEVIATION	Mean	Variance		
	0.1131	0.1034	0.1131	0.0986	0.1034				95% Confidence			
	0.1059	0.1035	0.1011	0.0865	0.1035				t*= 1.68	F*=1.98		
	0.1087	0.1022	0.1022	0.0925	0.1038	RUN-IN	0.1043	0.0066		= 0.505	0.1206	0.0881
	0.1119	0.1046	0.1034	0.0972	0.1034							
	0.1182	0.1073	0.1092	0.1033	0.1082	XXXXXXXXXXXXXXXXXXXX						
	0.1131	0.1034	0.0792	0.0937	0.1131				DESIGN vs RUN-IN			
	0.1107	0.0986	0.0744	0.0720	0.0914				t	F		
	0.1200	0.0957	0.0763	0.0714	0.0925	DESIGN	0.0948	0.0165	0.2067	0.1597	0.1355	0.0541
	0.1229	0.0985	0.0813	0.0728	0.0924				No	Yes		
	0.1251	0.1023	0.0934	0.0775	0.0983	XXXXXXXXXXXXXXXXXXXX						
	0.0986	0.1034	0.0889	0.0986	0.1034				DESIGN vs CYCLE 3			
	0.0914	0.0986	0.0792	0.0841	0.0914				t	F		
	0.0925	0.1022	0.0763	0.0812	0.0925	CYCLE3	0.0931	0.0089	0.0334	3.4423	0.1151	0.0712
	0.0948	0.1021	0.0826	0.0826	0.0948				No	Yes		
	0.1082	0.1053	0.0934	0.0844	0.0973							
Mean	0.1090	0.1021	0.0903	0.0864	0.0993							
Std Dev	0.0107	0.0030	0.0130	0.0105	0.0068							

	DATA SET 131-135		Alloy Code II				MEAN	STD	TEST for	TEST for	90/95 Tolerance	
	STUD1	STUD2	STUD3	STUD4	STUD5		VALUE	DEVIATION	Mean	Variance		
	0.1421	0.1469	0.1469	0.1662	0.1662				95% Confidence			
	0.1325	0.1325	0.1640	0.1591	0.1664				t*= 1.68	F*=1.98		
	0.1362	0.1394	0.1653	0.1588	0.1927	RUN-IN	0.1596	0.0151			0.1970	0.1221
	0.1522	0.1571	0.1726	0.1644	0.1714							
	0.1662	0.1671	0.1756	0.1709	0.1766	XXXXXXXXXXXXXXXXXXXXX						
	0.1276	0.1421	0.1324	0.1566	0.1276				DESIGN vs RUN-IN			
	0.1107	0.1277	0.1204	0.1277	0.1277				t	F		
	0.1168	0.1314	0.1168	0.1265	0.1281	DESIGN	0.1261	0.0097	0.6754	2.4468	0.1500	0.1021
	0.1082	0.1229	0.1229	0.1266	0.1315				No	Yes		
	0.1182	0.1182	0.1290	0.1231	0.1310	XXXXXXXXXXXXXXXXXXXXX						
	0.1131	0.1228	0.1228	0.1179	0.1276				DESIGN vs CYCLE 3			
	0.1011	0.0986	0.1083	0.1035	0.1132				t	F		
	0.1006	0.0957	0.1087	0.1071	0.1119	CYCLE3	0.1102	0.0082	0.4459	1.4089	0.1303	0.0900
	0.1070	0.0972	0.1082	0.1119	0.1119				No	No		
	0.1102	0.1063	0.1142	0.1182	0.1162							
Mean	0.1228	0.1271	0.1339	0.1359	0.1400							
Std Dev	0.0194	0.0216	0.0245	0.0238	0.0269							

	DATA SET 136-140		Alloy Code SS		Studs 136-139 only		MEAN	STD	TEST for	TEST for	90/95 Tolerance	
	STUD1	STUD2	STUD3	STUD4	STUD5		VALUE	DEVIATION	Mean	Variance		
	0.1293	0.1223	0.1362	0.1129	0.1176				t*=1.70	F*=2.47		
	0.1333	0.1333	0.1533	0.1309	0.1144							
	0.1185	0.1285	0.1446	0.1285	0.1185	RUN-IN	0.1296	0.0104			0.1579	0.1013
	0.1157	0.1258	0.1313	ERR	0.1146							
	ERR	ERR	ERR	ERR	0.1124	XXXXXXXXXXXXXXXXXXXX						
	0.0990	0.0873	0.0966	0.0756	0.0733				DESIGN vs RUN-IN			
	0.1003	0.1062	0.0908	0.0885	0.0861				t	F		
	0.1022	0.1108	0.1038	0.1046	0.0902	DESIGN	0.0999	0.0105	0.7095	0.9852	0.1284	0.0713
	0.1084	0.1140	0.1101	ERR	0.0917				No	No		
	ERR	ERR	ERR	ERR	0.0907	XXXXXXXXXXXXXXXXXXXX						
	0.0709	0.0756	0.0826	0.0990	0.0756				DESIGN vs CYCLE 3			
	0.0838	0.0979	0.0861	0.1003	0.0779				t	F		
	0.0942	0.1108	0.0950	0.1100	0.0797	CYCLE3	0.0967	0.0141	0.0647	0.5553	0.1350	0.0584
	0.1017	0.1157	0.1028	0.1207	0.0794				No	No		
	ERR	ERR	ERR	ERR	0.0831							
Mean	0.1048	0.1107	0.1111	0.1071	0.0932							
Std Dev	0.0178	0.0170	0.0241	0.0174	0.0179							

	DATA SET 141-145		Alloy Code T				MEAN	STD	TEST for	TEST for	90/95 Tolerance	
	STUD1	STUD2	STUD3	STUD4	STUD5		VALUE	DEVIATION	Mean	Variance		
	0.1064	0.1015	0.1064	0.1039	0.1088				95% Confidence			
	0.1136	0.1062	0.1148	0.1050	0.1087				t*= 1.68	F*=1.98		
	0.1168	0.1128	0.1216	0.1063	0.1144	RUN-IN	0.1147	0.0097		= 0.505	0.1386	0.0908
	0.1139	0.1197	0.1273	0.1080	0.1150							
	0.1244	0.1267	0.1411	0.1134	0.1314	XXXXXXXXXXXXXXXXXXXX						
	0.0991	0.0942	0.0966	0.0796	0.0918				DESIGN vs RUN-IN			
	0.0989	0.1038	0.1026	0.0829	0.0940				t	F		
	0.1038	0.1095	0.1216	0.0954	0.1038	DESIGN	0.1058	0.0141	0.1868	0.4683	0.1408	0.0709
	0.1038	0.1174	0.1261	0.1019	0.1080				No	Yes		
	0.1121	0.1309	0.1392	0.1116	0.1176	XXXXXXXXXXXXXXXXXXXX						
	0.0820	0.0966	0.1039	0.1015	0.1039				DESIGN vs CYCLE 3			
	0.0903	0.1026	0.1075	0.0940	0.1050				t	F		
	0.0937	0.1071	0.1176	0.0987	0.1144	CYCLE3	0.1078	0.0136	-0.0357	1.0847	0.1413	0.0743
	0.0977	0.1226	0.1273	0.1038	0.1156				No	No		
	0.1052	0.1343	0.1377	0.1103	0.1221							
Mean	0.1041	0.1124	0.1194	0.1011	0.1103							
Std Dev	0.0110	0.0124	0.0140	0.0098	0.0102							

	DATA SET 146-150		Alloy Code AZ				MEAN	STD	TEST for	TEST for	90/95 Tolerance	
	STUD1	STUD2	STUD3	STUD4	STUD5		VALUE	DEVIATION	Mean	Variance		
	0.0931	0.1026	0.0900	0.1058	0.1090				95% Confidence			
	0.0935	0.1078	0.0856	0.0840	0.1063				t*= 1.68	F*=1.98		
	0.0930	0.1113	0.0898	0.0855	0.0984	RUN-IN	0.0966	0.0090		= 0.505	0.1189	0.0742
	0.0962	0.1130	0.0896	0.0888	0.0954							
	0.0936	0.1108	0.0911	0.0879	0.0917	XXXXXXXXXXXXXXXXXXXX						
	0.0773	0.0931	0.0773	0.0741	0.0773				DESIGN vs RUN-IN			
	0.0808	0.0951	0.0665	0.0776	0.0792				t	F		
	0.0877	0.0984	0.0780	0.0866	0.0855	DESIGN	0.0838	0.0088	0.3567	1.0523	0.1056	0.0620
	0.0880	0.1011	0.0749	0.0872	0.0839				No	No		
	0.0848	0.1013	0.0756	0.0816	0.0828	XXXXXXXXXXXXXXXXXXXX						
	0.0805	0.1058	0.0709	0.0678	0.0773				DESIGN vs CYCLE 3			
	0.0776	0.0935	0.0617	0.0649	0.0745				t	F		
	0.0887	0.0952	0.0726	0.0769	0.0791	CYCLE3	0.0807	0.0105	0.0815	0.7087	0.1066	0.0548
	0.0896	0.0929	0.0732	0.0798	0.0782				No	No		
	0.0873	0.0936	0.0743	0.0816	0.0796							
Mean	0.0875	0.1010	0.0781	0.0820	0.0865							
Std Dev	0.0061	0.0072	0.0092	0.0097	0.0110							

DATA SET 151-155 Alloy Code AR1

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST for Mean	TEST for Variance	90/95 Tolerance	
	0.1108	0.1152	0.1242	0.1152	0.1242				95% Confidence			
	0.1117	0.1159	0.1159	0.1138	0.1180				t*= 1.68	F*=1.98		
	0.1073	0.1192	0.1221	0.1206	0.1132	RUN-IN	0.1167	0.0054		= 0.505	0.1301	0.1033
	0.1078	0.1210	0.1188	0.1221	0.1122							
	0.1125	0.1178	0.1178	0.1291	0.1108	XXXXXXXXXXXXXXXXXXXX						
	0.1065	0.1065	0.1021	0.1065	0.1108				DESIGN vs RUN-IN			
	0.1095	0.1095	0.1050	0.1138	0.1138				t	F		
	0.1044	0.1118	0.1103	0.1147	0.1073	DESIGN	0.1108	0.0045	0.2970	1.4310	0.1220	0.0996
	0.1100	0.1089	0.1122	0.1155	0.1089				No	No		
	0.1143	0.1134	0.1169	0.1221	0.1151	XXXXXXXXXXXXXXXXXXXX						
	0.1021	0.1065	0.1065	0.1108	0.1152				DESIGN vs CYCLE 3			
	0.1074	0.1095	0.1050	0.1138	0.1222				t	F		
	0.1088	0.1162	0.1088	0.1118	0.1192	CYCLE3	0.1117	0.0051	-0.0452	0.7886	0.1242	0.0991
	0.1067	0.1188	0.1078	0.1199	0.1111				No	No		
	0.1116	0.1116	0.1108	0.1169	0.1125							
Mean	0.1088	0.1135	0.1123	0.1164	0.1143							
Std Dev	0.0032	0.0047	0.0067	0.0056	0.0048							

	DATA SET 156-160		Alloy Code MA				MEAN	STD	TEST for	TEST for	90/95 Tolerance	
	STUD1	STUD2	STUD3	STUD4	STUD5		VALUE	DEVIATION	Mean	Variance		
	0.0900	0.1152	0.1102	0.1102	0.1001				95% Confidence			
	0.0860	0.1088	0.0988	0.1063	0.0913				t*= 1.68	F*=1.98		
	0.0869	0.1094	0.1043	0.0999	0.0978	RUN-IN	0.1078	0.0133			0.1408	0.0749
	0.0989	0.1118	0.1196	0.1092	0.1079							
	0.1165	0.1175	0.1340	0.1360	0.1299	XXXXXXXXXXXXXXXXXXXX						
	0.0900	0.1203	0.1102	0.1051	0.1152				DESIGN vs RUN-IN			
	0.0888	0.1173	0.1038	0.0938	0.1063				t	F		
	0.0999	0.1065	0.1021	0.1065	0.1021	DESIGN	0.1064	0.0085	0.0340	2.4407	0.1275	0.0853
	0.1053	0.1105	0.1066	0.1053	0.0963				No	Yes		
	0.1062	0.1072	0.1186	0.1186	0.1165	XXXXXXXXXXXXXXXXXXXX						
	0.1051	0.0950	0.1001	0.1051	0.0950				DESIGN vs CYCLE 3			
	0.0913	0.0860	0.0988	0.1038	0.0963				t	F		
	0.0934	0.0836	0.0978	0.1094	0.1065	CYCLE3	0.1011	0.0084	0.1559	1.0425	0.1218	0.0804
	0.0976	0.0989	0.0976	0.1118	0.1028				No	No		
	0.1083	0.1000	0.1134	0.1144	0.1155							
Mean	0.0976	0.1059	0.1077	0.1090	0.1053							
Std Dev	0.0091	0.0111	0.0102	0.0095	0.0104							

	DATA SET 156-160		Alloy Code MA				MEAN	STD	TEST for	TEST for	90/95 Tolerance	
	STUD1	STUD2	STUD3	STUD4	STUD5		VALUE	DEVIATION	Mean	Variance		
	0.0900	0.1152	0.1102	0.1102	0.1001				95% Confidence			
	0.0860	0.1088	0.0988	0.1063	0.0913				t*= 1.74	F*=2.27		
	0.0869	0.1094	0.1043	0.0999	0.0978	RUN-IN	0.1031	0.0094			0.1273	0.0789
	0.0989	0.1118	0.1196	0.1092	0.1079							
	*					XXXXXXXXXXXXXXXXXXXX						
	0.0900	0.1203	0.1102	0.1051	0.1152				DESIGN vs RUN-IN			
	0.0888	0.1173	0.1038	0.0938	0.1063				t	F		
	0.0999	0.1065	0.1021	0.1065	0.1021	DESIGN	0.1046	0.0082	-0.0420	1.3146	0.1257	0.0835
	0.1053	0.1105	0.1066	0.1053	0.0963				No	No		
						XXXXXXXXXXXXXXXXXXXX						
	0.1051	0.0950	0.1001	0.1051	0.0950				DESIGN vs CYCLE 3			
	0.0913	0.0860	0.0988	0.1038	0.0963				t	F		
	0.0934	0.0836	0.0978	0.1094	0.1065	CYCLE3	0.0988	0.0072	0.1886	1.3100	0.1172	0.0804
	0.0976	0.0989	0.0976	0.1118	0.1028				No	No		
Mean	0.0944	0.1053	0.1041	0.1055	0.1015							
Std Dev	0.0068	0.0119	0.0066	0.0049	0.0067							

* Excludes the highest torque increment, see discussion under the Monel K-500 section of Phase II Test Results.

	DATA SET 161-165		Alloy Code AM				MEAN	STD	TEST for	TEST for	90/95 Tolerance	
	STUD1	STUD2	STUD3	STUD4	STUD5		VALUE	DEVIATION	Mean	Variance		
	0.1044	0.0988	0.0933	0.0905	0.0877				95% Confidence			
	0.0965	0.1063	0.0938	0.0938	0.0910				t*= 1.68	F*=1.98		
	0.1009	0.1066	0.0943	0.0971	0.0933	RUN-IN	0.0967	0.0052		= 0.505	0.1096	0.0839
	0.0983	0.1046	0.0935	0.0976	0.0907							
	0.1008	0.1018	0.0937	0.0965	0.0926	XXXXXXXXXXXXXXXXXXX						
	0.0794	0.0905	0.0877	0.0738	0.0766				DESIGN vs RUN-IN			
	0.0812	0.0993	0.0924	0.0868	0.0840				t	F		
	0.0924	0.1009	0.0962	0.0886	0.0867	DESIGN	0.0903	0.0074	0.2544	0.4996	0.1086	0.0721
	0.0969	0.1004	0.0907	0.0907	0.0892				No	Yes		
	0.0959	0.0981	0.0997	0.0909	0.0892	XXXXXXXXXXXXXXXXXXX						
	0.0766	0.0933	0.0683	0.0794	0.0794				DESIGN vs CYCLE 3			
	0.0854	0.0938	0.0910	0.0910	0.0826				t	F		
	0.0952	0.0943	0.0962	0.0943	0.0867	CYCLE3	0.0890	0.0072	0.0460	1.0531	0.1068	0.0712
	0.0914	0.0956	0.0907	0.0942	0.0864				No	No		
	0.0915	0.0997	0.0909	0.0904	0.0870							
Mean	0.0925	0.0989	0.0915	0.0904	0.0869							
Std Dev	0.0083	0.0048	0.0070	0.0065	0.0047							

DATA SET 166-170 Alloy Code AS

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST for Mean	TEST for Variance	90/95 Tolerance	
	0.0827	0.0752	0.0559	0.0660	0.1127				95% Confidence			
	0.0892	0.0736	0.0750	0.0712	0.1286				t*= 1.701	F*=2.49		
	0.1130	0.0831	0.1093	0.0926	0.1339	RUN-IN	0.0908	0.0235			0.1546	0.0270
	ERR	ERR	ERR	ERR	ERR							
	ERR	ERR	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX						
	0.0715	0.0752	0.0550	0.0715	0.0921				DESIGN vs RUN-IN			
	0.0750	0.0717	0.0622	0.0712	0.1004				t	F		
	0.0936	0.0763	0.0831	0.0923	0.1151	DESIGN	0.0804	0.0157	0.1327	2.2575	0.1229	0.0380
	ERR	ERR	ERR	ERR	ERR				No	No		
	ERR	ERR	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX						
	0.0651	0.0734	0.0541	0.0762	0.0846				DESIGN vs CYCLE 3			
	0.0693	0.0755	0.0622	0.0726	0.0826				t	F		
	0.0864	0.0800	0.0854	0.0847	0.1023	CYCLE3	0.0770	0.0118	0.0633	1.7731	0.1089	0.0451
	ERR	ERR	ERR	ERR	ERR				No	No		
	ERR	ERR	ERR	ERR	ERR							
Mean	0.0829	0.0760	0.0714	0.0776	0.1058							
Std Dev	0.0149	0.0035	0.0186	0.0098	0.0183							

DATA SET 171 Only 1 Stud   Alloy Code IMC2

	STUD1	STUD2	STUD3	STUD4	STUD5	
	0.1276	0.0000	0.0000	0.0000	0.0000	
	0.0962	0.0000	0.0000	0.0000	0.0000	
	0.0909	0.0000	0.0000	0.0000	0.0000	RUN-IN
	0.0948	0.0000	0.0000	0.0000	0.0000	
	0.1013	0.0000	0.0000	0.0000	0.0000	XXXXXXXX
	0.1082	0.0000	0.0000	0.0000	0.0000	
	0.0962	0.0000	0.0000	0.0000	0.0000	
	0.0990	0.0000	0.0000	0.0000	0.0000	DESIGN
	0.1009	0.0000	0.0000	0.0000	0.0000	
	0.1053	0.0000	0.0000	0.0000	0.0000	XXXXXXXX
	0.0986	0.0000	0.0000	0.0000	0.0000	
	0.0914	0.0000	0.0000	0.0000	0.0000	
	0.0941	0.0000	0.0000	0.0000	0.0000	CYCLE3
	0.1058	0.0000	0.0000	0.0000	0.0000	
	0.1082	0.0000	0.0000	0.0000	0.0000	
Mean	0.1012	0.0000	0.0000	0.0000	0.0000	
Std Dev	0.0092	0.0000	0.0000	0.0000	0.0000	

DATA SET 176 Only 1 Stud Alloy Code IMC3

	STUD1	STUD2	STUD3	STUD4	STUD5	
	0.1179	ERR	ERR	ERR	ERR	
	0.1035	ERR	ERR	ERR	ERR	
	0.1038	ERR	ERR	ERR	ERR	RUN-IN
	0.1070	ERR	ERR	ERR	ERR	
	0.1122	ERR	ERR	ERR	ERR	XXXXXXXX
	0.1179	ERR	ERR	ERR	ERR	
	0.1083	ERR	ERR	ERR	ERR	
	0.1022	ERR	ERR	ERR	ERR	DESIGN
	0.0997	ERR	ERR	ERR	ERR	
	0.1033	ERR	ERR	ERR	ERR	XXXXXXXX
	0.1082	ERR	ERR	ERR	ERR	
	0.1011	ERR	ERR	ERR	ERR	
	0.1006	ERR	ERR	ERR	ERR	CYCLE3
	0.0997	ERR	ERR	ERR	ERR	
	0.1023	ERR	ERR	ERR	ERR	
Mean	0.1059	ERR	ERR	ERR	ERR	
Std Dev	0.0061	ERR	ERR	ERR	ERR	

DATA SET 181 Only 1 Stud   Alloy Code IMA

	STUD1	STUD2	STUD3	STUD4	STUD5	
	0.0784	0.0000	0.0000	0.0000	0.0000	
	0.0824	0.0000	0.0000	0.0000	0.0000	
	0.0999	0.0000	0.0000	0.0000	0.0000	RUN-IN
	0.1117	0.0000	0.0000	0.0000	0.0000	
	ERR	0.0000	0.0000	0.0000	0.0000	XXXXXXXX
	0.0784	0.0000	0.0000	0.0000	0.0000	
	0.0847	0.0000	0.0000	0.0000	0.0000	
	0.0985	0.0000	0.0000	0.0000	0.0000	DESIGN
	0.1081	0.0000	0.0000	0.0000	0.0000	
	ERR	0.0000	0.0000	0.0000	0.0000	XXXXXXXX
	0.0923	0.0000	0.0000	0.0000	0.0000	
	0.0985	0.0000	0.0000	0.0000	0.0000	
	0.1079	0.0000	0.0000	0.0000	0.0000	CYCLE3
	0.1117	0.0000	0.0000	0.0000	0.0000	
	0.1114	0.0000	0.0000	0.0000	0.0000	
Mean	0.0972	0.0000	0.0000	0.0000	0.0000	
Std Dev	0.0128	0.0000	0.0000	0.0000	0.0000	

DATA SET 186 Alloy Code IMB

	STUD1	STUD2	STUD3	STUD4	STUD5	
	0.1009	ERR	ERR	ERR	ERR	
	0.1102	ERR	ERR	ERR	ERR	
	0.1286	ERR	ERR	ERR	ERR	RUN-IN
	0.1280	ERR	ERR	ERR	ERR	
	ERR	ERR	ERR	ERR	ERR	XXXXXXXXXXXX
	0.1009	ERR	ERR	ERR	ERR	
	0.1063	ERR	ERR	ERR	ERR	
	0.1192	ERR	ERR	ERR	ERR	DESIGN
	0.1207	ERR	ERR	ERR	ERR	
	ERR	ERR	ERR	ERR	ERR	XXXXXXXXXXXX
	0.0782	ERR	ERR	ERR	ERR	
	0.0964	ERR	ERR	ERR	ERR	
	0.1089	ERR	ERR	ERR	ERR	CYCLE3
	0.1191	ERR	ERR	ERR	ERR	
	ERR	ERR	ERR	ERR	ERR	
Mean	0.1098	ERR	ERR	ERR	ERR	
Std Dev	0.0145	ERR	ERR	ERR	ERR	

DATA SET 191-195 Alloy Code MK

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST for Mean	TEST for Variance	90/95 Tolerance	
	0.1348	0.1186	0.1121	0.1380	0.1348				95% Confidence			
	0.1256	0.1191	0.1093	0.1288	0.1272				t*= 1.68	F*=1.98		
	0.1231	0.1253	0.1088	0.1253	0.1198	RUN-IN	0.1205	0.0087		0.505	0.1420	0.0990
	0.1169	0.1210	0.1047	0.1202	0.1234							
	0.1147	0.1172	0.1056	0.1160	0.1229	XXXXXXXXXXXXXXXXXXX						
	0.1186	0.1510	0.1154	0.1283	0.1251				DESIGN vs RUN-IN			
	0.1256	0.1386	0.1142	0.1288	0.1142				t	F		
	0.1242	0.1275	0.1121	0.1297	0.1132	DESIGN	0.1219	0.0098	-0.0359	0.7783	0.1462	0.0975
	0.1161	0.1314	0.1097	0.1242	0.1153				No	No		
	0.1114	0.1272	0.1101	0.1191	0.1153	XXXXXXXXXXXXXXXXXXX						
	0.1121	0.1380	0.1154	0.1121	0.1186				DESIGN vs CYCLE 3			
	0.1223	0.1272	0.1175	0.1191	0.1240				t	F		
	0.1187	0.1242	0.1198	0.1286	0.1286	CYCLE3	0.1211	0.0067	0.0242	2.1413	0.1377	0.1044
	0.1113	0.1250	0.1169	0.1258	0.1290				No	Yes		
	0.1095	0.1185	0.1166	0.1210	0.1266							
Mean	0.1190	0.1273	0.1126	0.1243	0.1225							
Std Dev	0.0070	0.0093	0.0045	0.0065	0.0063							

	DATA SET 196-200		Alloy Code I				MEAN	STD	TEST for	TEST for	90/95 Tolerance	
	STUD1	STUD2	STUD3	STUD4	STUD5		VALUE	DEVIATION	Mean	Variance		
	0.1131	0.1034	0.1131	0.1082	0.0986				95% Confidence			
	0.0914	0.0914	0.1035	0.0889	0.0865				t*= 1.68	F*=1.98		
	0.0974	0.0909	0.0990	0.0941	0.0860	RUN-IN	0.0967	0.0079		= 0.505	0.1161	0.0773
	0.0972	0.0911	0.1009	0.0862	0.0924							
	0.0993	0.0924	0.1063	0.0904	0.0964	XXXXXXXXXXXXXXXXXXXX						
	0.0937	0.0889	0.1034	0.1034	0.1034				DESIGN vs RUN-IN			
	0.0744	0.0792	0.0986	0.0865	0.0914				t	F		
	0.0941	0.0812	0.0957	0.0844	0.0925	DESIGN	0.0926	0.0085	0.1263	0.8507	0.1136	0.0715
	0.0850	0.0875	0.0985	0.0887	0.0985				No	No		
	0.0914	0.0914	0.1112	0.0914	0.1003	XXXXXXXXXXXXXXXXXXXX						
	0.0840	0.0840	0.0937	0.1034	0.0986				DESIGN vs CYCLE 3			
	0.0744	0.0792	0.0914	0.0962	0.0914				t	F		
	0.0730	0.0812	0.1038	0.0957	0.0909	CYCLE3	0.0915	0.0100	0.0292	0.7304	0.1162	0.0669
	0.0801	0.0875	0.1058	0.0936	0.0960				No	No		
	0.0864	0.0874	0.1132	0.0964	0.1003							
Mean	0.0890	0.0878	0.1025	0.0938	0.0949							
Std Dev	0.0110	0.0063	0.0067	0.0069	0.0052							

DATA SET 201-205 Alloy Code ICR

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST for Mean	TEST for Variance	90/95 Tolerance	
	0.1469	0.1131	0.1034	0.1082	0.1518				95% Confidence			
	0.1398	0.1011	0.0914	0.1011	0.1277				t*= 1.68	F*=1.98		
	0.1362	0.1022	0.0925	0.1006	0.1265	RUN-IN	0.1155	0.0183			0.1608	0.0701
	0.1363	0.1021	0.0985	0.0997	0.1241							
	0.1396	0.1082	0.1053	0.1013	0.1290	XXXXXXXXXXXXXXXXXXXX						
	0.1228	0.1324	0.1034	0.1131	0.1131				DESIGN vs RUN-IN			
	0.1107	0.1204	0.0914	0.0938	0.1035				t	F		
	0.1071	0.1152	0.0925	0.0957	0.1006	DESIGN	0.1083	0.0114	0.1197	2.5769	0.1366	0.0801
	0.1180	0.1131	0.0936	0.0997	0.1034				No	Yes		
	0.1300	0.1172	0.1013	0.1033	0.1132	XXXXXXXXXXXXXXXXXXXX						
	0.1034	0.1324	0.1082	0.1131	0.1179				DESIGN vs CYCLE 3			
	0.1059	0.1083	0.0986	0.0986	0.1035				t	F		
	0.1119	0.1119	0.0990	0.1006	0.1038	CYCLE3	0.1087	0.0085	-0.0096	1.8209	0.1297	0.0878
	0.1119	0.1131	0.0985	0.1046	0.1046				No	No		
	0.1241	0.1211	0.1043	0.1082	0.1102							
Mean	0.1230	0.1141	0.0988	0.1028	0.1155							
Std Dev	0.0143	0.0096	0.0055	0.0057	0.0141							

	DATA SET 206-210		Alloy Code A				MEAN	STD	TEST for	TEST for	90/95 Tolerance	
	STUD1	STUD2	STUD3	STUD4	STUD5		VALUE	DEVIATION	Mean	Variance		
	0.1044	0.0988	0.1016	0.0988	0.0933				95% Confidence			
	0.1077	0.1063	0.1063	0.1077	0.1021				t*= 1.68	F*=1.98		
	0.1066	0.1085	0.1123	0.1076	0.1057	RUN-IN	0.1051	0.0044		= 0.505	0.1161	0.0942
	0.1066	0.1073	0.1115	0.1046	0.1046							
	0.1034	0.1050	0.1136	0.1018	0.1024	XXXXXXXXXXXXXXXXXXXX						
	0.0933	0.0933	0.0988	0.0877	0.0933				DESIGN vs RUN-IN			
	0.1105	0.1035	0.1091	0.0965	0.1035				t	F		
	0.1094	0.1066	0.1218	0.1057	0.1066	DESIGN	0.1055	0.0081	-0.0165	0.2976	0.1256	0.0855
	0.1115	0.1136	0.1157	0.1039	0.1108				No	Yes		
	0.1077	0.1120	0.1125	0.1018	0.1098	XXXXXXXXXXXXXXXXXXXX						
	0.0905	0.0905	0.1016	0.0766	0.1016				DESIGN vs CYCLE 3			
	0.1105	0.0952	0.1119	0.0965	0.1063				t	F		
	0.1142	0.1047	0.1161	0.0962	0.1057	CYCLE3	0.1045	0.0098	0.0290	0.6837	0.1288	0.0802
	0.1122	0.1080	0.1163	0.0983	0.1108				No	No		
	0.1120	0.1104	0.1146	0.0992	0.1130							
Mean	0.1067	0.1042	0.1109	0.0989	0.1046							
Std Dev	0.0067	0.0069	0.0064	0.0081	0.0058							

	DATA SET 211-215		Alloy Code T				MEAN	STD	TEST for	TEST for	90/95 Tolerance	
	STUD1	STUD2	STUD3	STUD4	STUD5		VALUE	DEVIATION	Mean	Variance		
	0.1137	0.1282	0.1258	0.1258	0.1088				95% Confidence			
	0.1173	0.1320	0.1234	0.1295	0.1246				t*= 1.68	F*=1.98		
	0.1176	0.1384	0.1312	0.1384	0.1264	RUN-IN	0.1302	0.0117		= 0.505	0.1591	0.1012
	0.1191	0.1337	0.1418	0.1452	0.1244							
	0.1309	0.1358	0.1577	0.1553	0.1290	XXXXXXXXXXXXXXXXXXX						
	0.1112	0.1331	0.1307	0.1282	0.1064				DESIGN vs RUN-IN			
	0.1148	0.1283	0.1295	0.1418	0.1050				t	F		
	0.1240	0.1288	0.1449	0.1481	0.1128	DESIGN	0.1330	0.0173	-0.0489	0.4579	0.1757	0.0903
	0.1355	0.1314	0.1537	0.1543	0.1156				No	Yes		
	0.1494	0.1397	0.1676	0.1657	0.1244	XXXXXXXXXXXXXXXXXXX						
	0.1064	0.1161	0.1331	0.1307	0.0991				DESIGN vs CYCLE 3			
	0.1160	0.1160	0.1369	0.1332	0.1050				t	F		
	0.1368	0.1232	0.1441	0.1409	0.1128	CYCLE3	0.1324	0.0188	0.0078	0.8470	0.1789	0.0860
	0.1441	0.1267	0.1532	0.1498	0.1203				No	No		
	0.1582	0.1397	0.1726	0.1642	0.1319							
Mean	0.1263	0.1301	0.1431	0.1434	0.1164							
Std Dev	0.0154	0.0074	0.0152	0.0128	0.0102							

DATA SET 216-220 Alloy Code AZ

	STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST for Mean	TEST for Variance	90/95 Tolerance	
	0.1406	0.1279	0.1058	0.1153	0.1058				95% Confidence			
	0.1237	0.1253	0.0983	0.1174	0.0951				t*= 1.68	F*=1.98		
	0.1113	0.1210	0.1059	0.1178	0.1006	RUN-IN	0.1113	0.0106			0.1376	0.0850
	0.1052	0.1130	0.1044	0.1170	0.1044							
	0.1025	0.1070	0.1013	0.1121	0.1044	XXXXXXXXXXXXXXXXXXX						
	0.1090	0.0995	0.0995	0.1153	0.0836				DESIGN vs RUN-IN			
	0.1094	0.1015	0.0967	0.1031	0.0951				t	F		
	0.1092	0.1092	0.0984	0.1102	0.1016	DESIGN	0.1035	0.0064	0.2294	2.7562	0.1194	0.0876
	0.1068	0.1052	0.0995	0.1060	0.1027				No	Yes		
	0.1064	0.1057	0.0994	0.1076	0.1070	XXXXXXXXXXXXXXXXXXX						
	0.1058	0.1026	0.0868	0.1090	0.0900				DESIGN vs CYCLE 3			
	0.1094	0.0967	0.0920	0.1015	0.0951				t	F		
	0.0995	0.0995	0.0984	0.1059	0.1016	CYCLE3	0.1003	0.0057	0.1321	1.2686	0.1144	0.0862
	0.0970	0.0978	0.0978	0.1044	0.1052				No	No		
	0.1025	0.1013	0.0962	0.1057	0.1057							
Mean	0.1092	0.1075	0.0987	0.1099	0.0999							
Std Dev	0.0106	0.0100	0.0049	0.0056	0.0067							

Appendix D

ANTI-SEIZING TEST RESULTS

TABLE 1 - ANTI-SEIZING TEST RESULTS

TEST MATERIAL - TYPE 304 CRES																				
LUBRICANT	TORQUE (ft-lbs)															BREAKAWAY TORQUE (ft-lbs) AFTER X WEEKS OF EXPOSURE AT 650°F				
	INITIAL RUN IN					INITIAL BREAKAWAY					INSTALLATION					1	3	6	10 A	10 B
	1	3	6	10A	10B	1	3	6	10A	10B	1	3	6	10A	10B					
N5000	123	123	125	123	123	73	75	75	72	73	125	123	123	123	122	118	478	505	610	600
N1000	126	125	125	125	125	83	80	80	80	82	125	125	125	124	125	139	285	436	424	352
Neolube No. 650	124	125	125	125	125	67	79	70	75	75	127	125	124	126	125	148	299	497	480	489
NIKAL	125	125	125	125	125	89	86	89	89	86	125	126	125	125	125	159	540	479	468	464
N2000	125	124	125	125	125	78	77	81	80	80	125	125	124	127	125	128	263	343	360	347
Never Seez	125	124	126	125	125	79	81	81	80	80	125	124	127	125	126	137	508	590	625	630
NM-91	125	125	125	125	125	85	90	85	90	89	126	125	126	125	124	147	297	491	453	289
Molykote P37	125	125	125	125	125	81	90	82	86	86	125	125	125	125	125	119	199	319	268	250
MDSI	125	125	125	125	124	69	70	70	66	70	126	125	125	125	124	94	110 +	180 +	148 +	132
RLGMO	126	125	125	125	126	80	79	80	81	80	125	125	125	125	125	85	133	179	200	183

+ The needle on the torque wrench jumped indicating possible galling

TABLE 2 - ANTI-SEIZING TEST RESULTS

TEST MATERIAL - K-MONEL/MONEL																				
LUBRICANT	TORQUE (ft-lbs)															BREAKAWAY TORQUE (ft-lbs) AFTER X WEEKS OF EXPOSURE AT 650°F				
	INITIAL RUN IN					INITIAL BREAKAWAY					INSTALLATION									
	1	3	6	10A	10B	1	3	6	10A	10B	1	3	6	10A	10B	1	3	6	10 A	10 B
N5000	175	175	175	175	175	95	100	95	95	97	177	175	175	175	175	120	481	303	469	487
N1000	175	175	175	175	176	102	105	101	100	102	180	175	175	176	177	135	366	445	480	479
Neolube No. 650	175	175	176	175	175	86	90	89	84	86	175	175	174	175	175	109	354	345	320	409
NIKAL	176	175	175	175	175	131	129	127	130	127	178	175	175	176	178	216	542	480	543	539
N2000	176	175	176	177	175	101	104	99	90	97	174	176	175	175	174	118	397	500	491	494
Never Seez	175	174	175	174	175	100	95	99	99	98	175	175	175	176	177	147	528	520	650	568
NM-91	175	175	177	176	175	127	132	130	140	136	177	175	175	175	175	243	386	400	387	304
Molykote P37	174	175	176	175	174	116	116	119	121	117	175	176	174	175	175	153	184	189	236	211
MDSI	175	176	175	175	175	91	87	87	90	86	174	175	175	175	175	155 +	200 +	185	200 +	212
RLGMO	176	175	176	175	176	105	104	104	106	106	175	176	176	177	175	131	173	210	242	239

+ The needle on the torque wrench jumped indicating possible galling

TABLE 3 - ANTI-SEIZING TEST RESULTS

TEST MATERIAL - ALLOY STEEL																				
LUBRICANT	TORQUE (ft-lbs)															BREAKAWAY TORQUE (ft-lbs) AFTER X WEEKS OF EXPOSURE AT 650°F				
	INITIAL RUN IN					INITIAL BREAKAWAY					INSTALLATION					1	3	6	10 A	10 B
	1	3	6	10A	10B	1	3	6	10A	10B	1	3	6	10A	10B					
N5000	230	230	230	230	231	155	135	150	150	160	230	230	230	230	232	275	321	284	283	284
N1000	230	230	230	230	230	150	151	150	151	155	231	229	230	230	232	227	338	245	255	280
Neolube No.650	230	228	230	231	230	112	100	134	109	112	229	230	230	230	229	270	309	222	222	248
NIKAL	237	230	234	231	230	194	175	186	170	170	236	230	229	230	230	515	482	450	412	404
N2000	228	231	230	231	230	138	148	145	145	148	232	230	234	230	229	240	281	238	282	230
Never Seez	231	232	229	234	230	150	152	141	154	157	232	230	230	230	231	261	401	390	323	346
NM-91	230	230	230	230	231	171	170	165	169	180	231	231	229	230	230	299	422	309	350	311
Molykote P37	228	231	229	230	232	151	160	157	156	157	228	230	230	231	230	202	244	250	263	249
MDSI	231	230	229	230	231	135	141	121	131	137	229	229	230	230	230	161	138	220 +	150 +	138
RLGMO	230	232	232	234	230	156	156	146	152	151	230	229	234	230	230	183	220 +	280 +	210 +	256

+ The needle on the torque wrench jumped indicating possible galling

Appendix E

ANTI-GALLING TEST RESULTS

TABLE 1 - ANTI-GALLING TEST RESULTS

TEST MATERIAL: K-Monel/Monel TEST LOADS: CYCLES 1-8 22300 lbs. CYCLES 9-12 33500 lbs

LUBRICANT/ SPECIMEN	INSTALLATION TORQUE VALUE PER TORQUING CYCLE (ft-lb)												NUMBER OF TORQUINGS TO GALLING	OTHER OBSERVATIONS
	1	2	3	4	5	6	7	8	9	10	11	12		
No Lubricant	295	*											2	Seized
N5000 -1	193	219	228	220	251	211	205	228	340	309	308	316	12	
-2	229	185	229	219	225	205	221	211	350	325	324	332	12	
N1000 -1	190	205	209	212	206	202	210	203	310	307	352	323	12	
-2	240	218	245	221	239	222	220	222	380	348	352	338	12	
Neolube -1	198	170	160	149	148	141	135	134	260	215	212	212	12	Coats uneven
No. 650 -2	132	130	118	115	114	110	110	120	189	213	222	231	12	
NIKAL -1	320*	444*	416*	342*									1	Discontinued
-2	303	375*	410*	355*									2	Discontinued
N2000 -1	233	195	178	175	216	219	193	203	360	352	338	301	12	
-2	224	215	220	222	229	233	232	238	313	311	326	330	12	
Never -1	229	197	199	200	185	202	200	221	469	403	395	380	12	
Seez -2	220	230	203	217	165	210	229	212	304	419	351	354	12	
NM-91 -1	274	274	256	243	250	255	242	232	458	409	400	364	No Galling	
-2	320	284	284	254	272	260	245	249	439	369	330	312	No Galling	
Molykote -1	211	209	210	210	209	211	221	210	380	403	360	350	12	
P37 -2	221	225	231	222	238	231	220	220	372	389	358	360	12	
MDSI -1	274	246	305	304	186	245	282	281	277	402	450	483	12	
-2	221	192	239	276	223	235	251	315	332	382	462	494	12	
RLGMO -1	168	158	148	142	139	135	152	136	244	221	243	262	12	
-2	186	132	121	130	136	132	132	134	203	253	250	250	12	

* The needle on the torque wrench jumped accompanied by audible clicking indicating possible galling.

TABLE 2 - ANTI-GALLING TEST RESULTS

TEST MATERIAL:K-Monel/Monel TEST LOADS: CYCLES 1-8 22300 lbs CYCLES 9-12 33500 lbs													
LUBRICANT/ SPECIMEN	BREAKAWAY TORQUE VALUE PER TORQUING CYCLE (ft-lb)												OTHER OBSERVATIONS
	1	2	3	4	5	6	7	8	9	10	11	12	
No Lubricant	•	*											Seized
N5000 -1	129	151	171	158	159	158	144	165	240	215	211	228	
-2	142	139	134	149	135	140	138	140	220	220	212	233	
N1000 -1	138	149	150	151	149	149	150	149	210	219	231	221	
-2	162	150	162	163	160	155	160	151	245	235	249	236	
Neolube No. 650 -1	130	123	110	101	93	89	82	81	144	147	135	129	
-2	82	76	72	70	68	60	63	77	118	140	130	135	
NIKAL -1	247*	360*	380*	320*									Discontinued
-2	205	279	350*	305*									Discontinued
N2000 -1	129	105	100	105	128	132	130	120	240	226	211	194	
-2	138	128	136	135	142	149	141	145	199	182	195	200	
Never Seez -1	165	140	149	142	134	145	135	151	325	294	294	279	
-2	161	169	138	150	112	140	163	157	218	265	249	253	
NM-91 -1	215	215	192	180	189	197	175	171	315	291	260	268	
-2	239	220	205	189	211	199	185	185	340	265	233	225	
Molykote P37 -1	140	140	131	133	142	139	139	137	259	238	228	228	
-2	170	166	161	160	168	161	154	151	260	269	250	237	
MDSI -1	182	159	168	178	135	185	189	219	185	255	296	333	
-2	161	142	161	169	163	170	184	215	223	245	315	335	
RLGMO -1	120	110	100	95	90	90	95	100	160	139	163	162	
-2	125	90	84	94	90	90	85	99	138	143	136	160	

* The needle on the torque wrench jumped accompanied by audible clicking indicating possible galling.

TABLE 3 - ANTI-GALLING TEST RESULTS

TEST MATERIAL: Type 304 CRES   TEST LOADS: CYCLES 1-8 15600 lbs   CYCLES 9-12 23400 lbs

LUBRICANT/ SPECIMEN	INSTALLATION TORQUE VALUE PER TORQUING CYCLE (ft-lb)												NUMBER OF TORQUINGS TO GALLING	OTHER OBSERVATIONS
	1	2	3	4	5	6	7	8	9	10	11	12		
No Lubricant	285	342	500	338									2	
N5000 -1	215	204	192	179	188	180	170	165	370	285	261	255	12	
-2	187	185	210	182	180	170	170	163	290	255	251	249	12	
N1000 -1	152	169	178	178	159	153	149	151	275	236	224	222	12	
-2	179	155	158	160	160	157	155	156	263	262	240	266	12	
Neolube No. 650 -1	159	153	125	125	150	131	131	110	313	220	179	180	12	
-2	200	209	171	159	148	149	171	131	300*	249	250	219	12	
NIKAL -1	262	310*	315*	308*	345*	295*	270*						2	Discontinued
-2	303	298*	300*	289*	284*	294*							2	Discontinued
N2000 -1	197	169	192	169	211	201	179	206	322	275	291	245	No Galling	
-2	232	182	182	172	202	194	195	191	339	269	253	268	No Galling	
Never Seez -1	210	175	168	161	191	165	160	155	311	250	243	249	12	Gouges
-2	191	192	174	181	217	208	196	188	410*	220	270	272	12	
NM-91 -1	95	186	193	190	209	189	189	182	342	276	259	252	12	
-2	228	190	190	183	218	218	191	180	313	269	348	346	12	
Molykote P37 -1	206	195	180	185	170	171	165	170	380*	280	265	260	12	
-2	167	154	150	141	162	161	167	165	285	275	263	285	12	
MDSI -1	219	270	255	222	178	178	182	190	319	418	460*	345*	8	
-2	175	160	178	180	220	232	270	279	435*	470*	460*	420*	8	
RLGMO -1	163	170	152	128	163	126	132	125	220	219	172	156	No Galling	
-2	139	122	121	122	123	118	117	112	211	175	180	170	No Galling	

* The needle on the torque wrench jumped accompanied by audible clicking indicating possible galling.

TABLE 4 - ANTI-GALLING TEST RESULTS

TEST MATERIAL: Type 304 CRES TEST LOADS: CYCLES 1-8 15600 lbs CYCLES 9-12 23400 lbs													
LUBRICANT/ SPECIMEN	BREAKAWAY TORQUE VALUE PER TORQUING CYCLE (ft-lb)												OTHER OBSERVATIONS
	1	2	3	4	5	6	7	8	9	10	11	12	
No Lubricant	400	245	265	245									
N5000 -1	140	155	150	135	135	130	120	120	275	220	190	180	
-2	125	131	140	125	131	129	123	121	221	196	195	185	
N1000 -1	105	110	103	110	114	115	111	109	164	159	154	156	
-2	121	109	100	98	106	112	112	102	178	181	167	166	
Neolube -1	116	115	95	89	109	90	86	78	204	149	118	120	
No. 650 -2	*	*	130	123	100	102	120	99	300*	190	190	162	
NIKAL -1	170	220*	238*	259*	230*	236*	233*						Discontinued
-2	209	265	262*	250*	211*	231*							Discontinued
N2000 -1	135	118	126	120	128	132	119	121	211	201	199	188	
-2	148	120	116	115	151	139	139	140	223	199	186	193	
Never -1	159	135	123	120	140	129	122	119	249	199	184	186	
Seez -2	142	155	131	134	180	169	162	148	970*	200	205	208	
NM-91 -1	161	151	142	150	160	149	139	131	265	214	200	179	
-2	160	142	142	139	180	159	142	141	240	210	185	184	
Molykote -1	161*	160	142	150	140	130	126	132	350*	211	200	190	
P37 -2	119	110	110	111	110	109	105	103	199	199	197	202	
MDSI -1	162	200	160	139	135	111	100	99	219	275	298*	330*	
-2	132	112	121	140	171	205	202	203	264	271	250*	290*	
RLGMO -1	118	123	118	100	128	97	98	92	169	160	128	112	
-2	90	86	86	85	18	80	79	76	149	121	120	119	

* The needle on the torque wrench jumped accompanied by audible clicking indicating possible galling.

TABLE 5 - ANTI-GALLING TEST RESULTS

TEST MATERIAL: Alloy Steel TEST LOADS: CYCLES 1-8 23400 lbs CYCLES 9-12 35000 lbs														
LUBRICANT/ SPECIMEN	INSTALLATION TORQUE VALUE PER TORQUING CYCLE (ft-lb)												NUMBER OF TORQUINGS TO GALLING	OTHER OBSERVATIONS
	1	2	3	4	5	6	7	8	9	10	11	12		
No Lubricant	*												1	Seized
N5000 -1	250	228	221	216	221	213	210	213	333	365	380	389	12	
-2	206	215	218	214	200	204	229	242	338	363	400	406	12	
N1000 -1	246	244	245	257	225	249	248	262	379	369	400	430	12	
-2	215	274	270	260	214	230	224	214	342	366	393	406	12	
Neolube No. 650 -1	159	148	149	148	136	130	136	136	214	230	260	251	12	Deep Gouges
-2	173	132	132	130	135	138	134	138	232	230	260	272	12	Deep Gouges
NIKAL -1	298	300	301	290	318	323	322	334	530	578	545	548	12	
-2	278	259	289	295	311	329	335	333	463	468	472	485	12	
N2000 -1	209	252	233	228	232	244	238	243	319	331	310	298	12	
-2	235	224	235	220	247	220	236	254	368	388	363	393	12	
Never Seez -1	212	202	207	210	200	206	212	222	450	389	386	396	12	
-2	200	193	399	207	185	178	183	186	279	269	305	311	12	
NM-91 -1	227	223	208	201	230	219	208	205	388	391	357	351	No Galling	
-2	230	230	225	220	258	277	258	236	411	397	414	403	No Galling	
Molykote P37 -1	202	199	199	199	214	233	202	202	398	353	349	349	No Galling	
-2	225	235	204	219	218	211	225	213	369	355	380	350	No Galling	
MDSI -1	292	328	340	369	264	343	384	417	372	421	545	600	12	
-2	212	233	250	253	272	350	423	425	546	529	555	600	12	
RLGMO -1	199	181	183	187	175	176	180	180	327	312	270	278	No Galling	
-2	200	189	189	180	173	172	169	170	328	304	292	277	12	

* The needle on the torque wrench jumped accompanied by audible clicking indicating possible galling.

TABLE 6 - ANTI-GALLING TEST RESULTS

TEST MATERIAL: Alloy Steel TEST LOADS: CYCLES 1-8 23400 lbs CYCLES 9-12 35000 lbs													
LUBRICANT/ SPECIMEN	BREAKAWAY TORQUE VALUE PER TORQUING CYCLE (ft-lb)												OTHER OBSERVATIONS
	1	2	3	4	5	6	7	8	9	10	11	12	
No Lubricant	*												Seized
N5000 -1	173	160	160	159	149	147	142	150	200	214	219	239	
-2	145	158	157	162	139	146	149	160	180	245	239	279	
N1000 -1	180	178	179	173	166	162	174	180	219	240	252	282	
-2	160	190	200	200	154	168	173	168	220	244	269	248	
Neolube No. 650 -1	110	98	92	88	80	72	80	80	122	138	142	142	
-2	99	78	73	71	88	91	88	82	120	129	148	161	
NIKAL -1	212	190	209	201	215	206	222	221	415	405	400	385	
-2	218	178	197	202	222	240	254	234	290	308	339	309	
N2000 -1	151	162	178	168	152	157	162	182	193	204	220	205	
-2	160	165	178	170	165	160	160	168	246	253	260	263	
Never Seez -1	150	148	150	155	140	151	156	167	321	261	289	271	
-2	140	141	140	150	124	122	131	134	191	182	181	188	
NM-91 -1	162	160	149	144	163	151	149	148	248	242	241	240	
-2	165	171	162	150	179	188	180	175	270	265	270	260	
Molykote P37 -1	139	136	135	142	155	141	148	145	237	218	215	212	
-2	149	151	142	148	154	150	140	141	242	230	234	230	
MDSI -1	192	198	210	200	160	160	212	232	254	300	385	458	
-2	161	171	180	189	202	245	281	295	365	410	405	430	
RLGMO -1	141	133	135	131	125	122	122	122	205	209	199	200	
-2	141	139	131	119	122	118	118	113	205	194	190	192	

* The needle on the torque wrench jumped accompanied by audible clicking indicating possible galling.