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

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ABSTRACT

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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 ± 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 $250^{\circ}\text{F} \pm 10^{\circ}\text{F}$ 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 $175^{\circ}\text{F} \pm 5^{\circ}\text{F}$ 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.

Test 4 - 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 $\pm$ 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 $\pm$ 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 RLGM0. 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.

Detrimental Material Evaluation

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.

Health and Environmental Evaluation

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.

Corrosion Testing Results

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

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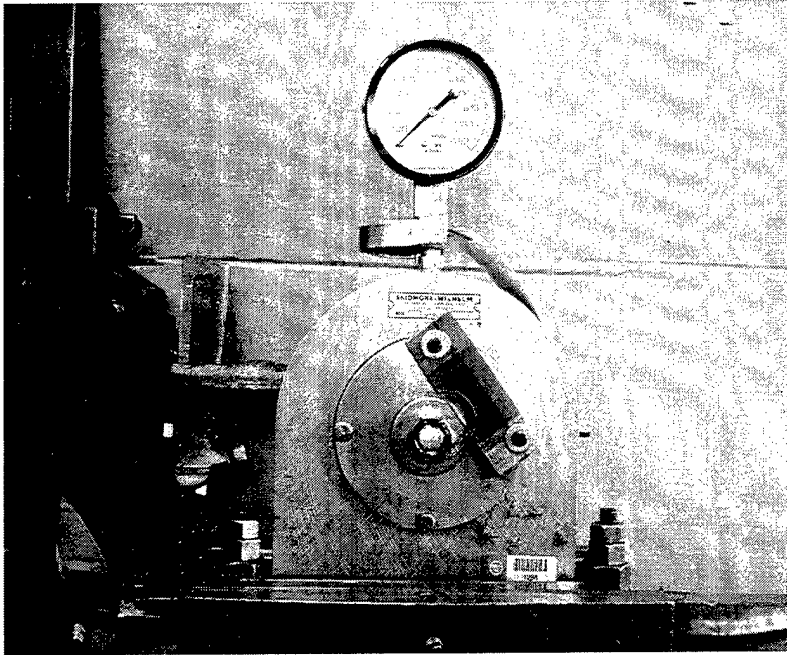


Figure 1. Skidmore-Wilhelm Torque Tension Unit, Model RL

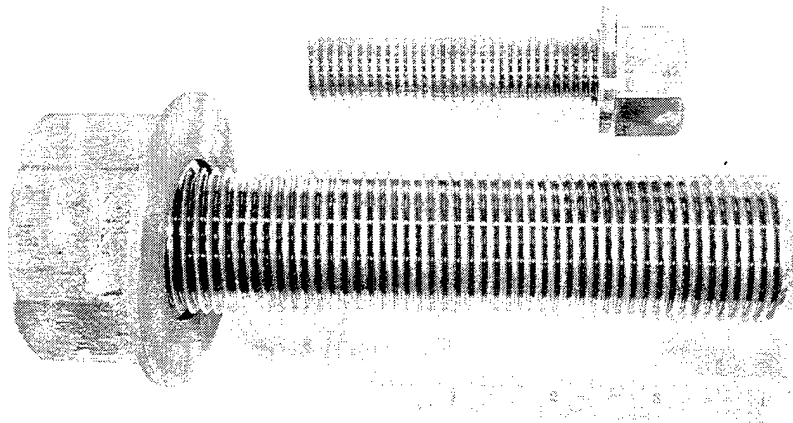


Figure 2. Typical Fastener Assemblies: 1.5-8UNC-2A Monel K-500 (Alloy Code MA) and 0.75-10UNC-3A Alloy 625 (Alloy Code IMC3)

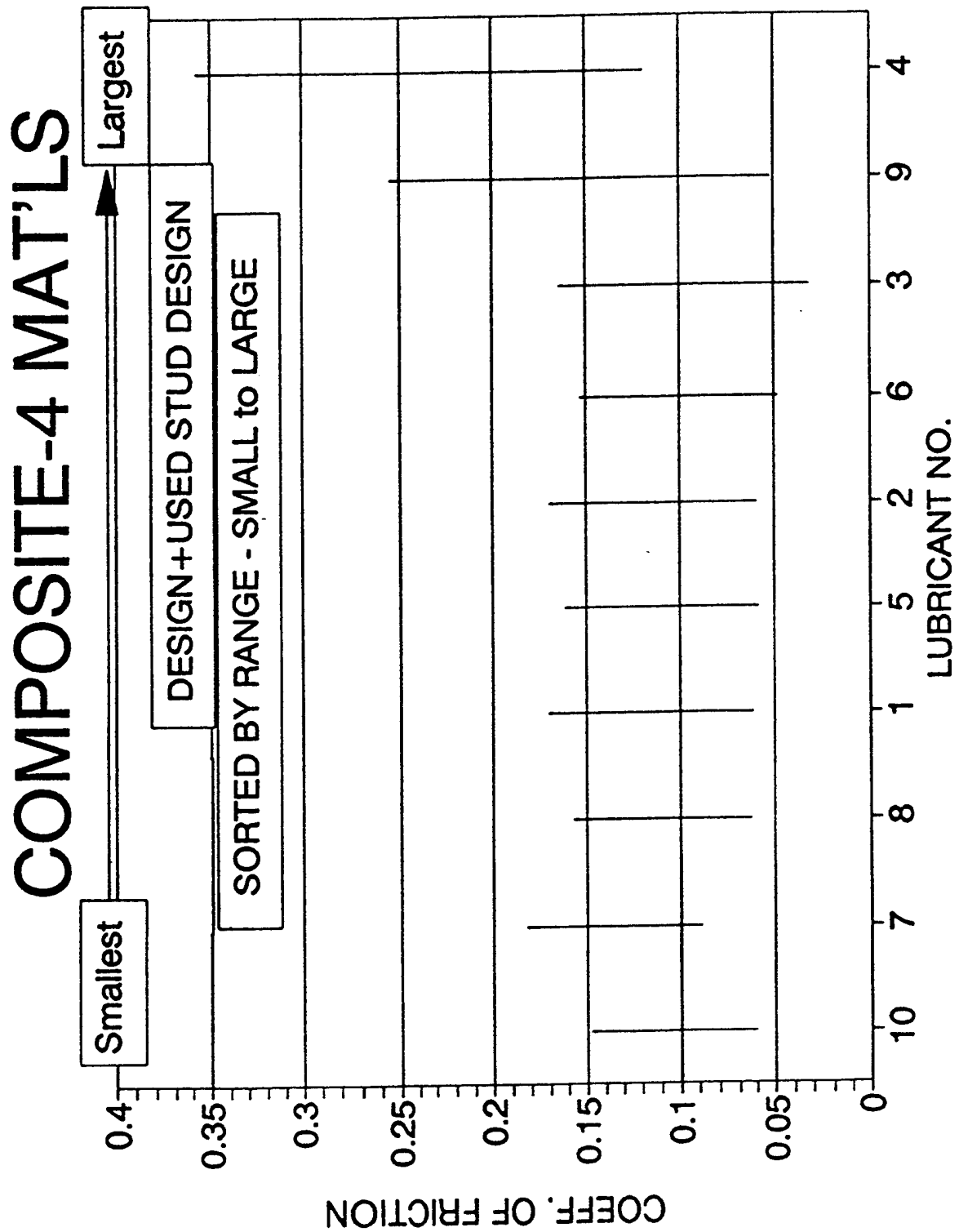


Figure 3. Coefficient of Friction Ranges of the Phase I Lubricants

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 = $\arctan \frac{1}{N E \pi}$

α_n = $\arctan (\tan \alpha \cos \lambda)$

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
Pittsburgh, PA 15235-5713

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				Stud-to Stud Change	Run-in vs Design	Design vs Used Stud Design Mean
	LOADING VALUES UP TO 2/3 Yield				Mean	Mean	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	0.016	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 Signif Diff. Y/N	Run-in vs Design Mean Signif Diff. Y/N*	Design vs Used Stud Design Mean Signif Diff. Y/N*
	Mean	Std Dev	Range	Normal Distr. 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	STD DEV	90/95 TOL		RANKED RANGE		4140 PHO		90/95 TOL		RANKED RANGE		HIGH		90/95 TOL		RANKED RANGE		RANGE/MEAN	
	INCONEL		LOW	HIGH	LOW	HIGH	MEAN	STD DEV	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH	LUBRICANT	
6	0.185	0.018	0.140468	0.229532	0.089064	0.481427	0.088	0.004	0.078104	0.097896	0.019792	0.019792	0.019792	0.019792	0.004	0.082946	0.101054	0.018108	8	0.224909
8	0.164	0.021	0.112046	0.215954	0.103908	0.833585	0.099	0.005	0.089104	0.108896	0.019792	0.019792	0.019792	0.019792	0.004	0.091946	0.110054	0.018108	1	0.199819
7	0.231	0.025	0.16915	0.29285	0.1237	0.535498	0.095	0.005	0.08263	0.10737	0.02474	0.02474	0.02474	0.02474	0.005	0.098928	0.123072	0.024144	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	0.02474	0.02474	0.02474	0.005	0.104928	0.129072	0.024144	6	0.277978
3	0.185	0.025	0.12315	0.24685	0.1237	0.688649	0.087	0.005	0.07463	0.09937	0.02474	0.02474	0.02474	0.02474	0.005	0.08591	0.11609	0.03018	5	0.284368
1	0.2	0.03	0.12578	0.27422	0.14844	0.7422	0.091	0.007	0.043692	0.078318	0.034636	0.034636	0.034636	0.034636	0.007	0.091682	0.126318	0.034636	3	0.567803
5	0.197	0.032	0.117832	0.276168	0.158336	0.803798	0.109	0.007	0.091682	0.126318	0.034636	0.034636	0.034636	0.034636	0.008	0.089208	0.108792	0.039584	7	0.317761
2	0.189	0.035	0.10241	0.27559	0.17318	0.916298	0.089	0.008	0.069208	0.108792	0.039584	0.039584	0.039584	0.039584	0.008	0.128208	0.167792	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	0.039584	0.039584	0.039584	0.008	0.061468	0.150532	0.089064	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	0.089064	0.089064	0.089064	0.018	0.095838	0.150162	0.054324	9	0.840226

90%/95% TOL										RANGE/MEAN									
90/95 TOL										LUBRICANT									
MAT'L>> K MONEL/MONEL	MEAN	STD DEV	90/95 TOL		RANKED RANGE		B7 ALLOY		90/95 TOL		RANKED RANGE		RANGE/MEAN						
LUBR.			LOW	HIGH	LOW	HIGH	MEAN	STD DEV	LOW	HIGH	LOW	HIGH	LOW	HIGH					
8	0.102	0.008	0.082208	0.121792	0.039584	0.388078	0.092	0.003	0.082946	0.101054	0.018108	0.018108	0.018108	0.018108					
9	0.087	0.009	0.064734	0.109266	0.044532	0.511862	0.101	0.003	0.091946	0.110054	0.018108	0.018108	0.018108	0.018108					
10	0.088	0.009	0.085734	0.110268	0.044532	0.508045	0.111	0.004	0.098928	0.123072	0.024144	0.024144	0.024144	0.024144					
2	0.108	0.009	0.085734	0.130268	0.044532	0.412333	0.117	0.004	0.104928	0.129072	0.024144	0.024144	0.024144	0.024144					
5	0.103	0.01	0.07826	0.12774	0.04948	0.480388	0.101	0.005	0.08591	0.11609	0.03018	0.03018	0.03018	0.03018					
4	0.15	0.01	0.12526	0.17474	0.04948	0.329867	0.152	0.006	0.133892	0.170108	0.036216	0.036216	0.036216	0.036216					
7	0.154	0.011	0.126786	0.181214	0.054428	0.353429	0.097	0.007	0.075874	0.118126	0.042252	0.042252	0.042252	0.042252					
3	0.074	0.012	0.044312	0.103688	0.059376	0.802378	0.071	0.008	0.046856	0.095144	0.048288	0.048288	0.048288	0.048288					
1	0.144	0.013	0.111838	0.176162	0.064324	0.446694	0.125	0.009	0.097838	0.152162	0.054324	0.054324	0.054324	0.054324					
6	0.097	0.015	0.05989	0.13411	0.07422	0.765155	0.123	0.009	0.095838	0.150162	0.054324	0.054324	0.054324	0.054324					

Table X. Initial Run-in Values; Tolerance Ranges

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

LUBRICANT	SORT ON RANGE		
	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													
LUBR.	DESIGN VALUES												
	MEAN	STD DEV	90/95 TOL		RANKED RANGE		4140 PHO		90/95 TOL		RANKED RANGE		RANGE/ MEAN
INCONEL			LOW	HIGH	MEAN	RANGE	MEAN	STD DEV	LOW	HIGH	MEAN	RANGE	LUBRICANT
8	0.108	0.01	0.08326	0.13274	0.04948	0.458148	0.107	0.005	0.09463	0.11937	0.02474	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	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	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	0.02474	3 0.515417
1	0.128	0.018	0.081468	0.170532	0.089064	0.708857	0.09	0.005	0.07763	0.10237	0.02474	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	0.029688	4 0.216294
2	0.12	0.02	0.07052	0.16948	0.08896	0.824667	0.076	0.006	0.061156	0.090844	0.029688	0.029688	5 0.390632
3	0.108	0.023	0.051098	0.164902	0.113804	1.053741	0.085	0.007	0.067882	0.102318	0.034636	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	0.039584	1 0.430261
4	0.239	0.048	0.120248	0.357752	0.237504	0.983741	0.102	0.02	0.05252	0.15148	0.09896	0.09896	9 0.970196

90/95 TOL													
MAT'L>> K MONEL/MONEL	DESIGN VALUES												
	MEAN	STD DEV	90/95 TOL		RANKED RANGE		B7 ALLOY		90/95 TOL		RANKED RANGE		RANGE/ MEAN
INCONEL			LOW	HIGH	MEAN	RANGE	MEAN	STD DEV	LOW	HIGH	MEAN	RANGE	LUBRICANT
10	0.075	0.008	0.060158	0.089844	0.029688	0.39584	0.119	0.004	0.106928	0.131072	0.024144	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	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	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	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	0.036216	4 0.258851
5	0.088	0.01	0.06326	0.11274	0.04948	0.562273	0.057	0.006	0.038892	0.075108	0.036216	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	0.036216	9 0.338467
4	0.153	0.014	0.118364	0.167636	0.069272	0.452758	0.1	0.007	0.078874	0.121128	0.042252	0.042252	1 0.42252
9	0.087	0.014	0.052364	0.121638	0.069272	0.79623	0.104	0.008	0.079856	0.128144	0.048288	0.048288	6 0.464308
6	0.085	0.015	0.04769	0.12211	0.07422	0.873176	0.096	0.01	0.06582	0.12618	0.06036	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 USED STUD DESIGN VALUES										SORT ON RANGE									
LUBR.	MEAN	STD DEV	90/95 TOL		HIGH	RANGE	RANGE/ MEAN	4140 PHO MEAN	STD DEV	LOW	HIGH	RANGE	LUBRICANT	RANGE/ MEAN					
1	0.122	0.011	0.094766	0.149214	0.054428	0.446131	0.084	0.009	0.061734	0.106266	0.044532	1	0.530143						
2	0.105	0.011	0.077766	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		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	0.056682	0.093318	0.034636	5	0.455737						
6	0.116	0.012	0.066312	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	0.072882	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						

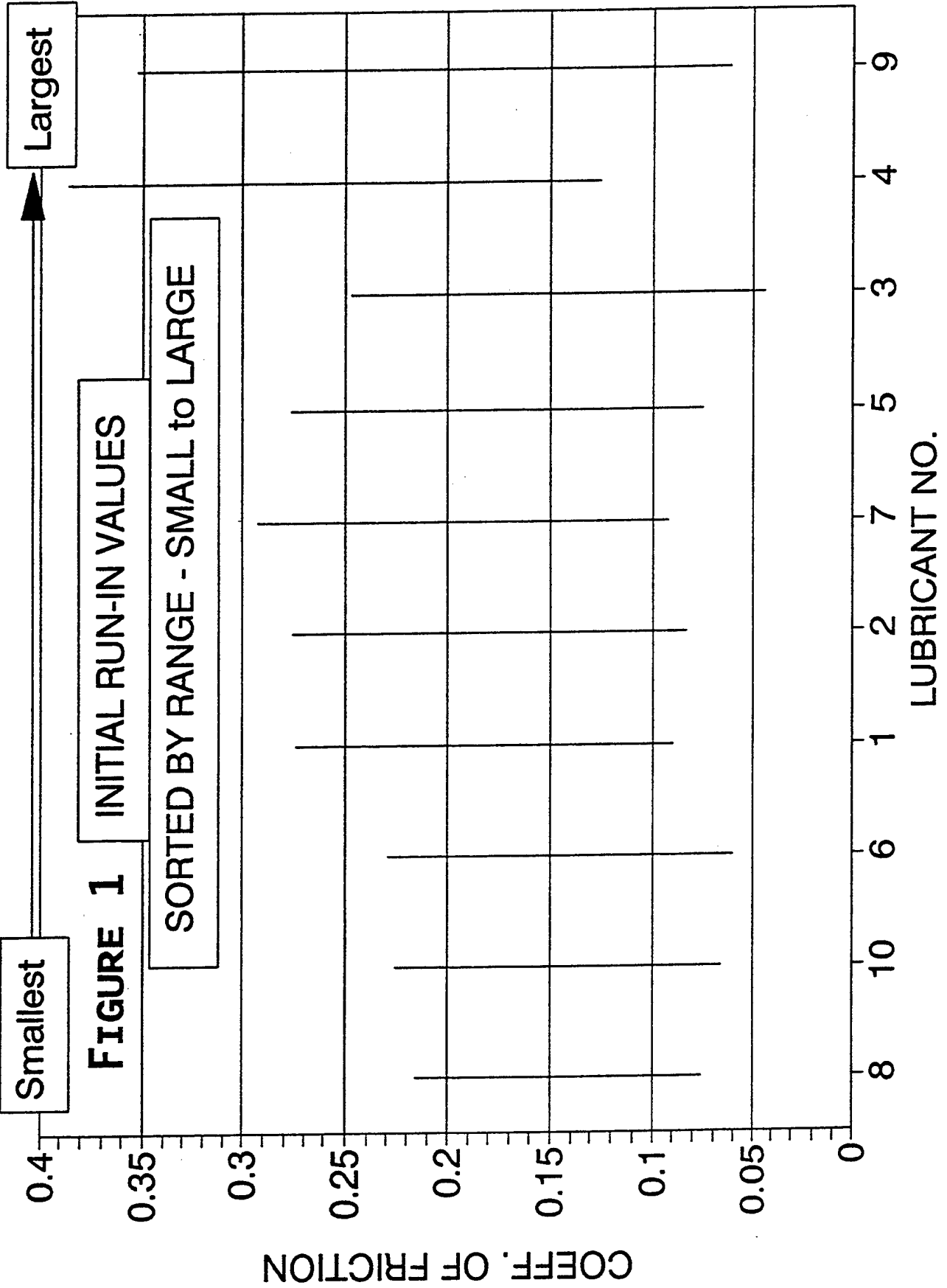
90%/95 TOL										B7 ALLOY									
LUBR.	MEAN	STD DEV	LOW	HIGH	RANGE	RANGE/ MEAN	90/95 TOL LOW	HIGH	RANGE	STD DEV	LOW	HIGH	RANGE	LUBRICANT	RANGE/ MEAN				
1	0.095	0.011	0.067786	0.122214	0.054428	0.572926	0.096	0.004	0.063928	0.108072	0.024144	1	0.2515						
2	0.098	0.012	0.068312	0.127688	0.059376	0.605978	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	0.11974	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

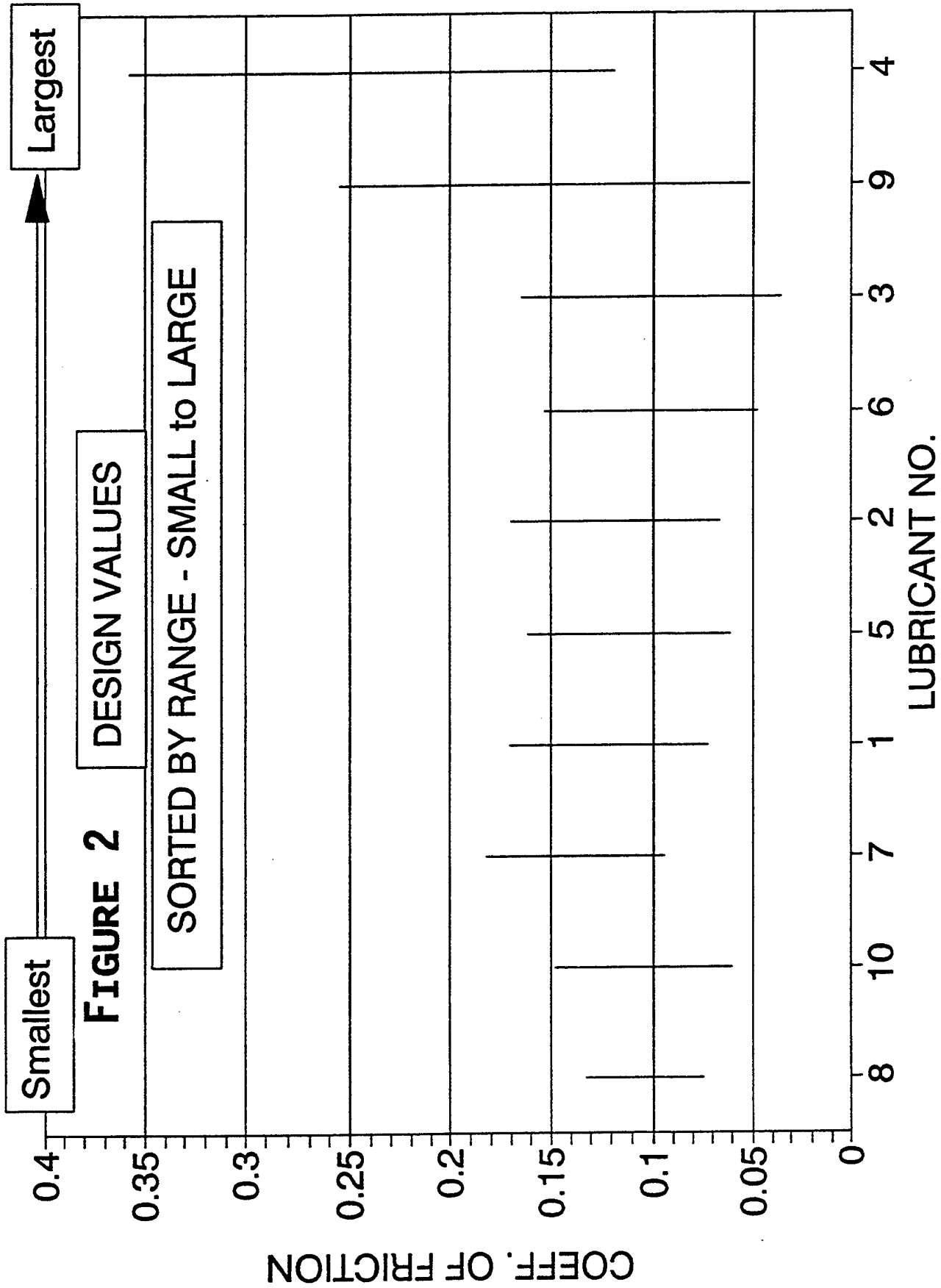
COMPOSITE MATERIALS - MIN/MAX 90/95 TOLERANCE - ALL FOUR MATERIALS

LUBRICANT	SORT ON RANGE		
	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

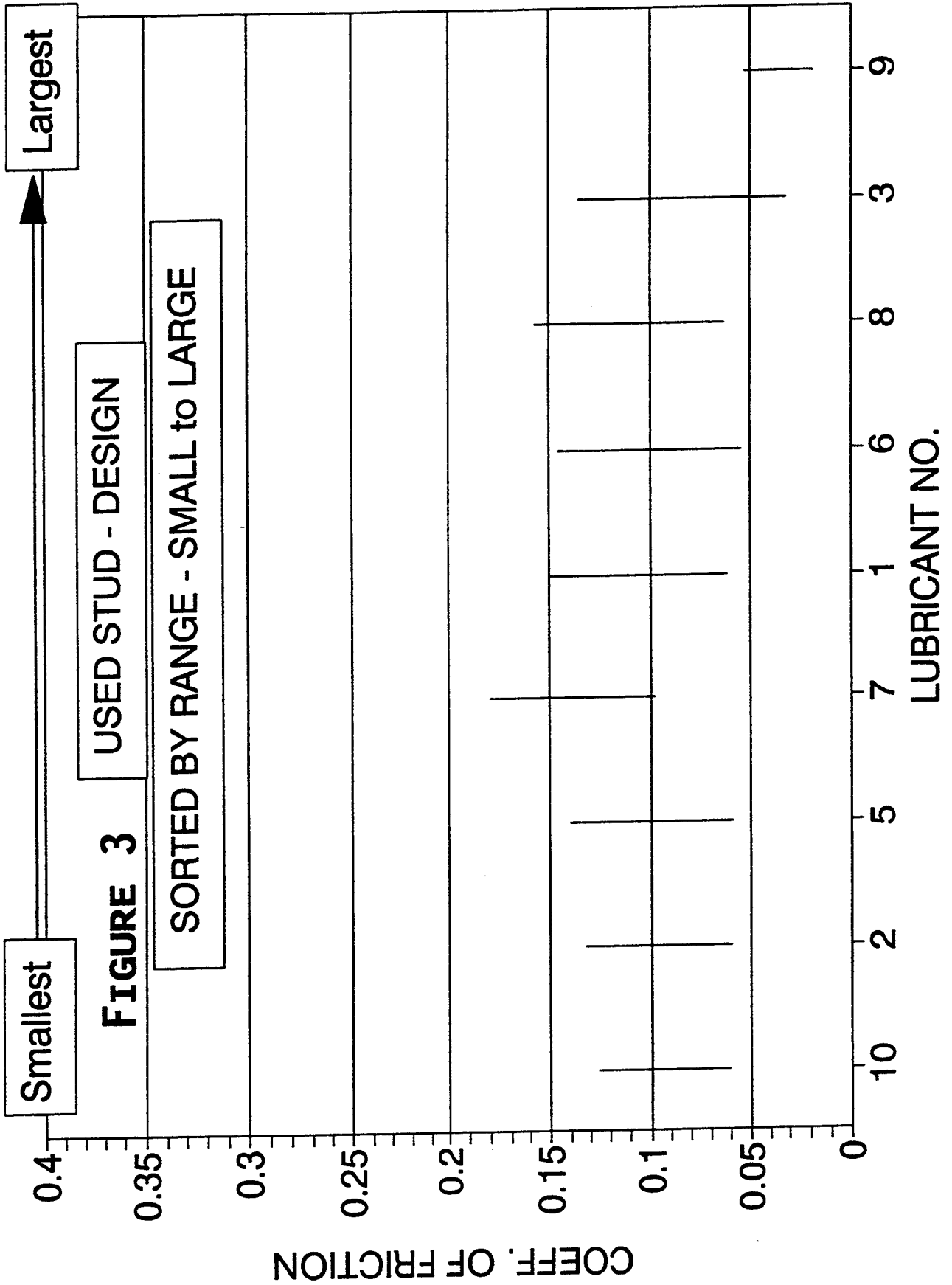
COMPOSITE - 4 MAT'S



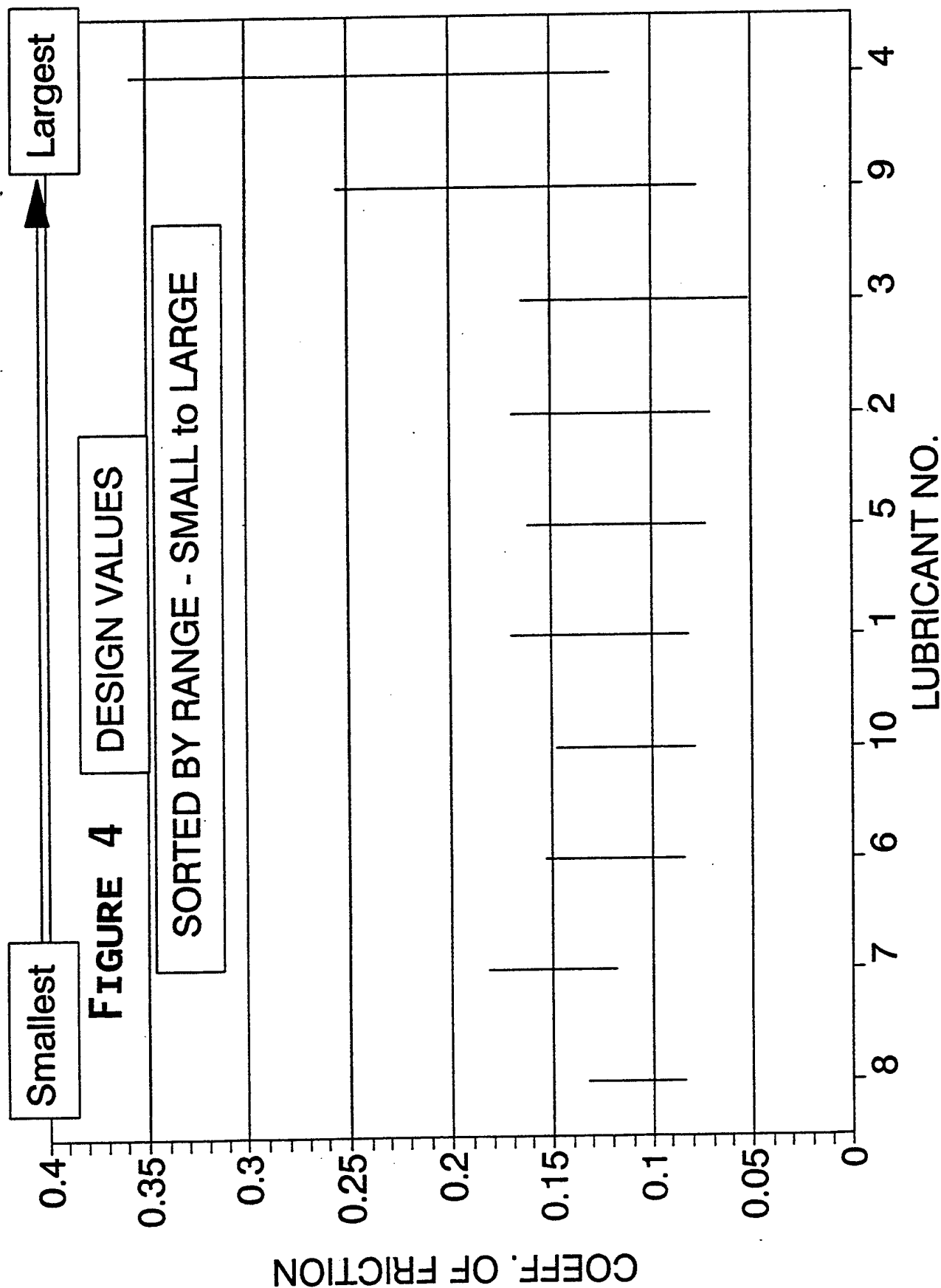
COMPOSITE-4 MAT'S



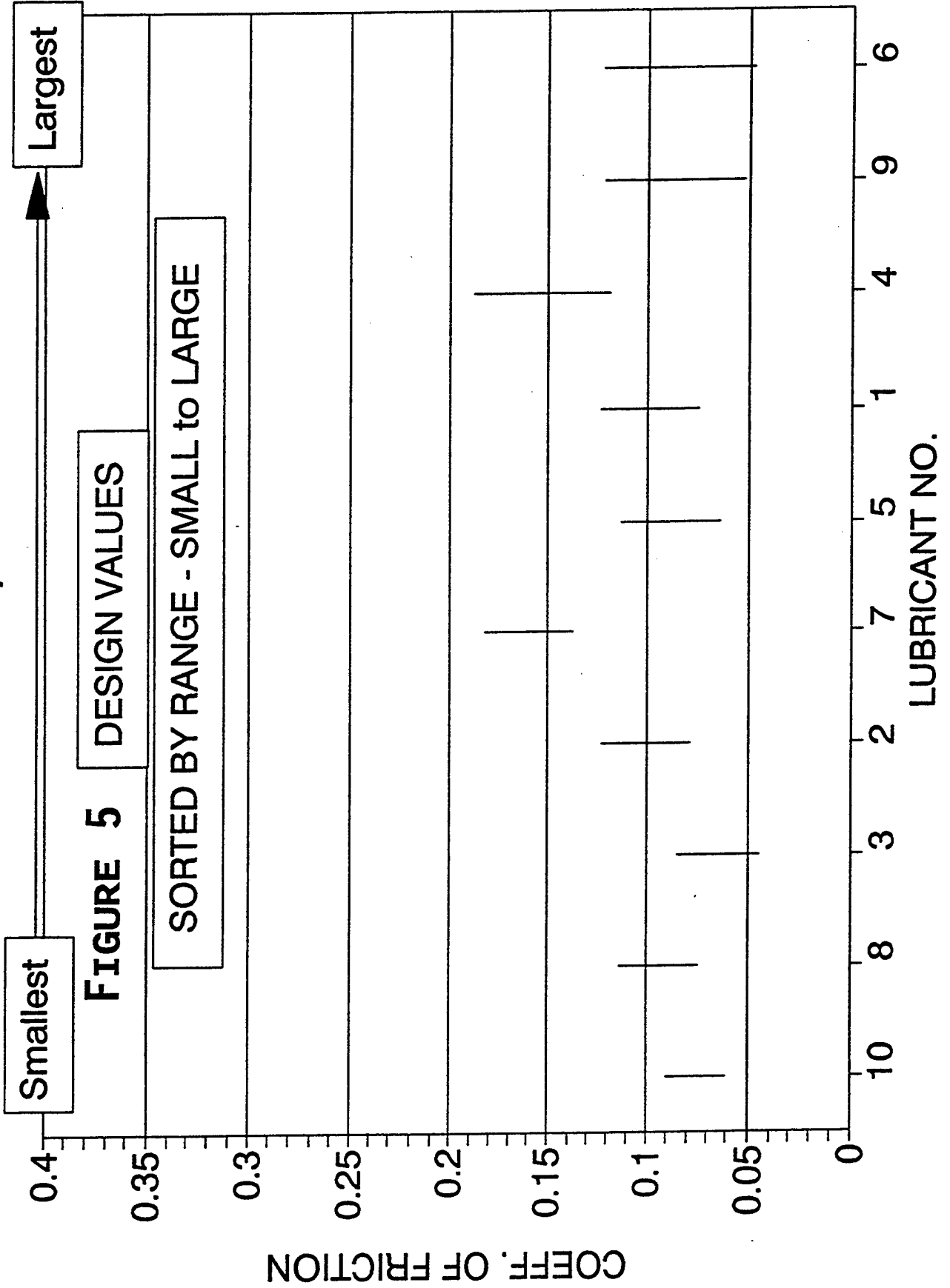
COMPOSITE - 4 MAT'S



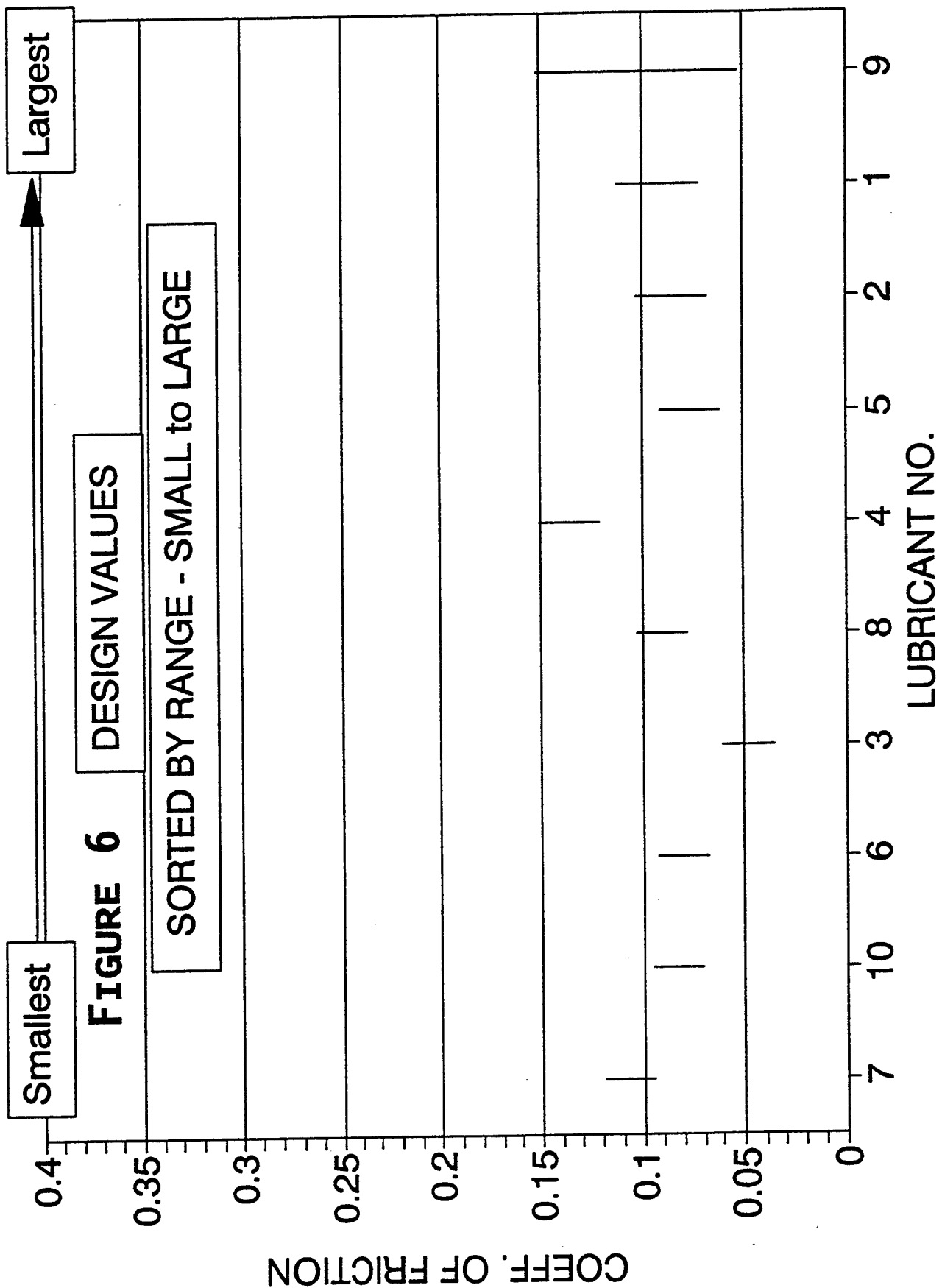
INCONEL



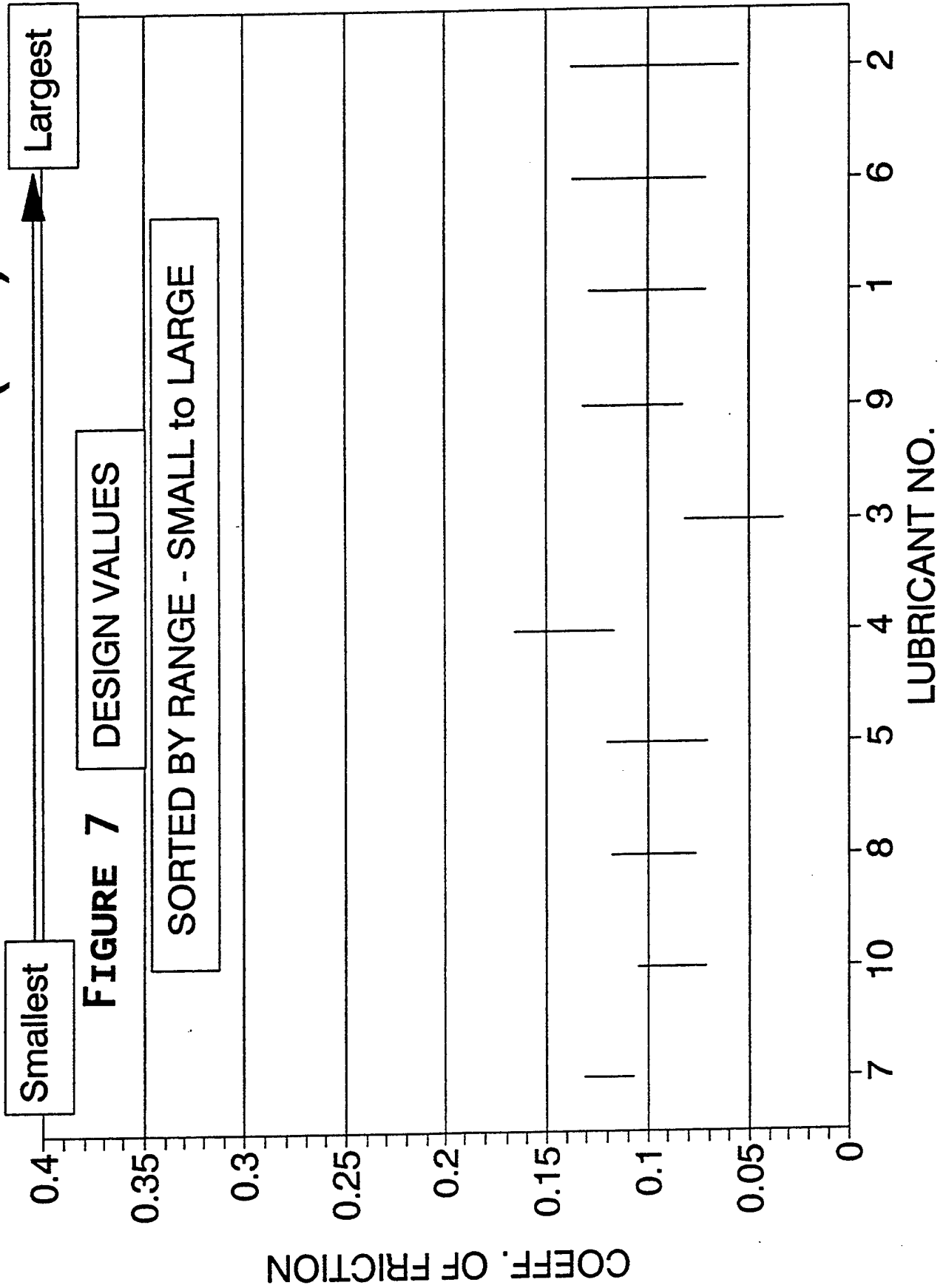
K MONEL/MONEL



AISI 4140 PHOSPHATE



ALLOY STEEL (B7)



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 t-TEST t* = 1.68	TEST FOR VARIANCE F-TEST F* = 1.98	95% Conf
0.206176	0.256768	0.276194	0.178885	0.182788					
0.18079	0.226041	0.249612	0.159115	0.184729					
0.176099	0.215795	0.225959	0.157524	0.201812	RUN-IN	0.199813	0.029919		
0.174479	0.193363	0.197991	0.190586	0.222039					
0.171377	0.185481	0.19643	0.175111	0.205186	XXXXXXXXXXXXXXXXXXXXXXXXXXXX				
0.12811	0.163275	0.171081	0.10072	0.139838					
0.109772	0.123599	0.139391	0.095936	0.125574					
0.112347	0.118997	0.133619	0.105696	0.121656	DESIGN	0.126179	0.017637	DESIGN VS RUN-IN t F	2.877566
0.118657	0.110578	0.141584	0.119687	0.127742				YES	YES
0.128863	0.11324	0.142914	0.125739	0.135889	XXXXXXXXXXXXXXXXXXXXXXXXXXXX				
0.167178	0.171081	0.182788	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	XXXXXXXXXXXXXXXXXXXXXXXXXXXX				
0.108549	0.147653	ERR	0.116375	0.143746					
0.101867	0.127549	ERR	0.111748	0.129523	USED STUD DESIGN			DESIGN VS 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	0.128733			NO	YES	
0.124958	0.121834	ERR	0.117147	0.124177	XXXXXXXXXXXXXXXXXXXXXXXXXXXX				
					OVERALL				
MEAN	0.140274	0.156699	0.180147	0.133934	0.152	0.037			
STD DEV	0.029683	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 t-TEST t* = 1.88	TEST FOR VARIANCE F-TEST F* = 1.98	95% Confl
0.31901	0.186768	0.171157	0.256881	0.217958					
0.222208	0.172987	0.16313	0.208437	0.18284					
0.198084	0.17485	0.17485	0.190448	0.176177	RUN-IN	0.188993	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					
0.135504	0.094	0.105887	0.101912	0.101912					
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	0.133858	0.117699					
0.123451	0.125014	0.132826	0.134388	0.119544	XXXXXXXXXXXXXXXXXXXXXXX				
0.186768	0.1399	0.128186	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		0.132888	0.017871		
0.134865	0.124769	0.134865	0.148428	0.107596					
0.130482	0.127358	0.132826	0.149028	0.1086	XXXXXXXXXXXXXXXXXXXXXXX				
0.128166	0.092929	0.092929	0.108597	0.104681					
0.105867	0.092022	0.094	0.101912	0.088065	USED STUD DESIGN				
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	0.098476					
0.116417	0.110945	0.105472	0.121888	0.109381	XXXXXXXXXXXXXXXXXXXXXXX				
					OVERALL				
MEAN	0.155136	0.128574	0.139217	0.144852	0.136581	0.038906			
STD DEV	0.051775	0.030889	0.023843	0.040161					

TABLE 3: ALLOY TYPE I, LUBRICANT NO. 3

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR		TEST FOR VARIANCE	F-TEST F* = 1.98	95% Confl
							t-TEST	t*			
0.237428	0.175061	0.19847	0.229642	0.167252							
0.220241	0.159185	0.202533	0.208437	0.151295							
0.203173	0.158922	0.208261	0.190448	0.168215	RUN-IN	0.164714	0.025132				
0.174556	0.173589	0.205484	0.163914	0.171654							
0.155757	0.176176	0.200167	0.148278	0.167717	XXXXXXXXXXXXXXXXXXXXXXX						
0.120341	0.100764	0.159441	0.08509	0.08117							
0.101912	0.080148	0.139453	0.082128	0.080148							
0.113728	0.087099	0.140324	0.084434	0.087099	DESIGN	0.107506	0.023478	DESIGN VS RUN-IN	t	F	
0.110627	0.116689	0.144553	0.089397	0.093443							
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							
0.066287	0.070248	0.105867	0.064306	0.076189	USED STUD DESIGN			DESIGN VS USED STUD DESIGN	t	F	
0.088431	0.079104	0.100417	0.077771	0.084434		0.091014	0.018451				
0.094454	0.086363	0.114669	0.103553	0.095465							
0.109381	0.092434	0.12267	0.110163	0.103842	XXXXXXXXXXXXXXXXXXXXXXX						
					OVERALL						
MEAN	0.12905	0.112529	0.166611	0.112028	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		VARIANCE	F-TEST F* = 1.98	95% Conf
								t-TEST	t*			
	0.307375	0.276316	0.249102	0.276316	0.418584							
	0.282827	0.279162	0.257576	0.257576	0.348837							
	0.260976	0.278778	0.279208	0.241303	0.340332	RUN-IN	0.287076	0.040144				
	0.284333	0.308375	0.316083	0.257553	0.315102							
	0.288956	0.288956	0.273911	0.219964	0.272327	XXXXXXXXXXXXXXXXXXXXXXXXXX						
	0.225748	0.252892	0.342262	0.167252	0.24132							
	0.202533	0.234004	0.307386	0.159185	0.239899							
	0.21589	0.2286	0.313061	0.172196	0.250031	DESIGN	0.238642	0.048284	DESIGN VS RUN-IN			
	0.250326	0.263875	0.287219	0.175523	0.25936				t	F		
	0.218408	0.233962	0.29934	0.169959	0.255717	XXXXXXXXXXXXXXXXXXXXXXXXXX			YES	NO		
						USED STUD RUN-IN	0	0				
						XXXXXXXXXXXXXXXXXXXXXXXXXXXX						
						USED STUD DESIGN	0	0	DESIGN VS USED STUD DESIGN			
									t	F		
						XXXXXXXXXXXXXXXXXXXXXXXXXXXX						
						OVERALL						
MEAN	0.126874	0.132151	0.195008	0.104841	0.147026		0.282859	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 VARIANCE	95% Confl
0.163347	0.276316	0.19457	0.225748	0.252892					
0.153268	0.251686	0.172987	0.208437	0.210405					
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					
0.101912	0.12563	0.092022	0.13353	0.10389					
0.105742	0.116389	0.096423	0.146988	0.105742	DESIGN VS RUN-IN				
0.107596	0.110627	0.103553	0.143584	0.116689	t				
0.107036	0.119544	0.116417	0.144538	0.121888	DESIGN	0.117324	0.018045	10,75773	3.183422
0.096847	0.214062	0.100764	0.120341	0.178964	YES			YES	
0.105867	0.161158	0.095979	0.117727	0.159185	XXXXXXXXXXXXXXXXXXXXXXX				
0.12171	0.156266	0.10308	0.129689	0.160249	USED STUD RUN-IN				
0.132846	0.153268	0.103553	0.129818	0.153268	0.134821	0.028662			
0.133607	0.150522	0.114072	0.130482	0.142196	XXXXXXXXXXXXXXXXXXXXXXX				
0.08117	0.1399	0.08901	0.100764	0.1399					
0.086086	0.111798	0.088065	0.105867	0.113774	DESIGN VS USED STUD DESIGN				
0.089763	0.113728	0.095091	0.105742	0.111066	t				
0.095465	0.112648	0.096476	0.112648	0.106585	USED STUD DESIGN	0.10534	0.014429	-2.5935	1.564176
0.103028	0.113291	0.098954	0.115638	0.107036	YES			YES	NO
					XXXXXXXXXXXXXXXXXXXXXXX				
					OVERALL				
MEAN	0.119742	0.160796	0.126263	0.143984	0.138505	0.04279			
STD DEV	0.028144	0.051371	0.038028	0.037777	0.043574				

TABLE 6: ALLOY 1, LUBRICANT NO. 6

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR		VARIANCE	F-TEST F*=1.98	95% Confi
							MEAN	t-TEST			
0.217958	0.19457	0.210165	0.210165	0.182867							
0.204501	0.1769	0.172987	0.202533	0.157213							
0.200629	0.187902	0.18281	0.187902	0.169922	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	XXXXXXXXXXXXXXXXXXXX						
0.112512	0.120341	0.120341	0.135989	0.128166							
0.097957	0.10389	0.10389	0.121679	0.105867							
0.099086	0.111066	0.111066	0.12836	0.116389	DESIGN	0.116394	0.013559	DESIGN VS RUN-IN t	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	XXXXXXXXXXXXXXXXXXXX						
0.19457	0.15534	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	XXXXXXXXXXXXXXXXXXXX						
0.1399	0.100764	0.147718	0.104681	0.124254							
0.117727	0.095979	0.115751	0.097957	0.111798	USED STUD DESIGN			DESIGN VS 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	0.121886	0.110945	0.116762	XXXXXXXXXXXXXXXXXXXX						
					OVERALL						
MEAN	0.147102	0.138868	0.153829	0.142886		0.142921	0.032045				
STD DEV	0.040202	0.031493	0.032008	0.032946							

TABLE 7: ALLOY I, LUBRICANT NO.7

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	
0.237428	0.202389	0.276316	0.276316	0.295733			t-TEST	F-TEST	95% Confl
0.220241	0.230072	0.251686	0.255613	0.234004			t* = 1.68	F* = 1.98	
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	XXXXXXXXXXXXXXXXXXXX				
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	0.154281	0.141415	XXXXXXXXXXXXXXXXXXXX				
0.167252	0.182867	0.178964	0.163347	0.162867					
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	XXXXXXXXXXXXXXXXXXXX				
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	0.144638	0.166222	0.152766	XXXXXXXXXXXXXXXXXXXX				
					OVERALL				
MEAN	0.168882	0.172373	0.188212	0.176814	0.174154	0.037108			
STD DEV	0.034557	0.027948	0.047352	0.039414	0.039189				

TABLE 8: ALLOY I, LUBRICANT NO. 8

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR MEAN t-TEST t* = 1.68	TEST FOR VARIANCE F-TEST F* = 1.98	95% Conf
0.19087	0.151628	0.206287	0.1399	0.175061					
0.192689	0.151295	0.18284	0.127605	0.153288					
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	XXXXXXXXXXXXXXXXXXXXXXX				
0.108597	0.098847	0.120341	0.098847	0.100764					
0.101912	0.105867	0.10389	0.092022	0.084107					
0.109735	0.112397	0.112397	0.101749	0.098423	DESIGN	0.107545	0.010072	DESIGN VS RUN-IN t F	4.527052
0.111972	0.114669	0.110827	0.108608	0.103553				YES	YES
0.130482	0.115636	0.115636	0.114854	0.110945	XXXXXXXXXXXXXXXXXXXXXXX				
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	0.112646					
0.146034	0.139073	0.139854	0.107036	0.114854	XXXXXXXXXXXXXXXXXXXXXXX				
0.147718	0.112512	0.132078	0.08509	0.08117					
0.131555	0.094	0.109821	0.105867	0.082128	USED STUD DESIGN				
0.135007	0.105742	0.113728	0.096423	0.089763	0.110464	0.018756		DESIGN VS USED STUD DESIGN t F	3.46767
0.138741	0.111638	0.115679	0.098498	0.096476				NO	YES
0.141415	0.114072	0.115636	0.106254	0.100583	XXXXXXXXXXXXXXXXXXXXXXX				
					OVERALL				
MEAN	0.146695	0.130677	0.14362	0.109244	0.127121	0.029144			
STD DEV	0.028947	0.025346	0.028528	0.018369	0.026724				

TABLE 9: ALLOY I, LUBRICANT NO. 9

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR MEAN t*-1.68	TEST FOR VARIANCE F-TEST F*=1.98	95% Confl
0.167252	0.19847	0.178984	0.326764	0.217958					
0.149321	0.192689	0.18284	0.265428	0.230072					
0.156266	0.201901	0.203173	0.26827	0.25368	RUN-IN	0.222099	0.05263		
0.154236	0.197152	0.220288	0.283953	0.263875					
0.152788	0.212573	0.255717	0.319916	0.288956	XXXXXXX	XXXXXXXXXXXXXXXXXXXX			
0.092929	0.19847	0.171157	0.178984	0.147718					
0.095979	0.200564	0.161158	0.171016	0.141427					
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					
0.12892	0.223853	0.203817	0.172947	0.181911	XXXXXXX	XXXXXXXXXXXXXXXXXXXX	YES	YES	
0.19067	0.182867	0.167252	0.163347	0.147718					
0.18087	0.18678	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	XXXXXXX	XXXXXXXXXXXXXXXXXXXX			
0.155534	0.128166	0.128166	0.167252	0.108597					
0.147348	0.12563	0.127605	0.141427	0.101912	USED STUD DESIGN				
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	
0.176176	0.142977	0.155009	0.137511	0.111727	XXXXXXX	XXXXXXXXXXXXXXXXXXXX			
					OVERALL				
MEAN	0.157095	0.185024	0.199925	0.194822		0.179107	0.047711		
STD DEV	0.03759	0.031901	0.030744	0.061986					

TABLE 10: ALLOY TYPE I, LUBRICANT NO.10

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	95% Confl
0.217958	0.188768	0.217958	0.128168	0.1399			t-TEST	F-TEST	
0.18087	0.171016	0.204501	0.137479	0.13353			t*=-1.68	F*=1.98	
0.164232	0.170869	0.189175	0.158266	0.132348	RUN-IN	0.025156			
0.154236	0.172622	0.166817	0.159076	0.139709					
0.144538	0.165475	0.152018	0.168464	0.146782	XXXXXXXXXXXXXXXXXXXXXXX				
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	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	XXXXXXXXXXXXXXXXXXXXXXX				
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	0.133878	0.132348		0.126361			
0.12073	0.124769	0.131837	0.136803	0.140678					
0.117199	0.125795	0.127358	0.129701	0.139854	XXXXXXXXXXXXXXXXXXXXXXX		DESIGN VS USED STUD DESIGN		
0.100764	0.08901	0.104681	0.092929	0.108597			t	F	
0.101912	0.088065	0.101912	0.094	0.095979	USED STUD DESIGN		2.762597	2.308292	
0.104411	0.093759	0.108405	0.105742	0.108405		0.104191	0.009164		
0.103553	0.098498	0.115679	0.107598	0.114869			YES	YES	
0.099769	0.113291	0.124232	0.110163	0.118762	XXXXXXXXXXXXXXXXXXXXXXX				
MEAN	0.123241	0.129488	0.143338	0.125086	OVERALL	0.126998			
STD DEV	0.032299	0.029883	0.035985	0.020125		R=0.1289			

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 t-TEST t* = 1.68	TEST FOR VARIANCE F-TEST F* = 1.98	95% Confl
0.108455	0.097655	0.094721	0.121113	0.097655					
0.113046	0.096638	0.102606	0.130931	0.09813					
0.125574	0.115489	0.108426	0.138517	0.111453	RUN-IN	0.114448	0.012856		
0.117683	0.118416	0.106684	0.138748	0.114017					
0.11954	0.126285	0.108293	0.131343	0.121789	XXXXXXXXXXXXXXXXXXXX				
0.088852	0.100589	0.082981	0.082981	0.091787					
0.089176	0.102606	0.08619	0.087683	0.095146					
0.098332	0.107417	0.092274	0.099342	0.10338	DESIGN	0.099245	0.010327	DESIGN VS RUN-IN t F 4.586031 1.57393	
0.100082	0.110351	0.092531	0.103017	0.108864				YES NO	
0.108855	0.117853	0.098483	0.113917	0.118415	XXXXXXXXXXXXXXXXXXXX				
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	0.007528		
0.10375	0.109618	0.105217	0.098615	0.102283					
0.109418	0.115604	0.109418	0.101419	0.109418	XXXXXXXXXXXXXXXXXXXX				
0.085917	0.088852	0.071235	0.088852	0.085917					
0.090688	0.095146	0.081711	0.08619	0.083204	USED STUD DESIGN			DESIGN VS USED STUD DESIGN t F -1.29875 1.101752	
0.10237	0.106408	0.100352	0.087224	0.097323		0.095353	0.01084	NO NO	
0.104484	0.105951	0.103017	0.087179	0.099349					
0.110543	0.113355	0.111105	0.091435	0.106043	XXXXXXXXXXXXXXXXXXXX				
					OVERALL				
MEAN	0.103056	0.106329	0.097715	0.104129		0.102344	0.01271		
STD DEV	0.01118	0.009879	0.008985	0.018382					

TABLE 2: ALLOY M, LUBRICANT NO. 2

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	TEST F-TEST	95% Confl
0.106455	0.100599	0.098852	0.091787	0.106455			t-TEST t*=-1.68	F-TEST F*=-1.98		
0.110084	0.110064	0.095146	0.095146	0.110064						
0.118515	0.115489	0.10237	0.10237	0.113471	RUN-IN	0.107763	0.008789			
0.115483	0.11475	0.10155	0.105217	0.113284	XXXXXX	XXXXXX	XXXXXX			
0.120102	0.116168	0.107168	0.115042	0.118978	XXXXXX	XXXXXX	XXXXXX			
0.103522	0.098852	0.077109	0.098852	0.100589						
0.099622	0.095146	0.083204	0.096638	0.095146						
0.106408	0.10237	0.095304	0.107417	0.109435	DESIGN	0.100858	0.009339	DESIGN VS RUN-IN t	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	XXXXXX	XXXXXX	XXXXXX			
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	XXXXXX	XXXXXX	XXXXXX			
0.082981	0.094721	0.077109	0.088852	0.094721						
0.081711	0.104098	0.084697	0.092161	0.095146	USED STUD DESIGN			DESIGN VS 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	XXXXXX	XXXXXX	XXXXXX			
					OVERALL					
MEAN	0.099334	0.109868	0.098673	0.100184	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 VARIANCE
0.065359	0.062421	0.062421	0.059482	0.065359			t-TEST t*=-1.68	F-TEST F*=-1.98
0.07275	0.059301	0.06229	0.063785	0.068268				95% Conf
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	XXXXXXXXXXXXXXXXXXXXXXXXXX			
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	XXXXXXXXXXXXXXXXXXXXXXXXXX			
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	XXXXXXXXXXXXXXXXXXXXXXXXXX			
0.050663	0.047723	0.050663	0.056543	0.056543			DESIGN VS USED STUD DESIGN	
0.057806	0.050331	0.053321	0.051826	0.057806	USED STUD DESIGN		t	F
0.068002	0.055989	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	XXXXXXXXXXXXXXXXXXXXXXXXXX			
					OVERALL			
MEAN	0.068078	0.060883	0.072118	0.061652	0.065159	0.010211		
STD DEV	0.011156	0.006727	0.009885	0.009917	0.009457			

TABLE 4: ALLOY M, LUBRICANT NO. 4

	TEST FOR MEAN				TEST FOR VARIANCE			
	STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	F-TEST F* = 1.98
	0.1504	0.144545	0.1504	0.1504	0.156252			
	0.139869	0.147314	0.144336	0.141358	0.154758			
	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	XXXXXXXXXXXXXXXXXXXX		
	0.132832	0.141618	0.159178	0.162103	0.1738			
	0.124971	0.133911	0.145825	0.153268	0.154756			
	0.13755	0.148189	0.153023	0.15689	0.162889	DESIGN	0.152599	0.014072
	0.137344	0.145063	0.156987	0.156286	0.156987			
	0.137863	0.158285	0.177492	0.175737	0.172226	XXXXXXXXXXXXXXXXXXXX		
	0.1504	0.158252	0.162103	0.153328	0.182569			
	0.141358	0.153268	0.160708	0.168145	0.168145	USED STUD RUN-IN		
	0.152057	0.161722	0.168554	0.177179	0.171384	0.16323	0.011214	
	0.145063	0.155585	0.161896	0.170292	0.166102			
	0.163445	0.172811	0.158638	0.178662	0.185097	XXXXXXXXXXXXXXXXXXXX		
	0.153326	0.165028	0.1738	0.194255	0.176724			
	0.154756	0.165171	0.169633	0.185985	0.177067	USED STUD DESIGN	0.176333	0.013195
	0.161722	0.177179	0.17235	0.178144	0.190372			
	0.156987	0.168204	0.168905	0.173719	0.183998			
	0.183342	0.190384	0.188606	0.202319	0.196353	XXXXXXXXXXXXXXXXXXXX		
						OVERALL		
MEAN	0.147067	0.157574	0.1564	0.168509	0.171183		0.160659	0.015836
STD DEV	0.01317	0.013902	0.008903	0.016978	0.012521			

DESIGN VS RUN-IN
t F
-0.61705 2.018427
NO YES

DESIGN VS USED STUD DESIGN
t F
6.151762 1.137418
YES NO

TABLE 5: ALLOY M, LUBRICANT NO. 5

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	t-TEST t*=1.68	F-TEST F*=1.98	95% Confi
0.085917	0.085917	0.091787	0.118182	0.100589							
0.093653	0.092161	0.093853	0.114537	0.085146							
0.105398	0.101361	0.101361	0.118515	0.098332	RUN-IN	0.102836	0.010448				
0.105951	0.096353	0.102283	0.11695	0.099349							
0.113917	0.101419	0.106805	0.125723	0.100832	XXXXXXXXXXXXXXXXXXXXXXX						
0.085917	0.077109	0.071235	0.100589	0.074172							
0.087683	0.078724	0.078724	0.093853	0.077231							
0.099342	0.082173	0.084194	0.099342	0.085204	DESIGN	0.08758	0.009691	DESIGN VS RUN-IN	t	F	
0.097881	0.081825	0.081825	0.099349	0.083355				5.282535	1.162519		
0.100832	0.088498	0.084385	0.107168	0.089086	XXXXXXXXXXXXXXXXXXXXXXX			YES	NO		
0.080045	0.080045	0.071235	0.109387	0.080045							
0.078724	0.084697	0.066774	0.102806	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							
0.078724	0.077231	0.07275	0.093853	0.077231	USED STUD DESIGN			DESIGN VS USED STUD DESIGN	t	F	
0.089244	0.082173	0.077121	0.092274	0.082173	0.083096	0.006668		-1.90598	2.11934		
0.088708	0.08412	0.074175	0.086414	0.08106				YES	YES		
0.090848	0.088498	0.076745	0.088498	0.080859	XXXXXXXXXXXXXXXXXXXXXXX						
					OVERALL						
MEAN	0.091196	0.08605	0.092467	0.104764	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		TEST FOR VARIANCE
							t-TEST t*=1.68	F-TEST F*=1.98	
0.077109	0.091787	0.077109	0.085917	0.094721					
0.075737	0.093853	0.08619	0.105589	0.09813					
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	XXXXXXXXXXXXXXXXXXXX				
0.063359	0.091787	0.085917	0.100589	0.098852					
0.06229	0.084897	0.083204	0.098622	0.075737					
0.060946	0.088234	0.087224	0.10338	0.079142	DESIGN	0.084523	0.014977	2.995584	1.003423
0.058102	0.084884	0.086414	0.108151	0.079531					
0.059667	0.089673	0.089673	0.115604	0.084385	XXXXXXXXXXXXXXXXXXXX				
0.068297	0.100569	0.085917	0.097855	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	XXXXXXXXXXXXXXXXXXXX				
0.074172	0.080045	0.077109	0.085917	0.085917					
0.063785	0.080218	0.07275	0.081711	0.077231	USED STUD DESIGN				
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	XXXXXXXXXXXXXXXXXXXX				
					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 VARIANCE
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
0.163655	0.15689	0.16752	0.147222	0.15109	0.153698	0.0109		95% Conf
0.161896	0.161194	0.147168	0.147168	0.150675				
0.163342	0.177492	0.156636	0.148401	0.151147	XXXXXXXXXXXXXXXXXXXXXXXX			
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
0.159091	0.170292	0.155585	0.155585	0.147168			YES	1.531555
0.172811	0.177492	0.176322	0.158834	0.151147	XXXXXXXXXXXXXXXXXXXXXXXX		YES	YES
0.1738	0.167853	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	XXXXXXXXXXXXXXXXXXXXXXXX		DESIGN VS USED STUD DESIGN	
0.159178	0.165028	0.156252	0.147473	0.1504			t	F
0.148802	0.157732	0.150291	0.150291	0.145925	USED STUD DESIGN		-3.11687	2.187584
0.15399	0.15979	0.150123	0.153023	0.154957	0.153145	0.005955	YES	YES
0.150675	0.159792	0.145765	0.145765	0.151377				
0.168958	0.159383	0.14895	0.147303	0.1495	XXXXXXXXXXXXXXXXXXXXXXXX			
					OVERALL			
MEAN	0.160343	0.161685	0.157928	0.149835	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				
0.099622	0.095146	0.092161	0.104098	0.092161				
0.106408	0.104389	0.098332	0.110444	0.097323	RUN-IN	0.102214	0.00768	
0.108151	0.106684	0.100816	0.108151	0.100082				
0.114479	0.114479	0.11223	0.11223	0.101419	XXXXXXXXXXXXXXXXXXXXXXX			
0.088852	0.091787	0.085917	0.085917	0.077109				
0.089176	0.093653	0.092161	0.092161	0.093204				
0.095304	0.10237	0.101361	0.096313	0.090254	DESIGN	0.094276	0.008149	1.131799
0.092531	0.105951	0.105217	0.092531	0.087943				
0.097309	0.111667	0.108293	0.097896	0.092023	XXXXXXXXXXXXXXXXXXXXXXX			
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	0.098722	0.101419	XXXXXXXXXXXXXXXXXXXXXXX			
0.074172	0.080045	0.077109	0.085917	0.077109				
0.081711	0.087683	0.084697	0.089176	0.08619	USED STUD DESIGN			
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				
0.102594	0.110543	0.106043	0.104355	0.102006	XXXXXXXXXXXXXXXXXXXXXXX			
MEAN	0.095903	0.100355	0.100401	0.098207	OVERALL			
STD DEV	0.009082	0.009516	0.009485	0.007719		0.09695	0.00931	

TABLE 9; ALLOY M, LUBRICANT NO. 9

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR		VARIANCE	F-TEST F* = 1.98	95% Confl
							t-TEST	MEAN			
0.077109	0.071235	0.085917	0.085917	0.082981							
0.081711	0.069762	0.083204	0.08619	0.08619							
0.097323	0.078131	0.091264	0.094294	0.096313	RUN-IN	0.08731	0.008625				
0.096353	0.077236	0.088708	0.082531	0.095588							
0.100832	0.079684	0.090848	0.096722	0.096722	XXXXXXXXXXXXXXXXXXXXXXX						
0.088852	0.071235	0.074172	0.077109	0.088852							
0.089176	0.063785	0.071256	0.084697	0.090668							
0.101361	0.069035	0.078131	0.091264	0.108426	DESIGN	0.087062	0.013904	DESIGN VS RUN-IN			
0.103017	0.065757	0.08259	0.093295	0.105217				t	F		
0.108293	0.074982	0.089673	0.099658	0.106043	XXXXXXXXXXXXXXXXXXXXXXX			NO	0.076033	2.598535	YES
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	XXXXXXXXXXXXXXXXXXXXXXX						
0.077109	0.082981	0.071235	0.091787	0.085917							
0.078724	0.075737	0.071256	0.089176	0.08619							
0.086214	0.084194	0.069035	0.107417	0.091264	USED STUD DESIGN			t	F		
0.084884	0.079531	0.063461	0.111084	0.088708		0.085095	0.013215	DESIGN VS USED STUD DESIGN	-0.5127	1.106859	NO
0.090848	0.084385	0.065794	0.118415	0.092023	XXXXXXXXXXXXXXXXXXXXXXX			NO			
					OVERALL						
MEAN	0.087455	0.075088	0.082293	0.09885		0.086656	0.013305				
STD DEV	0.01059	0.006685	0.007473	0.013253							

TABLE 10; ALLOY M, LUBRICANT 10

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR		95% Confl
							MEAN	VARIANCE	
0.097655	0.080045	0.082981	0.091787	0.085917			t-TEST	F-TEST	
0.090668	0.083204	0.083204	0.092161	0.081711			t* = 1.68	F* = 1.98	
0.088234	0.086214	0.085204	0.106408	0.083183	RUN-IN	0.088			
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	6.010842	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					
0.089762	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		0.076647		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 t-TEST t* = 1.68	TEST FOR VARIANCE F-TEST F* = 1.98	95% Conf
0.109049	0.100664	0.100664	0.095072	0.095072					
0.105852	0.099959	0.101383	0.097112	0.092842					
0.103715	0.097933	0.105642	0.097933	0.096005	RUN-IN	0.099195	0.00435		
0.101038	0.094737	0.103838	0.096837	0.094038					
0.100883	0.094627	0.103897	0.097422	0.094088	XXXXXXXXXXXXXXXXXXXX				
0.083884	0.081086	0.083884	0.081088	0.07549					
0.094265	0.089994	0.099959	0.091418	0.082873					
0.101788	0.091185	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					
0.100147	0.091831	0.104968	0.097422	0.088475	XXXXXXXXXXXXXXXXXXXX				
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			
0.088988	0.088258	0.103138	0.089718	0.086069					
0.089035	0.087916	0.102828	0.089584	0.083441	XXXXXXXXXXXXXXXXXXXX				
0.072691	0.069891	0.081086	0.07549	0.067092					
0.078599	0.081448	0.089994	0.081448	0.080024	USED STUD DESIGN				
0.083471	0.084435	0.098897	0.087328	0.080577	0.084251	0.008641	-3.36034	0.965028	
0.087529	0.088069	0.098838	0.080447	0.079501					
0.089035	0.087357	0.101754	0.09239	0.080085	XXXXXXXXXXXXXXXXXXXX				
					OVERALL				
MEAN	0.092496	0.088982	0.100351	0.090988	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	0.097868	0.086882	0.097868	0.095072			t-TEST t* = 1.68	F-TEST F* = 1.98
0.099859	0.097112	0.089994	0.098536	0.094285				
0.101788	0.096005	0.091185	0.102751	0.094077	RUN-IN	0.095334	0.004539	95% Conf
0.098938	0.094036	0.089718	0.101038	0.091177				
0.100147	0.09239	0.089594	0.098612	0.098475	XXXXXXXXXXXXXXXXXXXXXXXXXXXX			
0.072891	0.078288	0.078288	0.063884	0.072891			DESIGN VS RUN-IN	
0.080024	0.081448	0.082873	0.091418	0.078599			t	F
0.089257	0.085399	0.086364	0.098889	0.093471	DESIGN	0.085346	0.008673	6.063918 2.293197
0.091177	0.08534	0.087629	0.098837	0.08315			YES	YES
0.092949	0.085679	0.086238	0.099076	0.094001	XXXXXXXXXXXXXXXXXXXXXXXXXXXX			
0.081086	0.083884	0.07549	0.096882	0.086882				
0.085722	0.085722	0.084287	0.089994	0.089994	USED STUD RUN-IN			
0.094077	0.089257	0.086364	0.098897	0.091185		0.089109	0.003368	
0.095437	0.088258	0.089718	0.086137	0.089718				
0.099076	0.089035	0.088475	0.094827	0.087918	XXXXXXXXXXXXXXXXXXXXXXXXXXXX			
0.058691	0.07549	0.084292	0.081086	0.072891			DESIGN VS USED STUD DESIGN	
0.0729	0.078599	0.078599	0.091418	0.090024	USED STUD DESIGN		t	F
0.081542	0.083471	0.081542	0.098005	0.084435		0.081834	0.008563	-1.59912 1.552179
0.08388	0.08534	0.08388	0.095437	0.08534			NO	NO
0.08512	0.082882	0.084001	0.093608	0.085679	XXXXXXXXXXXXXXXXXXXXXXXXXXXX			
					OVERALL			
MEAN	0.087877	0.086775	0.086187	0.094599	0.087806	0.008183		
STD DEV	0.011254	0.008284	0.00443	0.005896	0.00639			

TABLE 3; ALLOY P, LUBRICANT NO. 3

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD. DEVIATION	TEST FOR MEAN		TEST FOR VARIANCE	
							t-TEST	F-TEST	t-TEST	F-TEST
							t*=-1.68	F*=-1.98	t*=-1.68	F*=-1.98
0.07549	0.072691	0.072691	0.081491	0.056691						
0.067199	0.070049	0.067199	0.058844	0.057218						
0.063207	0.065138	0.062242	0.057414	0.054517	RUN-IN	0.060968	0.008602			
0.059053	0.060614	0.059053	0.053939	0.052476						
0.05774	0.05949	0.053406	0.052486	0.050154	XXXXXXXXXXXXXXXXXXXXXXXXXXXX					
0.044682	0.053068	0.041879	0.047484	0.039075						
0.050087	0.057218	0.050087	0.045806	0.032961						
0.049688	0.055483	0.045824	0.04679	0.045824	DESIGN	0.047836	0.005083	7.727028	1.784087	
0.051014	0.053207	0.04736	0.048091	0.046697						
0.050738	0.051905	0.048987	0.047819	0.044901	XXXXXXXXXXXXXXXXXXXXXXXXXXXX					
0.050286	0.061491	0.050286	0.050286	0.081088						
0.051513	0.058844	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	0.051805	0.04957	0.04957	0.046832	XXXXXXXXXXXXXXXXXXXXXXXXXXXX					
0.044692	0.047494	0.061491	0.036272	0.039075						
0.047233	0.054366	0.061496	0.04438	0.042853	USED STUD DESIGN					
0.04679	0.05162	0.060311	0.04679	0.042826	0.046853	0.006726	0.48423	1.744486		
0.045897	0.050283	0.057591	0.04736	0.042973						
0.046652	0.050164	0.056573	0.047819	0.043149	XXXXXXXXXXXXXXXXXXXXXXXXXXXX					
					OVERALL					
MEAN	0.05269	0.05889	0.053119	0.049814	0.052345	0.008387				
STD DEV	0.008051	0.008624	0.008545	0.005566	0.010295					

TABLE 4: ALLOY P, LUBRICANT NO. 4

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR		95% Conf
							MEAN	VARIANCE	
0.164868	0.150925	0.150925	0.153714	0.150925			t-TEST	F-TEST	
0.158558	0.152558	0.153977	0.149718	0.155397			t* = 1.68	F* = 1.98	
0.158416	0.148109	0.149955	0.14257	0.150878	RUN-IN	0.147838	0.007672		
0.148377	0.144369	0.14303	0.137003	0.14303					
0.141531	0.144146	0.137346	0.131068	0.139982	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
0.142558	0.131383	0.136975	0.134184	0.142558			DESIGN VS RUN-IN		
0.142616	0.132671	0.141198	0.129828	0.139775			t	F	
0.14267	0.133334	0.138876	0.127791	0.139799	DESIGN	0.138713	0.005858	6.332499	1.715613
0.138342	0.132314	0.137003	0.124128	0.134993			YES	NO	
0.135254	0.134207	0.133954	0.1221	0.144689	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
0.142558	0.131383	0.136975	0.131383	0.136975					
0.149718	0.138354	0.146877	0.132871	0.142816	USED STUD RUN-IN				
0.150878	0.138876	0.143483	0.13241	0.148109		0.139976	0.006696		
0.147716	0.139882	0.137672	0.130974	0.14236					
0.149375	0.137346	0.13767	0.127404	0.148715	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
0.142558	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	
0.166584	0.147188	0.156416	0.134258	0.150878		0.147925	0.01082	4.982035	3.411894
0.160432	0.147047	0.15374	0.132314	0.153071			YES	YES	
0.16206	0.146761	0.151467	0.136823	0.167076	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
					OVERALL				
MEAN	0.150156	0.140888	0.141724	0.133883		0.142888	0.009478		
STD DEV	0.008533	0.007125	0.008123	0.007627					

TABLE 5: ALLOY P, LUBRICANT NO. 5

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR MEAN t-TEST t* = 1.68	TEST FOR VARIANCE F-TEST F* = 1.96	95% Conf
0.095072	0.089479	0.085072	0.081086	0.089479					
0.092842	0.089994	0.085722	0.081448	0.089994					
0.092149	0.082257	0.082506	0.081642	0.082257	RUN-IN	0.008966	0.004936		
0.091177	0.089998	0.080231	0.078771	0.082256	XXXXXXXXXXXXXXXXXXXXXXX				
0.089594	0.089798	0.080085	0.080085	0.082238	XXXXXXXXXXXXXXXXXXXXXXX				
0.081491	0.087092	0.081491	0.084292	0.072691					
0.074325	0.077174	0.0729	0.070049	0.077174	DESIGN	0.075851	0.0084	DESIGN VS RUN-IN t	1.680901
0.077683	0.082506	0.077683	0.076753	0.077683	DESIGN	0.075851	0.0084	YES	NO
0.081691	0.081691	0.078771	0.076951	0.078901	XXXXXXXXXXXXXXXXXXXXXXX				
0.08456	0.083441	0.078525	0.078966	0.077267	XXXXXXXXXXXXXXXXXXXXXXX				
0.07549	0.087092	0.087092	0.087092	0.072691	USED STUD RUN-IN				
0.07575	0.080024	0.078599	0.071475	0.080024	0.076041	0.005599			
0.080577	0.083364	0.081542	0.076718	0.080577					
0.08315	0.08388	0.08242	0.075851	0.078041	XXXXXXXXXXXXXXXXXXXXXXX				
0.085679	0.084001	0.082882	0.078166	0.077846	XXXXXXXXXXXXXXXXXXXXXXX				
0.089891	0.087092	0.081491	0.086891	0.087092	DESIGN VS USED STUD DESIGN t				
0.07575	0.07575	0.086824	0.086824	0.078599	USED STUD DESIGN	0.075601	0.007141	-0.02603	1.244782
0.078612	0.081642	0.076716	0.073624	0.080577				NO	NO
0.081691	0.08388	0.078591	0.07366	0.080981	XXXXXXXXXXXXXXXXXXXXXXX				
0.082322	0.086798	0.080644	0.076406	0.081204	XXXXXXXXXXXXXXXXXXXXXXX				
					OVERALL				
MEAN	0.081525	0.081642	0.079101	0.074416	0.079085	0.007603			
STD DEV	0.008346	0.007365	0.007743	0.008123	0.008123	0.00595			

TABLE 6: ALLOY P, LUBRICANT NO. 6

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR MEAN t*-1.68	TEST FOR VARIANCE F*-1.98	95% Conf
0.081086	0.100684	0.095072	0.095072	0.095072					
0.085722	0.092842	0.091418	0.092842	0.092842					
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	XXXXXXXXXXXXXXXXXXXXXXX				
0.081763	0.087357	0.086798	0.087916	0.087357	DESIGN VS RUN-IN				
0.087082	0.078288	0.081086	0.081086	0.07849					
0.0729	0.081448	0.082873	0.082873	0.077174					
0.071894	0.081542	0.085399	0.085399	0.081542	DESIGN	0.078596	0.005128	6.837252	1.147139
0.07074	0.080231	0.083115	0.08461	0.08242	YES				
0.07169	0.080085	0.084001	0.08512	0.081763	XXXXXXXXXXXXXXXXXXXXXXX				
0.078288	0.083894	0.083894	0.089891	0.095072	USED STUD RUN-IN				
0.077174	0.087146	0.087146	0.077174	0.089904	0.082336	0.005358			
0.078612	0.085399	0.086384	0.078718	0.085399					
0.077311	0.08242	0.08534	0.077311	0.08461	XXXXXXXXXXXXXXXXXXXXXXX				
0.077848	0.082882	0.08456	0.077848	0.08512	DESIGN VS USED STUD DESIGN				
0.072691	0.07649	0.078288	0.072691	0.072691					
0.071475	0.081448	0.085722	0.078599	0.077174	USED STUD DESIGN				
0.074789	0.082506	0.086384	0.078648	0.083471	0.07922	0.005013	-0.28202	1.046526	
0.07293	0.08242	0.08534	0.078581	0.08461	NO				
0.074489	0.08512	0.085679	0.077287	0.084001	XXXXXXXXXXXXXXXXXXXXXXX				
MEAN	0.076208	0.084556	0.086194	0.081867	OVERALL				
STD DEV	0.004938	0.005655	0.003527	0.008823	0.082585	0.006413			

TABLE 7: ALLOY P, LUBRICANT NO. 7

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR MEAN t*-1.68	TEST FOR VARIANCE F*-1.98	95% Conf
0.114637	0.131393	0.117431	0.114637	0.109049					
0.111343	0.121296	0.108497	0.112765	0.111343					
0.108532	0.110459	0.104878	0.109496	0.106532	RUN-IN	0.108794	0.0074		
0.109236	0.106636	0.098636	0.103136	0.104536					
0.10229	0.103997	0.087422	0.100893	0.10229	XXXXXXXXXXXXXXXXXXXXXXX				
0.100664	0.114637	0.103459	0.111843	0.106254					
0.102806	0.114188	0.104229	0.107075	0.108497					
0.105642	0.119127	0.103715	0.108496	0.108496	DESIGN	0.10726	0.00478	0.870828	2.398463
0.108037	0.113635	0.101036	0.101036	0.108037					
0.104433	0.110323	0.10229	0.104433	0.10711	XXXXXXXXXXXXXXXXXXXXXXX				
0.111843	0.126601	0.123017	0.111843	0.111843					
0.111343	0.124142	0.114188	0.107075	0.111343	USED STUD RUN-IN				
0.115276	0.122015	0.109496	0.103715	0.112365	0.111957	0.006866			
0.110837	0.115734	0.106636	0.103636	0.108737					
0.108181	0.111183	0.106576	0.100883	0.107646	XXXXXXXXXXXXXXXXXXXXXXX				
0.114637	0.114637	0.128601	0.100864	0.111843					
0.111343	0.11561	0.111343	0.102806	0.111343	USED STUD DESIGN	0.111977	0.005568	3.213669	1.358919
0.113348	0.117201	0.110459	0.106606	0.110459					
0.115734	0.117633	0.110137	0.106636	0.110137					
0.11183	0.118353	0.108717	0.106575	0.112465	XXXXXXXXXXXXXXXXXXXXXXX				
					OVERALL				
					0.109997	0.006433			
MEAN	0.109405	0.116583	0.108821	0.106262	0.109167				
STD DEV	0.004596	0.008751	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 t*-1.68	TEST FOR VARIANCE F*-1.98	95% Conf
0.092278	0.086882	0.089479	0.083884	0.095072					
0.084297	0.084297	0.089894	0.084297	0.086889					
0.083471	0.084435	0.088292	0.087328	0.096005	RUN-IN	0.004307			
0.08368	0.08368	0.087529	0.086089	0.094737					
0.082882	0.08456	0.08512	0.086798	0.092949	XXXXXXXXXXXXXXXXXXXX				
0.081086	0.078288	0.083884	0.081086	0.081086	DESIGN VS RUN-IN				
0.08857	0.082873	0.085722	0.089894	0.08857	t				
0.087328	0.088292	0.089257	0.095041	0.090005	F				
0.089718	0.090447	0.087529	0.094038	0.096137	-0.89631	0.005334	1.533241		
0.09239	0.092849	0.089479	0.095188	0.096304	NO				
0.097868	0.089479	0.089479	0.083884	0.083884	XXXXXXXXXXXXXXXXXXXX				
0.094285	0.089894	0.087148	0.087148	0.092842	USED STUD RUN-IN				
0.091185	0.090221	0.090221	0.089257	0.088897	0.091275	0.004388			
0.089718	0.091177	0.089718	0.088258	0.100338					
0.091272	0.094627	0.091831	0.089035	0.100147	XXXXXXXXXXXXXXXXXXXX				
0.100684	0.081086	0.081086	0.081086	0.072891	DESIGN VS USED STUD DESIGN				
0.094265	0.08857	0.082873	0.081448	0.087148	t				
0.093113	0.090221	0.084435	0.090221	0.083113	F				
0.093338	0.094038	0.090447	0.096437	0.098437	0.628202	0.006979	1.71194		
0.097981	0.085745	0.09239	0.088745	0.098612	NO				
					XXXXXXXXXXXXXXXXXXXX				
					OVERALL				
					0.089527	0.005439			
MEAN	0.090478	0.088093	0.088543	0.088282	0.092833				
STD DEV	0.005419	0.004716	0.002453	0.004897	0.00701				

TABLE 9: ALLOY P, LUBRICANT NO. 9

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR MEAN t-TEST t* = 1.68	TEST FOR VARIANCE F-TEST F* = 1.98	95% Conf
0.097968	0.100864	0.083884	0.108049	0.089479					
0.108497	0.108497	0.078598	0.124142	0.089994					
0.113348	0.113348	0.080577	0.131486	0.097833	RUN-IN	0.108612	0.018168		
0.117133	0.116734	0.079601	0.134993	0.090637	XXXXXXXXXXXXXXXXXXXX				
0.12317	0.124775	0.080644	0.138916	0.101219	XXXXXXXXXXXXXXXXXXXX				
0.108049	0.089479	0.081088	0.117431	0.086682	DESIGN VS RUN-IN				
0.11561	0.092842	0.07575	0.126885	0.08857	t				
0.122878	0.098897	0.074789	0.124903	0.090221	DESIGN	0.102122	0.020334	0.838843	1.282716
0.131644	0.105238	0.07366	0.124827	0.087529	NO			NO	
0.135777	0.109788	0.07337	0.128357	0.089594	XXXXXXXXXXXXXXXXXXXX				
0.095072	0.072891	0.072891	0.083884	0.089891	USED STUD RUN-IN				
0.111343	0.084297	0.088824	0.097112	0.07875	0.08899	0.017279			
0.118238	0.094077	0.087068	0.098897	0.078612					
0.112836	0.096137	0.087088	0.083336	0.081691	XXXXXXXXXXXXXXXXXXXX				
0.127828	0.098863	0.088239	0.108717	0.08456	DESIGN VS USED STUD DESIGN				
0.103459	0.082278	0.078288	0.088882	0.081086	t				
0.108652	0.088536	0.082873	0.097112	0.085722	USED STUD DESIGN				
0.107569	0.088897	0.078612	0.102751	0.094435	0.094438	0.011151	-1.85705	3.325182	
0.108037	0.087538	0.081691	0.108037	0.089718	NO		NO	YES	
0.110859	0.095188	0.078408	0.113536	0.092849	XXXXXXXXXXXXXXXXXXXX				
					OVERALL				
MEAN	0.113708	0.099288	0.075036	0.112458	0.08779	0.018038			
STD DEV	0.010537	0.011548	0.00557	0.01636	0.007423				

TABLE 10: ALLOY P, LUBRICANT 10

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR		95% Conf
							MEAN	VARIANCE	
0.092276	0.086882	0.086882	0.117431	0.069479			t-TEST t*=-1.68	F-TEST F*=1.98	
0.091418	0.081448	0.089984	0.101383	0.069984					
0.080221	0.079612	0.086364	0.082149	0.091185	RUN-IN	0.089188	0.007808		
0.090447	0.078041	0.08534	0.086789	0.090447					
0.084827	0.077846	0.08512	0.084001	0.080713	XXXXXXXXXXXXXXXXXXXXXXX				
0.081086	0.072891	0.083884	0.086072	0.081086					
0.084297	0.081448	0.078598	0.085722	0.084297					
0.084435	0.082506	0.081542	0.083471	0.087328	DESIGN	0.083461	0.004521	3.144089	3.088247
0.086789	0.080231	0.08242	0.079501	0.086988			YES	YES	
0.086238	0.080085	0.083441	0.078525	0.091831	XXXXXXXXXXXXXXXXXXXXXXX				
0.078288	0.088891	0.07549	0.081086	0.081086					
0.080024	0.074325	0.077174	0.078599	0.080024	USED STUD RUN-IN				
0.079812	0.077683	0.080677	0.078646	0.084435		0.077648	0.003413		
0.075851	0.075121	0.075851	0.075121	0.08315					
0.075606	0.073929	0.075608	0.07281	0.081204	XXXXXXXXXXXXXXXXXXXXXXX				
0.072691	0.067082	0.072691	0.07549	0.088891					
0.080024	0.078599	0.07575	0.080024	0.081448	USED STUD DESIGN				
0.079812	0.080577	0.079812	0.083471	0.086364		0.078505	0.004577	-3.8519	1.024934
0.080231	0.078771	0.078041	0.080861	0.08534			YES	NO	
0.076727	0.076727	0.078525	0.077846	0.08512	XXXXXXXXXXXXXXXXXXXXXXX				
					OVERALL				
MEAN	0.083026	0.077865	0.081872	0.084455		0.0822	0.00703		
STD DEV	0.008299	0.004529	0.004547	0.010417					

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 t-TEST t*=1.734	TEST FOR VARIANCE F-TEST F*=3.18	95% Confidence
0.114637	0.114637	ERR	ERR	ERR	RUN-IN	0.116372	0.00414		
0.118454	0.118454	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX				
0.115275	0.121052	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX				
0.110837	0.120631	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX				
0.109252	0.120494	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX				
0.089479	0.089479	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX				
0.101363	0.095689	ERR	ERR	ERR	DESIGN	0.100011	0.007379	6.115088	3.176365
0.100824	0.103715	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX				
0.099638	0.109437	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX				
0.09854	0.111193	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX				
0.109049	0.109049	ERR	ERR	ERR	USED STUD RUN-IN				
0.108497	0.10992	ERR	ERR	ERR	0.107416	0.002308			
0.110459	0.106605	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX				
0.105938	0.105238	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX				
0.103361	0.106039	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX				
0.089479	0.089479	ERR	ERR	ERR	DESIGN VS USED STUD DESIGN				
0.092842	0.097112	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX				
0.095041	0.098897	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX				
0.096137	0.101038	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX				
0.096304	0.101754	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX				
MEAN	0.103271	0.106533	ERR	ERR	OVERALL	0.104902	0.0092		
STD DEV	0.008638	0.009671	ERR	ERR					

TABLE 2; ALLOY A, LUBRICANT NO. 2

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	95% Confidence
0.103459	0.089479	ERR	ERR	ERR			t-TEST t* = 1.734	F-TEST F* = 3.18	
0.104229	0.101383	ERR	ERR	ERR					
0.105642	0.098897	ERR	ERR	ERR	RUN-IN	0.101114			
0.103138	0.100338	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
0.103361	0.101219	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
0.089478	0.072691	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
0.092842	0.089994	ERR	ERR	ERR	DESIGN	0.095944	0.010072	DESIGN VS RUN-IN 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	XXXXXX	XXXXXXXXXXXXXXXXXXXX	No	Yes	
0.106039	0.103361	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
0.095072	0.072691	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
0.099959	0.082873	ERR	ERR	ERR	USED STUD RUN-IN				
0.104678	0.089257	ERR	ERR	ERR	0.093906	0.009391			
0.102438	0.094036	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
0.101754	0.096304	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
0.081086	0.069891	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
0.089994	0.082873	ERR	ERR	ERR	USED STUD DESIGN				
0.093113	0.087328	ERR	ERR	ERR	0.088497	0.00853	-1.78429	1.394303	
0.095437	0.092636	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX	Yes	No	
0.09854	0.094068	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
MEAN	0.098698	ERR	ERR	ERR	OVERALL				
STD DEV	0.006671	ERR	ERR	ERR	0.094865	0.009417			

TABLE 3: ALLOY A, LUBRICANT NO. 3

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR MEAN t-TEST t* = 1.734	TEST FOR VARIANCE F-TEST F* = 3.18	95% Confidence
0.086882	0.067092	ERR	ERR	ERR	RUN-IN	0.070654	0.008133		
0.080024	0.065773	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
0.075753	0.065138	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
0.07074	0.061245	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
0.07169	0.062408	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
0.061491	0.050286	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
0.064348	0.051513	ERR	ERR	ERR	DESIGN	0.056909	0.005939	4.316342	1.875367
0.062242	0.05162	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
0.060514	0.051014	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
0.063573	0.052488	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
0.058691	0.050286	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
0.061496	0.051513	ERR	ERR	ERR	USED STUD RUN-IN				
0.085138	0.048722	ERR	ERR	ERR	0.056942	0.008226			
0.067088	0.048091	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
0.068822	0.04957	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
0.050286	0.047484	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
0.054366	0.047233	ERR	ERR	ERR	DESIGN VS USED STUD DESIGN				
0.056449	0.047756	ERR	ERR	ERR	t				
0.058322	0.048091	ERR	ERR	ERR	0.052021	0.005314	-1.93953	1.249019	
0.061823	0.048403	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
					OVERALL				
MEAN	0.064977	0.053286	ERR	ERR	0.059132	0.009749			
STD DEV	0.008766	0.006804	ERR	ERR					

TABLE 4; ALLOY A, LUBRICANT NO. 4

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	t-TEST F*-1.734	F-TEST F*-3.18	95% Confidence
0.15929	0.156502	ERR	ERR	ERR	RUN-IN	0.152273	0.00647				
0.161075	0.152558	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX					
0.157339	0.151801	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX					
0.151063	0.146377	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX					
0.145715	0.141008	ERR	ERR	ERR	DESIGN	0.141301	0.005845	DESIGN VS RUN-IN			
0.145346	0.142556	ERR	ERR	ERR							
0.151138	0.146877	ERR	ERR	ERR							
0.140723	0.141646	ERR	ERR	ERR							
0.139682	0.137672	ERR	ERR	ERR							
0.135777	0.131591	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX					
0.150925	0.150925	ERR	ERR	ERR	USED STUD RUN-IN						
0.151138	0.156817	ERR	ERR	ERR							
0.150878	0.150878	ERR	ERR	ERR							
0.145038	0.145038	ERR	ERR	ERR							
0.141008	0.139962	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX					
0.142556	0.156502	ERR	ERR	ERR	DESIGN VS USED STUD DESIGN						
0.148298	0.151138	ERR	ERR	ERR							
0.149032	0.15457	ERR	ERR	ERR	USED STUD DESIGN						
0.145708	0.151063	ERR	ERR	ERR							
0.142577	0.146236	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX					
					OVERALL						
MEAN	0.147715	0.147586	ERR	ERR		0.147651	0.00669				
STD DEV	0.006637	0.006915	ERR	ERR							

TABLE 5: ALLOY A, LUBRICANT NO.5

TABLE 5: ALLOY A, LUBRICANT NO.5									
STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	95% Confidence
0.100664	0.106254	ERR	ERR	ERR			t-TEST t* = 1.734	F-TEST F* = 3.18	
0.097112	0.104229	ERR	ERR	ERR	RUN-IN	0.101049	0.002971		
0.097933	0.102751	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXX			
0.087538	0.101038	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXX			
0.100683	0.10229	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXX			
0.089479	0.092276	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXX			
0.08657	0.099959	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXX			
0.091185	0.103715	ERR	ERR	ERR	DESIGN	0.095351	0.006133	DESIGN VS RUN-IN t F	
0.089718	0.101738	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXX	2.644028	4.260592	Yes
0.093508	0.103361	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXX			
0.083884	0.103459	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXX			
0.087146	0.104229	ERR	ERR	ERR	USED STUD RUN-IN	0.096964	0.010005		
0.088292	0.110459	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXX			
0.088988	0.108037	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXX			
0.090713	0.104433	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXX			
0.081086	0.081086	ERR	ERR	ERR	USED STUD DESIGN	0.086706	0.007214	DESIGN VS USED STUD DESIGN t F	
0.080024	0.089994	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXX	-2.88709	1.383502	No
0.081542	0.094077	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXX			
0.081691	0.096137	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXX			
0.082882	0.09854	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXX			
MEAN	0.089632	0.100403	ERR	ERR	OVERALL	0.095018	0.008595		
STD DEV	0.006617	0.00884	ERR	ERR					

TABLE 6; ALLOY A6, LUBRICANT NO. 6

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE
0.100864	0.111843	ERR	ERR	ERR			t-TEST t*=1.734	F-TEST F*=3.18
0.107075	0.114188	ERR	ERR	ERR	0.110833	0.004473		
0.113348	0.116238	ERR	ERR	ERR				
0.110837	0.113635	ERR	ERR	ERR				
0.108181	0.110323	ERR	ERR	ERR				
0.089479	0.100664	ERR	ERR	ERR				
0.094265	0.105652	ERR	ERR	ERR				
0.100824	0.110459	ERR	ERR	ERR				
0.101738	0.115035	ERR	ERR	ERR				
0.104968	0.115142	ERR	ERR	ERR				
0.089479	0.103459	ERR	ERR	ERR				
0.095689	0.111343	ERR	ERR	ERR				
0.097933	0.110459	ERR	ERR	ERR				
0.098238	0.110137	ERR	ERR	ERR				
0.10229	0.111394	ERR	ERR	ERR				
0.083884	0.100664	ERR	ERR	ERR				
0.094265	0.104229	ERR	ERR	ERR				
0.097933	0.113348	ERR	ERR	ERR				
0.097538	0.117133	ERR	ERR	ERR				
0.104433	0.119424	ERR	ERR	ERR				
MEAN	0.099653	0.110738	ERR	ERR				
STD DEV	0.007424	0.005324	ERR	ERR				

DESIGN VS RUN-IN	t	F	Yes	Yes
DESIGN	0.103823	0.008319	2.280067	3.458908
USED STUD RUN-IN				
	0.103042	0.007688		
DESIGN VS USED STUD DESIGN	t	F	No	No
USED STUD DESIGN	0.103285	0.010985	-0.12348	1.736985
OVERALL				
	0.105196	0.008495		

TABLE 7: ALLOY A, LUBRICANT NO. 7

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	F-TEST	95% Confidence
0.134184	0.136975	ERR	ERR	ERR	RUN-IN	0.124958	0.009434	t-TEST	t* = 1.734	
0.131249	0.134092	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX		F-TEST	F* = 3.18	
0.125866	0.126828	ERR	ERR	ERR	DESIGN	0.11935	0.003855	DESIGN VS RUN-IN		
0.119232	0.117833	ERR	ERR	ERR	DESIGN	0.11935	0.003855	t	1.740091	5.987533
0.113536	0.109788	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX		F	Yes	Yes
0.128601	0.123017	ERR	ERR	ERR	USED STUD RUN-IN	0.127099	0.005836			
0.118454	0.119876	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX				
0.118164	0.118164	ERR	ERR	ERR	DESIGN VS USED STUD DESIGN			t	1.252214	1.056363
0.117833	0.116434	ERR	ERR	ERR	USED STUD DESIGN	0.12148	0.003751	F	No	No
0.115142	0.117818	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX				
0.139766	0.128601	ERR	ERR	ERR	OVERALL	0.123222	0.006658			
0.132671	0.126985	ERR	ERR	ERR	MEAN	0.124112	0.122332			
0.12394	0.128715	ERR	ERR	ERR	STD DEV	0.00673	0.006635			
0.122029	0.126225	ERR	ERR	ERR						
0.12103	0.12103	ERR	ERR	ERR						
0.128601	0.123017	ERR	ERR	ERR						
0.121298	0.118454	ERR	ERR	ERR						
0.122978	0.118164	ERR	ERR	ERR						
0.123428	0.115734	ERR	ERR	ERR						
0.12424	0.118889	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	t-TEST F-TEST	95% Confidence
0.114637	0.089479	ERR	ERR	ERR	RUN-IN	0.098523	0.006683		t*=1.734 F*=3.18	
0.095689	0.092842	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX				
0.096005	0.094077	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX				
0.096137	0.095437	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX				
0.095186	0.095745	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX				
0.099479	0.092276	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX				
0.094265	0.092842	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX				
0.096969	0.101788	ERR	ERR	ERR	DESIGN	0.097136	0.005142		t	DESIGN VS RUN-IN
0.098238	0.103138	ERR	ERR	ERR	DESIGN	0.097136	0.005142		F	
0.096863	0.105504	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			No	No
0.100664	0.095072	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			No	No
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	XXXXXX	XXXXXXXXXXXXXXXXXXXX				
0.09854	0.105504	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX				
0.095072	0.095072	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX				
0.095689	0.097112	ERR	ERR	ERR	USED STUD DESIGN				t	DESIGN VS USED STUD DESIGN
0.101788	0.098897	ERR	ERR	ERR	0.099898	0.004097			F	
0.103138	0.101738	ERR	ERR	ERR	0.099898	0.004097			1.328358	1.574854
0.103897	0.106575	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			No	No
					OVERALL					
MEAN	0.09829	0.098715	ERR	ERR	0.098503	0.005181				
STD DEV	0.005044	0.005436	ERR	ERR						

TABLE 9; ALLOY A, LUBRICANT NO. 9

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR MEAN t-TEST t* = 1.734	TEST FOR VARIANCE F-TEST F* = 3.18	95% Confidence
0.106254	0.109049	ERR	ERR	ERR	RUN-IN	0.122833	0.009415		
0.118454	0.118454	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXXX				
0.12394	0.124903	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXXX				
0.131644	0.130974	ERR	ERR	ERR	DESIGN	0.106845	0.00843	4.378945	2.144374
0.132114	0.130544	ERR	ERR	ERR	DESIGN VS RUN-IN				
0.106254	0.111843	ERR	ERR	ERR	t				
0.104229	0.112765	ERR	ERR	ERR	F				
0.098897	0.114312	ERR	ERR	ERR	Yes				
0.099638	0.112236	ERR	ERR	ERR	No				
0.097422	0.110859	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXXX				
0.089479	0.103459	ERR	ERR	ERR	USED STUD RUN-IN				
0.082873	0.104229	ERR	ERR	ERR	0.091473	0.012043			
0.079612	0.100824	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXXXX				
0.075851	0.101038	ERR	ERR	ERR	DESIGN VS USED STUD DESIGN				
0.075608	0.101754	ERR	ERR	ERR	t				
0.083884	0.089479	ERR	ERR	ERR	F				
0.080024	0.091418	ERR	ERR	ERR	USED STUD DESIGN				
0.077683	0.094077	ERR	ERR	ERR	0.086116	0.010659	-5.26619	2.748152	
0.07366	0.097538	ERR	ERR	ERR	Yes				
0.070571	0.102826	ERR	ERR	ERR	No				
					XXXXXXXXXXXXXXXXXXXXXXXX				
					OVERALL				
MEAN	0.095405	0.108129	ERR	ERR	0.101767	0.01726			
STD DEV	0.019658	0.011826	ERR	ERR					

TABLE 10; ALLOY A, LUBRICANT NO. 10

	STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR		95% Confidence
								MEAN	VARIANCE	
	0.097668	0.092276	ERR	ERR	ERR			t-TEST	F-TEST	
	0.091418	0.089994	ERR	ERR	ERR			t*=-1.734	F*=-3.18	
	0.094077	0.090221	ERR	ERR	ERR	RUN-IN	0.091591	0.003475		
	0.093338	0.087529	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
	0.093508	0.085679	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
	0.089479	0.083884	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
	0.091418	0.085722	ERR	ERR	ERR	DESIGN	0.088193	0.003625	2.139811	1.088131
	0.094077	0.089257	ERR	ERR	ERR	DESIGN	0.088193	0.003625	2.139811	1.088131
	0.091177	0.08388	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
	0.089035	0.084001	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
	0.083884	0.083884	ERR	ERR	ERR	USED STUD RUN-IN				
	0.084297	0.089994	ERR	ERR	ERR	0.0884	0.003753			
	0.084435	0.093113	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
	0.08315	0.090447	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
	0.082322	0.088475	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
	0.083884	0.081096	ERR	ERR	ERR	DESIGN VS USED STUD DESIGN				
	0.087146	0.082873	ERR	ERR	ERR	t	-2.85739	2.048436		
	0.085399	0.087328	ERR	ERR	ERR	USED STUD DESIGN	0.084197	0.002533		
	0.08388	0.08461	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
	0.079525	0.086238	ERR	ERR	ERR	XXXXXX	XXXXXXXXXXXXXXXXXXXX			
						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 STUD1	Alloy Code MK			STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST for Mean 95% Confidence t*= 1.68	TEST for Variance F*=1.98 = 0.505	90/95 Tolerance
	STUD2	STUD3	STUD4								
0.1445	0.1283	0.1445	0.1413	0.1186							
0.1305	0.1223	0.1256	0.1191	0.1256							
0.1341	0.1242	0.1220	0.1165	0.1132	RUN-IN		0.1246	0.0092			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							
0.1028	0.1126	0.1256	0.1207	0.1256							
0.1121	0.1242	0.1165	0.1231	0.1176	DESIGN		0.1184	0.0059	0.2046	2.4695	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							
0.1012	0.1093	0.1110	0.1093	0.1028							
0.1033	0.1143	0.1110	0.1099	0.1099	CYCLE3		0.1114	0.0079	0.2534	0.5617	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							
STD DEV	0.0143	0.0081	0.0084	0.0079							

DATA SET 6,7 Alloy Code MS						
STUD1	STUD2	STUD3		STUD4		STUD5
0.1380	0.1380		ERR	ERR	ERR	ERR
0.1419	0.1337		ERR	ERR	ERR	ERR
0.1462	0.1275		ERR	ERR	ERR	ERR RUN-IN
0.1513	0.1258		ERR	ERR	ERR	ERR
0.1660	0.1372		ERR	ERR	ERR	ERR XXXXXXXXXXXXX
	0.0959		ERR	ERR	ERR	ERR
	0.1044		ERR	ERR	ERR	ERR
	0.1143		ERR	ERR	ERR	ERR DESIGN
	0.1266		ERR	ERR	ERR	ERR
	0.1310		ERR	ERR	ERR	ERR XXXXXXXXXXXXX
	0.1056		ERR	ERR	ERR	ERR
	0.0931		ERR	ERR	ERR	ERR
	0.1055		ERR	ERR	ERR	ERR CYCLE3
	0.1145		ERR	ERR	ERR	ERR
	0.1222		ERR	ERR	ERR	ERR
Mean	0.1238		ERR	ERR	ERR	ERR
Std Dev	0.0217		ERR	ERR	ERR	ERR

DATA SET 11,12 Alloy Code MI						
STUD1	STUD2	STUD3	STUD4	STUD5		
0.1413	0.1348	ERR	ERR	ERR	ERR	ERR
0.1305	0.1402	ERR	ERR	ERR	ERR	ERR
0.1363	0.1610	ERR	ERR	ERR	ERR	ERR RUN-IN
ERR	ERR	ERR	ERR	ERR	ERR	ERR
ERR	ERR	ERR	ERR	ERR	ERR	ERR XXXXXXXXXXXX
0.1121	0.1056	ERR	ERR	ERR	ERR	ERR
0.1110	0.1093	ERR	ERR	ERR	ERR	ERR
0.1220	0.1286	ERR	ERR	ERR	ERR	ERR DESIGN
ERR	ERR	ERR	ERR	ERR	ERR	ERR
ERR	ERR	ERR	ERR	ERR	ERR	ERR XXXXXXXXXXXX
0.1121	0.1024	ERR	ERR	ERR	ERR	ERR
0.1093	0.1028	ERR	ERR	ERR	ERR	ERR
0.1176	0.1154	ERR	ERR	ERR	ERR	ERR CYCLE3
ERR	ERR	ERR	ERR	ERR	ERR	ERR
ERR	ERR	ERR	ERR	ERR	ERR	ERR
0.1214	0.1222	ERR	ERR	ERR	ERR	ERR
0.0119	0.0203	ERR	ERR	ERR	ERR	ERR
Mean						
Std Dev						

DATA SET 16-20					Alloy Code		MCU		MEAN VALUE	STD DEVIATION	TEST for Mean 95% Confidence t*= 1.68	TEST for Variance F*=1.98	90/95 Tolerance	
STUD1	STUD2	STUD3	STUD4	STUD5	STUD3	STUD4								
0.1218	0.1234	0.1684	0.1459	0.1234			0.1310	0.0137					0.1649	0.0970
0.1256	0.1186	0.1380	0.1186	0.1154										
0.1418	0.1210	0.1340	0.1167	0.1145			RUN-IN							
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										
ERR	0.0927	0.1024	0.0829	0.1056										
ERR	0.0863	0.0972	0.0820	0.0972			DESIGN	0.1009		0.0103	0.5263	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										
ERR	0.0862	0.0862	0.0829	0.0959										
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										
STD DEV	0.0234	0.0180	0.0255	0.0221										

DATA SET 21.22 Alloy Code MH						
STUD1	STUD2	STUD3	STUD4	STUD5		
0.1445	0.1413	ERR	ERR	ERR	ERR	ERR
0.1386	0.1402	ERR	ERR	ERR	ERR	ERR
0.1494	0.1473	ERR	ERR	ERR	ERR	ERR RUN-IN
0.1529	0.1498	ERR	ERR	ERR	ERR	ERR
0.1569	0.1539	ERR	ERR	ERR	ERR	ERR XXXXXXXXXXXXXXXXXXXXXXXX
	0.1121	ERR	ERR	ERR	ERR	ERR
	0.1175	ERR	ERR	ERR	ERR	ERR
	0.1209	ERR	ERR	ERR	ERR	ERR DESIGN
	0.1234	ERR	ERR	ERR	ERR	ERR
	0.1297	ERR	ERR	ERR	ERR	ERR XXXXXXXXXXXXXXXXXXXXXXXX
	0.1121	ERR	ERR	ERR	ERR	ERR
	0.1028	ERR	ERR	ERR	ERR	ERR
	0.1110	ERR	ERR	ERR	ERR	ERR CYCLE3
	0.1226	ERR	ERR	ERR	ERR	ERR
	0.1235	ERR	ERR	ERR	ERR	ERR
Mean	0.1279	ERR	ERR	ERR	ERR	ERR
Std Dev	0.0168	ERR	ERR	ERR	ERR	ERR

DATA SET 36-40	Alloy Code II				MEAN VALUE	STD DEVIATION	TEST for Mean 95% Confidence t*= 1.68	TEST for Variance F*=1.98	90/95 Tolerance
	STUD2		STUD3						
	STUD1	STUD2	STUD3	STUD4					
0.1469	0.1373	0.1373	0.1276	0.1179					
0.1519	0.1470	0.1374	0.1422	0.1325					
0.1572	0.1556	0.1346	0.1556	0.1362	RUN-IN	0.1492	0.0145		0.1134
0.1632	0.1679	0.1498	0.1607	0.1449					0.1850
0.1700	0.1756	0.1567	0.1681	0.1557	XXXXXXXXXXXXXXXXXXXX				
0.1131	0.1179	0.1373	0.1082	0.1179					
0.1059	0.1035	0.1204	0.1083	0.1107					
0.1087	0.1071	0.1330	0.1168	0.1071	DESIGN	0.1156	0.0089	0.7176	0.1377
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					
0.0986	0.0962	0.1011	0.0986	0.0962					
0.0974	0.1022	0.1071	0.1038	0.1006	CYCLE3	0.1067	0.0072	0.2760	0.1244
0.1034	0.1021	0.1119	0.1119	0.1046				No	No
0.1152	0.1132	0.1132	0.1201	0.1092					
Mean	0.1249	0.1248	0.1250	0.1264					
Std Dev	0.0253	0.0256	0.0169	0.0215					

DATA SET 41-45				Code SS		Studs 41-44 only		MEAN VALUE	STD DEVIATION	TEST for		90/95 Tolerance
STUD1	STUD2	STUD3	STUD4	STUD5	STUD6	STUD7	STUD8			Mean	Variance	
0.1455	0.1455	0.1642	0.1525	0.1223								
0.1521	0.1603	0.1851	0.1603	0.1215								
0.1475	0.1638	0.1814	0.1711	0.1115	RUN-IN			0.1633	0.0150	t*= 1.70	F*=2.47	0.2040
0.1565	0.1674	0.1961		0.1034								0.1226
				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
0.1313	0.1368	0.1527		0.1084						No	No	0.0959
				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
0.1179	0.1230	0.1379	0.1439	0.1062						No	No	0.0750
				0.1045								
Mean	0.1282	0.1353	0.1454	0.1308								
Std Dev	0.0564	0.0589	0.0658	0.0672								

DATA SET 46-50				Alloy Code T													
STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST for Mean	TEST for Variance									
0.1039	0.1039	0.1112	0.1088	0.1015													
0.1124	0.1062	0.1148	0.1087	0.1087													
0.1184	0.1168	0.1160	0.1120	0.1160	RUN-IN	0.1166	0.0092	t*= 1.68	F*=1.98								
0.1273	0.1255	0.1185	0.1168	0.1215													
0.1324	0.1358	0.1253	0.1253	0.1267	XXXXXXXXXXXXXXXXXXXX												
0.1088	0.0893	0.0966	0.1088	0.0869													
0.1111	0.0952	0.0989	0.1209	0.0940													
0.1152	0.1012	0.1063	0.1256	0.1029	DESIGN	0.1123	0.0142	0.0908	0.4152								
0.1168	0.1145	0.1168	0.1308	0.1180				No	Yes								
0.1329	0.1226	0.1338	0.1338	0.1267	XXXXXXXXXXXXXXXXXXXX												
0.1137	0.0966	0.1015	0.1088	0.0942													
0.1185	0.0989	0.0927	0.1099	0.0964													
0.1232	0.1071	0.1021	0.1176	0.1087	CYCLE3	0.1145	0.0146	-0.0378	0.9397								
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													
Std Dev	0.0100	0.0131	0.0147	0.0100													

DATA SET 51-55				Alloy Code AZ			MEAN		STD	TEST for	TEST for	90/95 Tolerance
STUD1	STUD2	STUD3	STUD4	STUD5	VALUE	DEVIATION	Mean	Variance				
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				
0.0909	0.0844	0.0791	0.0844	0.0877	RUN-IN			F*=1.98				
0.0904	0.0847	0.0782	0.0831	0.0896				= 0.505				
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				
0.0834	0.0791	0.0758	0.0877	0.0791	DESIGN			F				
0.0814	0.0806	0.0749	0.0872	0.0855				0.2089	0.0072	0.0813	0.0091	0.0636
0.0867	0.0841	0.0756	0.0867	0.0905	XXXXXXXXXXXXXXXXXXXX			No				
0.0709	0.0805	0.0741	0.0773	0.0741				Yes				
0.0745	0.0808	0.0633	0.0776	0.0713				DESIGN vs CYCLE 3				
0.0834	0.0898	0.0726	0.0887	0.0801	CYCLE3			t				
0.0847	0.0888	0.0773	0.0896	0.0904				F				
0.0886	0.0886	0.0789	0.0924	0.0924				0.0033	0.0079	0.0812	0.1009	0.0616
								No				
								No				
Mean	0.0849	0.0841	0.0765	0.0846								
Std Dev	0.0072	0.0044	0.0058	0.0051								

DATA SET 56-60					Alloy Code AR1		90/95 Tolerance	
STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST for Mean 95% Confidence	TEST for Variance F*=1.98
0.1195	0.1289	0.1195	0.0934	0.1108			t*= 1.68	F*=1.98
0.1243	0.1180	0.1095	0.0905	0.1117				
0.1206	0.1132	0.0987	0.0987	0.1073	RUN-IN	0.1106	0.0099	= 0.505
0.1199	0.1144	0.1045	0.0979	0.1056				
0.1186	0.1195	0.1072	0.1037	0.1090	XXXXXXXXXXXXXXXXXXXX			
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
0.1254	0.1243	0.1199	0.1199	0.1265			No	No
0.1291	0.1274	0.1169	0.1186	0.1256	XXXXXXXXXXXXXXXXXXXX			
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
0.1166	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				
Std Dev	0.0039	0.0103	0.0071	0.0120				

90/95 Tolerance

TEST for
Variance

TEST for
Mean

STD
DEVIATION

MEAN
VALUE

Alloy Code MA

DATA SET 61-65

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

Mean
Std Dev

0.1224	0.1195	0.1304	0.1325	0.1280					
0.0121	0.0122	0.0131	0.0138	0.0195					

90/95 Tolerance

TEST for
Variance

TEST for
Mean

STD
DEVIATION

MEAN
VALUE

Alloy Code MA

DATA SET 61-65

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

Mean
Std Dev

0.1190	0.1159	0.1284	0.1278	0.1232					
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 VALUE	STD DEVIATION	TEST for	TEST for	90/95 Tolerance
STUD1	STUD2	STUD3	STUD4	STUD5	Mean	Variance					
0.0905	0.0933	0.0988	0.0960	0.0738							
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
0.0990	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
0.1101	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
0.1108	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 76-80					Alloy Code IMC3			MEAN VALUE	STD DEVIATION	TEST for		TEST for Variance	90/95 Tolerance
STUD1	STUD2	STUD3	STUD4	STUD5	DESIGN vs RUN-IN		F						
										t	No		
0.1082	0.1034	0.1082	0.1034	0.0986						0.3777	0.7405		
0.0962	0.0986	0.0962	0.0962	0.0841						No	No		
0.0990	0.0974	0.0974	0.1022	0.0860	RUN-IN								
0.0985	0.1070	0.1021	0.1021	0.0936									
0.1053	0.1182	0.1132	0.1092	0.0964	XXXXXXXXXXXXXXXXXXXX								
0.0986	0.0937	0.1082	0.0889	0.0889									
0.0865	0.0841	0.0889	0.0792	0.0744									
0.0795	0.0893	0.0795	0.0763	0.0747	DESIGN					0.1103	0.0665		
0.0887	0.0936	0.0899	0.0875	0.0789									
0.0924	0.1033	0.0983	0.0983	0.0884	XXXXXXXXXXXXXXXXXXXX								
0.0889	0.0889	0.0889	0.0937	0.0937									
0.0841	0.0841	0.0744	0.0841	0.0792									
0.0763	0.0779	0.0779	0.0763	0.0747	CYCLE3					1.7248			
0.0838	0.0838	0.0875	0.0875	0.0789				No		No			
0.0864	0.0934	0.0944	0.0973	0.0894									
Mean					0.0937		0.0922		0.0853				
Std Dev					0.0106		0.0103		0.0082				

DATA SET 96-100					Alloy Code MK				TEST for		90/95 Tolerance	
STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST for Mean	Variance	TEST for Variance			
0.1056	0.1186	0.1089	0.1154	0.1056			t*= 1.68	F*=1.98				
0.1012	0.1142	0.0931	0.1093	0.0979	RUN-IN	0.1046	0.0073					
0.1011	0.1165	0.0934	0.1055	0.1011								
0.1014	0.1145	0.0972	0.1047	0.0997								0.1227
0.1017	0.1108	0.0958	0.1036	0.0984	XXXXXXXXXXXXXXXXXXXX							0.0866
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
0.0980	0.1014	0.0980	0.0896	0.0980			No	No				0.0821
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
0.0997	0.0880	0.0829	0.0838	0.0905			No	No				0.0767
0.1004	0.0880	0.0800	0.0841	0.0899								
Mean	0.0984	0.1049	0.0949	0.0961								
Std Dev	0.0040	0.0111	0.0079	0.0101								

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	XXXXXXXXXX
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	XXXXXXXXXX
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	
Mean	0.1077	0.1044	0.0000	0.0000	
Std Dev	0.0158	0.0142	0.0000	0.0000	

DATA SET 106,107 Alloy Code MI					
STUD1	STUD2	STUD3	STUD4	STUD5	
0.1186	0.1186	ERR	ERR	ERR	ERR
0.1175	0.1158	ERR	ERR	ERR	ERR
0.1308	0.1319	ERR	ERR	ERR	ERR RUN-IN
ERR	ERR	ERR	ERR	ERR	ERR
ERR	ERR	ERR	ERR	ERR	ERR XXXXXXXXXXXXX
0.1154	0.1121	ERR	ERR	ERR	ERR
0.1093	0.1093	ERR	ERR	ERR	ERR
0.1220	0.1231	ERR	ERR	ERR	ERR DESIGN
ERR	ERR	ERR	ERR	ERR	ERR
ERR	ERR	ERR	ERR	ERR	ERR XXXXXXXXXXXXX
0.0927	0.1218	ERR	ERR	ERR	ERR
0.0947	0.1126	ERR	ERR	ERR	ERR
0.1099	0.1220	ERR	ERR	ERR	ERR CYCLE3
ERR	ERR	ERR	ERR	ERR	ERR
ERR	ERR	ERR	ERR	ERR	ERR
0.1123	0.1186	ERR	ERR	ERR	ERR
0.0124	0.0070	ERR	ERR	ERR	ERR
Mean					
Std Dev					

DATA SET 111,112 Alloy Code MCU									
STUD1	STUD2	STUD3	STUD4	STUD5					
0.1347	0.1403	ERR	ERR	ERR	ERR				
0.1154	0.1186	ERR	ERR	ERR	ERR				
0.1167	0.1231	ERR	ERR	ERR	ERR				
0.1175	0.1288	ERR	ERR	ERR	ERR				
0.1232	0.1375	ERR	ERR	ERR	ERR				
0.1065	0.1234	ERR	ERR	ERR	ERR				
0.0894	0.1056	ERR	ERR	ERR	ERR				
0.0820	0.1058	ERR	ERR	ERR	ERR				
0.0865	0.1093	ERR	ERR	ERR	ERR				
0.0932	0.1153	ERR	ERR	ERR	ERR				
0.0895	0.1178	ERR	ERR	ERR	ERR				
0.0959	0.1024	ERR	ERR	ERR	ERR				
0.0907	0.0972	ERR	ERR	ERR	ERR				
0.0914	0.1028	ERR	ERR	ERR	ERR				
0.0906	0.1036	ERR	ERR	ERR	ERR				
Mean	0.1015	ERR	ERR	ERR	ERR				
Std Dev	0.0160	ERR	ERR	ERR	ERR				

DATA SET 116, 117 Alloy Code MH

STUD1	STUD2	STUD3	STUD4	STUD5	
0.1478	0.1348	ERR	ERR	ERR	ERR
0.1337	0.1337	ERR	ERR	ERR	ERR
0.1385	0.1440	ERR	ERR	ERR	ERR RUN-IN
0.1338	0.1451	ERR	ERR	ERR	ERR
0.1310	0.1496	ERR	ERR	ERR	ERR XXXXXXXXXXXXXXXXXXXXXXXX
	0.1024	ERR	ERR	ERR	ERR
	0.0931	ERR	ERR	ERR	ERR
	0.0989	ERR	ERR	ERR	ERR DESIGN
	0.1039	ERR	ERR	ERR	ERR
	0.1114	ERR	ERR	ERR	ERR XXXXXXXXXXXXXXXXXXXXXXXX
	0.0862	ERR	ERR	ERR	ERR
	0.0865	ERR	ERR	ERR	ERR
	0.0945	ERR	ERR	ERR	ERR CYCLE3
	0.1056	ERR	ERR	ERR	ERR
	0.1095	ERR	ERR	ERR	ERR
Mean	0.1118	ERR	ERR	ERR	ERR
Std Dev	0.0201	ERR	ERR	ERR	ERR

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

DATA SET 131-135 Alloy Code II										90/95 Tolerance	
STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST for Mean 95% Confidence t*= 1.68	TEST for Variance F*= 1.98			
0.1421	0.1469	0.1469	0.1662	0.1662							
0.1325	0.1325	0.1640	0.1591	0.1664							
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	XXXXXXXXXXXXXXXXXXXX						
0.1276	0.1421	0.1324	0.1566	0.1276							
0.1107	0.1277	0.1204	0.1277	0.1277							
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	XXXXXXXXXXXXXXXXXXXX						
0.1131	0.1228	0.1228	0.1179	0.1276							
0.1011	0.0986	0.1083	0.1035	0.1132							
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							
Std Dev	0.0194	0.0216	0.0245	0.0238							

DATA SET 136-140				Alloy Code SS		Studs 136-139 only		MEAN VALUE	STD DEVIATION	TEST for Mean t*=1.70	TEST for Variance F*=2.47	90/95 Tolerance
STUD1	STUD2	STUD3	STUD4	STUD5	STUD6	STUD7	STUD8					
0.1293	0.1223	0.1362	0.1129	0.1176								
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
0.1157	0.1258	0.1313	ERR	ERR	ERR							0.1013
ERR	ERR	ERR	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX						
0.0990	0.0873	0.0966	0.0756	0.0733								
0.1003	0.1062	0.0908	0.0885	0.0861								
0.1022	0.1108	0.1038	0.1046	0.0902	DESIGN			0.0999	0.0105	0.7095	0.9852	0.1284
0.1084	0.1140	0.1101	ERR	ERR	ERR					No	No	0.0713
ERR	ERR	ERR	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXX						
0.0709	0.0756	0.0826	0.0990	0.0756								
0.0838	0.0979	0.0861	0.1003	0.0779								
0.0942	0.1108	0.0950	0.1100	0.0797	CYCLE3			0.0967	0.0141	0.0647	0.5553	0.1350
0.1017	0.1157	0.1028	0.1207	0.0794						No	No	0.0584
ERR	ERR	ERR	ERR	ERR	ERR							
Mean	0.1048	0.1107	0.1071	0.0932								
Std Dev	0.0178	0.0170	0.0241	0.0174								

[illegible]

DATA SET 146-150				Alloy Code AZ		MEAN VALUE	STD DEVIATION	TEST for	TEST for	90/95 Tolerance
STUD1	STUD2	STUD3	STUD4	STUD5	Mean			Variance		
0.0931	0.1026	0.0900	0.1058	0.1090						
0.0935	0.1078	0.0856	0.0840	0.1063						
0.0930	0.1113	0.0898	0.0855	0.0984	RUN-IN	0.0966	0.0090	t*= 1.68	F*=1.98	
0.0962	0.1130	0.0896	0.0888	0.0954					= 0.505	
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	
0.0880	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	
0.0896	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						
Std Dev	0.0061	0.0072	0.0092	0.0097						
								</		

DATA SET 151-155 Alloy Code AR1										90/95 Tolerance	
STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST for Mean 95% Confidence t*= 1.68	TEST for Variance F*=1.98 = 0.505			
0.1108	0.1152	0.1242	0.1152	0.1242							
0.1117	0.1159	0.1159	0.1138	0.1180							
0.1073	0.1192	0.1221	0.1206	0.1132	RUN-IN	0.1167	0.0054			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							
0.1095	0.1095	0.1050	0.1138	0.1138							
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							
0.1074	0.1095	0.1050	0.1138	0.1222							
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							
Std Dev	0.0032	0.0047	0.0067	0.0056							

90/95 Tolerance

MEAN
VALUE

Alloy Code MA

DATA SET 156-160

STUD1

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST for Mean 95% Confidence	TEST for Variance F*	90/95 Tolerance
0.0900	0.1152	0.1102	0.1102	0.1001					
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
0.0989	0.1118	0.1196	0.1092	0.1079					0.0749
0.1165	0.1175	0.1340	0.1360	0.1299	XXXXXXXXXXXXXXXXXXXX				
0.0900	0.1203	0.1102	0.1051	0.1152					
0.0888	0.1173	0.1038	0.0938	0.1063					
0.0999	0.1065	0.1021	0.1065	0.1021	DESIGN	0.1064	0.0085	DESIGN vs RUN-IN t	
0.1053	0.1105	0.1066	0.1053	0.0963				No	0.1275
0.1062	0.1072	0.1186	0.1186	0.1165	XXXXXXXXXXXXXXXXXXXX			Yes	0.0853
0.1051	0.0950	0.1001	0.1051	0.0950					
0.0913	0.0860	0.0988	0.1038	0.0963					
0.0934	0.0836	0.0978	0.1094	0.1065	CYCLE3	0.1011	0.0084	DESIGN vs CYCLE 3 t	
0.0976	0.0989	0.0976	0.1118	0.1028				No	0.1218
0.1083	0.1000	0.1134	0.1144	0.1155				No	0.0804

Mean

Std Dev

90/95 Tolerance

MEAN
VALUE

Alloy Code MA

DATA SET 156-160

STUD1

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST for Mean 95% Confidence	TEST for Variance F*	90/95 Tolerance
0.0900	0.1152	0.1102	0.1102	0.1001					
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
0.0989	0.1118	0.1196	0.1092	0.1079					0.0789
0.0900	0.1203	0.1102	0.1051	0.1152	XXXXXXXXXXXXXXXXXXXX				
0.0888	0.1173	0.1038	0.0938	0.1063					
0.0999	0.1065	0.1021	0.1065	0.1021	DESIGN	0.1046	0.0082	DESIGN vs RUN-IN t	
0.1053	0.1105	0.1066	0.1053	0.0963				No	0.1257
0.1062	0.1072	0.1186	0.1186	0.1165	XXXXXXXXXXXXXXXXXXXX			1.3146	0.0835
0.1051	0.0950	0.1001	0.1051	0.0950					
0.0913	0.0860	0.0988	0.1038	0.0963					
0.0934	0.0836	0.0978	0.1094	0.1065	CYCLE3	0.0988	0.0072	DESIGN vs CYCLE 3 t	
0.0976	0.0989	0.0976	0.1118	0.1028				No	0.1172

Mean

Std Dev

* 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 VALUE	STD DEVIATION	TEST for Mean 95% Confidence t*= 1.68	TEST for Variance F*=1.98	90/95 Tolerance
STUD1	STUD2	STUD3	STUD4	STUD5							
0.1044	0.0988	0.0933	0.0905	0.0877							
0.0965	0.1063	0.0938	0.0938	0.0910							
0.1009	0.1066	0.0943	0.0971	0.0933	RUN-IN	0.0967	0.0052			0.1096	0.0839
0.0983	0.1046	0.0935	0.0976	0.0907							
0.1008	0.1018	0.0937	0.0965	0.0926	XXXXXXXXXXXXXXXXXXXX						
0.0794	0.0905	0.0877	0.0738	0.0766							
0.0812	0.0993	0.0924	0.0868	0.0840							
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	XXXXXXXXXXXXXXXXXXXX						
0.0766	0.0933	0.0683	0.0794	0.0794							
0.0854	0.0938	0.0910	0.0910	0.0826							
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							
Std Dev	0.0083	0.0048	0.0070	0.0065							

DATA SET 166-170 Alloy Code AS										90/95 Tolerance	
STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST for Mean 95% Confidence t*= 1.701	TEST for Variance F*=2.49			
0.0827	0.0752	0.0559	0.0660	0.1127							
0.0892	0.0736	0.0750	0.0712	0.1286							
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							
Std Dev	0.0149	0.0035	0.0186	0.0098							

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	XXXXXXXXXX		
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	XXXXXXXXXX		
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			
Std Dev	0.0092	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			
Std Dev	0.0061	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	XXXXXXXXXX		
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	XXXXXXXXXX		
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			
Std Dev	0.0128	0.0000	0.0000	0.0000			

DATA SET 186 Alloy Code IMB									
STUD1	STUD2		STUD3		STUD4		STUD5		
0.1009	ERR	ERR			ERR	ERR	ERR	ERR	ERR
0.1102	ERR	ERR			ERR	ERR	ERR	ERR	ERR
0.1286	ERR	ERR			ERR	ERR	ERR	ERR	ERR RUN-IN
0.1280	ERR	ERR			ERR	ERR	ERR	ERR	ERR
ERR	ERR	ERR			ERR	ERR	ERR	ERR	ERR XXXXXXXXXXXX
	0.1009	ERR	ERR		ERR	ERR	ERR	ERR	ERR
	0.1063	ERR	ERR		ERR	ERR	ERR	ERR	ERR
	0.1192	ERR	ERR		ERR	ERR	ERR	ERR	ERR DESIGN
	0.1207	ERR	ERR		ERR	ERR	ERR	ERR	ERR
	ERR	ERR	ERR		ERR	ERR	ERR	ERR	ERR XXXXXXXXXXXX
	0.0782	ERR	ERR		ERR	ERR	ERR	ERR	ERR
	0.0964	ERR	ERR		ERR	ERR	ERR	ERR	ERR
	0.1089	ERR	ERR		ERR	ERR	ERR	ERR	ERR CYCLE3
	0.1191	ERR	ERR		ERR	ERR	ERR	ERR	ERR
	ERR	ERR	ERR		ERR	ERR	ERR	ERR	ERR
Mean	0.1098	ERR	ERR		ERR	ERR	ERR	ERR	ERR
Std Dev	0.0145	ERR	ERR		ERR	ERR	ERR	ERR	ERR

DATA SET 191-195					Alloy Code MK		MEAN VALUE	STD DEVIATION	TEST for Mean 95% Confidence t*= 1.68 F*=1.98	TEST for Variance F	90/95 Tolerance
STUD1	STUD2	STUD3	STUD4	STUD5							
0.1348	0.1186	0.1121	0.1380	0.1348							
0.1256	0.1191	0.1093	0.1288	0.1272							
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	XXXXXXXXXXXXXXXXXXXX						
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	XXXXXXXXXXXXXXXXXXXX						
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							
Std Dev	0.0070	0.0093	0.0045	0.0065							

DATA SET 196-200	Alloy Code 1				MEAN VALUE	STD DEVIATION	TEST for Mean 95% Confidence t*= 1.68 F*=1.98 = 0.505	TEST for Variance	90/95 Tolerance
	STUD2		STUD3						
	STUD1	STUD2	STUD3	STUD4					
0.1131	0.1034	0.1131	0.1082	0.0986					
0.0914	0.0914	0.1035	0.0889	0.0865					
0.0974	0.0909	0.0990	0.0941	0.0860	RUN-IN	0.0967			
0.0972	0.0911	0.1009	0.0862	0.0924					0.1161
0.0993	0.0924	0.1063	0.0904	0.0964	XXXXXXXXXXXXXXXXXXXX				0.0773
0.0937	0.0889	0.1034	0.1034	0.1034					
0.0744	0.0792	0.0986	0.0865	0.0914					
0.0941	0.0812	0.0957	0.0844	0.0925	DESIGN	0.0926			
0.0850	0.0875	0.0985	0.0887	0.0985					0.1136
0.0914	0.0914	0.1112	0.0914	0.1003	XXXXXXXXXXXXXXXXXXXX				0.0715
0.0840	0.0840	0.0937	0.1034	0.0986					
0.0744	0.0792	0.0914	0.0962	0.0914					
0.0730	0.0812	0.1038	0.0957	0.0909	CYCLE3	0.0915			
0.0801	0.0875	0.1058	0.0936	0.0960					0.1162
0.0864	0.0874	0.1132	0.0964	0.1003					0.0669
Mean	0.0890	0.0878	0.1025	0.0938					
Std Dev	0.0110	0.0063	0.0067	0.0069					

DATA SET 201-205					Alloy Code ICR		STUD5	STD DEVIATION	TEST for Mean 95% Confidence t*=1.68	TEST for Variance F*=1.98	90/95 Tolerance
STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE						
0.1469	0.1131	0.1034	0.1082	0.1518							
0.1398	0.1011	0.0914	0.1011	0.1277							
0.1362	0.1022	0.0925	0.1006	0.1265	RUN-IN						
0.1363	0.1021	0.0985	0.0997	0.1241							0.1608
0.1396	0.1082	0.1053	0.1013	0.1290	XXXXXXXXXXXXXXXXXXXX						0.0701
0.1228	0.1324	0.1034	0.1131	0.1131							
0.1107	0.1204	0.0914	0.0938	0.1035							
0.1071	0.1152	0.0925	0.0957	0.1006	DESIGN						
0.1180	0.1131	0.0936	0.0997	0.1034							0.1366
0.1300	0.1172	0.1013	0.1033	0.1132	XXXXXXXXXXXXXXXXXXXX						0.0801
0.1034	0.1324	0.1082	0.1131	0.1179							
0.1059	0.1083	0.0986	0.0986	0.1035							
0.1119	0.1119	0.0990	0.1006	0.1038	CYCLE3						
0.1119	0.1131	0.0985	0.1046	0.1046							
0.1241	0.1211	0.1043	0.1082	0.1102							0.1297
Mean	0.1230	0.1141	0.0988	0.1028							0.0878
Std Dev	0.0143	0.0096	0.0055	0.0057							

DATA SET 206-210				Alloy Code A			MEAN VALUE	STD DEVIATION	TEST for Mean 95% Confidence t*= 1.68 F*=1.98 = 0.505	TEST for Variance	90/95 Tolerance
STUD1	STUD2	STUD3	STUD4	STUD5	RUN-IN						
0.1044	0.0988	0.1016	0.0988	0.0933							
0.1077	0.1063	0.1063	0.1077	0.1021							
0.1066	0.1085	0.1123	0.1076	0.1057	RUN-IN		0.1051	0.0044			
0.1066	0.1073	0.1115	0.1046	0.1046							0.1161
0.1034	0.1050	0.1136	0.1018	0.1024	XXXXXXXXXXXXXXXXXXXX						0.0942
0.0933	0.0933	0.0988	0.0877	0.0933							
0.1105	0.1035	0.1091	0.0965	0.1035							
0.1094	0.1066	0.1218	0.1057	0.1066	DESIGN		0.1055	0.0081	-0.0165	0.2976	0.1256
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							
0.1105	0.0952	0.1119	0.0965	0.1063							
0.1142	0.1047	0.1161	0.0962	0.1057	CYCLE3		0.1045	0.0098	0.0290	0.6837	0.1288
0.1122	0.1080	0.1163	0.0983	0.1108					No	No	
0.1120	0.1104	0.1146	0.0992	0.1130							
Mean	0.1057	0.1042	0.1109	0.0989	0.1046						
Std Dev	0.0057	0.0069	0.0064	0.0081	0.0058						

Mean

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	10A	10B	1	3	6	10A	10B	1	3	6	10A	10B	1	3	6	10	10	B
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						136 10 A B				
	1	3	6	10A	10B		1	3	6	10A	10B		1	3	6	10A	10B						
N5000	175	175	175	175	175		95	100	95	95	97		177	175	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	10A	10B	1	3	6	10A	10B	1	3	6	10A	10B	1	3	6	10	10	A	B	
N5000	230	230	230	230	231	155	135	150	150	160	230	230	230	230	232	275	321	284	283				
N1000	230	230	230	230	230	150	151	150	151	155	231	229	230	230	232	227	338	245	255				
Neolube No.650	230	228	230	231	230	112	100	134	109	112	229	230	230	230	229	270	309	222	222				
NIKAL	237	230	234	231	230	194	175	186	170	170	236	230	229	230	230	515	482	450	412				
N2000	228	231	230	231	230	138	148	145	145	148	232	230	234	230	229	240	281	238	282				
Never Seez	231	232	229	234	230	150	152	141	154	157	232	230	230	230	231	261	401	390	323				
NM-91	230	230	230	230	231	171	170	165	169	180	231	231	229	230	230	299	422	309	350				
Molykote P37	228	231	229	230	232	151	160	157	156	157	228	230	230	231	230	202	244	250	263				
MDSI	231	230	229	230	231	135	141	121	131	137	229	229	230	230	230	161	138	220	150				
RLGMO	230	232	232	234	230	156	156	146	152	151	230	229	234	230	230	183	220	280	210				

+ 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 -2	193	219	228	220	251	211	205	228	340	309	308	316	12		
	229	185	229	219	225	205	221	211	350	325	324	332	12		
N1000 -1 -2	190	205	209	212	206	202	210	203	310	307	352	323	12		
	240	218	245	221	239	222	220	222	380	348	352	338	12		
Neolube -1 No. 650 -2	198	170	160	149	148	141	135	134	260	215	212	212	12	Coats uneven	
	132	130	118	115	114	110	110	120	189	213	222	231	12		
NIKAL -1 -2	320*	444*	416*	342*									1	Discontinued	
	303	375*	410*	355*									2	Discontinued	
N2000 -1 -2	233	195	178	175	216	219	193	203	360	352	338	301	12		
	224	215	220	222	229	233	232	238	313	311	326	330	12		
Never -1 Seez -2	229	197	199	200	185	202	200	221	469	403	395	380	12		
	220	230	203	217	165	210	229	212	304	419	351	354	12		
NM-91 -1 -2	274	274	256	243	250	255	242	232	458	409	400	364	No Galling		
	320	284	284	254	272	260	245	249	439	369	330	312	No Galling		
Molykote -1 P37 -2	211	209	210	210	209	211	221	210	380	403	360	350	12		
	221	225	231	222	238	231	220	220	372	389	358	360	12		
MDSI -1 -2	274	246	305	304	186	245	282	281	277	402	450	483	12		
	221	192	239	276	223	235	251	315	332	382	462	494	12		
RLGMO -1 -2	168	158	148	142	139	135	152	136	244	221	243	262	12		
	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 -1	130	123	110	101	93	89	82	81	144	147	135	129	
No. 650 -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 -1	165	140	149	142	134	145	135	151	325	294	294	279	
Seez -2	161	169	138	150	112	140	163	157	218	265	249	253	
NIM-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 -1	140	140	131	133	142	139	139	137	259	238	228	228	
P37 -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 1-6 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 -2	215	204	192	179	188	180	170	165	370	285	261	255	12	
	187	185	210	182	180	170	170	163	290	255	251	249	12	
N1000 -1 -2	152	169	178	178	159	153	149	151	275	236	224	222	12	
	179	155	158	160	160	157	155	156	263	262	240	266	12	
Neolube -1 No. 650 -2	159	153	125	125	150	131	131	110	313	220	179	180	12	
	200	209	171	159	148	149	171	131	300*	249	250	219	12	
NIKAL -1 -2	262	310*	315*	308*	345*	295*	270*						2	Discontinued
	303	298*	300*	289*	284*	294*							2	Discontinued
N2000 -1 -2	197	169	192	169	211	201	179	206	322	275	291	245	No Galling	
	232	182	182	172	202	194	195	191	339	269	253	268	No Galling	
Never -1 Seez -2	210	175	168	161	191	165	160	155	311	250	243	249	12	Gouges
	191	192	174	181	217	208	196	188	410*	220	270	272	12	
NM-91 -1 -2	95	186	193	190	209	189	189	182	342	276	259	252	12	
	228	190	190	183	218	218	191	180	313	269	348	346	12	
Molykote -1 P37 -2	206	195	180	185	170	171	165	170	380*	280	265	260	12	
	167	154	150	141	162	161	167	165	285	275	263	285	12	
MDSI -1 -2	219	270	255	222	178	178	182	190	319	418	460*	345*	8	
	175	160	178	180	220	232	270	279	435*	470*	460*	420*	8	
RLGMO -1 -2	163	170	152	128	163	126	132	125	220	219	172	156	No Galling	
	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 -2	140	155	150	135	135	130	120	120	275	220	190	180	
	125	131	140	125	131	129	123	121	221	196	195	185	
N1000 -1 -2	105	110	103	110	114	115	111	109	164	159	154	156	
	121	109	100	98	106	112	112	102	178	181	167	166	
Neolube -1 No. 650 -2	116	115	95	89	109	90	86	78	204	149	118	120	
	*	*	130	123	100	102	120	99	300*	190	190	162	
NIKAL -1 -2	170	220*	238*	259*	230*	236*	233*						Discontinued
	209	265	262*	250*	211*	231*							Discontinued
N2000 -1 -2	135	118	126	120	128	132	119	121	211	201	199	188	
	148	120	116	115	151	139	139	140	223	199	186	193	
Never -1 Seez -2	159	135	123	120	140	129	122	119	249	199	184	186	
	142	155	131	134	180	169	162	148	970*	200	205	208	
NM-91 -1 -2	161	151	142	150	160	149	139	131	265	214	200	179	
	160	142	142	139	180	159	142	141	240	210	185	184	
Molykote -1 P37 -2	161*	160	142	150	140	130	126	132	350*	211	200	190	
	119	110	110	111	110	109	105	103	199	199	197	202	
MDSI -1 -2	162	200	160	139	135	111	100	99	219	275	298*	330*	
	132	112	121	140	171	205	202	203	264	271	250*	290*	
RLGMO -1 -2	118	123	118	100	128	97	98	92	169	160	128	112	
	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 -2	250	228	221	216	221	213	210	213	333	365	380	389	12		
	206	215	218	214	200	204	229	242	338	363	400	406	12		
N1000 -1 -2	246	244	245	257	225	249	248	262	379	369	400	430	12		
	215	274	270	260	214	230	224	214	342	366	393	406	12		
Neolube -1 No. 650 -2	159	148	149	148	136	130	136	136	214	230	260	251	12	Deep Gouges	
	173	132	132	130	135	138	134	138	232	230	260	272	12	Deep Gouges	
NIKAL -1 -2	298	300	301	290	318	323	322	334	530	578	545	548	12		
	278	259	289	295	311	329	335	333	463	468	472	485	12		
N2000 -1 -2	209	252	233	228	232	244	238	243	319	331	310	298	12		
	235	224	235	220	247	220	236	254	368	388	363	393	12		
Never -1 Seez -2	212	202	207	210	200	206	212	222	450	389	386	396	12		
	200	193	399	207	185	178	183	186	279	269	305	311	12		
NM-91 -1 -2	227	223	208	201	230	219	208	205	388	391	357	351	No Galling		
	230	230	225	220	258	277	258	236	411	397	414	403	No Galling		
Molykote -1 P37 -2	202	199	199	199	214	233	202	202	398	353	349	349	No Galling		
	225	235	204	219	218	211	225	213	369	355	380	350	No Galling		
MDSI -1 -2	292	328	340	369	264	343	384	417	372	421	545	600	12		
	212	233	250	253	272	350	423	425	546	529	555	600	12		
RLGMO -1 -2	199	181	183	187	175	176	180	180	327	312	270	278	No Galling		
	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 -1	110	98	92	88	80	72	80	80	122	138	142	142	
No. 650 -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 -1	150	148	150	155	140	151	156	167	321	261	289	271	
Seez -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 -1	139	136	135	142	155	141	148	145	237	218	215	212	
P37 -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.