TORQUE TENSION TESTING OF FASTENERS USED FOR NASA FLIGHT HARDWARE APPLICATIONS

Ed Hemminger, Alan Posey and Michael Dube

NASA Goddard Space Flight Center

Greenbelt, Maryland 20771

ABSTRACT

The effect of various lubricants and other compounds on fastener torque-tension relationships is evaluated. Testing was performed using a unique test apparatus developed by Posey at the NASA Goddard Space Flight Center. A description of the test methodology, including associated data collection and analysis will be presented. Test results for 300 series CRES and A286 heat resistant fasteners, torqued into various types of inserts will be presented. The primary objective of this testing was to obtain torque-tension data for use on NASA flight projects.

1.0 INTRODUCTION

Threaded fasteners are used extensively in flight hardware assembly at the Goddard Space Flight Center. The reliability and safety of the assembly is dependent primarily on the preload which is applied by trained and certified technicians using a calibrated torque wrench of the proper size. It has been shown that most of the applied torque is used in overcoming the head bearing and thread friction leaving only a small fraction for fastener elongation or tension resulting in joint pre-load application. The torque tension relationship is therefore highly dependent on the friction coefficients and lubrication applied to the threads and washer to bolt head bearing surfaces. . Even the most reliable torque application methods have been shown to result in wide scatter and do not accurately predict the joint preload. This can result in premature joint or fastener failure due to over or under estimation of the applied preload. Typical failure mechanisms are vibration loosening, fastener fatigue due to insufficient preload or joint failure due to excessive preload.

Alan Posey has developed a new bolt preload measurement system which incorporates three miniature load cells and an instrumented torque wrench for measurement of applied torque and joint preload see Figures 1.1 and 1.2 below.

Figure 1.1 Bolt Preload Test Fixture & Test Plate

Figure 1.2 Bolt Preload Measurement System

In the past, one load washer was typically used for torque tension testing but this was not practical for the smaller #0 to #6 size fasteners as load washers this size were not available. The system consists of three load cells mounted in a high strength steel fixture plate in an equilateral triangle configuration. A counter-bored bushing, sized for the fastener being tested, is centered in this triangular pattern. The system is connected to a laptop computer with Labview and Matlab software for data collection and analysis, Figure 1.3. Fastener from size #0 to 1/4" diameter have been tested using this system.

Governing Equation:

- ***T=KDP***
-
- ***T=Torque,***
-
- ***K=Torque Coefficient,***
-
- ***D=Bolt Dia,***
-
- ***P=Preload***

Testing to Determine "*K*"

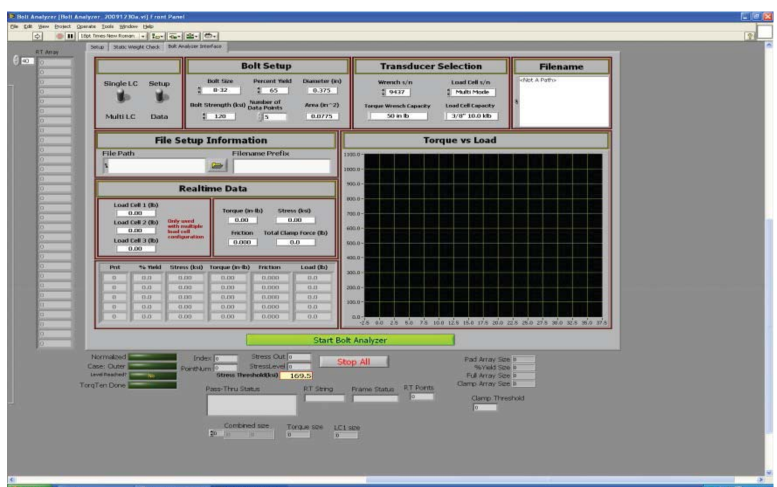


Figure 1.3 Bolt Analyzer Interface

2.0 TEST OBJECTIVES

The primary objective was to obtain torque-tension data for use of various lubricants such as Braycote 601EF and compounds such as Arathane and Super Koropon. Arathane has been used as a thread locking compound to replace worn out locking features on helical-wire inserts and Super Koropon is used as a corrosion inhibitor/sealer on threaded fasteners and inserts as specified in NASA/JSC PRC-4004, "*Sealing of Joints and Faying Surfaces"*. Some secondary objectives of this testing was to identify the effect of the following variables on torque coefficient (or nut factor) and running torque:

- Multiple cycling of locking inserts.
- Fastener and washer replacement in multiple cycling of inserts.
- The use of multiple lot and or multiple type inserts of a given size.
- The use of Ultrasonic cleaning in IPA of all hardware as compared to use in as received, un-cleaned condition.

3.0 SMALL FASTENER TESTING (#2, #4 & #6)

Torque-tension testing of A286 and 300-series CRES fasteners threaded into free running phosphor bronze and silver plated CRES helical-wire inserts was performed using the system developed by Posey. Fastener testing was performed both with a low outgassing flight-approved lubricant (Braycote 601EF) and dry insertion. Torque-tension measurements were taken up to 65% of the fastener yield strength which represents the standard preload currently used at Goddard. Both torque and preload were measured at five equally spaced increments up to the target preload. All hardware was ultrasonically cleaned and handled with gloves similar to flight..

Each fastener tested was torque cycled three times while each insert was cycled six times. After three torque cycles into a given insert, the fasteners and washers were replaced with new hardware and re-lubricated. Separate test plates were used for dry and Braycote lubricated samples. Lubrication was applied to the threads and under the fastener head. The fasteners were torqued at a rate of approximately 6 rpm until the target preload was reached. The data tables and plots below, provide a summary of the statistics for the torque coefficient (K) for fasteners installed both lubricated and dry into two different types of helical-wire inserts (Silver Plated CRES and Phosphor Bronze). The standard deviation of the torque coefficient was calculated for each grouping and also combined for all groups. The B-Basis tolerance limit factors of Kmax and Kmin were also calculated based on the sample size and are given in the tables below. Running torque was included in all measured torque values.

3.1 SMALL FASTENER TEST RESULTS AND CONCLUSIONS

Table 3.1 and Figures 3.1 and 3.2 below, provide a summary of the statistics for the torque coefficient (K) for each of the types of fasteners into the different types of inserts (Silver Plated CRES and Phosphor Bronze).

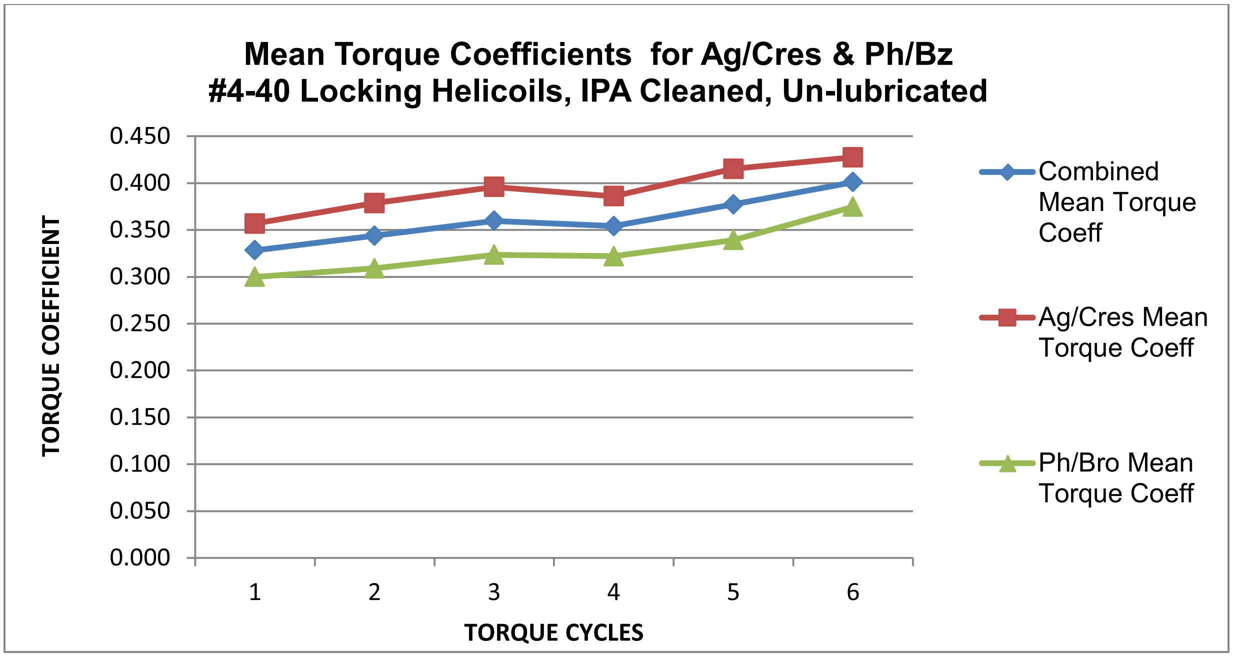


Figure 3.1 Unlubricated Cyclic Mean Torque Coefficients Example

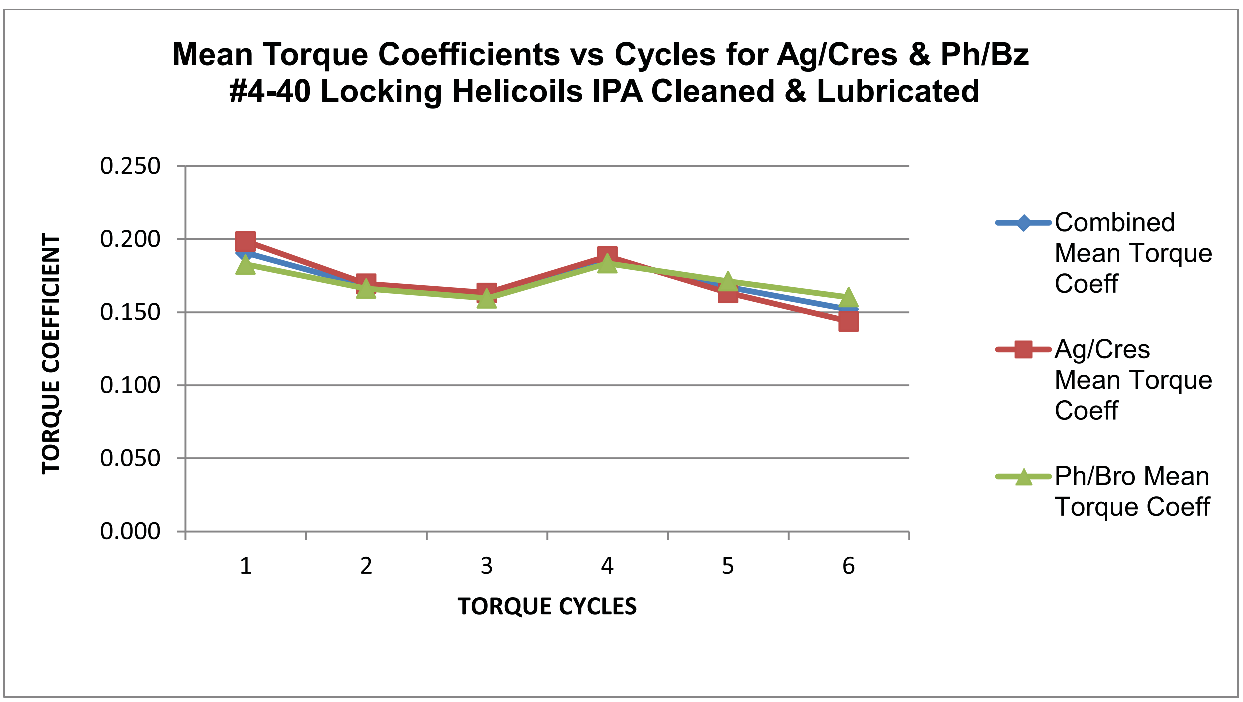


Figure 3.2 Lubricated Cyclic Mean Torque Coefficients Example

Table 3.1 Phosphor Bronze Data Summary

	Phosphor Bronze Inserts											
	Wet Lubrication						Dry					
Fastener	Mean Torque Coefficient K	STD Dev	No. Samples	Tolerance Limit Factor	B-Basis Limits K-Low	B-Basis Limits K-High	Mean Torque Coefficient K	STD Dev	No. Samples	Tolerance Limit Factor	B-Basis Limits K-min	B-Basis Limits K-max
A286	0.169	0.024	48	1.654	0.129	0.210	0.373	0.084	46	1.664	0.233	0.513
300 CRES	0.174	0.022	36	1.725	0.136	0.211	0.339	0.028	36	1.725	0.290	0.387
NAS1352N A286	0.182	0.032	18	1.974	0.119	0.244	0.401	0.102	17	2.002	0.198	0.605
NAS1101 A286	0.167	0.016	18	1.974	0.135	0.198	0.375	0.071	18	1.974	0.236	0.514
NAS8100/1 A286	0.154	0.017	12	2.21	0.117	0.192	0.326	0.056	11	2.275	0.199	0.453
NAS 1352C 300 CRES	0.170	0.018	18	1.974	0.133	0.206	0.333	0.028	18	1.974	0.278	0.389
MS51957 300 CRES	0.181	0.025	18	1.974	0.132	0.231	0.344	0.028	18	1.974	0.289	0.399

	Silver Plated Inserts											
	Wet Lubrication						Dry					
Fastener	Mean Torque Coefficient K	STD Dev	No. Samples	B-Basis Tolerance Limit Factor	B-Basis Limits K-Low	B-Basis Limits K-High	Mean Torque Coefficient K	STD Dev	No. Samples	Tolerance Limit Factor	B-Basis Limits K-Low	B-Basis Limits K-High
A286	0.165	0.019	48	1.654	0.134	0.197	0.422	0.098	45	1.664	0.259	0.585
300 CRES	0.180	0.025	36	1.725	0.137	0.224	0.413	0.081	36	1.725	0.273	0.552
NAS1352N A286	0.173	0.022	18	1.974	0.129	0.216	0.432	0.072	17	2.002	0.287	0.577
NAS1101 A286	0.160	0.013	18	1.974	0.134	0.187	0.444	0.106	18	1.974	0.234	0.653
NAS8100/1 A286	0.162	0.017	12	2.210	0.125	0.199	0.225	0.021	10	2.355	0.175	0.275
NAS 1352C 300 CRES	0.174	0.028	18	1.974	0.119	0.230	0.429	0.074	18	1.974	0.283	0.575
MS51957 300 CRES	0.186	0.021	18	1.974	0.145	0.227	0.396	0.086	18	1.974	0.226	0.566

Conclusions and Observations based on the results above:

1. For dry un-lubricated cases, the torque coefficient was found to increase with cycles, whereas for the lubricated cases the reverse was true.
2. The dispersion (standard deviation) of the torque coefficient for all the groups of fasteners was much greater for the dry installation verses the lubricated installation. The smaller dispersion for lubrication make it a better choice (when acceptable to the project) than installing dry since there is less uncertainty with the torque-tension relationship
3. The torque coefficients for dry silver plated CRES inserts were higher than for phosphor bronze inserts. In addition, the dispersion was also higher for the dry silver plated CRES inserts. This was more pronounced for larger size fasteners and goes counter to the assumption that silver plating will act as an effective lubricant. For lubricated samples there was little difference.
4. The torque coefficients for smaller fasteners were found to be higher than those specified by the Goddard Torque Guideline. In this document the lubricated torque coefficient is specified at 0.15 and dry coefficient at 0.2. Based on the small fastener test results these values were revised to a wet coefficient of 0.18 and dry coefficient of 0.37. Also, based on un-cleaned test results, a coefficient of 0.25 was specified for dry un-cleaned samples.

4.0 ARATHANE TESTING

The purpose of this testing was to determine the differences in torque coefficient when applying Arathane 5753 thread locking compound versus Braycote 601EF lubricant to the fasteners at installation. The use of Arathane as a secondary locking feature, was proposed when locking inserts were worn due to repeated torque application cycles. The test sequence was as follows:

- First the locking phosphor bronze inserts were worn by (10) torque application cycles to 65% yield. This was performed for three different size inserts, #8, #10 and 1/4" with Braycote lubrication applied to the fastener threads and washer to bolt head bearing surface for first cycles only.
- During each of the (10) torque application cycles, torque-tension measurements were recorded.
- After ten cycles, the worn insert was thoroughly cleaned and a new fastener and washer were installed with Arathane applied to threads and washer to bolt head bearing surface.

Also investigated was the case where a new fastener is installed into a new locking phosphor bronze insert with both Arathane and Braycote. Two different cleaning agents, (IPA and HFE7100) for removal of the Braycote lubricant from worn inserts were also investigated.

4.1 ARATHANE TEST RESULTS AND CONCLUSIONS

The average torque coefficients (Kmean) were determined by two methods as follows:

1. First method was to use the average total torque at the target preload of 65% fastener yield.
2. The second more involved method was to perform a linear regression curve fit of actual test data and determine the torque coefficient from the slope of the linear regression curve. As shown in the Table below, there was little difference between the two methods for the various data sets.

Table 4.1 Torque Coefficient Comparison: Average vs Linear Regression Method

Configuration	Ave Torque Coeff @ 65%	Ave Torque Coeff Linear Regression (LR)	% Difference of Methods
Worn #8 Braycote	0.145	0.137	5.4
Worn #8 Arathane	0.284	0.277	2.6
Worn #10 Braycote	0.175	0.168	4.2
Worn #10 Arathane	0.314	0.312	0.6
Worn 1/4" Braycote	0.227	0.219	3.5
Worn 1/4" Arathane	0.316	0.321	1.8

A comparison of torque coefficients for use of Arathane and Braycote is shown in the Figure 4.1 below. The cyclic data was combined into one data set for each fastener/insert size to generate this comparison data plot.

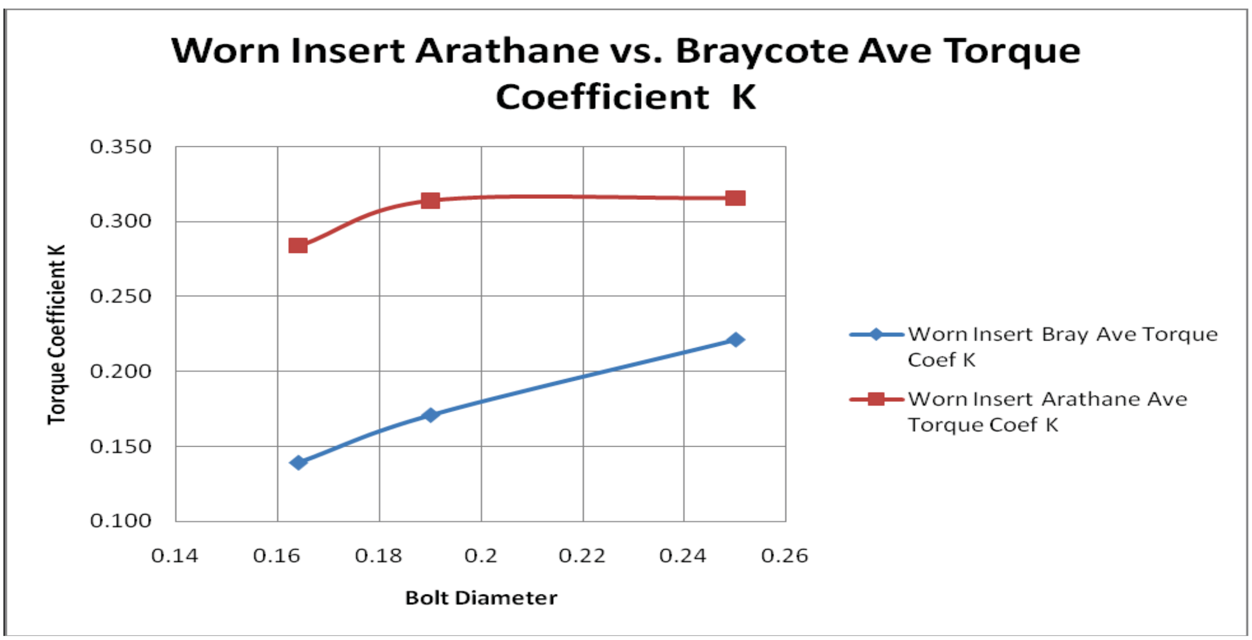


Figure 4.1 Arathane and Braycote Torque Coefficient Comparison

A typical plot of torque coefficients for individual torque application cycles is shown in Figure 4.2 below for #10-32 size fasteners. Cycles 1-10 are Braycote wear cycles, cycle 11 is for a new fastener and washer used in the worn insert with Arathane and cycle 12 for a new fastener and washer used in a new insert with Arathane. The Kmax and Kmin torque coefficients are based on B-basis calculations similar to those used for small fasteners.

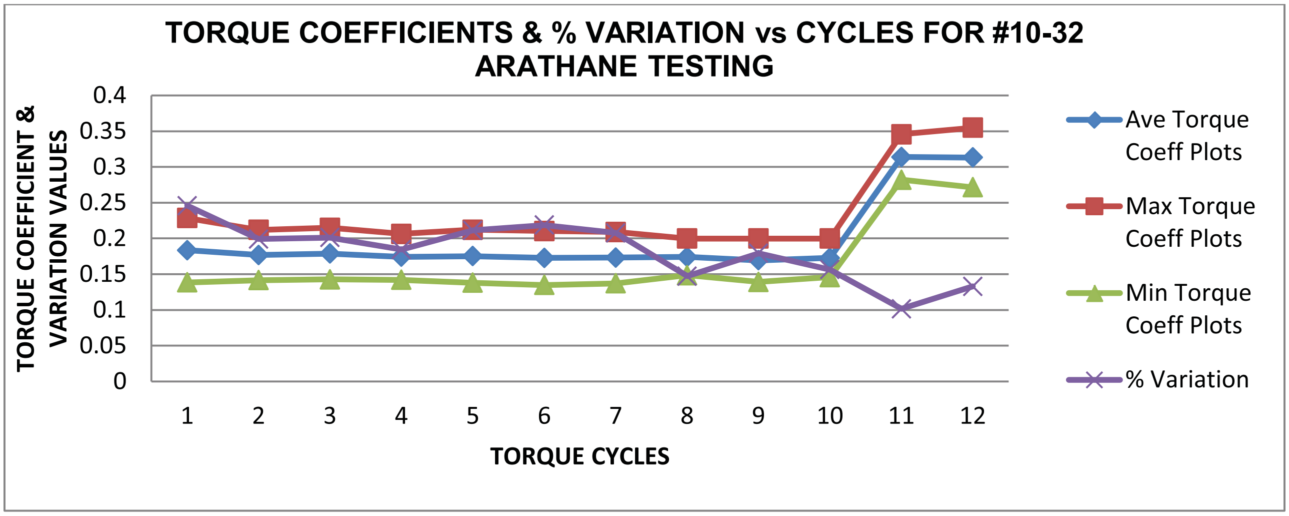


Figure 4.2 Cyclic Torque Coefficients, Braycote (1-10), Arathane (11-12)

The variation curve in Figure 4.2 above is based on data scatter or difference from Kmean and was calculated as follows:

Variation = (Kmax-Kmin)/(2*Kmean)

Table 4.1 Data Summary Tables for A286 Fasteners

Fastener	Braycote Lubrication Phosphor Bronze Insert (Worn)							
	Mean Torque Coefficient Kmean	STD Dev	No. Samples	Tolerance Limit Factor	B-Basis Limits Kmin	B-Basis Limits Kmax	% Below mean	% Above mean
#8 - 0.25"	0.182	0.039	300	1.417	0.127	0.238	30.5	30.5
Fastener	**Arathane Installation Phosphor Bronze Insert (Worn)**							
#8 - 0.25" IPA & HFE Clean	0.304	0.028	30	1.777	0.254	0.355	16.5	16.5

Fastener	Arathane and Braycote Comparison New Phosphor Bronze Insert							
	Mean Torque Coefficient Kmean	STD Dev	No. Samples	Tolerance Limit Factor	B-Basis Limits Kmin	B-Basis Limits Kmax	% Below mean	% Above mean
Arathane #8 - 0.25"	0.322	0.024	30	1.777	0.278	0.365	13.5	13.5
Braycote #8 - 0.25"	0.205	0.044	30	1.777	0.128	0.283	37.7	37.7

The following conclusions were noted based on the above test results and Figure 4.3 for combined Arathane and Small Fastener Testing which were both based on similar A286, 160 ksi strength fasteners installed into Braycote 601EF lubricated phosphor bronze inserts.

1. For both worn and new inserts, the torque coefficient for Arathane installed fasteners was significantly higher than the same size fastener lubricated with Braycote.
2. For worn inserts, the Arathane torque coefficient was ~71% higher than Braycote (K: 0.304 vs. 0.178). It is recommended that for worn inserts the torque should be based on a torque coefficient of 0.30 when Arathane is used .
3. For new inserts, the Arathane torque coefficient was ~ 57% higher than Braycote (K: 0.322 vs. 0.205). It is recommended that for new wire inserts the torque should be based on a torque coefficient of 0.32 when Arathane is used.
4. There was not an appreciable difference of the Arathane torque coefficient for those inserts cleaned with IPA vs. HFE7100.
5. The torque coefficient was lowest for the #8 fasteners and highest for the 0.25" diameter fasteners.
6. If all the data is combined the resulting average torque coefficient is 0.180. As previously noted, the Goddard torque spec tables in 540-PG-8072.1.2, specify a torque coefficient of 0.150 for lubricated fasteners. This data shows that for a very commonly used (@ GSFC) combination of A286/160 ksi fasteners installed with Braycote 601EF into phosphor bronze wire inserts, a change to the 540 torque spec should specify a torque coefficient of 0.18
7. Also, the B-Basis scatter of the Torque coefficient is +/- 30%. Typically a torque coefficient range of +/- 25% is commonly used at GSFC.

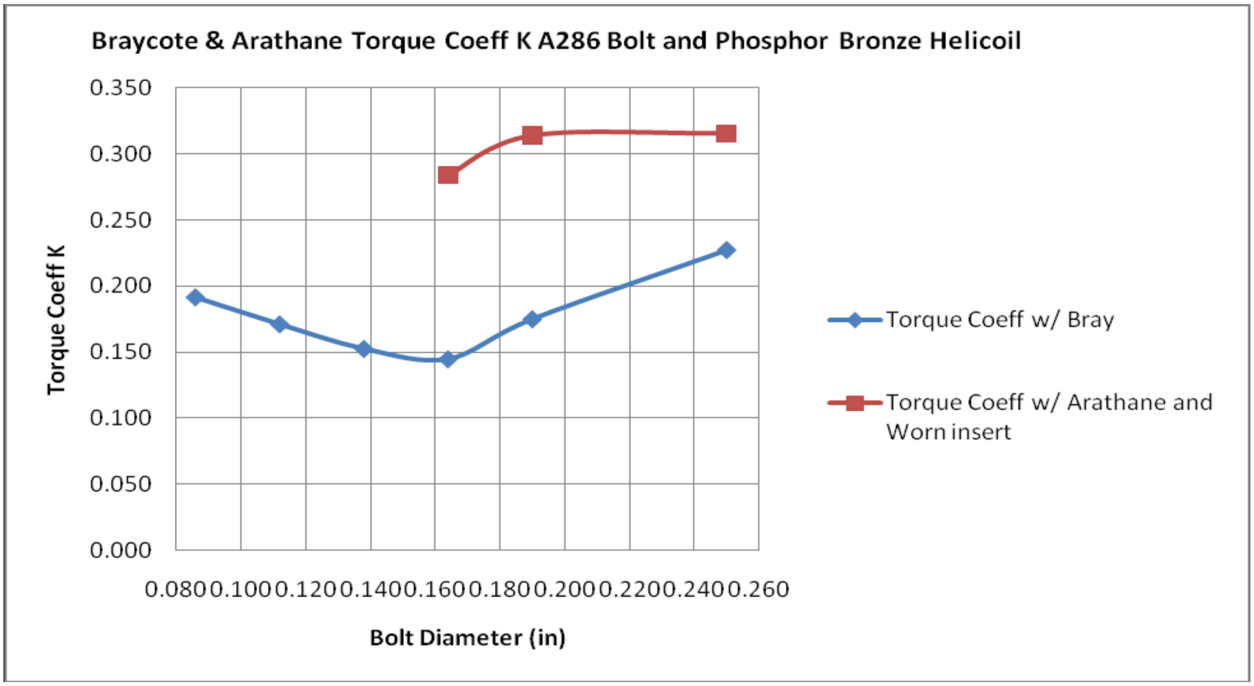


Figure 4.3 Combined Torque Coefficients Arathane & Small Fastener Testing

5.0 "ORION" SUPER KOROPON TESTING

ORION is a manned spacecraft proposed for beyond low earth orbit that is being designed and built jointly by Lockheed Martin for NASA and the European Space Agency. Two Phases of torque-tension testing was performed for ORION. Phase I (6) cycle testing was performed to determine if as-received and un-cleaned fasteners, inserts and washers could be used for assembly of flight hardware. All inserts were received with Moly Di Sulfide Dry Film Lubricant (DFL) applied to the threads by the manufacturer. The fastener and insert combinations tested are shown in Table 5.1 below. In addition to the different insert types and cleanliness, various lot numbers for each size and type were also tested to determine the effect on torque coefficient.

Table 5.1 Test Hardware Phase I & II Fasteners/Inserts & Washers

	Fasteners	Washers
1	#10-32 Hex Head A286 NAS6703U12	LMC21D5AC3C/A286 CS
2	1/4-28 Hex Head A286 NAS6704U12	LMC21D5AC3C/A286 CS

Keensert	Type	HD	EXHD	LW
1	#10-32	MS51831CA201L	MS51832CA201L	MS51830CA201L
2	1/4-28	MS51831CA202L	MS51832CA202L	

The Phase I (6) Cycle test sequence was as follows:

- One half of the fasteners/inserts and washers were cleaned in IPA and the other half were tested as received and un-cleaned.
- Super Koropon, an Epoxy-Polymide corrosion inhibitor/sealer for threaded assemblies, was applied to the fastener and washer bearing surfaces of all Koropon installed samples. Fastener threads were not lubricated with Koropon.

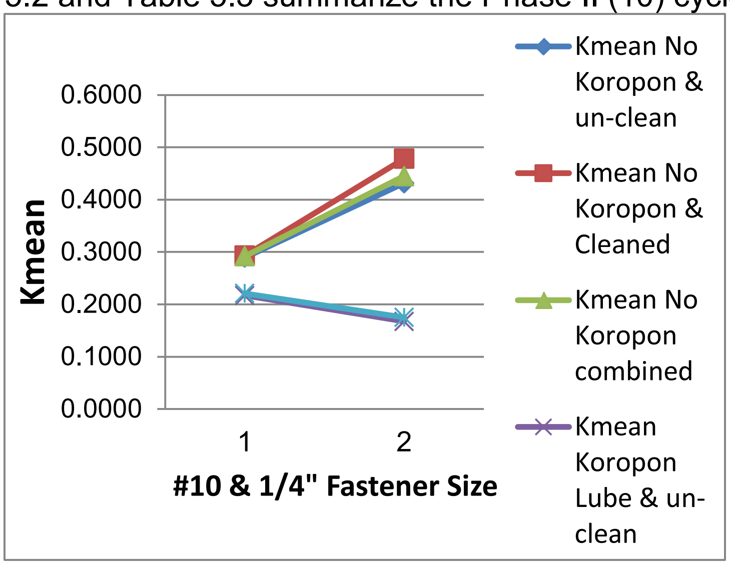
- Some cleaned and un-cleaned/as received sample sets were also tested dry without Super Koropon applied to fastener and washer bearing surface.
- All inserts were torqued to 65% fastener yield for total of six cycles with fastener and washer replacement after the third cycle.

Phase II (10) Cycle testing was performed to determine the effect of ten cycles on running torque and also if additional benefit could be derived by lubrication of fastener threads with Braycote. All hardware was tested as received and un-cleaned. Super Koropon was applied to fastener and washer bearing surfaces of Koropon samples with some sample sets also being tested dry, without Koropon. Some fastener threads were also lubricated with Braycote to determine the effect on torque coefficient. Two types of Braycote lubricant were tested, Type 601 for anti-rust and Type 602EF with moly disulfide for anti-galling. Phase II test sequence was as follows:

- As received DFL inserts with no additional Braycote lubrication.
- As received DFL inserts with fastener threads lubricated with Braycote 601.
- As received DFL inserts with fastener threads lubricated with Braycote 602EF
- Fastenerss were replaced only if running torque was less than 3 in-lbs.

5.1 PHASE I AND II TEST RESULTS

The data plots and Tables below provide a summary of the statistics for Phase I and II testing. Figure 5.1 and Table 5.2 summarize the Phase I (6) cycle test results. Figures 5.2 and Table 5.3 summarize the Phase II (10) cycle results.



Koropon Lubricated Samples:
- Lower Kmean.
- Cleaning has little affect.
- Kmean decrease vs. size.

No Koropon Lubrication:
- Higher Kmean.
- Cleaning has some affect.
- Kmean increase vs. size.

Figure 5.1 Kmean with and without Koropon Lube

Table 5.2 Phase I (6) Cycle Statistics for #10-32 & 1/4-28 Fasteners

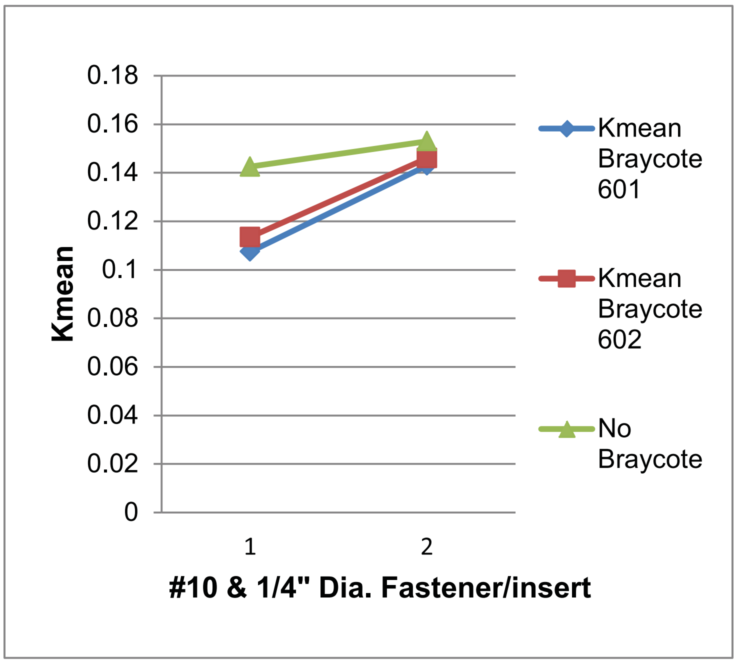
Koropon Lube cleaned and un-cleaned

	Koropon/un-clean		Koropon/cleaned		Koropon/Combined	
Size	#10	1/4"	#10	1/4"	#10	1/4"
Kmean	0.217	0.167	0.221	0.175	0.219	0.170

Kmax	0.273	0.203	0.270	0.214	0.268	0.208
Kmin	0.161	0.132	0.172	0.137	0.169	0.132
Variation	0.259	0.212	0.223	0.219	0.226	0.223
N=cycles	60	96	48	90	108	186

No Koropon Lube #10, cleaned and un-cleaned

	No Koropon/un-clean		No Koropon/cleaned		No Koropon/Combined	
Size	#10	1/4"	#10	1/4"	#10	1/4"
Kmean	0.289	0.432	0.293	0.478	0.292	0.445
Kmax	0.393	0.554	0.390	0.632	0.384	0.568
Kmin	0.186	0.309	0.196	0.325	0.200	0.322
Variation	0.359	0.284	0.331	0.321	0.316	0.277
N=cycles	30	30	54	12	84	42



Additional Braycote Lubrication applied to fastener threads is beneficial for smaller size #10-32 fasteners but less so for larger size 1/4-28 fasteners.

For larger size fasteners the head to washer bearing surface becomes more dominant and thread friction is less of a factor.

Use of Braycote 601 or 602EF are equally effective with respect to Kmean.

Figure 5.2 Kmean for Koropon with and without Braycote Lube

For Fastener Statistics in Tables 5.2 for (6) cycle test results and Table 5.3 for (10 cycle test results, the data variation was calculated as follows:

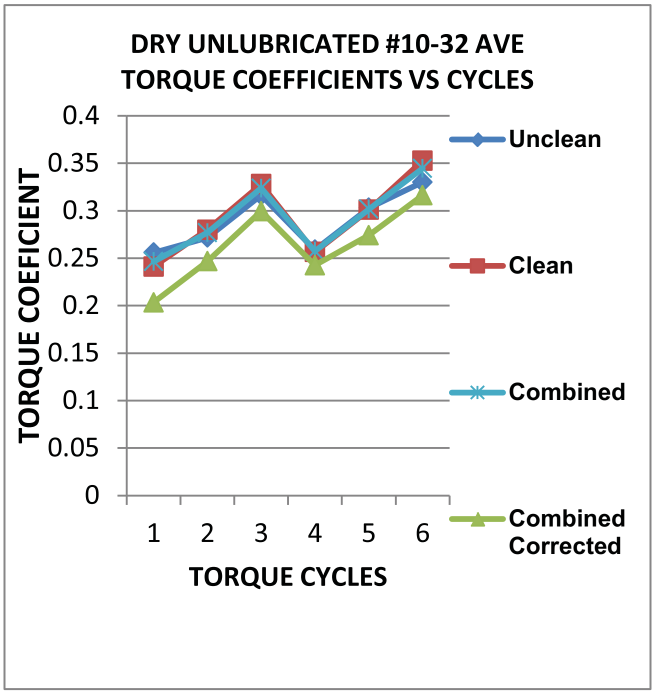
$$\text{Variation} = (\text{Kmax}-\text{Kmin})/(2*\text{Kmean})$$

Table 5.3 Phase II Kmean for Koropon with and without use of Braycote

EXHD & HD Keenserts Koropon Lube Applied

	Braycote 601		Braycote 602		Combined		No Braycote	
Size	#10	1/4"	#10	1/4"	#10	1/4"	#10	1/4"
Kmean	0.108	0.143	0.114	0.146	0.111	0.144	0.143	0.153
STDVA	0.013	0.031	0.024	0.022	0.019	0.027	0.025	0.028

Kmax	0.137	0.204	0.168	0.191	0.149	0.195	0.193	0.210
Kmin	0.078	0.082	0.059	0.102	0.072	0.094	0.092	0.097
Variation	0.274	0.427	0.480	0.305	0.351	0.351	0.356	0.369
N	20	50	20	40	40	90	40	50



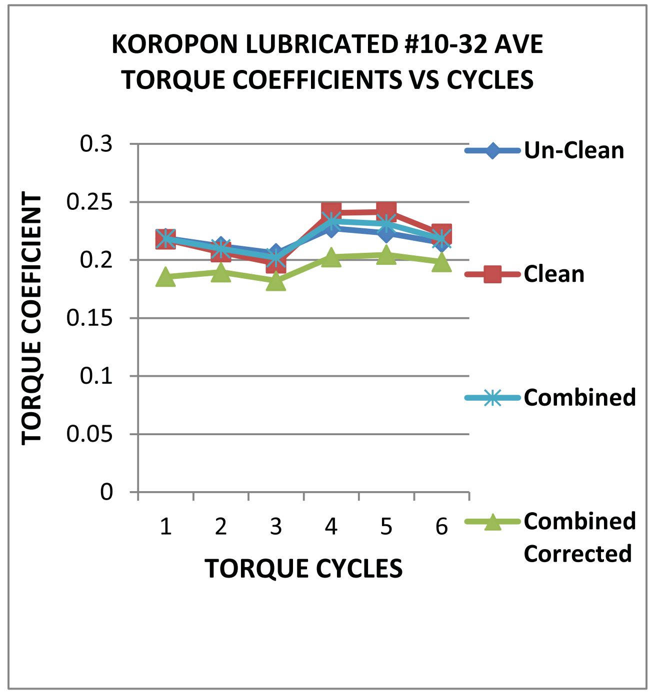
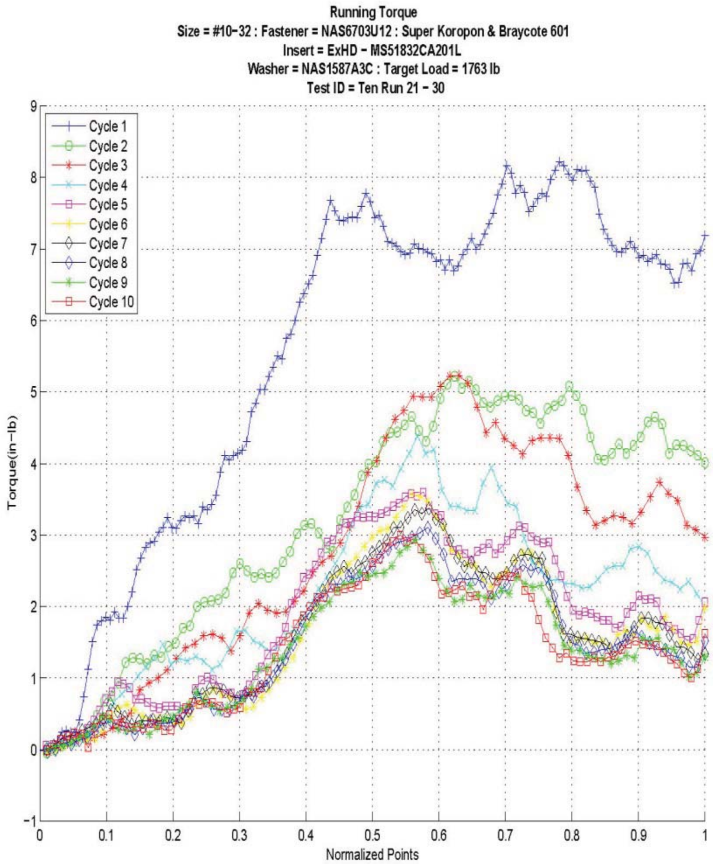


Figure 5.3 Cyclic Kmean for Un-lubricated and Lubricated Samples

The following generalized conclusions can be drawn based six and ten cycle testing:

1. For Dry/no-Koropon, Kmean and Variation were found to increase with fastener size. The reverse was true for use of Koropon.
2. There was little difference in Kmean for cleaned and un-cleaned test samples.
3. Removal of running torque was found to reduce Kmean by as much as 20%, refer to corrected plots, Figure 5.3 below.
4. The Kmean vs. cycles for un-lubricated samples was found to increase. For lubricated samples the trend was reversed. Refer to Figure 5.3 below. Replacement of fastener, washer and re-lubrication after third cycle is beneficial in reducing Kmean.
5. For cycles 1-6 into the same insert without Koropon, there was a large change in torque coefficients. With Koropon use there was little change.
6. Running Torque was reduced significantly after first torque application but remained above a minimum of 3 in-lbs in all but (3) sample sets, Figure 5.4.



<u>With Braycote Lubrication</u>
Running Torque 8 in-lb max.
Is 30% less than 12 in-lb for no Braycote Lube.

Follow-on cycles are also lower due to the lubrication effect but remain above minimum required 3 in-lb.

Figure 5.4 Typical Running Torque Plot for (10) Cycles, Koropon + Braycote Lube

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