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REPORT NO. (14) LR-25049

DATE 12-23-71

MODEL All

COPY NO. 15

(6) TITLE TORQUE-TENSION RELATIONSHIPS AND STATIC PRELOAD LOSS OF HIGH STRENGTH, HEAT RESISTANT, AND CORROSION RESISTANT AIRCRAFT ALLOY FASTENERS

DDC

REFERENCE (11) 23 Dec 71 (12) 38p.

DEC 18 1972

CONTRACT NUMBER(S)

DEVELOPED AT PRIVATE EXPENSE W/O 41-5587-5978

PREPARED BY: and

(10) V. G./Hart, Components Engineer, Parts and Equipment

J. F./Jones, Components Engineer, Sr., Parts and Equipment

APPROVED BY: E. J. Murphy, Design Specialist, Parts and Equipment

APPROVED BY: J. R. Zierbower, Group Engineer, Parts and Equipment

APPROVED BY: W. R. Zelenka, Department Manager, Parts and Equipment

APPROVED BY: R. L. Dickinson, Division Manager, Development Design Division

REVISIONS

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I. ABSTRACT

This report was prepared by the Parts and Equipment Department under an Independent Development Program. It describes torque-tension and static preload loss tests conducted on high strength, heat resistant, and corrosion resistant fasteners that are currently used or intended for future use in Lockheed-California Company aircraft. All testing was conducted by Almay Research and Testing Corporation. All fastener hardware was supplied by Lockheed. The results of this report may be used to determine the installation torque requirements for optimum joint preload.

The test data resulting from this program was generated by wrenching the nut and was limited to two installation cycles. The effect of two different added lubricants was determined. These lubricants were MIL-T-5544, a graphite base lubricant, and MIL-L-23398 (LAC-C34-1209A), a dry film lubricant.

The conclusions of this report are that the installation torque requirements of fasteners vary due to fastener materials, lubricants used, rated strength of the fastener, finishes, and installation cycle number. In addition, each installed fastener is subject to a loss of preload during the first 72 hours after installation; this loss may be as much as 11 percent of the initial preload.

II. ACKNOWLEDGEMENTS

The authors wish to acknowledge the valuable assistance provided during the course of this program by the following fastener companies: Elastic Stopnut Division of Amerace Esna Corporation, Kaynar Manufacturing Co., Inc., Omark Industries Precision Fastening Subsidiary, P. B. Fasteners Division of Paul R. Briles, Inc., Standard Pressed Steel Co., Valley Todeco, Inc., Subsidiary of The Lamson Sessions Co. and Voi-Shan, a division of VSI Corporation.

The authors futher acknowledge the contribution of Almay Research and Testing Corporation in performance of the testing, which was accomplished under the competent direction of Mr. Harry S. Brenner.

III. TABLE OF CONTENTS

IV. LIST OF TABLES

V. INTRODUCTION

Shear, tension, and fatigue critical bolts and nuts require different installation torque limits in order to achieve optimum joint preload. Fatigue-sensitive, highly loaded joints are subject to premature failure of the structure or fastener if the fastener installation torque is below optimum. An installation torque greater than optimum can cause premature fastener failure by inducing preloads greater than the fastener yield strength. Torque-tension relationships for alloy steel, cadmium plated bolts and steel, cadmium plated, dry film lubricated nuts are well documented (1).* These established relationships are available to designers via various reference manuals. The first objective of this test program was to establish torque-tension relationships for fasteners of materials other than those already documented. It had been suggested that fastener preload attained from torque is subject to a loss with time. This loss may be a result of relaxation in the joint or room temperature creep in the fastener. This phenomena has not been investigated to any great degree by prior investigators. The second objective of this program was to determine the magnitude of preload loss as a function of time for fasteners that are currently in use.

After this test program was initially defined a recent torque-tension test report (2) prepared by Almay Research and Testing Corporation under a NASA contract was made available to us. After review of this test report our proposed program was revised to eliminate duplication. The two programs now complement each other.

*Numbers in parenthesis refer to references listed in the Appendix.

V. INTRODUCTION (Continued)

Almay Research and Testing Corporation was selected to conduct the testing for this program. Almay was chosen because: 1. they had just completed the torque-tension study for NASA (which resulted in a report of over 700 pages, see Ref 2), 2. they were located in the Los Angeles area so testing could be monitored and coordination could be conducted easily, and 3. their estimate of cost was in line with budget predictions. Testing was conducted under the supervision of Mr. Harry S. Brenner, Director of Research. Mr. Brenner offered to provide a written report, besides the test data required by contract at no additional charge. It was felt that this report, which includes observations, photos, description of test equipment, and comments, would add greatly to the value of this program. For this reason Mr. Brenner's offer was accepted. His report (3) has been submitted to the Lockheed-California Company library under separate cover. The Central Library Accession Number is 72-3296.

VI. OBJECTIVE

The first objective of this program was to provide torque-tension data for bolts and nuts from which installation torque requirements could be determined.

The second objective of this program was to determine the magnitude of any static preload loss, as a function of time, so that its significance could be established.

VII. CONCLUSIONS/RECOMMENDATIONS

The test results will provide aircraft design engineers with accurate torque-tension relationships from which fastener optimum installation torque limits can be determined.

The data generated by this test program may result in: (1) longer lived, more reliable aircraft, (2) industry standardization of installation torque limits and methods, and (3) extending the life of the fastener wrenching surfaces.

It is recommended that further torque-tension tests be conducted on high strength, heat resistant, corrosion resistant fasteners. The object of these tests would be to determine the influence on joint preload due to:

(1) Fastener yield to ultimate ratio caused by flush, hex, and 12-point bolt head configurations,

(2) Wrenching the bolt versus wrenching the nut,

(3) Nut configuration (thin wall, thick wall, and plate nut types),

(4) Nonlocking versus self-locking nuts,

(5) Varying the thread pitch from fine to coarse (in preparation for "intermediate" pitch of future metric standards),

(6) Varying washer materials, heat treat levels, finishes, and dimensions,

VII. CONCLUSIONS/RECOMMENDATIONS (Continued)

(7) 15 installation-removal cycles with and without added lubricants and methods of achieving minimum variation between cycles,

(8) Sealants for either environmental or dissimilar metal protection, and

(9) Other fastener materials. An example is Multiphase (MP-35N), a proprietary material of the Standard Pressed Steel Co. Multiphase has several properties that an excellent fastener alloy should have. It is elevated temperature resistant, has a very low magnetic permeability, is very corrosion resistant, heat treatable to 260 KSI minimum ultimate tensile strength, and dynamically it is at least equal to the best of the available noncorrosion resistant materials. It is hoped that any future torque-tension test program would include sufficient quantities of MP-35N bolts so that torque-tension relationship data for this material could be established.

Future preload loss studies are also recommended. The effect of vibration on preload loss in the joint needs to be determined.

VII. CONCLUSIONS/RECOMMENDATIONS (Continued)

Finally it is recommeuded that the data generated by this program be reduced into a form more readily useable, by design engineers, in specifying installation torque limits for optimum joint preload. This information should be published in the Stress Memo Manual.

VIII. PARTS TESTED

The parts tested are shown in Tables I and II. These parts were paired as shown in the tables. The tables also show that the parts were treated either as a tension combination or shear combination, and the added lubricant used, if any.

In some cases the as received parts were only tested with added lubricants. It was felt that these parts should always be installed with added lubricants in order to minimize the installation torque requirements, and that the adding of a lubricant would provide the most consistent torque-tension relationships between specimens and between installation cycles.

TABLE I - Torque-Tension Test
Specimen Combinations

Bolt Part No.	Nut Part No. *	Combination Rating	Lubrication Condition
NAS6403U12 NAS6404U15 NAS6405U31 NAS6406U34 NAS6407U28D	NAS1291C3M NAS1291C4M NAS1291C5M NAS1291C6M NAS1291C7M	Tension	As Received
NAS6408U34 NAS6410U52H	109LH9074-8 109LH9074-10	Shear	As Received
NAS6403U12 NAS6404U15 NAS6405U31 NAS6406U34 NAS6407U28D	LH7875-3 LH7875-4 LH7875-5 LH7875-6 NAS679C7	Tension	As Received
NAS6408U34 NAS6410U52H	BMN4122C1S-8 BMN4122C1S-10	Shear	As Received
NAS6403U12	73178-1032	Tension	As Received
NAS6403U12 NAS6404U16 NAS6405U31 NAS6406U34 NAS6407U28D	NAS1291C3M NAS1291C4M NAS1291C5M NAS1291C6M NAS1291C7M	Tension	MIL-T-5544
NAS6408U34 NAS6410U52H	109LH9074-8 109LH9074-10	Shear	MIL-T-5544
NAS6403U12 NAS6404U16 NAS6405U31 NAS6406U34 NAS6407U28D	LH7875-3 LH7875-4 LH7875-5 LH7875-6 NAS679C7	Tension	MIL-T-5544
NAS6408U34 NAS6410U52H	BMN4122C1S-8 BMN4122C1S-10	Shear	MIL-T-5544

* Sources of manufacturer's part numbers are shown below Table II.

TABLE I (Continued)

Bolt Part No. *	Nut Part No. *	Combination Rating	Lubrication Condition
NAS6403U12 NAS6404U16 NAS6405U31 NAS6406U34 NAS6407U28	LH7559-3 LH7559-4 LH7559-5 LH7559-6 NAS679A7	Tension	MIL-T-5544
NAS6408U34 NAS6410U52H	48FT-820 48FT-1018	Shear	MIL-T-5544
NAS6303U13D NAS6304U17D NAS6305U28D NAS6306U28 NAS6307U29H	NAS1291C3M NAS1291C4M NAS1291C5M NAS1291C6M NAS1291C7M	Tension	As Received
NAS6303U13D NAS6304U17D NAS6305U28D NAS6306U28 NAS6307U29H	NAS1291C3M NAS1291C4M NAS1291C5M NAS1291C6M NAS1291C7M	Tension	MIL-T-5544
NAS6303U13D NAS6304U17D NAS6305U28D NAS6306U28 NAS6307U29H	MS21043-3 MS21043-4 MS21043-5 MS21043-6 NAS679C7	Tension	MIL-T-5544
VEP220555-4-16 VEP220555-5-22 VEP220555-6-22 VEP220555-7-28 VEP220555-10-52	LH10205-4 LH10205-5 LH10205-6 LH10205-7 LH10205-10	Tension	MIL-T-5544
VEP220555-4-16 VEP220555-5-22 VEP220555-6-22 VEP220555-7-28 VEP220555-10-52	LH10205-4 LH10205-5 LH10205-6 LH10205-7 LH10205-10	Tension	MIL-L-23398
72914-7-36	LH10205-7	Tension	MIL-L-23398

* Sources of manufacturer's part numbers are shown below Table II.

TABLE II - Preload Loss Test -
Specimen Combinations

Bolt Part No.	Nut Part No. *	Lubrication Condition
NAS1103-12 NAS1104-17D NAS1105-22D NAS1106-24D	MS21042L3 MS21042L4 MS21042L5 MS21042L6	As Received
MS21250-04016	H49049-4	As Received
MS21250-04016 MS21250-05022 MS21250-06024 MS21250-07028	H49049-4 H49049-5 H49049-6 H49049-7	MIL-T-5544
MS21250-04016 MS21250-05022 MS21250-06024 MS21250-07028	H49049-4 H49049-5 H49049-6 H49049-7	MIL-L-23398
NAS6403U12 NAS6404U15 NAS6405U31 NAS6406U34	LH7559-3 LH7559-4 LH7559-5 LH7559-6	As Received
NAS6403U12 NAS6404U15 NAS6405U31 NAS6406U34	LH7875-3 LH7875-4 LH7875-5 LH7875-6	As Received
NAS6403U12 NAS6404U15 NAS6405U31 NAS6406U34	NAS1291C3M NAS1291C4M NAS1291C5M NAS1291C6M	As Received
NAS6303U13D NAS6304U17D NAS6305U28D NAS6306U28	NAS1291C3M NAS1291C4M NAS1291C5M NAS1291C6M	As Received

* Sources of manufacturer's part numbers are shown below.

TABLE II - (Continued)

Bolt * Part No.	Nut * Part No.	Lubrication Condition
NAS6303U13D NAS6304U17D NAS6305U34D NAS6306U28	MS21043-3 MS21043-4 MS21043-5 MS21043-6	As Received
VEP220555-4-16 VEP220555-5-22 VEP220555-6-22	LH10205-4 LH10205-5 LH10205-6	MIL-T-5544
70718-4-16 70718-6-28	69678M428 69678M624	MIL-T-5544
70718V4-14 70718V6-23	69678M428 69678M624	MIL-T-5544
69680-4-18	69678M428	As Received
69680-4-18 69680-5-20 69680-6-19	69678M428 69678M524 69678M624	MIL-T-5544
69680V5-18 69680V6-24	69678M524 69678M624	MIL-T-5544

NOTE: All fastener combinations tested were considered to be tension rated. There were no shear rated fastener combinations tested.

* Part Number Series	Manufacturer
BMN4122	Omark
H49049	Kaynar
LH10205, LH7559, LH7875, 109LH9074	ESNA
VEP220555	Valley Todeco
48FT, 69678, 69680, 70718, 72914, 73178	Standard Pressed Steel

IX. TEST SPECIMENS

The test specimens consisted of a bolt, a nut, 2 washers, and a load cell assembled in a fixture. The load cells utilized strain gages so that loads could be determined. These load cells were designed to compensate for bending and therefore bending in the test specimen did not effect the load readings. The arrangement of the test set up is represented by Figure I.

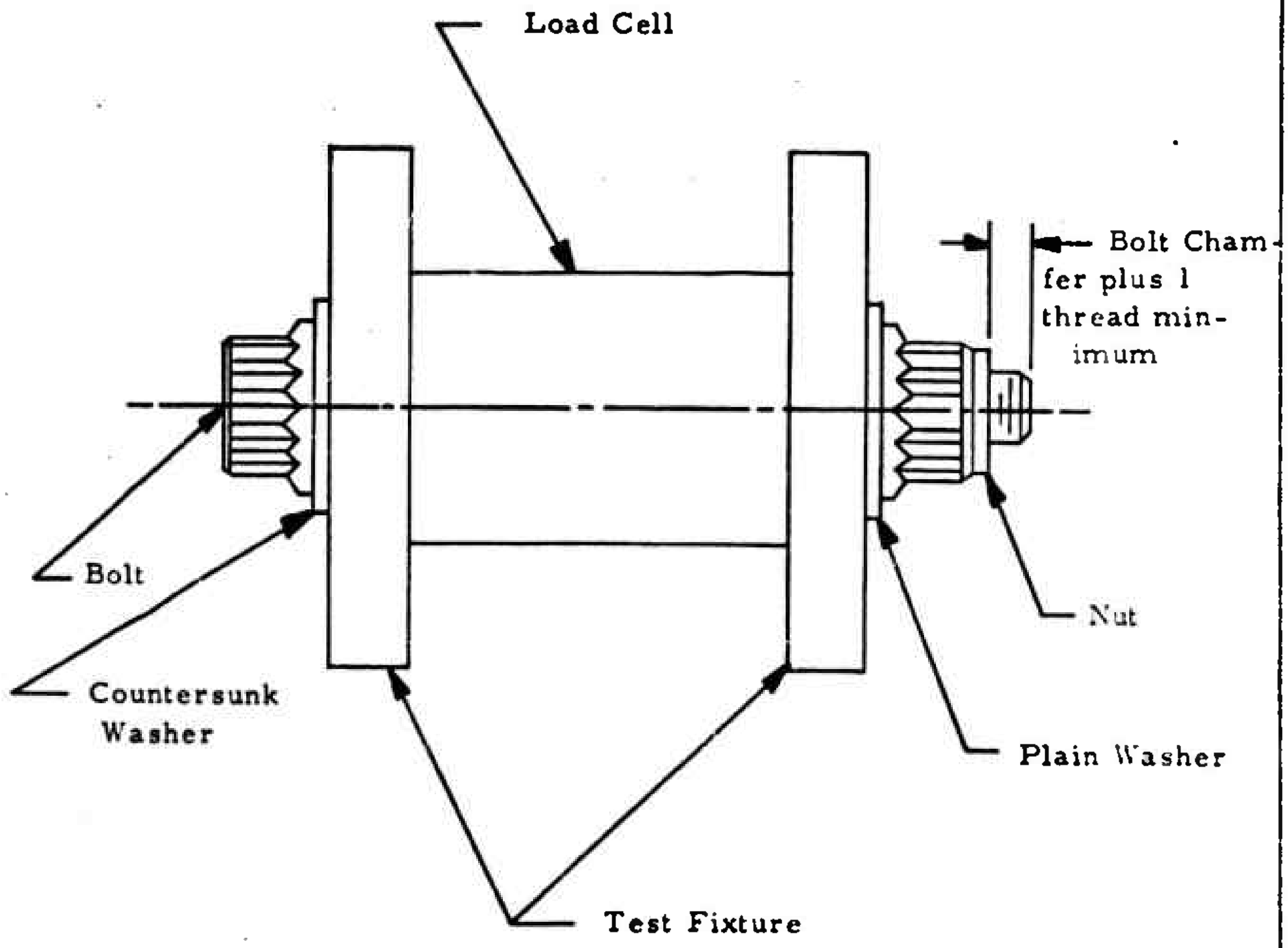

FIGURE 1 - TEST SET UP

X. TEST PROCEDURE

All tests were performed during the period between September 1, 1971 and December 23, 1971.

In order to preload the bolts to loads between 80 and 90 percent of yield strength it was necessary to determine bolt-nut combination yield strengths. Two methods were permitted. The first method was in accordance with Test 8 of MIL-STD-1312. This involves loading the nut and bolt axially in a tensile machine and obtaining a load-deflection curve. Bolt yield strength was then determined using Johnson's 2/3 approximate method. The second method utilized the torque-tension test fixture. Using a torque wrench, the nut was turned on to the bolt in increments of torque. Torque and strain were recorded for each increment. Torque was increased until strain readings indicated that the bolt-nut combination had been loaded past yield point or to failure. In subsequent tests the fasteners were loaded proportional to the yield strength as determined by either of these methods.

Torque-tension tests were conducted in accordance with Test 15 of MIL-STD-1312 except for the following. Compression load cells were used in conjunction with torque wrenches to determine the torque-tension relationships. The load cells were calibrated and calibration curves were obtained. Torque wrenches were accurate to within ±6 percent.

X. TEST PROCEDURE (Continued)

Countersunk washers were placed under bolt heads, and plain washers were placed under the nut. Test specimens were assembled in the test fixture as represented by Figure I. Torque was applied in increments until strain readings approached values indicating that the desired preload of 80 to 90 percent of bolt-nut yield strength had been reached. The fastener was then disassembled and the procedure was repeated to obtain a second set of datum points. Where lubricants were added, they were applied to bolt threads and nut-washer interface in a conservative manner. The bolt head was held stationary and the nut was turned onto the bolt in all cases. Three specimens were tested for each test condition.

The preload-loss tests utilized the same test fixtures. The bolt-nut combination was preloaded to 80 to 90 percent of yield as indicated by strain readings. Strain readings were made at one hour intervals for the first eight hours, twice in the next 24 hours, and daily for the next two days. Total time for each test was not less than 70 hours. Application of torque was to the nut with the bolt held stationary. Lubricants, where used, were applied to the bolt threads and nut-washer interface in a conservative manner. The initial strain readings were made while the installation seating torque was maintained. The second strain reading was made 3 minutes after the

X. TEST PROCEDURE (Continued)

torque wrench was removed from the fastener. Three specimens were tested for each test condition.

All testing was conducted at room ambient temperature and humidity.

XI. DISCUSSION OF TEST RESULTS

The reduction of the test data was beyond the scope of this program and therefore no specific recommendations for installation torque limits are made herein.

Generally speaking the torque-tension tests indicated that there was considerable difference between the 3 individual specimens in a given group and between the groups of specimens of each thread size. For example, for all groups of .1900-32 threaded fasteners, installed to 40 inch pounds of torque, there was a difference of 1,739 pounds in the induced bolt preload between the lowest and highest values. For 160 KSI tension rated fasteners this amounts to 50% of the minimum ultimate tensile strength. This can be attributed to the differences in materials, finishes, lubricants, and the configuration of the parts tested. This amount of variation would indicate that one set of general torque limits is not going to utilize each fastener at its optimum capability.

Preload loss tests showed similar differences in the fastener preload as a result of the installation torque, however, the object of this portion of the program was to determine how loss of fastener preload varies in a static joint as a function of time. It was determined that every specimen lost some of its preload, and the loss varied between 1 and 11 percent. The greatest losses occurred in the first eight hours after installation. The preload appeared to be stabilizing by the end of the 72 hour observation period.

XI. DISCUSSION OF TEST RESULTS (Continued)

The extensive detailed test results are recorded in Almay Research and Testing Corporation Report Number A5417, and is available from Lockheed-California Company library. The accession number is 72-3296.

For those interested in further study of torque-tension relationships a bibliography of recent publications is appended to this report.

The appendix also includes an IDC which reports the results of a torque-tension test on the 1 inch diameter VEP220555 bolts and LH10205 nuts. This IDC has been included because this fastener is part of the series tested in this program. Since the information in this IDC supplements the data in this report, it has been included as part of this report.

XII. APPENDIX

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INTERDEPARTMENTAL COMMUNICATION

PE70/522

TO G. W. Davis DEPT./ORGN. 73-61 BLDG./ZONE 90 PLANT/FAC. A-1 DATE 7-28-70

FROM J. B. Bierbower DEPT./ORGN. 77-16 BLDG./ZONE 80 PLANT/FAC. A-1 EXT. 74943

SUBJECT: TORQUE-TENSION RELATIONSHIP - ENGINE TO PYLON ATTACH BOLTS

REF: Letter, RHG/1011-1844, dated 6-19-70

Tests were performed, as promised, to determine the torque value to be specified for subject bolts. Results of the tests run are attached.

If we may be of further service, please call.

J. B. Bierbower
Group Engineer, Mechanical Systems
Parts and Equipment Department

JBB:JFJ:jb

cc: J. F. Jones
J. A. Morgan
M. VanDyl
W. R. Zelenka
PE File
SPSF (VEP220555)

TORQUE-TENSION VEP 220555-16 INCONEL 718 BOLT VS LH10205-16 SILVER PLATED A286 NUT

OBJECTIVE:

To determine the torque-tension relationship of 1.0000-12 UNJF Inconel 718 bolt and silver plated A286 nuts.

INTRODUCTION:

The L-1011 engine pylon attach bolts and nuts are 1.0000-12 UNJF thread size. The bolts are Inconel 718, part number VEP220555-16. The mating nuts are part number LH10205-16, made from A286 with silver-plated threads only. Data were not available in this combination of size and material so that the proper torque to provide the desired preload could be specified. Because of the critical nature of the engine attachment, it was necessary to perform torque-tension tests to determine the proper installation torque.

PROCEDURE:

The torque-tension tests were performed at Valley-Todeco, Inc. of Sylmar, California. Mr. Gene Bukont and Mr. Stewart Edwards, under the direction of Mr. Russ Sherman, performed the tests.

Test bolts were over runs from a lot of production bolts manufactured by Valley-Todeco. Test nuts were production nuts disbursed from Lockheed stock.

NOTE: The LH10205 nut should have silver-plated threads only. The parts obtained from stock had no plate. However, the samples used for these tests were silver plated all over at Valley-Todeco, and the plating was removed from the nut bearing surface prior to testing.

A Lockheed Electronics Company force washer, 1 inch I. D. Model No. 2016, was assembled on the bolt between hardened steel bushings to adjust for the bolt grip. The force washer was attached to a strain indicating gauge, Model P-350, manufactured by The Budd Co. A graph of the torque-strain relationship for a bolt of this size and material had previously been prepared and is shown on Figure 1. The silver-plated nut was assembled on the bolt. The assembled bolt, force washer, bushing and nut assembly was then placed in a 5 to 1 torque multiplier fixture.
Torque was applied in approximately 75 ft-lb increments, using a P. A. Sturtevant Co. torque wrench, Model No. S-600 (0-600 ft-lb range). Strain gauge readings were taken at each torque increment and recorded. The applied load was then determined from Figure 1.

The above test was repeated except MIL-T-5544 lubricant was applied to the bolt thread. This assembly was torqued and the results tabulated in Table III and plotted on Figure 2.

RESULTS AND DISCUSSION:

The length of torque wrench arm, 5 feet, made it impossible to apply the torque continuously. In some instances, between intervals, the wrench had to be removed from the fixture socket and repositioned in order to fully apply the next increment of torque. This may account for some of the erratic results. In the first test yielding in the system was observed near 1500 ft-lbs of torque. Further application of torque produced a failure in one of the socket drive inserts in the multiplier fixture. The test was rerun using the same fasteners. The results of both of these tests are reported in Table I and Table II and plotted in Figure 2. From the graph it appears that approximately 1250 ft-lbs of torque is required to obtain 70,000 lbs preload in the bolt when a silver-plated nut, with no subsequent lubricant, is used. This torque could exceed 1700 ft-lbs after the first use if the "2nd run" curve of Figure 2 was extended.

The required torque dropped drastically as would be expected when MIL-T-5544 anti-seize lubricant was applied to the bolt thread. The curve of this data indicates only about 600 ft-lbs torque required for 70,000 lbs preload in the bolt. It is expected that some loss of preload would also occur if this assembly was reused. However, preload would probably be restored if the bolt was relubricated before assembly.

CONCLUSIONS:

The engine to pylon attach bolts should be lubricated prior to assembly with MIL-T-5544 anti-seize applied to bolt threads. The assembly should be torqued to 600 ft-lbs. The engineering installation drawings should be reviewed and an installation torque, in accordance with this data, be specified.

TEST WITNESSES:

The above tests were witnessed by the following Lockheed personnel:

Jim Jones	Dept. 77-16
Mike VanDyl	Dept. 53-73

TABLE I

VEP220555-16 Bare Inconel 718 Bolt -
LH10205-16 Silver-Plated Nut

Torque Ft-Lbs	Strain Gauge Reading In/In	Load Lbs x 10^3
250	1.15	13.2
325	1.22	14.2
500	2.46	27.8
625	2.60	29.5
750	3.17	35.5
875	3.78	42.0
1000	4.42	49.3
1125	5.47	60.7
1250	5.50	61.2
1375	6.80	75.5
1500	6.91	77.0

TABLE II

VEP220555-16 Bare Inconel 718 Bolt -
LH10205-16 Silver-Plated Nut - 2nd Run (1)

Torque Ft-Lbs	Strain Gauge Reading In/In	Load Lbs x 10^3
375	1.74	20.0
500	1.74 (2)	20.0
625	2.34	26.5
750	2.46	27.1
875	3.22	36.0
1000	3.22 (2)	36.0
1125	4.03	45.5
1375	5.60	62.5
1500	5.80	64.5
1625	6.24	69.5
1750	6.36	70.7
1875	7.27	80.5
2000	7.59	84.5

(1) Socket drive sheared off after 1500 ft-lbs. Test rerun with same bolt and nut.

(2) No change seen in strain gauge.

TABLE III

VEP220555-16 Bare Bolt, Threads
Coated with MIL-T-5544 Anti-Seize -
LH10205-16 Silver-Plated Nut

Torque Ft-Lbs	Strain Gauge Reading In/In	Load Lbs x 10^3
250	2.09	24.0
375	4.06	45.5
500	5.73	64.0
625	6.81	75.5
750	8.03	89.5

$$T = \frac{R\ Pbi}{Ar}$$ (From SM79b dtd January 15, 1970)

where T = Wrench Torque, in-lbs
R = Wrench Torque ratio (from Table VII of SM79b)
Pbi = Preload in bolt due to tightening, lbs
Ar = Root area of bolt, sq. in.

for 1.0000-12 UNJF:

R = 0.04993 for MIL-T-5544 lubricant
= 0.06675 for MIL-T-23398 lubricant
NOTE: R values are for cadmium plated steel bolts and fitting and are being used only for approximation of test results
Ar (MIL-S-8879) = .64156

Pbi = Ar x 100,000 psi = 64,156 lbs
or = 70,000 lbs

@ 64,156 lbs w/MIL-T-5544

$$T = \frac{.04993 \times 64{,}156}{.64156}$$
= 4993 in-lbs
= 4.6 ft-lbs

@ 70,000 lbs w/MIL-T-5544

$$T = \frac{.04993 \times 70{,}000}{.64156}$$
= 5447 in-lbs
= 454 ft-lbs

@ 64,156 lbs w/MIL-L-23398

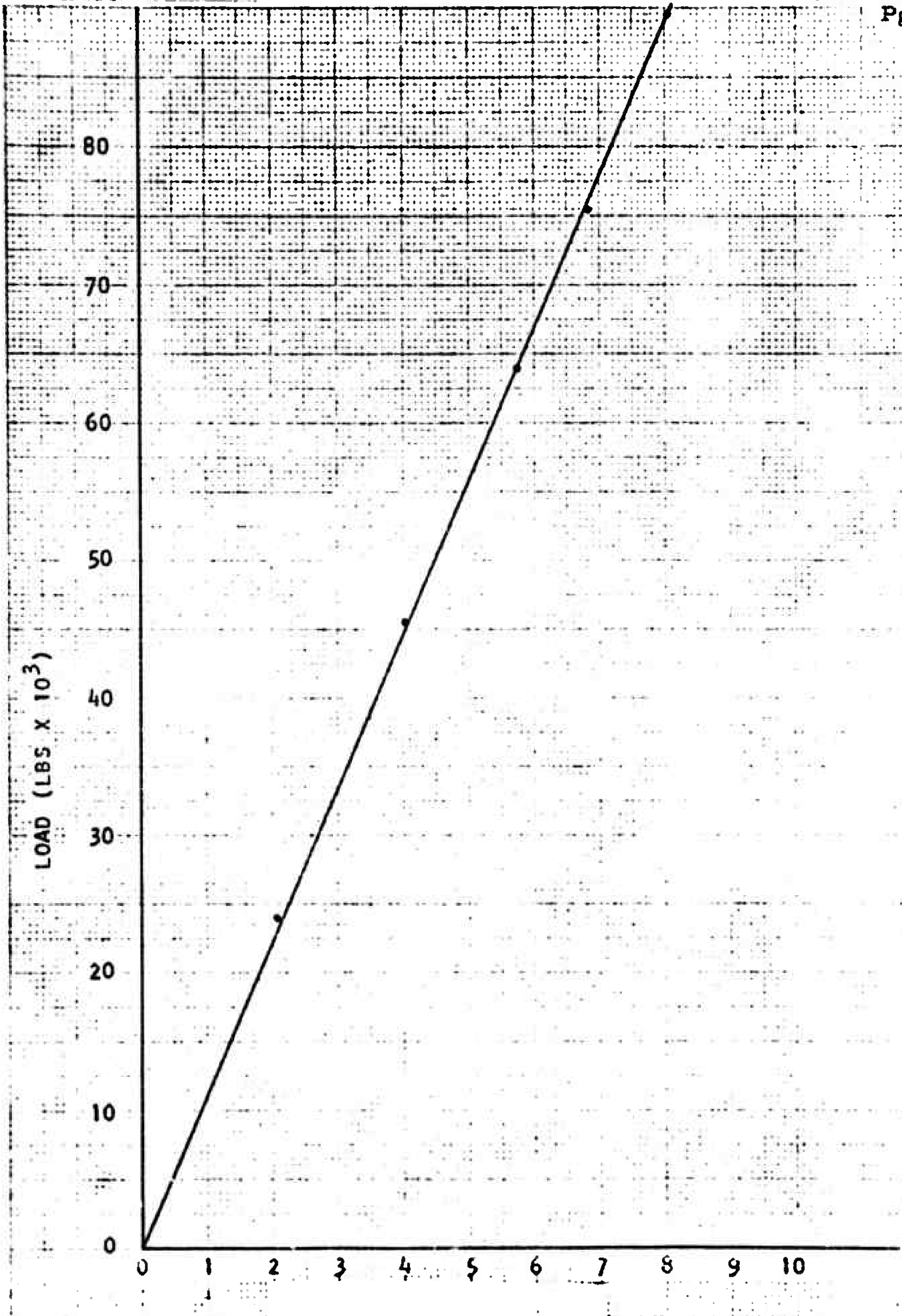
$$T = \frac{.06675 \times 64{,}156}{.64156}$$
= 6675 in-lbs
= 556 ft-lbs

@ 70,000 lbs w/MIL-L-23398

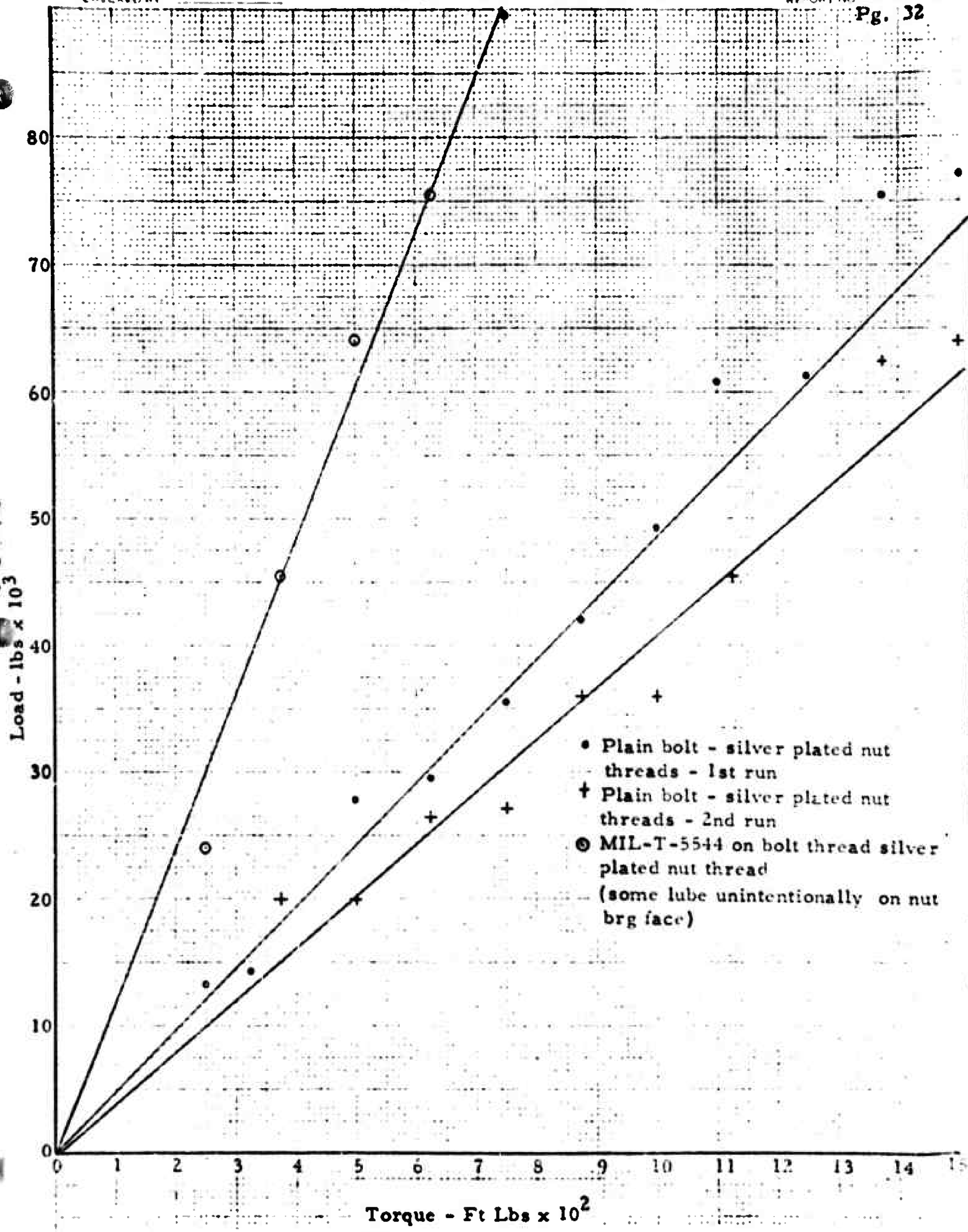
$$T = \frac{.06675 \times 70{,}000}{.64156}$$
= 7282 in-lbs
= 607 ft-lbs

500 ft-lbs

$$Pbi = \frac{T\ Ar}{R} = \frac{6000 \times .64156}{.04993} = 77{,}100 \text{ lbs}$$



T-T TESTS VEP220555-16
STRAIN - (IN./IN.)



Torque - tension VEP220555-16 bolt (bare Inconel) vs LH10205-16 (Silver plated A286) nut