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EVALUATION OF INSTALLATION FOR TITANIUM 6AI-4V HI-LOKS AND SIX-WING BOLTS ASSEMBLED IN TITANIUM 8AI-IMo-IV SHEET MATERIAL

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EVALUATION OF INSTALLATION VARIABLES FOR TITANIUM 6AI-4V HI-LOKS AND SIX-WING BOLTS ASSEMBLED IN TITANIUM 8AI-1Mo-1V SHEET MATERIAL

By

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EVALUATION OF INSTALLATION VARIABLES FOR TITANIUM 6Al-4V HI-LOKS AND SIX-WING BOLTS ASSEMBLED IN TITANIUM 8Al-1Mo-1V SHEET MATERIAL

By

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ABSTRACT

This report describes development studies conducted to establish manufacturing process parameters for the installation of Titanium 6Al-4V Hi-Lok fasteners and Six-Wing bolts in structures made from Titanium 8Al-1Mo-1V alloy material. Fasteners were tested in two thicknesses of material for hole tolerance, hole angle, induced defects, and a combination of 5 percent salt spray and induced defects.

The study indicated that close tolerance holes and minimum hole angles result in the highest yield strength and minimum ultimate strength; induced defects and corrosion tests had no appreciable effect on the joint strength.

It is recommended that holes reamed to the maximum shank diameter and plus 0.0508mm (0.002 inch), minus 0.000mm (0.000 inch) and hole angles within 3.49×10^{-2} radian (2 degrees) be used with wet zinc chromate primer per MIL-P-8585for the installation of fasteners in titanium structures.

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EVALUATION OF INSTALLATION VARIABLES FOR TITANIUM 6Al-4V HI-LOKS AND SIX-WING BOLTS ASSEMBLED IN TITANIUM 8Al-1Mo-1V SHEET MATERIAL

SUMMARY

To establish manufacturing process parameters for titanium fasteners installed in titanium sheet material, a test program was conducted to evaluate fastener joint strength relative to hole size, hole angles, corrosion, and induced defects. Titanium 6Al-4V Hi-Loks and Six-Wing bolts in 4.826mm (0.190 in.), 6.350mm (0.250 in.), 7.938mm (0.3125 in.), and 9.525mm (0.375 in.) nominal diameters were tested in tandem fastened lap joints made from 2.54mm (0.100 in.) and 3.175mm (0.125 in.) nominal thickness duplex annealed titanium 8Al-1Mo-1V sheet material.

Joint strength tests were conducted by using the secondary modulus method to establish yield strength criteria corresponding to permanent set of the joint at 4 percent of the nominal shank diameter and 0.305mm (0.012 in.) offset. Yield strength was also tabulated at 0.508mm (0.020 in.) "Extension" and 0.762mm (0.030 in.) "Extension," which was read directly from the load extension autographic chart.

Yield strength values for 4.826mm (0.190 in.) and 6.350mm (0.250 in.) Hi-Loks and Six-Wing bolts decreased with the increased hole size and hole angle, but the ultimate strength increased as the hole size was increased and no significant change was apparent for the increased hole angle.

There was no significant change in yield and ultimate strength values for 4.826mm (0.190 in.) nominal diameter Hi-Loks tested for corrosion and corrosion with induced defects.

Tests conducted on Hi-Loks and Six-Wing bolts for the effect of induced defects showed good results on Hi-Loks with no effect on either yield or ultimate strength values. There was some scatter in the results of the Six-Wing bolts and the cause is not known. Results of the 5 percent salt spray indicate the titanium alloy material is virtually unaffected but the aluminum Hi-Lok collars require wet zinc chromate primer for protection.

It is therefore recommended that reamed holes and hole angles within $\pm 3.49 \times 10^{2}$ radian (2 degrees) be used with wet zinc chromate primer in the fabrication of titanium space vehicle structures.

INTRODUCTION

In view of the advantages of the application of titanium alloys to large space vehicles, the Marshall Space Flight Center, approximately one and a half years ago, established a program to investigate manufacturing parameters of the 8Al-1Mo-1V titanium alloy in sheet and plate form.

As a part of this program, an Engineering Project was set up by the Manufacturing Engineering Laboratory to evaluate the mechanical joints in this alloy made with titanium fasteners of 6Al-4V alloy. The purpose of evaluation was to obtain in-house experience pertinent to the installation of these fasteners in the lap joints; to establish fabrication parameters, as related to hole sizes and angularity; to determine structural integrity of the joints thus made in various metal thicknesses, including the salt spray influence on the fasteners and joints; and to find out the effect of scratches or shallow grooves, crossing the holes, on the strength of the joints.

Accordingly, 121 double lap joint straps were fabricated in MEL facilities from two thicknesses of 8Al-1Mo-1V titanium alloy material provided by Titanium Metals Corporation of Dallas, Texas.

The 6Al-4V titanium alloy fasteners of Hi-Lok and Six-Wing bolt types in 4.826mm (0.190 inch), 6.350mm (0.250 inch), 7.937mm (0.3125 inch), and 9.525mm (0.375 inch) nominal diameters and of various grip lengths were supplied by the Hi-Shear Corporation of Torrence, California.

After necessary measurements and cleaning, the straps were assembled, while under preload into lap joints with these fasteners, approximately one-half of the total quantity with each type. Measurements of the fastener diameters were also made. The fasteners of both types were tested for single shear and all the lap joints were tested for tension/shear on the Universal Testing Machines, all in appropriate fixtures, including two types that were salt sprayed before testing.

From the autographic stress-strain charts of the Universal Testing Machines, yield strength values were determined by two extensions and two or one offsets/secondary modulus methods.

The results of all the testing are presented in tabulated form in this report, including some representative load-extension curves and the curves of the torque-induced load relationship of the four sizes of titanium bolts and nuts.

TEST PROGRAM

Two thicknesses of 8Al-1Mo-1V titanium alloy sheet and plate and four diameters of Hi-Lok and Six-Wing 6Al-4V titanium alloy fasteners were used in this series of tests.

The distribution of the lap joint test samples by material thicknesses, sample condition and fastener-diameters and types is presented in Table I.

The distribution of the fasteners for single shear by nominal diameters, grips, and applied torque is given in Table II. This was to be done for comparison with shear values to be obtained from testing of the lap joints.

In addition Table II shows the quantities of bolts by diameter that were tested for torque-tension relationship. This was accomplished for determination of approximately 70 percent of the ultimate strength of the bolts to be used in assembling the preloaded lap joints.

Numbers under "single" shear represent quantities of fasteners, and diameter tested in each case. Numbers under "applied torque" are the torques required to twist off the hexagon part of the aluminum alloy nut of the Hi-Loks. In the Six-Wing bolts the applied torque was to produce tension in the bolt for single shear test.

Altogether, 121 (two-fastener) lap joint pairs were manufactured and assembled under preload. Approximately 70 percent of the ultimate tensile strength was used for the Six-Wing bolts. With the Hi-Loks the tension was controlled by the nut twist-off torque.

All joints were tension tested to shear failure at room temperature. The numbers under "material thickness" present quantities of each combination of joints tested. In the joint type number, the first figure shows nominal diameter of the holes, the second figure gives the type of hole whether angular, reamed, or interference (forced) fit or clearance fit, and the last two numbers indicate nominal material thickness in hundredths of an inch. The project group figures tie in with the Engineering Project paragraphs and the stress/strain charts.

The ultimate tensile strength, the yield points, and elongation of titanium sheet and plate were checked by cutting seven flat tensile specimens from each of the two thicknesses of the material. The shape of the tensile specimen is shown in Figure 1.

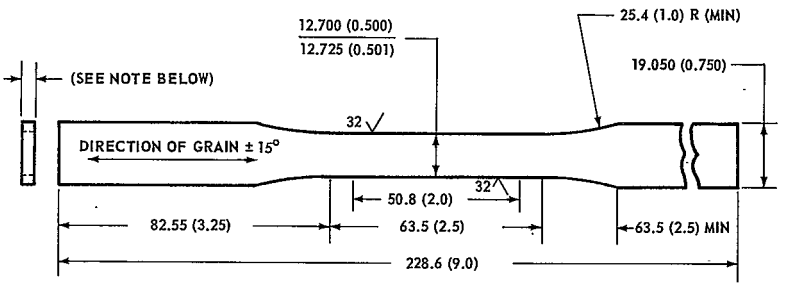


FIGURE 1. TITANIUM 8Al-1Mo-1V FLAT TENSILE SPECIMEN

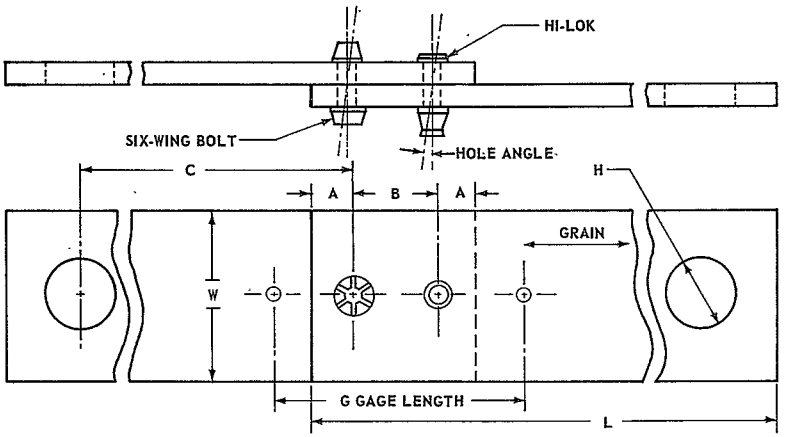
As a part of the 121 lap joint pairs test program there were 34 joint pairs with "induced defects" and 10 pairs (of which 5 pairs were with induced defects and 5 pairs without) were subjected to 600 hours of salt spray prior to the tension/shear testing.

APPARATUS AND PROCEDURES

Specimens and Fasteners Preparation

The configuration of the lap joint test specimens is shown in Figure 2. Each test specimen was made up of two halves of equal nominal thickness with long dimension parallel to the direction of rolling.

All specimens were sheared or sawed oversize in width and length, then machine milled on both side and end edges to the dimensions specified in Figure 2.



2nd DASH NO.
FINISHED HOLE ANGLE AND SIZE

PART NO.	NOMINAL FASTENER DIAMETER MM. (INS)	-1 0 RAD 0°		-4 0 RAD 0°		-5 $3.49X10^{-2}$ RAD 2°		-6 $6.98X10^{-2}$ RAD 4°		-7 0 RAD 0°	
	4.826	4.699	(.185)	4.813	(.1895)	4.813	(.1895)	4.813	(.1895)	4.876	(.192)
MR&T-SK-1110-1-	(NO. 10)	4.749	(.187)	4.838	(.1905)	4.838	(.1905)	4.838	(.1905)	4.937	(.194)
	6.350	6.223	(.245)	6.337	(.2495)	6.337	(.2495)	6.337	(.2495)	6.400	(.252)
MR&T-SK-1110-2-	(0.250)	6.299	(.248)	6.362	(.2505)	6.362	(.2505)	6.362	(.2505)	6.451	(.254)
	7.938			7.924	(.312)						
MR&T-SK-1110-3-	(0.3125)			7.950	(.313)						
	9.525			9.512	(.3745)						
MR&T-SK-1110-4-	(0.375)			9.537	(.3755)						

TEST SPECIMEN DIMENSIONS, CM. (INS)

A	B	C	G	H	L	W
0.952	1.905	10.477	5.080	1.275	16.827	3.810
(0.375)	(0.750)	(4.125)	(2.000)	0.502	(6.625)	(1.500)
1.270	2.540	13.970	10.160	1.275	21.590	5.080
(0.500)	(1.000)	(5.500)	(4.00)	0.502	(8.500)	(2.000)
1.587	3.175	17.462	10.160	2.233	28.257	6.350
(0.625)	(1.250)	(6.875)	(4.000)	0.879	(11.125)	(2.500)
1.905	3.810	20.955	10.160	2.233	33.020	7.620
(0.750)	(1.500)	(8.250)	(4.000)	0.879	13.000	(3.000)

FIGURE 2. BASIC DIMENSIONS OF TITANIUM 8Al-1Mo-1V SINGLE SHEAR LAP JOINT TEST SPECIMENS USED TO DETERMINE SINGLE SHEAR YIELD AND MAXIMUM STRENGTH FOR TITANIUM 6Al-4V HI-LOKS AND SIX-WING BOLTS

All hole drilling was accomplished on a tape controlled drill press except that when angularity of holes other than 0 radian (0 degree) was specified, the drilling was done in a fixture with drill bushings.

Micro-stop tools were used to control the size of standard 0.785 radian (45 degrees) chamfering of the holes on the fastener head side only.

For Hi-Loks the chamfers were:

Nominal Diameter	Chamfer Diameter
4.826mm (0.190 inch)	5.766mm (0.227 inch)
6.350mm (0.250 inch)	7.518mm (0.296 inch)
7.937mm (0.3125 inch)	9.246mm (0.364 inch)
9.525mm (0.375 inch)	10.795mm (0.425 inch)

For assemblies with Six-Wing bolts which have a larger root radius between shank and head than the Hi-Loks, the chamfer diameters were machined as follows:

Nominal Diameter	Chamfer Diameter
4.826mm (0.190 inch)	6.680mm (0.263 inch)
6.350mm (0.250 inch)	8.458mm (0.333 inch)
7.937mm (0.3125 inch)	10.033mm (0.395 inch)
9.525mm (0.375 inch)	12.466mm (0.490 inch)

Micro-stop tool adjustment was finalized when a trial indicated no clearance between the underside of a fastener head and surface of a specimen.

Fastener diameters were measured in two locations, separated by approximately 1.57 radian (90 degrees), with micrometer-calipers which could be read on the vernier scale to 0.00254mm (0.0001 inch). The measurements were made just before single shear testing or just before preassembly for preloading of each group of the 5 lap joint specimens. For identification, the fasteners were marked on their heads with a "Magic Marker."

The average diameters and cross-sectional areas of the fasteners used for single shear tests, along with shearing loads and strengths, are presented in Tables XII and XIII.

The same micrometer calipers were used for measuring specimen thicknesses in two locations near fasteners holes. The hole diameters of the individual specimens were measured with inside micrometers readable to fourth place on the vernier scale. The distances between fastener holes and their alignment with the pulling pin holes were measured on a Ferranti-Sheffield Coordinate Inspection Machine Type D-52.

The dimensions resulting from the measurements of the lap joint specimens, their average thickness, individual hole sizes, and average diameters of the fasteners used in each pair of the specimens are given in Tables III through X.

Upon completion of all measurements, 8 groups (3A5, 4A4, 5A2, 6B2, 3A9, 4A13, 5A15, and 6B4) of lap joint specimens were selected to receive "induced defects" in form of lap joint specimens with scratches across the fastener holes on one (outer) face of each specimen. This was for establishing scratch or notch sensitivity, if any, of the titanium lap joints. Then, before preassembly, all specimens were cleaned in a standard nitric/hydrofluoric acid bath, rinsed, and dried.

The final assembly of the lap joints and tightening of the fasteners were accomplished while individual joints were under preload as follows:

Nominal Fastener Diameter	Preload per Fastener
4.826mm (0.190 inch)	1330 newtons (300 pounds)
6.350mm (0.250 inch)	1770 newtons (400 pounds)
7.938mm (0.3125 inch)	2220 newtons (500 pounds)
9.525mm (0.375 inch)	2660 newtons (600 pounds)

The fasteners were first snugged-up; then the preload was applied and, while under load, the fasteners were given final tightening.

In the case of Hi-Lok fasteners the hexagon part of the collar twist-off torque controlled the amount of tension applied to the fastener:

Nominal Fastener Diameter	Collar Torque Off	
	Nm	(Inch - Pounds)
4.826mm (0.190 inch)	2.93 - 3.05	(26 - 27)
6.350mm (0.250 inch)	7.34 - 7.56	(65 - 67)
7.938mm (0.3125 inch)	15.25 - 15.47	(135 - 137)
9.525mm (0.375 inch)	22.59 - 23.72	(200 - 210)

It was planned that torque-induced load tests would be conducted before assembly of the lap joints, but the fixtures available with the Skidmore-Wilhelm Torque-Tension Tester were not suitable for use with the short bolts that would be used in the lap joint strength test. It was also planned that the nuts would be tightened to 70 percent of the fastener yield strength. Because of the lack of timely torque-induced load data, the following torque values were selected for use.

Nominal Bolt Shank Diameter	Torque Applied	
	Nm	(Inch - Pounds)
4.826mm (0.190 inch)	6.78	(60)
6.350mm (0.250 inch)	19.77	(175)
7.938mm (0.3125 inch)	48.02	(425)
9.525mm (0.375 inch)	54.23	(480)

During the process of tightening the nuts on Group 3A9 with the 6.98×10^{-2} radian (4 degrees) hole angle, there was one premature bolt tensile failure. It was therefore decided to reduce the torque to 5.65 Nm (50 inch-pounds) for this group.

Fastener Shear Test Fixtures

The fasteners prepared for single shear tests are illustrated in Figure 3 along with the shear plates.

The single shear tests were performed in a Huck Manufacturing Company fixture design which tests fastener diameters through 1.27cm (0.500 inch) and grip lengths up to 1.27cm (0.500 inch). The fixture is shown in Figure 3 and the test setup in the Riehle Model KA-60 Universal Testing Machine is pictured in Figure 4.

Load/Extension Measuring System

A snap-on Model DNX-20A differential transformer type extensometer for 5.08cm (2 inch) gage length and a snap-on Model DNX-40A extensometer for 10.16cm (4 inch) gage length were used on Model KA-60, 266 800 newtons (60 000 pounds) capacity and Model FH-400, 1 779 000 newtons (400 000 pounds) capacity Universal Testing Machines in this Evaluation Project.

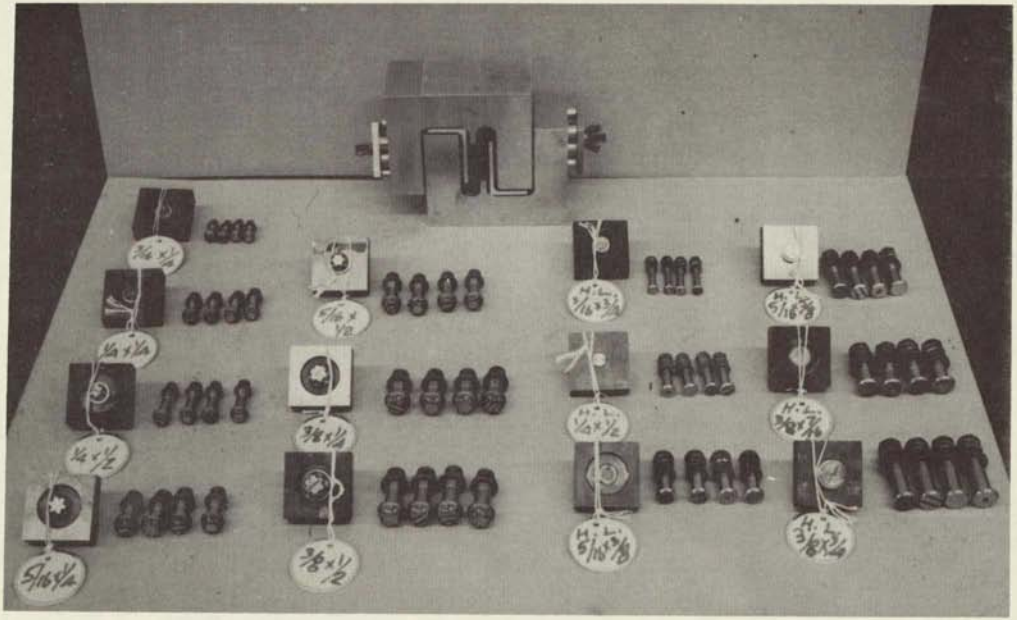


FIGURE 3. FASTENERS FOR SINGLE SHEAR TESTS AND SINGLE SHEAR FIXTURE

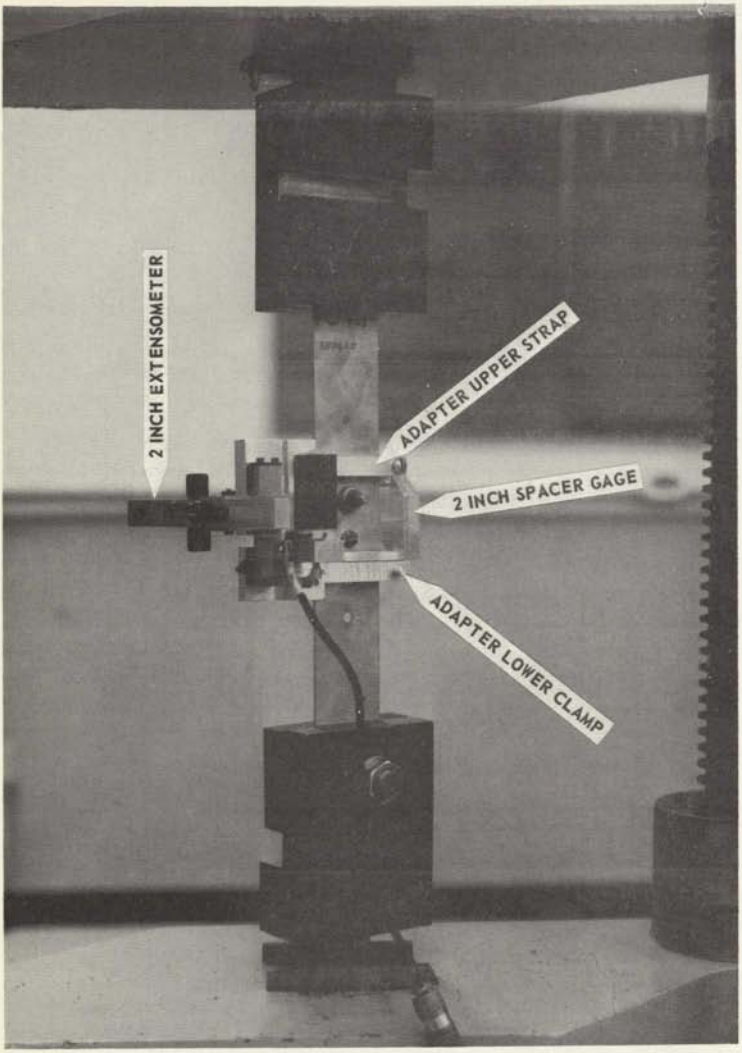


FIGURE 4. ARRANGEMENT OF JOINT PULLING FIXTURE, LAP JOINT SPECIMEN AND EXTENSOMETER FOR DETERMINING THE JOINT STRENGTH OF 4.826mm (0.190 in.) FASTENERS

Both machines were equipped with an integral Model RD-5 stress-strain recorder.

All this equipment was manufactured by the Riehle Testing Machine Division of Amtek, Incorporated, East Moline, Illinois.

The 5.08cm (2 inch) gage extensometer had 250X magnification while the 10.2cm (4 inch) gage extensometer was arranged for 150X magnification.

The extensometers were attached to specimens under test by means of adapters, each consisting of an Upper Clamp (P/N: MR& T-SK-1152), a Lower Clamp (P/N: MR& T-SK-1151), and two straps (P/N: MR& T-SK-1150). To minimize the effect of local bending of a specimen under load on the extensometer and thus minimize the possibility of erroneous indications on the recorder chart, both the clamps and the straps were modified so that the area of either in contact with the specimen would approach a knife edge by being only 1.52mm (0.06 inch) wide.

To assure repeatability of the distance and perpendicularity positioning of the clamps and the straps on joint specimens Spacer Gages, P/N MR& T-SK-964-1 was used with the 5.08cm (2 inch) extensometer and Spacer Gage, P/N MR& T-SK-964-5 for the 10.16cm (4 inch) extensometer.

Adapter clamps with straps, 5.08cm (2 inch) spacer gage and 5.08cm (2 inch) extensometer used on joint specimens with 4.826mm (0.190 inch) diameter fasteners are shown in Figure 4.

Wider clamps and longer straps were used on wider joint specimens assembled with 6.350mm (0.250 inch), 7.937mm (0.3125 inch), and 9.525mm (0.375 inch) diameter fasteners. These are shown in Figure 5.

Spacer gages were removed after the adapters were positioned and secured to the joint specimen.

Lap Joint Tension/Shear Fixtures

These fixtures were of an asymmetrical fork with pin type. The inside faces of the thicker part of the forks were located in the shear plane of the pull axis so that it was only necessary to bring the shear face of one strap of the joint in contact with that face of the fork fixture and the shear face of the other strap with the inside face of the second fixture. This automatically positioned

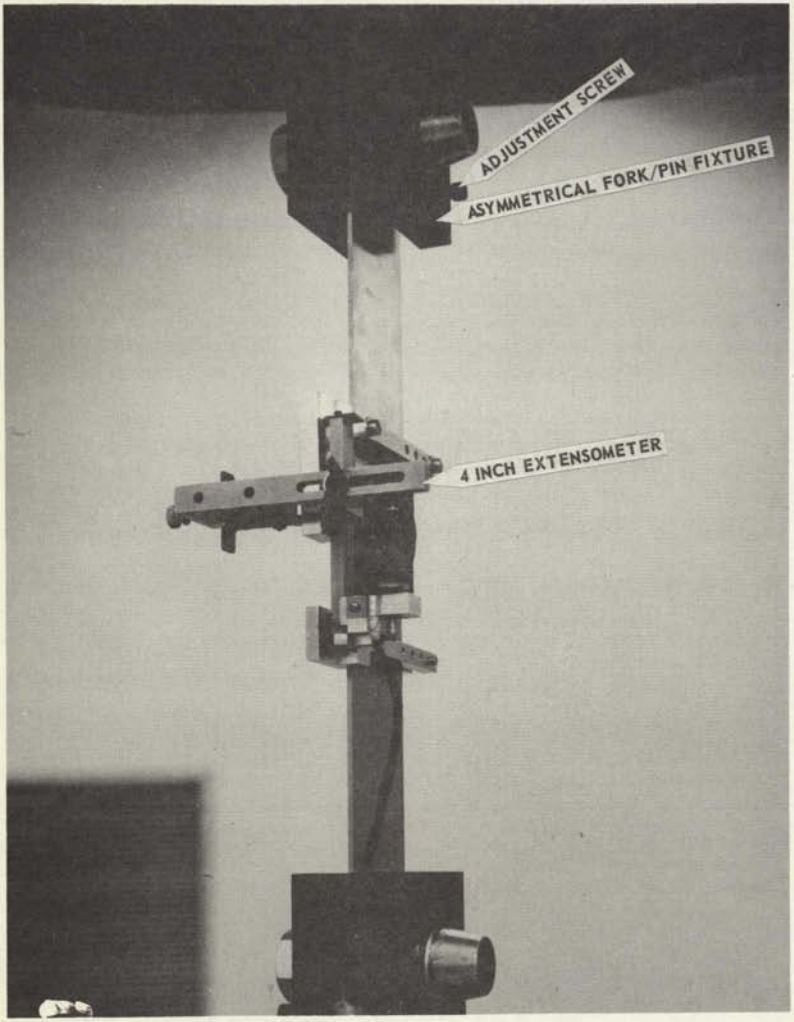


FIGURE 5. ARRANGEMENT OF JOINT PULLING FIXTURE, LAP JOINT SPECIMEN, AND EXTENSOMETER FOR DETERMINING THE JOINT STRENGTH OF 6.350mm (0.250 in.), 7.937mm (0.3125 in.) AND 9.525mm (0.375 in.) FASTENERS

the shear plane of the joint specimen in the pull axis. To assure an intimate contact of the fork and joint specimen faces, two adjustment screws were provided, threaded into the thinner part of the asymmetrical fork fixture.

In a few cases where main pin holes were erroneously located too close to the end of straps, clamping plates were inserted between adjustment screws and the back face of a specimen joint, and tightened securely to provide more friction between the specimen and the inside face of the asymmetrical fixture.

For the thinner material of the lap joints, the test fixtures were not of the fork but of the clamping type where the clamping plate was an original part of the fixture. It was held to the fixture by a 12.7mm (0.500 inch) bolt, which performed two functions: one to carry the load of the joint specimen under stress, the other to hold the clamp plate tightly against the joint face to reduce possibility of local buckling or tear out of the specimen through the end edge. This fixture is shown in Figure 5.

Single Shear Fastener Test Procedure

The fixtures in which these tests were performed are described under Fastener Shear Test Fixtures, above, and their setup in KA-60 Riehle machine is illustrated in Figure 3.

Fastener types, their nominal diameters, grip lengths, and applied torque are given in Table II.

Altogether, 25 Six-Wing type bolts and 20 Hi-Lok type fasteners were tested in single shear to failure. The load application rates were:

Nominal Fastener Diameter	Load Rate/Per 60 Seconds	
4.826mm (0.190 inch)	6 220 newtons	(1400 pounds)
6.350mm (0.250 inch)	10 890 newtons	(2450 pounds)
7.937mm (0.3125 inch)	17 120 newtons	(3850 pounds)
9.525mm (0.375 inch)	24 460 newtons	(5500 pounds)

Torque vs. Induced Load Test Procedure

A Model J Torque-Tension Tester, made by Skidmore-Wilhelm Manufacturing Company, of Cleveland, Ohio, was used to determine the torque induced load relationship of titanium 6Al-4V alloy bolts. The quantity of the

bolts tested, their diameters, and grip lengths are shown in Table II. Fixtures were not available to test the Six-Wing bolts SW2565-5-4; therefore the Hexagon Bolt NAS675V16 and nut SW65-5 were substituted.

The torque increase steps were selected arbitrarily until fastener failure was reached. The tension load was read directly from the machine gage.

In the majority of the cases, up to approximately 45.2 Nm (400 inch-pounds), a present slip clutch type of torque wrench made by Joline Tools Inc., was used. Above this value, a spring leaf type indicating torque wrench, Sturtevant Model F-150, of 203.4 Nm (1800 inch-pounds) capacity was used.

Single Shear Lap Joint Test Procedure

The overall testing setup for the lap joints in the FH-400 Riehle Universal Testing Machine is illustrated in Figure 6. The extensometer installation and the test fixtures were outlined under Load/Extension Measuring System and Lap Joint Tension/Shear Fixtures, above.

Figures 7, 8, 9, and 10 are typical of the 121 load-extension curve charts obtained from all the lap joint tests.

It is seen from these charts that two methods were employed in determination of the yield points of each joint: the secondary modulus method and the permanent set method. Both methods are based on the same curve. The curve was obtained by applying a tension load to the single shear joint and continuing the load application up to the approximate yield point, then dropping the load down to 5 percent of the range used and re-applying the load until failure. The extensometer was removed before the failure point was reached.

The slope of the load re-application curve was the basis for drawing two offset parallel lines, one at 4 percent of the fastener diameter and the other at 0.305mm (0.012 inch) deflection, for the secondary modulus method.

The second method was to draw lines perpendicular to the strain coordinate, one at 0.508mm (0.020 inch) extension and the other at 0.762mm (0.030 inch) extension, for the permanent set method.

Intersection points of all four lines with the load-extension curve were taken as the four possible yield point locations.

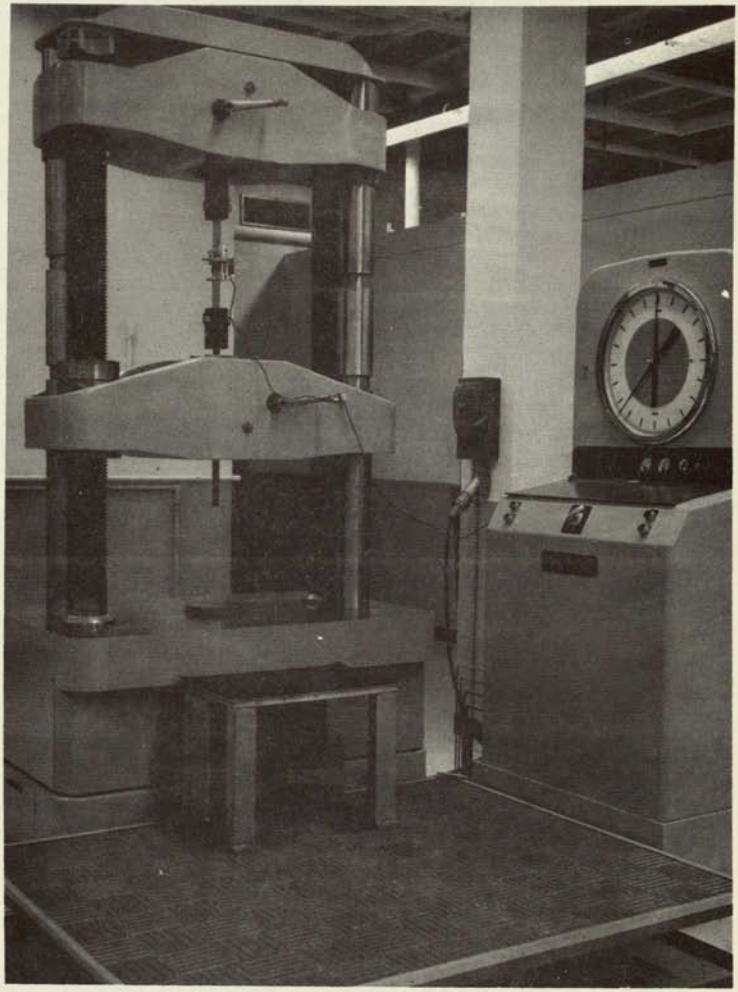


FIGURE 6. LAP JOINT TEST SET-UP IN RIEHLE FH-400 UNIVERSAL TESTING MACHINE

4% OF DIA. 0.254mm (.010") = 76.8% = 41,000 newtons (9220 lbs.)
0.305mm (.012") OFFSET = 78.1% = 41,700 newtons (9370 lbs.)
0.508mm (.020") EXTENSION = 58.2% = 31,100 newtons (6980 lbs.)
0.762mm (.030") EXTENSION = 73.9% = 39,500 newtons (8870 lbs.)

84.4% x 53,400N (12,000) = 45,200N (10,140 lbs.) ULTIMATE LOAD
BOTH FASTENERS SHEARED

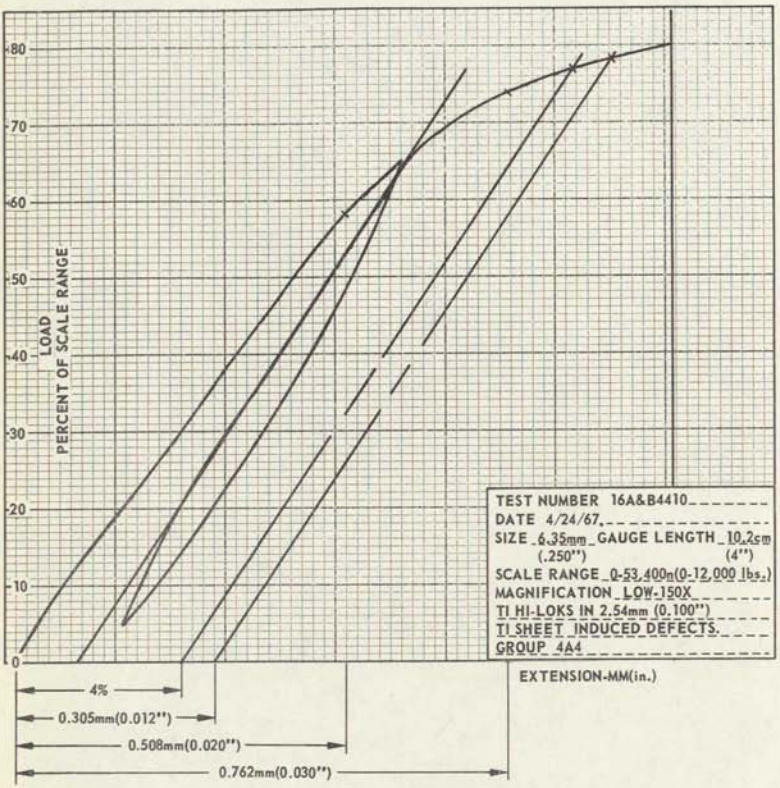


FIGURE 7. AUTOGRAPHIC LOAD-DEFLECTION RECORD OF SHEAR TEST OF LAP JOINT SPECIMEN 16A&B4410 USING TITANIUM 6Al-4V 6.350mm (0.250 in.) HI-LOKS

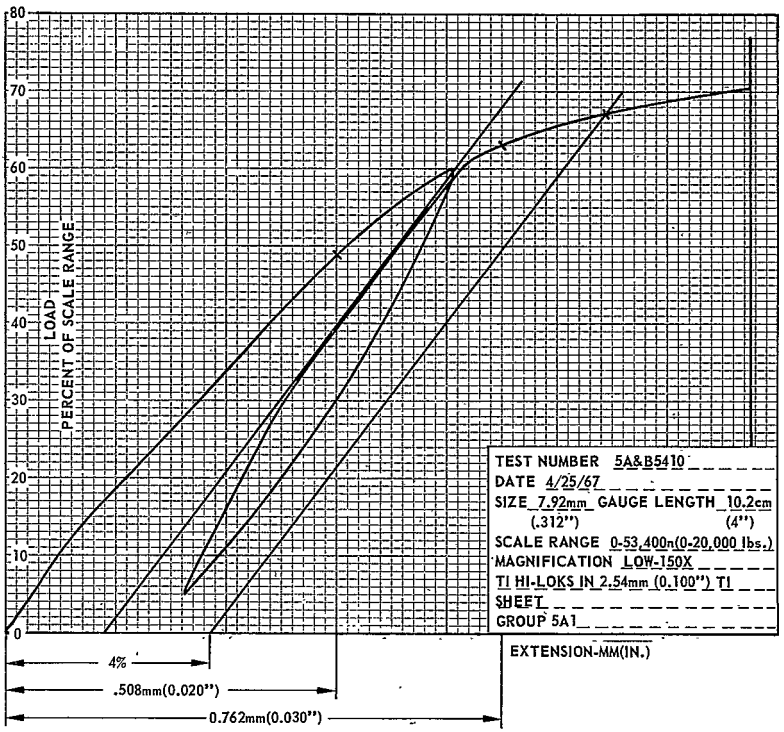


FIGURE 8. AUTOGRAPHIC LOAD-DEFLECTION RECORD OF SHEAR TEST OF LAP JOINT SPECIMEN 5A&B5410 USING TITANIUM 6Al-4V 7.937mm (0.3125 in.) HI-LOKS

4% OF DIA. = 2.54mm (.010") = 52.0% = 40,300 newtons (10,400 lbs.) ESTIMATED
0.305mm (.012") OFFSET = 52.7% = 47,000 newtons (10,540 lbs.)
0.508mm (.020") EXTENSION = 39.2% = 34.900 newtons (7,840 lbs)
0.762mm (.030") EXTENSION = 50.2% = 44,700 newtons (10,040 lbs.)

56.2% x 89,000 newtons (20,000) = 49,800 newtons (11,200 lbs.) ULTIMATE LOAD
BOTH BOLTS SHEARED

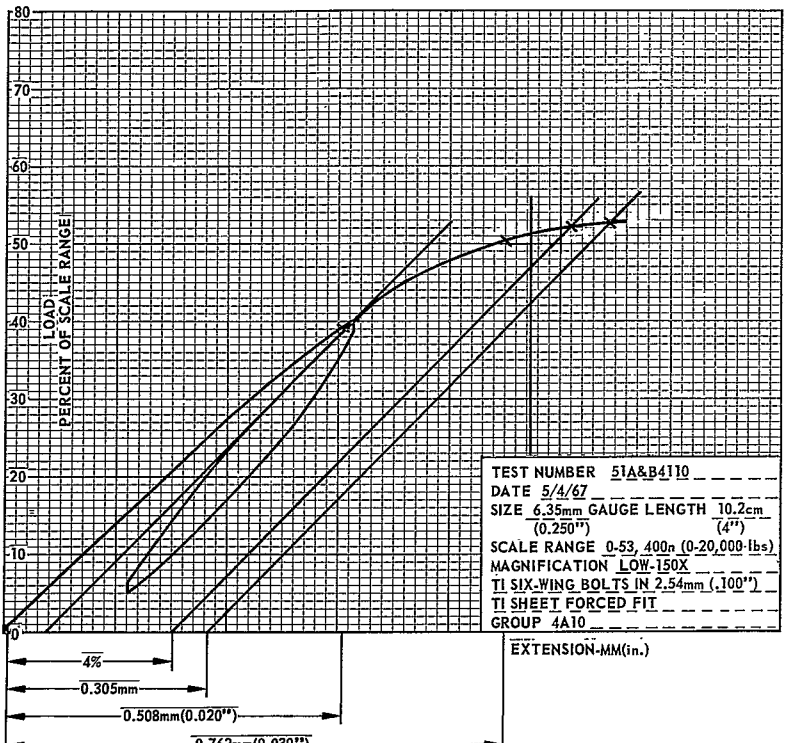


FIGURE 9. AUTOGRAPHIC LOAD-DEFLECTION RECORD OF SHEAR TEST OF LAP JOINT SPECIMEN 51A&B4110 USING TITANIUM 6Al-4V 6.350mm (0.250 in.) SIX-WING BOLTS

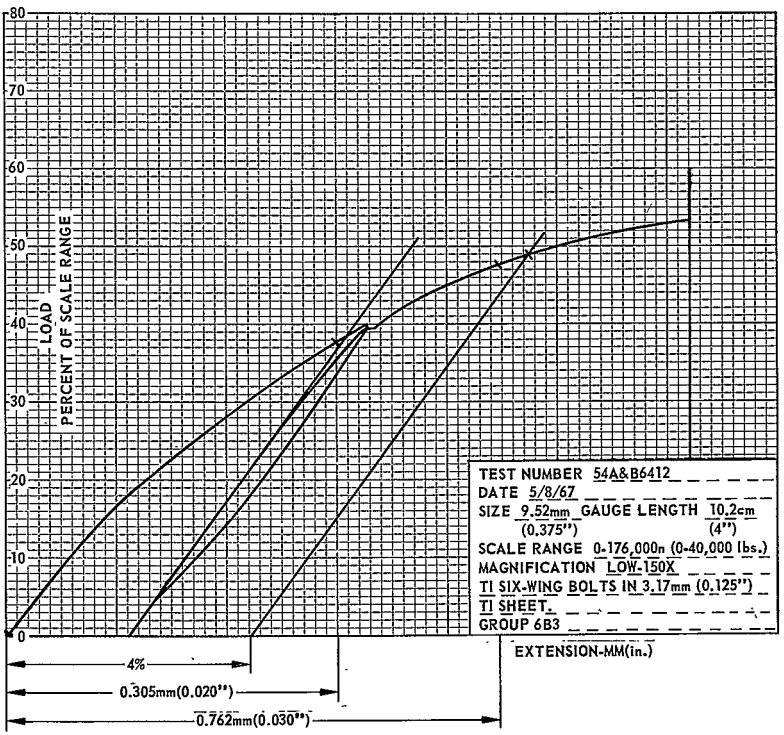


FIGURE 10. AUTOGRAPHIC LOAD-DEFLECTION RECORD OF SHEAR TEST OF LAP JOINT SPECIMEN 54A&B6412 USING TITANIUM 6Al-4V 9.525mm (0.375 in.) SIX-WING BOLTS

When any of the four lines would intersect the load-extension curve beyond the line of extensometer removal, the curve was then extended by hand to include the intersections and on the chart it was noted that such yield point was estimated.

Since 4 percent of 7.937mm (0.3125 inch) equals to 0.317mm (0.0125 inch) and 4 percent of 9.525mm (0.375) equals to 0.381mm (0.015 inch), the 0.305mm (0.012 inch) offset method was omitted in the joints with these diameters for Hi-Loks and with Six-Wing bolts.

Salt Spray Tests

To determine the influence of salt spray tests on titanium sheet and titanium fasteners with 2024-T6 anodized nuts as well as A.I.S.I. type 303 stainless steel fasteners with 303 stainless steel nuts assembled with and without zinc chromate primer, the following 6 pairs of panel joints were fabricated and subjected to 251 hours of salt spray.

All panels were 10.16 cm × 10.16 cm × 0.254 cm (4 × 4 inches × 0.100 inch) thick 8Al-1Mo-1V titanium sheet. Titanium fasteners were of 6Al-4V alloy. All panels and fasteners were cleaned with acetone before their use.

Panel No. 1, assembled with titanium fasteners and aluminum alloy nuts, served as control standard and was not subjected to salt spray.

Panel No. 2 was identically assembled but was subjected to the salt spray.

Panel No. 3 was assembled with identical fasteners and nuts, but fasteners were inserted with zinc chromate primer from the head side.

Panel No. 4 had stainless steel fasteners and nuts assembled and covered with zinc chromate primer. Stainless steel washers under the nuts were added to absorb the extra grip length.

Panel No. 5 had titanium fasteners and stainless steel nuts without zinc chromate protection.

Panel No. 6 had stainless steel fasteners and nuts without zinc chromate protection.

TEST RESULTS

General Results

The results of tensile tests on the duplex annealed titanium 8Al-1Mo-1V sheet material are given in Tables XI and XIA. Tensile ultimate strength, yield strength at 0.2 percent offset and elongation in 5.08cm (2 inches) are given for each tensile specimen.

The guaranteed room temperature strength values published by Titanium Metals Corporation of America for titanium 8Al-1Mo-1V are 89 630 Newtons per square centimeter (130 000 psi) ultimate tensile strength and 82 740 Newtons per square centimeter (120 000 psi) yield strength at 0.2 percent offset, and the sheet material used in this program was above these values.

The results of the single shear tests for the 6Al-4V Hi-Loks and Six Wing bolt are given in Tables XII and XIII. The guaranteed room temperature shear strength values for both the 6Al-4V titanium Hi-Loks and Six-Wing bolts are 65 000 Newtons per square centimeter (95 000 psi). All fasteners had shear values above the required minimum strength. There is no correlation between shear strength values for material subjected to both single and double shear tests. Some experience gained in this program indicates that single shear strength values for 6Al-4V titanium would be approximately 3 percent higher than double shear strength values. The shear test results of the HL10V70-10-6 Hi-Loks, therefore, would be very close to the required minimum shear strength. The scatter of data indicates that the fasteners may not have been heat treated at the same time.

The results of the torque vs. induced load tests for the Six-Wing bolts are given in Tables XIV through XVII. Prevailing torque was recorded for each nut just before being tightened. The test results are shown in Figures 11 through 14; the prevailing torque values for the nuts were subtracted from the applied torque before making the chart.

The lap joint yield and ultimate strength values are given in Tables XVIII through XXVA. The load/extension charts were made by using the secondary modulus method so that a comparison of yield strengths could be made on a basis of two values each of specified offset and permanent set. Some difficulty in the determination of yield values was experienced because of the lack of adequate guidelines and the judgement required to select the slope of

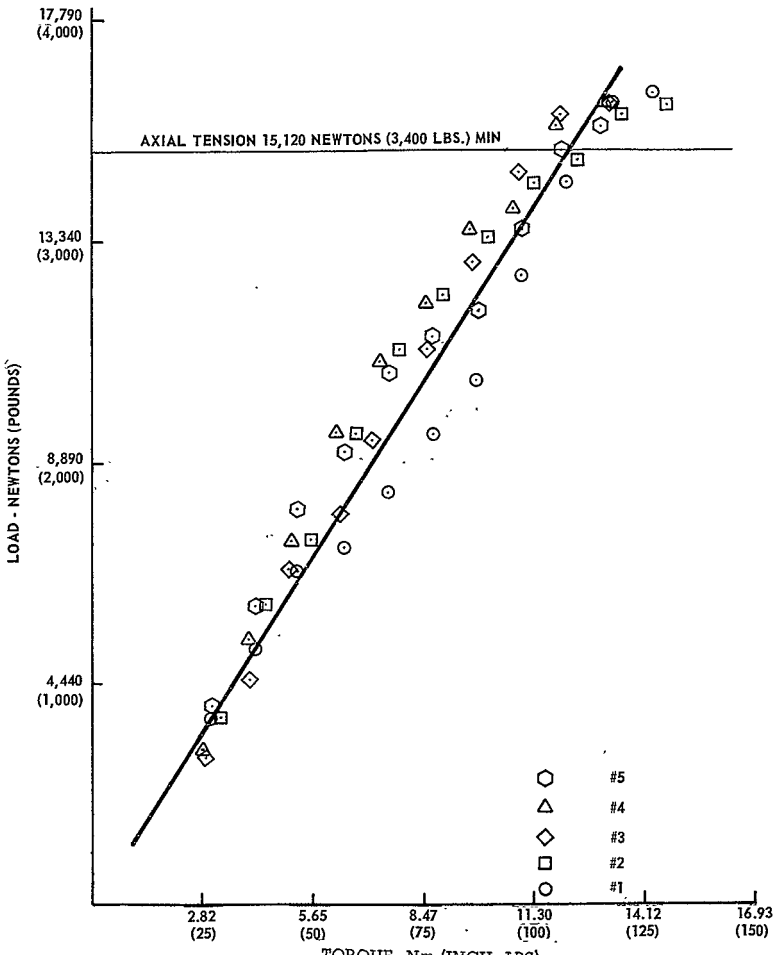


FIGURE 11. TORQUE VS. INDUCED LOAD FOR TITANIUM 6Al-4V SIX-WING BOLT ASSEMBLY P/N SW2565-3-8

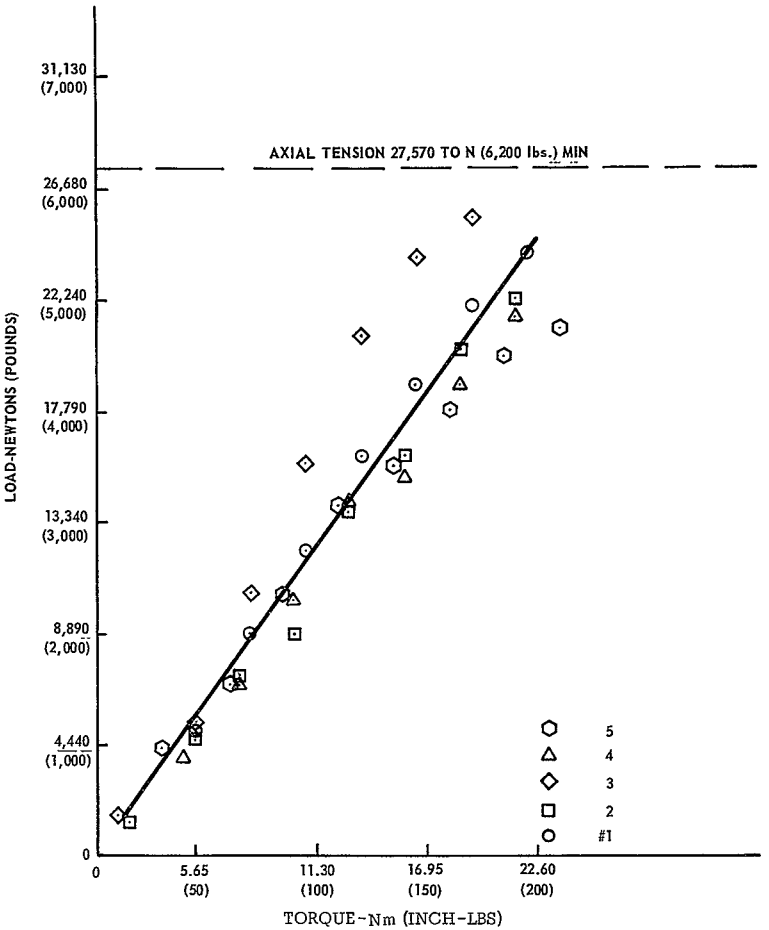


FIGURE 12. TORQUE VS. INDUCED LOAD FOR TITANIUM 6Al-4V SIX-WING BOLT ASSEMBLY, P/N SW2565-4-24

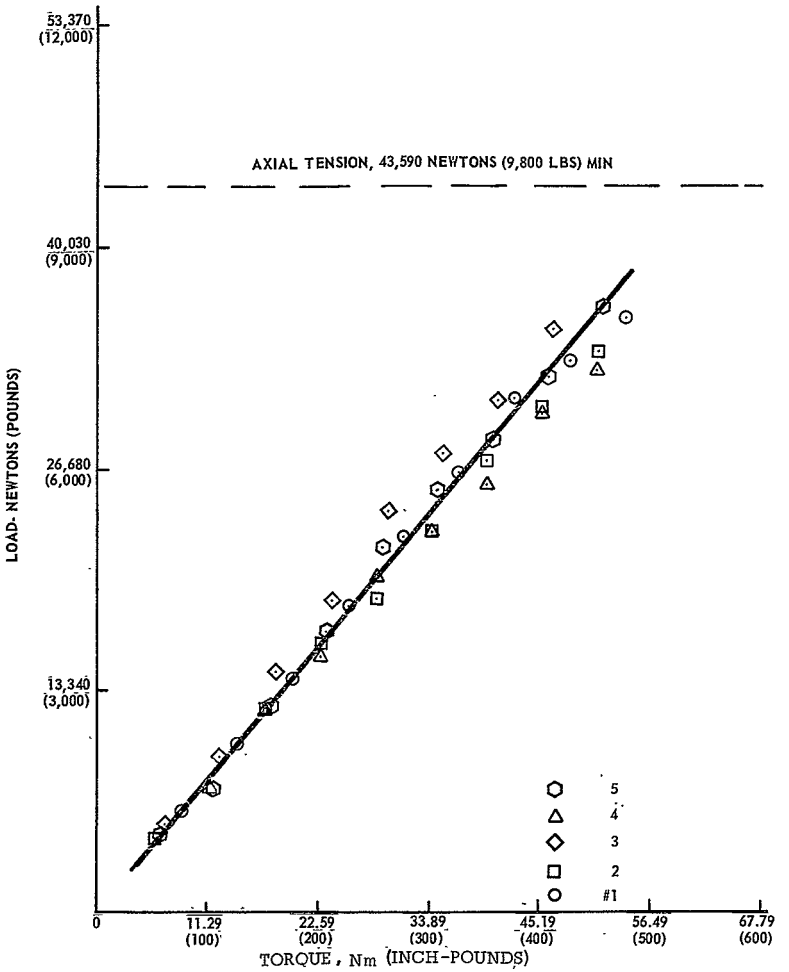


FIGURE 13. TORQUE VS. INDUCED LOAD FOR TITANIUM 6Al-4V NAS675V16 BOLT AND SW65-5 NUT

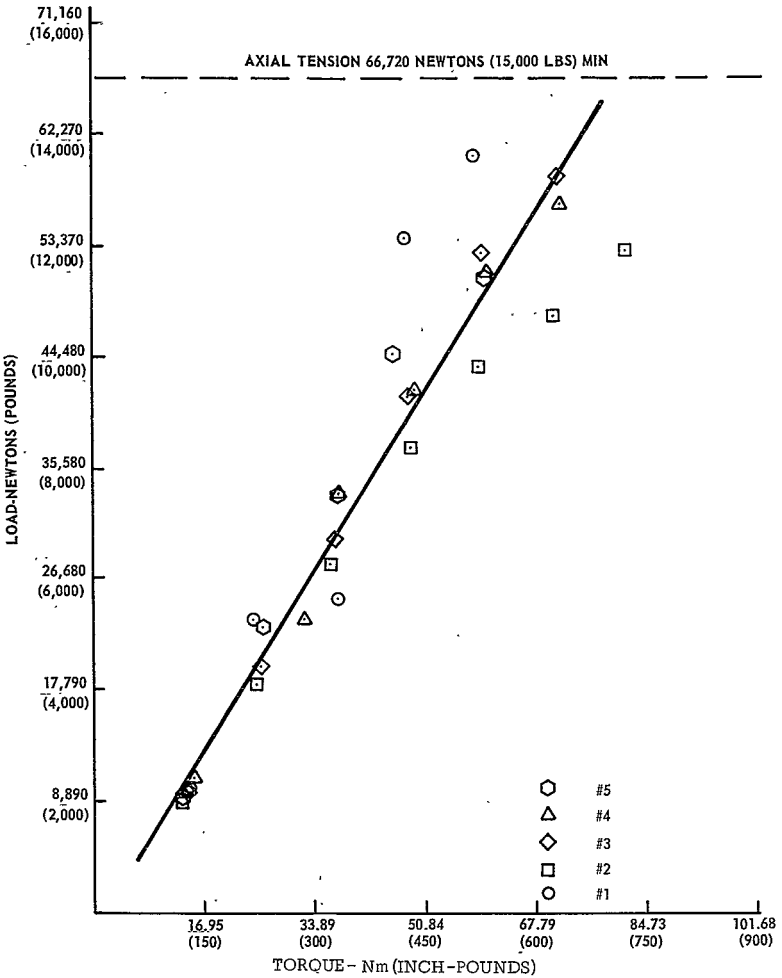


FIGURE 14. TORQUE VS. INDUCED LOAD FOR TITANIUM 6Al-4V SIX-WING BOLT ASSEMBLY, P/N SW2565-6-24

the modulus line. It was not always possible to record data so that the four yield strength values were available on the load/extension chart.

This was particularly true when testing the small diameter fastener. In these cases the load/extension line was extended to include all of the yield values.

Many problems were encountered by using the secondary modulus method to record the load/extension relationship of the lap joints. Among these were controlling the load rate of the testing machine when decreasing the load, inconsistency in forming the secondary modulus loop, and the slippage of the extensometer.

Salt Spray Results

Figures 15, 16, 17, and 18 are photographs taken of the head and the nut side of the panels, with the photographs of the joint numbers 17 and 18 having been taken after 251 hours of salt spray, impinging on the nut side.

Examination of the panels themselves shows that No. 2 panel nuts (Fig. 18) have considerable corrosion of aluminum alloy, including tops of the nuts where twisting off of the hexagon part left a ring of unanodized metal. The fastener heads were unaffected.

Panel No. 3 showed less corrosion than No. 2 on top and bottom of the nuts, and trace of yellow zinc chromate can still be seen where it penetrated from the heat side.

Panel No. 4 showed that zinc chromate protected the heads and washers, but the surface of the stainless steel nuts has salt corrosion deposits and the second and fourth nuts from the joint edge show rust, especially the fourth one.

Panel No. 5 was striking in that the panel and titanium fastener heads remained entirely unaffected while stainless steel nuts show salt corrosion deposits and substantial amount of rust.

Panel No. 6 clearly showed a large amount of corrosion on the stainless steel fasteners, under-head washers, and nuts while the titanium panels are only stained by the rust as seen in the bare metal portions between the first and the second, from top, nuts where rust particles fell off.

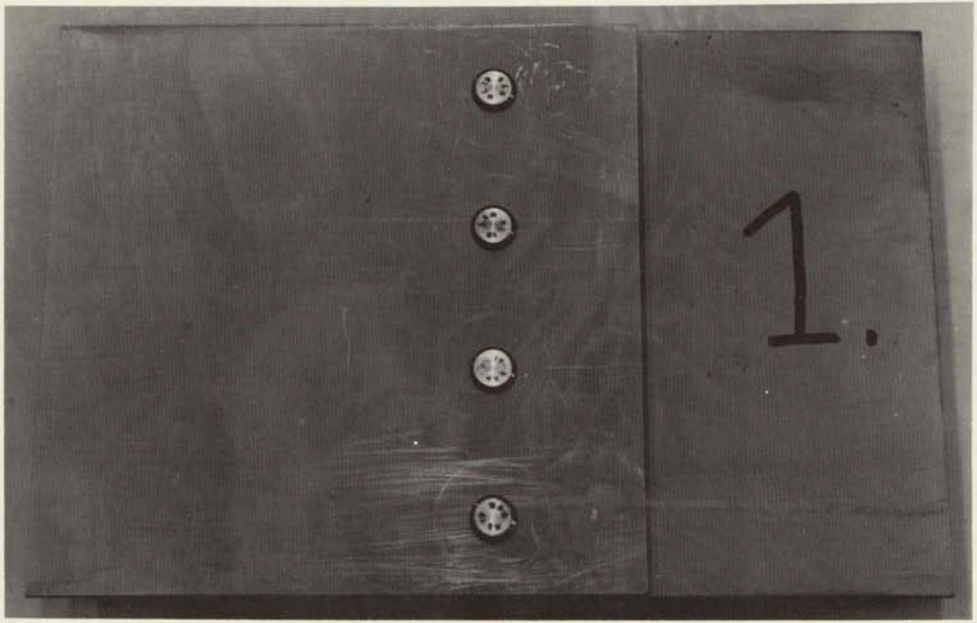


FIGURE 15. CONTROL PANEL NO. 1 SHOWING HEAD END OF TITANIUM 6Al-4V HI-LOK FASTENERS INSTALLED IN TITANIUM 8Al-1Mo-1V SHEET MATERIAL

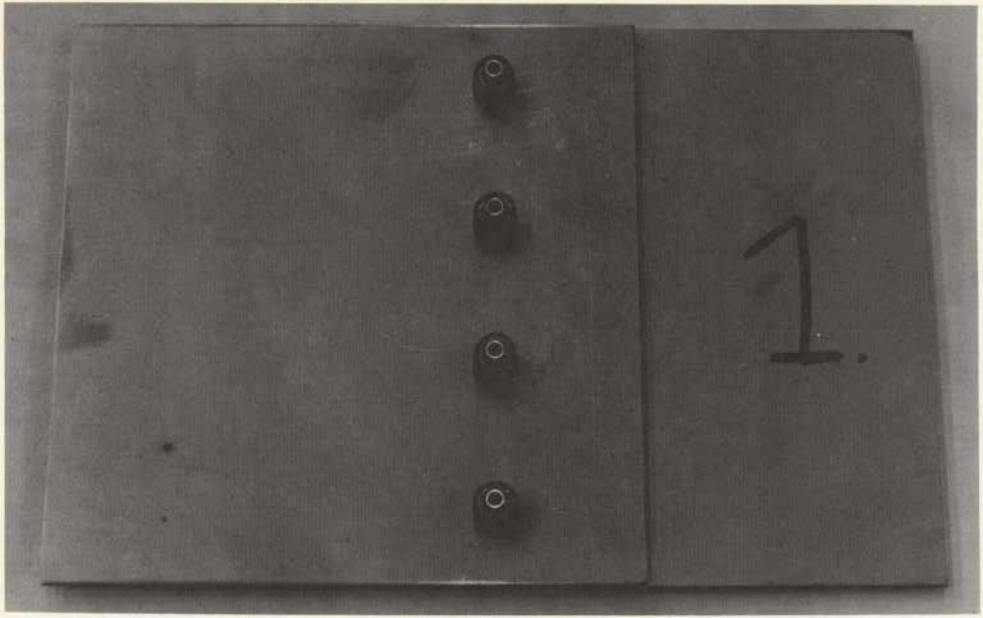


FIGURE 16. CONTROL PANEL NO. 1 SHOWING NUT END OF TITANIUM 7Al-4V HI-LOK FASTENERS INSTALLED IN TITANIUM 8Al-1Mo-1V SHEET MATERIAL

FIGURE 17. PANEL NO. 2 SHOWING HEAD END OF TITANIUM 6Al-4V HI-LOK FASTENERS INSTALLED IN TITANIUM 8Al-1Mo-1V SHEET MATERIAL AFTER 251 HOUR SALT SPRAY TEST

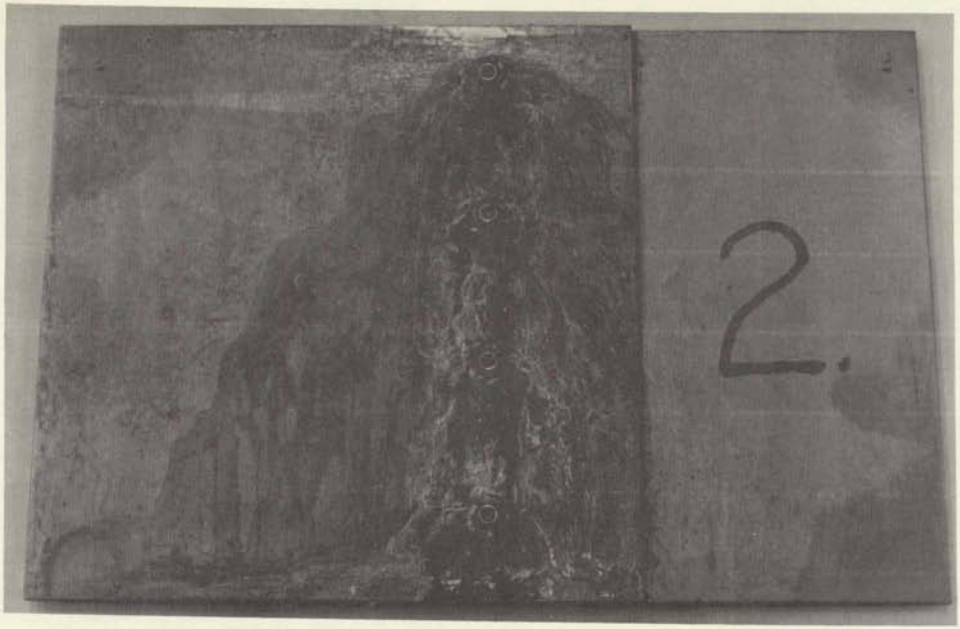


FIGURE 18. PANEL NO. 2 SHOWING NUT END OF TITANIUM 6Al-4V HI-LOK FASTENERS INSTALLED IN TITANIUM 8Al-1Mo-1V SHEET MATERIAL AFTER 251 HOUR SALT SPRAY TEST

DISCUSSION

Torque vs. Induced Load Testing

The proper amount of preload (clamping force) for a fastener system is very important because the preload should equal or exceed the maximum working load on the joint. For this reason it is desirable to perform torque tension testing to specify sufficient torque that will result in the proper preload for the bolt-nut-washer combination. The torque wrench is perhaps the most widely used and least expensive method to apply a load to a fastener, but the results usually vary up to ±25 percent. It is for this reason that torque values for fasteners utilize a limited amount of the available strength of the fastener system.

The type of lubricant/plating used on the bolt-nut combination will have an effect on the torque-tension relationship: therefore the data in this report cannot be used for other fastener combinations. The Six-Wing nuts used in this program were coated with a proprietary anti-galling coating by the Hi-Shear Corporation. The bolts are made from 6Al-4V titanium, but without any coating.

Self-locking nuts used in the aerospace industry usually have a wide variation in the allowable prevailing torque. For this reason the amount of prevailing torque in a specific nut should be added to the torque value specified for a bolt-nut installation. The torque values shown in Figures 6 through 9 were plotted without prevailing torque and, therefore, when installing any of the Six-Wing nuts, the prevailing torque value should be added to the engineering drawing torque requirement.

The torque vs. induced load values shown in Figures 6 and 8 gave good results because of a consistent torque-tension relationship, but values in Figures 7 and 9 vary considerably at the higher loads. Examination of the nut's washer face revealed that the coating had been removed during installation and the resultant galling caused the wide variance.

Hole Tolerance Evaluation

A summary of lap joint test results is given in Table XVI for 4.826mm (0.190 inch) Hi-Loks and 6.350mm (0.250 inch) diameter Six-Wing bolts that were evaluated for their strength-hole size relationship. All lap joint materials were machined from one sheet of 2.54mm (0.100 inch) thick 8Al-1Mo-1V

titanium alloy. The Hi-Loks and Six-Wing bolts were all from the same lot of material for the specific fastener. The only variable remaining would be the hole size variation for the fastener.

Examination of the load data shows there was an insignificant change in both yield and ultimate strength values for the 4.826mm (0.190 inch) diameter Hi-Loks. There was some difference for the 6.350mm (0.250 inch) diameter Six-Wing bolt; this was indicated by a decrease in yield strength and an increase in the ultimate strength of the fastener as the hole size increased. The reason for the decrease in yield strength is thought to be the point loading on the side of the hole, which causes an increase in the unit bearing strength as the canting of the fastener increased because of the larger hole sizes. The increase in ultimate shear strength is caused by the larger shear area that is exposed as a result of the canting of the fastener shank as the hole size is increased.

Hole Angle Evaluation

A summary of the lap joint test results is given in Table XXVII for 4.826mm (0.190 inch) diameter Six-Wing bolts and 6.350mm (0.250 inch) diameter Hi-Loks that were evaluated for their strength-hole angle relationship. Again all the lap joint materials were machined from one sheet of 2.54 mm (0.100 inch) thick 8Al-1Mo-1V titanium alloy. The Six-Wing bolts and Hi-Loks were all from the same lot of material for the specific fastener. Again, the holes were all machined to essentially the same diameter but with hole angles of 0 radian, 3.49×10^{-2} radian (2 degrees), and 6.98×10^{-2} radian (4 degrees) variation from perpendicularity. The hole angles were made so that the angle decreased as the load decreased, and this is undoubtedly the reason for the small change in the ultimate shear strength of both fastener sizes. This time though there was a reduction in the yield strength of both fasteners, probably because of the point loading in the side of the hole, which increased as the hole angle was increased.

Salt Spray and Induced Defect Evaluation

A summary of the results of the lap joint salt spray and induced defect evaluation is given in Table XXVIII for 4.826mm (0.190 inch) diameter Hi-Loks. All lap joint materials were machined from one sheet of 2.54mm (0.100 inch) thick 8Al-1Mo-1V titanium alloy, and the 6Al-4V titanium Hi-Lok fasteners were made from the same lot of rod material. The Hi-Lok collars were made

from 2014-T6 aluminum alloy and were coated with zinc chromate primer per MIL-P-8585 before initiation of the 600 hour salt spray test.

The holes were drilled and reamed to essentially the same size for each joint test.

Review of the tabulated data reveals no significant variation in average results of the three type joints. The data given in Table XVIII and XVIIIA for results of individual lap joint tests show that the yield strength would not be appreciably affected if the estimated data were deleted from the average results.

The zinc chromate primer did protect the fastener assembly from corrosion and the effect on the joint strength was negligible.

Induced Defect Evaluation

The summary of the results of the lap joint tests is given in Table XXIX for three sizes of Hi-Loks and four sizes of Six-Wing bolts installed in two thicknesses of 8Al-1Mo-1V titanium sheet material. All lap joint materials of the same thickness were machined from one sheet and the fasteners of the same size and type were taken from the same lot of fasteners. The induced defects were made on both parts making up a lap joint and these were scratches approximately 0.127mm (0.005 inch) deep across the joint width through both fastener holes. The holes were drilled and reamed to essentially the same size for each joint test. The material thickness was 2.54mm (0.100 inch) thick for all joints except for the 9.44mm (0.375 inch) fasteners, and it was 3.175mm (0.125 inch).

A review of the tabulated test results shows that in the majority of joints there was no significant difference in the strength of the joint because of defects resulting from fabrication carelessness. The entire results of the Hi-Lok tests were very close, but there was some variation for the Six-Wing bolts in both yield and ultimate strength. In some tests the yield or ultimate strength of joint groups with defects are higher than groups without defects and in other tests the opposite is true. The reason for this difference is not known.

The 6.350mm (0.250 inch) diameter Hi-Loks and Six-Wing bolts had substantially the same ultimate shear strength. The yield strengths are nearly equal, but the ultimate strength of the Six-Wing bolt joint is considerably higher. The reason for this increase would be the higher preload applied to the Six Wing bolt joints.

RECOMMENDATIONS

For installation of 6Al-4V titanium fasteners in 8Al-1Mo-1V titanium sheet material used in the manufacture of structural components for space vehicles, it is recommended that the following specifications be implemented:

1. Holes for fastener installation shall be reamed to the maximum shank diameter plus 0.050mm (0.002 inch), minus 0.000mm (0.000 inch).

2. Holes shall be reamed perpendicular to the sheet material surface within 3.49×10^{-2} radian (2 degrees).

3. Fasteners using stainless steel or aluminum alloy components shall be coated with zinc chromate primer per MIL-P-8585 before installation and will include a touch-up of all uncoated surfaces.

For future work, it is recommended that fatigue tests be conducted of lap joints with induced defects and corrosion.

TABLE I. DISTRIBUTION OF LAP JOINT TEST SPECIMENS
BY FASTENER SIZE, HOLE FIT, AND MATERIAL THICKNESS

Project Group	Fastener	Mfg's Part No	Nom. Dia. mm (in)	Lap Joint Marking	Hole Fit	Nom. Material Thickness 2.54mm(0.100in)	Nom. Material Thickness 3.175mm(0.125in)	T/D
3A1	Hi-Lok	HL10V70-6-4	4.826(0.190)	3110	Interference	5		0.526
3A2	Hi-Lok	HL10V70-6-4	4.826(0.190)	3410	Ream	4		0.526
3A3	Hi-Lok	HL10V70-6-4	4.826(0.190)	3710	Clearance	4		0.526
3A4	Hi-Lok	HL10V70-6-4	4.826(0.190)	3410	Ream & Salt Spray	5		0.526
3A5	Hi-Lok	HL10V70-6-4	4.826(0.190)	3410	Ream, Salt Spray & Induced Defects	5		0.526
4A1	Hi-Lok	HL10V70-8-8	6.350(0.250)	4410	Ream	5		0.400
4A2	Hi-Lok	HL10V70-8-8	6.350(0.250)	4510	Ream & 3.49×10^{-2} Radian (2^{o}) Angle	4		0.400
4A3	Hi-Lok	HL10V70-8-8	6.350(0.250)	4610	Ream & 6.98×10^{-2} Radian (4^{o}) Angle	5		0.400
4A4	Hi-Lok	HL10V70-8-8	6.350(0.250)	4410	Ream & Induced Defects	5		0.400
5A1	Hi-Lok	HL10V70-10-6	7.938(0.3125)	5410	Ream	5		0.320
5A2	Hi-Lok	HL10V70-10-6	7.938(0.3125)	5410	Ream & Induced Defects	5		0.320
6B1	Hi-Lok	HL10V70-12-7	9.525(0.375)	6412	Ream		5	0.333
6B2	Hi-Lok	HL10V70-12-7	9.525(0.375)	6412	Ream & Induced Defects		5	0.333
3A6	Six-Wing	SW2565-3-4	4.826(0.190)	3410	Ream	5		0.526
3A7	Six-Wing	SW2565-3-4	4.826(0.190)	3510	Ream & 3.49×10^{-2} Radian (2^{o}) Angle	5		0.526
3A8	Six-Wing	SW2565-3-4	4.826(0.190)	3610	Ream & 6.98×10^{-2} Radian (4^{o}) Angle	5		0.526
3A9	Six-Wing	SW2565-3-4	4.826(0.190)	3410	Ream & Induced Defects	5		0.526

TABLE I. (Concluded)

Project Group	Fastener	Mfg's Part No	Nom. Dia. mm (in)	Lap Joint Marking	Hole Fit	Nom. Material Thickness 2.54mm(0.100in)	Nom. Material Thickness 3.175mm(0.125in)	T/D
4A10	Six-Wing	SW2565-4-4	6.350(0.250)	4110	Interference	5		0.400
4A11	Six-Wing	SW2565-4-4	6.350(0.250)	4410	Ream	5		0.400
4A12	Six-Wing	SW2565-4-4	6.350(0.250)	4710	Clearance	4		0.400
4A13	Six-Wing	SW2565-4-4	6.350(0.250)	4410	Ream & Induced Defects	5		0.400
5A14	Six-Wing	SW2565-5-4	7.938(0.3125)	5410	Ream	5		0.320
5A15	Six-Wing	SW2565-5-4	7.938(0.3125)	5410	Ream & Induced Defects	5		0.320
6B3	Six-Wing	SW2565-6-4	9.525(0.375)	6412	Ream		5	0.333
6B4	Six-Wing	SW2565-6-4	9.525(0.375)	6412	Ream & Induced Defects		5	0.333

NOTES:

1. Hi-Lok identification code is as follows: HL10V70- indicates Hi-Lok Fastener Assembly which includes 6AL-4V Titanium HL10V pin and 2024 aluminum alloy HL70 collar; first dash number indicates pin nominal diameter in 1/32ths; second dash number indicates maximum grip in 1/16ths.

2. Six-wing identification code is as follows: SW2565 indicates six-wing bolt-nut assembly which includes 6AL-4V Titanium Bolt and SW65 nut; first dash number indicates bolt nominal diameter in 1/16ths; second dash number indicates maximum grip in 1/16ths.

3. Lap Joint marking code is as follows: First number indicates nominal hole size in 1/16ths; second number indicates joint drawing part number by dash number; last two numbers indicate sheet thickness in 1/100ths inch.

TABLE II. DISTRIBUTION OF FASTENER TESTS

PROJECT GROUP	FASTENER	MFG.'S PART NUMBER	NOM. DIA. MM. (IN.)	SINGLE SHEAR	TORQUE vs. INDUCED LOAD	APPLIED TORQUE Nm (INCH-POUNDS)
3A1-3A5	Hi-Lok	HLV1070-6-4	4.826(0.190)	5		2.82-3.95 (25-35)
4A1-4A4	Hi-Lok	HLV1070-8-8	6.350(0.250)	5		7.34-9.04 (65-80)
5A1-5A2	Hi-Lok	HLV1070-10-6	7.938(0.3125)	5		14.69-18.08 (130-160)
6B1-6B2	Hi-Lok	HLV1070-10-7	9.527(0.375)	5		22.60-27.11 (200-240)
3A6-3A9	Six-Wing	SW2565-3-4	4.826(0.190)	5		3.38 (30)
-	Six-Wing	SW2565-3-8	4.826(0.190)		5	To bolt failure
4A10-4A13	Six-Wing	SW2565-4-4	6.350(0.250)	5		7.34 (65)
-	Six-Wing	SW2565-4-24	6.350(0.250)		5	To bolt failure
5A14-5A15	Six-Wing	SW2565-5-4	7.938(0.3125)	5		15.25 (135)
-	(1)		7.938(0.3125)		5	To bolt failure
6B3-6B4	Six-Wing	SW2565-6-4	9.525(0.375)	5		23.72 (210)
-	Six-Wing	SW2565-6-24	9.525(0.375)		5	To bolt failure

Note: 1. Fastener consisted of Bolt, NAS675V16 and Nut, SW65-5.

TABLE III. THICKNESS OF TITANIUM 8Al-1Mo-1V LAP JOINT SPECIMENS AND DIAMETER OF 4.826mm (0.190 inch) TITANIUM 6Al-4V HI-LOK FASTENERS

Project Group	Sample Designation	Average Thickness mm	Average Thickness Inch	No. 1 Hole Diameter mm	No. 1 Hole Diameter Inch	No. 1 Fastener Average Dia.(1) mm	No. 1 Fastener Average Dia.(1) Inch	No. 2 Hole Diameter mm	No. 2 Hole Diameter Inch	No. 2 Fastener Average Dia. (1) mm	No. 2 Fastener Average Dia. (1) Inch
3A1	1A3110	2.553	0.1005	4.727	0.1861	4.806	0.1892	4.719	0.1858	4.803	0.1891
Interference	1B3110	2.802	0.1103	4.714	0.1856			4.717	0.1858		
Fit	2A3110	2.789	0.1098	4.714	0.1856	4.806	0.1892	4.712	0.1855	4.803	0.1891
	2B3110	2.649	0.1043	4.707	0.1853			4.714	0.1856		
	3A3110	2.776	0.1093	4.724	0.1860	4.808	0.1893	4.719	0.1858	4.808	0.1893
	3B3110	2.860	0.1126	4.707	0.1853			4.722	0.1859		
	4A3110	2.837	0.1117	4.717	0.1857	4.806	0.1892	4.709	0.1854	4.806	0.1892
	4B3110	2.824	0.1112	4.714	0.1856			4.722	0.1859		
	5A3110	2.840	0.1118	4.717	0.1857	4.808	0.1893	4.712	0.1855	4.808	0.1893
	5B3110	2.840	0.1118	4.712	0.1855			4.707	0.1853		
3A2	6A3410	2.824	0.1112	4.826	0.1900	4.806	0.1892	4.823	0.1899	4.803	0.1891
Ream	6B3410	2.855	0.1124	4.818	0.1897			4.818	0.1897		
Fit	7A3410	2.827	0.1113	4.834	0.1903	4.806	0.1892	4.811	0.1894	4.813	0.1895
	7B3410	2.832	0.1115	4.813	0.1895			4.818	0.1897		
	8A3410	2.670	0.1051	4.818	0.1897	4.811	0.1894	4.811	0.1894	4.811	0.1894
	8B3410	2.855	0.1124	4.834	0.1903			4.816	0.1896		
	9A3410	2.847	0.1121	4.806	0.1892	4.808	0.1893	4.806	0.1892	4.808	0.1893
	9B3410	2.652	0.1044	4.811	0.1894			4.821	0.1898		
3A3	11A3710	2.819	0.1110	4.869	0.1917	4.803	0.1891	4.867	0.1916	4.813	0.1895
Clearance	11B3710	2.766	0.1089	4.877	0.1920			4.879	0.1921		
Fit	12A3710	2.824	0.1112	4.879	0.1921	4.808	0.1893	4.877	0.1290	4.808	0.1893
	12B3710	2.789	0.1098	4.884	0.1923			4.892	0.1926		
	13A3710	2.822	0.1111	4.882	0.1922	4.811	0.1894	4.877	0.1920	4.808	0.1893
	13B3710	2.731	0.1075	4.882	0.1922			4.882	0.1922		
	14A3710	2.880	0.1134	4.887	0.1924	4.816	0.1896	4.882	0.1922	4.813	0.1895
	14B3710	2.837	0.1117	4.862	0.1914			4.884	0.1923		
3A4	16A3410	2.449	0.0964	4.831	0.1902	4.806	0.1892	4.826	0.1900	4.808	0.1893
Ream	16B3410	2.441	0.0961	4.816	0.1896			4.818	0.1897		
Fit	17A3410	2.466	0.0971	4.821	0.1898	4.811	0.1894	4.808	0.1893	4.808	0.1893
Salt	17B3410	2.482	0.0977	4.867	0.1916			4.809	0.1917		
Spray	18A3410	2.446	0.0963	4.862	0.1914	4.808	0.1893	4.882	0.1922	4.808	0.1893
	18B3410	2.489	0.0980	4.867	0.1916			4.872	0.1918		
	19A3410	2.497	0.0983	4.884	0.1923	4.803	0.1891	4.887	0.1924	4.806	0.1892
	19B3410	2.461	0.0969	4.821	0.1898			4.818	0.1897		
	20A3410	2.502	0.0985	4.816	0.1896	4.811	0.1894	4.823	0.1899	4.806	0.1892
	20B3410	2.451	0.0965	4.818	0.1897			4.818	0.1897		
3A5	21A3410	2.423	0.0954	4.816	0.1896	4.808	0.1893	4.823	0.1899	4.808	0.1893
Ream	21B3410	2.489	0.0980	4.826	0.1900			4.801	0.1890		
Fit	22A3410	2.426	0.0955	4.823	0.1899	4.803	0.1891	4.823	0.1899	4.806	0.1892
Induced	22B3410	2.461	0.0969	4.823	0.1899			4.818	0.1897		
Defects	23A3410	2.441	0.0961	4.834	0.1903	4.806	0.1892	4.829	0.1901	4.801	0.1890
& Salt	23B3410	2.459	0.0968	4.818	0.1897			4.818	0.1897		
Spray	24A3410	2.482	0.0977	4.821	0.1898	4.801	0.1890	4.834	0.1903	4.803	0.1891
	24B3410	2.522	0.0993	4.831	0.1902			4.823	0.1899		
	25A3410	2.451	0.0965	4.829	0.1901	4.801	0.1890	4.821	0.1898	4.806	0.1892
	25B3410	2.497	0.0983	4.823	0.1899			4.826	0.1900		

NOTE: 1. Average of two measurements.

TABLE IV. THICKNESS OF TITANIUM 8Al-1Mo-1V LAP JOINT SPECIMENS AND DIAMETER OF 6.350mm (0.250 inch) TITANIUM 6Al-4V HI-LOK FASTENERS

Project Group	Sample Designation	Average Thickness mm	Inch	No. 1 Hole Diameter mm	Inch	No. 1 Fastener Average Dia.(1) mm	Inch	No. 2 Hole Diameter mm	Inch	No.2 Fastener Average Dia(1 mm	Inch
4A1	1A4410	2.657	0.1046	6.350	0.2500	6.330	0.2492	6.347	0.2499	6.332	0.2493
Ream	1B4410	2.560	0.1008	6.353	0.2501			6.352	0.2501		
Fit	2A4410	2.652	0.1044	6.350	0.2500	6.330	0.2492	6.347	0.2499	6.330	0.2492
	2B4410	2.565	0.1010	6.355	0.2502			6.352	0.2501		
	3A4410	2.565	0.1010	6.350	0.2500	6.330	0.2492	6.350	0.2500	6.330	0.2492
	3B4410	2.652	0.1044	6.353	0.2501			6.350	0.2500		
	4A4410	2.743	0.1080	6.350	0.2500	6.332	0.2493	6.355	0.2502	6.332	0.2493
	4B4410	2.624	0.1033	6.355	0.2502			6.350	0.2500		
	5A4410	2.715	0.1069	6.353	0.2501	6.332	0.2493	6.347	0.2499	6.332	0.2493
	5B4410	2.647	0.1042	6.347	0.2499			6.350	2500		
4A2	6A4510	2.697	0.1062	6.370	0.2508	6.332	0.2493	6.372	0.2509	6.330	0.2492
Ream	6B4510	2.672	0.1052	6.363	0.2505			6.370	0.2508		
Fit	7A4510	2.624	0.1033	6.370	0.2508	6.330	0.2492	6.370	0.2508	6.330	0.2492
3.49×10^{-2}	7B4510	2.662	0.1048	6.373	0.2509			6.372	0.2509		
Rad (2°)	8A4510	2.662	0.1048	6.378	0.2511	6.332	0.2493	6.375	0.2510	6.330	0.2492
Hole Angle	8B4510	2.510	0.0988	6.370	0.2508			6.372	0.2509		
	9A4510	2.649	0.1043	6.373	0.2509	6.332	0.2493	6.372	0.2509	6.332	0.2493
	9B4510	2.718	0.1070	6.116	0.2408			6.368	0.2507		
4A3	11A4610	2.682	0.1056	6.368	0.2507	6.320	0.2492	6.370	0.2508	6.322	0.2493
Ream	11B4610	2.680	0.1055	6.114	0.2407			6.370	0.2508		
Fit	12A4610	2.642	0.1040	6.373	0.2509	6.322	0.2493	6.370	0.2508	6.327	0.2491
6.98×10^{-2}	12B4610	2.723	0.1072	6.370	0.2508			6.375	0.2510		
Rad (2°)	13A4610	2.695	0.1061	6.368	0.2507	6.320	0.2492	6.370	0.2508	6.332	0.2493
Hole Angle	13B4610	2.692	0.1060	6.368	0.2507			6.373	0.2509		
	14A4610	2.611	0.1028	6.375	0.2510	6.320	0.2492	6.375	0.2510	6.320	0.2492
	14B4610	2.637	0.1038	6.373	0.2509			6.373	0.2509		
	15A4610	2.550	0.1004	6.370	0.2508	6.320	0.2492	6.370	0.2508	6.332	0.2493
	15B4610	2.667	0.1050	6.368	0.2507			6.370	0.2508		
4A4	16A4410	2.484	0.0978	6.355	0.2502	6.322	0.2493	6.350	0.2500	6.332	0.2493
Ream	16B4410	2.634	0.1037	6.353	0.2501			6.355	0.2502		
Fit	17A4410	2.619	0.1031	6.355	0.2502	6.327	0.2491	6.350	0.2500	6.327	0.2491
Induced	17B4410	2.629	0.1035	6.358	0.2503			6.350	0.2500		
Defects	18A4410	2.718	0.1070	6.355	0.2502	6.320	0.2492	6.352	0.2501	6.330	0.2492
	18B4410	2.682	0.1056	6.353	0.2501			6.352	0.2501		
	19A4410	2.604	0.1025	6.355	0.2502	6.320	0.2492	6.358	0.2503	6.330	0.2492
	19B4410	2.720	0.1071	6.355	0.2502			6.350	0.2500		
	20A4410	2.662	0.1048	6.358	0.2503	6.320	0.2492	6.350	0.2500	6.332	0.2493
	20B4410	2.560	0.1008	6.353	0.2501			6.350	0.2500		

NOTE: 1. Average of two measurements.

TABLE V. THICKNESS OF TITANIUM 8Al-1Mo-1V LAP JOINT SPECIMENS AND DIAMETER OF 7.937mm (0.3125 inch) TITANIUM 6Al-4V HI-LOK FASTENERS

Project Group	Sample Designation	Average Thickness		No. 1 Hole Diameter		No. 1 Fastener Average Dia.(1)		No. 2 Hole Diameter		No. 2 Fastener Average Dia.(1)	
		mm	inch	mm	inch	mm	inch	mm	inch	mm	inch
5A1	1A5410	2.697	0.1062	7.940	0.3126	7.922	0.3119	7.950	0.3130	7.917	0.3117
Ream	1B5410	2.568	0.1011	7.942	0.3127			7.948	0.3129		
Fit	2A5410	2.713	0.1068	7.942	0.3127	7.920	0.3118	7.950	0.3130	7.915	0.3116
	2B5410	2.682	0.1056	7.945	0.3128			7.948	0.3129		
	3A5410	2.609	0.1027	7.945	0.3128	7.917	0.3117	7.955	0.3132	7.917	0.3117
	3B5410	2.644	0.1041	7.950	0.3130			7.955	0.3132		
	4A5410	2.659	0.1047	7.945	0.3128	7.915	0.3116	7.953	0.3131	7.915	0.3116
	4B5410	2.680	0.1055	7.945	0.3128			7.955	0.3132		
	5A5410	2.697	0.1062	7.937	0.3125	7.920	0.3118	7.953	0.3131	7.917	0.3117
	5B5410	2.667	0.1050	7.937	0.3125			7.953	0.3131		
5A2	6A5410	2.708	0.1066	7.948	0.3129	7.917	0.3117	7.948	0.3129	7.920	0.3118
Ream	6B5410	2.702	0.1064	7.945	0.3128			7.953	0.3131		
Fit	7A5410	2.713	0.1068	7.950	0.3130	7.920	0.3118	7.950	0.3130	7.915	0.3116
Induced	7B5410	2.682	0.1056	7.953	0.3131			7.950	0.3130		
Defects	8A5410	2.695	0.1061	7.948	0.3129	7.917	0.3117	7.948	0.3129	7.920	0.3118
	8B5410	2.700	0.1063	7.950	0.3130			7.950	0.3130		
	9A5410	2.702	0.1064	7.948	0.3129	7.917	0.3117	7.950	0.3130	7.915	0.3116
	9B5410	2.652	0.1044	7.945	0.3128			7.948	0.3129		
	10A5410	2.614	0.1029	7.950	0.3130	7.915	0.3116	7.950	0.3130	7.915	0.3116
	10B5410	2.702	0.1064	7.948	0.3129			7.948	0.3129		

Notes:

1. Average of two measurements.

TABLE VI. THICKNESS OF TITANIUM 8Al-1Mo-1V LAP JOINT SPECIMENS AND DIAMETER OF 9.525mm (0.375 inch) TITANIUM 6Al-4V HI-LOK FASTENERS

Project Group	Sample Designation	Average Thickness mm	Average Thickness inch	No. 1 Hole Diameter mm	No. 1 Hole Diameter inch	No. 1 Fastener Average Dia.(1) mm	No. 1 Fastener Average Dia.(1) inch	No. 2 Hole Diameter mm	No. 2 Hole Diameter inch	No. 2 Fastener Average Dia(1 mm	No. 2 Fastener Average Dia(1 inch
6B1	1A6412	3.426	0.1349	9.535	0.3754	9.502	0.3741	9.939	0.3913	9.505	0.3742
Ream	1B6412	3.437	0.1353	9.533	0.3753			9.533	0.3753		
Fit	2A6412	3.238	0.1275	9.538	0.3755	9.505	0.3742	9.533	0.3753	9.502	0.3741
	2B6412	3.480	0.1370	9.535	0.3754			9.535	0.3754		
	3A6412	3.383	0.1332	9.533	0.3753	9.500	0.3740	9.538	0.3755	9.500	0.3740
	3B6412	3.152	0.1241	9.540	0.3756			9.538	0.3755		
	4A6412	3.477	0.1369	9.535	0.3754	9.505	0.3742	9.533	0.3753	9.502	0.3741
	4B6412	3.139	0.1235	9.538	0.3755			9.535	0.3754		
	5A6412	3.447	0.1357	9.530	0.3752	9.502	0.3741	9.535	0.3754	9.500	0.3740
	5B6412	3.297	0.1298	9.535	0.3754			9.535	0.3754		
6B2	6A6412	3.437	0.1353	9.530	0.3752	9.505	0.3742	9.530	0.3752	9.502	0.3741
Ream	6B6412	3.373	0.1328	9.538	0.3755			9.538	0.3755		
Fit	7A6412	3.416	0.1345	9.538	0.3755	9.502	0.3741	9.538	0.3755	9.500	0.3740
Induced	7B6412	3.429	0.1350	9.540	0.3756			9.538	0.3755		
Defects	8A6412	3.332	0.1312	9.540	0.3756	9.500	0.3740	9.540	0.3756	9.494	0.3788
	8B6412	3.457	0.1361	9.543	0.3757			9.540	0.3756		
	9A6412	3.170	0.1248	9.535	0.3754	9.502	0.3741	9.540	0.3756	9.505	0.3742
	9B6412	3.376	0.1329	9.535	0.3754			9.538	0.3755		
	10A6412	3.370	0.1327	9.533	0.3753	9.505	0.3742	9.535	0.3754	9.500	0.3740
	10B6412	3.345	0.1317	9.535	0.3754			9.538	0.3755		

Notes:

1. Average of two measurements.

TABLE VII. THICKNESS OF TITANIUM 8Al-1Mo-1V LAP JOINT SPECIMENS AND DIAMETER OF 4.826mm (0.190 inch) TITANIUM 6Al-4V SIX-WING BOLTS

Project Group	Sample Designation	Average Thickness mm	Average Thickness inch	No. 1 Hole Diameter mm	No. 1 Hole Diameter inch	No. 1 Fastener Average Dia.(1) mm	No. 1 Fastener Average Dia.(1) inch	No. 2 Hole Diameter mm	No. 2 Hole Diameter inch	No. 2 Fastener Average Dia.(1 mm	No. 2 Fastener Average Dia.(1 inch
3A6	51A3410	2.868	0.1129	4.813	0.1895	4.800	0.1890	4.816	0.1896	4.795	0.1888
Ream	51B3410	2.824	0.1112	4.818	0.1897			4.821	0.1898		
Fit	52A3410	2.497	0.0983	4.816	0.1896	4.803	0.1891	4.813	0.1895	4.808	0.1893
	52B3410	2.804	0.1104	4.818	0.1897			4.818	0.1897		
	53A3410	2.598	0.1023	4.821	0.1898	4.803	0.1891	4.818	0.1897	4.803	0.1891
	53B3410	2.525	0.0994	4.818	0.1897			4.818	0.1897		
	54A3410	2.774	0.1092	4.818	0.1897	4.806	0.1892	4.818	0.1897	4.808	0.1893
	54B3410	2.870	0.1130	4.821	0.1898			4.821	0.1898		
	55A3410	2.700	0.1063	4.821	0.1898	4.803	0.1891	4.821	0.1898	4.808	0.1893
	55B3410	2.718	0.1070	4.816	0.1896			4.816	0.1896		
3A7	56A3510	2.878	0.1133	4.813	0.1895			4.816	0.1896	4.803	0.1891
Ream	56B3410	2.865	0.1128	4.818	0.1897	4.808	0.1893	4.821	0.1898		
Fit	57A3410	2.471	0.0973	4.818	0.1897			4.821	0.1898	4.806	0.1892
3.49×10^{-2}	57B3410	2.786	0.1097	4.821	0.1898	4.803	0.1891	4.823	0.1899		
Rad (2°)	58A3410	2.868	0.1129	4.822	0.1899			4.821	0.1898	4.806	0.1892
Hole Angle	58B3410	2.763	0.1088	4.818	0.1897	4.818	0.1897	4.821	0.1898		
	59A3410	2.857	0.1125	4.816	0.1896			4.823	0.1899	4.808	0.1893
	59B3410	2.837	0.1117	4.818	0.1897	4.803	0.1891	4.816	0.1897		
	60A3410	2.878	0.1133	4.823	0.1899			4.823	0.1899	4.803	0.1891
	60B3410	2.829	0.1114	4.818	0.1897	4.808	0.1893	4.823	0.1899		
3A8	61A3610	2.878	0.1133	4.823	0.1899	4.806	0.1892	4.816	0.1896	4.806	0.1892
Ream	61B3610	2.527	0.0995	4.816	0.1896			4.818	0.1897		
Fit	62A3610	2.885	0.1136	4.816	0.1896	4.806	0.1892	4.821	0.1898	4.811	0.1894
6.98×10^{-2}	62B3610	2.883	0.1135	4.813	0.1895			4.816	0.1896		
Rad (4°)	63A3610	2.842	0.1119	4.818	0.1897	4.806	0.1892	4.826	0.1900	4.788	0.1885
Hole Angle	63B3610	2.852	0.1123	4.818	0.1897			4.823	0.1899		
	64A3610	2.791	0.1099	4.818	0.1897	4.806	0.1892	4.818	0.1897	4.806	0.1892
	64B3610	2.802	0.1103	4.816	0.1896			4.818	0.1897		
	65A3610	2.878	0.1133	4.816	0.1896	4.800	0.1890	4.821	0.1898	4.795	0.1888
	65B3610	2.870	0.1130	4.821	0.1898			4.826	0.1900		
3A9	66A3410	2.492	0.0981	4.818	0.1897	4.795	0.1888	4.816	0.1896	4.801	0.1890
Ream	66B3410	2.507	0.0987	4.813	0.1895			4.811	0.1894		
Fit	67A3410	2.527	0.0995	4.818	0.1897	4.798	0.1889	4.813	0.1895	4.798	0.1889
Induced	67B3410	2.728	0.1074	4.816	0.1896			4.813	0.1895		
Defects	68A3410	2.509	0.0988	4.818	0.1897	4.795	0.1888	4.818	0.1897	4.803	0.1891
	68B3410	2.520	0.0992	4.821	0.1898			4.821	0.1898		
	69A3410	2.852	0.1123	4.803	0.1891	4.803	0.1891	4.818	0.1897	4.806	0.1892
	69B3410	2.835	0.1116	4.816	0.1896			4.813	0.1895		
	70A3410	2.829	0.1114	4.816	0.1896	4.798	0.1889	4.816	0.1896	4.798	0.1889
	70B3410	2.862	0.1127	4.816	0.1896			4.821	0.1898		

Notes:
1. Average of two measurements.

TABLE VIII. THICKNESS OF TITANIUM 8Al-1Mo-1V LAP JOINT SPECIMENS AND DIAMETER OF 6.350mm (0.250 inch) TITANIUM 6Al-4V SIX-WING BOLTS

Project Group	Sample Designation	Average Thickness mm	Inch	No. 1 Hole Diameter mm	Inch	No. 1 Fastener Average Dia.(1) mm	Inch	No. 2 Hole Diameter mm	Inch	No. 2 Fastener Average Dia. (1) mm	Inch
4A9	51A4110	2.697	0.1062	6.286	0.2475	6.327	0.2491	6.284	0.2474	6.322	0.2489
Inter-	51B4110	2.715	0.1069	6.289	0.2476			6.276	0.2471		
ference	52A4110	2.654	0.1045	6.284	0.2474	6.325	0.2490	6.291	0.2477	6.327	0.2491
Fit	52B4110	2.654	0.1045	6.274	0.2470			6.291	0.2471		
	53A4110	2.670	0.1059	6.284	0.2474	6.325	0.2490	6.289	0.2476	6.325	0.2490
	53B4110	2.504	0.0986	6.291	0.2477			6.294	0.2478		
	54A4110	2.578	0.1015	6.281	0.2473	6.327	0.2491	6.279	0.2472	6.322	0.2489
	54B4110	2.476	0.0975	6.281	0.2473			6.289	0.2476		
	55A4110	2.669	0.1051	6.286	0.2475	6.319	0.2488	6.286	0.2475	6.322	0.2489
	55B4110	2.606	0.1026	6.276	0.2471			6.289	0.2476		
4A10	56A4410	2.675	0.1053	6.350	0.2500	6.330	0.2492	6.350	0.2500	6.327	0.2491
Ream	56B4410	2.657	0.1046	6.345	0.2498			6.347	0.2499		
Fit	57A4410	2.479	0.0976	6.347	0.2499	6.327	0.2491	6.347	0.2499	6.325	0.2490
	57B4410	2.492	0.0981	6.347	0.2499			6.345	0.2498		
	58A4410	2.563	0.1009	6.342	0.2497	6.325	0.2490	6.342	0.2497	6.325	0.2490
	58B4410	2.601	0.1024	6.347	0.2499			6.342	0.2497		
	59A4410	2.692	0.1060	6.355	0.2502	6.325	0.2490	6.350	0.2500	6.319	0.2488
	59B4410	2.535	0.0998	6.352	0.2501			6.358	0.2503		
	60A4410	2.598	0.1023	6.355	0.2502	6.332	0.2493	6.355	0.2502	6.325	0.2490
	60B4410	2.672	0.1052	6.355	0.2502			6.350	0.2500		
4A11	61A4710	2.494	0.0982	6.439	0.2535	6.332	0.2493	6.441	0.2536	6.322	0.2489
Clearance	61B4710	2.563	0.1009	6.444	0.2537			6.444	0.2537		
Fit	62A4710	2.530	0.0996	6.441	0.2536	6.325	0.2490	6.444	0.2537	6.330	0.2492
	62B4710	2.636	0.1038	6.444	0.2537			6.441	0.2536		
	63A4710	2.649	0.1043	6.441	0.2536	6.325	0.2490	6.444	0.2537	6.322	0.2489
	63B4710	2.499	0.0984	6.444	0.2537			6.446	0.2538		
	64A4710	2.591	0.1020	6.444	0.2537	6.325	0.2490	6.444	0.2537	6.332	0.2493
	64B4710	2.581	0.1016	6.441	0.2536			6.441	0.2536		
4A12	66A4410	2.690	0.1059	6.350	0.2500	6.330	0.2492	6.347	0.2499	6.325	0.2490
Ream	66B4410	2.639	0.1039	6.347	0.2499			6.350	0.2500		
Fit	67A4410	2.535	0.0998	6.342	0.2497	6.327	0.2491	6.345	0.2498	6.330	0.2492
Induced	67B4410	2.563	0.1009	6.347	0.2499			6.347	0.2499		
Defects	68A4410	2.555	0.1006	6.345	0.2498	6.325	0.2490	6.342	0.2497	6.327	0.2391
	68B4410	2.730	0.1075	6.350	0.2500			6.347	0.2499		
	69A4410	2.728	0.1074	6.350	0.2500	6.325	0.2490	6.350	0.2500	6.325	0.2490
	69B4410	2.565	0.1010	6.352	0.2501			6.350	0.2500		
	70A4410	2.642	0.1040	6.355	0.2502	6.327	0.2491	6.355	0.2502	6.330	0.2492
	70B4410	2.685	0.1057	6.350	0.2500			6.350	0.2500		

NOTE: 1. Average of two measurements.

TABLE IX. THICKNESS OF TITANIUM 8Al-1Mo-1V LAP JOINT SPECIMENS AND DIAMETER OF 7.937mm (0.3125 inch) TITANIUM 6Al-4V SIX-WING BOLTS

Project Group	Sample Designation	Average Thickness		No. 1 Hole Diameter		No. 1 Fastener Average Dia.(1)		No. 2 Hole Diameter		No. 2 Fastener Average Dia.(1)	
		mm	inch	mm	inch	mm	inch	mm	inch	mm	inch
5A13	51A5410	2.591	0.1020	7.950	0.3130	7.917	0.3117	7.950	0.3130	7.922	0.3119
Ream	51B5410	2.735	0.1077	7.953	0.3131			7.955	0.3132		
Fit	52A5410	2.657	0.1046	7.953	0.3131	7.927	0.3121	7.960	0.3134	7.922	0.3119
	52B5410	2.586	0.1018	7.955	0.3132			7.958	0.3133		
	53A5410	2.738	0.1078	7.955	0.3132	7.920	0.3118	7.955	0.3132	7.922	0.3119
	53B5410	2.723	0.1072	7.958	0.3133			7.958	0.3133		
	54A5410	2.710	0.1067	7.955	0.3132	7.927	0.3121	7.955	0.3132	7.920	0.3118
	54B5410	2.591	0.1020	7.950	0.3130			7.960	0.3134		
	55A5410	2.702	0.1064	7.953	0.3131	7.920	0.3118	7.958	0.3133	7.920	0.3118
	55B5410	2.697	0.1062	7.953	0.3131			7.960	0.3134		
5A14	56A5410	2.735	0.1077	7.937	0.3125	7.922	0.3119	7.948	0.3129	7.917	0.3117
Ream	56B5410	2.560	0.1008	7.940	0.3126			7.950	0.3130		
Fit	57A5410	2.682	0.1056	7.940	0.3126	7.922	0.3119	7.953	0.3131	7.922	0.3119
Induced	57B5410	2.733	0.1076	7.940	0.3126			7.960	0.3134		
Defects	58A5410	2.687	0.1058	7.950	0.3130	7.925	0.3120	7.950	0.3130	7.925	0.3120
	58B5410	2.697	0.1062	7.948	0.3129			7.953	0.3131		
	59A5410	2.662	0.1048	7.945	0.3128	7.920	0.3118	7.953	0.3131	7.920	0.3118
	59B5410	2.687	0.1058	7.945	0.3128			7.950	0.3130		
	60A5410	2.682	0.1056	7.945	0.3128	7.920	0.3118	7.953	0.3131	7.922	0.3119
	60B5410	2.687	0.1058	7.945	0.3128			7.950	0.3130		

Notes:

1. Average of two measurements.

TABLE X. THICKNESS OF TITANIUM 8Al-1Mo-1V LAP JOINT SPECIMENS AND DIAMETER OF 9.525mm (0.375 inch) TITANIUM 6Al-4V SIX-WING BOLTS

Project Group	Sample Designation	Average Thickness mm	Average Thickness inch	No. 1 Hole Diameter mm	No. 1 Hole Diameter inch	No. 1 Fastener Average Dia.(1) mm	No. 1 Fastener Average Dia.(1) inch	No. 2 Hole Diameter mm	No. 2 Hole Diameter inch	No. 2 Fastener Average Dia.(1) mm	No. 2 Fastener Average Dia.(1) inch
6B3	51A6412	3.279	0.1291	9.535	0.3754	9.500	0.3740	9.530	0.3752	9.515	0.37.
Ream	51B6412	3.345	0.1317	9.527	0.3751			9.535	0.3754		
Fit	52A6412	3.200	0.1260	9.535	0.3754	9.502	0.3741	9.535	0.3754	9.510	0.3744
	52B6412	3.325	0.1309	9.530	0.3752			9.530	0.3752		
	53A6412	3.193	0.1257	9.530	0.3752	9.502	0.3741	9.535	0.3754	9.507	0.3743
	53B6412	3.193	0.1257	9.533	0.3753			9.533	0.3753		
	54A6412	3.282	0.1292	9.533	0.3753	9.502	0.3741	9.535	0.3754	9.507	0.3743
	54B6412	3.208	0.1263	9.533	0.3753			9.533	0.3753		
	55A6412	3.241	0.1276	9.533	0.3753	9.512	0.3745	9.530	0.3752	9.510	0.3744
	55B6412	3.228	0.1271	9.530	0.3752			9.530	0.3752		
6B4	56A6412	3.089	0.1216	9.533	0.3753	9.505	0.3742	9.535	0.3754	9.505	0.3742
Ream	56B6412	3.183	0.1253	9.533	0.3753			9.533	0.3753		
Fit	57A6412	3.472	0.1367	9.530	0.3752	9.500	0.3740	9.540	0.3756	9.505	0.3742
Induced	57B6412	3.429	0.1350	9.530	0.3752			9.527	0.3751		
Defects	58A6412	3.274	0.1289	9.535	0.3754	9.494	0.3738	9.535	0.3754	9.510	0.3744
	58B6412	3.279	0.1291	9.533	0.3753			9.535	0.3754		
	59A6412	3.421	0.1347	9.533	0.3755	9.500	0.3740	9.538	0.3755	9.507	0.3743
	59B6412	3.457	0.1361	9.535	0.3754			9.535	0.3754		
	60A6412	3.312	0.1304	9.535	0.3754	9.500	0.3740	9.538	0.3755	9.497	0.3739
	60B6412	3.373	0.1328	9.535	0.3754			9.535	0.3754		

Notes:

1. Average of two measurements.

TABLE XI. MECHANICAL PROPERTIES OF TITANIUM 8Al-1Mo-1V SHEET MATERIAL

Sample No	THK mm	Width mm	Area SQ CM	Maximum Load Newtons	Tensile Strength Nm/m^2	Yield Load Newtons	Yield Strength at 0.2% Offset Nm/m^2	Elongation in 5.08 CM, percent
1A	2.642	12.830	3.389	35,000	1,032.8	32,400	957.6	11.5
2A	2.581	12.789	3.300	34,000	1,032.1	31,400	953.5	12.0
3A	2.631	12.789	3,364	34,600	1,030.7	32,400	964.5	10.5
4A	2.616	12.781	3.343	34,500	1,030.7	32,000	957.6	10.5
5A	2.578	12.822	3.305	34,400	1,041.1	31,300	948.0	10.7
6A	2.616	12.822	3.354	34,700	1,036.9	32,200	962.5	10.7
7A	2.604	12.723	3.313	34,200	1,034.9	32,000	966.6	10.5
8A	2.588	12.741	3.297	33,900	1,030.0	31,400	954.9	11.0
			Average		1,032.8			10.9
1B	3.122	12.776	3.988	39,500	992.1	37,100	930.0	11.5
2B	3.147	12.781	4,056	40,100	996.9	37,300	928.7	11.5
3B	3.124	12.789	3.995	39,900	998.3	37,100	928.0	12.1
4B	3,096	12.776	3.955	39,400	996.9	36,400	921.8	11.5
5B	3.099	12.802	3,936	39,900	1,006.6	36,300	914.9	12.3
6B	3.175	12.764	4.032	41,000	1,012.8	38,100	941.8	12.9
7B	3,147	12.774	4,020	40,800	1,015.6	37,300	929.4	12.5
			Average		1,002.5		927.3	12.0

TABLE XIA. MECHANICAL PROPERTIES OF TITANIUM 8Al-1Mo-1V SHEET MATERIAL

Sample No	THK In.	Width In.	Area Sq. In.	Maximum Load Lbs.	Tensile Strength psi	Yield Load lbs.	Yield Strength at 0.2% Offset psi	Elongation in 2 inches Percent
1A	0.1040	0.5051	0.0525	7,870	149,800	7,300	138,900	11.5
2A	0.1016	0.5035	0.0511	7,660	149,700	7,080	138,300	12.0
3A	0.1036	0.5035	0.0521	7,800	149,500	7,300	139,900	10.5
4A	0.1030	0.5032	0.0518	7,760	149,500	7,200	138,900	10.5
5A	0.1015	0.5048	0.0512	7,740	151,000	7,050	137,500	10.7
6A	0.1030	0.5048	0.0519	7,820	150,400	7,260	139,600	10.7
7A	0.1025	0.5009	0.0513	7,710	150,100	7,200	140,200	10.5
8A	0.1019	0.5016	0.0511	7,640	149,400	7,080	138,500	11.0
			Average		149,800		138,900	10.9
1B	0.1229	0.5030	0.0618	8,900	143,900	8,340	134,900	11.5
2B	0.1239	0.5032	0.0623	9,020	144,600	8,400	134,700	11.5
3B	0.1230	0.5035	0.0619	8,970	144,800	8,340	134,600	12.1
4B	0.1219	0.5030	0.0613	8,870	144,600	8,200	133,700	11.5
5B	0.1220	0.5040	0.0614	8,980	146,000	8,160	132,700	12.3
6B	0.1250	0.5025	0.0628	9,230	146,900	8,580	136,600	12.9
7B	0.1239	0.5029	0.0623	9,180	147,300	8,400	134,800	12.5
			Average		145,400		134,500	12.0

TABLE XII. RESULTS OF SINGLE SHEAR TESTS OF TITANIUM 6Al-4V HI-LOKS

Project Group	Mfg's Part Number	Specimen No	Average Dia.(1) mm	Dia.(1) (in)	Load Newtons	Load (Pounds)	Ultimate Shear Stress Nm/m^2	Ultimate Shear Stress (PSI)
3A1-3A5	HL10V70-6-4(2)	1	4.810	0.1894	13,430	3,020	739.1	107,200
		2	4.810	0.1894	14,320	3,220	788.0	114,300
		3	4.810	0.1894	13,830	3,110	761.1	110,400
		4	4.810	0.1894	14,320	3,320	812.2	117,800
		5	4.815	0.1896	14,010	3,150	771.5	111,900
		6	4.808	0.1893	13,870	3,120	763.9	110,800
		7	4.815	0.1896	14,270	3,210	783.2	113,600
			Average		14,050	3,160	773.5	112,200
4A1-4A4	HL10V70-8-8(3)	1	6.329	0.2492	22,680	5,100	720.5	104,500
		2	6.329	0.2492	23,170	5,210	736.3	106,800
		3	6.329	0.2492	24,060	5,410	764.6	110,900
		4	6.329	0.2492	24,330	5,470	772.9	112,100
		5	6.329	0.2492	24,150	5,430	767.3	111,300
			Average		23,660	5,320	752.2	109,100
5A1-5A2	HL10V70-10-6(4)	1	7.919	0.3118	32,330	7,270	656.3	95,200
		2	7.922	0.3119	33,710	7,580	683.9	99,200
		3	7.919	0.3118	33,310	7,490	676.3	98,100
		4	7.922	0.3119	33,000	7,420	669.4	97,100
		5	7.922	0.3119	33,130	7,450	672.2	97,500
			Average		33,090	7,440	671.5	97,400
6B1-6B2	HL10V70-12-7(5)	1	9.504	0.3742	53,820	12,100	758.4	110,000
		2	9.507	0.3743	54,930	12,350	773.5	112,200
		3	9.509	0.3744	53,770	12,090	757.0	109,800
		4	9.509	0.3744	51,240	11,520	721.1	104,600
		5	9.504	0.3742	53,590	12,050	754.9	109,500

Notes:
1. Average of two measurements.
2. Shear blade thickness was 2.387mm (0.094 in) and hole diameter was 4.775mm (0.188 in).
3. Shear blade thickness was 6.096mm (0.240 in) and hole diameter was 6.375mm (0.251 in).
4. Shear Blade thickness was 4.775mm (0.188 in) and hole diameter was 7.950mm (0.313 in).
5. Shear blade thickness was 4.775mm (0.188 in) and hole diameter was 9.550mm (0.376 in).

TABLE XIII. RESULTS OF SINGLE SHEAR TESTS OF TITANIUM 6Al-4V SIX-WING BOLTS

Project Group	Mfg's Part Number	Specimen No	Average Dia.(1) mm	(in)	Load Newtons	(Pounds)	Ultimate Shear Stress MN/m^2	(PSI)
3A6-3A9	SW2565-3-4(2)	1	4.813	0.1895	14,230	3,200	781.8	113,400
		2	4.813	0.1895	14,580	3,280	801.8	116,300
		3	4.813	0.1895	14,580	3,280	801.8	116,300
		4	4.808	0.1893	13,430	3,020	739.8	107,300
		5	4.815	0.1896	13,520	3,040	742.5	107,700
			Average		14,050	3,160	773.5	112,200
4A10-4A13	SW2565-4-4(3)	1	6.332	0.2493	23,350	5,250	741.1	107,500
		2	6.329	0.2492	23,170	5,210	736.3	106,800
		3	6.329	0.2492	24,590	5,530	781.1	113,300
		4	6.332	0.2493	24,810	5,580	788.0	114,300
		5	6.327	0.2491	22,240	5,000	721.1	104,600
			Average		23,610	5,310	753.6	109,300
5A14-5A15	SW2565-5-4(4)	1	7.924	0.3120	38,690	8,700	783.9	113,700
		2	7.922	0.3119	38,870	8,740	788.0	114,300
		3	7.919	0.3118	37,980	8,540	770.8	111,800
		4	7.919	0.3118	36,780	8,270	746.7	108,300
		5	7.922	0.3119	39,270	8,830	796.3	115,500
			Average		38,290	8,610	777.0	112,700
6B3-6B4	SW2565-6-4(5)	1	9.507	0.3743	48,480	10,900	682.9	99,060
		2	9.502	0.3741	50,480	11,350	712.2	103,300
		3	9.509	0.3744	50,700	11,400	713.6	103,500
		4	9.509	0.3744	50,700	11,400	713.6	103,500
		5	9.504	0.3742	52,700	10,850	680.3	98,680
			Average		49,720	11,180	700.5	101,600

Notes:
1. Average of two measurements.
2. Shear blade thickness was 2.387mm (0.094 in) and hole diameter was 4.775mm (0.188 in). Applied Torque was 3.38 Nm (30 in-lbs).
3. Shear blade thickness was 3.175mm (0.125in) and hole diameter was 6.375mm(0.251 in). Applied Torque was 7.34 Nm (65 in-lbs).
4. Shear blade thickness was 3.962mm (0.156in) and hole diameter was 7.950mm (0.313 in). Applied torque was 15.25Nm (135 in-lbs).
5. Shear blade thickness was 4.775 mm (0.188in) and hole diameter was 9.550mm (0.376in). Applied torque was 23.72 Nm (210 in-lbs).

TABLE XIV. TORQUE VS. INDUCED LOAD FOR TITANIUM 6Al-4V SIX-WING BOLT ASSEMBLY, P/N SW2565-3-8, 4.826mm (0.190 in.) NOMINAL DIAMETER x 12.7mm (0.50 in.) GRIP

Torque Nm	(in lbs)	BOLT AND NUT ASSY NO. 1		2		3		4		5	
		PREVAILING TORQUE, Nm (IN-LBS)									
		0.339	(3)	0.113	(1)	0.452	(4)	0.565	(5)	0.339	(3)
		LOAD, NEWTONS (POUNDS)									
3.39	(30)	3,730	(840)	3,780	(850)	2,980	(670)	3,110	(700)	4,000	(900)
4.52	(40)	5,110	(1,150)	6,040	(1,360)	4,530	(1,020)	5,330	(1,200)	6,000	(1,350)
5.65	(50)	6,670	(1,500)	7,330	(1,650)	6,670	(1,500)	7,250	(1,630)	7,910	(1,780)
6.78	(60)	7,160	(1,160)	9,470	(2,130)	7,820	(1,760)	9,470	(2,130)	9,110	(2,050)
7.91	(70)	8,270	(1,860)	11,120	(2,500)	9,340	(2,100)	10,890	(2,450)	10,670	(2,400)
9.04	(80)	9,470	(2,130)	12,230	(2,750)	11,120	(2,500)	12,000	(2,700)	11,430	(2,570)
10.17	(90)	11,600	(2,610)	13,340	(3,000)	12,810	(2,880)	13,520	(3,040)	11,960	(2,690)
11.30	(100)	12,630	(2,840)	14,450	(3,250)	14,630	(3,290)	13,960	(3,140)	13,560	(3,050)
12.43	(110)	14,450	(3,250)	14,900	(3,350)	15,790	(3,550)	15,560	(3,500)	15,120	(3,400)
13.56	(120)	16,010	(3,600)	15,790	(3,550)	15,960	(3,590)	16,010	(3,600)	15,560	(3,500)
14.69	(130)	16,230	(3,650)	16,010	(3,600)		Broke		Broke		Broke
15.82	(140)		Broke		Broke						

Notes:

1. Test Conducted on Skidmore-Wilhelm Torque Tension Tester, Model J, Serial # 1752.
2. Torque Wrench was in compliance with Federal Specification GGG-W-686, Wrench, Torque.
3. Accessories included:

   1 - Washer AN 960-10

TABLE XV. TORQUE VS. INDUCED LOAD FOR TITANIUM 6Al-4V SIX-WING BOLT ASSEMBLY, P/N SW2565-4-24, 6.350mm (0.250 in.) NOMINAL DIAMETER × 5.08cm (1.5 in.) GRIP

TORQUE Nm	TORQUE (in lbs)	BOLT AND NUT ASSY NO. 1		2		3		4		5	
		PREVAILING TORQUE, Nm						(IN-LBS)			
		3.39	(30)	3.95	(35)	3.39	(30)	3.95	(35)	4.52	(40)
		LOAD, NEWTONS (POUNDS)									
5.65	(50)			1,460	(330)	1,730	(390)				
8.47	(75)	4,890	(1,100)	4,670	(1,050)	5,380	(1,210)	3,910	(880)	4,310	(970)
11.30	(100)	8,890	(2,000)	7,200	(1,620)	10,450	(2,350)	6,710	(1,510)	6,890	(1,550)
14.12	(125)	12,270	(2,760)	8,890	(2,000)	15,650	(3,520)	10,140	(2,280)	10,540	(2,370)
16.95	(150)	16,010	(3,600)	13,780	(3,100)	20,720	(4,660)	13,430	(3,020)	13,960	(3,140)
19.77	(175)	18,900	(4,250)	16,050	(3,610)	23,930	(5,380)	15,120	(3,400)	15,610	(3,510)
22.60	(200)	22,010	(4,950)	20,280	(4,560)	25,530	(5,740)	18,770	(4,220)	17,830	(4,010)
25.42	(225)	24,010	(5,400)	22,280	(5,010)	Broke		21,430	(4,820)	20,010	(4,500)
28.24	(250)	Broke		Broke				Broke		21,080	(4,740)
33.89	(300)									Broke	

Notes:

1. Test conducted on Skidmore-Wilhelm Torque Tension Tester Model J. Serial # 1752.
2. Torque Wrench was in compliance with Federal Specification GGG-W-666, Wrench, Torque.
3. Accessories included:

   1 - Washer, MS20002C4
   1 - Washer, MS20002-4
   1 - Spacer, 6.502mm (0.256 in) ID. X 13.487mm (0.531 in) O.D. 14.300mm (0.563 in.) Lg. Hardened to RC 40-45.

TABLE XVI. TORQUE VS. INDUCED LOAD FOR TITANIUM 6Al-4V NAS675V16 BOLT AND SW65-5 NUT, 7.938mm (0.3125 in.) NOM. DIA. × 2.54 cm (1.0 in.) GRIP

Torque Nm (in lbs)	BOLT AND NUT ASSY. NO.									
	1		2		3		4		5	
	PREVAILING TORQUE Nm (IN-LBS)									
	2.82	(25)	5.64	(50)	4.51	(40)	5.64	(50)	5.08	(45)
	LOAD, NEWTONS (POUNDS)									
11.29 (100)	5,960	(1,340)	4,310	(970)	5,240	(1,180)	4,090	(920)	4,530	(1,020)
16.94 (150)	9,960	(2,240)	7,600	(1,710)	9,340	(2,100)	7,510	(1,690)	7,510	(1,690)
22.59 (200)	13,960	(3,140)	12,140	(2,730)	14,410	(3,240)	12,000	(2,700)	12,230	(2,750)
28.24 (250)	18,280	(4,110)	16,100	(3,620)	18,590	(4,180)	15,210	(3,420)	16,810	(3,780)
33.89 (300)	22,590	(5,080)	19,120	(4,300)	24,060	(5,410)	20,010	(4,500)	21,880	(4,920)
39.54 (350)	26,420	(5.940)	22,900	(5,150)	27,660	(6,220)	22,950	(5,160)	25,440	(5,720)
45.19 (400)	30,950	(6,960)	27,080	(6,090)	30,780	(6,920)	25,790	(5,800)	28,600	(6,430)
50.84 (450)	33,040	(7,430)	30,330	(6,820)	35,050	(7,880)	29,930	(6,730)	32,070	(7,210)
56.49 (500)	35,670	(8,020)	33,710	(7,580)	Broke		32,510	(7,310)	36,510	(8,210)
62.13 (550)	Broke		Broke				Broke		Broke	

Notes:
1. Test Conducted on **Skidmore**-Wilhelm Torque Tension Tester, Model J, Serial # 1752.
2. Torque Wrench was in compliance with Federal Specification GGG-W-686, Wrench, Torque.
3. Accessories included:
   2 - **Washer MS2002-5**
   2 - **Spacer** - 8.001mm (0.315 in) X 20.320mm (0.800) X 2.286mm (0.090 in) thick, Hardened to RC 40-45.

TABLE XVII. TORQUE VS. INDUCED LOAD FOR TITANIUM 6Al-4V SIX-WING BOLT ASSEMBLY, P/N SW2565-6-24, 9.525mm (0.375 in.) NOMINAL DIAMETER × 5.08cm (1.5 in.) GRIP

Torque		BOLT AND NUT ASSY NO. 1		2		3		4		5	
Nm	(in lbs)	PREVAILING TORQUE									
		2.26	(20)	3.39	(30)	2.82	(25)	1.69	(15)	2.26	(20)
		LOAD, NEWTONS (POUNDS)									
16.95	(150)	9,780	(2,200)	8,890	(2,000)	9,780	(2,200)	10,670	(2,400)	9,340	(2,100)
28.24	(250)	23,120	(5,200	18,230	(4,100)	19,570	(4,400)	23,120	(5,200)	22,680	(5,100)
39.54	(350)	24,900	(5,600)	28,020	(6,300)	29,800	(6,700)	33,360	(7,500)	33,360)	(7,500)
50.84	(450)	53,820	(12,100)	36,470	(8,200)	41,140	(9,250)	41,810	(9,400)	44,480	(10,000)
62.14	(550)	60,490	(13,600)	43,590	(9,800)	52,480	(11,800)	51,150	(11,500)	50,700	(11,400)
73.44	(650)	Broke		47,590	(10,700)	58,710	13,200	56,480	(12,700)	Broke	
84.73	(750)			52,930	(11,900)		Broke		Broke		
				No Failure							

Notes:

1. Test Conducted on Skidmore-Wilhelm Torque Tension Tester, Model J, Serial # 1752.
2. Torque Wrench was in compliance with Federal Specification GGG-W-686, Wrench, Torque.
3. Accessories included:

   1 - Washer, MS20002C6
   1 - Washer, MS20002-6
   1 - Spacer, 9.728mm (0.383 in.) I.D. X 17.450mm (0.687 in.) O.D. X 15.875mm (0.625 in.) Lg. Hardened to RC 40-45.

TABLE XVIII. RESULTS OF SINGLE SHEAR LAP JOINTS TESTS OF 4.826mm DIAMETER TITANIUM 6Al-4V HI-LOKS IN TITANIUM 8Al-1Mo-1V MATERIAL

Proj. Group Part No. & Material Thickness	Sample Designation	Yield Strength Per Fastener, Newtons 4% Dia. Offset 0.193mm	0.305mm Offset	0.508mm Extension	0.762mm Extension	Ult. Shear Strength Per Fastener Newtons	Type Failure
3A1	1A&B3110	12,890 (a)	13,160(a)	12,810(a)	13,560(a)	13,560	1
MR&T-SK-	2A&B3110	12,580	13,030(a)	12,490	13,250(a)	13,560	1
1110-1-1	3A&B3110	13,120 (a)	13,380(a)	13,070(a)	13,520(a)	13,740	1
Inter-	4A&B3110	12,450	12,810	12,320	12,850(a)	12,890	1
ference	5A&B3110	12,940 (a)	12,980(a)	12,940(a)	13,340(a)	13,380	1
Fit							
2.54mm	Average	12,790	13,070	12,720	13,300	13,420	
3A2	6A&B3410	12,810	13,430(a)	11,200	13,160(a)	13,650	1
MR&T-SK-	7A&B3410	13,160 (a)	13,690(a)	11,920(a)	13,690	14,140	1
1110-1-4	8A&B3410	12,760	13,290(a)	11,960	13,340(a)	14,180	1
Ream Fit	9A&B3410	12,760	13,290(a)	11,960	13,340(a)	13,830	1
2.54 mm							
	Average	12,870	13,420	11,760	13,380	13,950	
3A3	11A&B3710	12,400	13,210(a)	11,520	13,210(a)	14,140	1
MR&T-SK-	12A&B3710	12,760 (a)	13,470(a)	12,000	13,560(a)	14,100	1
1110-1-7	13A&B3710	12,810	13,430(a)	11,870	13,560(a)	14,180	1
Clearance	14A&B3710	12,720 (a)	13,520(a)	11,870	13,610(a)	14,410	1
Fit 2.54 mm							
	Average	12,670	13,400	11,810	13,480	14,200	
3A4	16A&B3410	12,360	12,760(a)	11,650	12,810(a)	13,960	1
MR&T-SK-	17A&B3410	12,230 (a)	12,670(a)	11,430(a)	12,720(a)	13,160	1
1110-1-4	18A&B3410	12,180	13,070(a)	11,290	13,210(a)	13,560	1
Salt Spray	19A&B3410	12,270	12,980(a)	11,600	13,070(a)	13,210	1
2.54 mm	20A&B3410	11,690	12,890	11,430	12,450(a)	12,890	1
	Average	12,140	12,870	11,480	12,850	13,350	
3A5	21A&B3410	12,360	12,940(a)	12,000	13,210(a)	13,470	1
MR&T-SK-	22A&B3410	11,830	12,630(a)	11,290	12,810(a)	13,290	1
1110-1-4	23A&B3410	11,740	12,360(a)	11,290	12,630(a)	12,160	1
Induced	24A&B3410	12,000	12,630(a)	11,070	12,720(a)	13,610	1
Defects &	25A&B3410	12,940 (a)	13,340(a)	12,230	15,470(a)	14,670	1
Salt Spray							
2.54 mm	Average	12,170	12,780	11,570	13,360	13,640	

Type of Failure:

1. Both fasteners sheared.

Note:

a. Estimated.

TABLE XVIIIA. RESULTS OF SINGLE SHEAR LAP JOINTS TESTS OF 0.190 in. DIAMETER TITANIUM 6Al-4V HI-LOKS IN TITANIUM 8Al-1Mo-1V MATERIAL

Proj. Group Part No. & Material Thickness	Sample Designation	Yield Strength Per Fastener, Pounds: 4% Dia. Offset 0.0076 In.	0.012 In. Offset	0.020 In. Extension	0.030 In. Extension	Ult. Shear Strength Per Fastener Pounds	Type Failure
3A1	1A&B3110	2900(a)	2960(a)	2880(a)	3050(a)	3050	1
MR&T-SK-	2A&B3110	2830	2930(a)	2810	2980(a)	3050	1
1110-1-1	3A&B3110	2950(a)	3010(a)	2940(a)	3040(a)	3090	1
Inter-	4A&B3110	2800	2880	2770	2890(a)	2900	1
ference Fit	5A&B3110	2910(a)	2920(a)	2910(a)	3000(a)	3010	1
0.100"	Average	2870	2940	2860	2990	3020	
3A2	6A&B3410	2880	3020(a)	2520	2980(a)	3070	1
MR&T-SK-	7A&B3410	2960(a)	3080(a)	2680	3080(a)	3180	1
1110-1-4	8A&B3410	2870	2990(a)	2690	3000(a)	3190	1
Ream Fit	9A&B3410	2870	2990(a)	2690	3000(a)	3110	1
0.100"	Average	2890	3020	2640	3010	3130	
3A3	11A&B3710	2790	2970(a)	2590	2970(a)	3180	1
MR&T-SK-	12A&B3710	2870(a)	3030(a)	2700	3050(a)	3170	1
1110-1-7	13A&B3710	2880	3020(a)	2670	3050(a)	3190	1
Clearance Fit 0.100"	14A&B3710	2860(a)	3040(a)	2670	3060(a)	3240	1
	Average	2850	3010	2650	3030	3190	
3A4	16A&B3410	2780	2870(a)	2620	2880	3140	1
MR&T-SK-	17A&B3410	2850(a)	2850(a)	2570	2860	2960	1
1110-1-4	18A&B3410	2740	2940(a)	2540	2970	3050	1
Salt Spray	19A&B3410	2760	2920(a)	2610	2940	2970	1
0.100"	20A&B3410	2630	2900	2570	2800	2900	1
	Average	2750	2890	2580	2890	3000	
3A5	21A&B3410	2780	2910(a)	2700	2970	3030	1
MR&T-SK-	22A&B3410	2660	2840(a)	2540	2880	2990	1
1110-1-4	23A&B3410	2640	2780(a)	2540	2840	2960	1
Induced	24A&B3410	2700	2840(a)	2490	2860	3060	1
Defects & Salt Spray	25A&B3410	2910(a)	3000(a)	2750	3030	3300	1
0.100"	Average	2730	2870	2600	2910	3060	

Type of Failure:

1. Both fasteners sheared.

Note:

a. Estimated.

TABLE XIX. RESULTS OF SINGLE SHEAR LAP JOINTS TESTS OF 6.350mm DIAMETER TITANIUM 6Al-4V HI-LOKS IN TITANIUM 8Al-1Mo-1V MATERIAL

Proj. Group Part No. & Material Thickness	Sample Designation	Yield Strength Per Fastener, Newtons 4% Dia. Offset 0.25 mm	0.305mm Offset	0.508mm Extension	0.762mm Extension	Ult. Shear Strength Per Fastener Newtons	Type Failure
4A1	1A&B4410	20,950	21,260	15,210	19,920	22,320	1
MR&T-SK-	2A&B4410	20,810	21,210	15,520	20,010	22,410	1
1110-2-4	3A&B4410	20,540	20,950	15,120	19,520	22,370	1
Ream Fit	4A&B4410	20,950	21,350	16,010	20,140	22,370	1
2.54 mm	5A&B4410	20,950	21,430	15,700	20,100	22,370	1
	Average	20,840	21,240	15,510	19,930	22,360	
4A2	6A&B4510	20,540	21,210	15,340	19,970	22,460	1
MR&T-SK-	7A&B4510	19,790	20,320	15,300	19,340	22,370	1
1110-2-5	8A&B4510	19,880	20,370	14,810	19,170	22,370	1
Ream Fit	9A&B4510	20,410	20,990	15,210	19,790	22,410	1
3.49×10^{-2} Radian Hole Angle, 2.54mm	Average	20,150	20,720	15,160	19,560	22,400	
4A3	11A&B4610	19,480	20,320	14,270	18,850	22,280	1
MR&T-SK-	12A&B4610	19,210	19,880	13,210	18,100	22,280	1
1110-2-6	13A&B4610	19,340	20,140	13,650	18,500	22,280	1
Ream Fit	14A&B4610	19,740	20,500	13,250	18,500	22,370	1
6.98×10^{-2} Radian Hole Angle, 2.54mm	15A&B4610	19,570	20,140	13,520	18,410	22,320	1
	Average	19,460	20,190	13,580	18,470	22,300	
4A4	16A&B4410	20,500	20,810	15,520	19,700	22,550	1
MR&T-SK-	17A&B4410	20,320	20,680	15,300	19,480	22,550	1
1110-2-4	18A&B4410	20,990	21,350	17,030	20,540	22,590	1
Ream Fit	19A&B4410	20,900	21,210	17,880	20,680	22,460	1
Induced Defects	20A&B4410	20,810	21,120	15,790	19,970	22,550	1
2.54 mm	Average	20,700	21,030	16,260	20,070	22,540	

Type of Failure:

1. Both fasteners sheared.

TABLE XIXA. RESULTS OF SINGLE SHEAR LAP JOINTS TESTS OF 0.250 in. DIAMETER TITANIUM 6Al-4V HI-LOKS IN TITANIUM 8Al-1Mo-1V MATERIAL

Project Group Part No. & Material Thickness	Sample Designation	Yield Strength Per Fastener, Pounds				Ult. Shear Strength Per Fastener Pounds	Type Failure
		4% Dia. Offset 0.010 In.	0.012 In. Offset	0.020 In. Extension	0.030 In. Extension		
4A1	1A&B4410	4710	4780	3420	4480	5020	1
MR&T-SK-	2A&B4410	4680	4770	3490	4500	5040	1
1110-2-4	3A&B4410	4620	4710	3400	4390	5030	1
Ream Fit	4A&B4410	4710	4800	4600	4530	5030	1
0.100"	5A&B4410	4710	4820	3530	4520	5030	1
	Average	4680	4770	3480	4480	5030	
4A2	6A&B4510	4620	4770	3450	4490	5050	1
MR&T-SK-	7A&B4510	4450	4570	3440	4350	5030	1
1110-2-5	8A&B4510	4470	4580	3330	4310	5030	1
Ream Fit	9A&B4510	4590	4720	3420	4450	5040	1
2° hole Angle 0.100"							
	Average	4530	4660	3410	4400	5030	
4A3	11A&B4610	4380	4570	3210	4240	5010	1
MR&T-SK-	12A&B4610	4320	4470	2970	4070	5010	1
1110-2-6	13A&B4610	4350	4530	3070	4160	5010	1
Ream Fit	14A&B4610	4440	4610	2980	4160	5030	1
4° Hole Angle 0.100"	15A&B4610	4400	4530	3040	4140	5020	1
	Average	4370	4540	3050	4150	5010	
4A4	16A&B4410	4610	4680	3490	4430	5070	1
MR&T-SK-	17A&B4410	4570	4650	3440	4380	5070	1
1110-2-4	18A&B4410	4720	4800	3830	4620	5080	1
Ream Fit	19A&B4410	4700	4770	4020	4650	5050	1
Induced Defects 0.100"	20A&B4410	4680	4750	3550	4490	5070	1
	Average	4650	4730	3660	4510	5060	

Type of Failure:

1. Both fasteners sheared.

TABLE XX. RESULTS OF SINGLE SHEAR LAP JOINTS TESTS OF 7.937mm DIAMETER TITANIUM 6Al-4V HI-LOKS IN TITANIUM 8Al-1Mo-1V MATERIAL

Proj. Group Part No. & Material Thickness	Sample Designation	Yield Strength Per Fastener, Newtons			Ult. Shear Strength per Fastener Newtons	Type Failure
		4% Dia. Offset 0.317mm	0.508mm Extension	0.762mm Extension		
5Al	1A&B5410	29,350	20,590	26,680	33,800	1
MR&T-SK-	2A&B5410	29,570	21,350	27,440	34,160	1
1110-3-4	3A&B5410	28,910	22,410	27,130	32,510	1
Ream Fit	4A&B5410	29,350	21,210	26,910	33,130	1
2.54 mm	5A&B5410	29,800	21,660	27,970	34,290	1
	Average	29,390	21,440	27,220	33,570	
5A2	6A&B5410	28,530	22,860	28,020	33,130	1
MR&T-SK-	7A&B5410	28,490	20,590	26,680	34,290	1
1110-3-4	8A&B5410	28,730	20,770	26,330	33,040	1
Ream Fit	9A&B5410	29,260	21,880	27,480	33,360	1
Induced Defects	10A&B5410	29,800	24,100	28,460	34,440	1
2.54 mm						
	Average	28,960	22,040	27,390	33,650	

Type of Failure:

1. Both fasteners sheared.

TABLE XXA. RESULTS OF SINGLE SHEAR LAP JOINTS TESTS OF 0.3125 in. DIAMETER TITANIUM 6Al-4V HI-LOKS IN TITANIUM 8Al-1Mo-1V MATERIAL

Proj. Group Part No. & Material Thickness	Sample Designation	Yield Strength Per Fastener, Pounds			Ult. Shear Strength Per Fastener Pounds	Type Failure
		4% Dia. Offset 0.0125 In.	0.020 In. Extension	0.030 In. Extension		
5A1	1A&B5410	6600	4630	6000	7600	1
MR&T-SK-	2A&B5410	6650	4800	6170	7680	1
1110-3-4	3A&B5410	6500	5040	6100	7310	1
Ream Fit	4A&B5410	6600	4770	6050	7450	1
0.100"	5A&B5410	6700	4870	6290	7710	1
	Average	6610	4820	6120	7550	
5A2	6A&B5410	6640	5140	6300	7450	1
MR&T-SK-	7A&B5410	6630	4630	6000	7710	1
1110-3-4	8A&B5410	6460	4670	5920	7430	1
Ream Fit	9A&B5410	6580	4920	6180	7500	1
Induced Defects 0.100"	10A&B5410	6700	5420	6400	7520	1
	Average	6600	4950	6160	7520	

Type of Failure:

1. Both fasteners sheared.

TABLE XXI. RESULTS OF SINGLE SHEAR LAP JOINTS TESTS OF 9.525mm DIAMETER TITANIUM 6Al-4V HI-LOKS IN TITANIUM 8Al-1Mo-1V MATERIAL

Proj. Group Part No. & Material Thickness	Sample Designation	Yield Strength Per Fastener, Newtons			Ult. Shear Strength per Fastener Newtons	Type Failure
		4% Dia. Offset 0.381 mm	0.508 mm Extension	0.762 mm Extension		
6B1	2A&B6412	47,860	31,580	41,090	53,680	1
MR&T-SK-	3A&B6412	46,610 (a)	30,060	39,580	53,730	1
1110-4-4	4A&B6412	46,880 (a)	29,890	39,320	52,480	1
Ream Fit	5A&B6412	47,050	27,350	39,140	52,570	1
3.175mm						
	Average	47,100	29,720	39,780	53,100	
6B2	6A&B6412	46,250	27,220	38,250	52,790	1
MR&T-SK-	7A&B6412	47,500	29,530	39,850	54,040	1
1110-4-4	8A&B6412	46,520	29,080	39,140	52,790	1
Ream Fit,	9A&B6412	46,610	27,480	37,270	53,240	1
Induced	10A&B6412	47,500	29,350	39,320	53,240	1
Defects						
3.175mm						
	Average	46,870	28,530	38,760	53,220	

Type of Failure:

1. Both fasteners sheared.

Note:

a. Estimated.

TABLE XXIA. RESULTS OF SINGLE SHEAR LAP JOINTS TESTS OF 0.375in. DIAMETER TITANIUM 6Al-4V HI-LOKS IN TITANIUM 8Al-1Mo-1V MATERIAL

Proj. Group Part No. & Material Thickness	Sample Designation	Yield Strength Per Fastener, Pounds 4% Dia. Offset 0.015 In.	0.020 In. Extension	0.030 In. Extension	Ult. Shear Strength per Fastener Pounds	Type Failure
6B1	2A&B6412	10760	7100	9240	12070	1
MR&T-SK-	3A&B6412	10480 (a)	6760	8900	12080	1
1110-4-4	4A&B6412	10540 (a)	6720	8840	11800	1
Ream Fit	5A&B6412	10580	6600	8800	11820	1
0.125"						
	Average	10590	6790	8940	11940	
6B2	6A&B6412	10400	6120	8600	11870	1
MR&T-SK-	7A&B6412	10680	6640	8960	12150	1
1110-4-4	8A&B6412	10460	6540	8800	11870	1
Ream Fit,	9A&B6412	10480	6180	8380	11970	1
Induced	10A&B6412	10680	6600	8840	11970	1
Defects.						
0.125"						
	Average	10540	6410	8710	11960	

Type of Failure:

1. Both fasteners sheared.

Note:

a. Estimated.

TABLE XXII. RESULTS OF SINGLE SHEAR LAP JOINTS TESTS OF 4.826mm DIAMETER TITANIUM 6Al-4V SIX-WING BOLTS IN TITANIUM 8Al-1Mo-1V MATERIAL

Project Group Part No. & Material Thickness	Sample Designation	Yield Strength Per Fastener, Newtons 4% Dia. Offset 0.19 mm	0.305 mm Offset	0.508 mm Extension	0.762 mm Extension	Ult. Shear Strength Per Fastener Newtons	Type Failure
3A6	51A&B3410	13830 (a)	14270 (a)	14100 (a)	14850 (a)	15210	1
MR&T-SK-	52A&B3410	13250	13830 (a)	13610	14140 (a)	14320	1
1110-1-4	53A&B3410	13120	13610 (a)	13470	13780 (a)	13920	1
Ream Fit	54A&B3410	13290	13780 (a)	13740	14180 (a)	14450	1
2.54 mm	55A&B3410	12940	13520 (a)	13430	14050 (a)	14100	1
	Average	13280	13800	13670	14200	14400	
3A7	56A&B3510	12720	13470 (a)	12940	13780 (a)	13920	1
MR&T-SK-	57A&B3510	12230	13160 (a)	13120	13780 (a)	13960	1
1110-1-5	58A&B3510	12360	13470 (a)	13430	14270 (a)	14500	1
Ream Fit	59A&B3510	12850	13560 (a)	13520 (a)	14270 (a)	14450	1
2° Hole	60A&B3510	12580	13340 (a)	13290	13740 (a)	13830	1
2.54 mm	Average	12540	13400	13260	13960	14130	
3A8 (b)	61A&B3610	10270	12130	11920	13040 (a)	13650	1
MR&T-SK-	62A&B3610	11690	12810 (a)	12720 (a)	13690 (a)	13920	1
1110-1-6	63A&B3610	11030	12540	12490	13740 (a)	13830	1
Ream Fit	64A&B3610	11740	12810	12670	13560 (a)	13650	1
4° Hole	65A&B3610	11560	12980	12850	14050 (a)	14140	1
Angle 2.54 mm	Average	11250	12660	12530	13610	13830	
3A9	66A&B3410	12450	13030 (a)	13070 (a)	14140 (a)	14410	1
MR&T-SK-	67A&B3410	12670	13290 (a)	13070	13610 (a)	13780	1
1110-1-4	68A&B3410	12270	12760	12670	13970 (a)	13970	1
Ream Fit	69A&B3410	12630	13210	13160	13830 (a)	13830	1
Induced	70A&B3410	13290	13830 (a)	13740 (a)	14410 (a)	14540	1
Defects 2.54 mm	Average	12660	13220	13140	13810	13920	

Type of Failure:
1. Both fasteners sheared.

NOTE:
a. Estimated.
b. Torque was reduced from 6.78 Nm (60 in-lbs) to 5.65 Nm (50 in-lbs).

TABLE XXIIA. RESULTS OF SINGLE SHEAR LAP JOINTS TESTS OF 0.190 in. DIAMETER TITANIUM 6Al-4V SIX-WING BOLTS IN TITANIUM 8Al-1Mo-1V MATERIAL

Project Group Part No. & Material Thickness	Sample Designation	Yield Strength Per Fastener, Pounds				Ult. Shear Strength Per Fastener Pounds	Type Failure
		4% Dia. Offset 0.0076 In.	0.012 In. Offset	0.020 In. Extension	0.030 In. Extension		
3A6	51A&B3410	3110 (a)	3210 (a)	3170 (a)	3340 (a)	3420	1
MR&T-SK-	52A&B3410	2980	3110 (a)	3060	3180 (a)	3220	1
1110-1-4	53A&B3410	2950	3060 (a)	3030	3100 (a)	3130	1
Ream Fit	54A&B3410	2990	3100 (a)	3090 (a)	3190 (a)	3250	1
0.100"	55A&B3410	2910	3040 (a)	3020	3160 (a)	3170	1
	Average	2980	3100	3070	3190	3230	
3A7	56A&B3510	2860	3030 (a)	2910	3130 (a)	3130	1
MR&T-SK-	57A&B3510	2750	2960 (a)	2950	3100 (a)	3140	1
1110-1-5	58A&B3510	2780	3030 (a)	3020	3210 (a)	3260	1
Ream Fit	59A&B3510	2890	3050 (a)	3040 (a)	3210 (a)	3250	1
2° Hole Angle 0.100"	60A&B3510	2830	3000 (a)	2990	3090 (a)	3110	1
	Average	2820	3010	2980	3140	3170	
3A8	61A&B3610	2310	2740	2680	2930 (a)	3070	1
MR&T-SK-	62A&B3610	2630	2880 (a)	2860 (a)	3080 (a)	3130	1
1110-1-6	63A&B3610	2480	2820	2810	3090	3110	1
Ream Fit	64A&B3610	2640	2880	2850	3050	3070	1
4° Hole Angle 0.100"	65A&B3610	2600	2920	2890	3160	3180	1
	Average	2530	2840	2810	3060	3110	
3A9	66A&B3410	2800	2930 (a)	2940 (a)	3180 (a)	3240	1
MR&T-SK-	67A&B3410	2850	2990 (a)	2940	3060 (a)	3100	1
1110-1-4	68A&B3410	2760	2870	2850	2940 (a)	2940	1
Ream Fit	69A&B3410	2840	2970	2960	3110 (a)	3110	1
Induced Defects 0.100"	70A&B3410	2990	3110 (a)	3090 (a)	3240 (a)	3270	1
	Average	2840	2970	2950	3100	3130	

Type of Failure:

1. Both fasteners sheared.

Note:

a. Estimated.

TABLE XXIII. RESULTS OF SINGLE SHEAR LAP JOINTS TESTS OF 6.350mm DIAMETER TITANIUM 6Al-4V SIX-WING BOLTS IN TITANIUM 8Al-1Mo-1V MATERIAL

Proj. Group, Part No. & Material Thickness	Sample Designation	Yield Strength Per Fastener, Newtons				Ult. Shear Strength Per Fastener Newtons	Type Failure	
		4% Dia. Offset 0.25 mm	0.305mm Offset	0.508mm Extension	0.762mm Extension			
4A10	51A&B4110	23,120	23,440	17,430	22,320	24,990	1	
MR&T-SK-	52A&B4110	22,010	23,040	19,120	23,390	25,970	1	
1110-2-1	53A&B4110	21,790	22,410	19,340	22,680	24,190	1	
Interference	54A&B4110	20,370	21,390	17,560	22,150	24,100	1	
Fit	55A&B4110	21,790	22,320	17,650	21,970	24,730	1	
2.54mm								
	Average	21,810	22,520	18,220	22,300	24,790		
4A11	56A&B4410	21,120	22,060	18,100	22,680	25,390	1	
MR&T-SK-	57A&B4410	19,700	21,210	18,140	22,410	26,680	1	
1110-2-4	58A&B4410	20,460	21,350	19,570	22,640	24,060	1	
Ream Fit	59A&B4410	20,680	21,790	17,340	22,190	24,990	1	
2.54 mm	60A&B4410	22,240	23,120	19,830	22,660	24,240	1	
	Average	20,840	22,900	18,590	22,710	25,470		
4A12	62A&B4710	24,240(a)	24,730(a)	23,040(a)	25,530(a)	26,590	1	b
MR&T-SK-	63A&B4710	20,280	21,300	15,920	20,460	23,790	1	b
1110-2-7	64A&B4710	19,430	20,900	16,590	21,350	25,970	1	b
Clearance Fit	65A&B4710	19,340	21,520	17,560	23,170	26,950	1	b
2.54 mm								
	Average	19,680	21,240	16,690	21,660	25,820		
4A13	66A&B4410	20,500	21,430	18,140	22,060	23,520	1	
MR&T-SK-	67A&B4410	19,970	21,120	18,190	22,240	24,100	1	
1110-2-4	68A&B4410	20,370	21,260	18,100	21,880	23,390	1	
Ream Fit	69A&B4410	21,260	22,320	17,960	22,550	24,990	1	
Induced Defects	70A&B4410	21,970	22,810	20,370	23,880	25,440	1	
2.54 mm								
	Average	20,710	21,780	18,550	22,520	24,280		

Type of Failure:

1. Both fasteners sheared.

Notes:

a. Exclude from average.
b. Fastener holes elongated.

TABLE XXIIIA. RESULTS OF SINGLE SHEAR LAP JOINTS TESTS OF 0.250 in. DIAMETER TITANIUM 6Al-4V SIX-WING BOLTS IN TITANIUM 8Al-1Mo-1V MATERIAL

Project Group, Part No. & Material Thickness	Sample Designation	Yield Strength Per Fastener, Pounds 4% Dia. Offset 0.010 In.	0.012 In. Offset	0.020 In. Extension	0.030 In. Extension	Ult. Shear Strength Per Fastener Pounds	Type Failure	Note
4A10	51A&B4110	5200	5270	3920	5020	5620	1	
MR&T-SK-	52A&B4110	4950	5180	4300	5260	5840	1	
1110-2-1	53A&B4110	4900	5040	4350	5100	5440	1	
Inter-	54A&B4110	4580	4810	3950	4980	5420	1	
ference	55A&B4110	4900	5020	3970	4940	5560	1	
Fit								
0.100"	Average	4900	5060	4090	5060	5570		
4A11	56A&B4410	4750	4960	4070	5100	5710	1	
MR&T-SK-	57A&B4410	4430	4770	4080	5040	6000	1	
1110-2-4	58A&B4410	4600	4800	4400	5090	5410	1	
Ream Fit	59A&B4410	4650	4900	3900	4990	5620	1	
0.100"	60A&B4410	5000	5200	4460	5320	5900	1	
	Average	4680	4920	4180	5100	5720		
4A12	61A&B4710	5450 (a)	5560 (a)	5180 (a)	5740 (a)	5980	1	b
MR&T-SK-	62A&B4710	4560	4790	3580	4600	5350	1	b
1110-2-7	63A&B4710	4370	4700	3730	4800	5840	1	b
Clearance	64A&B4710	4350	4840	3950	5210	6060	1	b
Fit, 0.100"								
	Average	4420	4770	3750	4870	5800		
4A13	66A&B4410	4610	4820	4080	4960	5290	1	
MR&T-SK-	67A&B4410	4490	4750	4090	5000	5420	1	
1110-2-4	68A&B4410	4580	4780	4070	4920	5260	1	
Ream Fit,	69A&B4410	4780	5020	4040	5070	5620	1	
Induced	70A&B4410	4940	5130	4580	5370	5720	1	
Defects								
0.100"								
	Average	4680	4900	4170	5060	5460		

Type of Failure:

1. Both fasteners sheared.

Notes:

a. Exclude from average.
b. Fastener holes elongated.

TABLE XXIV. RESULTS OF SINGLE SHEAR LAP JOINTS TESTS OF 7.937mm DIAMETER TITANIUM 6Al-4V SIX-WING BOLTS IN TITANIUM 8Al-1Mo-1V MATERIAL

Project Group, Part No. & Material Thickness	Sample Designation	Yield Strength Per Fastener, Newtons 4% Dia. Offset 0.318 mm	0.508 mm Extension	0.762 mm Extension	Ult. Shear Strength Per Fastener Newtons	Type Failure	Note
5A14	51A&B5410	33040	26990	33360 (c)	37050	2	a
MR&T-SK-	52A&B5410	31000	23350	30600	37220	2	a
1110-3-4	53A&B5410	34330	28150	34470	37890	2	a
Ream Fit	54A&B5410	32150	24950	32290	37270	2	a
2.54 mm	55A&B5410	32470 (c)	27880	33580 (c)	38250	1	b
	Average	32590	26260	32860	37530		
5A15	56A&B5410	31440	27440	33710	39360	2	a,b
MR&T-SK-	57A&B5410	29570	25220	32470	38510	1	b
1110-3-4	58A&B5410	29800	23880	31040	39850	1	b
Ream Fit	59A&B5410	27310	23840	31400	38600	1	b
Induced Defects 2.54 mm	60A&B5410	32510	31130	35760 (c)	39140	1	b
	Average	30120	26300	32870	39020		

Type of Failure:

1. Both fasteners sheared.
2. One fastener sheared.

Notes:

a. Pulling hole elongated or torn.
b. Clamping plates used in jaws.
c. Estimated.

TABLE XXIVA. RESULTS OF SINGLE SHEAR LAP JOINTS TESTS OF 0.3125 in. DIAMETER TITANIUM 6Al-4V SIX-WING BOLTS IN TITANIUM 8Al-1Mo-1V MATERIAL

Project Group Part No. & Material Thickness	Sample Designation	Yield Strength Per Fastener, Pounds			Ult. Shear Strength Per Fastener Pounds	Type Failure	Notes
		4% Dia. Offset 0.0125 In.	0.020 In. Extension	0.030 In. Extension			
5A14	51A&B5410	7430	6070	7500 (c)	8330	2	a
MR&T-SK-	52A&B5410	6970	5250	6880	8370	2	a
1110-3-4	53A&B5410	7720	6330	7750	8520	2	a
Ream Fit	54A&B5410	7230	5610	7260	8380	2	a
0.100"	55A&B5410	7300 (c)	6270	7550 (c)	8600	1	b
	Average	7330	5900	7380	8440		
5A15	56A&B5410	7070	6170	7580	8850	2	a,b
MR&T-SK-	57A&B5410	6650	5670	7300	8660	1	b
1110-3-4	58A&B5410	6700	5370	6980	8960	1	b
Ream Fit	59A&B5410	6140	5360	7060	8680	1	b
Induced Defects 0.100"	60A&B5410	7310	7000	8040 (c)	8800	1	b
	Average	6790	5910	7390	8790		

Type of Failure:
1. Both fasteners sheared.
2. One fastener sheared.

Notes:
a. Pulling hole elongated or torn.
b. Clamping plates used in jaws.
c. Estimated.

TABLE XXV. RESULTS OF SINGLE SHEAR LAP JOINTS TESTS OF 9.525mm DIAMETER TITANIUM 6Al-4V SIX-WING BOLTS IN TITANIUM 8Al-1Mo-1V MATERIAL

Project Group, Part No. & Material Thickness	Sample Designation	Yield Strength Per Fastener, Newtons 4% Dia. Offset 0.381 mm	0.508 mm Extension	0.762 mm Extension	Ult. Shear Strength Per Fastener Newtons	Type Failure
6B3	51A&B6412	44560	34330	43140	55550	1
MR&T-SK-	52A&B6412	43050	32640	41720	54570	1
1110-4-4	53A&B6412	43940	32820	42160	54350	1
Ream Fit	54A&B6412	43590	33530	42340	53370	1
3.175mm	55A&B6412	43050	27570 (a)	38510 (a)	55370	1
	Average	43630	33330	42340	54640	
6B4	56A&B6412	41,090	33090	41720	53590	1
MR&T-SK-	57A&B6412	45280	35490	45010	52930	1
1110-4-4	58A&B6412	45280	34070	42340	54040	1
Ream Fit	59A&B6412	47940	38340	46340	55150	1
Induced Defects	60A&B6412	47860	33980	43320	53900	1
3.175mm	Average	45490	34990	43740	53920	

Type of Failure:

1. Both fasteners sheared.

Notes:

a. Exclude from average.

TABLE XXVA. RESULTS OF SINGLE SHEAR LAP JOINTS TESTS OF 0.375 in. DIAMETER TITANIUM 6Al-4V SIX-WING BOLTS IN TITANIUM 8Al-1Mo-1V MATERIAL

Project Group, Part No. & Material Thickness	Sample Designation	Yield Strength Per Fastener, Pounds			Ult. Shear Strengt' Per Fastener Pounds	Type Fail-ure
		4% Dia. Offset 0.015 In.	0.020 In. Extension	0.030 In. Extension		
6B3	51A&B6412	10020	7720	9700	12490	1
MR&T-SK-	52A&B6412	9680	7340	9380	12270	1
1110-4-4	53A&B6412	9880	7380	9480	12220	1
Ream Fit	54A&B6412	9800	7540	9520	12000	1
0.125"	55A&B6412	9680	6200 (a)	8660 (a)	12450	1
	Average	9810	7490	9520	12280	
6B4	56A&B6412	9240	7440	9380	12050	1
MR&T-SK-	57A&B6412	10180	7980	10120	11900	1
1110-4-4	58A&B6412	10180	7660	9520	12150	1
Ream Fit	59A&B6412	10780	8620	10420	12400	1
Induced Defects	60A&B6412	10760	7640	9740	12120	1
0.125"	Average	10220	7860	9830	12120	

Type of Failure:
1. Both fasteners sheared.

Notes:
a. Exclude from average.

TABLE XXVI. AVERAGE SINGLE SHEAR STRENGTH OF TITANIUM 6Al-4V HI-LOKS AND SIX-WING BOLTS IN 8Al-1Mo-1V TITANIUM LAP JOINTS WITH INTERFERENCE, REAM, AND CLEARANCE FIT HOLES

Fastener	Group	Fit	4% Dia. Offset Newtons	Offset 0.305mm Newtons	Extension 0.508mm Newtons	Extension 0.761mm Newtons	Ultimate Shear Newtons
4.826mm	3A1	Interference	12,790	13,070	12,720	13,300	13,420
Hi-Lok	3A2	Ream	12,870	13,420	11,760	13,380	13,950
	3A3	Clear	12,670	13,400	11,810	13,480	14,200
6.350mm	4A10	Interference	21,810	22,520	18,220	22,300	24,790
Six-Wing	4A11	Ream	20,840	21,900	18,590	22,710	25,470
	4A12	Clear	19,680	22,240	16,690	21,660	25,820
Fastener	Group	Fit	4% Dia. Offset Pounds	Offset 0.012 In Pounds	Extension 0.020 In Pounds	Extension 0.030 In Pounds	Ultimate Shear Pounds
0.190 in	3A1	Interference	2,870	2,940	2,860	2,990	3,020
Hi-Lok	3A2	Ream	2,890	3,020	2,640	3,010	3,130
	3A3	Clear	2,850	3,010	2,650	3,030	3,190
0.250 in	4A10	Interference	4,900	5,060	4,090	5,060	5,570
Six-Wing	4A11	Ream	4,680	4,920	4,180	5,100	5,720
	4A12	Clear	4,420	4,770	3,750	4,870	5,800

TABLE XXVII. AVERAGE SINGLE SHEAR STRENGTHS OF TITANIUM 6Al-4V HI-LOKS AND SIX-WING BOLTS IN TITANIUM 8Al-1Mo-1V LAP JOINTS WITH REAM FIT HOLES AND THREE HOLE ANGLES

Fastener	Group	Fit	Hole Angle Radian $X10^{-2}$	4% Dia Offset Newtons	0.305 mm Offset Newtons	0.508 mm Extension Newtons	0.762 mm Extension Newtons	Ultimate Shear Newtons
4.826	3A6	Ream	0	13,280	13,800	13,670	14,200	14,400
mm	3A7	Ream	3.49	12,540	13,400	13,260	13,960	14,130
Six-Wing	**3A8(a)**	Ream	6.98	11,250	12,660	12,530	13,610	13,830
	4A1		0	20,840	21,240	15,510	19,930	22,360
6.350mm	4A2		3.49	20,150	20,720	15,160	19,560	22,400
Hi-Lok	4A3		6.98	19,460	20,190	13,580	18,470	22,300

Fastener	Group	Fit	Hole Angle Degree	4% Dia. Offset Pounds	0.012 Inch Offset Pounds	0.020 Inch Extension Pounds	0.030 Inch Extension Pounds	Ultimate Shear Pounds
0.190 Inch	3A6	Ream	0	2980	3100	3070	3190	3230
Six-Wing	3A7		2	2820	3010	2980	3140	3170
	3A8(a)		4	2530	2840	2810	3060	3110
0.250	4A1		0	4680	4770	4480	5030	5030
Hi-Lok	4A2		2	4530	4660	3410	4400	5030
	4A3		4	4370	4540	3050	4150	5010

NOTE:

(a) Torque was reduced from 6.78 Nm (60 in-lbs) to 5.65 Nm (50 in-lbs).

TABLE XXVIII. AVERAGE SINGLE SHEAR STRENGTHS OF TITANIUM 6Al-4V HI-LOKS IN TITANIUM 8Al-1Mo-1V LAP JOINTS WITH REAM HOLE FIT, INDUCED DEFECTS AND 600 HOUR SALT SPRAY

Fastener	Group	Fit	Salt Spray	Induced Defects	4% Dia. Offset Newtons	0.305mm Offset Newtons	0.508mm Extension Newtons	0.761mm Extension Newtons	Ultimate Shear Newtons
4.826mm	3A2	Ream	No	No	12,870	13,420	11,760	13,380	13,950
Hi-Loks	3A4	Ream	Yes	No	12,140	12,870	11,480	12,850	13,350
	3A5	Ream	Yes	Yes	12,170	12,780	11,570	13,360	13,640
Fastener	Group	Fit	Salt Spray	Induced Defects	4% Dia. Offset Pounds	0.012 In Offset Pounds	0.020 In Extension Pounds	0.030 In Extension Pounds	Ultimate Shear Pounds
0.190 in.	3A2	Ream	No	No	2,890	3,020	2,640	3,070	3,130
Hi-Loks	3A4	Ream	Yes	No	2,750	2,890	2,580	2,890	3,000
	3A5	Ream	Yes	Yes	2,730	2,870	2,600	2,910	3,060

TABLE XXIX. AVERAGE SINGLE SHEAR STRENGTHS OF THREE SIZES OF TITANIUM 6Al-4V HI-LOKS AND FOUR SIZES OF SIX-WING BOLTS IN TWO THICKNESSES OF TITANIUM 8Al-1Mo-1V LAP JOINTS WITH INDUCED DEFECTS

Fastener	Nom Dia. mm	Group	Fit	Induced Defects	4% Dia. Offset Newtons	0.305mm Offset Newtons	0.508mm Ext. Newtons	0.762mm Ext. Newtons	Ultimate Shear Newtons
Hi-Lok	6.350	4A1	Ream	No	20,840	21,240	15,510	19,930	22,360
Hi-Lok	6.350	4A4		Yes	20,700	21,030	16,260	20,070	22,540
Hi-Lok	7.937	5A1		No	29,390	Not Used	21,440	27,220	33,570
Hi-Lok	7.937	5A2		Yes	28,960	Not Used	22,040	27,390	33,650
Hi-Lok	9.525	6B1		No	47,100	Not Used	29,720	39,780	53,100
Hi-Lok	9.525	6B2		Yes	46,870	Not Used	28,530	34,760	53,220
Six-Wing	4.826	3A6		No	13,280	13,800	13,670	14,200	14,400
Six-Wing	4.826	3A9		Yes	12,660	13,220	13,140	13,810	13,920
Six-Wing	6.350	4A11		No	20,840	21,900	18,590	22,710	25,470
Six-Wing	6.350	4A13		Yes	20,710	21,780	18,550	22,520	24,280
Six-Wing	7.920	5A14		No	32,590	Not Used	26,260	32,860	37,530
Six-Wing	7.920	5A15		Yes	30,120	Not Used	26,300	32,870	39,020
Six-Wing	9.525	6B3		No	43,630	Not Used	33,330	42,340	54,640
Six-Wing	9.525	6B4		Yes	45,490	Not Used	34,990	43,740	53,920

Fastener	Nom. Dia. Inch	Group	Fit	Induced Defects	4% Dia. Offset Pounds	0.012 Inch Offset Pounds	0.020 Inch Extension Pounds	0.030 Inch Extension Pounds	Ultimate Shear Pounds
Hi-Lok	0.250	4A1	Ream	No	4680	4770	3480	4480	5030
Hi-Lok	0.250	4A4		Yes	4650	4730	3660	4510	5060
Hi-Lok	0.3125	5A1		No	6610	Not Used	4820	6120	7550
Hi-Lok	0.3125	5A2		Yes	6600	Not Used	4950	6160	7520
Hi-Lok	0.375	6B1		No	10590	Not Used	6790	8940	11940
Hi-Lok	0.375	6B2		Yes	10540	Not Used	6410	8740	11960
Six-Wing	0.190	3A6		No	2980	3100	3070	3190	3230
Six-Wing	0.190	3A9		Yes	2840	2970	2950	3100	3130
Six-Wing	0.250	4A11		No	4680	4920	4180	5100	5720
Six-Wing	0.250	4A13		Yes	4680	4900	4170	5060	5460
Six-Wing	0.3125	5A14		No	7330	Not Used	5900	7380	8440
Six-Wing	0.3125	5A15		Yes	6790	Not Used	5910	7390	8790
Six-Wing	0.375	6B3		No	9810	Not Used	7490	9520	12280
Six-Wing	0.375	6B4		Yes	10220	Not Used	7860	9830	12120

APPROVAL

IN-ME-68-15

EVALUATION OF INSTALLATION VARIABLES FOR TITANIUM 6AI-4V HI-LOKS AND SIX-WING BOLTS ASSEMBLED IN TITANIUM 8AI-1Mo-1V SHEET MATERIAL

By

Carl M. Wood

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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