Center-wide
Procedures and Guidelines (PG)

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EXPIRATION DATE:	July 7, 2025	**TITLE:**	Director Of

COMPLIANCE IS MANDATORY

Responsible Office: 540/Mechanical Systems Division (MSD)

Title: Mechanical Fastener Torque Guidelines

PREFACE

P.1 PURPOSE

This PG establishes guidelines and requirements for the installation of mechanical fasteners along with providing generalized torque values for flight and non-flight spacecraft hardware including critical Mechanical Ground Support Equipment (MGSE). It covers the procedure for the installation and torqueing of nuts, bolts, and screws. The generalized torque tables that are presented within this PG are based on preloading fasteners to 65% of the fastener's yield strength.

P.2 APPLICABILITY

This procedure applies to the mechanical design and development of all Goddard Space Flight Center (GSFC) flight products and processes, including Critical MGSE, covered by the scope of the GSFC Quality Management System.

This specification covers fastener sizes #0 (0.06") to 1.0" diameters. Fasteners with diameters outside this range of sizes will be handled as special cases with torque values provided by the responsible stress analysis group.

This specification covers fasteners manufactured from alloy steel, 300 series CRES, and A286. Also, the metallic insert materials tested to develop the torque force data in Section 3 include Nitronic 60 and Phosphor Bronze. Data used to generate the tables can be found at:

https://spaces.gsfc.nasa.gov/display/CODE543/Home

Note that this guideline specifically does NOT apply to Long-Lok fasteners, or other fasteners that have a plug, patch, or strip type locking feature. This specification also does not cover shear-only type fasteners.

Preloaded Bolt Criteria and Use of Torque Tables

The torque tables within this PG can be utilized provided that all of the following requirements are met:

1. The joint is not a tension joint in which gapping cannot be tolerated. A "tension joint" is defined as a joint in which the largest component of the applied load is tension.
2. Fastener prying effects are correctly accounted for.
3. The fastener is in a local pattern of two or more fasteners.
4. The fastener is a high-quality military standard, national aircraft standard, or equivalent commercial fastener that is fabricated and inspected in accordance with aerospace flight quality hardware specifications.
5. The joint fittings are metallic.
6. No significant thermal loading that changes preload is present during mechanical loading.
7. The joints are not for pressure containment, including crew module environmental containment, or hazardous material containment.

If the above conditions are satisfied, then the fastener torque tables within this PG shall be utilized and referenced in the appropriate engineering drawings/Work Order Authorization (WOA).

Project specific torque tables may be developed and used instead of the tables contained within this PG provided that hardware specific torque-tension testing is performed/referenced.

If the enclosed torque tables are not used and hardware specific torque-tension testing is not performed/referenced, a rationale shall be generated and vetted during the detailed peer design reviews (Preliminary and/or Critical) justifying the projects position.

If the above criteria (1-7) are not met, use of the torque tables within this PG should be evaluated and approved for the specific joint by the responsible project stress engineer and Product Design Lead.

Nonstandard Torques

Nonstandard torque values not covered in this specification will be specified on the controlling drawing/WOA, with applicable procedures referenced as a drawing note.

a. In this document, all citations are assumed to be the latest version unless otherwise noted.

b. In this document, all mandatory actions (i.e., requirements) are denoted by statements containing the term "shall." The terms "may" or "can" denote discretionary privilege or permission; "should" denotes a good practice and is recommended but not required; "will" denotes expected outcome; and "are/is" denotes descriptive material.

P.3 AUTHORITY

N/A

P.4 APPLICABLE DOCUMENTS AND FORMS

541-PG-8072.1.2 Goddard Space Flight Center Fastener Integrity Requirements

541-WI-5330.1.41	Fastener Locking Using Arathane 5753
Fed-Std-H28/2B	Screw - Tread Standards for Federal Services Section 2 Unified Inch Screw Threads - UN and UNR Thread Forms
GSFC-STD-1000	Rules for the Design, Development, Verification, and Operation of Flight Systems
NASA STD 8739.1	Workmanship Standard for Polymeric Application on Electronic Assemblies
SP-R-0022	Vacuum Stability Requirements of Polymeric Materials for Spacecraft Application

P.5 CANCELLATION

540-PG-8072.1.2A

P.6 SAFETY

N/A

P.7 TRAINING

N/A

P.8 RECORDS

No unique quality records are generated as a result of this PG.

Record Title	Record Custodian	Retention

** NRRS 1441.1 – NASA Records Retention Schedule*

P.9 MEASUREMENT/VERIFICATION

N/A

PROCEDURES

1. GENERAL REQUIREMENTS

1.1 FASTENER INTEGRITY REQUIREMENTS

1.1.1 All fasteners used in flight hardware and for critical nuts and bolts used on ground support equipment, including all flight hardware to ground support equipment interfaces, will comply with the Fastener Integrity Requirements document, 541-PG-8072.1.2.

1.1.1.1 This document defines the practices for acquisition, control, and inspection of fasteners depending on the criticality of the fastener.

1.1.1.2 541-PG-8072.1.2 categorizes fasteners as critical, controlled, or non-controlled fasteners. Refer to section P.10 Definitions or Appendix A, for the distinction.

1.2 THREAD FORM COMBATIBILITY

1.2.1 Mating parts will have compatible thread forms.

Avoid the following conditions:

- Fine thread mated to coarse threads
- Inch based threads mated to metric threads
- External UNJ threads mated with internal UN threads
- External MJ threads mated with internal M threads

1.3 TOOLS AND SPECIAL EQUIPMENT

The following types of hand tools should be used to apply final torques to nuts, bolts, screws, washers and Hi-Lok fasteners:

a. Hand torque wrenches (either ratchet or screwdriver style, either dial or click type) that have been calibrated not more than one year prior to use, unless otherwise specified
b. Only dial type or digital electronic torque wrenches should be used to determine the running torque of locking fasteners prior to torqueing.
c. Calibrated torque boxes

Other tools that may be required to seat fasteners prior to torqueing:

1. Mallets, nonmetallic
2. Blocks, nonmetallic
3. Punches, nonmetallic
4. Other tools may be used where approved by the cognizant engineer

1.3.1 Use of Adapters and Extensions

1.3.1.1 Adapters or extensions should be used only with wrenches designed for their use.

1.3.1.2 When using an adapter or extension bar with a torque wrench, the calibration data will indicate the combination of wrench and extension arm necessary to produce a specified torque.

1.3.1.3 When a torque wrench adapter is used to tighten fasteners the reading will be corrected by applying the following formulas:

$$\boldsymbol{R = \frac{T * Lw}{Lt}}$$

$$\boldsymbol{T = \frac{R * Lt}{Lw}}$$

Where:

R = Reading on the torque wrench
T = Actual torque applied
Lw = Length from head to the point at which the wrench is gripped
Lt = Total length of adapter plus Lw

Example: If a six-inch adapter is needed to apply 20 in-lbs of torque to a bolt, what torque value should be indicated on a torque wrench gripped at 12-inches from the head?

T = 20 in-lbs
Lw = 12 inches
Lt = 12 + 6 = 18 inches

$$\mathbf{R} = \frac{20\ in{-}lbs * 12\ in}{18\ in} = 13.3\ \text{in} - \text{lbs}$$

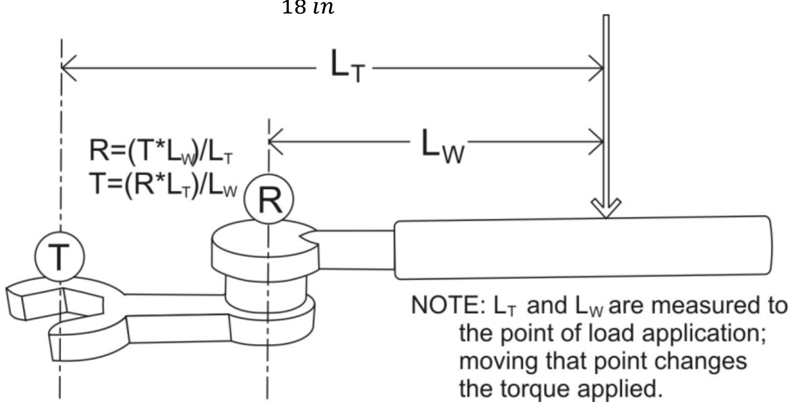

Figure 1.3-1 Use of adapters and extensions

1.3.2 Torque Wrench Angle

The rotation axis of the torque wrench should be within 15 degrees of the fastener axis.

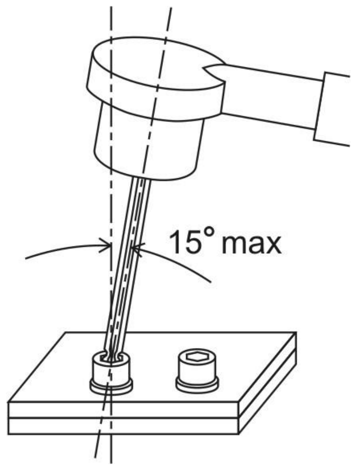

Figure 1.3-2 Torque wrench angle

1.3.3 Calibration

1.3.3.1 All torque wrenches used on assembly of spacecraft or critical MGSE will be calibrated at intervals not to exceed one year, or be approved for use via an approved Goddard organization torque box procedure.

1.3.3.2 All torque wrenches will have a visible calibration sticker that states when the next calibration is due, or be approved for use via an approved Goddard organization torque box procedure.

1.4 LOCKING FEATURES

1.4.1 Each threaded fastening system in spaceflight hardware will incorporate a minimum of one locking feature other than, or in addition to, preload in accordance with GSFC-STD-1000 Rule 4.20.

1.4.2 Spring type, star type, and split lock washers should not be used due to metallic particle generation.

1.4.3 Examples of Acceptable Fastener Locking Features:

- Locking Nuts
  - Deformed-thread nuts, such as those defined by NASM25027 and used on MS21043 Nuts
  - Castellated nut with cotter pin

- Locking Bolts
  - Locking pellet, patch or strip (Vespel or similar aerospace-qualified material), such as those defined in NAS1283 and available on fasteners such as NAS1351 SHCS.
- Locking Threaded Inserts
  - 'Keensert' (i.e.,NAS1394) or 'Helicoil' (i.e., MS33537) type inserts with deformed-thread locking
- Lock-wire or locking pins (i.e., cotter pins)
- Liquid Locking Compounds as described in section 1.5 below
- For non-structural applications, such as is used on electrical connectors and small electronic boxes, Arathane like compounds on the head of the fastener after torqueing are acceptable. These are typically for small diameter fasteners (#4 or smaller) in accordance with NASA STD 8739.1

1.4.4 Acceptable Torque Range from Locking Features:

Unless otherwise specified on the engineering drawings or in the assembly procedures/WOAs, all locking features will meet the prevailing (same as 'running' or 'resistive') torque requirements shown in the Table 1.4-1 below:

Table 1.4-1 Torque range from locking features

Locking Helical Inserts (Per NAS M8846)				Locking Element (Plug, Pellet, or Strip Per MIL-DTL-18240)				Deformed Hex Locking Nut (Per NASM25027)			
Size	Major Dia (in)	Minimum Running Torque (In-lb)	Max Runnin g Torque (In-lb)	Size*	Major Dia. (in)	Minimum Running Torque (In-lb)	Max Running Torque (In-lb)	Size	Major Dia. (in)	Minimum Running Torque (In-lb)	Max Running Torque (In-lb)
#2-56	0.086	3 in-oz	2	**#2**	0.086	NA	NA	**#2-56**	0.086	0.2	2.5
#4-40	0.112	10 in-oz	3	**#4**	0.112	0.5	5	**#4-40**	0.112	0.5	5
#6-32	0.138	1	6	**#6**	0.138	1	8	**#6-32**	0.138	1	10
#8-32	0.164	1.5	9	**#8**	0.164	1.5	12	**#8-32**	0.164	1.5	15
#10-24	0.19	2	13	**#10**	0.19	2	18	**#10-24**	0.19	2	18
#10-32	0.19	2	13	**.250**	0.25	3	40	**#10-32**	0.19	2	18
.25-20	0.25	4.5	30	**.312**	0.3125	5	85	**.25-20**	0.25	4.5	30
.25-28	0.25	3.5	30	**.375**	0.375	9	110	**.25-28**	0.25	3.5	30
.312-18	0.3125	7.5	60	**.438**	0.4375	12	150	**.312-18**	0.3125	7.5	60
.312-24	0.3125	6.5	60	**.500**	0.5	16	220	**.312-24**	0.3125	6.5	60
.375-16	0.375	12	80	**.562**	0.5625	22	270	**.375-16**	0.375	12	80
.375-24	0.375	9.5	80	**.625**	0.625	30	250	**.375-24**	0.375	9.5	80
.438-14	0.4375	16.5	100	**.75**	0.75	45	460	**.438-14**	0.4375	16.5	100
.438-20	0.4375	14	100	**.875**	0.875	65	700	**.438-20**	0.4375	14	100
.500-13	0.5	24	150	**1**	1	85	900	**.500-13**	0.5	24	150
.500-20	0.5	18	150					**.500-20**	0.5	18	150
.562-12	0.5625	30	200					**.562-12**	0.5625	30	200
.562-18	0.5625	24	200					**.562-18**	0.5625	24	200
.625-11	0.625	40	300					**.625-11**	0.625	40	300
.625-18	0.625	32	300					**.625-18**	0.625	32	300
.750-10	0.75	60	400					**.750-10**	0.75	60	400
.750-16	0.75	50	400					**.750-16**	0.75	50	400
.875-9	0.875	82	600					**.875-9**	0.875	82	600
.875-14	0.875	70	600					**.875-14**	0.875	70	600
1-8	1	110	800					**1-8**	1	110	800
1-12	1	90	800					**1-12**	1	90	800

* Values for coarse and fine are the same

1.4.5 If a fastener locking system does not meet these requirements, then the locking feature, nut, insert or bolt should be replaced in order to re-gain the prevailing torque required. If replacement is not practical, then it may be acceptable to apply a liquid locking compound per the requirements of section 1.5 below in order to comply with GSFC-STD-1000 Rule 4.20.

1.5 LUBRICANTS AND LOCKING COMPOUNDS

1.5.1 Lubricants and locking compounds will be used only as specified on the engineering drawings or in the assembly procedures/WOA.

1.5.1.1 It is strongly recommended to use wet lubrication and not install fasteners dry (wherever possible) due to the greater possibility of galling, high torque levels required for the same preload resulting in the possibility of head stripping, and the larger scatter in the Torque-Tension relationship.

1.5.1.2 Fastener lubricants should be avoided when possible where liquid locking compounds will be used later in the assembly process, due to the cleaning required to ensure adhesion of liquid locking compounds.

1.5.2 Lubricants, locking compounds, or staking compounds used on spacecraft or critical MGSE shall be used within their expiration dates or be recertified in accordance with Management of Shelf Life Materials Purchased by the Materials Engineering Branch, 541-PG-4100.1.

1.5.3 Acceptable Lubricants (use "Lubricated" torque values)/Application

Dry Lubricants:
Molybdenum Disulfide
Tiolube®

Wet Lubricants:
Braycote®, 601 or 602 grease
Rheolube®2000 grease
Dupont Krytox® 240 AC

1.5.3.1 If torque is applied from nut side, the wet lubricant should be applied only to the bolt threads.

1.5.3.2 If torque is applied from the head side, the wet lubricant should be applied to the bolt threads and may be applied under the head of the bolt, although contamination concerns should be considered.

1.5.3.3 Lubricants should be applied sparingly to the lead threads. Excess lubricant should be wiped off after torqueing. Project specific requirements must be considered when using lubricants on contamination critical instruments.

1.5.4 Liquid Locking or Staking Compounds

1.5.4.1 For flight applications, locking compounds will be approved by the engineering authority for the project.

They should be selected to meet the outgassing requirements specified in NASA Johnson Space Center specification SP-R-0022, Vacuum Stability Requirements of Polymeric Materials for

Spacecraft Application. Outgassing data for specific compounds can be found in NASA Reference Publication 1124, Outgassing Data for Selecting Spacecraft Materials, or on-line at http://outgassing.nasa.gov/.

1.5.4.2 Fasteners installed wet with Arathane 5753 as a locking compound shall use a torque coefficient of **0.22** if no specific torque-tension data for the specific fastener – insert/bolt combination is available.

Note: *Test data has shown that Arathane has an approximately 18% higher K value than Wet Lubricants. Data from the testing can be found at:*

https://spaces.gsfc.nasa.gov/display/CODE543/Home

1.5.4.3 When used as a locking compound, Arathane 5753 should be applied per GSFC Materials Processing Document 541-WI-5330.1.41.

Note: *Adding CAB-O-SIL® in small percentages did not appear to change the K factor. Testing was done with 0%, 7.3% and 14% CAB-O-SIL® fill with negligible differences in the K value.*

1.5.4.4 When required for paint adhesion or sealant adhesion, remove the lubricant on the exposed surface after installation.

2. INSTALLATION INSTRUCTIONS

2.1 FASTENER PREPARATION

2.1.1 The assembly technician should visually inspect every fastener prior to installation to ensure that there are no gross flaws (burrs, foreign material, malformed threads, etc.) that will interfere with installation of the fastener.

Do not remove approved lubricants from fasteners if the hardware is supplied that way. Correct function is dependent on retention of original vendor-applied lubricant.

2.1.2 Reusability of Fasteners

a. Each time a flight bolt is removed it should be visually inspected and replaced (not re-used) if damaged
b. Reused bolts should be thoroughly cleaned (along with the mating female interface nut/insert) and bagged for installation later.
c. Extreme care should be given when removing critical bolts (non-failsafe) after the interface has been structurally qualified. Removal may require re-qualification.

2.1.2 Bolts and Hi-Lok Pins

When installing close tolerance bolts where the fit is sufficiently close to require driving, use a plastic or rawhide mallet or non-metallic blocks between metal tools and bolt heads. Use only bolts with clean threads that are free of chips, grease and identification dye. Threads that are lubricated by drawing authorization are acceptable.

2.1.3 Nuts and Inserts

2.1.3.1 The use of a threading tap on self-locking nuts, nut-plates or self-locking inserts is not permitted.

2.1.3.2 Do not use self-locking nuts that have had the locking element reworked or reprocessed by other than the nut manufacturer.

2.1.3.3 Threaded Insert Material

Tables 3.2 through 3.7 below, were calculated using K values derived from testing of Nitronic 60 and Phosphor Bronze threaded inserts. Both variations of the material included locking and non-locking inserts. The following paragraphs discuss some of the considerations when choosing the insert for an application.

2.1.3.3.1 Nitronic 60 Threaded Inserts

Nitronic 60 threaded inserts with tangs should not be used where there is a possibility the insert will need to be replaced over the course of its life. The removal process involves driving or "setting" a removal tool into the upper wire of the insert, forming an indent that the tool uses to un-screw the insert. The Nitronic 60 material is very hard and it is not always easy to "set" the removal tool properly, especially if the insert has been installed well below the parent material surface. Additionally, in the case where the parent material is softer than the insert, removal may damage the threads in the parent material requiring rework of the parts.

For the above conditions, it is recommended to use the tangless versions of the Nitronic 60 threaded inserts. This version has proven to be easier to remove.

2.1.3.3.2 Phosphor Bronze Threaded Inserts

Phosphor bronze threaded inserts are used to prevent galling between similar materials. Phosphor bronze is a softer material that can be installed and removed relatively easily. However, with multiple installations of fasteners, they tend to lose their "locking feature" more quickly than harder threaded inserts. Care should be taken to measure the running torque for multiple use applications.

2.1.3.3.3 Silver Plated Steel Threaded Inserts

Silver plating is added to steel threaded inserts to help reduce the possibility of galling between similar materials. Over the course of installing fasteners in the inserts, the silver plating may flake off. The flakes are a source of contamination that can get into electrical systems and cause shorts or failure of the system. They can also land on critical optical surfaces that will affect the image generated by the optic. Silver plated threaded inserts are not recommended for use.

2.1.4 Hi-Lok Fasteners

Hi-Lok fasteners are to be installed per manufacturer's procedures.

2.1.5 Head Shaving

Flush bolts or flush head Hi-Lok pins shall not have their heads shaved to obtain the correct seating in countersinks.

2.1.6 Fastening to a Honeycomb Insert

If one of the fittings in the joint consists of a honeycomb panel with a post-cure insert, as shown in the figure below, the following criteria should be met:

1. The diameter of hole in the clamped fitting (d_{hole}) in contact with the insert is less than the diameter of the body of the post-cured insert (d_{insert})
2. Post-cured inserts are flush with the surface of the honeycomb panel.

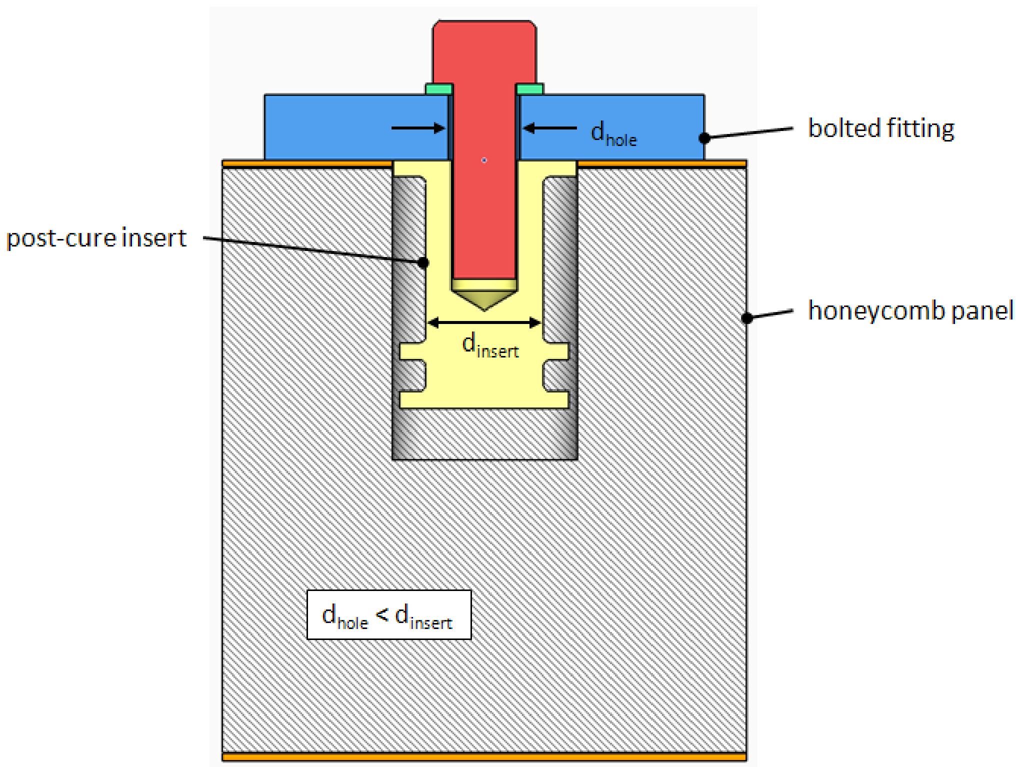

Figure 2.1-1 Fastened part preparation

2.2.1 Washer Installation

Unless otherwise specified, flat washers should be installed as follows:

- For flush head bolts, install the washer under the nut.
- For protruding head bolts, install washers under both the bolt head and nut if possible. If only one washer is used, install the washer under the member that is being turned to tighten the joint.
- Install washer such that larger radius is under the head of the bolt.
- Install countersunk washers with countersink toward the bolt head radius.

2.3 PRE-TORQUING PROCEDURE

2.3.1 Protrusion of Bolts through Nuts, Nut-Plates and Inserts (Minimum Engagement)

2.3.1.1 Protrusion through Installed Self-Locking Nuts and Nut-Plates

Install bolts through the companion internal thread to meet the minimum protrusion requirements of Figure 2.3-1.

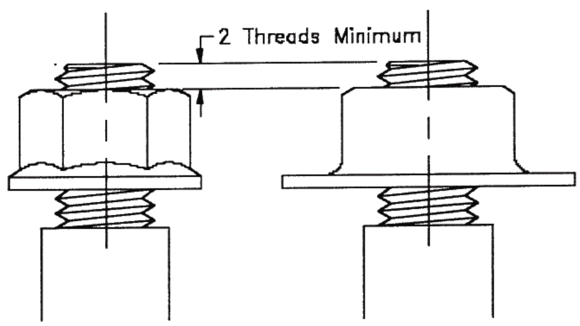

Figure 2.3-1 Minimum Bolt Thread Protrusion through Self-Locking Nuts and Nut-Plates

2.3.1.2 Penetration through Inserts and Blind Tapped Holes

2.3.1.2.1 Install bolts into non-locking inserts and other blind tapped holes so that there is at least one full diameter of thread engagement (unless otherwise specified).

2.3.1.2.2 For locking inserts, the length of the bolt and the penetration depth shall insure that the locking feature is fully engaged.

a) Tighten at least two turns past locking feature torque increase.

b) Verify that the bolt does not bottom out in a blind hole.

2.3.2 Thread Locking Devices

If a thread-locking device is used, the bolt thread should be engaged in the locking device a minimum of two full turns.

2.3.3 Threads in Bearing

Install bolts with unthreaded shank such that:

2.3.3.1 For bolts carrying primary shear loads, the threads should start at least two threads lengths beyond the shear plane. For bolts that carry tension only, threads may be allowed between the joints.

Exception:

Bolts containing an unthreaded shank used in the attachment of tubing and electrical clips and clamps may have more than one thread in bearing.

The unthreaded shank should not protrude through the parts being joined far enough for the nut to bottom on the unthreaded shank. See Figure 2.3-2 (For definition of shanking refer to Section P.10)

(Unacceptable) Nut Bottomed on Unthreaded Shank

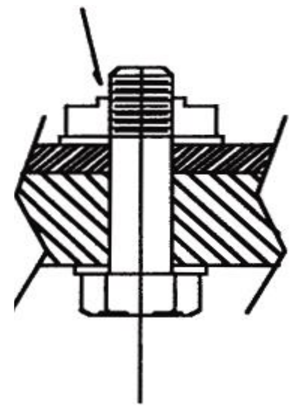

Figure 2.3-2 Grip Length Requirements for Bolts in Bearing

2.3.3.2 Bolts containing an unthreaded shank that do not carry primary shear loads may have threads in the shear plane.

2.3.4 Seating of Flush Head Bolts and Screws (countersunk head)

Install flush head bolts so that they seat flush-to-low in countersinks. Heads can seat up to 0.015 inch maximum below the surface of structure. These fasteners should primarily be used with nuts or floating nut-plates. They should only be used in tapped holes if the holes are located with a precise template. If a template is not used to locate the tapped holes, high stresses may be induced into the head of the fastener when it is seated.

2.4 WORKMANSHIP

Do not damage the bolt head or nut during installation. Install bolt, nut and washer so that each item seats firmly, does not extend into a spot-face radius or fillet, and does not interfere with adjacent structure.

2.5 TORQUING PROCEDURE

Always tighten bolts or nuts with a torque wrench to the applicable torque values specified on the design drawing. If no value is specified on design drawing then the procedures specified in this document should be followed.

Note:

If an unusual condition is encountered during any torqueing operation, notify QC and/or the responsible engineer.

An unusual condition is defined as a fastener in a pattern of fasteners that feels noticeably different than other fasteners when it is installed or torqued. Examples are fasteners that:

- *Refuse to start into their threads*
- *Have an unusually high or low running torque (compared to adjacent fasteners)*
- *Are noticeably looser or tighter than adjacent fasteners*

2.5.1 Torque from Nut or Head Preference

Tightening from Nut Side

- Whenever possible, torque from the nut side.

Tightening from the Head Side

- When it is not possible to torque from the nut side, torque from the bolt side to the high side of the torque range specified on the design drawing or applicable Torque Tables.

2.5.2 Torque Reading Details

Take final torque reading while the nut or bolt is rotating. If the maximum torque is applied without causing rotation, back off the nut or bolt one to one-and-one-half full turns and re-torque.

Caution:

A check of the torque required by backing off the nut is not an indicative of the installation torque. Due to such conditions as static friction, corrosion, and yielding, the torque necessary to break the nut or bolt free may be different than the installation torque.

2.5.3 Lock-wiring and Cotter Pinning

For nuts and bolts that are to be tightened and subsequently lock-wired or cotter pinned, tighten to the low side of the torque range specified on the design drawing or applicable Torque Tables. If necessary for alignment, continue tightening until the next slot aligns with the hole. DO NOT exceed the maximum value of the specified torque range.

Caution:

Do not loosen the nuts or bolts to obtain slot alignment.

Caution:

If a non-locking fastener is encountered that is not free running (that is, cannot be fully inserted finger tight to its seat), notify the cognizant engineer and/or Quality Control representative.

2.5.4 Protruding Head or Countersink Fasteners

If the drawing does not specify a torque value, determine the material specification for the fastener to be torqued, then refer to the applicable Torque Table. Next, use the torque value for the specific fastener size and lubrication condition. If the specification for the fastener to be torqued is not listed in Table, determine the Ultimate Tensile Strength (UTS) of the fastener and use the Torque Table appropriate for that fastener strength. If the exact UTS value is not listed, use the Torque Table for the next lower UTS.

2.5.5 Locking Spacecraft Fasteners Procedure

Quantity: To determine the average running torque of the locking feature, measure the greater of:

- Five (5) fasteners, or
- One-tenth (10%) of the total fasteners of the same type and size to be torqued into similar assemblies. This should be done on the same day by the same person.

OR

- Measure running torque on each individual fastener as it is being installed. Measurement will be taken after the locking feature is fully engaged and before preloading has started.

Determine the average running torque of the locking feature (or the measured running torque for each individual fastener if that method is selected) and add it to the appropriate torque value from Table 3-1 through 3-6 as follows:

1. Select the number of fasteners to be measured based on the ***Quantity*** statement above.
2. Install these fasteners to a depth that engages the locking feature, but does not seat the fastener.
3. With a dial-type or digital electronic torque wrench, rotate each fastener and record the running torque reading before the fastener begins to seat.
4. Average the readings. A data sheet is provided in Appendix B to record running torques and to calculate average running torque.
5. Torque the fasteners to the sum of average running torque and indicated torque from Table 3-1 through 3-6 for that fastener size, material and lubrication condition.

2.5.6 Torquing Sequence

2.5.6.1 Access Doors, Cover Plates, Angles and Channels

Torque items such as access doors, cover plates, angles and channels, attached with a series of bolts or studs that subsequently require tightening, in such a manner as to load the parts uniformly.

2.5.6.2 Rigid Flange Type Joints or Cylinders

Unless otherwise specified, torque the fasteners of flange type joints employing gaskets or similar sealing devices, or cylindrical sections joined by multiple bolt-nut combinations, in the following manner:

1. Insert and tighten all fasteners finger tight or until contact is made with the structure. (If locking fasteners are used, determine average running torque in accordance with section 2.5.5)

2. Torque all fasteners toward their final value in increments no greater than ¼ turn, in a crisscross fashion such as the following sequence shown in Figure 2.5-1 such that the preload is applied uniformly:
    a. Torque one fastener 1/4 of a turn.
    b. Torque the fastener opposite (if the pattern has an even number of fasteners) or slightly clockwise from opposite (if the pattern has an odd number of fasteners).
    c. Torque the fastener that is adjacent to and clockwise from the first.
    d. Proceed around the pattern, torqueing opposite adjacent fasteners in turn by 1/4 of a turn until all fasteners have been torqued to their final value.

3. Continue this tightening procedure until the torque specified on the design drawing is reached on all bolts. In most instances, it is not necessary to record the exact torqueing sequence, but a final check that all bolts are torqued should be made.

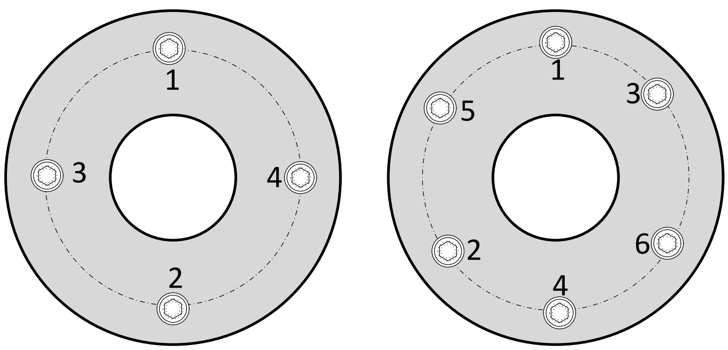

Figure 2.5-1 Tightening Sequence

Note:

On assemblies having bolt patterns of more than seven bolts, tighten any pair that is approximately 180 degrees apart. Select the next bolt midway between two bolts already partially tightened; repeat the same cycle until all bolts have been tightened.

3. FASTENER TORQUE TABLES

Tables 3-2 to 3-6 (for A286) and 3-7 (for CRES) itemize the tightening torques for spacecraft fasteners for sizes from #0 to 1" diameters (UNC or UNF only*), made of select materials with ultimate (yield) strengths of 80 (26) Ksi to 200 (180) Ksi. The torque values listed in Tables 3-2 to 3-7 are designed to develop a preload of 65% of the fasteners specified yield strength.

Note:

Per MIL-HDBK-60 for UNJ thread form, the stress area is a little bigger than the UNC/UNF thread form, so the required torque to attain the same 65% Fty is a little greater. To take advantage of this, calculate the required torque for a UNJ fastener by multiplying the appropriate value in the torque tables by the following: $[(Dn-0.6495)/(Dn-0.9743)]^2$ *Where D is the basic major diameter and n is the number of threads per inch.*

These torques are set assuming that the full strength of the fastener can be developed and are not limited by the nut or insert strength. Shear tear-out of the insert and or parent material threads are not considered in the torque tables and must be calculated separately.

These generalized Torque Tables have been developed assuming an average torque coefficient 'K' of **0.30** for dry fasteners that have been ultrasonically cleaned in IPA and **0.18** for lubricated fasteners. These "K" values were derived from torque/tension testing of some commonly used fasteners at GSFC. For this testing, the hardware was processed in a flight-like manner where the fasteners were ultrasonically cleaned in IPA then bagged and installed using clean room gloves. It is strongly recommended that lubrication is used and that the fasteners are not installed dry (wherever possible) due to the greater possibility of galling, and higher torque levels required for the same preload resulting in the possibility of head stripping, and a larger scatter in the Torque-Tension relationship.

Note:

*All fasteners should be ultrasonically cleaned with IPA or other solvent prior to use. If fasteners are not ultrasonically cleaned (thus removing the light machining oils that are typically present in the as received condition) prior to installation, there may be machining oils that could reduce the **0.30** K factor to a lower value resulting in a higher than expected preload. Testing of the fasteners could be performed to determine a more accurate preload for a non-ultrasonically cleaned, non-lubricated condition.*

Note:

*It should be noted that the high torque coefficient (**0.30**) for dry (ultrasonically cleaned) fasteners may cause head stripping of certain types of head configuration, typically small diameters, if a preload level corresponding to 65% Fty is used. Prior to using this high torque coefficient on any flight fasteners, an assessment should be made of the fastener ability to withstand these high torque levels.*

Data for the development of the torque values can be found at:

https://spaces.gsfc.nasa.gov/display/CODE543/Home

The torque values have been rounded to either 1 or 0.1 torque units based on fastener size.

Table 3-1 Torque values for various fastener conditions

Fastener Condition	K Value
No lubrication (Dry)	0.3
Lubricated threads	0.18
Arathane on threads	0.22

Table 3-2 Material: A286 Ftu = 200 Ksi Fty = 180 Ksi

		Dry Ultrasonically Cleaned (K=0.30)		Lubricated (K=0.18)		Arathane (K=0.22)	
Fastener Size	Preload (lbs)	Target Torque (in-lb)	Target Torque (ft-lb)	Target Torque (in-lb)	Target Torque (ft-lb)	Target Torque (in-lb)	Target Torque (ft-lb)
#0-80	234	4.2		2.5		3.1	
# 2-56	468	12.1		7.2		8.9	
# 4-40	702	23.6		14.2		17.3	
# 6-32	1053	44		26.2		32.0	
# 8-32	1638	81		48		59	
#10-24	2106	120		72		88	
#10-32	2340	133	11	80	7	98	98
1/4-20	3744	281	23	168	14	206	206
1/4-28	4212	316	26	190	16	232	232
5/16-18	6201	582	49	349	29	427	427
5/16-24	6786	637	53	382	32	467	467
3/8-16	9009	1014	84	608	51	743	743
3/8-24	10296	1158	97	695	58	849	849
7/16-14	12519	1645	137	987	82	1206	1206
7/16-20	13923	1829	152	1098	91	1342	1342
1/2-13	16614	2492	208	1495	125	1828	1828
1/2-20	18720	2808	234	1685	140	2059	2059
9/16-12	21294	3597	300	2158	180	2637	2637
9/16-18	23751	4012	334	2407	201	2942	2942
5/8-11	26442	4958	413	2975	248	3636	3636
5/8-18	29952	5616	468	3370	281	4118	4118
3/4-10	39078	8793	733	5276	440	6448	6448
3/4-16	43641	9819	818	5892	491	7201	7201
7/8-9	54054	14189	1182	8514	709	10405	10405
7/8-14	59553	15633	1303	9380	782	11464	11464
1-8	70902	21271	1773	12762	1064	15598	15598
1-12	77571	23271	1939	13963	1164	17066	17066

Table 3-3 Material: A286

Bolts ≤ 0.5" D: Ftu = 180 Ksi, Fty = 155 Ksi; Bolts > 0.5" D: Ftu = 170 Ksi, Fty = 150 Ksi (Ref. FF-S-86E)

		Dry Ultrasonically Cleaned (K=0.30)		Lubricated (K=0.18)		Arathane (K=0.22)	
Fastener Size	Preload (lbs)	Target Torque (in-lb)	Target Torque (ft-lb)	Target Torque (in-lb)	Target Torque (ft-lb)	Target Torque (in-lb)	Target Torque (ft-lb)
#0-80	202	3.6		2.2		2.7	
# 2-56	403	10.4		6.2		7.6	
# 4-40	605	20.3		12.2		14.9	
# 6-32	907	38		23		28	
# 8-32	1411	69		42		51	
#10-24	1814	103		62		76	
#10-32	2015	115	10	69	6	84	7
1/4-20	3224	242	20	145	12	177	15
1/4-28	3627	272	23	163	14	199	17
5/16-18	5340	501	42	301	25	368	31
5/16-24	5844	549	46	329	27	402	34
3/8-16	7758	873	73	524	44	640	53
3/8-24	8866	997	83	598	50	731	61
7/16-14	10780	1417	118	850	71	1039	87
7/16-20	11989	1575	131	945	79	1155	96
1/2-13	13845	2077	173	1246	104	1523	127
1/2-20	15600	2340	195	1404	117	1716	143
9/16-12	17745	2997	250	1798	150	2198	183
9/16-18	19793	3343	279	2006	167	2451	204
5/8-11	22035	4132	344	2479	207	3030	252
5/8-18	24960	4680	390	2808	234	3432	286
3/4-10	32565	7327	611	4396	366	5373	448
3/4-16	36368	8183	682	4910	409	6001	500
7/8-9	45045	11824	985	7095	591	8671	723
7/8-14	49628	13027	1086	7816	651	9553	796
1-8	59085	17726	1477	10635	886	12999	1083
1-12	64643	19393	1616	11636	970	14221	1185

Table 3-4 Material: A286 Ftu = 160 Ksi Fty = 120 Ksi

		Dry Ultrasonically Cleaned (K=0.30)		Lubricated (K=0.18)		Arathane (K=0.22)	
Fastener Size	Preload (lbs)	Target Torque (in-lb)	Target Torque (ft-lb)	Target Torque (in-lb)	Target Torque (ft-lb)	Target Torque (in-lb)	Target Torque (ft-lb)
#0-80	156	2.8		1.7		2.1	
# 2-56	312	8.0		4.8		5.9	
# 4-40	468	15.7		9.4		11.5	
# 6-32	702	29		17		21	
# 8-32	1092	54		32		39	
#10-24	1404	80		48		59	
#10-32	1560	89	7	53	4	65	5
1/4-20	2496	187	16	112	9	137	11
1/4-28	2808	211	18	126	11	154	13
5/16-18	4134	388	32	233	19	285	24
5/16-24	4524	425	35	255	21	312	26
3/8-16	6006	676	56	405	34	495	41
3/8-24	6864	772	64	463	39	566	47
7/16-14	8346	1097	91	658	55	804	67
7/16-20	9282	1220	102	732	61	894	75
1/2-13	11076	1661	138	997	83	1218	102
1/2-20	12480	1872	156	1123	94	1373	114
9/16-12	14196	2398	200	1439	120	1758	147
9/16-18	15834	2674	223	1605	134	1961	163
5/8-11	17628	3305	275	1983	165	2424	202
5/8-18	19968	3744	312	2246	187	2746	229
3/4-10	26052	5862	488	3517	293	4299	358
3/4-16	29094	6546	546	3928	327	4801	400
7/8-9	36036	9459	788	5676	473	6937	578
7/8-14	39702	10422	868	6253	521	7643	637
1-8	47268	14180	1182	8508	709	10399	867
1-12	51714	15514	1293	9309	776	11377	948

Table 3-5 Material: A286 Ftu = 140 Ksi Fty = 95 Ksi

		Dry Ultrasonically Cleaned (K=0.30)		Lubricated (K=0.18)		Arathane (K=0.22)	
Fastener Size	Preload (lbs)	Target Torque (in-lb)	Target Torque (ft-lb)	Target Torque (in-lb)	Target Torque (ft-lb)	Target Torque (in-lb)	Target Torque (ft-lb)
#0-80	124	2.2		1.3		1.6	
# 2-56	247	6.4		3.8		4.7	
# 4-40	370.5	12.4		7.5		9.1	
# 6-32	556	23		14		17	
# 8-32	864.5	43		26		31	
#10-24	1112	63		38		46	
#10-32	1235	70	6	42	4	52	4
1/4-20	1976	148	12	89	7	109	9
1/4-28	2223	167	14	100	8	122	10
5/16-18	3273	307	26	184	15	225	19
5/16-24	3581.5	336	28	202	17	247	21
3/8-16	4755	535	45	321	27	392	33
3/8-24	5434	611	51	367	31	448	37
7/16-14	6607	868	72	521	43	637	53
7/16-20	7348.25	966	80	579	48	708	59
1/2-13	8769	1315	110	789	66	965	80
1/2-20	9880	1482	124	889	74	1087	91
9/16-12	11239	1898	158	1139	95	1392	116
9/16-18	12535.25	2117	176	1270	106	1553	129
5/8-11	13956	2617	218	1570	131	1919	160
5/8-18	15808	2964	247	1778	148	2174	181
3/4-10	20625	4641	387	2784	232	3403	284
3/4-16	23032.75	5182	432	3109	259	3800	317
7/8-9	28528.5	7489	624	4493	374	5492	458
7/8-14	31430.75	8251	688	4950	413	6050	504
1-8	37420.5	11226	936	6736	561	8233	686
1-12	40940.25	12282	1024	7369	614	9007	751

Table 3-6 Material: A286 Ftu = 130 Ksi Fty = 85 Ksi

		Dry Ultrasonically Cleaned (K=0.30)		Lubricated (K=0.18)		Arathane (K=0.22)	
Fastener Size	Preload (lbs)	Target Torque (in-lb)	Target Torque (ft-lb)	Target Torque (in-lb)	Target Torque (ft-lb)	Target Torque (in-lb)	Target Torque (ft-lb)
#0-80	111	2.0		1.2		1.5	
# 2-56	221	5.7		3.4		4.2	
# 4-40	331.5	11.1		6.7		8.2	
# 6-32	497	21		12		15	
# 8-32	773.5	38		23		28	
#10-24	995	57		34		42	
#10-32	1105	63	5	38	3	46	4
1/4-20	1768	133	11	80	7	97	8
1/4-28	1989	149	12	90	7	109	9
5/16-18	2928	275	23	165	14	202	17
5/16-24	3204.5	301	25	181	15	221	18
3/8-16	4254	479	40	287	24	351	29
3/8-24	4862	547	46	328	27	401	33
7/16-14	5912	777	65	466	39	570	47
7/16-20	6574.75	864	72	518	43	634	53
1/2-13	7846	1177	98	706	59	863	72
1/2-20	8840	1326	111	796	66	972	81
9/16-12	10056	1698	142	1019	85	1245	104
9/16-18	11215.75	1894	158	1137	95	1389	116
5/8-11	12487	2341	195	1405	117	1717	143
5/8-18	14144	2652	221	1591	133	1945	162
3/4-10	18454	4152	346	2491	208	3045	254
3/4-16	20608.25	4637	386	2782	232	3400	283
7/8-9	25525.5	6700	558	4020	335	4914	409
7/8-14	28122.25	7382	615	4429	369	5414	451
1-8	33481.5	10044	837	6027	502	7366	614
1-12	36630.75	10989	916	6594	549	8059	672

Table 3-7 Material: 300 Series Cres

Bolts ≤ to 5/8" dia.: Ftu = 80 Ksi, Fty = 30 Ksi; Bolts > 5/8" dia.: Ftu = 70 Ksi, Fty = 26 Ksi (Ref. FF-S-86E)

		Dry Ultrasonically Cleaned (K=0.30)		Lubricated (K=0.18)		Arathane (K=0.22)	
Fastener Size	Preload (lbs)	Target Torque (in-lb)	Target Torque (ft-lb)	Target Torque (in-lb)	Target Torque (ft-lb)	Target Torque (in-lb)	Target Torque (ft-lb)
#0-80	39	0.7		0.4		0.5	
# 2-56	78	2.0		1.2		1.5	
# 4-40	117	3.9		2.4		2.9	
# 6-32	176	7		4		5	
# 8-32	273	13		8		10	
#10-24	351	20		12		15	
#10-32	390	22	2	13	1	16	1
1/4-20	624	47	4	28	2	34	3
1/4-28	702	53	4	32	3	39	3
5/16-18	1034	97	8	58	5	71	6
5/16-24	1131	106	9	64	5	78	6
3/8-16	1502	169	14	101	8	124	10
3/8-24	1716	193	16	116	10	142	12
7/16-14	2087	274	23	164	14	201	17
7/16-20	2320.5	305	25	183	15	224	19
1/2-13	2769	415	35	249	21	305	25
1/2-20	3120	468	39	281	23	343	29
9/16-12	3549	599	50	360	30	440	37
9/16-18	3958.5	669	56	401	33	490	41
5/8-11	4407	826	69	496	41	606	50
5/8-18	4992	936	78	562	47	686	57
3/4-10	5645	1270	106	762	64	931	78
3/4-16	6303.7	1418	118	851	71	1040	87
7/8-9	7807.8	2050	171	1230	102	1503	125
7/8-14	8602.1	2258	188	1355	113	1656	138
1-8	10241.4	3072	256	1843	154	2253	188
1-12	11204.7	3361	280	2017	168	2465	205

Appendix A – Definitions

a. Critical Fastener: A fastener, including fasteners used in ground support equipment, used in such a way that failure of a single fastener would present a Catastrophic Hazard.

b. Controlled Fastener: A fastener used on a spacecraft, flight instrument, or interface between ground support equipment and flight hardware in such a way that failure of the fastener would not present a Catastrophic Hazard.

c. Catastrophic Hazard: Catastrophic Hazard: a condition that may cause disabling or fatal personnel injury, the loss of a spacecraft, launch vehicle, or major national asset.

d. Fastener: An installable component used to transfer load across an interface. This includes, but is not limited to, bolts, screws, nuts, anchor nuts, rivets, shear pins, helical wire inserts, cylindrical inserts, and setscrews.

e. Torque Coefficient (K) also called Nut Factor: Factor representing the effect of friction and geometry in the preload to torque relation as follows:

$$T = KDP$$

where:
T = Torque (inch-lbs)
D = Nominal Fastener Diameter (inches)
P = Preload (lbs)

The Preload "P" is calculated based on material yield strength "y_s "(typically 65% of yield) times the stress area of the fastener "A".

$$P = 0.65\ y_s\ A \qquad A = .7854\ (D - .9743/n)^2$$

where: n = number of threads per inch

Table A-1 Fastener data by size

Fastener Size	Nominal Dia (in)	Pitch	Stress Area (in^2)
#0-80	0.06	80	0.002
# 2-56	0.086	56	0.004
# 4-40	0.112	40	0.006
# 6-32	0.138	32	0.009
# 8-32	0.164	32	0.014
#10-24	0.19	24	0.018
#10-32	0.19	32	0.02
1/4-20	0.25	20	0.032
1/4-28	0.25	28	0.036
5/16-18	0.313	18	0.053
5/16-24	0.313	24	0.058
3/8-16	0.375	16	0.077
3/8-24	0.375	24	0.088
7/16-14	0.438	14	0.107
7/16-20	0.438	20	0.119
1/2-13	0.5	13	0.142
1/2-20	0.5	20	0.16
9/16-12	0.563	12	0.182
9/16-18	0.563	18	0.203
5/8-11	0.625	11	0.226
5/8-18	0.625	18	0.256
3/4-10	0.75	10	0.334
3/4-16	0.75	16	0.373
7/8-9	0.875	9	0.462
7/8-14	0.875	14	0.509
1-8	1	8	0.606
1-12	1	12	0.663

Note: *For details on stress area calculation see Fed-Std-H28/2B*

f. Non-Controlled Fastener: Fasteners not covered by this document. This includes fasteners used in MGSE that neither directly interface with flight hardware nor are classified as critical fasteners.

g. Preload (P): Developed Fastener Load due to torque application.

h. Running Torque: Measured Torque when all threads are fully engaged, fastener is in motion, and the washer face has not yet made contact. The torque that generates bolt preload is that applied above running torque.

i. Separation: (Also referred to as "gapping.") The state of no compressive load between mating parts local to the fastener. For a joint designed to maintain a seal, it is further defined as any condition that enables a liquid or gas to penetrate the seal at an unacceptable rate.

j. Separation Critical Joint: A joint which fails to function properly when separated. For example, a joint where mating surface alignment is critical for mission and/or instrument performance.

k. Shanking: The unthreaded bolt shank protruding through the parts being joined such that the nut bottoms on the unthreaded shank.

Appendix B – Acronyms

CRES	Corrosion Resistance Steel
IPA	Isopropyl Alcohol
GSFC	Goddard Space Flight Center
MGSE	Mechanical Ground Support Equipment
QC	Quality Control
UNC	Unified National Coarse
UNF	Unified National Fine
UTS	Ultimate Tensile Strength
WOA	Work Order Authorization

CHANGE HISTORY LOG

Revision	Effective Date	Description of Changes
Baseline	01/04/08	Initial Release
A	06/29/2011	Primary revision had to do with updating torque tables based on in-house torque tension testing of fasteners processed in flight like manner
	08/07/2013	This document has been administratively changed at the template block from Procedures and Guidelines to Center-Wide Procedures and Guidelines.
	06/09/2016	This document has been administratively extended for a period of one year.
	03/09/2017	This document has been administratively extended for a period of one year.
	06/13/2018	This document has been administratively extended for a period of one year.
B	07/07/2020	Revised the document to reflect numerous changes from requirements to good practice where appropriate. Updated to include Nitronic 60 inserts. Updated torque tables to reflect new values for K, torque coefficient, based on new test data. Added torque values for fasteners that use Arathane as a lubricant/locking feature. Updated to the latest PG format.