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SHIP SYSTEMS AND EQUIPMENT—THREADED FASTENERS—INSPECTION, TEST, AND INSTALLATION REQUIREMENTS

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1. Scope—This SAE Standard covers both quality assurance and installation requirements for fasteners.

This document establishes engineering criteria and guidance for quality assurance requirements (including Test and Inspection) for procurement of threaded fasteners where such criteria and guidance is not otherwise provided by existing fastener standards or specifications. The document also provides requirements and test procedures for self-locking fasteners including those manufactured by the installing activity.

This document also provides requirements for the selection and use of fastener lubricants, additional corrosion protection treatments, fastener tightening procedures, and the use of thread-locking compounds.

1.1 Field of Application—This document applies specifically to fasteners for ship systems and equipment. This document is intended for commercial and military ships and vehicles, not watercraft for recreational use.

2. References

2.1 Applicable Documents—The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the latest issue of all documents shall apply. (NOTE—Contracts invoking this document may establish an effectivity date for referenced documents.)

2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

AMS 2526—Molybdenum Disulfide Coating, Thin Lubricating Film, Impingement Applied
AMS 3090—Lubricant, Dry Film, Heat Cured, For Fasteners, Polysulfide Sealant Compatible
AS1701—Lubricant, Solid Dry Film

2.1.2 ASME PUBLICATIONS—Available from ASME, 1430 East 47th Street, New York, NY 10017.

ASME B1.2—Gages and gaging for Unified Inch Screw Threads
ASME B1.3M—Screw Thread Gaging Systems for Dimensional Acceptability - Inch and Metric Threads (UN, UNR, UNJ, M and MJ)
ASME B1.16M—Gages and Gaging for Metric M Screw Threads
ASME B18.16.1M—Mechanical and Performance Requirements for Prevailing Torque Type Steel Metric Hex Nuts and Hex Flange Nuts
ASME B18.18.1M—Inspection and Quality Assurance for General Purpose Fasteners
ASME B18.18.2M—Inspection and Quality Assurance for High Volume Machine Assembly Fasteners
ASME B18.18.3M—Inspection and Quality Assurance for Special Purpose Fasteners
ASME B18.18.4M—Inspection and Quality Assurance for Fasteners for Highly Specialized Engineered Applications

2.1.3 ASTM PUBLICATIONS—Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM A 194—Carbon and Alloy Steel Nuts for High-Pressure and High-Temperature Service, Standard Specification for
ASTM A 342—Standard Test Methods for Permeability of Feebly Magnetic Materials
ASTM F 606/F 606M—Determining the Mechanical Properties of Externally and Internally Threaded Fasteners, Washers, and Rivets
ASTM F 1470—Standard Guide for Fastener Sampling for Specified Mechanical Properties and Performance Inspection

2.1.4 IFI PUBLICATIONS—Available from IFI, 1717 East Ninth St., Suite 1505, Cleveland, OH 44114-2879.

IFI-100/107—Prevailing-Torque Type Steel Hex and Hex Flange Nuts - Regular and Light Hex Series
IFI-124—Test Procedure for the Locking Ability Performance of Non-Metallic Locking Element Prevailing-Torque Lock Screws

2.1.5 U.S. GOVERNMENT PUBLICATIONS—Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

2.1.5.1 Military Specifications

MIL-A-907—Antiseize Thread Compound, High Temperature
MIL-M-7866—Molybdenum Disulfide, Technical, Lubrication Grade
MIL-S-8660—Silicone Compound, NATO Code Number S-736
MIL-S-8802—Sealing Compound, Temperature Resistant, Integral Fuel Tanks and Fuel Cell Cavities, High Adhesion
MIL-F-18240—Fastener Element, Self-Locking, Threaded Fastener, 250°F Maximum
MIL-S-22473—Sealing, Locking, and Retaining Compounds: (Single Component)
MIL-L-23398—Lubricant, Solid Film, Air-cured, Corrosion Inhibiting, NATO Code S-749
MIL-L-24131—Lubricant, Colloidal Graphite in Isopropanol
MIL-L-24478—Lubricant, Molybdenum Disulfide in Isopropanol
DOD-L-24574—Lubricating Fluid for Low and High Pressure Oxidizing Gas Mixtures
MIL-N-25027—Nut, Self-locking, 250°F, 450°F, 800°F, 125 ksi F_{tu}, 60 ksi F_{tu}, and 30 ksi F_{tu}
MIL-G-27617—Grease, Aircraft and Instrument, Fuel and Oxidizer Resistant

MIL-L-46010—Lubricant, Solid Film, Heat Cured, Corrosion Inhibiting
MIL-S-46163—Sealing, Lubricating, and Wicking Compounds: Thread Locking, Anaerobic, Single Component
MIL-S-81733—Sealing and Coating Compound, Corrosion Inhibitive

2.1.5.2 Military Standards

MIL-STD-1312—Fastener, Test Methods

2.1.5.3 Military Handbooks

MIL-HDBK-60—Threaded Fasteners—Tightening to Proper Tension

2.2 Order of Precedence—In the event of a conflict between the text of this document and the references cited herein (excluding fastener part standards), the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

3. Definitions

3.1 Breakaway Torque—Breakaway torque is the torque required to start the rotation of a fastener. The magnitude of this torque is significant when checking the bonding of an anaerobic locking compound. The term is also used to describe the torque required to start the rotation of a fastener when loosening it or restarting its rotation when tightening a group of fasteners in successive increments. Breakaway torque will generally be higher than that required to continue the rotation.

3.2 Dry-film Lubricant—See solid-film lubricant.

3.3 Liquid-film Lubricant—A petroleum-based liquid or paste which adheres to the fastener and provides for reduction in friction or galling.

3.4 Magnetic Permeability—(1) The relationship, expressed in Oersteds, between magnetic induction and magnetizing force. Absolute permeability is the quotient of a change in magnetic induction divided by the corresponding change in magnetizing force. Relative permeability is the ratio of absolute permeability to the permeability of free space. (2) The ease with which a material can become magnetized.

3.5 Major Diameter—On a straight thread, the major diameter is the diameter of the crest of the external thread or the root of the internal thread.

3.6 Maximum Material Condition—Maximum material is the condition where the crest and root of an externally threaded fastener are at their maximum diameter, or the crest and root of an internally threaded fastener are at their minimum diameter.

3.7 Minimum Material Condition—Minimum material is the condition where crest and root of an externally threaded fastener are at their minimum diameter, or the crest and root of an internally threaded fastener are at their maximum diameter.

3.8 Minor Diameter—On a straight thread, the minor diameter is the diameter of the root of the external thread or the crest of the internal thread.

3.9 Preload—The initial amount of clamping or tension force exerted by a fastener on joined members that is solely attributed to fastener stress induced by tightening. The stress will decrease shortly after installation due to embedment, thermal creep, and other factors. See Relaxation.

3.10 Prevailing-torque Self-locking Fastener—A prevailing-torque self-locking fastener is one which has frictional resistance to rotation due to a self-contained prevailing torque feature and not because of a compressive load developed against the bearing surface of the fastener.

3.11 Relaxation—The decrease in stress over time while the total strain remains essentially constant. Relaxation can result from vibration loosening, temperature expansion, and other factors.

3.12 Solid-film Lubricant—As generally used, nonpetroleum lubricants, such as graphite and molybdenum disulfide, which may be used directly or as a colloidal suspension in some fluid such as oil or alcohol. The lubricants facilitate fastener installation by reducing friction or galling.

3.13 Tensile Strength—Tensile strength, also referred to as ultimate strength, is the maximum load (usually expressed as tensile stress in pounds per square inch or megapascals) a material can sustain without tearing apart.

3.14 Tensile Stress Area—Tensile stress area is the circular cross-sectional area of a theoretical unthreaded rod whose cross-sectional area is such that it would fail in tension at the same load as a particular threaded fastener.

3.15 Thread Gages—Devices used to determine if a screw thread conforms to the dimensional requirements of the specification. Gages may be classified as attribute/fixed limit (qualitative) or variables/indicating (quantitative). Classification of specific gages is found in ASME B1.3M.

3.16 Thread Gaging—The process, using suitably calibrated gages, of determining if thread dimensional characteristics conform to specified requirements.

3.17 Tolerance(s)—Tolerances are specified amounts by which dimensions are permitted to vary. The tolerance is the difference between the maximum and the minimum limits permitted.

3.18 Torque—(1) Application of a force at a distance producing a torsional moment. (2) A turning or twisting force exerted on a fastener.

3.19 Torque Control—A procedure for tightening fasteners using a torque wrench to control the amount of preload that is applied.

4. Quality Assurance Requirements—Procurement documents must include Quality Assurance requirements to ensure the fastener meets the end user's performance requirements. When adequate requirements are not identified in the applicable fastener standard or specification; appropriate manufacturing, test, marking, and inspection requirements shall be identified in the fastener procurement document.

4.1 Test and Inspection Requirements—Threaded fasteners shall be manufactured, tested, inspected, and marked in accordance with their part standard and acquisition specifications.

4.2 Selection of Tests and Inspections—All mandatory tests and inspections provided by the fastener standard or specification shall be performed. Optional tests and inspections are required only when needed to meet end use performance requirements or when specifically invoked.

4.2.1 When testing and inspection criteria are not identified in the applicable fastener standard or specification, the fastener properties needed for the design shall be determined. The appropriate tests shall then be specified to ensure the fastener provides the needed properties. The following documents shall be used for guidance in selecting appropriate tests.

a. Test Methods—Test methods in accordance with ASTM F 606 or MIL-STD-1312 shall be used as applicable for mechanical and performance testing. ASTM F 606 establishes procedures for conducting tests to determine the mechanical properties of externally and internally threaded fasteners, washers, and rivets. MIL-STD-1312 presents unified standard methods of testing, analysis of data, and presentation of results for use in research, development, procurement, design selection, assembly and maintenance.
b. Dimensional and Other Nondestructive Tests—Applicable requirements in ASME B18.18.1M through B18.18.4M are recommended for use when identifying and specifying inspection and quality assurance requirements for fasteners that do not have dimensional and other nondestructive requirements identified in their associated part standard, industry standard, or drawing.
c. Mechanical and Physical Properties—ASTM F 1470 is recommended for use when identifying requirements for the test and inspection of mechanical properties, physical properties, and other quality requirements. In the event of a conflict between the material specification and ASTM F 1470 as to the number of samples required, it is recommended that the larger number be inspected/tested.
d. Magnetic Permeability—This test is applicable only when the application requires nonmagnetic fasteners. Magnetic permeability shall be measured with a permeability indicator that is in accordance with ASTM A 342. Tests shall be conducted on the finished fastener product as cold working can affect magnetic permeability. Unless otherwise specified, or required for sensitive instrumentation, a value of 2.0 Oersteds maximum is adequate.

4.3 Test and Inspection Data—Certification shall be provided that shows compliance with the applicable fastener specification or procurement document. When fastener tests are specified, the test and certification data that is to be submitted to the contracting activity to ensure fastener compliance shall be identified. Review of data shall be performed as part of receipt inspection.

5. Test and Inspection Procedures—The procedures herein shall be used when applicable and they do not conflict with or duplicate requirements in the fastener procurement standard. Accordingly, they are particularly applicable to fasteners not covered by industry or military part standards and specifications.

5.1 Fastener Dimensional Inspection—Table 1 lists the major parameters required for dimensional inspection by the fastener manufacturer. Fastener gaging shall be in accordance with the applicable fastener specification. Where no guidance on gaging is given, the fastener thread gages and gaging shall be in accordance with ASME B1.2 or B1.16M as applicable. Fastener thread gaging shall be in accordance with the requirements of System 21 or 22 of ASME B1.3M and Table 1.

TABLE 1—FASTENER DIMENSION AND MARKING INSPECTION PARAMETERS

Parameter to be Examined	Fastener Type	Recommended for Receipt Inspection
Marking	Bolts, studs, screws, and nuts	Yes[1]
Major diameter	Bolts, studs, and screws	Yes
Minor diameter (rounded root)	Bolts, studs, and screws	
Minor diameter	Nuts	Yes
Go maximum material	Bolts, studs, screws, and nuts	Yes
Minimum material or NOT GO Functional diameter	Bolts, studs, screws, and nuts	Yes
Root profile of J threads	Bolts, studs, and screws	
Thickness	Nuts	Yes
Head height	Bolts and screws	Yes
Distance across flats	Bolts, screws, and nuts	Yes
Width across corners	Bolts and screws	
Total run-out	Bolts, studs, and screws	
Shank diameter	Bolts, studs, and screws	
Overall length	Bolts, studs, and screws	Yes
Thread length	Bolts, studs, and screws	Yes
Fillet radius	Bolts and screws	
Straightness	Bolts, studs, and screws	Yes[2]
Location and type locking element	Bolts, studs, screws, and nuts	Yes

1 Marking applies to 6 mm (1/4 in) or larger diameter fasteners.
NOTE—In some cases low strength carbon steel products are not marked in larger sizes.)
2 Visual only.

5.1.1 RECEIPT INSPECTION—Even though inspection requirements are invoked on the manufacturer, a receipt inspection of fasteners by the installing activity is recommended. In Table 1, those parameters recommended for receipt inspection are identified. More or less stringent receipt inspection requirements may be implemented depending upon the criticality of particular parameters in the fastener application. ASTM F 1470 and ASME B18.18.1M through ASME B18.18.4M can be used to develop receipt inspection plans.

5.2 Self-locking Fasteners Test and Inspection Procedures

5.2.1 COMMERCIAL SELF-LOCKING FASTENERS—Commercially available prevailing-torque self-locking fasteners shall comply to an industry or military standard such as IFI 124, MIL-F-18240, or MIL-N-25027. Testing and inspection shall be in accordance with the applicable standard.

5.2.2 USER MANUFACTURED SELF-LOCKING EXTERNALLY THREADED FASTENERS—Self-locking fasteners that are manufactured for specific applications, such as those produced by shipyards, shall be inspected in accordance with the applicable industry or military standard or in accordance with the following procedure to verify locking characteristics:

a. Starting fasteners shall be certified as meeting the requirements of the applicable fastener standard prior to installation of locking elements. Certification shall consist of receipt inspection for commercial products or appropriate in-house testing for shipyard manufacture. Fasteners not damaged by testing may be used.
b. The nut shall be of the same material type as the nut or set material to be used in the installation.
c. Sampling shall be in accordance with Table 2.

TABLE 2—LOT SIZE FOR SELF-LOCKING FASTENER TESTS

Lot Size (Pieces)	Sample Size
50 or less	2
51-500	3
Over 500	5

d. The locking torque test shall be in accordance with the following, as applicable:

(1) A sample self-locking fastener shall be lubricated using the same lubricant to be used in the installation and assembled with a test washer and a test nut with the test washer located adjacent to the component to be turned. During the complete performance of the test, either the fastener or the test nut shall be turned. When the fastener is turned, the restraining mechanism shall be such that it imparts no radial distortion to the test nuts.

(2) The fastener or test nut shall be advanced until its bearing surface is seated against the test washer. The total thickness of spacer material in the test assembly shall be selected so that at seating the locking feature of the fastener shall be fully engaged within the test nut. A minimum of two full thread pitches of the fastener shall project through the top of the test nut.

(3) During this first installation the maximum prevailing (or running) torque occurring while the fastener or test nut is in motion and prior to development of any axial load shall be measured and recorded. A calibrated torque wrench or similar device may be used to measure the torque.

(4) Tightening shall be continued until the torque load, as specified in Table 3A or 3B, for the applicable fastener, is developed. The clamp load torques in Tables 3A (metric) and 3B (inch size) are based on the yield strength of the fastener. If the yield strength of the fasteners to be tested does not match any of the yield strengths presented in Table 3A or 3B, use the torque specified for fastener with the next lower yield strength. A calibrated torque wrench may be used to establish the torque.

NOTE—The actual torque used shall be the specified clamping fastener torque plus the actual prevailing torque measured during installation of the fastener.

(5) The axial tensile clamp load in the fastener shall be reduced to zero by backing the fastener or test nut off until the test washer is free to turn by the fingers. Following a pause (it is generally necessary to change the wrench to one of a lower torque capacity) removal shall be continued and the maximum prevailing (or running) torque occurring while the fastener or test nut is being backed off throughout the next 360 degrees of rotation shall be measured and recorded. The fastener or test nut shall then be backed off until the locking element is disengaged from the test nut.

(6) The fastener and test nut shall be reassembled and disassembled four more times. On each reassembly the fastener shall be assembled with the test nut until the turned element is seated against the test washer but no tensile load shall be induced in the fastener.

TABLE 3A—PREVAILING TORQUES FOR METRIC NONMETALLIC LOCKING ELEMENT TYPE FASTENERS

Fastener Size	Torque Required to Develop Clamp Test Load 205 MPa Y.S. (CRES, Ni-Cu) N·m	Torque Required to Develop Clamp Test Load 720 MPa Y.S. Class 9.8 (M3-M14) N·m	Torque Required to Develop Clamp Test Load Alloy Steel (ASTM F 568 Class 10.9) N·m	Prevailing Torque (max) N·m	1st Removal Prevailing Torque (min) N·m	5th Removal Prevailing Torque (min) N·m
M3	.3	.9	-	0.60	0.14	0.06
M3.5	.4	1.4	-	0.90	0.22	0.11
M4	.6	2.1	-	1.2	0.26	0.16
M5	1.2	4.1	5.3	2.3	0.36	0.23
M6	2	7.1	8.6	3.0	0.45	0.30
M8	5	17	22	10	0.90	0.58
M10	10	34	43	14	1.8	1.1
M12	17	59	75	21	2.6	1.5
M14	27	94	120	30	3.6	2.3
		660 MPa Y.S. (M16-M36) Cl 8.8				
M16	43	150	190	40	5.0	3.4
M20	83	260	360	60	8.0	5.5
M24	144	460	630	90	13	8.5
M30	286	900	1300	120	19	13
M36	500	1600	2200	150	28	18

NOTE—Torque values are based on friction factor of 0.12 (well lubricated) for loads representing 75% of a proof load which represents 90% of yield strength of the material.

TABLE 3B—PREVAILING TORQUES FOR INCH NONMETALLIC LOCKING ELEMENT TYPE FASTENERS

Fastener Size UNC & UNF Threads	Torque Required to Develop Clamp Test Load 30 ksi Y.S. (CRES, Ni-Cu) ft-lb	Torque Required to Develop Clamp Test Load 81-92 ksi Y.S. Gr 5, Ni-Cu-Al ft-lb	Torque Required to Develop Clamp Test Load 130 ksi and greater Y.S. ft-lb	Prevailing Torque (max) ft-lb	1st Removal Prevailing Torque (min) in-lb	5th Removal Prevailing Torque (min) in-lb
1/4	19 in-lb	52 in-lb	84 in-lb	40 in-lb	5	3
5/16	40 in-lb	110 in-lb	172 in-lb	85 in-lb	8	5
3/8	70 in-lb	16	26	9	14	9
7/16	113 in-lb	25	41	12.5	20	12
1/2	173 in-lb	39	62	18	26	16
5/8	29	77	124	29	45	30
3/4	51	137	220	38	60	45
7/8	82	220	350	58	95	65
1	123	330	530	75	130	85
1-1/8	174	470	750	87.5	150	110
1-1/4	245	660	1060	96	200	140
1-3/8	320	870	1400	108	240	150
1-1/2	430	1160	1850	133	275	180

NOTE—Torque values are based on friction factor of 0.12 (well lubricated) for loads representing 75% of a proof load which represents 90% of yield strength of the material.

(7) During the fifth removal, the maximum and minimum prevailing (or running) torque occurring while the fastener or test nut is being backed off throughout the first 360 degrees of rotation shall be measured and recorded. At no time during the four additional installations and removals should the prevailing torque exceed the maximum prevailing torque, as specified in Table 3. The maximum prevailing torque developed by fasteners during the first and fifth removals shall be not less than the minimum removal torque specified in Table 3. The minimum torque recorded shall not be less than that specified for the fifth removal.

NOTE—The intent of this requirement is to demonstrate that galling between the sample fastener and test nut has not occurred. With certain designs of locking features there may be an increase in the prevailing torque during the five assembly cycles, and in rare instances the specified maximum prevailing torque may be exceeded. In such instances the shipyard shall ensure that galling is not a contributing factor.

(8) Sufficient time shall elapse between torquing cycles to prevent overheating of the test assembly.

6. Installation Requirements—This section establishes requirements and guidelines for installation of fasteners. This includes the use of lubricants, establishment of preload tensions, generic installation considerations, tightening procedures, general corrosion protection, and the use of thread locking compounds.

6.1 Lubrication Requirements—Lubricants are used on fasteners to reduce wear, prevent or inhibit galling or seizure, inhibit fretting, aid in the installation and removal of fasteners, and control the installation torque or the preload of the joint. Unless otherwise specified in the system or equipment specifications or otherwise warranted by the application, a lubricant shall be used for fastener installation. When no lubricant is to be applied, this restriction should be explicitly stated in the assembly instruction, drawing, or other documentation. The fastener lubrication requirements in this section do not apply to fasteners which act as a bearing shaft .

6.1.1 APPLICATIONS

6.1.1.1 Electrical Applications—Silver plating is suitable for use in applications where the fastener provides electrical continuity and the use of a thread lubricant is required.

6.1.1.2 Interference Fit Applications—The lubricant shall permit full installation of the fastener without detriment to the hole or fastener. Minor scraping of plating from the plated fastener is not considered detrimental in this regard.

6.1.1.3 Fluid System Applications—When a fastener is exposed to fluid in a system, only lubricants permitted by that system may be used. Use of metallic-based lubricants on fasteners in systems that require periodic fluid analysis may cause false indication of premature internal wear of components.

6.1.1.4 Corrosion Barriers—The lubricants identified herein do not provide a sufficient electrolytic corrosion barrier and shall not be used as the sole corrosion barrier regardless of the metallic material combinations or the environment.

6.1.2 TYPES OF LUBRICANTS—Lubricants fall into several categories. Silver and dry film lubricants are often permanently applied to the fastener while other lubricants are applied at the time of fastener installation.

6.1.2.1 Silver Plating—Silver plated fasteners may be encountered in some applications, usually associated with high temperature. The silver plating acts as a lubricant and prevents galling during installation and removal. Often a very thin flash coating, silver plating is not for corrosion protection and should not be used in environments subject to corrosion unless applied to fastener materials that are more noble than silver such as nickel-copper and nickel based alloys. Silver plated fasteners should not be used with titanium fasteners or in contact with titanium structures.

6.1.2.2 Dry Film Lubricants—The use of dry (solid) film lubricants on thread surfaces is recommended to prevent galling. Nickel-copper (Alloy 400/405) nuts when used with nickel-copper screws are particularly subject to galling. Dry film lubricants are used under the following conditions:

a. To touch up worn surfaces originally coated with dry film lubricant.
b. Where conventional lubricants are difficult to apply or retain, or where other lubricants may be easily contaminated with dirt and dust.
c. Where temperatures may range from –68 to 204 °C (–90 to 400 °F).
d. If mechanisms are operated at infrequent intervals or are lubricated for life.
e. Where long-term corrosion protection is required.
f. Where a solvent-resistant coating is required.

6.1.2.2.1 MIL-L-46010 Solid Film Lubricants—These lubricants may be used with aluminum, aluminum alloys, copper and copper alloys, steel and stainless steel, titanium, and chromium and nickel bearing surfaces. These lubricants shall not be used on materials which will be adversely affected by the curing temperatures of 150 to 204 °C (302 to 400 °F) for 1 h. This lubricant shall not be used where there is potential contact with liquid oxygen.

6.1.2.2.2 SAE AS1701 Dry Film Lubricants—These lubricants are of six types and one or more types are compatible with aluminum, alloy steels, corrosion-resistant steels, heat-resistant steels, nickel base alloys, and titanium alloys. Both molybdenum disulfide and graphite lubricants are covered. Refer to AS1701 for binder used in each type and usage recommendations. These lubricants shall not be used on fastener materials which will be adversely affected by the curing temperature which ranges from 200 to 400 °C (400 to 750 °F) depending upon type.

6.1.2.2.3 SAE AMS 3090 Dry Film Lubricant—This dry film lubricant must be heat cured and is in the form of a sprayable liquid containing lubricating solids dispersed in a resin binder and suitable solvents. This dry film lubricant is typically used for fasteners in aircraft fuel tanks but it may be used in other applications requiring compatibility with fuels, hydraulic fluids, lube oils and polysulfide sealants. (See AMS 3090 for a list of fluids used to test compatibility.)

6.1.2.2.4 MIL-L-23398 Solid Film Lubricants—Air cured lubricants in accordance with MIL-L-23398 or equivalent may be used for applications where the use of other dry film lubricants is impractical due to their curing temperature. These lubricants are especially for use with steel, titanium and aluminum bearing surfaces. A film thickness between 0.005 and 0.013 mm (0.0002 and 0.0005 in) is recommended.

6.1.2.3 Liquid and Powder Lubricants—These lubricants are generally applied at the time of fastener installation. Table 4 contains a list of lubricants considered suitable for use on marine vehicles subject to the application guidance and restrictions listed therein and in the specifications. Table 4 lists many of these type lubricants.

6.1.2.4 System Fluids as Lubricants—For hydraulic and lube oil system fasteners where precise torque control is not required, system fluid may be used as a thread lubricant.

6.1.3 LUBRICANT SELECTION—When not specified by installation drawing or other governing documents, lubricants shall be selected from those lubricants identified herein. Selection shall be based on the fastener material, the application requirements, restrictions in this Section, and Table 4.

6.1.4 LUBRICANT APPLICATION—In addition to the threaded surfaces, apply lubricant to the bearing face of nuts and under the heads of screws which will be turned during installation.

NOTE—Some lubricants, such as some molybdenum disulfide product, require multiple coats. Proper instructions may be found on installation documents or the lubricant container.

6.2 Determining Preload—When fastener preload control is a design consideration, the proper preload should be specified on the assembly instruction or drawing either explicitly, or more commonly, as a torque value. Proper fastener preload extends the fatigue life of the fastener and reduces the possibility of its loosening. The installing activity shall have written guidance to cover the installation of fasteners where preload is not identified on drawings or installation instructions. The requirements and guidance in this document may be tailored to suit the particular applications of the installing activity. Fastener lubricants and sealants, self-locking features, gasket applications, thread formation, and the properties of the mating materials shall be considered when determining preload values.

6.2.1 METHODS FOR OBTAINING PRELOAD—When the method or sequence of applying preload is significant, the procedure is identified on the assembly instruction or drawing. Many methods for applying preload exist including feel, torque wrench, turn of the nut, preload indicating washers, sensor wrenches, bolt elongation, and strain gages. These methods are explained in detail in MIL-HDBK-60 along with estimates of the accuracy and cost.

6.2.1.1 Torque Control—Unless otherwise warranted by the application, torque control shall be the preferred method of preloading fasteners. Although torque control is not the most accurate method available, it is usually the most expedient, cost effective, and least imposing on the design.

6.2.1.2 The "feel" method is not recommended because it does not tend to be very accurate.

6.2.2 TORQUE TABLES—Tables listing generic torque values corresponding with common fastener preload requirements may be used. These generic values may be used when preload or torque values are not identified in technical documentation.

6.2.2.1 Torque tables identify torque with respect to fastener size, thread pitch and material. Torque values are established by determining the required torque needed to generate a specific percentage of yield stress of the particular material.

6.2.2.2 Fastener torque tables do not always consider lubrication, self-locking feature, and other factors. The installer should be aware of the limitations of the tables.

6.2.3 COMPUTER PROGRAMS—In addition to fastener torque tables, there are computer programs available which may be used to determine the proper fastener torque for a given application.

6.3 Standard Installation Requirements—Fasteners shall be installed using applicable preload (or torque) values and lubricants.

6.3.1 NUT-TORQUING—The nut shall be torqued on nut-bolt assemblies. However, in applications where this is not practical, the bolt may be turned as is the case with cap screw applications. In such instances, lubricate under the head of the screw or bolt.

TABLE 4—GUIDE FOR SELECTION OF THREAD LUBRICANTS

Lubricant	Applications/Service	Limitations/Prohibitions
MIL-A-907[1] or commercial grade equivalent **Copper Based or Nickel Based Anti-seize compound**	High temperature (up to 560 °C), Steel nuts and bolts of super-heated steam systems. Areas where fastener will be immersed in water or subject to regular wetting or splashing.	Not to be used with stainless steels above 120 °C. Not to be used in air systems.
MIL-A-907[1] or commercial grade equivalent **Copper Based Anti-seize Compound** High temperature	Preferred thread lubricant to reduce friction and galling where pre-load is established by torque Class 5 Fits (Driven End Only) Nickel-copper and Nickel-Copper-Aluminum	
SAE AMS 2526, MIL-A-907[1] or equivalent **Molybdenum disulfide based compound**	Nickel-copper and Nickel-Copper-Aluminum Titanium alloys	Not to be used in air systems or fasteners with class 5 fits. See footnote 2.
MIL-S-8660 **Silicon compound mixed with** MIL-M-7866 **molybdenum disulfide powder**	Lubrication of threads on recompression chambers and systems using air oxygen and other gases	See footnote 2.
DOD-L-24574 Lubricating fluid for low and high pressure oxidizing gas mixtures		Type I –45 to 0 °C Type II –20 to 40 °C Type III 20 to 70 °C
MIL-G-27617 Grease, Aircraft, and Instrument, Fuel and Oxidizer Resistant		Type I –54 to 150 °C Type II –40 to 200 °C Type III –35 to 200 °C Type IV –38 to 200 °C
MIL-L-24478 Lubricant, Molybdenum Disulfide in Isopropanol	Thread lubricant to reduce friction and galling in applications having limited clearances and where control of impurities is required.	Not to be used on stainless steels or chrome-nickel alloy 17-4 or at temperatures above 345 °C. See footnote 2.
MIL-L-24131 Lubricant, Colloidal Graphite In Isopropanol	Thread lubricant to reduce friction and galling where lead or sulfur contamination cannot be tolerated.	Not a preferred lubricant where pre-load is established by torque. See footnote 3 for restrictions.

[1] There may be no qualified sources for MIL-A-907E, which is being revised. However, thread lubricants of the type indicated which are manufactured to other revisions of MIL-A-907 or equivalent standards may be used.

[2] Except on titanium, thread lubricants containing molybdenum disulfide shall not be used in areas where the fastener will be immersed in or regularly wetted or splashed with water. Bacteria in the water can cause the molybdenum disulfide to breakdown to form compounds (especially sulfur) which attack the fastener, except titanium which is immune to Microbiologically Influenced Corrosion (MIC) or sulfur attack.

[3] MIL-L-24131 should not be used on (1) Nickel-Chrome-Iron alloys above 650 °C, (2) stainless steels, low-alloy, and carbon steels above 535 °C, and (3) Nickel-copper, nickel-copper-aluminum and chrome nickel (17-4 PH) alloys above 350 °C.

6.3.2 THREAD PROTRUSION—When installing and tightening fasteners, the protrusion of the male threads shall have as a minimum a protrusion equivalent to one thread pitch above the top of the nut or plastic locking element, as applicable.

NOTE—The first thread on both male and female fasteners is likely to be an incomplete thread and thus the full strength of the joint may not be developed if the male fastener is installed flush with the top of the nut.

Strength of the joint should not be compromised by accepting a self-locking nut without a full thread protrusion beyond the locking element. In any application where the thread protrusion exceeds 10 threads, verification shall be made that the proper length fastener was installed. Washers shall not be added to reduce protrusion except as specifically required by design drawings or technical manuals.

6.3.3 THREADS FOR CLAMPING—It is important that sufficient exposed threads exist between the bearing surfaces in clamping installations involving studs, screws, and bolts such that the bolt will not be restricted from obtaining the required preload during assembly. Determination of sufficient threads needs to be verified before installing the nut since verification is often impossible after assembly. If less than four threads are available for obtaining the required preload, documentation shall be provided that will permit verification after installation that the nut has not bottomed on the end of the threads.

NOTE—With less than four threads exposed between the nut and the thread runout, it is possible that the failure mode may change from tensile fracture to thread shear. With less than four threads exposed, the tensile strength of the fastener may increase while necking of the threads occurs in the threaded length engaged by the nut increasing the thread shear stress.

6.4 Tightening Procedures—When multiple fasteners are used for joining a piece of equipment or structural components, warping or cracks may develop if the fasteners are not tightened in the proper sequence. Severe damage to the equipment, structure or joint, or a compromise of ship or crew safety can result from improper tightening techniques. Premature fastener loosening or reduced fastener fatigue life can be experienced if the proper procedures are not followed. Fastener tightening sequence and fastener torque requirements identified herein are for general applications. Specific design applications may require additional amplification and modification to these procedures.

6.4.1 MULTIPLE PASSES—Fasteners should be tightened in increments by making multiple passes around the bolt pattern. At least three passes should be made, followed by a pass to check the torque of each fastener. The check pass should be performed in a sequence that is the reverse of the sequence used to tighten the fasteners. (For example, if a torque of 120 N·m is required, the torque for the first pass is 40 N·m; followed by torques of 80 and 120 N·m for the second and third passes, respectively. After the last fastener had been torqued to 120 N·m, a check pass in the reverse sequence would be conducted at 120 N·m.)

6.4.2 TIGHTENING SEQUENCE—Unless otherwise specified, the following tightening sequences shall be used, as applicable:

a. Single Row—When fasteners are arranged in a single row, tightening shall begin at the center and proceed toward the ends, alternating from either side of the center.
b. Double Row (or Greater)—When tightening fasteners that are arranged in a double row (or greater) and in linear fashion, the single row tightening procedure shall apply, except that the center two (or more) fasteners shall be tightened first.

c. Single Circular Pattern—When fasteners are arranged in a single circular pattern, tighten in stages, following a pattern of tightening a pair of opposite bolts, then a pair of opposite bolts 90 degrees away, followed by pairs of opposite bolts in between. To illustrate, a twelve bolt (clock face) pattern would be tightened in the order of 12, 6, 3, 9, 1, 7, 4, 10, 2, 8, 5, 11. Similarly, an eight-bolt pattern (numbered clockwise with 1 at the top) would be tightened in the order of 1, 5, 3, 7, 2, 6, 4, 8 and a six-bolt pattern in the order of 1, 4, 6, 3, 5, 2.

d. Concentric Circular Pattern—When fasteners are arranged in concentric circular patterns, fastener tightening shall follow the same procedure as for a single circular pattern, except that the inner circular pattern is tightened first, followed by the next outward circular pattern. The first fastener tightened in the next outward circular arrangement should be the one most directly opposite to the first fastener tightened in the previous inner circle.

6.5 Providing Additional Corrosion Protection for Steel Fasteners—These requirements apply to the installation of uncoated steel fasteners, black oxide-coated steel fasteners, and other steel fasteners in applications requiring additional corrosion protection. The requirements in this section do not authorize the use of noncorrosion-resistant steel fasteners in any application. These installation requirements apply when use of noncorrosion-resistant fasteners is authorized for wetted spaces and no additional guidance is provided by other installation documents.

6.5.1 FASTENER SURFACE CONDITION PREPARATION—This step applies to uncoated steel fasteners, black oxide-coated steel fasteners, and other steel fasteners to which a supplementary preservative treatment or lubricating oil has been applied. If such a treatment has been applied, it must be removed in order to obtain proper adhesion of the coating to be applied.

6.5.2 TREATMENT DURING INSTALLATION—Immediately prior to installation dip fastener in polysulfide sealant or paint with polysulfide sealant. Install fastener before the polysulfide sealant cures. After installation make sure that all exposed parts of the fastener are protected with polysulfide sealant. Satisfactory polysulfide sealants include MIL-S-8802, Type II, Class A and non-chromate equivalents of MIL-S-81733.

6.5.3 TREATMENT AFTER INSTALLATION—After the polysulfide sealant has dried, coat the fastener with a coat of epoxy polyamide primer. Subsequently, it is permissible to coat with the same paint as used on adjacent equipment.

6.6 Use of Anaerobic Thread Locking Compounds

6.6.1 GENERAL—Anaerobic thread locking compounds usually have a methylacrylate-ester base. These compounds cure (polymerize or harden) in the absence of air. The hardened compound bonds to the threads as an adhesive and provides a resistance to rotation of the fastener parts.

6.6.2 MATERIAL COMPATIBILITY—Thread locking compounds may be used with metals, glass, ceramics, and many thermoset plastics such as phenolic, polyester and nylon. They will soften and sometimes craze (etching, shallow cracking) thermoplastics such as ABS, polycarbonate, vinyl, and methylacrylate.

6.6.3 SURFACE PREPARATION—All parts must be chemically cleaned and have active surfaces to achieve reasonable cure times and proper strength. Primers are available from the locking compound manufacturers that activate the thread surface and also contain a solvent such as trichloromethane. These primers will provide a clean and active surface when used as directed by the manufacturer. Preliminary cleaning using an approved solvent, followed by wiping, is recommended for any parts having oily surfaces or surfaces that have been cleaned with diesel fuel or other solvents that leave a thin film after drying.

6.6.4 PRIMERS (ACTIVATORS) AND CURE TIME—The anaerobic compounds begin to cure on active surfaces as soon as they are deprived of contact with air. Fixture time, the point at which the compound is no longer a liquid, varies from 15 s to 30 min depending upon the grade of primer used and the ambient temperature. Primers are available that provide curing times of 4 to 6 h vice up to 24 h without primers. Heat can be used to activate and accelerate the curing process. Curing time is approximately halved for each 10 °C increase in temperature.

6.6.5 COMPOUND SELECTION—The compound selection depends upon the fastener which is to be used and the desired end result. Factors involved in the selection process include: fastener material, fastener size, service temperature, required breakaway, and prevailing torque (locking torque strength) and size of gap (class of thread fit) to be filled. MIL-S-22473 and MIL-S-46163 cover suitable compounds and additional compounds are available commercially. The following grades (or equivalent MIL-S 22473 grades) will satisfy most shipboard thread locking needs:

a. MIL-S-46163 Type II, Grade M—150 °C (300 °F) service temperature, low strength, permits some fastener adjustment after curing, removable with hand tools, suitable for 6 mm (1/4 in) diameter and smaller fasteners.
b. MIL-S-46163 Type II, Grade N—150 °C (300 °F) service temperature, medium strength, general purpose, suitable for fasteners larger than 6 mm (1/4 in) diameter. This is the most commonly used grade.
c. MIL-S-46163 Type I, Grade K—150 °C (300 °F) service temperature, high strength for fasteners up to 25 mm (1 in) diameter, permanent locking, requires heat (260 °C) and hand tools to remove.
d. MIL-S-46163 Type I, Grade L—150 °C (300 °F) service temperature, high strength for fasteners over 25 mm (1 in) diameter, permanent locking, requires heat (260 °C) and hand tools to remove.
e. Commercially Available—230 °C (450 °F) service temperature, high strength, permanent locking, requires heat (260 °C) and hand tools to remove.

6.6.6 STUD INSTALLATION VERIFICATION—The following procedure is provided for use to verify that the anaerobic compound has properly set up. The torque method of the procedure may be used with higher torques to verify higher locking torque strengths when required.

a. In each joint containing more than three installed fasteners, select two fasteners that are 180 degrees apart, or as close thereto as possible. Examine one fastener in applications having three fasteners or less.

b. Use a marking pencil or other device to temporarily mark the position of the fasteners to be tested on their exposed ends. For fasteners in a flange or bolting circle, a line can be drawn on the stud which points to the center of the flange or bolting circle. The marking shall be used to determine if the fasteners move during the test.

c. Apply torque from one of the following two methods. (Either method may be used unless a particular method is specified.) Do not restrain fasteners from turning during the test by any methods other than the locking compound in the set end of the stud.

   (1) Self-Locking Nut Method—Test studs by installing and removing an unused self-locking nut with plastic locking elements at least 3 threads beyond the self-locking insert. Verify nut has not been used by examination of the inside diameter of the locking element for thread marks. It is recommended that the self-locking nut used be to one of the part standards listed in the supplement to MIL-N-25027 or a commercial nut meeting the requirements of IFI-100/107. When a self-locking nut with plastic insert is used for final assembly, it is recommended that the self-locking nut used for proofing be the same as the one for final installation. The self-locking nut for proofing shall be installed with the same lubricant as specified for final assembly.