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FEDERAL AVIATION ADMINISTRATION
AIRCRAFT CERTIFICATION SERVICE

TECHNICAL REPORT

AVIATION FASTENER AUDIT
FINAL REPORT
JUNE 13, 2001

FEDERAL AVIATION ADMINISTRATION
AIRCRAFT CERTIFICATION SERVICE
800 Independence Avenue S.W.
Washington, D.C. 20591

This technical report presents the results of an audit conducted by the Federal Aviation Administration (FAA), Aircraft Certification Service. The purpose of the audit was to investigate the cause of variation in measurement (including the effect of different types of measuring equipment), ascertain the airworthiness of fasteners used in the production of civil aircraft, and assess the threaded fastener industry's compliance with FAA approved design data and applicable industry specifications.

> NOTE: This audit was not designed to replicate the requirements of the FAA Aircraft Certification System Evaluation Program (ACSEP). This audit did not evaluate or assess compliance to the facility's quality manual. Although deficiencies identified in this audit may be similar to those identified through ACSEP, they may not be substantiated as regulatory noncompliances.

This audit was conducted with the cooperation of aircraft/aircraft engine/propeller manufacturers, fastener manufacturers, gage manufacturers, Department of Defense laboratories, and industry associations.

APPROVED FOR RELEASE:

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EXECUTIVE SUMMARY

The Federal Aviation Administration (FAA), Aircraft Certification Service conducted a fastener audit from September 9, 2000 through March 2, 2001. The purpose of the audit was to investigate the cause of variation in measurement (including the effect of different types of measuring equipment), ascertain the airworthiness of fasteners used in the production of civil aircraft, and assess the threaded fastener industry's compliance with FAA approved design data and applicable industry specifications.

NOTE: This audit was not designed to replicate the requirements of the FAA Aircraft Certification System Evaluation Program (ACSEP). This audit did not evaluate or assess compliance to the facility's quality manual. Although deficiencies identified in this audit may be similar to those identified through ACSEP, they may not be substantiated as regulatory noncompliances.

The audit was conducted in two phases. In Phase I (Inspections and Tests), the FAA collected threaded fasteners (total of 2,264 test samples) from nine different FAA Production Approval Holders (PAH) and had them inspected by the PAH and three accredited independent laboratories. Phase II (In-Process Audits) involved in-process audits at nine fastener manufacturers who were either PAHs or suppliers to PAH to assess the threaded fastener industry's state of compliance with FAA approved design data and applicable industry specifications. The following are the Phase I conclusions and recommendations:

Within the scope of this audit:

- The PAH found:
  - Of the 547 bolts inspected, 31 (5.7%) were dimensionally nonconforming.
  - Of the 88 non-crimped nuts inspected, 1 (1.1%) was dimensionally nonconforming.
- The independent laboratories found:

  NOTE: Test bolts identified as nonconforming during initial inspections were subjected to a disposition process to confirm the nonconformance, ensure repeatability of measurement, assess variation-in-measurement using alternate gages, and implement referee inspection criteria. This disposition process is a common practice in industry to truly identify nonconforming parts.

- Of the 910 bolts inspected, 308 (33.8%) were initially identified as nonconforming. These parts were then subjected to the disposition process.

- Of the 308 bolts subjected to the disposition process, 103 (11.3%) were confirmed as dimensionally nonconforming.

- Of 132 non-crimped nuts inspected, four (3.0%) were dimensionally nonconforming.

• The difference between the PAHs and independent laboratories in bolt non-conformance rate was principally due to the different types of gages used to measure maximum material (functional diameter). The FAA noted a significant amount of variation-in-measurement between the three types of gages used. This report contains several conclusions and recommendations regarding gages and inspection methods.

• The difference between the PAH and independent laboratories in non-crimped nut non-conformance rate was attributed to the fact that the PAH did not inspect the dimensional characteristic on which the independent laboratories identified non-conformances.

• To the extent that variation-in-measurement of maximum material does exist, the FAA questions the use of a zero clearance allowance design specification.

• The PAH and independent laboratories found that all 484 crimped nuts passed functional assembly inspection.

• All 288 test pieces (13% of total audit population) met their mechanical performance and/or material property requirements.

• To the extent dimensional nonconformity existed in the test samples it did not preclude the samples from meeting mechanical performance requirements.

• MIL-S-8879 is used extensively by the commercial aviation industry, its inactivation without supersession by the DOD has had a negative affect on the industry.

• The inspection and acceptance criteria established within MIL-S-8879C does not meet FAA regulatory requirements that product conform to approved design data.

It is recommended that:

- Industry develop a consensus commercial specification that the DOD would designate as a superseding document to MIL-S-8879C.

- Industry resolve the disparity between “acceptable” and “conforming” product, and develop design and inspection specifications that are consistent with FAA regulatory requirements.

The following are the Phase II conclusions and recommendations:

Within the scope of this audit:

- All facilities (100%) exhibited deficiencies relating to the manufacturers’ calibration program. Industry appears to be lacking standardized criteria regarding the inspection, maintenance, and calibration of indicating thread gages, working thread ring gages, and thread setting plug gages.

- All facilities (100%) exhibited deficiencies relating to the manufacturers’ control of suppliers. Initial and periodic evaluations of suppliers were not made, as necessary, or corrective actions were not taken to correct system deficiencies.

- All facilities (100%) exhibited deficiencies relating to the manufacturers’ final inspection process. The manufacturers’ processes of final inspection/acceptance contain systemic weaknesses. Deficiencies identified were related to insufficient inspection methods and plans to ensure that parts were inspected for conformity with FAA-approved design data.

- Eight of the nine facilities (89%) exhibited deficiencies relating to the manufacturers’ availability and use of measuring and test equipment.

- Seven of the nine facilities (78%) exhibited deficiencies relating to the manufacturers’ statistical sampling inspection plans. The deficiencies identified were related to acceptance/rejection criteria and/or the absence of an adequate system classifying inspection characteristics.

- Six of the nine facilities exhibited (67%) deficiencies relating inadequate in-process controls. Special processes were not accomplished in accordance with the established process specifications. Work instructions did not adequately control the manufacturing process. Facilities manufacturing internally threaded hardware were not performing an in-process final inspection/acceptance of thread geometry prior to deformation/crimping.

It is recommended that:

- Industry develop standardized criteria regarding the inspection, maintenance, and calibration of indicating thread gages, working ring gages, and thread-setting plug gages.

- Industry resolve supplier control deficiencies relating to supplier audits, corrective action, and accurate flow-down of technical/quality requirements.

- Manufacturers conduct a comprehensive review of their final inspection/acceptance process, thus ensuring that all products conform to the FAA-approved design data.

- FAA continue on-going initiatives placing special emphasis during certificate management functions (surveillance) at PAH facilities. Special emphasis areas address all aspects of manufacturing compliance, use of measuring and test equipment, statistical sampling, supplier surveillance, and supplier control.

- FAA continue to support industry's commitment to improvement. FAA initiatives include working collaboratively with industry associations, aircraft, aircraft engine, propeller, and fastener manufacturers to correct quality and manufacturing deficiencies resulting from this audit.

INTRODUCTION

BACKGROUND

1. The Department of Transportation Office of Inspector General (DOT-OIG) in 1998 initiated an audit of the FAA's oversight of the production of fasteners used in commercial aviation. The DOT-OIG audit selected fasteners and other hardware with threaded features from three aircraft operators and four repair stations. The fasteners were inspected dimensionally at Hill Air Force Base (AFB) Quality Verification Center (QVC). The DOT-OIG (reference 1) reported that out of 176 fasteners inspected, 48 (27%) had at least one dimension that did not meet the FAA-approved design data. The FAA sent the nonconforming hardware to the responsible FAA Manufacturing Inspection District Office (MIDO) for re-inspection by the manufacturer. The manufacturers could confirm only six pieces out of the original 48 were nonconforming. The manufacturers evaluated the six nonconforming pieces under their material review board procedures and found them acceptable for use. The DOT-OIG report criticized the FAA for not further investigating why the manufacturers' inspections did not agree with their audit results. The FAA countered that the complete regimen of inspections (including verification of initial nonconforming measurements) was not performed in the DOT-OIG audit, which accounted for the disparity in results. In its report the DOT-OIG recommended that the FAA investigate the cause of variation in measurement, including the effect of different types of measuring equipment.

2. The FAA began its audit of fastener quality in September 2000. The purpose was to investigate the cause of variation in measurement (including the effect of different types of measuring equipment), ascertain the airworthiness of fasteners used in the production of civil aircraft, and assess the threaded fastener industry's compliance with FAA approved design data and applicable industry specifications. Though similar in approach, the FAA audit was substantively different from that of the DOT-OIG. The following are highlights of those differences. The FAA audit:

- Selected fasteners from only the finished stores of manufacturers holding FAA Production Approval Holders (PAH) (OIG audit: airlines and repair stations).
- Inspected 2,264 individual fasteners (OIG audit: 176 fasteners).
- Inspected additional major dimensional characteristics (OIG audit: threads only).
- Conducted production lot acceptance tests for mechanical performance and/or materials properties on 98% of all part numbers.
- Inspected dimensional characteristics to the full extent required by the specifications, including "referee methods." In order to assess variation in measurement the FAA obtained alternate approved inspection equipment.

- Performed parts inspections at three accredited laboratories (OIG used one).
- Had product inspected by eight FAA PAHs.
- Performed on-site process audits at nine facilities (OIG audit did not perform facility process audits).

3. The FAA audit was conducted according to "The FAA Fastener Evaluation Plan" of October 23, 2000. The FAA reviewed the plan with the DOT-OIG Atlanta Office (who performed their original audit) and the DOT-OIG Washington Headquarters management. The DOT-OIG was told of, and invited to participate in, any and all FAA evaluation activities. They attended several inspection events. The FAA shared interim results with the DOT-OIG on a periodic basis.

4. The issue of screw thread inspection has been debated extensively for more than 20 years. Many industry and Government reports have been published. There are 30 separate geometrical features and dimensional characteristics in the design and construction of screw threads. The most rigorous standard for threaded components in the United States inspects 11 major thread characteristics (reference 2). A comprehensive study, initiated by the National Institute of Standards and Technology and administered by the American Society of Mechanical Engineers (ASME), produced the report, *Screw Thread Gaging Systems for Determining Conformance to Thread Standards (reference 3)*. The following paragraphs are excerpted from this report to provide some perspective on the state of thread manufacturing and inspection.

> "Screw thread technology is complex. This complexity arises in part from the basic design of a screw thread, which involves helical geometry. In the manufacturing of threaded product, the influence of service wear on dimensional accuracy of tools adds to the complexity." (page 2)
>
> "A vast network of standardization documents is the foundation of screw thread technology. A complete set of interrelated standards for the design, manufacture, and inspection of screw-thread products includes at least the following four types of standards: 1) a screw thread standard, 2) a nomenclature standard, 3) an inspection standard, and 4) a gage standard." (page 6)

5. For a FAA PAH, this vast network of documents begins with the FAA-approved design data, specific to an individual part number. Design data usually refers to proprietary procurement specifications that have specific design, manufacturing, qualification, and lot acceptance procedures. These proprietary specifications may refer to established industry or U.S. Government specifications. When there are conflicts in the requirements, the higher-level document takes precedence.

6. The following documentation list presents a typical example of the hierarchical order of documents involved just in the design, manufacture, inspection, and acceptance of threads. There would be similar lists for other characteristics of fasteners such as

materials and performance . Each major document refers to the document(s) listed beneath it.

- BACB30US, Bolt Design Data
  - BPS-F-69, Part Technical Specification
    - MIL-S-8879, Thread Specification
      - FED-STD-H28/1, Nomenclature, Definitions, and Letter Symbols for Screw Threads
      - FED-STD-H28/2, Unified Inch Screw Threads
      - FED-STD-H28/4, Controlled Radius Root Screw Threads
      - FED-STD-H28/6, Gages and Gaging for Unified Screw Threads
      - FED-STD-H28/20, Inspection Methods for Acceptability
      - ANSI Y14.5M, Dimensioning and Tolerancing
      - ANSI/ASME B1.1, Unified Inch Screw Threads
      - ANSI/ASME B1.2, Gages and Gaging for Unified Screw Threads
      - ANSI/ASME B1.3M, Screw Thread Gaging Systems for Dimensional Acceptability
      - ANSI/ASME B1.7, Nomenclature, Definitions, and Letter Symbols for Screw Threads
      - ANSI/ASME B46.1, Surface Texture

7. The FAA and OIG audits showed that the commercial aviation industry makes extensive use of military specification MIL-S-8879 (most recent revision "C") (reference 4). With the Department of Defense (DOD) initiative to replace military specifications with non-Government specifications, the industry convened a task force to develop a commercial specification. That effort, however, failed to reach consensus and the DOD on May 14, 1997, inactivated MIL-S-8879C without supersession. The FAA has learned that the DOD had identified technical deficiencies in MIL-S-8879C but did not make the corrections before inactivation. Furthermore, the DOD was not aware of the extent of non-Governmental use of MIL-S-8879. The inactivation of MIL-S-8879C without supersession has had a profound effect on FAA design and production approval holders. The Society of Automotive Engineers (SAE) Aerospace Standard (AS) AS8879 (REV A) states that the document "was generated to provide a non-government

specification to replace government specification MIL-S-8879 for the UNJ profile, inch screw threads." This statement is considered misleading since the DOD did not designate AS8879 as superceding MIL-S-8879C. It is recommended that SAE consider removing any statements from AS8879 that would mislead the industry to believe that AS8879 supercedes MIL-S-8879C.

8. FAA Advisory Circular 21-41, *Continued Use of MIL-S-8879C, General Specification For Screw Threads, Controlled Radius Root With Increased Minor Diameter* (reference5), establishes that FAA approval holders should continue to use MIL-S-8879 when referenced on their approved drawings until they apply for and receive FAA design change approval, or the DOD designates a superseding document. Within the scope of this audit, MIL-S-8879 is used extensively by the commercial aviation industry, its inactivation without supersession by the DOD has had a negative affect on the industry. It is recommended that industry develop a consensus commercial specification that the DOD would designate as a superseding document to MIL-S-8879C.

PURPOSE

GENERAL

9. The purpose of the FAA audit was to investigate the cause of variation in measurement (including the effect of different types of measuring equipment), ascertain the airworthiness of fasteners used in the production of civil aircraft, and assess the threaded fastener industry's compliance with FAA approved design data and applicable industry specifications. The FAA team used a two-phase approach to collect data and other environmental information for this audit and to develop the conclusions and recommendations in this report.

INTERNATIONAL CONSIDERATIONS

10. The FAA Aircraft Certification System Evaluation Program (ACSEP) has generated over 5 years of trend data relating to PAH and supplier performance. The ACSEP data clearly demonstrates that suppliers, perform virtually the same, whether or not the facility is in the United States. The FAA does not issue production approvals outside the United States. However, PAHs do purchase parts from suppliers located in other countries. The FAA began this audit assuming, based on the ACSEP data, that any irregularities discovered in the United States would likely exist at PAH supplier facilities in other countries.

11. The FAA did not perform any audit activities at facilities outside the U.S. Rather, the FAA focused resources domestically where all PAHs and the greatest concentration of suppliers are. The FAA considers PAH domestic irregularities to be international with respect to their suppliers in other countries. Therefore, any and all actions resulting from this FAA audit will extend to supplier facilities in other countries.

INSPECTIONS AND TEST (PHASE I)

12. Phase I assessed the airworthiness (both dimensional conformance and functional performance) of fasteners used in the production of commercial aircraft. Phase I also simultaneously collected data to evaluate the extent of variation-in-measurement.

IN-PROCESS AUDITS (PHASE II)

13. The in-process audits were to give the FAA an assessment of the threaded fastener industry's compliance with FAA approved design data and applicable industry specifications. The information from these audits will be used to identify areas needing special emphasis during routine FAA surveillance.

> NOTE: This audit was not designed to replicate the requirements of the FAA Aircraft Certification System Evaluation Program (ACSEP). This audit did not evaluate or assess compliance to the facility's quality manual. Although deficiencies identified in this audit may be similar to those identified through ACSEP, they may not be substantiated as regulatory noncompliances.

<u>SCOPE OF TEST</u>

DIMENSIONAL INSPECTIONS

<u>General</u>

14. Dimensional inspections were focused on (though not limited to) thread geometry. Dimensional inspections were conducted according to FAA-approved design data and applicable specification. For most fasteners in this audit that specification was MIL-S-8879 (most recent revision "C"). MIL-S-8879C established two application categories, *Safety Critical Thread* or *Other Thread*. These application categories define dimensional inspection requirements. None of the 114 part numbers inspected or tested in this audit was classified per MIL-S-8879C. Therefore, per the specification, by default the *Other Thread* inspection requirements applied. However, MIL-S-8879C also established that the absence of any inspection requirement in the specification does not relieve the producer from ensuring that all products conform to the specification. This provision of MIL-S-8879C is consistent with FAA requirements. The FAA inspections (at the laboratories) exceeded those required by MIL-S-8879C *Other Thread* application category. See Table I for a comparison of MIL-S-8879C and the FAA inspection requirements.

15. The "*Other Thread*" inspection loosely correlates with the System 22[1] inspection defined in FED-STD H-28/20. ANSI/ASME B1.3M describes System 22 as follows:

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[1] System 22 inspects five dimensional characteristics of a screw thread: Functional Diameter, Pitch Diameter, Major Diameter, Minor Diameter, and Thread Root Radius.

> "System 22 provides for interchangeable assembly with functional size control at the maximum-material limits, within the length of standard gaging elements, and also control of the minimum-material size limits over the length of the full thread. The cumulative form variation of thread characteristics such as lead, flank angle, taper, and roundness is confined within the maximum- and minimum-material limits."

16. Dimensional inspections of fasteners were made at both the PAHs and independent laboratories. Not all characteristics were inspected at all locations. Appendix D, Figure 1, shows the basic dimensional characteristics of a screw thread assembly. The following dimensional characteristics were inspected on the fasteners as applicable: functional diameter[2], pitch diameter, major diameter, minor diameter, root radius, lead and flank angle. Additional characteristics were inspected as practicable. For bolts this included head-to-shank fillet radius, overall length, shank diameter, and thread-to-shank runout; for nuts this included overall height, thread-axis/bearing-face perpendicularity, crimp location, and a functional assembly check on crimped nuts. A disposition process was used by the FAA to confirm non-conformities, assess variation-in-measurement, and implement referee inspection methods.

Table I
COMPARISON OF INSPECTIONS

Thread Characteristic	MIL-S-8879C		FAA Inspections
	Other Thread	Safety Critical Thread	
GO Functional Diameter	X	X2	X2
Pitch Diameter Size	X	X	X
Major Diameter Size 1	X	X	X
Minor Diameter Size	X	X	X
Root Radius (UNJ only) 1	X	X	X
Flank Angle	-	X3	X3
Lead (including helix variation)	-	X3	X3
Circularity (roundness)	-	X	-
Taper	-	X	-
Runout (concentricity)	-	X	-
Surface Roughness	-	X	-

Notes: 1. Not inspected on internal threads.

2. GO functional diameter size is required to assess lead and flank angle in accordance with Note 3.

3. Only measured if the difference between GO functional size and pitch diameter size is more than 40% of the pitch diameter tolerance.

[2] Functional Diameter tolerances are the same as for pitch diameter. An inspection for functional diameter unites pitch diameter size with the cumulative effects of variation in specified profile. Functional Diameter is always larger than pitch diameter for external threads, except when the thread has perfect form.

Variation in Measurement

17. The DOT-OIG report recommended that "the FAA evaluate the cause of variation in measurement including different equipment." To respond, the FAA obtained different types of gages (hereafter referred to as "FAA Gages") to supplement those available at the independent laboratories. Additionally, the FAA collected data to assess variation in measurement across all the PAHs and laboratories. The FAA obtained full "W" tolerance thread setting plug gages at both minimum and maximum material for sizes #10-32 through ¾-16. These set plugs were inspected for pitch and functional diameter at the PAHs and independent laboratories coincident with the test sample inspections.

Production Approval Holders' (PAH) Inspections

18. For each part number selected, eight samples were made available for inspection by the PAH. If the PAH was a fastener manufacturer, dimensional inspections were conducted per FAA-approved design data and referenced specifications. If the PAH was procuring fasteners from suppliers, dimensional inspections were conducted per the PAH's normal receiving inspection procedures[3]. Some PAHs were not performing receiving inspections, but had implemented compatible source inspection and acceptance procedures at their supplier facilities. There the PAH was allowed to use an accredited laboratory or approved supplier to perform their inspections. One PAH was unable to inspect their test samples due to resource constraints, scheduling conflicts, and a full FAA audit during the same time.

Independent Laboratory Inspections

19. The original FAA plan envisioned each laboratory inspecting equal quantities of the same part numbers. However, the quantities and part numbers had to be adjusted due to individual laboratory inspector staff availability and other workload priorities. The FAA, committed to completing the inspection of all parts as planned, made the following changes: The New Cumberland laboratory inspected both bolts (312 pieces) and nuts (144 pieces). The Columbus laboratory inspected bolts (312 pieces). The Hill AFB laboratory inspected both bolts (286 pieces) and nuts (288 pieces). At the Defense Logistics Agency (DLA) New Cumberland Laboratory samples were inspected using both the laboratory and FAA gages. The FAA gages were only used during the disposition process at the DLA Columbus Laboratory and Hill AFB QVC. The inspections were conducted to be consistent with the intent of System 22 described above, except that the magnitude of lead and flank angle was assessed in the disposition process.

[3] PAHs who procure fasteners from suppliers do not maintain all gaging, equipment, and technical staff that are used in the manufacturing and inspection process. The FAA used the results of their "normal" receiving inspection practices as an indicator of how well their receiving inspection system was actually functioning.

FUNCTIONALITY TESTING

General

20. Functionality testing consisted of mechanical performance tests and/or material properties testing. The test scope was limited to those that would be performed as part of a normal production lot acceptance procedure (not qualification tests). The scope was further limited by the availability of test equipment. Some PAHs were not equipped to perform all tests on all the fasteners selected. Even so, over 98% (112 out of 114 part numbers) underwent some form of functionality testing. Functionality testing was conducted primarily by the PAHs or their designated facility. Hill AFB QVC conducted additional testing.

Mechanical Performance Tests

21. Bolt mechanical performance tests included tensile strength, shear strength, and/or tension fatigue. Nut mechanical performance was assessed during axial tensile strength tests. Run-on and breakaway torque tests were performed on nuts incorporating a self-locking feature.

Material Properties Tests

22. Material properties tests were primarily conducted where no mechanical performance tests were specified for production lot acceptance. Tests included material composition, eddy-current inspection, and/or material hardness verification.

IN-PROCESS AUDITS (PHASE II)

23. The FAA evaluated the in-process production system at nine fastener manufacturers. Unlike the Phase I visits to manufacturers, the Phase II visits assessed the control of manufacturing and inspection processes. This information will be used to identify special emphasis areas for routine FAA surveillance of fastener manufacturers and/or their suppliers.

> NOTE: This audit was not designed to replicate the requirements of the FAA Aircraft Certification System Evaluation Program (ACSEP). This audit did not evaluate or assess compliance to the facility's quality manual. Although deficiencies identified in this audit may be similar to those identified through ACSEP, they may not be substantiated as regulatory noncompliances.

24. The FAA reviewed the manufacturing process for aviation fasteners, beginning with the receipt of raw material through final inspection/acceptance. The FAA evaluated the following:

- Receiving Inspection
- Control of Raw Materials
- In-Process Controls
- In-Process Inspection Requirements
- Implementation of Design/Quality Requirements
- Proper Use and Implementation of Specifications
- Availability/Use of Measuring and Test Equipment
- Calibration Program
- Statistical Sampling Inspection Plans
- Statistical Process Control
- Final Inspection/Acceptance
- Control and Disposition of Rejected Material
- Control of Suppliers
- Customer Base

TEST ARTICLES

TEST ARTICLE SELECTION

25. The FAA identified 114 different part numbers ranging in size between 0.190 and 0.750 inch. The audit included part numbers identified as nonconforming during the DOT-OIG audit. In some cases, the selection of a specific part number was limited by availability and on-hand quantities. Approximately one-third of the part numbers identified contained internally threaded features. Selection criteria were established to avoid industry standard fasteners (i.e., MS, AN, NAS, etc.) and special hardware (i.e., cone bolts), and to minimize exposure to low height nuts, castellated nuts, and dry film lubricated fasteners.

26. The FAA selected fasteners from FAA PAH's inventory. The fasteners selected had been accepted through the PAH's quality system. All fasteners selected were in the original (unopened) containers maintaining complete vendor/lot traceability.

27. For each part number identified, 20 samples were collected and separated into four groups (A through D). Group A (eight samples) was inspected by the PAHs for dimensional characteristics (including thread geometry), material properties, and mechanical performance. Groups B, C, and D (four samples each) were inspected by the independent laboratories for dimensional characteristics (including thread geometry). One laboratory also performed functionality tests (material properties and mechanical performance).

28. Additionally, at the time of fastener selection/inspection at the PAH facilities, the FAA collected three copies of the complete data set (all applicable drawings/specifications) for each part number. Each independent laboratory was sent a complete data set before inspection/testing.

DESCRIPTION OF TEST ARTICLES

General

29. The summary of the test articles by size and type is presented in Table II. Complete descriptions of the test bolts and nuts are in Appendix E, Table I and II, respectively. A total of 114 different part numbers were selected, 78 externally threaded (69%) and 36 internally threaded (31%). The bolts, with a few exceptions, were structural fasteners with tensile, shear, and/or fatigue performance requirements. The nuts were also principally structural fasteners. Several of the nuts were used in fluid systems. The following characteristics of the test articles are described in the sub-paragraphs below: thread specification, plating and/or coating on the threaded portion of the fastener, and self-locking features.

Table II
TEST ARTICLE SUMMARY

Thread Basic Size	Part Numbers	
	Bolts	Nuts
#10	7	0
1/4"	18	7
5/16"	14	10
3/8"	11	8
7/16"	8	3
1/2"	8	3
5/8"	3	1
9/16"	5	2
3/4"	4	2
1-1/16"	0	1
Sub-Total	78 (69%)	36 (31%)
TOTAL	114	

Thread Specification

External Threaded Product (Bolts)

30. This audit included only *unified inch screw threads*, specifically UN and UNJ thread forms. Designers of aviation products determine the *thread series* and *thread class* based upon the needs of the application. The thread series establishes the basic diameter of the thread and the number of threads per inch. Thread class establishes the dimensional tolerances and clearance allowance between mating hardware. All bolts selected within this audit were Class 3A. As shown in Appendix D, Figure 2, there is zero allowance (no design clearance) between Class 3 bolts and nuts at maximum material. The vast majority (83%) of the bolts were UNJ thread form. Their design data referenced MIL-S-8879. Of the remaining bolts, 8% referenced MIL-S-7742 (reference 6) and 9% were designated as specials. The special bolts were all standard *Unified Inch Screw-Threads (*UN Thread Form) in terms of diameter-pitch combination, but had reduced pitch, major, and minor diameters. It is significant that of the bolts that referenced MIL-S-8879, 77% had at least one customized[4] dimension, principally reduced major diameter. One manufacturer explained that the increased clearance provided more uniform prevailing locking torque on crimped nuts. The FAA did not observe any design data, designating application category (e.g. *Safety Critical Thread* or *Other Thread*) per MIL-S-8879C. Per the specification, absent such a designation the default application category is *Other Thread*. It is recommended that aircraft, aircraft engine, and propeller manufacturers conduct a comprehensive review of their procedures governing the classification (per MIL-S-8879C) of threaded product used within their applicable type designs.

[4] A customized dimension is a specific characteristic that was changed by the design approval holder during the design approval process.

Internal Threaded Product (Nuts)

31. The thread series establishes the size and form of the thread for any given fastener. Thread classes establish the dimensional tolerances and clearance allowance between mating hardware. Designers of aviation products make decisions about the selection of thread series and thread class based upon the needs of the application. All nuts selected within this audit were Class 3B. As shown in Appendix D, Figure 2, there is zero allowance (no design clearance) between Class 3 bolts and nuts at maximum material. All the nuts referenced MIL-S-8879 on their applicable design data and and/or specifications.

Plating and Coating

External Threaded Product (Bolts)

32. Plating and/or coating on the threaded portion of a bolt was documented. Forty-five percent (46%) of the bolts had no plating or coating. Fourteen percent (14%) were plated (cadmium, nickel-cadmium, or silver). The remaining 40% of the bolts had an aluminum pigment coating. Aluminum pigment coat provides a barrier to galvanic response between dissimilar materials and in some formulations serves as a lubricant during installation. The coating is sprayed on, then baked. The application process yields considerable variation in plating thickness and surface finish. A picture (at 23X) of aluminum pigment coating on a bolt shank is presented in Appendix D, Figure 3. See paragraph 119 for a discussion of variation-in-measurement due to aluminum pigment coating.

Internal Threaded Product (Nuts)

33. Plating and/or coating on the threaded portion of a nut was documented. Sixty-five percent (65%) of the nuts were plated, with the vast majority (82%) using silver. Fourteen percent (14%) of the nuts had dry film lube applied to the threads.

Self-Locking Feature

External Threaded Product (Bolts)

34. A self-locking feature on the threaded portion of the bolt was documented. None of the bolts in the test sample incorporated any sort of self-locking device.

Internal Threaded Product (Nuts)

35. Self-locking devices on the threaded portion of the nut were documented. Sixty-seven percent (67%) of the nuts incorporated a self-locking feature. In all cases they had some type of deflected thread, commonly referred to as *crimp*, which creates a prevailing torque effect. The thread deflection was accomplished through either a two-or three-point "crimping" process at either the top or middle of the nut barrel.

TEST EQUIPMENT USED AT LABORATORIES

FAA GAGES

36. To fulfill the DOT-OIG's recommendation that the FAA evaluate the variation in measurement due to different types of gages, the FAA obtained the following alternate measuring equipment (sizes 0.1900-32 through 0.7500-16):

- For external threads:
  - Thread groove diameter indicating gages (type 4.6)(Appendix D, Figure 4 and 13).
  - Full profile roll GO functional diameter indicating gages (type 4.3) (Appendix D, Figure 5).
    - To set the above gages, calibrated thread setting plug gages at both GO (maximum material) and NOT GO (minimum material).
  - GO thread working split ring gages (type 1.1) (Appendix D, Figure 6).
  - Optical comparitor overlay charts (50X) for assessing wear on gage elements and to inspect root radius. (Appendix D, Figures 7 and 8).
  - Thread setting plug gages at both GO (maximum material) and NOT GO (minimum material). (Appendix D, Figure 9).
- For internal threads:
  - Pitch diameter (type 4.5) and GO functional diameter (type 4.1) indicating gages with applicable threaded solid set ring gages.
  - GO thread working plug gages (type 1.1).

Summaries of the gages and measuring equipment used for inspection of each dimensional characteristic on bolts and nuts are in Appendix E, Table III and IV, respectively.

37. The FAA gages, although calibrated according to applicable specifications, were not calibrated by the independent laboratories and therefore were not under their A2LA approval. Laboratory personnel were trained to use the FAA gages and conducted all measurements. However, the laboratories did not attest to the accuracy of measurements made with the FAA gages.

EXTERNAL THREADS

Functional Diameter

38. The FAA provided full profile roll indicating gages and GO thread ring gages for inspection of functional diameter (Appendix D, Figure 10). The laboratories used full form segment indicating gages (Appendix D, Figure 11). (One lab also had GO thread ring gages.) All of these gages are approved devices for inspecting functional diameter. However, there are substantial differences in the gages. The GO thread ring is a limit gage and does not provide a size. A properly set GO thread ring gage will assure, within the length of the gage, that the product does not exceed maximum material and will assemble with a nut at maximum material. A threaded ring gage is properly set by transferring the pitch cylinder from the truncated portion of the applicable threaded "W" tolerance thread setting plug gage. A properly set threaded ring gage was defined by the FAA as one that would receive the truncated portion of an un-lubricated threaded "W" tolerance setting plug gage for a "snug" fit (no freeplay) between the gages. Additionally, the full form portion of the un-lubricated setting plug gage should not enter the gage more than 1 full turn, using light (finger tight) torque. This standard was established by the FAA, after verification on a new (unopened package) GO thread ring gage. There are other issues associated with the use of the GO thread ring gage. ASME B1.2 (Paragraph A3.1.2) states that pitch diameter on a GO thread ring gage fitted to a setting plug may be 0.0001" to 0.0002" larger than the measured pitch diameter on the setting plug because the pitch diameter equivalents from permissible pitch, lead, and flank angle tolerances on matched plugs and rings cause unavoidable discrepancies. Though setting of the ring gage is relatively simple, calibration of ring gages is considerably more complex than for plug gages. As stated in ASME B1.2 the purpose of the GO ring gage is to assure interchangeable assembly of maximum-material mating parts. However above 9/16" diameter, the ratio of length-of-engagement to diameter drops significantly and the GO gage increasingly become less representative of mating hardware (see paragraph 111 and Table VIII for further discussion on length-of-engagement).

39. The difference between the full profile rolls and full form segments is shown in Appendix D, Figure 12. The full profile rolls have consecutive annular (non-helical) ribs that make tangential contact at three points on the bolt. The full form segments have a helical thread form and make substantially more circumferential and peripheral contact with the thread. The laboratory full form segment gages had 50% minimum circumferential contact. As explained by one gage manufacturer, the full form segments are essentially a GO thread ring gage cut in half and mounted on a digital indicator. The rolls, segments, and ring gages all had the same length of engagement per ASME B1.2.

Pitch Diameter

40. The FAA provided thread groove diameter type indicating gages. Per ANSI/ASME B1.3M (reference 7), though both the thread groove diameter (cone only profile) and pitch diameter type (cone & vee profile) gages inspect for minimum material, a thread groove diameter type gage is not acceptable for measuring *pitch diameter size* (required by MIL-S-8879C). Appendix D, Figure 13, a diagram from ANSI/ASME B1.2 (reference 8), shows the difference between the thread groove diameter and cone & vee full profile rolls. However, ANSI/ASME B1.2 is inconsistent, showing thread groove diameter rolls measuring pitch diameter. Only on page 173 does ANSI/ASME B1.2 explain the distinction, stating that thread groove diameter is equal to pitch diameter "only on a thread with perfect pitch spacing." Because they are not acceptable for measuring pitch diameter, the thread groove diameter type gages were not used by the FAA in making conformity determinations. However, given the extensive industry use of thread groove diameter type gages, the FAA wanted to assess whether use of thread groove diameter type gages had an impact on airworthiness.

INTERNAL THREADS

Functional and Pitch Diameter

41. The laboratory and FAA gages for inspecting functional and pitch diameter were of the same type (4.1 and 4.5, respectively). The primary difference was in the amount of circumferential contact. Both gages met the minimum requirements of ANSI/ASME B1.2 to contact at least 25% of the circumference (90º), but the laboratory gages had considerably more contact area. For example, the laboratories ¾" size gage had a contact arc of 158º, whereas the FAA ¾" size gage contacted an arc of 98º. The FAA also obtained GO thread plug gages for inspecting functional diameter and performing functional assembly checks on crimped nuts.

METHOD OF INSPECTION AND TEST (PHASE I)

GENERAL

42. The PAH removed acetyl alcohol coating using a hot water wash when the FAA collected the test samples. Test samples were sequentially numbered for positive identification at all inspection sites (PAHs and laboratories). Test samples were kept in their original protective materials to prevent damage. To assess variation in measurement and to provide a check on data quality, the FAA obtained calibrated "W" tolerance[5] thread setting plug gages (at both maximum and minimum material) for each size to be inspected during the audit (0.1900-32 through 0.7500-16). The PAHs and independent laboratories measured the FAA thread setting plug gages for pitch and functional diameter (Appendix D, Figure 14) coincident with the product inspections.

DIMENSIONAL INSPECTION – PRODUCTION APPROVAL HOLDERS

43. The PAHs inspected eight samples per part number. PAHs manufacturing fasteners conducted dimensional inspections in accordance with Table I. At PAHs procuring fasteners from suppliers[6], inspections were conducted in accordance with normal receiving inspection procedures; therefore, all characteristics may not have been inspected at the PAH facility. Measuring equipment in accordance with ANSI/ASME B1.3M was used, except where noted. All gages and measuring equipment were under current calibration. The PAHs were instructed to inspect the samples using their normal procedures and practices. The FAA evaluated inspection techniques to the extent that they complied with applicable specifications and/or accepted practices. Where PAHs inspection technique differed from the independent laboratories, it was noted.

DIMENSIONAL INSPECTION – INDEPENDENT LABORATORIES

General

44. For bolts, each of the three independent laboratories inspected four samples per part number for the dimensional characteristics listed in Table I. For nuts, Hill AFB QVC and DLA New Cumberland inspected eight and four samples per part number, respectively, for the dimensional characteristics listed in Table I. Measuring equipment, in accordance with ANSI/ASME B1.3M, was used except where noted. All gages and measuring equipment were under current calibration.

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[5] "W" tolerances are defined (ANSI/ASME B1.2, Table 7) as those representing the highest commercial grade of accuracy and workmanship and are specified for thread-setting gages.

[6] PAHs who procure fasteners do not maintain all gaging, equipment, and technical staff that are used in the manufacturing and inspection process. The FAA accepted their "normal" receiving inspection practices for use to indicate of how well their receiving inspection system was actually functioning.

45. The sub-paragraphs below describe the equipment (primary and alternate) and method used to inspect individual dimensional characteristics. The laboratory gages were used as the primary measurement devices. The FAA gages were designated as the alternates. The New Cumberland Laboratory routinely inspected with both the laboratory gages and the FAA gages. At Columbus and Hill AFB QVC the FAA gages were used only in the disposition process described below. Summaries of the gages and measuring equipment used for inspection of each dimensional characteristic on bolts and nuts are in Appendix E, Table III and IV, respectively.

Disposition Process

46. Test samples identified as nonconforming during an initial inspection were subjected to a disposition process to confirm the nonconformance, assess variation-in-measurement using alternate gages, and implement any available referee inspection criteria. The disposition process consisted of the following steps:

- Cleaning the fastener with a soft nylon brush.
- Visual inspection of the fastener for damage.
- Cleaning and re-setting of the gages.
- Re-inspect using the same gages or measuring equipment to assure repeatability of measurement. If long thread length bolt was re-inspected because of an initial non-conform on differential analysis of lead and flank angle, the inspector measured pitch diameter within the length of the functional diameter gage element.
- Inspection using alternate acceptable gages or measuring equipment.
- For bolts, a referee inspection, direct individual inspection of lead and flank angle.
- Functional assembly check using a properly set GO thread ring or plug gage.

47. Final findings of nonconformance were based upon the criteria established in ANSI/ASME B1.2 paragraph 2.2.1 which states:

> "Product threads accepted by a gage of one type may be verified by other types. It is possible that parts, which are near a limit, may be accepted by one type and rejected by another. Also, it is possible for two individual limit gages of the same type to be at opposite extremes of the gage tolerances permitted, and borderline product threads accepted by one gage could be rejected by another. For these reasons, a product screw thread is considered acceptable when it passes a test by any of the permissible gages in ANSI/ASME B1.3M for the gaging system specified provided the gages being used are within the tolerances specified in this standard."

<u>Classification of Inspection Results</u>

48. The FAA classified inspection results as follows:

- A sample was classified **conforming** if all inspected dimensional characteristics, measured on acceptable measurement equipment, were found to be within design tolerances, or

- A non-conformity was identified, but the sample passed referee inspection criteria[7].

- A sample was classified as **conforming with variation** * if:

  - The sample had at least one dimensional characteristic out of design tolerances.

  - The nonconformity was not confirmed by other acceptable inspection equipment, and

* For the purposes of product acceptance, in accordance with ANSI/ASME B1.2, these samples are conforming.

- A sample was classified as **nonconforming** if:

  - The sample failed the functional assembly check using a properly set GO thread ring or plug gages, or

  - The sample had at least one dimensional characteristic out of design tolerances, and

    - The nonconformity was confirmed by all other acceptable measurement equipment, or

    - The sample failed any referee inspection criteria allowed by the design data or referenced specifications.

[7] If the differential between functional and pitch diameters exceeded 40% of pitch diameter tolerance but passed direct inspection for lead and flank angle, it was classified as conforming in accordance with MIL-S-8879C or if applicable BPS-F-69 or –67.

Inspection of External Threads

GO Functional Diameter

49. Primary inspection of GO functional diameter size was conducted using full form segment indicating thread gages (type 4.1) (Appendix D, Figure 11). FAA gages included full profile roll indicating thread gages (type 4.3) and GO thread ring gages (type 1.1) (Appendix D, Figure 10). The differences in the gages is discussed in paragraphs 38 and 39. For the indicating gages, the product thread was presented to the gage and rotated to ensure proper seating. The segment gages have considerably more surface contact than roll gages. Therefore, rotation of the part in the segment gage was limited to +/- 15 º to minimize modification of plated parts. At one laboratory no rotation was allowed. See paragraph 119 for further discussion on the effect of plating on measurement. The full form portion of the thread was checked front, center, and back (depending on length) at 0º and 90º rotation. The largest observed value was recorded. Additionally, the lead threads were checked to ensure they did not exceed maximum material limits.

50. Functional assembly (functional diameter) was checked using a GO thread ring gage (type 1.1). The gage was held stationary and the bolt was threaded into gage. (See Appendix D, Figure 15.) The product was considered acceptable if the entire full form portion of the thread passed *freely* through the gage. *Freely* was defined as a light touch, thus producing minimal force (torque) generated only by the fingers and unaided by any wrist and/or arm rotation.

Pitch Diameter Size

51. The laboratories inspected for pitch diameter size using “cone & vee” indicating thread gages (type 4.5) (Appendix D, Figure 13 and 16). The FAA gages were thread groove diameter indicating thread gages (type 4.6) (Appendix D, Figure 4 and 13) (see paragraph 40). The product thread was presented to the gage and rotated to ensure proper seating. The full form portion of the thread was checked front, center, and back (depending on length) at 0º and 90º rotation. The smallest observed value was recorded.

Major Diameter Size

52. The laboratories inspected for major diameter using either a plain micrometer or “super micrometer” (type 14) (Appendix D, Figure 17). The full form portion of the thread was checked front, center, and back (depending on length) at 0º and 90 º rotation. Any measurement out of specification limit was recorded. Otherwise, an approximate average of the measurements was recorded.

Minor Diameter Size

53. The laboratories inspected for minor diameter using a minor diameter type plain indicating gage (type 5.2) and optical comparitor (type 9). The product thread was

presented to the gage and rotated to ensure proper seating. The middle of the thread was checked at 0º and 90 º rotation. Minor diameter was inspected on the optical comparitor at 50X magnification. The test sample was positioned so that the light source was aligned with the thread helix angle. Uniformity was checked visually. A datum was established on one side of the fastener at the bottom of the thread root. The distance to the bottom of the thread root on the opposite side of the fastener was recorded from the table traverse readout.

Thread Root Radius

54. The laboratories inspected for root radius on the optical comparitor at 50X magnification, using an overlay chart for each fastener size (Appendix D, Figures 7 and 8). The test sample was positioned so that the light source was aligned with the thread helix angle. The table was positioned such that the profile of the fastener flanks matched the outline on the overlay. The projected profile of the thread root was checked to assure it was within the maximum/minimum limits defined on the overlay. The incomplete threads were also checked to assure that the radius, as it approached the unthreaded portion of the shank, was not less than the full thread portion. The inspector recorded pass/fail results. At one laboratory the FAA requested that the inspector record a numerical value. Though the inspectors fulfilled the FAA's request, they lacked confidence in the repeatability of measurement due to overlay chart resolution.

55. The FAA observed a PAH using the following technique for inspection of thread root radius on the optical comparitor. The thread valley flanks were positioned to match the +/- 30 º (from vertical) lines on the overlay. The intersection point of the +/- 30 º lines located the sharp "V" of the thread valley. The distance from the sharp "V" to the bottom of the thread root is equivalent to the root radius, and was recorded from the table traverse readout. At one laboratory, the FAA tried to compare the results of this inspection technique with those using optical comparitor overlay charts; however, the resolution of the overlay charts was not sufficient to provide reliable numerical measurement.

Lead

56. The laboratories inspected lead on the optical comparitor at 50X magnification. The comparitor was not adjusted for thread lead or helix angle, as ASME B1.2 states lead is measured parallel to the axis of the thread. Lead was measured only on full form threads for a length of 1.0 to 1.5 times basic major diameter. The inspectors noted that on all bolts, lead was uniform. This observation is consistent with the fact that all bolts had rolled threads. Using the optical comparitor overlay, a datum was established when the thread flank was positioned to match a 30º line (from vertical). The table was translated for the appropriate number of pitches and the distance was recorded from the table traverse readout. This distance was then compared to nominal (nominal distance = number of pitches x (1/threads-per-inch). The difference between measured and nominal value was the lead deviation.

Flank Angle

57. The laboratories inspected for flank angle (half-angle) on the optical comparitor at 50X magnification. The test sample was positioned so that the light source was aligned with the thread helix angle. The correction factor to observed flank angle due to helix angle was determined to be less than 0 degrees, 3 minutes and was disregarded. Two similar inspection techniques were used. The first used the optical comparitor software to establish datum at the thread roots and on the thread flank. The software computed the included angle (nominal 60º). The half-angle was the difference between 90º and the computed value. The second method was similar except that a datum perpendicular to the thread roots was established. Those two datum were used to directly compute the half-angle. The flank angle deviation was the difference between the measured value and 30º.

Incomplete Threads, Runout of Threads-to-Shank

58. Incomplete threads were inspected using the optical comparitor at 50X magnification. Runout threads were inspected visually and could be no less than one, or more than two, pitches in length. The inspection of the root of runout threads was part of the root radius inspection described above. Unless otherwise specified, the number of incomplete threads could be no less than one and no more than two.

59. Many of the test samples were subject to the runout requirements of BPS-F-67 (reference 9) or BPS-F-69 [8] (reference 10). These specifications establish a maximum distance between the last full form thread and the end-of-the-grip. BPS-F-67 and BPS-F-69 specify the use of overlay charts to provide precise location (axial and radial) of the last full form thread and location of the end-of-the-grip. Without the required overlay charts, inspection of runout per BPS-F-69 and BPS-F-67 was difficult, and the laboratory inspectors lacked confidence in the repeatability of measurement.

Other Characteristics

60. At various times during the audit, additional characteristics were inspected. Selection was based upon the PAHs classification of that feature as a *major characteristic*. The characteristics and inspection equipment are listed below:

- Head-to-shank fillet radius: optical comparitor.
- Shank diameter: micrometer.
- Overall length: calipers

61. The inspectors made observations on the presence of circularity (out-of-round) and taper. However, these characteristics are not within the scope of the MIL-S-8879 *Other*

[8] BPS-F-67, Boeing Part Specification, Fasteners, Hex Drive Bolts,
BPS-F-69, Boeing Part Specification, Fasteners, Externally Threaded

Thread inspection. They apply only to *Safety Critical Threads*, therefore inspection results for circularity and taper were not documented.

Inspection of Internal Threads – Crimped Nuts

Dimensional Inspection

62. Sixty-seven percent (67%) of the nuts in the test sample incorporated a deflected thread self-locking feature, commonly referred to as crimp. Though the crimp is most often applied at the top of the nut, the effect propagates down the nut barrel. The specifications state that thread dimensions apply before crimp. Nevertheless, the FAA had dimensional inspections performed although it was difficult to get consistent measurement on crimped parts. The inspector tried to take measurements where the effect of crimp was not perceptible. The inspectors used calibrated plain pins to ascertain the propagation of crimp effects. In general, the inspectors lacked confidence in the repeatability of measurement on crimped nuts. Therefore, the measurement results for GO functional diameter and pitch diameter on crimped nuts are not being reported. The inspection results for minor diameter are being reported.

Functional Assembly Inspection

63. Crimped nuts were checked for functional assembly using a GO thread plug gage (type 1.1). The GO plug gage must pass into the nut the minimum specified amount (most often three-fourths of one turn). Some nuts coated with dry film lube required the use of a test bolt in lieu of a GO plug gage, these were inspected only at the PAH. Some PAHs were using NOT GO thread plug gages. These gages when applied to the product internal thread may engage only the end threads (which may not be representative of the complete thread). A nut was acceptable if the gage did not enter more than three complete turns.

Inspection of Internal Threads – Non-Crimped Nuts

GO Functional Diameter

64. For non-crimped nuts the laboratories inspected for GO functional diameter using full form segment indicating thread gages (type 4.1) (Appendix D, Figure 18). FAA gages were also type 4.1, but of different design (see discussion on test equipment paragraph 41). The product thread was presented to the gage and rotated slightly to ensure proper seating. The smallest observed value was recorded.

65. FAA gages also included GO thread plug gages (type 1.1). Product inspection using the GO thread plug gage (type 1.1) was accomplished by holding the nut stationary and threading the gage into the product. For non-crimped nuts, the product was considered acceptable if the gage passed *freely* through the nut. *Freely* was defined as a light touch, thus producing minimal force (torque) generated only by the fingers and unaided by any wrist and/or arm rotation.

Pitch Diameter Size

66. For non-crimped nuts, the laboratories inspected for pitch diameter size using "cone & vee" indicating thread gages (type 4.5) (Appendix D, Figure 19). FAA gages were also type 4.5, but of different design (see description of test equipment paragraph 41). The nut thread was presented to the gage and rotated to ensure proper seating. If there was sufficient thread length the nut was checked at two locations. The largest observed value was recorded.

Minor Diameter Size

67. The laboratories inspected for minor diameter using plain inside calipers (type 14). For non-crimped nuts, the middle of the thread was checked at 0º and 90 º rotation. For crimped nuts, measurement was taken where the effect of the crimp was not perceptible. The propagation of crimp effect was ascertained through the use of calibrated plain pins.

Other Characteristics

68. At various times during the audit additional physical features were inspected. Selection was based upon the PAHs classification of that feature as a *major characteristics*. The characteristics and inspection equipment are listed below:

- Nut height: Micrometer.
- Thread depth on fluid fittings: GO thread plug gage.
- Nut thread to bearing surface perpendicularity: Squareness table and thickness gage.

FUNCTIONALITY TESTING

Mechanical Performance Tests

69. Mechanical performance tests were in accordance with PAH production lot acceptance procedures. Bolt mechanical performance tests included tensile strength, shear strength, and /or fatigue. Nut mechanical performance was assessed during axial tensile strength tests. Run-on and breakaway torque tests were performed on nuts incorporating a self-locking feature. All tests were conducted at room temperature using calibrated test equipment. Test articles were selected based on dimensional inspection results. If a nonconformance was identified, that sample was tested. Otherwise, a sample was selected for each test based on its most critical dimension, i.e., a fatigue test article had the smallest measured thread root-radius. The majority of the samples were tested at the PAH. A limited amount of testing was conducted at Hill AFB QVC.

Material Properties Tests

70. Material properties tests were in accordance with PAH production lot acceptance procedures. Tests included material composition, eddy-current inspection, and/or hardness (macro and micro as applicable). All tests used calibrated test equipment. Test samples were randomly selected. The majority of the samples were tested at the PAH. A limited amount of testing was at Hill AFB.

METHOD OF AUDIT (PHASE II)

RECEIVING INSPECTION

71. The FAA objective was to evaluate the manufacturers' inspection/testing of purchased goods and services (i.e., plating, heat treat, and machining, etc.). The FAA used the following criteria:

- All incoming shipments are accompanied by appropriate documentation. The FAA reviewed certification documentation and inspection records for verification of compliance to applicable design/quality requirements as flowed down to multi-tier suppliers/vendors.

- All incoming shipments are verified for dimensional compliance (i.e., plating thickness, thread geometry, etc.), either directly or indirectly.

- The manufacturer does not rely solely on material certifications or certificates of compliance. The manufacturer has implemented procedures for verification of material properties (i.e., chemical analysis, mechanical properties, etc.).

CONTROL OF RAW MATERIALS

72. The FAA objective was to assure that all manufacturers' maintained adequate controls of raw materials. The FAA reviewed the areas dealing with material handling, storage, inspection, testing, and acceptance. The FAA used the following criteria:

- All material was stored within a controlled area.

- All material maintained positive identification, including vendor documentation/certification.

- The manufacturer was performing an adequate receiving inspection (i.e., dimensional, chemical, etc.).

- All material maintained an indication of status within the manufacturers' quality system (i.e., new receipts, in-process material pending laboratory analysis, and material accepted following laboratory analysis).

- All material was segregated, within the controlled area, based on status. There are areas identified for new receipts, areas identified for in-process material pending laboratory analysis, and areas identified for material that was accepted following laboratory analysis.

- All rejected material was stored independently from other material.

IN-PROCESS CONTROLS

73. The FAA objective was to assess the manufacturers' in-process controls as relating to various machining operations and special processes (i.e., grinding, thread roll, thread tap, plating, heat treat, etc.). The FAA used the following criteria to evaluate the manufacturers' in-process controls:

- Evaluation of the extent of the manufacturers' in-process control (i.e., First Article Test, Statistical Process Control, Functionality Testing, etc.).

- Use of proper measuring and test equipment (i.e., gages identified as "reference only" vice those controlled through the calibration system).

- The manufacturer has developed adequate work instructions for all applicable machining operations and special processes (i.e., plating, heat treat, etc.).

IN-PROCESS INSPECTION REQUIREMENTS

74. The FAA objective was to assure that the manufacturer has in-process inspections for characteristics, and that subsequent processes would preclude conformance verification to the FAA-approved design. The FAA used the following criteria:

- The manufacturer verifies thread dimensions before plating when required by the applicable product specification.

- The manufacturer verifies thread dimensions before crimping operations for internally threaded hardware.

- The manufacturer does in-process inspections for any other characteristic for which subsequent processes preclude conformance verification.

- The manufacturer does in-process inspections at the required sample size and/or any other inspection requirements as specified in the applicable product specification.

- The manufacturer uses appropriate personnel (i.e., quality department) to accept/verify characteristics inspected in process.

IMPLEMENTATION OF DESIGN/QUALITY REQUIREMENTS

75. The FAA objective was to verify that all design/quality requirements are adequately flowed down to all levels within the manufacturing process. Additionally, the FAA verified that all design/quality requirements flowed down are implemented at all applicable levels within the manufacturing process. The FAA used the following criteria:

- Review of manufacturing documentation (i.e., operation sheets, work orders, inspection/test records, etc.) to verify implementation of design/quality requirements received through incoming purchase orders.

- Review of outgoing purchase orders to verify proper flow-down of applicable design/quality requirements to multi-tier suppliers/vendors.

PROPER USE AND IMPLEMENTATION OF SPECIFICATIONS

76. The FAA objective was to evaluate the use of required specifications. Specifically, the FAA was investigating the potential unauthorized substitution of AS8879 (reference 11) in lieu of MIL-S-8879. The FAA used the following criteria:

- All manufacturers are using the specifications as referenced within the FAA-approved design data. The FAA reviewed drawing requirements and verified that all manufacturing, inspections, and tests are in accordance with the applicable specification. If the design data referred to a specific revision level (i.e., MIL-S-8879A), the FAA assured that the specific revision level (i.e., MIL-S-8879A) was being used. If the design data did not specify a specific revision level (i.e., MIL-S-8879), the FAA assured that the latest revision level was being used (i.e., MIL-S-8879C).

- These same criteria were used for all other referenced specifications.

AVAILABILITY/USE OF MEASURING AND TEST EQUIPMENT

77. The FAA objective was to evaluate the manufacturers' availability and use of measuring and test equipment. The FAA used the following criteria:

- Evaluation of the manufacturers' use of approved gages. The manufacturer is in compliance with industry standards (ANSI/ASME B1.3M) or the designer's product specifications.

- Evaluation of the manufacturers' use of "Reference Only" gages for product acceptance or SPC.

- Assessment of the improper use of indicating thread gages [i.e., using working (split type) ring gages as a setting master in lieu of solid type].

- Assessment of the availability of the setting plug/ring master in proximity to the indicating thread gages while in use (i.e., setting/zeroing intervals).

CALIBRATION PROGRAM

78. The FAA objective was to evaluate the manufacturers' calibration program to assure that product inspection/acceptance adhered to industry calibration standards. The FAA used the following criteria:

- All manufacturers maintained a documented calibration program, including an adequate recall system ensuring the collection of, or prohibiting the use of, expired gages/equipment.
- All manufacturers had the gage/equipment manufacturers' maintenance procedures or other suitable maintenance procedures.
- All gages/equipment are calibrated in accordance with industry practices/standards (i.e., ANSI/ASME B1.2).
- All manufacturers maintained adequate control of outside calibration sources.
- All manufacturers maintained an adequate identification system for all individual gages/equipment (i.e., serial numbers, calibration stickers, etc.).
- Verification that no gages/equipment were in use with overdue/expired calibration.
- All manufacturers doing in-house calibration maintained adequate environmental controls (i.e., temperature/humidity) in calibration laboratories.

STATISTICAL SAMPLING INSPECTION PLANS

79. The FAA objective was to assure that all manufacturers use a statistical sampling inspection plan based upon C=0[9] acceptance/rejection criteria and that a system of classification of characteristics was used. The FAA used the following criteria:

- All sampling plans were based on C=0 acceptance/rejection criteria, including those flowed down to multi-tier suppliers.
- Verification that production lots of material with nonconformances identified during sampling (i.e., those exceeding acceptance/rejection criteria) were appropriately dispositioned (i.e., 100% lot screening, scrap, Material Review Board, etc.).

[9] C=0: Refers to a statistical sampling inspection plan based upon zero acceptance numbers. The acceptance number in all cases is zero. The inspector only accepts the lot if zero nonconformances are found in the lot (reference 12).

- All design characteristics subjected to statistical sampling were appropriately classified.
- All multi-tier suppliers adhered to the statistical sampling requirements as flowed down.

STATISTICAL PROCESS CONTROL

80. The FAA objective was to evaluate the manufacturers' use and implementation of Statistical Process Control (SPC). The FAA used the following criteria to evaluate the manufacturers' SPC system:

- Evaluate the manufacturers ability to monitor and detect variation in a manufacturing process.
- Evaluate the manufacturers ability to determine if the process is capable of meeting design specifications.
- Verify that the manufacturer had implemented a SPC system that was consistently producing characteristics within engineering design tolerances.
- Assess whether the manufacturers SPC system is used for acceptance, in-process control, or a combination thereof.
- Verify that the manufacturers SPC system is in compliance with the designer's requirements or product specifications, as specified (i.e., capability index C_p/C_{pk})[10].
- Verify that the manufacturers SPC system provides for timely corrective action when the process does not yield results within established parameters.
- Verify the adequacy of the manufacturers SPC training program. Assess whether the personnel employing SPC techniques are trained and have adequate knowledge of the process.
- Verify that the manufacturers SPC control charts clearly defined the specification limits, with control limits describing the inherent variation in sample ranges and averages.

[10] Capability Index (C_p/C_{pk}): The capability of a process or a machine can be expressed as a number, which is referred to as the capability index. This index number is derived by comparing the process spread to the specification spread, and expresses it in terms of the standard deviation (reference 13).

FINAL INSPECTION/ACCEPTANCE

81. The FAA objective was to evaluate the manufacturers' final inspection/acceptance of product. The FAA used the following criteria:

- The manufacturer was using the proper specifications, including applicable revision levels.
- The manufacturer was using the proper measuring and test equipment as referenced in applicable product specifications or industry standards (i.e., ANSI/ASME B1.3M).
- The manufacturer verifies conformance to all product characteristics.
- The manufacturer inspects to the prescribed sample size as found in the applicable product specification or drawing.
- The manufacturer adheres to an acceptance/rejection criteria of C=0 or that as specified within the designer's product specification.
- For internal threaded hardware, manufacturers do final inspection of threads prior to deformation/crimping.
- Manufacturers are not using "Reference Only" gages for final inspection or product acceptance.

CONTROL AND DISPOSITION OF REJECTED MATERIAL

82. The FAA objective was to evaluate the manufacturer's control and disposition of rejected material. The FAA used the following criteria:

- All manufacturers maintained procedures for control and disposition of rejected material.
- All manufacturers maintained a secured area exclusively for the storage of rejected material.
- All rejected material was identified accordingly (i.e., rejection tags).
- The manufacturers' scope and authority of Material Review Board determinations was reviewed and evaluated.

CONTROL OF SUPPLIERS

83. The FAA objective was to assess the manufacturers' ability to ensure that supplier materials, parts, and services conform to FAA-approved design. The FAA used the following criteria:

- The manufacturer maintains control of supplier design, including changes.
- The manufacturer performs initial evaluations of its suppliers before approval and purchase of product/services.
- The manufacturer periodically evaluates its suppliers and implements corrective action for deficiencies.
- The manufacturer adequately flows down design and quality requirements to suppliers. The quality department verifies all outgoing purchase orders to assure proper flow down of requirements.
- The manufacturer uses receiving inspection to verify that supplier-furnished parts or services conform to the FAA-approved design data.

CUSTOMER BASE

84. The FAA objective was to analyze the manufacturers' customer base to verify compliance with Title 14 Code of Federal Regulations, Part 21, Certification Procedures for Products and Parts, § 21.303, Replacement and Modification Parts. The FAA used the following criteria:

- All products are produced under the authority of the manufacturers' FAA production approval (i.e., Part Manufacturer Approval (PMA), Technical Standard Order (TSO)).
- Products produced without evidence of a FAA production approval are produced under the control of a FAA PAH.

TESTING LABORATORIES

85. The FAA selected testing laboratories which met standards similar to those outlined within the original version of the Fastener Quality Act (Public Law 101-592, November 6, 1990). The testing laboratories selected were accredited through the American Association for Laboratory Accreditation (A2LA).

Participating Laboratories

Science and Engineering Laboratory
United States Air Force
Ogden Air Logistics Center (OO-ALC-TIEL)
7278 4th Street
Hill Air Force Base, UT 84056-5205
Ronald J. Clay, Manager
Phone: 801-777-2874

Defense Logistics Agency
Product Testing Center
Mechanical East
New Cumberland, PA 17070-5001
Michael N. Yakubick, Manager
Phone: 717-770-4098

Defense Logistics Agency
Product Testing Center
DSCC-TM, Building 9-1
3990 East Broad Street
Columbus, OH 43216-5000
Phone: 614-692-3589

AMERICAN ASSOCIATION FOR LABORATORY ACCREDITATION

86. The A2LA is a non-profit, non-Governmental, public service, membership organization dedicated to operating a nationwide, broad-spectrum laboratory accreditation system. Accreditation is defined as a formal recognition of competence that a laboratory can perform specific tests or types of tests. The general requirements for accreditation used by A2LA are from the international standard, ISO/IEC Guide 25, 1990. Additional program requirements for specific fields of testing or specific programs, which are necessary to meet particular user needs, complement these general requirements in particular areas.

CHRONOLOGY

87. The following is a chronology of the FAA audit activities:

- **6/8/2000:** The Department of Transportation - Office of Inspector General (DOT-OIG) released the draft report "Oversight of Manufacturers' Quality Assurance Systems for Threaded Fasteners," to the FAA.

- **8/28/2000:** The FAA developed an action plan addressing the DRAFT DOT-OIG report and received concurrence from the DOT-OIG.

- **9/6/2000:** The FAA visited the American Association for Laboratory Accreditation (A2LA) to develop an understanding of the laboratory accreditation process. The FAA verified the A2LA scope of accreditation for each of the two DLA laboratories selected. Additionally, because the Hill Air Force Base (AFB) Quality Verification Center (QVC) participated in the DOT-OIG audit, the FAA also verified their A2LA scope of accreditation. A representative from the DOT-OIG was present and participated in these discussions.

- **9/7/2000:** The FAA met with representatives from the two selected Defense Logistics Agency (DLA) laboratories to review test facilities and test techniques, discuss measurement sensitivity and variation, and develop a process implementing data quality measures. A representative from the DOT-OIG was present and participated in these discussions.

- **9/15/2000:** The FAA met with representatives from the Hill AFB QVC to review/discuss results and inspection processes from the DOT-OIG audit. Representatives from the DOT-OIG were present and participated in these discussions. At the time of this visit, the FAA's action plan did not include Hill AFB QVC as a participating test facility. The Hill AFB laboratory was not added to the FAA's action plan until its revision 10/23/2000.

- **9/11/2000 – 10/27/2000:** The FAA visited nine production approval holders' (PAH) facilities for implementation of phase 1 of the action plan. This phase included efforts to identify part numbers, the selection of samples, and any applicable inspection/testing that was to be accomplished at the PAH's facilities.

- **10/11/2000:** The DOT-OIG issued report (AV-2001-003), "Oversight of Manufacturers' Quality Assurance Systems for Threaded Fasteners."

- **10/23/2000:** The FAA released an official response to the DOT-OIG, "Action Plan for Oversight of Manufacturers' Quality Assurance Systems for Threaded Fasteners."

- **11/13/2000 – 11/22/2000:** The FAA conducted laboratory inspection/testing at the DLA Product Testing Center, New Cumberland, PA. Inspections and tests performed included dimensional (including thread geometry), material properties, and performance testing.

- **12/4/2000 – 12/8/2000:** The FAA conducted laboratory inspection/testing at the DLA Product Testing Center, Columbus, OH. Inspections and tests performed included dimensional (including thread geometry), material properties, and performance testing.

- **12/11/2000 – 12/15/2000:** The FAA conducted laboratory inspection/testing at the Hill AFB QVC, Salt Lake City, UT. Inspections and tests performed (internal threaded hardware only) included dimensional (including thread geometry), material properties, and performance testing. Representatives from the DOT-OIG were present two of the five days and participated in the week's activities. Due to insufficient resources, the laboratory could not complete inspection/testing of all samples. An additional week was scheduled (2/26/2001) to complete the required inspection/testing.

- **1/8/2001 – 1/12/2001:** The FAA conducted in-process audits at four fastener manufacturing facilities. These audits were designed to assess the control of manufacturing and inspection processes. The FAA reviewed the complete manufacturing process, beginning with the receipt of raw materials through final inspection/acceptance.

- **1/22/2001 – 1/26/2001:** The FAA concluded in-process audits at five additional fastener manufacturing facilities. These audits were designed to assess the control of manufacturing and inspection processes. The FAA reviewed the complete manufacturing process, beginning with the receipt of raw materials through final inspection/acceptance.

- **2/26/2001 – 3/2/2001:** The FAA concluded laboratory inspection/testing at the Hill AFB QVC, Salt Lake City, UT. Inspections and tests performed (external threaded hardware only) included dimensional (including thread geometry), material properties, and performance testing. Representatives from the DOT-OIG were present and participated in the week's activities.

- **3/30/2001:** The FAA issued the final report outlining all relevant audit findings and recommendations.

RESULTS AND DISCUSSIONS

INSPECTIONS AND TESTS (PHASE I)

DIMENSIONAL INSPECTION RESULTS - SUMMARY

External Threaded Product (Bolts)

88. The PAHs inspected 547 bolts for dimensional conformance in accordance with their normal receiving or final inspection procedures. The three independent laboratories inspected 910 bolts for dimensional conformance per paragraphs 49 - 61. It is important to note that though the laboratory results are being reported collectively, individually they were within 2.6% of each other. A summary of bolt dimensional inspection results is presented in Table III. Within the scope of this audit, the PAH found 31 of 547 (5.7%) bolts to be dimensionally nonconforming. Within the scope of this audit, based on inspection by the independent laboratories, the FAA found that of the 910 bolts inspected, 103 (11.3%) were dimensionally nonconforming. See paragraph 48 for definitions of classification of inspection results.

Table III
BOLTS - DIMENSIONAL INSPECTION RESULTS

	# Pieces inspected	Nonconforming	
		# Pieces	Rate
Production Approval Holders	547	31	5.7%
Laboratories (3)	910	103	11.3%

Variation in Results - Bolts

89. The FAA analyzed the variation in nonconformance results between the PAH (5.7%) and the laboratory inspections (11.3%). The causes are many, but the FAA would like to highlight the following:

- Seventy-six (76%) of nonconformities at the laboratories and 100% at the PAH were due to not meeting lead requirements. The full profile roll indicating gages used by the vast majority of PAHs did not detect the full extent of lead deviation present on the part. The FAA questions whether the full 40% of pitch diameter tolerance should be applied when using full profile rolls in differential gaging methods. Furthermore, the audit found that the full profile roll indicating gages should be supplemented by the use of GO thread ring gages to detect product that exceeds the maximum thread envelope.

- There does not exist any written standards or practices for the setting and use of GO thread ring gages (see discussion in paragraph 166). To the extent the industry relies on these gages to detect nonconforming product, these documents need to be developed.

- The laboratories expressed concern over lack of repeatability of measurement using the full form segment indicating gages on aluminum pigment coated parts (40% of the bolts). A frequent comment by laboratory inspectors was that it seemed as if they were taking the high spots off the coating. The aluminum pigment is a sprayed-on and baked coating, which is highly non-uniform due to its application process.

- The specifications require that the maximum and minimum material limits not be violated anywhere on the full form thread. The FAA observed only one PAH checking more than one location along the length of the thread for minimum material.

- In general, the FAA has noted the dissonance between the requirements for dimensional inspection and the requirements for performance. Dimensional inspection is not an end in itself. Dimensional characteristics are checked along with materials to establish confidence that the part will meet its intended function. With that in mind, the following dimensional characteristics are defined along with their principal performance indicators:

  - Minimum material – the product carries its design load and meets fatigue requirements.
  - Maximum material – the product assembles without interference with mating hardware at maximum material.
  - Thread form – the product assembles, installation torque values establish proper joint clamp-up forces, and those clamp-up forces are maintained (mating hardware stays together).

90. The affect of thread dimensional nonconformity on fastener performance has been the explored in recent research (references 14 and 15). Reference 14 reported that dimensional nonconformity of 150% out of tolerance for pitch diameter yielded a 4% reduction in tensile strength. In this audit, the variation in measurement of minimum material (between the laboratories and between the thread groove and cone & vee rolls) was no more than 0.0005” (15% of tolerance on a 3/8” bolt). Within the scope of this audit, the degree of variation-in-measurement of minimum material was an order of magnitude less than the degree of non-conformance at which performance degradation is discernable.

91. A significant amount of variation was noted in measurement of maximum material. This was principally due to the use of different types of gages (paragraph 39). Dimensional conformity at maximum material is important for Class 3 hardware. Class 3 threads have zero clearance allowance between a nut and bolt both at maximum material. Exceeding maximum material to the extent it causes improper assembly could have airworthiness implications by causing interference, galling, improper installation torque, and inadequate joint clamp-up forces. This audit identified 26 bolts (2.9%) that failed

functional assembly inspection. Within the scope of this audit, given the problems of inspection of plated/coated parts (particularly aluminum pigment) and the issues inherent in the use of GO thread ring gages (paragraph 38), the FAA questions whether the use of a specification with zero clearance allowance is advisable.

Internal Threaded Product (Nuts) – Self-Locking/Crimped

92. It is difficult to inspect thread geometry after crimping. Inspectors generally lacked confidence in the repeatability of measurement on crimped nuts. Therefore, except for minor diameter (discussed below), dimensional inspection results for crimped nuts are not reported. Crimped nuts were inspected for functional assembly per procedures in paragraph 63. Within the scope of this audit, the PAHs and independent laboratories found that all 484 crimped nuts passed functional assembly inspection.

Internal Threaded Product (Nuts) – Non-crimped

93. The PAH inspected 88 non-crimped nuts for dimensional conformance under their normal receiving or final inspection procedures. Two laboratories inspected 132 non-crimped nuts for dimensional conformance per paragraph 64 - 68. Within the scope of this audit, the PAHs found 1 of 88 (1.1%) non-crimped nuts to be dimensionally nonconforming. Within the scope of this audit, based on inspection by the independent laboratories, the FAA found that of 132 non-crimped nuts inspected, 4 (3.0%) were dimensionally nonconforming and an additional 10 (7.6%) were *conforming with variation*. See paragraph 48 for definitions of classification of inspection results.

Table IV
NON-CRIMPED NUTS - DIMENSIONAL INSPECTION RESULTS

	Samples Inspected	Nonconforming (# of pieces)	Conform with variation (# pieces, %)
Production Approval Holders	88	1 (1.1%)	NA
Laboratories	132	4 (3.0%)	10 (7.6%)

Variation in Results - Non-Crimped Nuts

94. The FAA analyzed the variation in nonconformance results between the PAHs (1.1%) and the laboratory inspections (3.0%). All four nuts found nonconforming by the laboratories were due to oversized pitch diameters (below minimum material). The FAA obtained the non-crimped nuts from a PAH who was purchasing them from a single supplier. In receiving inspection, the PAH was checking for assembly using GO and NOT GO thread plug gages. The GO plug gage is not designed to detect product below minimum material. The NOT GO gage only checks for undersized condition on the lead threads. In this case the NOT GO gage detected the oversized condition on one nut. Upon further investigation with the manufacturer of the nonconforming parts, the FAA

found the nuts were tapped by an outside vendor, and there was no objective evidence that the nuts had been inspected for minimum material. Within the scope of this audit, the lack of detection of the undersized non-crimped nuts was due to inadequate flow-down of inspection requirements, inadequate supplier surveillance, and inadequate receiving inspection by the fastener manufacturer. This is described further in the In-Process Audit (Phase II) results.

FUNCTIONALITY TESTING RESULTS - SUMMARY

95. Functionality testing was conducted in accordance with PAH production lot acceptance procedures (not qualification tests). Of the 114 part numbers in the audit, 112 (98%) underwent some form of functionality testing. Of a total audit population of 2,264 test samples, 288 individual test pieces (13%) were subjected to mechanical performance and/or material properties tests. The preponderance of these tests (80%) were mechanical performance (axial tension, tension fatigue, shear, or torque testing of self-locking nuts). The PAH conducted all mechanical performance tests on the bolts and torque tests on the nuts. Hill AFB tested 27 part numbers for nut axial tensile strength, hardness, and material composition.

96. A summary of functionality tests performed appears in Table V. All test pieces passed their functional requirements. Industry design guides establish minimum tensile requirements based on minimum material strength and pitch diameter. Recently published research (reference 14) proposes that a more physically meaningful strength model would be a function of major and pitch diameter. The magnitude of the nonconformance observed in this audit was small and usually not consistent across the entire thread. The maximum nonconformance for pitch diameter was 0.0002” below minimum (7% out of tolerance). The maximum nonconformance for major diameter was 0.0003” below minimum (5% out of tolerance).

97. The results of this audit are consistent with the results of reference 14, which showed a 4% reduction in tensile strength on a bolt that was 0.0050” undersized on pitch diameter (150% out of tolerance). Based on the results of reference 14, the FAA has concluded bolt yield and tensile strength are insensitive to small non-conformities in pitch diameter. Furthermore, reference 14 states that “variation in bolt pitch diameter was found to affect the yield and tensile strength by about an order of magnitude more than variations in bolt major diameter or nut pitch and minor diameters.” This is consistent with the finding of reference 15 which reported that nut pitch diameter non-conformance in excess of 300% had no discernable effect on the axial tensile strength of the nut. Within the scope of this audit, all 288 test pieces (13% of total audit population) met their mechanical performance and/or material properties requirements. Within the scope of this audit, to the extent dimensional nonconformities existed in the test samples, they were of small magnitude and did not prevent the samples from meeting mechanical performance requirements.

Table V
SUMMARY OF FUNCTIONALITY TESTING

	Materials Tests			Performance Tests				Total # Pieces Tested
	Composition	Eddy Current	Hardness	Tensile	Fatigue	Shear	Torque	
Bolts	12	NA	11	122	29	23	NA	197 (13%)
Nuts	15	1	13	22	NA	NA	40	91 (13%)

LABORATORY DIMENSIONAL INSPECTION RESULTS - BOLTS

Disposition Process – Bolts

98. Test bolts identified as nonconforming during an initial inspection were subjected to a disposition process to confirm the nonconformance, assess variation-in-measurement using alternate gages, and implement referee inspection criteria. The results of the disposition were classified according to the definitions of paragraph 48 as conforming, *conforming with variation*, or nonconforming. The disposition process consisted of the following steps:

- Cleaning the fastener with a soft nylon brush.
- Visual inspection of the fastener for damage.
- Cleaning and re-setting of the gages.
- Re-inspection using the same gages or measuring equipment to assure repeatability of initial inspection.
- Inspection using alternate acceptable gages or measuring equipment.
- A referee inspection method of individual inspection lead and flank angle, only applicable when an initial nonconformity was observed on differential.
- Functional assembly check using a properly set GO thread ring gage.

99. The three independent laboratories had the following combined results. Of 910 bolts inspected, 308 bolts (33.8%) were subject to the disposition process. Of the 308 bolts subjected to the disposition process, 103 (33.4%) were confirmed as nonconforming for a final nonconformance rate of 11.3% (103 of 910 bolts). Detailed breakdowns of the inspections and disposition process for differential analysis of lead and flank angle are in Table VI and for functional diameter in Table VII.

100. As explained in the notes to the tables, inspection technique was modified at the third laboratory. No rotation of the bolt was allowed in the gage in order to minimize the changes to plating. Consequently, a significantly higher percentage of bolts (35%) went through disposition process at the third laboratory than at the first two laboratories (21%). However, this discrepancy did not have a significant effect on final nonconformance rates. All three laboratories had final nonconformance rates within 2.6% of each other.

Table VI
DIFFERENTIAL ANALYSIS OF LEAD AND FLANK ANGLE - SUMMARY OF INSPECTIONS INCLUDING DISPOSITION PROCESS

Functional Diameter Gage, Inspector Technique [1]	Initial Inspection		Disposition Process: Number of bolts nonconforming			Final number of bolts non-conforming
	Number of bolts inspected	Number of bolts non-conforming [2]	Re-inspect (same gages as initial insp.) [2]	Re-inspect (alternate gages) [3]	Referee inspection methods [4]	
Bolt rotation in the gage $\pm 15° - 30°$ (2 laboratories)	624	222 (36%)	101 (16.2%)	27 (4.3%)	47 (7.5%)	47 (7.5%)
No rotation of bolt in the gage (1 laboratory)	286	- [5]	81 (28.3%)	13 (4.5%)	31 (10.8%)	31 (10.8%)
TOTAL	910	-	182 (20%)	40	78	78 (8.6%)

Notes: 1. At the first two laboratories, 55% of nonconformities for differential were not verified on re-measurement. In order to minimize the effect of the inspection on the bolt plating at the third laboratory, the inspector technique was changed. The bolts were not rotated in the functional diameter gages.

2. The differential between functional diameter (full form segment indicating gages) and pitch diameter exceeded 40% of pitch diameter tolerance.

3. The differential between functional diameter (full profile roll indicating gages) and pitch diameter exceeded 40% of pitch diameter tolerance.

4. Individual inspection of lead and flank angle.

5. This laboratory had only one gage stand for all sizes. To eliminate the variable of tear-down/setup of the gage, re-measures were conducted coincident with initial inspections. Neither the initial number of bolt nonconformances nor their measurement values were retained.

Table VII
FUNCTIONAL DIAMETER – SUMMARY OF INSPECTIONS INCLUDING DISPOSITION PROCESS

	Initial Inspection [2]		Disposition Process			
			Number of bolts nonconforming			
			Re-Inspect		Functional Assembly	
Functional Diameter Gage, Inspector Technique [1]	Number of bolts inspected	Number of bolts non-conforming	Same gages as initial insp. [2]	Full profile rolls	GO thread ring gage	Final number of bolts non-conforming
Bolt rotation in The gage ± 15° – 30° (2 laboratories)	624	71 (11.4%)	26 (4.2%)	0 (0%)	20 (3.2%)	20 (3.2%)
No rotation of bolt in the gage (1 laboratory)	286	- [3]	19 (6.6%)	1 (0.3%)	6 (2.1%)	6 (2.1%)
TOTAL	910	-	45 (4.9%)	1 (0.1%)	26 (2.9%)	26 (2.9%)

Notes: 1. At the first two laboratories, 63% of nonconformities for functional diameter were not verified on re-measurement. In order to minimize the effect of the inspection on the bolt plating at the third laboratory, the inspector technique was changed. The bolts were not rotated in the functional diameter gages.

2. Functional diameter measured with full form segment indicating gages.

3. This laboratory had only one gage stand for all sizes. To eliminate the variable of tear-down/setup of the gage, re-measures were conducted coincident with initial inspections. Neither the initial number of bolt nonconformances nor their measurement values were retained.

GO Functional Diameter - Bolts

101. Inspection for functional diameter (maximum material) was made using full form segment indicating gages, full profile roll indicating gages, and GO thread ring gages per paragraph 49 and 50. Given the broad industry use of full profile rolls and GO thread ring gages, an attempt was made to correlate those results with that of the full form segments (see discussion below). Within the scope of this audit, based on inspection by the independent laboratories, the FAA found that of 910 bolts inspected, 26 bolts (2.9%) did not meet design requirements for functional diameter.

Variation in Measurement Due to Equipment

102. An analysis of findings of nonconformance for Functional Diameter with each type of gage was conducted. At the independent laboratories, a total of 26 bolts did not pass inspection using a GO thread ring gage. Of those 26 bolts, 25 bolts (96%) were nonconforming on the full form segment indicating gages, and nine bolts (35%) were nonconforming on the full profile roll indicating gages. Additionally, 12 of the 26 bolts (46%) were found to be nonconforming on direct inspection for lead. Inspection for functional diameter under the *Other Thread* application category can be performed (ANSI/ASME B1.3M) using either a GO thread ring gage, a full profile roll indicating gage, or full form segment indicating gage.

103. The FAA observed that, although not required by ANSI/ASME B1.3M, all fastener manufacturers used GO thread ring gages in conjunction with full profile roll indicating gages. All bolts in this audit had Class 3A threads, meaning that the design specification provides no clearance allowance between a nut and bolt, both at maximum material. It is possible to have a nut and a bolt that both meet dimensions but will not assemble. Exceeding maximum material to the extent it causes improper assembly could have airworthiness implications by causing interference, galling, and improper joint clamp-up forces. Therefore, the issue of variation-in-measurement at maximum material is significant. A design specification that provided some clearance allowance equal to or greater than variation in measurement would eliminate the issue.

104. Within the scope of this audit, To the extent that variation-in-measurement of maximum material does exist, the FAA questions the use of a zero clearance allowance design specification. Within the scope of this audit, based on inspection by the independent laboratories, the FAA found that the GO full profile roll indicating gages detected only 35% of bolts that did not pass a GO thread ring gage. It is recommended that industry revise ANSI/ASME B1.3M to require the use of the GO thread ring gage in conjunction with the full profile roll thread indicating gage for inspection of functional diameter.

Pitch Diameter - Bolts

105. The laboratories inspected for pitch diameter (minimum material) by using indicating gages with cone & vee profile rolls per paragraph 51. Given their broad industry use, thread groove diameter type indicating gages were used to inspect for minimum material. The maximum observed nonconformance was 0.0002" (7% out of tolerance). This was detected by both the cone & vee and thread groove diameter indicating gages. Within the scope of this audit, based on inspection by the independent laboratories, the FAA found that of 910 bolts inspected, 1 bolt (0.1%) did not meet design requirements for pitch diameter. It is recommended that industry resolve whether the use of thread groove diameter type thread indicating gages can assure conformance for minimum material.

Major Diameter - Bolts

106. Inspection for major diameter was conducted using plain micrometer per paragraph 52. The maximum observed nonconformance was 0.0004" (7% out of tolerance). Within the scope of this audit, based on inspection by the independent laboratories, the FAA found that of 910 bolts inspected, four bolts (0.4%) did not meet design requirements for major diameter.

Minor Diameter - Bolts

107. Inspection for minor diameter was conducted at the three laboratories using minor diameter-type gages per paragraph 53. One laboratory also used the optical comparitor per paragraph 53. Inspectors commented that on larger hardware, setting the gage and inspecting product was difficult due to the weight of the product. Some inspectors set the gage with it turned on its side. Within the scope of this audit, based on inspection by the independent laboratories, the FAA found that all bolts (100%), inspected on both the indicating gages and optical comparitor, met design requirements for minor diameter.

Thread Root Radius - Bolts

108. Optical comparitor overlay charts (paragraph 54) and the technique described in paragraph 55 were used to inspect for thread root radius. Within the scope of this audit, based on inspection by the independent laboratories, the FAA found that all bolts (100%) met design requirements for thread root radius. It is recommended that industry review the thread root radius inspection technique described in paragraph 55 and determine its acceptability and limitations.

Lead and Flank Angle - Bolts

109. Lead and flank angle were inspected collectively by calculating the differential between pitch diameter and functional diameter (gage type 4.10). The specification requires that this differential not exceed 40% of the pitch diameter tolerance. However, the specification also allows that when the differential does exceed 40%, the diameter equivalent of variation in lead or flank angle individually not exceed 40% of the pitch diameter tolerance. See Table VI for a summary of audit results. Assessed collectively, 182 of 910 bolts (20%) were nonconforming for lead and/or flank angle. Inspected individually, one bolt was nonconforming for flank angle and 78 bolts were nonconforming for lead. In fact, seventy-six (76%) of all nonconformities at the laboratories (100% at the PAH) were due to not meeting lead requirements. Within the scope of this test, the full profile roll indicating gages did not detect the full extent of lead deviation (including helical variation) on bolts. It is recommended that the industry review whether the full 40% of pitch diameter tolerance should be allowed when using full profile roll indicating gages for differential analysis of lead and flank angle.

110. Judging from discussions with several fastener manufacturers, there is considerable confusion over the application of the specifications as it relates to control of lead. Furthermore, several fastener manufacturers stated they purposely manufacture "retracted threads" (negative lead) to improve fatigue characteristics. They explained that the intent

of the System 22/Other Thread inspection is to control the variation lead and flank within the maximum- and minimum-material limits. As long as the product met minimum-material requirements and passed a GO thread ring gage, the intent of this inspection was met and the product was acceptable. None of the design data in this audit specified lead. Therefore, the requirements of MIL-S-8879C apply. Within the scope of this audit, based on inspection by the independent laboratories, the FAA found that 76% of the nonconforming bolts were due to not meeting design requirements for lead. Within the scope of this audit, FAA design approval holders were not defining dimensional requirements for lead when they differed from standard.

Design vs. Inspection Requirements

111. MIL-S-8879C, paragraph 3.4.4, establishes that design requirements' "tolerances are applicable for lengths of engagement of these threads of 1.0 to 1.5 times basic major diameter" (100-150% of basic major diameter). However, standard gages do not inspect over that length of engagement. Table VIII shows the standard length of gaging elements compared with the length of engagement specified in MIL-S-8879 for the nine sizes inspected in this audit. For four of nine sizes (particularly the larger sizes), gage lengths were less than 100% of basic major diameter. The other five sizes were within 100-138% of basic major diameter. Although not part of this audit, for sizes above 3/4" the GO gage increasingly become less representative of mating hardware.

Table VIII
COMPARISON OF MIL-S-8879C REQUIREMENTS FOR LENGTH OF ENGAGEMENT vs. STANDARD GAGE LENGTH

Nominal Thread Size	Basic major diameter (inch)	Threads per inch (UNJF)	Standard gage length [1] (inch)	Ratio of gage length to basic major diameter (%)
#10	.1900	32	.1875	99%
1/4"	.2500	28	.3438	138%
5/16"	.3125	24	.3438	110%
3/8"	.3750	24	.4375	117%
7/16"	.4375	20	.4375	100%
1/2"	.5000	20	.4375	88%
5/8"	.5625	18	.5625	100%
9/16"	.6250	18	.5625	90%
3/4"	.7500	16	.5625	75%

Note: 1. Standard length of AGD threaded ring gage blanks per ANSI B47.1

112. System 22/Other Thread inspection controls the variation of lead and flank within the maximum- and minimum-material limits. This is fulfilled as long as the product meets minimum pitch diameter requirements and passes a GO thread ring gage. However, the FAA audit results showed that these inspection criteria allow product to be nonconforming to the design requirements of MIL-S-8879C. This was best exhibited by test article E-24 (0.6250-18 UNJF-3A MOD major diameter), which was nonconforming for differential on both segment and tri-roll indicating gages. Upon direct measurement

of lead, 12 pieces were found to be an average of 104% out-of-tolerance with one piece 233% out-of-tolerance. However all pieces met minimum material requirements and passed a GO thread ring gage (E-24 also met tensile and fatigue requirements).

113. Conversely, test articles with similar lead nonconformance (for example, test article J-5) failed a GO thread ring gage. The difference was that average pitch diameter for E-24 was in the 25th percentile of the tolerance, and J-5 was in the 46th percentile. Test article J-5 was also Cadmium plated and build-up of plate in the gage may have impacted the inspection results. The FAA observed one PAH applying lubricant to Cadmium plated bolts, prior to inspection with a GO thread ring gage, to prevent such plating build-up. In terms of passing a GO thread ring gage, there is an inverse relationship between the amount of material and the amount of lead deviation. A product at maximum material, in order to pass a GO thread ring gage, could have no lead deviation. Within the scope of this audit, a properly set GO thread ring gage passed externally threaded product that did not meet design requirements for lead. It is recommended that industry resolve the discrepancies between the design and inspection requirements for control of lead and flank angle.

114. The Code of Federal Regulations requires that all parts conform to FAA-approved design data. Within the scope of this audit, the inspection criteria established within MIL-S-8879C does not meet FAA regulatory requirements that product conform to approved design data. It is recommended that industry resolve the disparity between “acceptable” and “conforming” product, and develop design and inspection specifications consistent with FAA regulatory requirements.

Head-to-Shank Fillet Radius - Bolts

115. Inspection for head-to-shank fillet radius was made using optical comparitor with overlay charts. Within the scope of this audit, all bolts (100%) met design requirements for head-to-shank fillet radius.

Shank Diameter - Bolts

116. Inspection for shank diameter was made using a micrometer. Within the scope of this audit, based on inspection by the independent laboratories, the FAA found that of the 910 bolts inspected, two bolts (0.2%) did not meet design requirements for shank diameter.

Incomplete Threads - Runout

117. Inspection for incomplete threads was made using an optical comparitor per paragraph 58. Within the scope of this audit, the independent laboratories found that all bolts (100%) met design requirements for incomplete threads and thread root radius in the runout area.

Variation in Measurement - Bolts

118. Variation in measurement can come from multiple sources, but it usually involves the gage, the user of the gage, and the condition of the part itself. By far the predominant factor in this audit has been the condition of the part. Plating, coating, slight damage, and variation on the part itself had a significant effect on repeatability of measurement.

Plating and Coatings

119. The purposes for plating and coating vary. For instance, aluminum pigment coating serves primarily as a barrier to prevent galvanic response between dissimilar materials and in some formulations as a lubricant during installation. It should be pointed out that plating and/or coating do not contribute to, nor detract from, the strength of the part. The FAA and the laboratories assessed the effect of plating and coating on the repeatability of measurement. Even with the precautions taken in this audit, there was considerable evidence that the surface condition was being modified by the gage. This was particularly evident on the bolts with aluminum pigment coating. This is a sprayed- and baked-on coating, which by its nature of application method is not uniform. Appendix D, Figure 3, shows aluminum pigment coating on a bolt shank at 23 X magnification. The surface is highly non-uniform with several pits and lumps. In the course of the audit, bolts with the aluminum pigment coating would measure noticeably smaller in a second measurement, but then subsequent measurements would be consistent. Inspectors often commented that it felt as though they were taking the high spots off the coating, particularly with the full form segment gages, due to their large surface contact area. Over 50% of the aluminum pigment coated bolts were subject to the disposition process. The aluminum coated parts were a significant contributor to the amount of parts subjected to the disposition process. They constituted 61% of the disposition bolt population, though they comprised only 40% of the entire bolt population. Within the scope of this audit, the independent laboratories found that the non-uniformity of the aluminum pigment coating on bolts had considerable affect on repeatability of measurement of functional diameter.

Damaged Threads

120. Slight damage to the threads can influence measurement. On several pieces, small nicks barely visible to the unaided eye had considerable impact on measured values. The damaged threads were generally identified in the disposition process when the alternate gaging was used. The effect on measurement was evident on both the full profile rolls and the full form segments, but the segments were particularly sensitive due to their considerably greater circumferential and peripheral contact. Measured values were generally 0.001” greater on the segments than the rolls. When damage was identified, re-measurements were taken on undamaged threads. Damaged threads were a minor contributor to amount of parts subjected to the disposition process. Within the scope of this audit, based on inspection by the independent laboratories, the FAA found that bolt thread damage that was barely visible to the unaided eye had a significant affect on repeatability of measurement of functional diameter on bolts.

Condition of the Gages

121. Accumulation of plate, coat, or debris in a gage could have a significant impact on measurement. The gages were cleaned very frequently. However, in one instance, gage contamination was detected during the normal measurement of the FAA set plugs (see paragraph 17). The GO plug measured properly; however, the NOT GO plug measured 0.0009" above specified value. This was confirmed using a second NOT GO set plug. The segments were removed from the gage and inspected under a microscope. Some build-up of foreign material was noticed. The segments were ultrasonically cleaned, but the results did not change. Closer inspection at 100X revealed a small sliver of metal embedded in the surface of the segment. Common gage setting practice is to "zero" the gage using only a GO set plug. The FAA observed that many fastener manufacturers were using a GO set plug to set the gage and then checking for proper measurement using the NOT GO plug. Based on the above situation, this is good practice. It is recommended that both GO and NOT GO set plugs be available for setting and checking thread-indicating gages.

LABORATORY DIMENSIONAL INSPECTION RESULTS - NUTS

Disposition Process – Nuts

122. Nuts identified as nonconforming during an initial inspection were subjected to a disposition process. The disposition process included:

- Re-inspection using the same gages or measuring equipment to assure repeatability of the initial inspection.

- Inspection using alternate gages or measuring equipment as authorized by the applicable specifications to assess variation in measurement.

It should be pointed out that unlike the inspection for the bolts, the laboratory and FAA gages were the same type. The primary difference was the amount of circumferential contact (see paragraph 41).

GO Functional Diameter - Nuts

123. Inspection for functional diameter (maximum material) was conducted using full form segments and GO thread plug gages per paragraph 64. Inspection of a nut with a GO thread plug gage does not have the same issues as inspection of a bolt with a GO thread ring gage (see paragraph XX). The GO thread plug gage is easily calibrated, is not adjustable, and engages the full length of the threads for all standard product. Within the scope of this audit, based on inspection by the independent laboratories, the FAA found that all non-crimped nuts met design requirements for functional diameter.

Variation in Measurement

124. Generally, the laboratory gages with their increased surface contact reported smaller values for functional diameter (more material) than the FAA gages. This is intuitive, as any variation would be detected to a greater extent. None of the nuts were nonconforming for functional diameter on either gage. Selection of gages is at the manufacturer's discretion as long as they meet accepted industry specifications. In addition to the use of indicating gages, the manufacturers were observed inspecting nuts using GO thread plug gages. These gages establish with certainty that maximum material limits have not been exceeded. It should be noted the issues associated with the use of the GO thread ring gage for inspecting bolts (calibration, setting, length of engagement, etc.) do not apply to the use of the GO plug gage for inspecting nuts. Given current industry practice, the FAA is not concerned about the variation in measurement observed in the audit. It is recommended that industry review the criteria in ANSI/ASME B1.2 regarding minimum circumferential contact and also consider developing a maximum value to enhance repeatability of measurement between different gages.

Pitch Diameter - Nuts

125. Inspection for pitch diameter (minimum material) was made using indicating gages with cone & vee profile segments per paragraph 66. All nuts found nonconforming or conforming-with-variation were due to oversized pitch diameters (minimum material). Furthermore, there were indications that some of the crimped nuts may have had oversized pitch diameters. The thread tapping process uses high-precision tooling, which wears in the direction of smaller size. Therefore, these parts were produced using an oversized tap. The specifications allow a manufacturer to tap the thread 0.001" oversized on pitch diameter to accommodate subsequent plating processes. However, the product must meet specification requirements after plate. Manufacturers stated that electro-deposit plating on nut threads is a highly variable process. And, since nuts are plated after crimp, it is not possible to get accurate measurement of pitch diameter after plate. The audit results raise the question whether enough plating is being deposited on the threads in a uniform manner to compensate for the 0.001" oversized tap. The FAA observed nut manufacturers routinely using the full 0.001" allowed. However, at one manufacturer, the tap size was varied depending on the type of plating to be applied. Within the scope of this audit, based on inspection by the independent laboratories, the FAA found that all the nuts determined to be *nonconforming* or *conforming-with-variation* (total of 14, 10.6%) had oversized pitch diameters. It is recommended that manufacturers review their procedures for specifying tap size based on the type of plating to be applied. It is also recommended that for crimped nuts, industry develop a means of establishing whether sufficient plate has been deposited on the threads and that the threads meet dimensional requirements after plating.

Minor Diameter – Nuts

126. It was possible to inspect for minor diameter on crimped nuts. Inspection for minor diameter was conducted using inside calipers and calibrated plain pins. The laboratories found 12 of 12 pieces of a single part number oversized on minor diameter. The pieces ranged from 27% to 53% out of tolerance (avg. 36%). Two pieces from that production lot had been previously tested and found to meet installation, breakaway, and removal torque requirements. On a subsequent FAA visit the manufacturer tested 5 pieces from that production lot for axial tensile strength, all passed. Within the scope of this test, based on inspection by the independent laboratories, the FAA found that all non-crimped nuts and all but 12 crimped nuts (100% of one part number) met design requirements for minor diameter.

Other Characteristics – Nuts

127. At a subsequent visit to a manufacturer of fluid fittings, internally threaded product was inspected for functional assembly using a GO thread plug gage. On two samples the gage face did not reach the seating surface inside the nut. The inspector stated this was an indication of insufficient thread depth. Using a depth gage, the distance from the top of the nut to the face of the plug gage was found it to be within limits. However it was noted there was a length of gage without thread. Adjusting for this length the parts were found to have insufficient thread depth. FED-STD-H28/6A establishes special requirements for thread depth plug gages. These gages can have a maximum distance of ½ pitch between the gage face and centerline of the start of the full form thread. A standard GO thread plug gage may not meet this requirement. ASME B1.2, paragraph 4.1.10 allows a GO thread plug gage to have up to one complete turn (1 pitch) of the end threads to be removed from the gage. Using a standard GO thread plug gage and visually checking that it "bottoms" in the nut is not a reliable inspection method. It may reject conforming hardware or accept non-conforming hardware, depending on the design of the part and the condition on the plug gage. FED-STD-H28/6A also specifies a feature on the gage at minimum thread depth to provide pass/fail indication.

Functional Assembly – Crimped Nuts

128. Crimped nuts were checked for functional assembly using GO thread plug gages. The GO plug gage must engage the nut a minimum of ¾ of 1 turn. Within the scope of this audit, based on inspection by the independent laboratories, the FAA found that all crimped nuts (100%) met functional assembly requirements.

Variation in Measurement - Nuts

129. Variation in measurement can come from three basic sources: the gage, the user of the gage, and the condition of the part itself. Variation in measurement of internal threads was difficult to assess because of the impact of crimp, non-uniformity of plating, and inability to visually inspect the threads. Within the scope of this test, based on inspection by the independent laboratories, the FAA found that measurement was repeatable on nuts that were neither plated nor crimped.

IN-PROCESS AUDITS (PHASE II)

RECEIVING INSPECTION

130. Discussion: Manufacturers are required to verify that the goods/services procured from outside sources conform to the FAA-approved design data and are in a condition for safe operation. The FAA evaluated the manufacturers' inspection/testing of purchased goods and services (i.e., plating, heat treat, and machining, etc.). The FAA conducted a review of incoming shipments to ascertain the manufacturers' receipt of documentation from their supplier. The FAA evaluated whether the manufacturer relies solely on material certifications or certificates of compliance. Nearly all manufacturers visited have implemented procedures for the verification of material properties (i.e., chemical analysis, mechanical properties, etc.).

131. The FAA reviewed certification documentation and inspection records for compliance to applicable design/quality requirements as flowed down to their suppliers/vendors. Additionally, incoming shipments were evaluated for verification of dimensional compliance (i.e., plating thickness, thread geometry, etc.).

132. Summary: Receiving inspections did not provide adequate verification that supplier-furnished products/services conformed to FAA-approved design data. At three of the nine facilities visited, the FAA observed inadequate verification that the goods/services procured from outside sources were in conformance with the FAA-approved design data. Within the scope of this audit, all non-crimped internally threaded hardware, identified as nonconforming, was product where the thread-tapping operation was performed by an outside source.

133. At one facility, the manufacturer was not inspecting for plating thickness or thread geometry using acceptable inspection techniques. This occurred where the manufacturer rejected a lot of material and was in the process of screening the lot 100% for thread geometry. The FAA witnessed the operator applying excessive pressure (squeezing) on the jaws of the indicating gage to achieve a dimensional reading within specification limits. This technique was believed to alter the condition of plating to achieve desirable results.

134. At one facility, the manufacturer was not verifying dimensional conformance for internal thread characteristics. This occurred where the manufacturer sent out product for a thread tapping operation. The manufacturer was not verifying thread geometry nor were they verifying conformance via source inspections or receipt of the vendor's inspection records/documentation.

135. At one facility, the manufacturer was performing inadequate receiving inspection for thread geometry. This occurred where the manufacturer was verifying thread geometry (after plating) with GO/NOT GO gages only. The use of GO/NOT GO gages cannot independently assure compliance with all specification requirements. The use of GO/NOT GO gages (after plating) is acceptable only when thread geometry is verified in

accordance with applicable thread specifications prior to plating. The manufacturer could not provide objective evidence that thread geometry was verified prior to plating. Additionally, these inspections (prior to plating) are required using appropriate sampling plans and inspection personnel.

CONTROL OF RAW MATERIALS

136. Discussion: The FAA evaluated the manufacturer's control of raw materials. Areas of particular interest were those dealing with the handling, storage, inspection, testing, and acceptance of raw materials. The FAA evaluated whether all material was appropriately identified and stored within an area having limited and controlled access. Inspection records were reviewed to assure that adequate receiving inspections were performed, indicating compliance with dimensional and chemical requirements.

137. Shipments of raw material (bar/coil stock) were selected at random to discern whether the manufacturer was maintaining positive indication of status within their quality system (i.e., new receipts, material pending laboratory analysis, and accepted material). The manufacturers' process for controlling the storage of rejected material was also evaluated. The FAA evaluated whether material was segregated based upon its status, such as areas identified for new receipts, material pending laboratory analysis, and accepted material.

138. The FAA evaluated whether material released from storage areas was accountable to a production order, maintained appropriate identification, and was accompanied by the required documentation.

139. Summary: Raw materials were not adequately verified or identified. At three of the nine facilities visited, the FAA witnessed insufficient indication of status within the manufacturers' quality system. At these facilities, material was not being segregated/identified according to its status (i.e., new receipts, material pending laboratory analysis, and accepted material).

140. At one facility, the FAA witnessed excess material located within the manufacturing area. This occurred when the material storage area issued a 300-pound coil of raw material, the manufacturing area used only 200 pounds during production, and the remaining material was not properly returned to the material storage area. This excess material was located within the manufacturing area in excess of 10 days, with no identification or documentation.

141. At one facility, the FAA witnessed several coils of raw material located within the manufacturing area and without "*Raw Material Release Tags,*" as required per the manufacturers' procedure.

IN-PROCESS CONTROLS

142. Discussion: The FAA evaluated the manufacturers' in-process controls relating to various machining operations and special processes (i.e., grinding, thread roll, thread tap, plating, heat treat, etc.). The FAA evaluated the manufacturers' in-process control through the implementation and use of first article testing, statistical process control, and in-process functionality testing. The FAA evaluated the manufacturers' proper use of measuring and test equipment for in-process inspections. The FAA evaluated the manufacturers' implementation and use of detailed work instructions for all applicable machining operations and special processes.

143. Summary: The manufacturers' work instructions did not adequately control the manufacturing process. Special processes were not accomplished in accordance with the established process specifications. The FAA identified deficiencies relative to inadequate in-process controls at six of the nine facilities visited.

144. At one facility, the manufacturer did not maintain detailed work instructions for the operators within their plating department. This manufacturer maintained that conformance to all plating requirements was controlled through dimensional inspections. Dimensional inspections alone will not assure quality plating. The manufacturer did not provide the operator with documented work instructions detailing the various parameters of the plating process (i.e., processing time and/or temperature of chemical solutions).

145. Within the scope of this audit, six facilities were performing in-house plating/coating operations. The remaining three facilities relied exclusively on outside sources for plating/coating (note: deficiencies identified within these facilities were reported under the subtitles of Receiving Inspection and/or Control of Suppliers). Of the six facilities performing in-house plating, the FAA observed deficiencies at four of the six. The deficiencies identified were in the categories of tank cleanliness, frequency of chemical analysis, maintaining chemical solutions within their proper range, and the lack of documented procedures/instructions. The FAA observed no deficiencies at the two facilities that were committed to third party evaluation/certification of their plating department.

146. At one facility, the manufacturer was observed producing nonconforming material. This was observed during a machining operation where the operator was charting dimensions, via statistical methods, that were outside specification limits. According to the SPC charts, nonconforming material was being produced for approximately 4 hours. Once these errors were identified, the operator took immediate corrective action.

147. At one facility, the manufacturer did not adequately control "split lot" manufacturing. This occurs when smaller quantities of larger production lots are split off and accelerated due to urgent needs. The FAA observed various split lots that were not appropriately identified and were not accompanied by a "shop traveler" or "work order." This observation was found to be in conflict with the manufacturers' quality manual,

which indicated that all production lots be accompanied by the applicable "shop traveler" or "work order."

148. At two facilities, the manufacturers did not adequately identify material in process to a production lot. In-process material transported in containers/pans did not contain the required container/pan tags to provide adequate identification to the production lot. Additionally, those lots requiring multiple containers/pans did not contain sequential numbering (container/pan 1 of 6, 2 of 6, 3 of 6, etc.).

IN-PROCESS INSPECTION REQUIREMENTS

149. Discussion: The FAA evaluated the manufacturers' use of in-process inspections for characteristics that subsequent processing would preclude conformance verification to the FAA-approved design data. Additionally, the FAA evaluated whether in-process inspections were performed in accordance specification requirements.

150. The FAA evaluated whether thread geometry was verified for dimensional compliance prior to plating or crimping (internal thread) operations. Additionally, the FAA evaluated whether final acceptance of characteristics, performed in-process, were being accomplished by appropriate inspection personnel (those identified for final acceptance) and that required inspection levels (sampling requirements) were followed.

151. Summary: Within the scope of this audit, the FAA observed considerable inconsistency with regards to in-process inspections. All manufacturers are not inspecting product in accordance with the designers' product specification requirements. The performance of in-process inspections, for the final acceptance of selected characteristics, was not being accomplished by the appropriate inspection personnel and according to the required sampling criteria.

152. Of the three facilities manufacturing internally threaded hardware, the FAA witnessed only one facility performing an in-process *final inspection* of thread geometry prior to the crimping operation. Two other facilities were inspecting thread geometry prior to crimping, but were not performing those inspections under final acceptance criteria, using appropriate personnel and required inspection levels.

IMPLEMENTATION OF DESIGN/QUALITY REQUIREMENTS

153. Discussion: The FAA evaluated whether all pertinent design/quality requirements were adequately flowed-down to all levels within the manufacturing process. To assess compliance with FAA-approved design requirements and proper implementation thereof, the FAA reviewed specification requirements, manufacturing documentation (including operation sheets, work orders, inspection/test records, etc.), outgoing purchase orders, and the vendor's invoice, certifications, and receiving documentation.

154. Summary: At two of the nine facilities visited, the FAA identified discrepancies with flow down and implementation of design/quality requirements.

155. At one facility, the manufacturer could not provide evidence that proper inspection requirements were flowed-down to subtier manufacturers. Additionally, inspection documentation (receiving inspection) did not provide objective evidence that thread geometry was verified.

156. At one facility, the manufacturer did not flow-down accurate SPC requirements to the subtier manufacturer. This manufacturer did not flow-down the requirement to monitor pitch diameter, after plating or solid film lubrication, by SPC methods.

PROPER USE AND IMPLEMENTATION OF SPECIFICATIONS

157. Discussion: On May 14, 1997, DOD inactivated MIL-S-8879C through Notice 1. On August 12, 1997, the DOD issued MIL-S-8879C Notice 2, which provided notification that the specification had not been cancelled and it was available for use by any private sector firm or Government entity other than DOD. Unlike other inactivated military specifications, the DOD did not reference a superseding document for MIL-S-8879C.

158. On February 26, 1999, the FAA issued Advisory Circular (AC) 21-41, *Continued Use of MIL-S-8879C, General Specification for Screw Threads, Controlled Radius Root With Increased Minor Diameter*. AC 21-41, paragraph 3.c., states that when military specifications are referenced, those specifications become part of the FAA-approved design. When MIL-S-8879 is referenced within an FAA-approved drawing, civil aviation entities will continue to use MIL-S-8879C as the approved means of ascertaining thread geometry.

159. Summary: The FAA observed the use of AS8879 at four of the nine facilities visited. The DOD did not specify AS8879 as superseding MIL-S-8879. A FAA design approval holder must receive explicit FAA approval to use AS8879 in place of MIL-S-8879. Additionally, all changes must be reflected and approved within their drawings and specifications. Any unauthorized substitution of AS8879 in lieu of MIL-S-8879 is in conflict with the FAA-approved design.

160. Although it was not the primary focus of this audit, the FAA observed other instances in which the manufacturer was not in compliance with the designer's process specifications.

161. The latest revision levels of the designer's process specifications were not in use. This observation was apparent at two of the nine facilities visited. At one facility, the manufacturer was not charting (via statistical methods) the required "Key Characteristics" (i.e., functional thread pitch diameter) as specified in the designer's process specification. At another facility, the manufacturer was not following the designer's process specification with regard to sample size when using the optical comparitor for inspection.

AVAILABILITY/USE OF MEASURING AND TEST EQUIPMENT

162. Discussion: The FAA evaluated the manufacturers' availability and use of measuring and test equipment. The FAA evaluated the manufacturers' compliance with industry standards (ANSI/ASME B1.3M) and/or the designer's product specifications relating to the use of measuring/test equipment.

163. Summary: At eight of the nine facilities visited, the FAA identified deficiencies relating to the manufacturers' availability and use of measuring and test equipment. Seven of nine facilities were observed using *"Thread Groove Diameter Profile Rolls"* to measure pitch diameter of externally threaded hardware. In accordance with the requirements of ANSI/ASME B1.3M, the only gaging elements authorized are identified as *"Cone & Vee Profile Rolls."* At one facility, the FAA observed *"Full Form Segments"* being used to measure the pitch diameter of internally threaded hardware. In accordance with the requirements of ANSI/ASME B1.3M, the only gaging elements authorized are identified as *"Cone & Vee Form Segments."* At another facility, the manufacturer was observed using *"Full Profile Rolls,"* with alternate ribs removed, to measure functional diameter. Since these rolls were not being used elsewhere and the fact that ANSI/ASME B1.3M remains silent, the FAA finds their use questionable. At two facilities, the FAA observed the use of adjustable (split) threaded ring gages as set masters for indicating thread gages. There are no provisions identified within ANSI/ASME B1.2 permitting the use of adjustable (split) threaded ring gages as setting masters. To consider this as an acceptable practice, the adjustable threaded ring gages would need to be manufactured to class "W" tolerances. The inherent inaccuracies in setting/calibrating an adjustable threaded ring gage makes their use highly questionable.

164. The FAA evaluated the manufacturers' process of locating the set plug/ring master in proximity to indicating thread gages during use. As observed at the four of the nine facilities visited, indicating gages are set within the calibration laboratory and then issued to the inspection area for use. Once the gages are issued to the inspection area, calibration personnel routinely reset the gages using the appropriate set masters on an average of once/twice per day. The set masters are kept in the calibration laboratory while the gages are being used within the inspection area. The FAA has observed that in most facilities, the set masters are included with each gage when they are issued to the inspection area. ANSI/ASME B1.2 establishes that for screw-thread gaging, a temperature of 68°F ±2°F is the standard used internationally for linear measurements. As product threads are frequently checked at temperatures which are not controlled, it is desirable that the coefficient of the thermal expansion of gages be the same as that of the product on which they are used. The accredited laboratories utilized within the scope of this audit accounted for thermal expansion by requiring measurement equipment and product to stabilize for a minimum of 4 hours. Recognizing that ANSI/ASME B1.2 requires temperature stabilization for inspecting product, the FAA finds it unacceptable to set a gage without first allowing the gage and the set masters to stabilize at the same temperature. Additionally, the FAA questions the frequency of setting these gages (once/twice per day) and finds that the allowable gage errors may lead to the production and acceptance of nonconforming product.

165. The FAA evaluated whether the manufacturers were using gages identified as "*Reference Only*" for product acceptance or statistical process control. Gages identified as such are widely used throughout the fastener industry for in-process dimensional checks performed by the machine operator. One facility indicated that equipment identified as "*Reference Only*" was removed from use due to their on-going AS9000 certification. It was stated that AS9000 prohibits the use of measuring and test equipment identified as "*Reference Only*." However, the FAA observed two facilities using these gages for the acceptance of product.

166. As required by the designers' product specification, the manufacturer is required to inspect thread-to-shank runout using overlay charts and an optical comparitor. This requirement applied to five of the nine facilities visited. Of the five facilities, three were not utilizing inspection equipment as required.

167. At one facility, the manufacturer applied a lubricant when inspecting cadmium-plated parts using a GO thread ring gage. When inspected without the use of a lubricant, the parts were found to be nonconforming. The FAA questions the use of a lubricant to reduce friction when inspecting product with a GO/NOT GO ring gage. At another facility, the manufacturer was observed using gaging elements designed to measure functional diameter size to measure pitch diameter size on internal threads. The FAA was unable to locate gaging elements, authorized by ANSI/ASME B1.3M, to measure pitch diameter size within this facility.

CALIBRATION PROGRAM

168. <u>Discussion:</u> The FAA evaluated the manufacturers' calibration program to assure that product inspection/acceptance was based upon adherence to industry calibration standards. The FAA evaluated whether the manufacturer had a documented calibration program, including an adequate recall system prohibiting the use of expired gages/equipment. The FAA evaluated whether the manufacturer was maintaining all gages/equipment in accordance with the gage/equipment manufacturers' maintenance procedures or other documented maintenance procedures. The FAA evaluated whether all calibration was performed in accordance with industry practices/standards and if there was adequate control of outside calibration sources. Any manufacturer performing in-house calibrations was evaluated for maintaining adequate environmental control of the calibration laboratory. The FAA evaluated whether all manufacturers maintained an adequate identification system for all individual gages/equipment (i.e., serial numbers, calibration stickers, etc.) and that no gages/equipment were in use with overdue/expired calibration.

169. <u>Summary:</u> Within the scope of this audit, the FAA observed deficiencies relating to calibration at all of the facilities visited. The FAA observed no standardized methods regarding the calibration, inspection, and maintenance of indicating thread gages or their associated components. For instance, none of the facilities visited was adequately inspecting the thread gaging elements. The manufacturer-suggested method to determine

wear on gaging elements is by optical projection (at a minimum of 50X magnification) against an overlay chart manufactured to "X" tolerances[11]. Additionally, none of the facilities visited could provide objective evidence that other characteristics such as perpendicularity, parallelism, spring tension, and overall wear were being verified. Not a single facility visited maintained documented calibration, inspection, or maintenance procedures for indicating thread gages or their associated components. ANSI/ASME B1.2 establishes minimum calibration standards for indicating thread gages and their components.

170. Working thread ring gages must be properly adjusted in order to assure the acceptance of conforming product. At seven of the nine facilities visited, the FAA observed inconsistencies relating to the adjustment/condition of working thread ring gages. The FAA identified instances where the full form portion of the "W" tolerance thread setting GO plug gage would completely enter the GO working thread ring gage. ANSI/ASME B1.2, paragraph 5.1.8, states, "The pitch cylinder is transferred by the setting of the thread ring gage to the applicable truncated setting plug gage." This is essentially repeated in ANSI/ASME B1.2, Appendix A, paragraph A3.1. The FAA recognizes that this is a qualitative judgement. However, the phrases "light drag" and "snug" have been used to describe proper adjustment. It has been FAA's experience that no more than one full turn of the full form portion of the applicable truncated thread setting plug gage should enter a properly adjusted working threaded ring gage. A properly set threaded ring gage was defined by the FAA as one that would receive the truncated portion of an un-lubricated "W" tolerance thread setting plug gage for a "snug" fit (no freeplay) between the gages. Additionally, the full form portion of the un-lubricated setting plug gage should not enter the gage more than one full turn, using light (finger tight) torque.

171. Thread-setting plug gages are used to set adjustable threaded ring gages, check solid threaded ring gages, and set indicating thread gages. They are also applied to detect wear on indicating gages and their gaging elements while in use. Thread-setting plug gages must be calibrated to "W" tolerances for pitch diameter, lead, flank angle, major diameter, and minor diameter in accordance with ANSI/ASME B1.2. ANSI/ASME B1.2, Appendix A, provides methods for the calibration and inspection of these gages. The FAA did not observe proper calibration and inspection of thread-setting plug gages at seven of the nine facilities visited. At best, the facilities visited were performing a visual inspection and measuring for pitch diameter. The FAA observed thread-setting gages that, when compared to a known master, were outside "W" tolerances with no indication on the gage of the actual measured value. The FAA observed thread-setting gages that, when compared to a known master, were outside "X" tolerances and because of this were not usable. The FAA observed the use of thread-setting gages that were outside "W" tolerances but within "X" tolerances. However, the indicating gage was not adjusted to the actual measured pitch diameter of the setting gage as required. One facility utilizing an outside source for the calibration of thread setting plug gages exhibited no deficiencies.

[11] "X" tolerances are defined (ANSI/ASME B1.2, Table 6) as those being larger than "W' tolerances and are used for product inspection gages.

172. At one facility, the FAA observed measuring and test equipment that was available for use beyond its established calibration due date, indicating inadequacies in their calibration recall system. At two facilities, the FAA observed inadequate environmental controls of in-house calibration. These facilities either were not monitoring the temperature/humidity of the calibration facility or there were documentation errors while manually charting the environmental conditions.

STATISTICAL SAMPLING INSPECTION PLANS

173. Discussion: Throughout the aviation manufacturing industry, various military and/or industry standards regarding statistical sampling inspection plans (e.g., Mil-Std-105, Mil-Std-414, ANSI/ASQC Z1.4-1993, and ANSI/ASQC Z1.9-1993) are referenced within FAA-approved design data or as part of an FAA-approved quality control system. Historically, the FAA has accepted these documents/standards for use by the PAH as the basis for statistical sampling inspection plans. These documents/standards, when properly applied, provide adequate assurance that parts and materials will conform to the FAA-approved type design and will be in a condition for safe operation.

174. Title 14 Code of Federal Regulations, Part 21, Certification Procedures for Products and Parts, §21.165(b), §21.303(k), and §21.607(b) require the PAHs to ensure their product conforms to design data and is in condition for safe operation. Therefore, the use of acceptance/rejection criteria in sampling tables where the number of defectives in the lot sample is greater than zero may NOT be used for inspection/acceptance of anything other than minor characteristics.

175. Statistical sampling inspection plans are based upon a classification of characteristics of product design parameters. This classification determines the appropriate inspection level, based on the potential of specific characteristics affecting safety. When a PAH implements statistical sampling as part of its quality control system, it must establish a system of evaluation and classification of design parameters that will preclude the acceptance of nonconforming characteristics affecting safety. The most commonly specified characteristic classifications are critical, major, and minor.

176. Summary: Nearly all inspections performed within the fastener industry are accomplished in accordance with some sort of statistical sampling inspection plan. The FAA observed deficiencies related to statistical sampling at seven of the nine facilities visited. Five facilities were not using a statistical sampling inspection plan based on C=0 acceptance/rejection criteria. All facilities were either using their own statistical sampling inspection plans or sampling requirements that were flowed down within the purchase order. In either case, statistical sampling inspection plans are required to be based on C=O acceptance/rejection criteria.

177. The FAA identified discrepancies relating to the classification of characteristics at five of the nine facilities visited. These facilities were either not adhering to the

classification that had been developed (including purchase order/process specification requirements), or they lacked a system of classification of characteristics altogether.

STATISTICAL PROCESS CONTROL

178. Discussion: SPC may be implemented for three primary purposes: (1) to monitor and detect variation in a manufacturing process, (2) to determine if the process is capable of meeting design specification, and (3) to provide a basis for statistical sampling. When properly implemented, SPC is also a continuous inspection/verification of the manufacturing process to which it is applied and may help to reduce defects in the specific characteristics being monitored. Implementation should include a process capability study and a determination of the level of application.

179. Process capability describes the ability of a process to meet design specifications. A process is said to be in statistical control if the manufactured characteristic exhibits only random variation from the process output average. Random or natural variation occurs by chance, cannot be traced to a single cause, and can be reduced only by improving the process. The limits of random variation can be predicted; thus, the conditions producing the variation are said to be under control. A capable process should consistently produce characteristics that fall within engineering design tolerances.

180. Summary: Within the scope of this audit, the FAA observed extensive use of SPC techniques as well as various levels of implementation. The FAA observed the majority of manufacturers utilizing computerized/automated SPC programs. However, we did note that four of the nine facilities visited used non-computerized (paper/pen) techniques. With one exception, all SPC-related deficiencies were identified within facilities where SPC was not computerized/automated.

181. At three of the nine facilities visited, the SPC control charts in use did not adequately identify the upper and lower control limits (UCL/LCL). The control charts merely charted values to be within the minimum/maximum specification limits. It was apparent that specification limits were confused with control limits. Specification limits are the established design parameters, whereas control limits are based strictly on the variation in the process, describing inherent variation in sample ranges and averages.

182. At one facility, the FAA observed that the upper control limits (UCL) and lower control limits (LCL) were established within 0.0001" of the minimum/maximum specification limits. The FAA questions whether this practice is in compliance with the designer's statistical process requirements. By utilizing much of the specification tolerance within the control limits, there is a reduction in the degree of certainty that the process is in control.

183. At one facility, the FAA discovered inconsistencies between the work order and SPC control plan. The SPC control plan identifies which characteristics are to be controlled via SPC techniques. The control plan also specifies sample size and sample frequency. The FAA observed instances in which SPC was required per the work order

but there was no indication of such on the control plan (one questions what sample size/frequency the operator would use). Additionally, there were instances where SPC was required on the control plan but there was no indication of such reflected on the work order (one questions whether the operator would utilize SPC or not).

184. At one facility, the FAA observed that the resolution (0.0005” increments) of the SPC control chart was not compatible with the established control parameters. The resolution of 0.0005” enveloped the established control parameters, thus providing no indication of process control. Additionally, the FAA questions the adequacy of SPC training provided for the operators. In one case, the operator was not clear on what should be plotted on the control chart.

185. The FAA observed at a facility that the manufacturer was not charting the required “Key Characteristics” (functional thread pitch diameter) as specified within the designer’s process specifications.

FINAL INSPECTION/ACCEPTANCE

186. Discussion: The FAA evaluated whether the manufacturers’ process of final inspection and acceptance provided the necessary assurance that all products were in compliance with the FAA-approved design data. The FAA assessed whether the manufacturer was utilizing the proper specifications, including applicable revision levels.

187. All inspections relating to product acceptance must be performed using calibrated measuring and test equipment. The FAA evaluated whether the manufacturers were using proper measuring and test equipment, as referenced in applicable product specifications or industry standards. The FAA evaluated whether the manufacturers were using measuring and test equipment identified as “*Reference Only*” for the acceptance of product, and if the manufacturer was verifying conformance to all product characteristics, as specified within the FAA-approved design data.

188. The FAA evaluated whether the manufacturers were inspecting product to the prescribed sample size, as referenced in the applicable product specification or drawing. Additionally, the FAA evaluated whether the manufacturer was adhering to C=0 acceptance/rejection criteria or, in the case of a supplier, that as specified within the designer’s product specification.

189. For those manufacturing internally threaded hardware, the FAA evaluated whether the manufacturers were performing final inspection of thread geometry prior to deformation/crimping.

190. Summary: Within the scope of this audit, the FAA observed systemic weaknesses in the area of final inspection/acceptance. The deficiencies identified indicate insufficient inspection methods and plans ensuring that product was inspected for conformance to the FAA-approved design data. Within the scope of this audit, the final

inspection/acceptance process reestablished many of the same deficiencies previously identified throughout the manufacturing process.

191. Improper use of specifications. The FAA observed instances in which the manufacturer had erroneously substituted AS8879 in lieu of MIL-S-8879, were not using the latest revision, and/or were not adhering to the requirements of the designers' product specifications.

192. Improper use of measuring and test equipment. The FAA identified cases in which the manufacturers were not employing authorized measuring and test equipment as specified within ANSI/ASME B1.3M. The FAA observed two facilities using measuring and test equipment identified as "*Reference Only*" for the acceptance of product. As echoed throughout the facilities visited, measuring and test equipment identified as "*Reference Only*" is not calibrated in accordance with industry standards.

193. Adherence to technical/quality requirements specified within the FAA-approved design data. Within the scope of this audit, there were no manufacturers that could provide objective evidence that all characteristics were being verified per specification/drawing requirements. Although some manufacturers were performing the required inspections, all results were not documented accordingly. Not all facilities manufacturing internally threaded hardware were performing final acceptance of thread geometry prior to crimping/deformation.

194. The FAA identified deficiencies relating to strict adherence to statistical sampling requirements and miscellaneous records/documentation errors.

CONTROL AND DISPOSITION OF REJECTED MATERIAL

195. Discussion: The FAA evaluated the manufacturers' control and disposition of rejected material. The areas of special interest included: (1) the assurance that the manufacturers maintained adequate procedures addressing rejected material; (2) the manufacturers maintained a secured area, with limited access, exclusively for the storage of rejected material; and (3) all rejected material was properly identified (i.e., rejection tags were used). Additionally, the FAA reviewed and evaluated the manufacturers' scope and authority of Material Review Board (MRB) determinations.

196. Summary: Within the scope of this audit, there were no deficiencies identified relating to the control and disposition of rejected material.

CONTROL OF SUPPLIERS

197. Discussion: The FAA evaluated the manufacturers' ability to ensure that supplier materials, products, and services were in conformance to the FAA-approved design data. Within the fastener industry, special processes such as plating, anodizing, and heat-treating rely heavily on the manufacturers' supplier control system. Additionally, various machining/tapping operations performed by outside sources are dependent on an

adequate system of supplier control. The FAA evaluated the manufacturers' control of supplier design, including their system of controlling changes. The FAA evaluated whether the manufacturers were performing initial and periodic evaluations of their suppliers and implementing corrective action when deficiencies were identified. The FAA evaluated the manufacturers' ability to adequately flow-down design and quality requirements to their suppliers. The FAA evaluated whether the manufacturers were utilizing receiving inspection, inspection at source, or equivalent to verify that supplier-furnished products or services were in conformance with the FAA-approved design data.

198. Summary: As viewed within the scope of this audit, supplier control can be improved dramatically. Initial and periodic evaluations of suppliers were not made, as necessary, or corrective actions were not taken to correct system deficiencies. The evaluated facilities did not adequately flow-down applicable technical and quality requirements to suppliers. There were inconsistencies relating to the flow-down of technical/quality requirements at various levels at all the facilities visited. The FAA was unable to validate whether the manufacturers' quality departments were reviewing/verifying all outgoing purchase orders to assure the proper flow-down of technical/quality requirements.

199. At one facility, the FAA observed three consecutive incoming lots of material (all received from the same plating source) that were rejected for an oversized plating condition. Upon review, the manufacturer's receipt inspection log indicated that oversized conditions were routinely received from this plating source, confirming the absence or lack of adequate corrective action

200. Within the scope of this audit, the FAA observed that the majority of supplier audits are performed via questionnaire/survey rather than on site. Also, the frequency of supplier audits ranged anywhere between 2 and 3 years.

201. There were no discrepancies identified relating to the manufacturers' control of supplier design, including their system of controlling changes.

CUSTOMER BASE

202. Discussion: The FAA evaluated the manufacturers' customer base to ascertain compliance to Title 14 Code of Federal Regulations, Part 21, Section 21.303. The process used was designed to detect the production of unapproved parts. The FAA sought to assure that all products were produced pursuant to a FAA production approval (i.e., PMA, TSO, etc.). For those products manufactured without evidence of a FAA production approval, the FAA evaluated whether production was under the direct control of a FAA production approval holder. The FAA evaluated, through purchasing documentation, whether the quantities produced and sold through supplier/distributor relationships exceeded the quantities ordered by the FAA production approval holder.

203. Summary: At four of the nine facilities visited, the FAA observed the manufacturer producing product without a FAA production approval, or producing product for persons

other than those holding a FAA production approval (i.e., direct sales to an authorized supplier/distributor). In some instances, purchasing and/or manufacturing documentation indicated that the product was intended for "end use" by a FAA production approval holder. However, in most cases there was no objective evidence that production was under the direct control of the FAA PAH.

204. During a review of purchasing documentation, the FAA identified inconsistencies among the various subtier purchase orders. For example, the purchase order between the *FAA production approval holder and their authorized supplier (first tier)* contained information that was inconsistent with the information delineated in the purchase order between the *authorized supplier (first tier) and the manufacturer (second tier)*. The most common inconsistencies were related to drawing/specification revision levels, quality requirements, and/or production quantities.

205. The FAA observed that the PAHs are not maintaining adequate control of production quantities throughout all levels of manufacturing.

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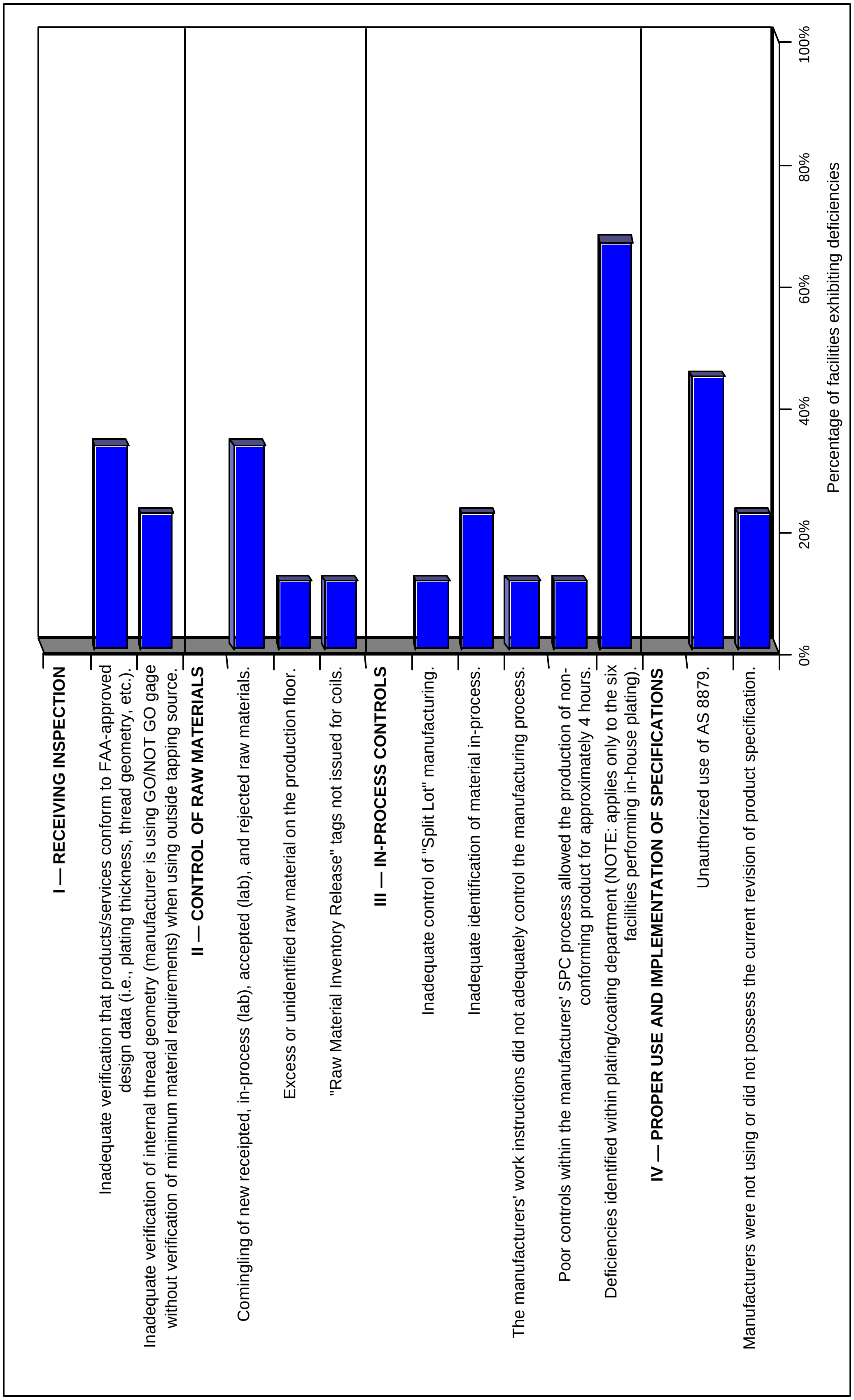
I — RECEIVING INSPECTION
Inadequate verification that products/services conform to FAA-approved design data (i.e., plating thickness, thread geometry, etc.).
Inadequate verification of internal thread geometry (manufacturer is using GO/NOT GO gage without verification of minimum material requirements) when using outside tapping source.
II — CONTROL OF RAW MATERIALS
Comingling of new receipted, in-process (lab), accepted (lab), and rejected raw materials.
Excess or unidentified raw material on the production floor.
"Raw Material Inventory Release" tags not issued for coils.
III — IN-PROCESS CONTROLS
Inadequate control of "Split Lot" manufacturing.
Inadequate identification of material in-process.
The manufacturers' work instructions did not adequately control the manufacturing process.
Poor controls within the manufacturers' SPC process allowed the production of non-conforming product for approximately 4 hours.
Deficiencies identified within plating/coating department (NOTE: applies only to the six facilities performing in-house plating).
IV — PROPER USE AND IMPLEMENTATION OF SPECIFICATIONS
Unauthorized use of AS 8879.
Manufacturers were not using or did not possess the current revision of product specification.
0%
20%
40%
60%
80%
100%
Percentage of facilities exhibiting deficiencies

Figure 1

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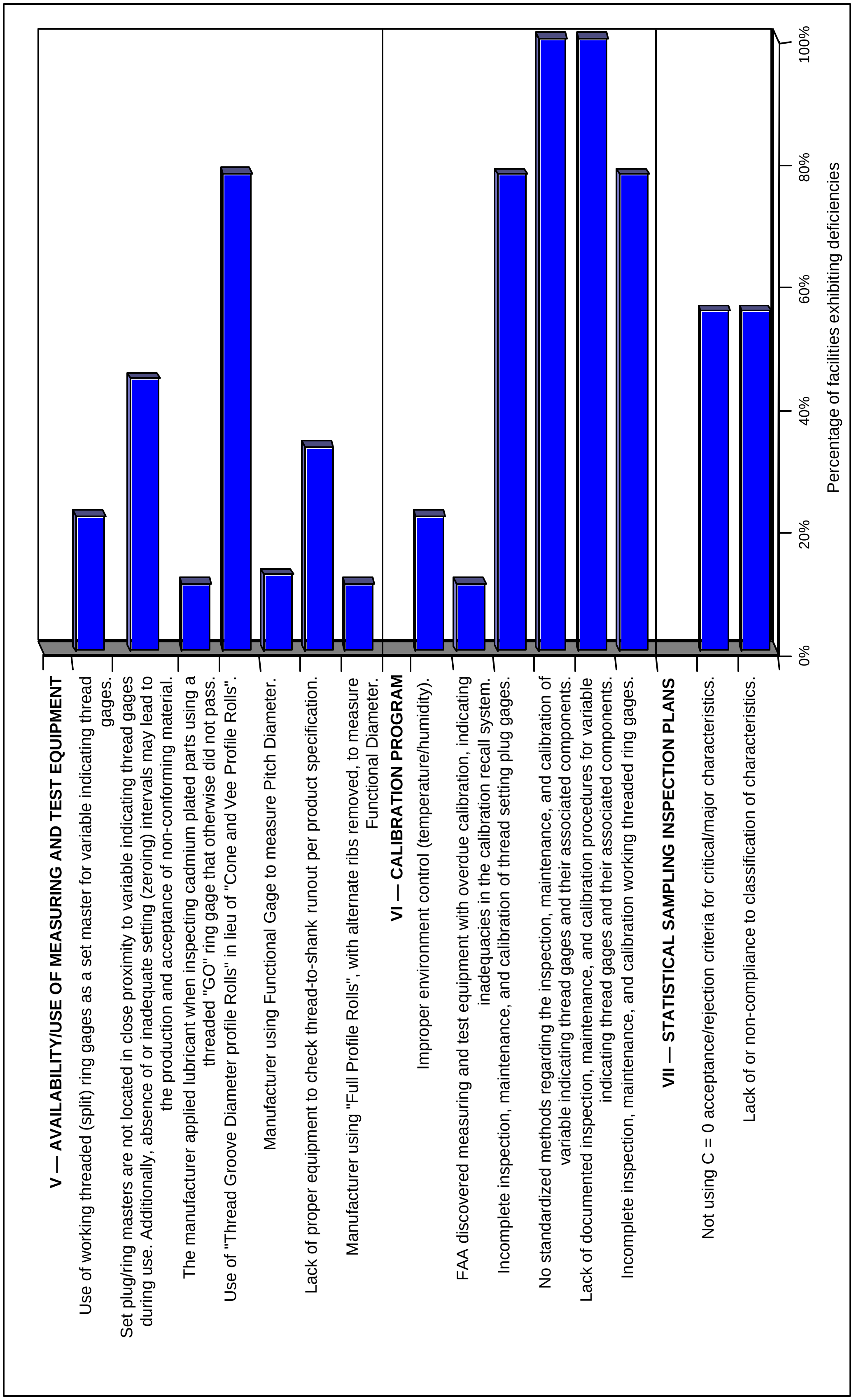
V — AVAILABILITY/USE OF MEASURING AND TEST EQUIPMENT
Use of working threaded (split) ring gages as a set master for variable indicating thread gages.
Set plug/ring masters are not located in close proximity to variable indicating thread gages during use. Additionally, absence of or inadequate setting (zeroing) intervals may lead to the production and acceptance of non-conforming material.
The manufacturer applied lubricant when inspecting cadmium plated parts using a threaded "GO" ring gage that otherwise did not pass.
Use of "Thread Groove Diameter profile Rolls" in lieu of "Cone and Vee Profile Rolls".
Manufacturer using Functional Gage to measure Pitch Diameter.
Lack of proper equipment to check thread-to-shank runout per product specification.
Manufacturer using "Full Profile Rolls", with alternate ribs removed, to measure Functional Diameter.
VI — CALIBRATION PROGRAM
Improper environment control (temperature/humidity).
FAA discovered measuring and test equipment with overdue calibration, indicating inadequacies in the calibration recall system.
Incomplete inspection, maintenance, and calibration of thread setting plug gages.
No standardized methods regarding the inspection, maintenance, and calibration of variable indicating thread gages and their associated components.
Lack of documented inspection, maintenance, and calibration procedures for variable indicating thread gages and their associated components.
Incomplete inspection, maintenance, and calibration working threaded ring gages.
VII — STATISTICAL SAMPLING INSPECTION PLANS
Not using C = 0 acceptance/rejection criteria for critical/major characteristics.
Lack of or non-compliance to classification of characteristics.
0%
20%
40%
60%
80%
100%
Percentage of facilities exhibiting deficiencies

Figure 2

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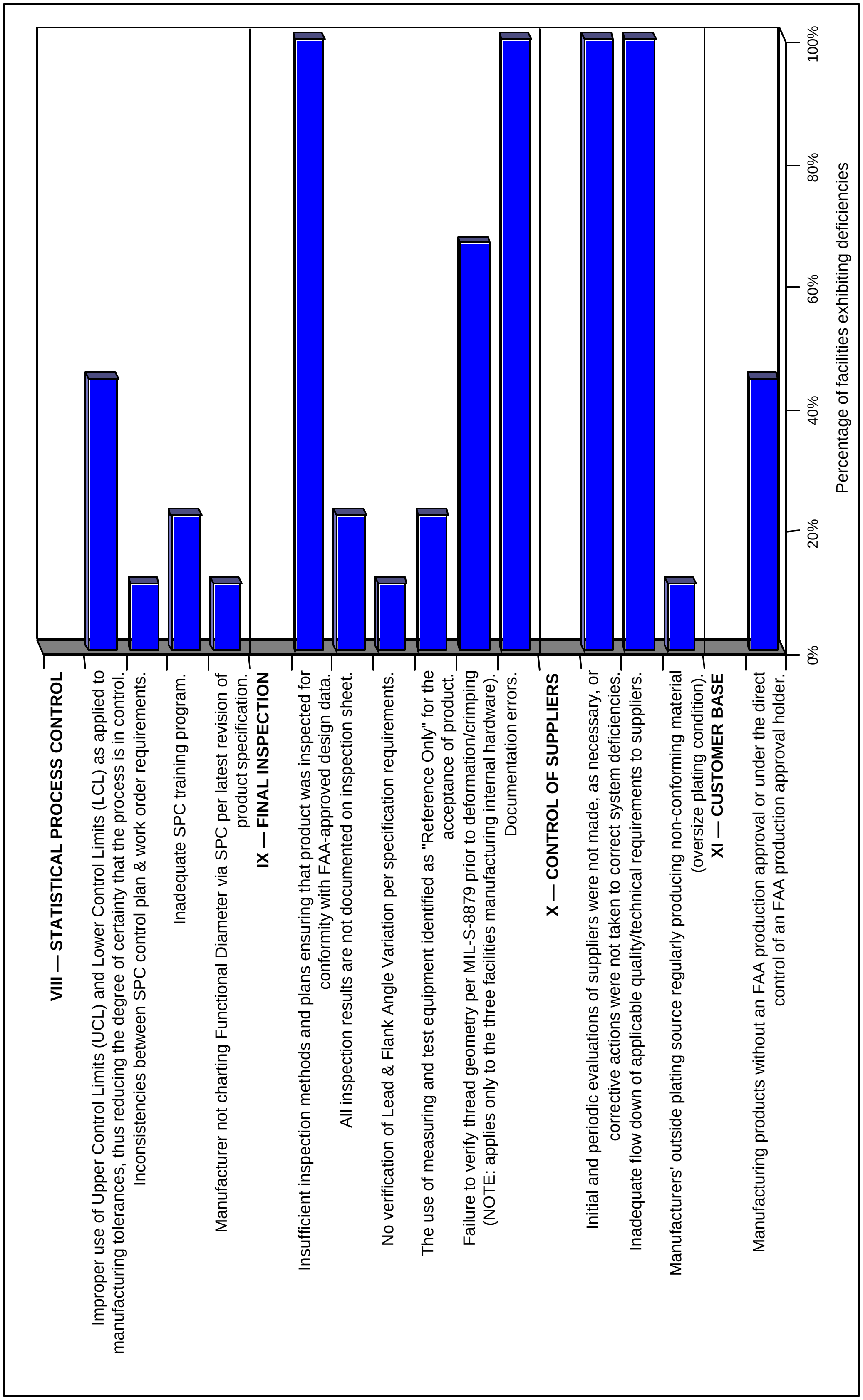
VIII — STATISTICAL PROCESS CONTROL
Improper use of Upper Control Limits (UCL) and Lower Control Limits (LCL) as applied to manufacturing tolerances, thus reducing the degree of certainty that the process is in control.
Inconsistencies between SPC control plan & work order requirements.
Inadequate SPC training program.
Manufacturer not charting Functional Diameter via SPC per latest revision of product specification.
IX — FINAL INSPECTION
Insufficient inspection methods and plans ensuring that product was inspected for conformity with FAA-approved design data.
All inspection results are not documented on inspection sheet.
No verification of Lead & Flank Angle Variation per specification requirements.
The use of measuring and test equipment identified as "Reference Only" for the acceptance of product.
Failure to verify thread geometry per MIL-S-8879 prior to deformation/crimping (NOTE: applies only to the three facilities manufacturing internal hardware).
Documentation errors.
X — CONTROL OF SUPPLIERS
Initial and periodic evaluations of suppliers were not made, as necessary, or corrective actions were not taken to correct system deficiencies.
Inadequate flow down of applicable quality/technical requirements to suppliers.
Manufacturers' outside plating source regularly producing non-conforming material (oversize plating condition).
XI — CUSTOMER BASE
Manufacturing products without an FAA production approval or under the direct control of an FAA production approval holder.
0%
20%
40%
60%
80%
100%
Percentage of facilities exhibiting deficiencies

Figure 3

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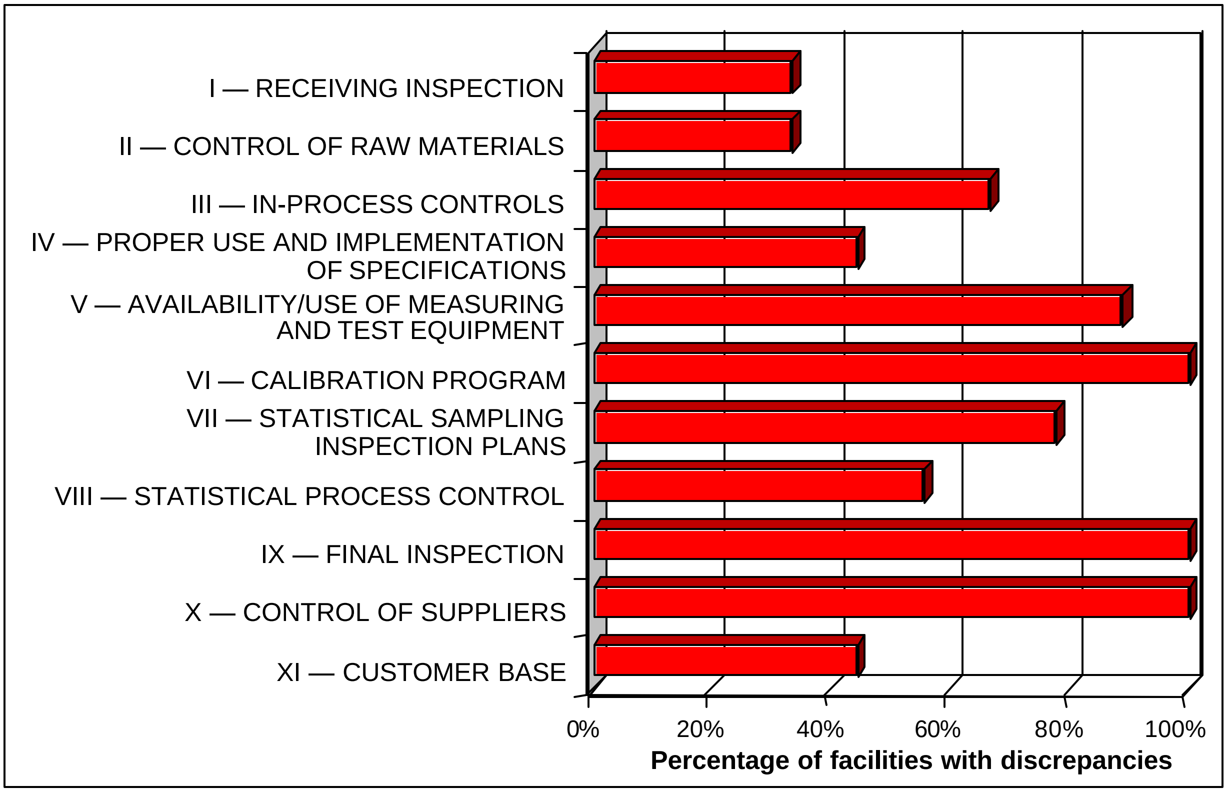
I — RECEIVING INSPECTION
II — CONTROL OF RAW MATERIALS
III — IN-PROCESS CONTROLS
IV — PROPER USE AND IMPLEMENTATION OF SPECIFICATIONS
V — AVAILABILITY/USE OF MEASURING AND TEST EQUIPMENT
VI — CALIBRATION PROGRAM
VII — STATISTICAL SAMPLING INSPECTION PLANS
VIII — STATISTICAL PROCESS CONTROL
IX — FINAL INSPECTION
X — CONTROL OF SUPPLIERS
XI — CUSTOMER BASE
0%
20%
40%
60%
80%
100%
Percentage of facilities with discrepancies

Figure 4

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CONCLUSIONS

INSPECTIONS AND TESTS (PHASE I)

GENERAL

206. Within the scope of this audit:

a. MIL-S-8879 is used extensively by the commercial aviation industry, its inactivation without supersession by the DOD has had a negative affect on the industry (paragraph 8).

b. The PAH found 31 of 547 (5.7%) bolts to be dimensionally nonconforming (paragraph 88).

c. Based on inspection by the independent laboratories, the FAA found that of 910 bolts inspected 103 (11.3%) were dimensionally nonconforming (paragraph 88).

d. The PAHs and independent laboratories found that all 484 crimped nuts passed functional assembly inspection (paragraph 92).

e. The PAHs found 1 of 88 (1.1%) non-crimped nuts to be dimensionally nonconforming (paragraph 93).

f. Based on inspection by the independent laboratories, the FAA found that of 132 non-crimped nuts inspected, four (3.0%) were dimensionally nonconforming and an additional 10 (7.6%) to be conforming-with-variation (paragraph 93).

g. All 288 test pieces (13% of total audit population) met their mechanical performance and/or material properties requirements (paragraph 97).

h. To the extent dimensional nonconformities existed in the test samples, they were of small magnitude and did not prevent the samples from meeting mechanical performance requirements (paragraph 97).

i. The inspection criteria established within MIL-S-8879C does not meet FAA regulatory requirements that product conform to approved design data (paragraph 114).

SPECIFIC

207. Within the scope of this audit, based on inspection by the independent laboratories, the FAA found that of the 910 bolts inspected:

a. Twenty-six bolts (2.9%) did not conform to design requirements for functional diameter (paragraph 101).

b. One bolt (0.1%) did not conform to design requirements for pitch diameter (paragraph 105).

c. Four bolts (0.4%) did not conform to design requirements for major diameter (paragraph 106).

d. Two bolts (0.2%) did not meet design requirements for shank diameter (paragraph 116).

208. Within the scope of this audit, based on inspection by the independent laboratories, the FAA found that:

a. All bolts (100%), inspected on both the indicating gages and optical comparitor, met design requirements for minor diameter (paragraph 107).

b. All bolts (100%) met design requirements for thread root radius (paragraph 108).

c. All bolts (100%) met design requirements for head-to-shank fillet radius (paragraph 115).

d. All bolts (100%) met design requirements for incomplete threads and thread root radius in the runout area (paragraph 117)

e. The GO full profile roll indicating gages detected only 35% of bolts that did not pass a GO thread ring gage (paragraph 104).

f. Seventy six percent (76%) of the nonconforming bolts were due to not meeting design requirements for lead (paragraph 110).

g. A properly set GO thread ring gage passed externally threaded product that did not meet design requirements for lead (paragraph 113).

h. The non-uniformity of the aluminum pigment coating on bolts had considerable affect on repeatability of measurement of functional diameter (paragraph 119).

i. Bolt thread damage that was barely visible to the unaided eye had a significant affect on repeatability of measurement of functional diameter (paragraph 120).

j. All non-crimped nuts (100%) met design requirements for functional diameter (paragraph 123).

k. All crimped nuts (100%) met functional assembly requirements (paragraph 128).

l. All non-crimped nuts and all but 12 crimped nuts (100% of one part number) met design requirements for minor diameter (paragraph 126).

m. Within the scope of this test, the independent laboratories found that measurement was repeatable on nuts that were neither plated nor crimped (paragraph 129).

209. Within the scope of this audit,:

a. The degree of variation in measurement of minimum material was an order of magnitude less than the degree of non-conformance at which performance degradation is discernable (paragraph 90).

b. Given the problems of inspection of plated/coated parts (particularly aluminum pigment) and the issues inherent in the use of GO thread ring gages (paragraph 38), the FAA questions whether the use of a specification with zero clearance allowance is advisable (paragraph 91).

c. To the extent that variation-in-measurement of maximum material does exist, the FAA questions the use of a zero clearance allowance design specification (paragraph 104).

d. The full profile roll indicating gages did not detect the full extent of lead deviation (including helical deviation) on bolts (paragraph 109).

e. FAA design approval holders were not defining dimensional requirements for lead when different from standard (paragraph 110).

f. All the nuts determined to be *nonconforming* or *conforming-with-variation* (total of 14, 10.6%) had oversized pitch diameters (paragraph 125).

g. The lack of detection of the undersized non-crimped nuts was due to inadequate flow-down of inspection requirements, inadequate supplier surveillance, and inadequate receiving inspection by the fastener manufacturer (paragraph 94).

IN-PROCESS AUDITS (PHASE II)

210. Within the scope of this audit, the FAA observed that:

a. The fastener industry was observed to be lacking standardized criteria regarding the inspection, maintenance, and calibration of indicating thread gages (paragraph 169).

b. Seven of the nine (77.8%) facilities exhibited deficiencies relating to the inspection, maintenance, and calibration of working threaded ring gages and thread-setting plug gages (paragraphs 170 - 171).

c. Seven of the nine (77.8%) facilities exhibited deficiencies relating to statistical sampling. The deficiencies identified were related to acceptance/rejection criteria and/or the absence of an adequate system classifying inspection characteristics (paragraphs 173 - 177).

d. Four of the nine (44.4%) facilities exhibited deficiencies relating to 14 CFR § 21.303 (paragraphs 202 - 205).

e. Three of the nine (33.3%) facilities exhibited deficiencies relating to the control and identification of raw materials (paragraph 136 - 141).

f. Six of the nine (66.6%) facilities exhibited deficiencies relating to inadequate in-process controls. Special processes were not accomplished in accordance with the established process specifications. Work instructions did not adequately control the manufacturing process (paragraphs 142 - 148).

g. Four of the nine (44.4%) facilities had erroneously substituted AS8879 in lieu of MIL-S-8879 (paragraph 157 - 159).

h. Two of the three (66.6%) facilities manufacturing internally threaded hardware were not performing an in-process final inspection/acceptance of thread geometry prior to deformation/crimping (paragraph 149 - 152).

i. Seven of the nine (77.8%) facilities were using “Thread Groove Diameter Rolls” in lieu of those authorized by ANSI/ASME B1.3M (paragraph 163).

j. Four of the nine (44.4%) facilities were not locating the set plug/ring master in proximity to the indicating thread gages during use (paragraph 164).

k. Three of the five (60%) facilities inspecting thread-to-shank runout were not using overlay charts, with the optical compatitor, as required by the designer’s product specification (paragraph 166).

l. Inadequate setting (zeroing) intervals of indicating thread gages during use may lead to the production and acceptance of nonconforming product (paragraph 164).

m. Initial and periodic evaluations of suppliers were not made, as necessary, or corrective actions were not taken to correct system deficiencies. The majority of supplier audits are performed via questionnaire/survey rather than on-site with the audit frequency ranging between 2 and 3 years (paragraphs 197 - 200).

n. The manufacturers' processes of final inspection/acceptance contain systemic weaknesses. Deficiencies identified were related to insufficient inspection methods and plans to ensure that parts were inspected for conformity with FAA-approved design data (paragraphs 186 - 194).

o. Three of the nine (33.3%) facilities exhibited deficiencies indicating that receiving inspections were not providing adequate verification that supplier-furnished products/services conformed to FAA-approved design data (paragraphs 130 - 135).

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RECOMMENDATIONS

INSPECTIONS AND TESTS (PHASE I)

GENERAL

211. It is recommended that:

a. Industry develop a consensus commercial specification that the DOD would designate as a superseding document to MIL-S-8879C (paragraph 8).

b. SAE consider removing any statements from AS8879 that would mislead the industry to believe that AS8879 supercedes MIL-S-8879C (paragraph 7).

c. Aircraft, aircraft engine, and propeller manufacturers conduct a comprehensive review of their procedures governing the classification (per MIL-S-8879C) of threaded product used within their applicable type designs (paragraph 30).

d. Industry resolve the disparity between “acceptable” and “conforming” product, and develop design and inspection specifications consistent with FAA regulatory requirements (paragraph 114).

SPECIFIC

212. It is recommended that:

a. Industry revise ANSI/ASME B1.3M to require the use of the GO thread ring gage in conjunction with the full profile roll thread indicating gage for inspection of functional diameter (paragraph 104).

b. Industry resolve whether the use of thread groove diameter type thread indicating gages can assure conformance for minimum material (paragraph 105).

c. Industry review the thread root radius inspection technique described in paragraph 55 and determine its acceptability and limitations (paragraph 108).

d. Industry review whether the full 40% of pitch diameter tolerance should be allowed when using full profile roll indicating gages for differential analysis of lead and flank angle (paragraph 109).

e. Industry resolve the discrepancies between the design and inspection requirements for control of lead and flank angle (paragraph 113).

f. Both GO and NOT GO set plugs be available for setting and checking indicating thread gages (paragraph 121).

g. Industry review the criteria in ANSI/ASME B1.2 regarding minimum circumferential contact and also consider developing a maximum value to enhance repeatability of measurement between different gages (paragraph 124).

h. Manufacturers review their procedures for specifying tap size based on the type of plating to be applied (paragraph 125).

i. For crimped nuts, industry develop a means of establishing whether sufficient plate has been deposited on the threads and that the threads meet dimensional requirements after plating (paragraph 125).

IN-PROCESS AUDITS (PHASE II)

213. It is recommended that:

a. Industry develop standardized criteria regarding the inspection, maintenance, and calibration of indicating thread gages (paragraph 169).

b. Industry develop standardized criteria regarding the inspection, maintenance, and calibration of working threaded ring gages and thread-setting plug gages (paragraphs 170 - 171).

c. Manufacturers conduct a comprehensive review of their final inspection and acceptance processes, ensuring that all products conform to the FAA-approved design data (paragraphs 190 - 194).

d. Industry resolve supplier control deficiencies relating to supplier audits, corrective action, and accurate flow-down of technical/quality requirements (paragraphs 197 - 201).

e. All aircraft, aircraft engine, and propeller manufacturers develop and enforce procedures to control and/or preclude the manufacture and distribution of production overruns (paragraph 202 - 205).

f. FAA continue on-going initiatives placing special emphasis during certificate management functions (surveillance) at PAH facilities. Special emphasis areas address all aspects of manufacturing compliance, use of measuring and test equipment, statistical sampling, supplier surveillance, and supplier control.

g. FAA continue to support industry's commitment to improvement. FAA initiatives include working collaboratively with industry associations, aircraft, aircraft engine, propeller, and fastener manufacturers to correct quality and manufacturing deficiencies resulting from this audit.

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LIST OF ACRONYMS

A2LA	The American Association for Laboratory Accreditation
ACSEP	Aircraft Certification Systems Evaluation Program
AFB	Air Force Base
AN	Air Force – Navy Aeronautical Standard
ANSI	The American National Standards Institute
ASME	The American Society of Mechanical Engineers
ASQC	American Society for Quality Control
DLA	Defense Logistics Agency
DOD	Department of Defense
DOT	Department of Transportation
FAA	Federal Aviation Administration
FED-STD	Federal Standard
LCL	Lower Control Limit
MIDO	Manufacturing Inspection District Office
MRB	Material Review Board
MS	Military Standard
NAS	National Aircraft Standard
NIST	The National Institute of Standards and Technology
OIG	Office of Inspector General
PAH	Production Approval Holder
PMA	Parts Manufacturer Approval
QVC	Quality Verification Center
SPC	Statistical Process Control
TSO	Technical Standard Order
UCL	Upper Control Limit
UN	Unified Inch Screw-Threads
UNJ	Unified Inch Screw-Threads, Controlled Root Radius

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PICTURES AND DIAGRAMS

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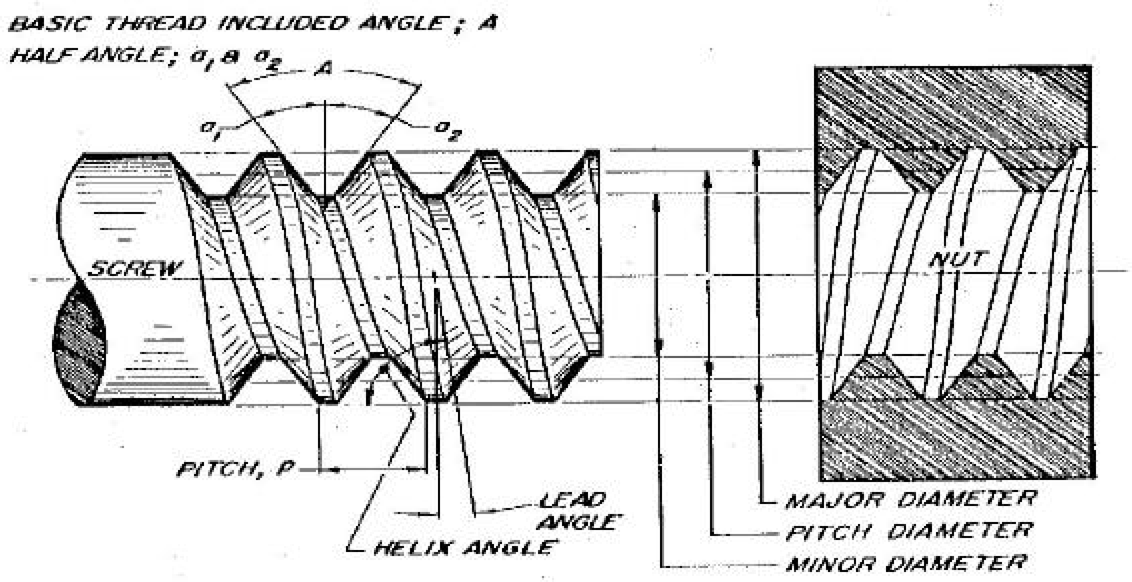


Figure 1
DIAGRAM OF THREAD GEOMETRY, MAJOR DIMENSIONAL CHARACTERISTICS

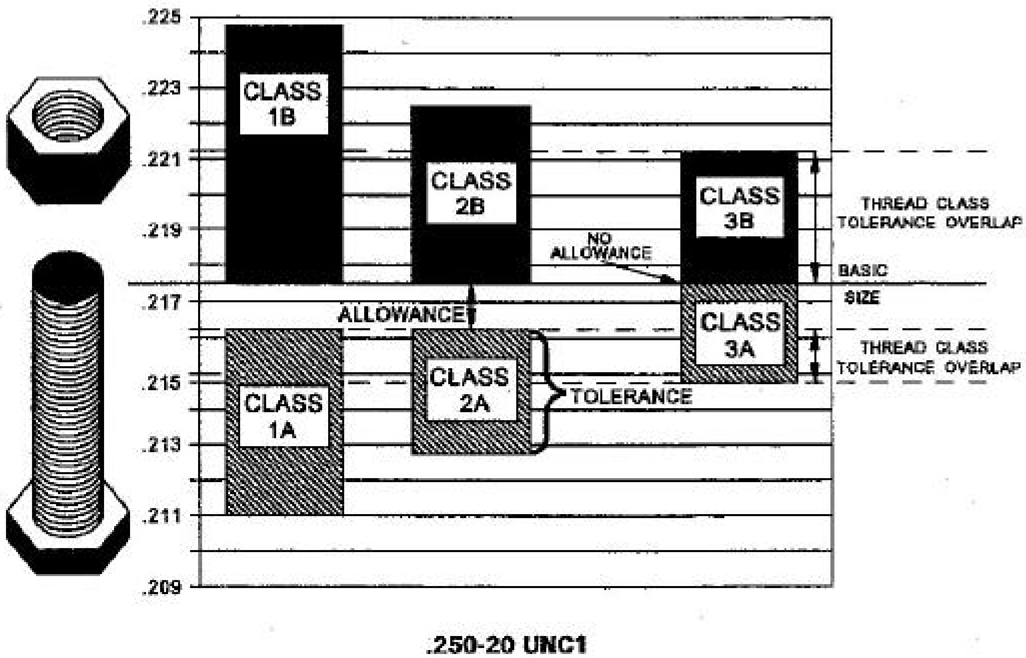
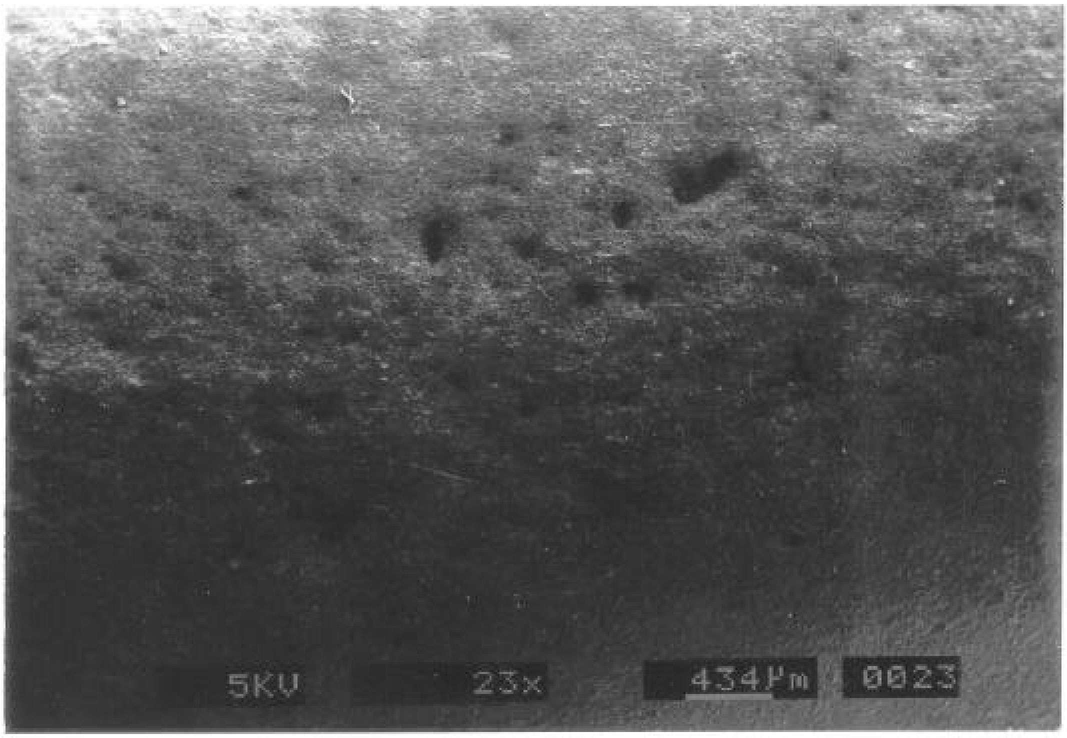


Figure 2
THREAD CLASSES, TOLERANCES AND CLEARANCE ALLOWANCES



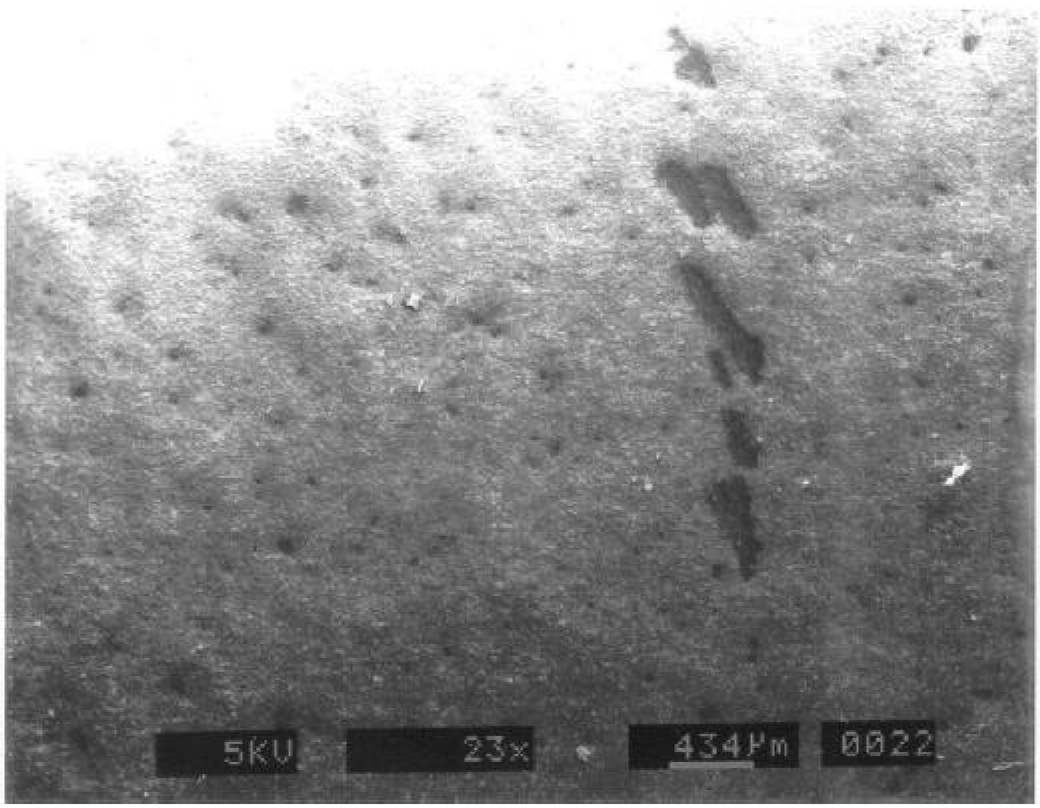


Figure 3
PICTURES OF ALUMINUM PIGMENT COATING ON A BOLT SHANK AT 23X MAGNIFICATION

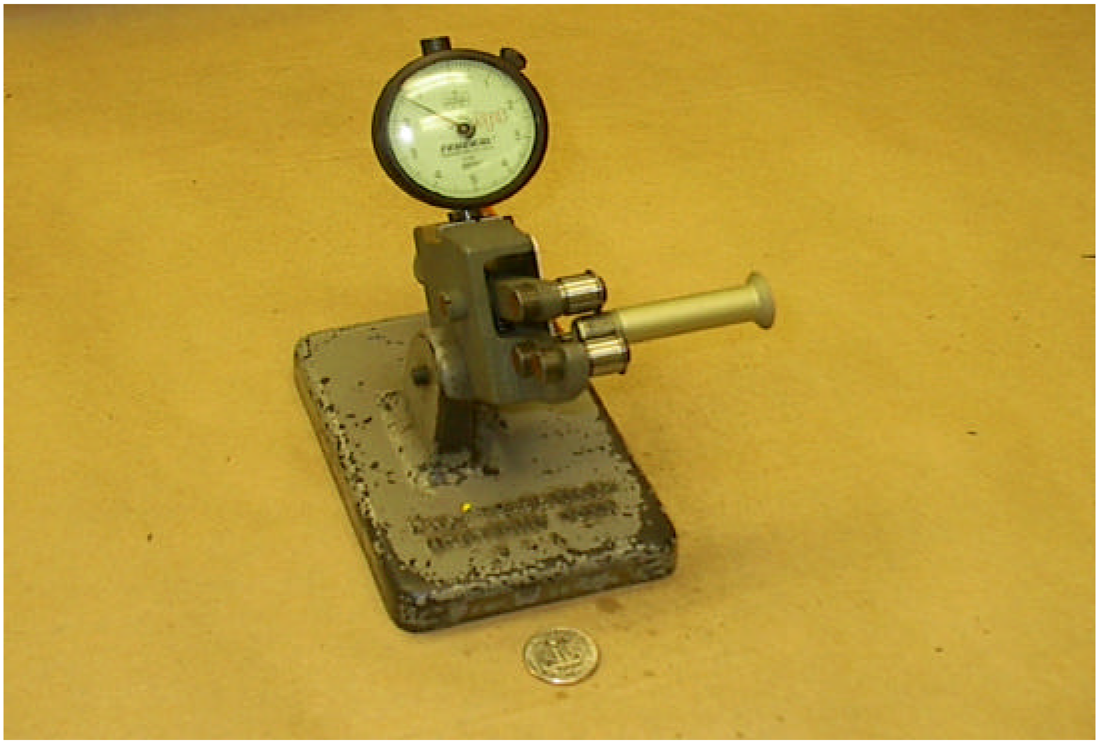


Figure 4
FAA GAGES, THREAD GROOVE DIAMETER (CONE ONLY) TYPE INDICATING GAGE

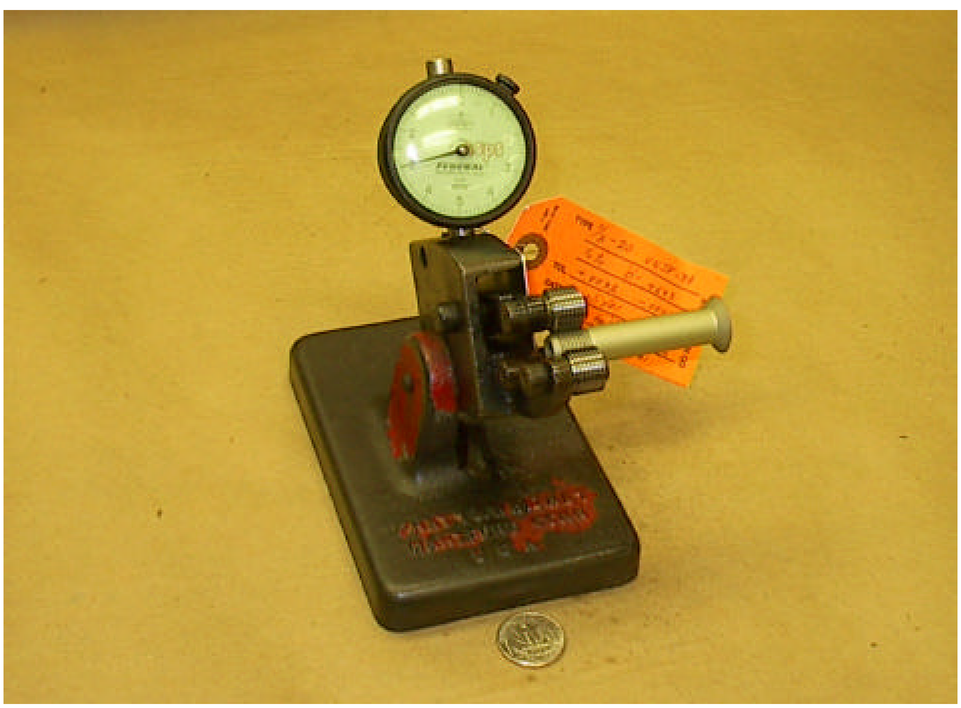


Figure 5
FAA GAGES, FULL PROFILE ROLL INDICATING GAGE

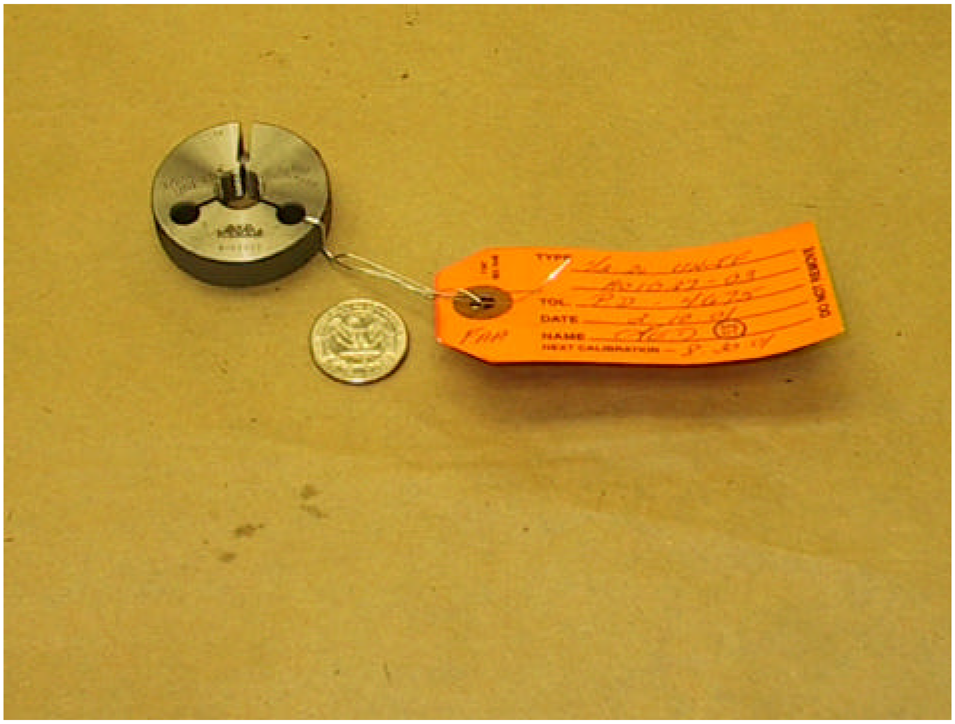


Figure 6
FAA GAGES, THREADED GO (WORKING) RING GAGE

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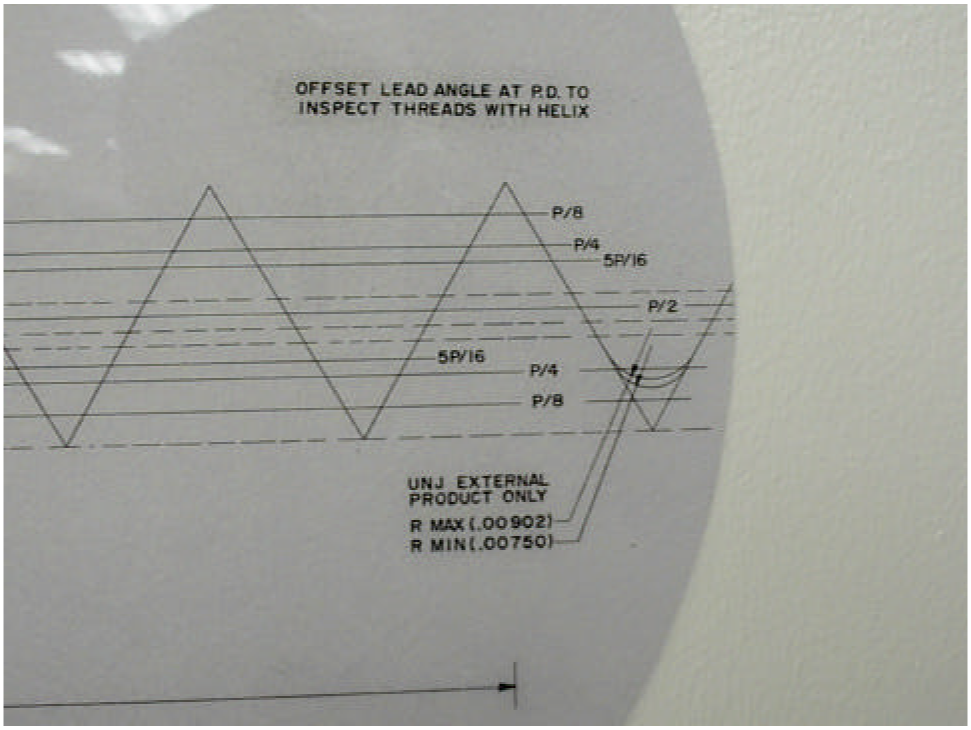

Figure 7
INSPECTION FOR THREAD ROOT RADIUS, OPTICAL COMPARITOR OVERLAY CHART

Figure 8
FAA GAGES, OPTICAL COMPARITOR WITH OVERLAY CHART

Figure 9
FAA GAGES, THREADED "W" TOLERANCE SET PLUG GAGES

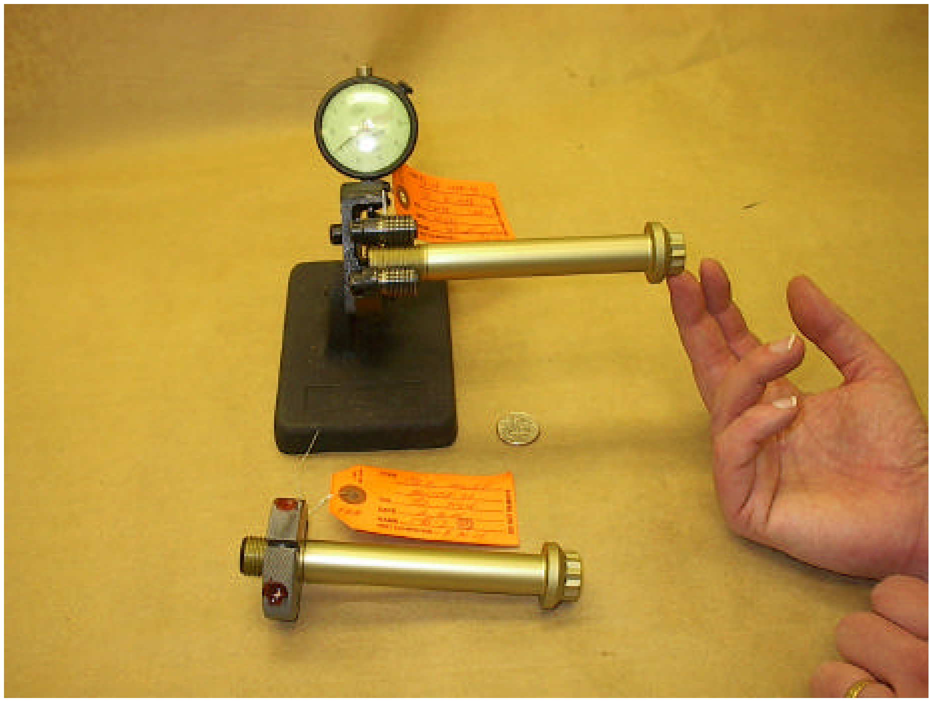

Figure 10
INSPECTION FUNCTIONAL DIAMETER ON FAA GAGES, FULL PROFILE ROLL INDICATING GAGE AND THREADED GO RING GAGE

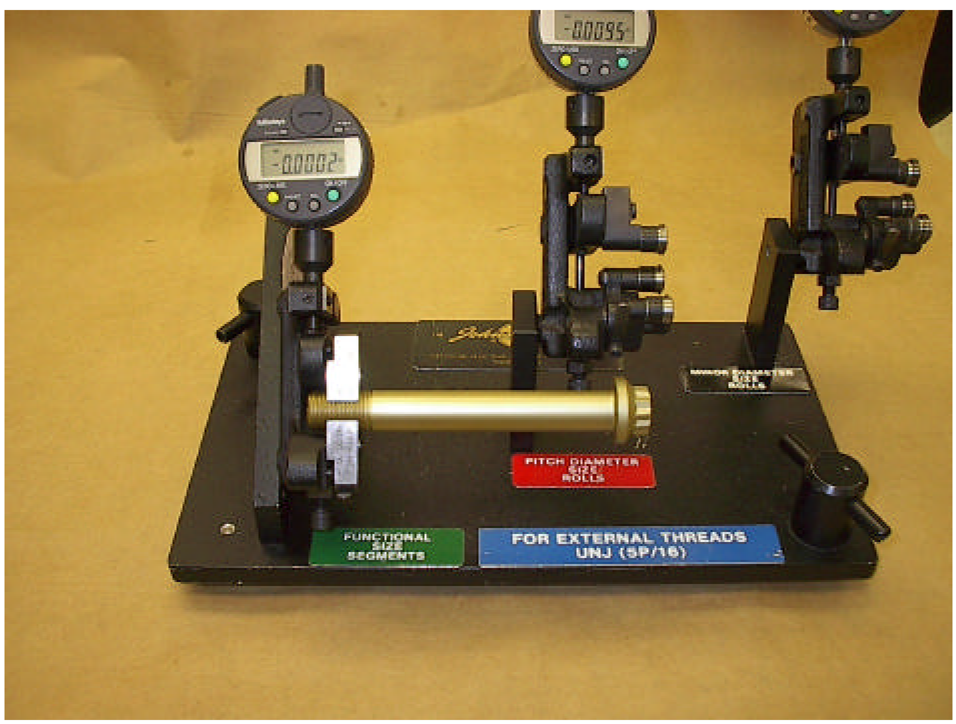

Figure 11
INSPECTION FOR FUNCTIONAL DIAMETER SIZE, FULL FORM SEGMENT INDICATING GAGE

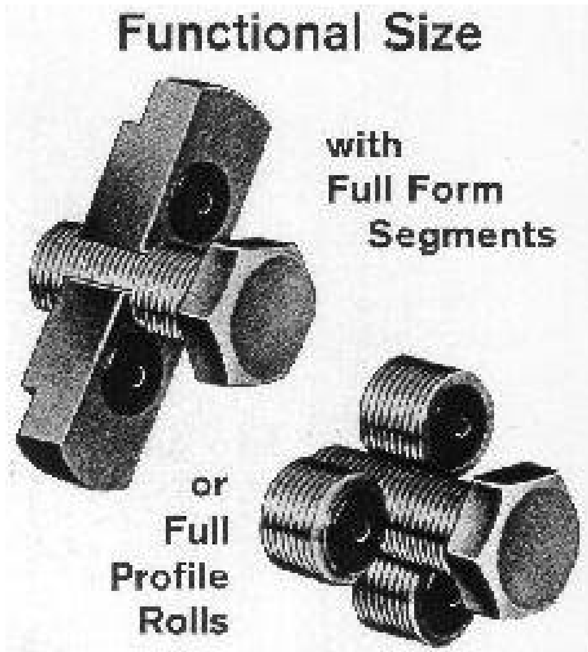

Figure 12
INSPECTION FOR FUNCTIONAL DIAMETER SIZE, FULL FORM SEGMENTS AND FULL PROFILE ROLLS

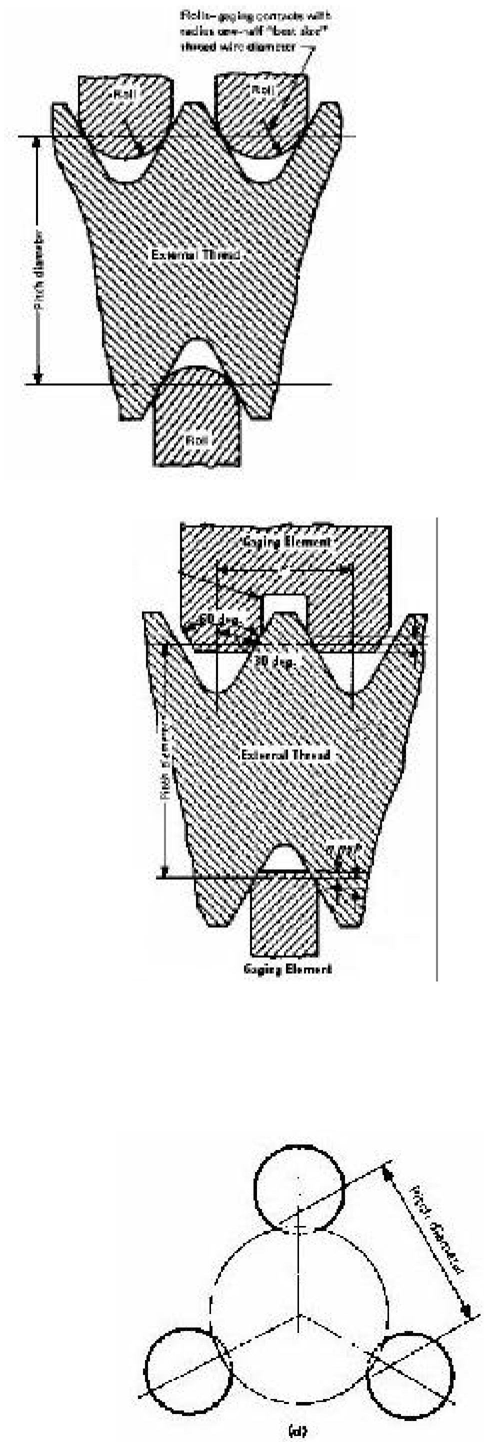

Figure 13
INSPECTION FOR PITCH DIAMETER SIZE, CONE & VEE PROFILE ROLLS VS. THREAD GROOVE DIAMETER PROFILE ROLLS

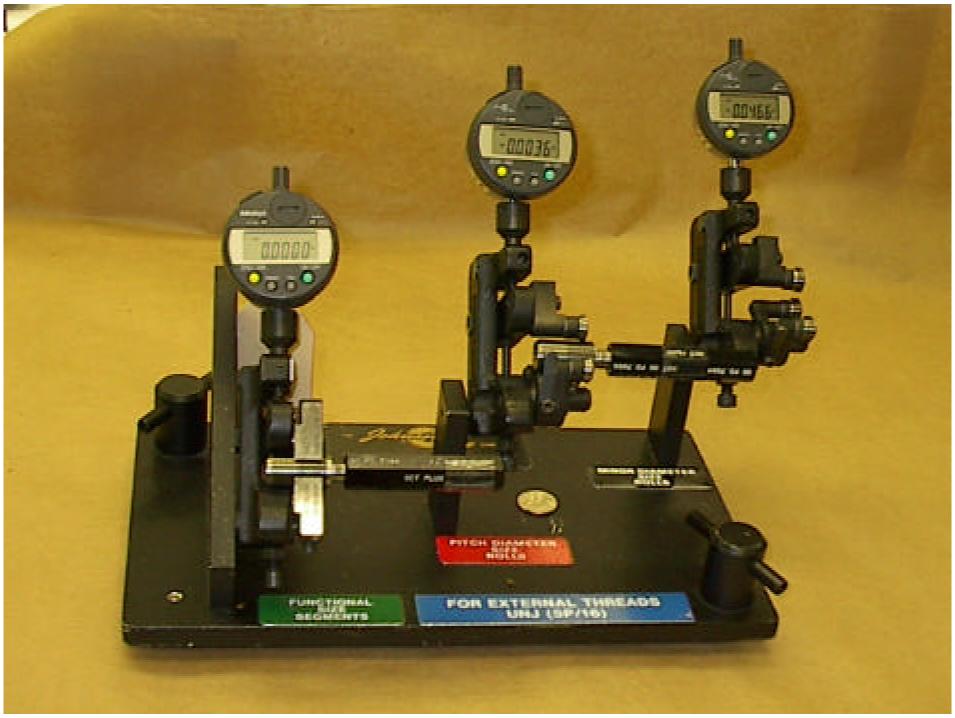

Figure 14
INSPECTION OF FAA GAGES, THREADED “W” TOLERANCE SET PLUG GAGES

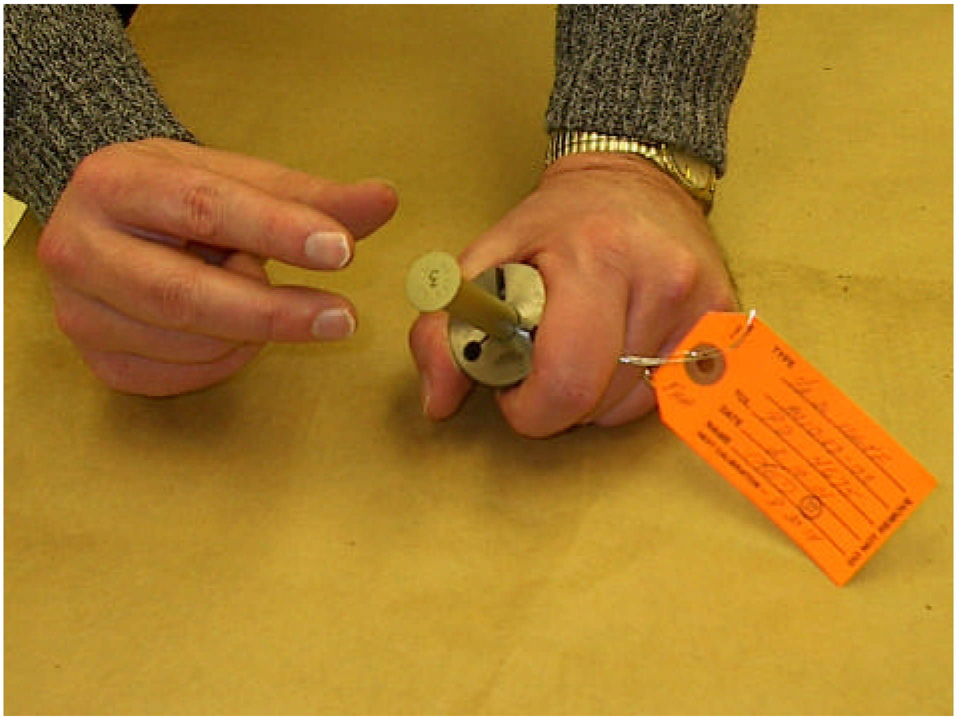

Figure 15
FUNCTIONAL ASSEMBLY (FUNCTIONAL DIAMETER) INSPECTION USING A THREADED GO RING GAGE

Figure 16
INSPECTION FOR PITCH DIAMETER SIZE ON CONE & VEE PROFILE ROLL INDICATING GAGE

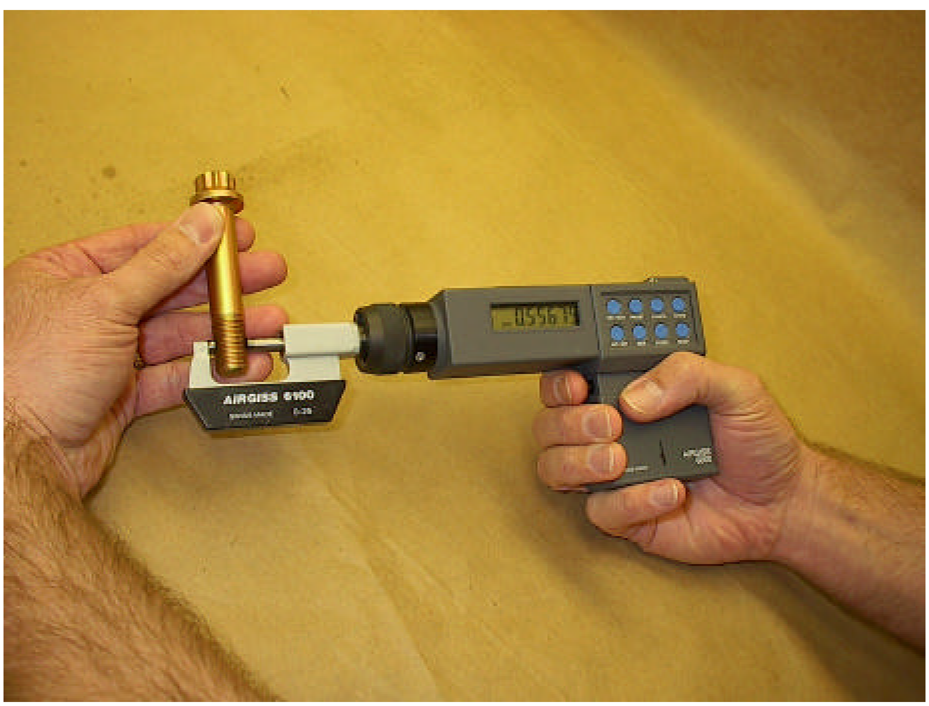

Figure 17
INSPECTION OF PRODUCT FOR MAJOR DIAMETER SIZE USING PLAIN MICROMETER

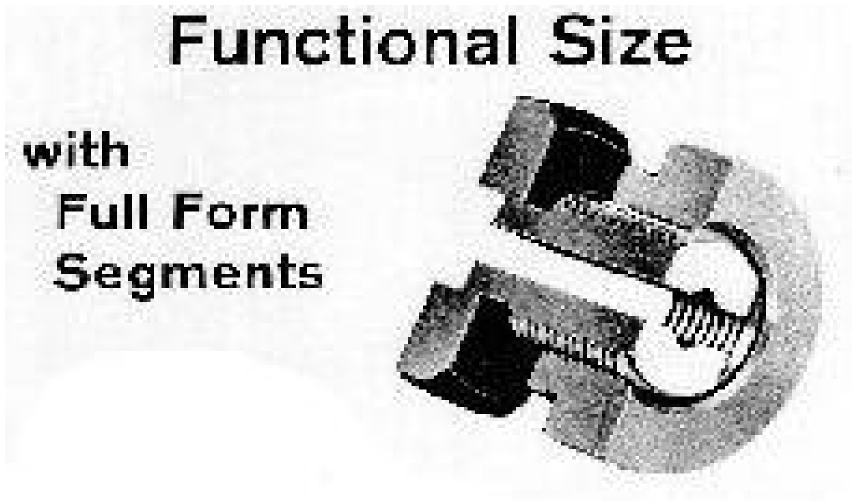

Figure 18
INSPECTION FOR FUNCTIONAL DIAMETER SIZE ON INTERNAL THREADS, FULL FORM SEGMENTS

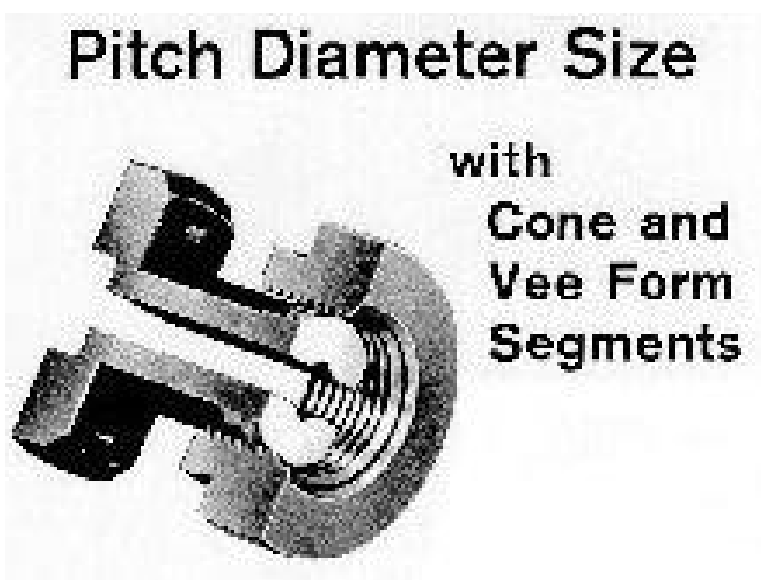

Figure 19
INSPECTION FOR PITCH DIAMETER SIZE ON INTERNAL THREADS, CONE & VEE FORM SEGMENTS

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TABLES

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Table I

DESCRIPTION OF EXTERNALLY THREADED ARTICLES (BOLTS)

Basic Major Diameter	Thread Series and Class	Thread Specification				Unplated	Plated			Coated	
		MIL-S-8879	MIL-S-7742	Special	-8879 Modified		Cadmium	NiCad	Silver	Aluminum Pigment	Cetyl Alcohol
0.1900	.1900-32 UNJF-3A MOD	1			1					1	removed
	.1900-32 UNJF-3A	1				1					
	.190-24 UNC-3A		1			1					
	.190-32 UNF-3A		1			1					
	.1900-32 UNJF-3A MOD	1			1					1	
	.1900-32 UNJF-3A MOD	1			1					1	
	.1900-32 UNJF-3A MOD	1			1	1					
0.2500	.250-28NS			1				1			
	.250-28NS			1				1			
	.250-28 UNS-3A			1		1					
	.2500-28 UNJF-3A MOD	1			1					1	removed
	.2500-28 UNJF-3A MOD	1			1	1					
	.2500-28 UNJF-3A	1				1					
	.2500-28 UNJF-3A MOD	1			1	1					
	.250-28 NS			1				1			
	.250-28 class 3A		1			1					
	.2500-28 UNJF-3A MOD	1			1	1					
	.2500-28 UNJF-3A MOD	1			1	1					
	.2500-28 UNJF-3A MOD	1			1	1					
	.2500-28 UNJF-3A MOD	1			1	1					
	.2500-28 UNJF-3A	1				1					
	.2500-28 UNJF-3A MOD	1			1	1					removed
	.2500-28 UNJF-3A MOD	1			1	1					removed
	.2500-28 UNJF-3A	1				1					
	.2500-28 UNJF-3A	1							1		
0.3125	.3125-24 UNS-3A			1		1					
	.3125-24 UNJF-3A	1				1					
	.3125-18 UNC-3A		1				1				
	.3125-24 UNJF-3A MOD	1			1	1					
	.3125-24 UNS-3A			1		1					
	.312-24 class 3A		1				1				
	.3125-24 UNJF-3A MOD	1			1					1	
	.3125-24 UNJF-3A MOD	1			1					1	
	.3125-24 UNJF-3A MOD	1			1					1	
	.3125-24 UNJF-3A MOD	1			1		1				
	.3125-24 UNJF-3A	1				1					
	.3125-24 UNJF-3A MOD	1			1					1	
	.3125-24 UNJF-3A MOD	1			1					1	
	.3125-24 UNJF-3A	1				1					

Table I (continued)

DESCRIPTION OF EXTERNALLY THREADED ARTICLES (BOLTS)

Basic Major Diameter	Thread Series & Class	Thread Specification				Unplated	Plated			Coated	
		MIL-S-8879	MIL-S-7742	Special	-8879 Modified		Cadmium	NiCad	Silver	Aluminum Pigment	Cetyl Alcohol
0.3750	.3750-24 UNJF-3A MOD	1			1	1					
	.3750-24 UNJF-3A MOD	1			1	1					
	.3750-24 UNJF-3A	1					1				
	.3750-24 UNJF-3A	1				1					
	.3750-24 UNJF-3A MOD	1			1					1	
	.3750-24 UNJF-3A MOD	1			1					1	
	.3750-24 UNJF-3A MOD	1			1	1					
	.3750-24 UNJF-3A	1				1					
	.3750-24 UNJF-3A MOD	1			1	1					
	.3750-24 UNJF-3A MOD	1			1	1					
	.3750-24 UNJF-3A	1				1					
0.4375	.4375-20 UNJF-3A MOD	1			1					1	removed
	.4375-20 UNJF-3A	1				1					
	.4375-20 UNJF-3A MOD	1			1					1	
	.4375-20 UNJF-3A MOD	1			1					1	
	.4375-20 UNJF-3A MOD	1			1					1	
	.4375-20 UNJF-3A MOD	1			1					1	
	.4375-20 UNJF-3A	1				1					
	.4375-20 UNJF-3A MOD	1			1					1	
0.5000	.5000-20 UNJF-3A MOD	1			1					1	removed
	.5000-20 UNJF-3A MOD	1			1					1	removed
	.5000-20 UNJF-3A	1				1					
	.500-28 UNS-3A			1					1		
	.5000-20 UNJF-3A MOD	1			1					1	
	.5000-20 UNJF-3A MOD	1			1					1	
	.5000-20 UNJF-3A MOD	1			1					1	
	.5000-20 UNJF-3A MOD	1			1					1	
0.5625	.562-12 class 3A		1			1					
	.5625-18 UNJF-3A MOD	1			1					1	
	.5625-18 UNJF-3A MOD	1			1					1	
	.5625-18 UNJF-3A MOD	1			1					1	
	.5625-18 UNJF-3A MOD	1			1		1				
0.6250	.6250-18 UNJF-3A MOD	1			1					1	
	.6250-18 UNJF-3A MOD	1			1					1	
	.6250-18 UNJF-3A MOD	1			1					1	
0.7500	.7500-16 UNJF-3A MOD	1			1		1				
	.7500-16 UNJF-3A MOD	1			1					1	
	.7500-16 UNJF-3A MOD	1			1					1	
	.7500-16 UNJF-3A MOD	1			1	1					
	TOTAL = 78	65	6	7	50	36	6	3	2	31	0
		83%	8%	9%	64%	46%	8%	4%	3%	40%	

Table II
DESCRIPTION OF INTERNALLY THREADED ARTICLES (NUTS)

Basic Major Diameter	Thread Series & Class	Crimped	Thread Specification	Unplated	Plated			Coated		
			MIL-S-8879		Cadmium	NiCad	Silver	Dry Film	Cetyl Alcohol	Anodize
0.2500	.2500-28 UNJF-3B	1	1				1			
	.2500-28 UNJF-3B	1	1				1			
	.2500-28 UNJF-3B	1	1					1		
	.2500-28 UNJF-3B	1	1				1			
	.2500-28 UNJF-3B	1	1				1			
	.2500-28 UNJF-3B	1	1					1		
	.2500-28 UNJF-3B	1	1				1			
0.3125	.3125-24 UNJF-3B	1	1				1			
	.3125-24 UNJF-3B		1	1						
	.3125-24 UNJF-3B		1	1						
	.3125-24 UNJF-3B	1	1				1			
	.3125-24 UNJF-3B		1		1				Yes	
	.3125-24 UNJF-3B	1	1				1			
	.3125-24 UNJF-3B	1	1				1			
	.3125-24 UNJF-3B	1	1					1		
	.3125-24 UNJF-3B	low hieght	1	1						
	.3125-24 UNJF-3B	1	1					1		
0.3750	.3750-24 UNJF-3B	1	1					1		
	.3750-24 UNJF-3B		1			1				
	.3750-24 UNJF-3B	1	1				1			
	.3750-24 UNJF-3B	1	1						Yes	1
	.3750-24 UNJF-3B	1	1				1			
	.3750-24 UNJF-3B	1	1				1			
	.3750-24 UNJF-3B	1	1				1			
	.3750-32 UNJEF-3B	1	1				1			
0.4375	.4375-20 UNJF-3B	1	1				1			
	.4375-20 UNJF-3B	1	1				1			
	.4375-20 UNJF-3B		1	1						
0.5000	.5000-20UNJF-3B		1			1				
	.5000-20UNJF-3B	1	1		1					
0.5625	.5625-18 UNJF-3B		1	1						
0.6250	.6250-18 UNJF-3B	castellated	1				1			
	.6250-18 UNJF-3B	1	1				1			
0.7500	.7500-16 UNJF-3B	1	1				1			
	.7500-16 UNJF-3B		1	1						
1.0625	1.0625-12 UNJ-3B		1							1
	TOTAL = 36	25	36	6	2	2	19	5	0	2
		69%	100%	17%	6%	6%	53%	14%		6%

Table III
SCREW THREAD GAGES AND MEASURING EQUIPMENT

	External Thread Gages and Measuring Equipment	Gage Source	Maximum Material "GO" Functional Diameter Func. Limit A1	Maximum Material "GO" Functional Diameter Func. Size A2	Minimum Material Pitch Diameter Limit B1	Minimum Material Pitch Diameter Size B2	Minimum Material Thread Groove Diameter Limit C1	Minimum Material Thread Groove Diameter Size C2	Lead incl. helix variation H	Flank Angle Variation I	Major Diameter Limit J1	Major Diameter Size J2	Minor Diameter Limit K1	Minor Diameter Size K2	Root Radius L
1	Threaded Ring Gages,														
	1.1 GO	FAA	X										note 1		
4	Indicating Thread Gages, Having either two contacts at 180 deg. or three														
	4.1 GO Full Form	LAB	X	X									note 1		
	4.3 GO Full Profile Rolls	FAA (note 3)	X	X									note 1		
	4.5 Minimum Material - pitch diameter type - cone and vee	LAB			X	X									
	4.6 Minimum Material - thread groove diameter	FAA (note 3)					X	X							
	4.10 Cumulative Form Gaging								Cumulative Form (note 4)						
5	Indicating plain diameter gages														
	5.2 Minor diameter type	LAB											X	X	
9	Optical Comparitor	LAB							X (note 5)	X			X	X	X (note 2)
14	Plain Micrometer and Calipers	LAB									X	X			

FOR EXTERNAL THREAD CHARACTERISTICS

NOTES: **1. Maximum minor diameter limit is acceptable when product passes GO gage on UN and UNJ threads.**
2. Optical comparitor overlays for inspecting root radius provided by FAA.
3. FAA also provided GO and NOT GO Thread Setting Plug Gages "W" Tolerance.
4. Maximum material and minimum material dimensions collectively establish cumulative form within limits defined by the applicable thread documents.
5. Measures only lead, does not check helix variation.

Table IV
SCREW THREAD GAGES AND MEASURING EQUIPMENT
FOR INTERNAL THREAD CHARACTERISTICS

	Internal Thread Gages and Measuring Equipment	Gage Source	Maximum Material "GO" Functional Diameter		Minimum Material Pitch Diameter		Minor Diameter	
			Func. Limit A1	Func. Size A2	Limit B1	Size B2	Limit K1	Size K2
1	Threaded Plug Gages							
	1.1 GO	FAA	X					
3	Plain Diameter Gages							
	3.1(a) Minimum (GO) plain cylindrical plug for minor diameter	LAB					X	
	3.1(b) Maximum (NOT GO) plain cylindrical plug for minor diameter	LAB					X	
4	Indicating Thread Gages, Having two contacts at 180 deg.							
	4.1 GO Full Form Segments	LAB & FAA (note 1)	X	X				
	4.5 Minimum Material - pitch diameter type - cone & vee profile	LAB & FAA (note 1)			X	X		
14	Inside Calipers	LAB					X	X

NOTES: 1. FAA also provided Thread Solid Set Ring Gages "W" tolerance.

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