DABJ—Design and Analysis of Bolted Joints

Includes a close look at NASA-STD-5020B

Course Overview: Just about everyone involved in developing hardware for space missions (or any other purpose, for that matter) has been affected by problems with joints using threaded fasteners. Common problems include rupture under a single application of load, fatigue, detrimental yielding, joint slip, galling, inadequate preload, loss of preload, hardware falling out completely, low or nonlinear stiffness, excessive weight, procurement cost and lead time, incompatibility with the space environment, and time-consuming assembly and disassembly.

The objectives of this course are to

- build an understanding of how bolted joints behave and how they fail
- impart effective processes, methods, and standards for design and analysis, drawing on a mix of theory, empirical data, and practical experience
- share guidelines, rules of thumb, and valuable references
- help you understand NASA-STD-5020B

This 3-day course includes many examples and class problems.

Target Audience: Mechanical design engineers, structural analysts, and others interested in or involved with bolted joints

Course Developer and Teacher:

Tom Sarafin is President of Instar Engineering and Consulting, Inc. He has worked in the space industry since 1979 as a structural engineer, a mechanical systems engineer, a project manager, and a consultant. Since founding Instar in 1993, he's consulted for NASA, DARPA, the DOD Space Test Program, Lockheed Martin, DigitalGlobe (Maxar), Sierra Nevada Corp (Sierra Space), and many other organizations. He was a key member of the team that developed NASA-STD-5020, "Requirements for Threaded Fastening Systems in Spaceflight Hardware" (March 2012). He is the editor and principal author of *Spacecraft Structures and Mechanisms: From Concept to Launch* and is a contributing author to *Space Mission Analysis and Design*. Since 1995, he has taught well over 300 courses to more than 6000 engineers and managers in the aerospace industry. He teaches the following courses: Space Mission Structures, from Concept to Launch (SMS), Design and Analysis of Bolted Joints (DABJ), Structural Design and Analysis for Aerospace Engineers (SDA), Structural Test Design and Interpretation (STDI), Vibration Testing of Small Satellites (VTSS), Notching and Force Limiting Workshop (NFLW), and Ten Principles for Successful Space Programs (TenP).

Testimonials

"It was a fantastic course—one of the most useful short courses I have ever taken."

"Interaction between instructor and experienced designers (in the class) was priceless."

"(The) examples (and) stories from industry were invaluable." "Everyone at NASA should take this course!"

"Your presentation skills are excellent, with patient attention paid to class questions."

"(This class) should be mandatory for design engineers at (our company)." "Wonderful course."

"(What I found most useful:) strong emphasis on understanding physical principles vs. blindly applying textbook formulas."

"Great course! Lots of lessons learned. The examples made it that much better."

(What you would tell others:) "Take it!" "You need to take it." "Take it. Tell everyone you know to take it."

"Excellent instructor. Great lessons learned on failure modes shown from testing."

"A must course for structural/mechanical engineers and anyone who has ever questioned the assumptions in bolt analysis"

"Well-researched, well-designed course." "Kudos to you for spreading knowledge!"

"Your bolted joints course is above and beyond the best engineering course I have taken."

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Course Outline

1. **Overview**
   - Common problems with bolted joints
   - A process for designing a bolted joint
   - Common required characteristics for structures
   - General design guidelines for bolted joints
   - The importance of preload
   - Introduction to NASA-STD-5020
   - Key definitions
   - High-level requirements from NASA-STD-5020B
   - Margin of safety
   - Establishing internal standards and criteria
2. **Screw Threads: Evolution and Important Characteristics**
   - Brief history of screw threads
   - Rolled vs. cut threads
   - Thread-form features and compatibility
   - Tensile stress area
   - Fine threads vs. coarse threads
3. **Developing a Concept for the Joint**
   - General types of joints and fasteners
   - Configuring the joint
   - Designing a stiff joint
   - Shear clips and tension clips
   - Avoiding problems with fixed fasteners
4. **Calculating Bolt Loads when Ignoring Preload**
   - How a preloaded joint carries load
   - Temporarily ignoring preload
   - What about friction as a load path?
   - Common assumptions and their limitations
   - An effective process for calculating bolt loads in a compact joint
   - Example
   - Appendix: more examples
5. **Failure Modes and Assessment Methods**
   - Understanding stress analysis from the engineer's perspective
   - An effective process for strength analysis
   - Bolt tension and shear
   - Tension joints
   - Shear joints
   - Class exercise: identifying potential failure modes
   - Bolted joints with composite materials
6. **Thread Stripping and Pull-out Strength**
   - How threads fail
   - Computing thread shear areas based on geometry
   - Including a knock-down factor
   - Test results with and without Heli-Coils®
   - Appendix: Comparison of analysis methods
7. **Selecting Hardware and Detailing the Design**
   - Selecting compatible materials
   - Selecting the nut: ensuring strength compatibility
   - Commonly used threaded inserts
   - Use of washers
   - Bolt features and geomtery
   - Selecting fastener length and grip
   - Guidelines for simplifying assembly
   - Establishing preload
   - Torque-preload relationship
   - Locking features and NASA-STD-5020B
   - Maintaining preload
   - Appendix: miscellaneous design data
8. **Mechanics of a Preloaded Joint Under Applied Tension**
   - How bolt load changes with applied load
   - Designing to reduce cyclic load in the bolt
   - Estimating bolt stiffness and clamp stiffness
   - Understanding the load-introduction factor
   - Worst case for steel bolts and aluminum fittings
   - Key conclusions regarding load sharing
   - Effects of bolt ductility
   - How temperature change affects preload
   - Appendix: supporting analysis
9. **Fastening System Analysis per NASA-STD-5020B**
   - Objectives and summary
   - Calculating maximum and minimum preloads
   - Tensile loading: ultimate-strength analysis
   - Separation analysis
   - Tensile loading: yield-strength analysis
   - Shear loading: ultimate-strength analysis
   - Interaction of tension, shear, and bending
   - Joint-slip analysis
   - Fatigue
   - Appendix 9A.1: Additional requirements for preload calculation
   - Appendix 9A.2: Accounting for bolt bending in a shimmed single-shear joint
   - Appendix 9A.3: Justification for low likelihood of fatigue failure

Appendix A. Finite element modeling of bolted joints

Appendix B. Design tables: preliminary bolt sizing

Summary

Download a PDF file containing all the course materials at no charge, along with PDF files for Tom's other courses, at https://instarengineering.com/resources.html.