MMPDS and Additive Metals

NRC Workshop on Advance Manufacturing Technologies for Nuclear Applications
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MMPDS

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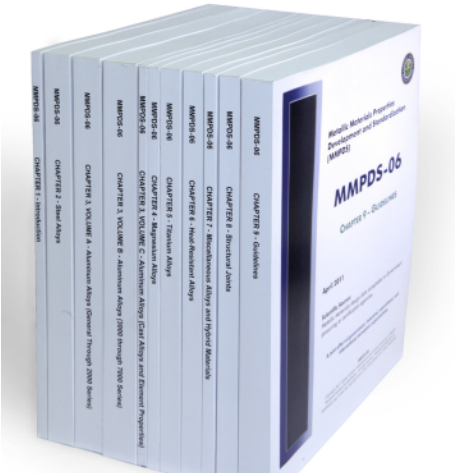
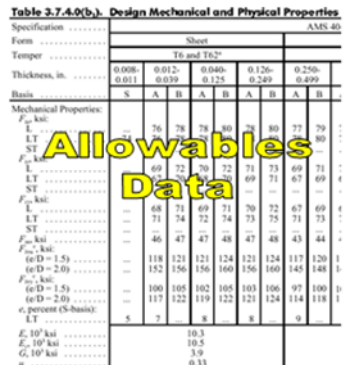
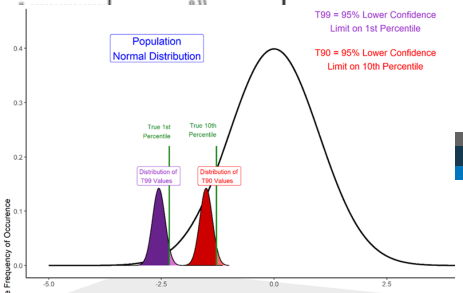
Metallic Materials Properties Development and Standardization







History

- ANC5 (1937-1954), MIL-HDBK-5 (USAF: 1954 – 2003), MMPDS (FAA: 2003-today)
- Battelle Memorial Institute - program Secretariat since 1956.
- MMPDS Handbook is the primary source of statistically-based material allowable properties for metallic materials and fasteners used in many different commercial and military weapon systems around the world.
- The MMPDS General Coordinating Committee is a collaboration between government agencies, aerospace companies, testing and data service companies, and metallic material producers.
- Biannual meetings to review and approve statistical analyses and guidelines.

Scope

- The Handbook currently contains 600+ A/B-Basis and 1000+ S-Basis entries, 400+ unique metal specifications.
- Two to five new alloys are added each year.†
- For more information visit www.mmpds.org

† Pandemic rate has been slower.

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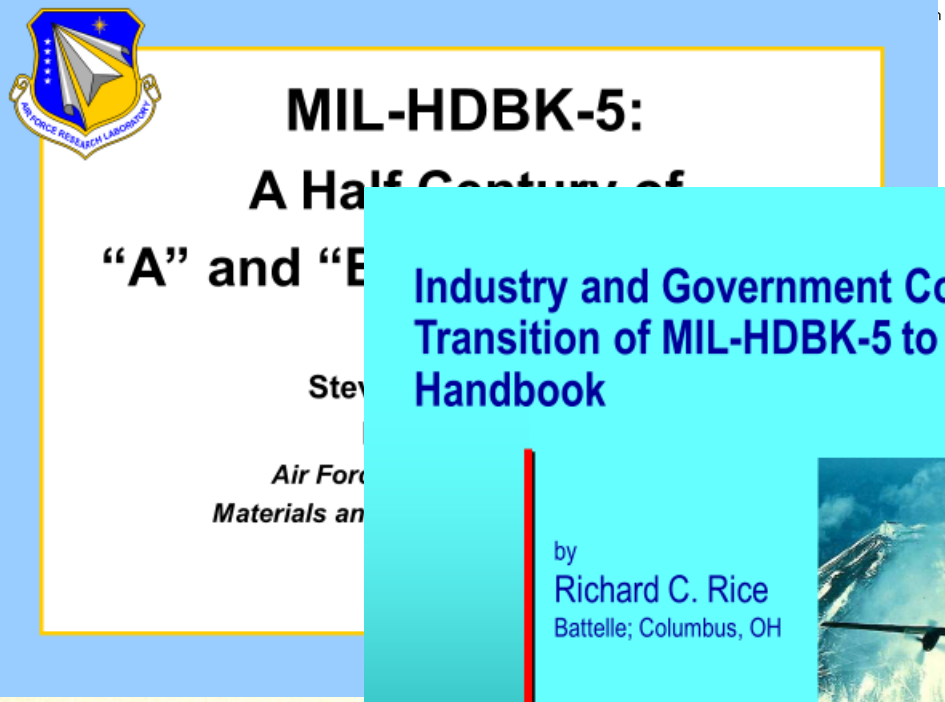
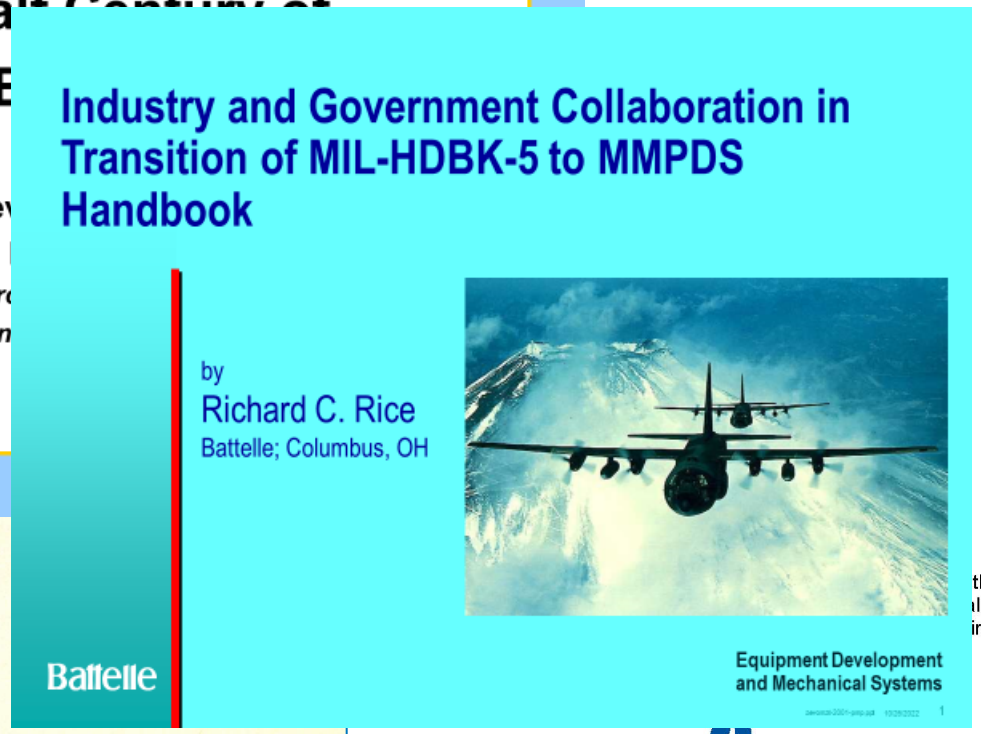
ANC5 / MIL-HDBK-5 / MMPDS / Volume I & II





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U.S. Department of Transportation
Federal Aviation Administration

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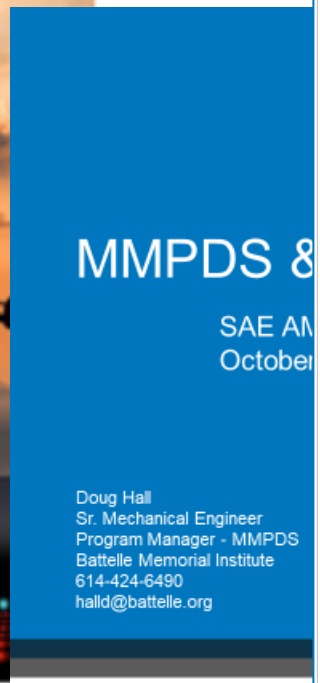
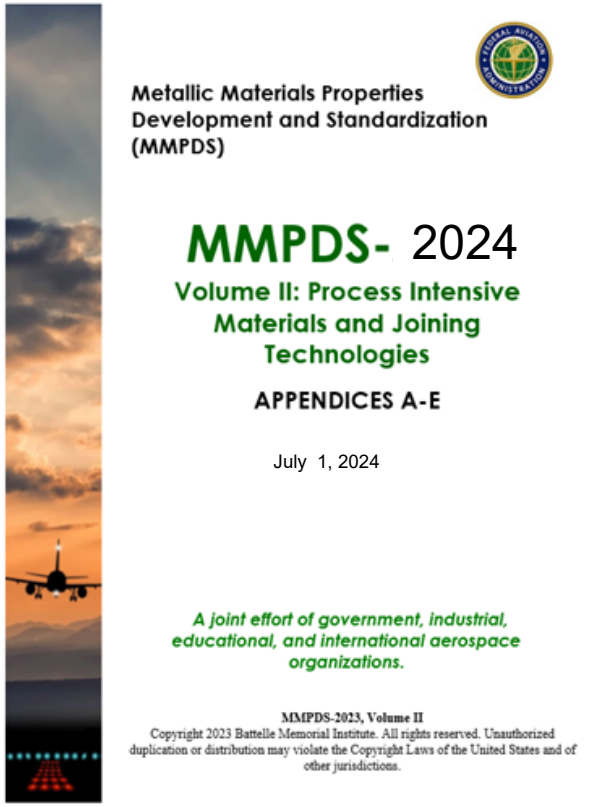
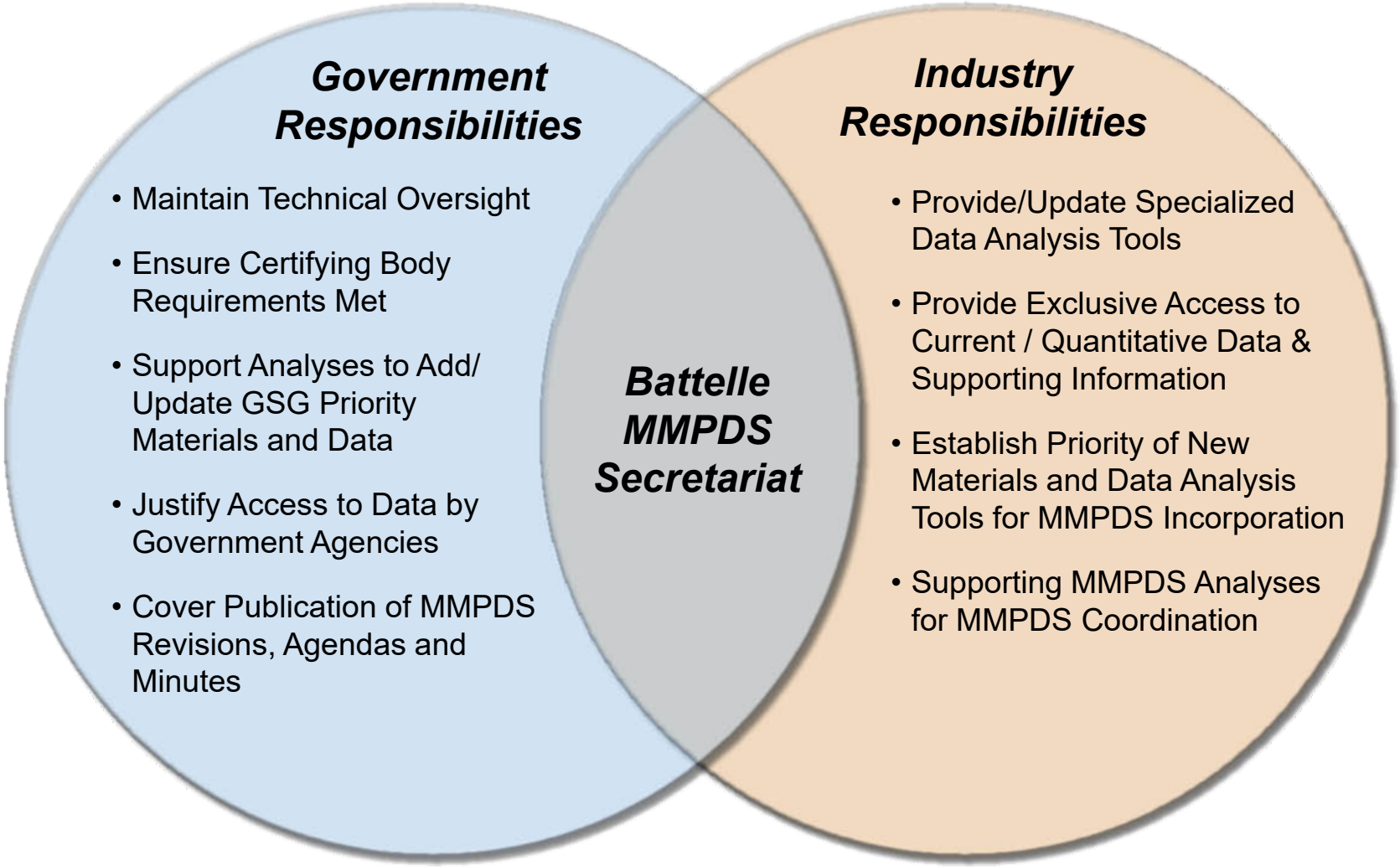
Metallic Materials Properties
Development and Standardization
(MMPDS)

MMPDS-2023
Volume I: Conventional
Mater





MMPDS General Coordination Committee



Task Groups:
Guidelines – approve **all** guidelines
Materials – Chapters 2-7
Fasteners – Chapter 8
Emerging Technology – Volume II

Steering Groups:
Get industry sector inputs
Airframe, Materials & Testing Services, and Propulsion

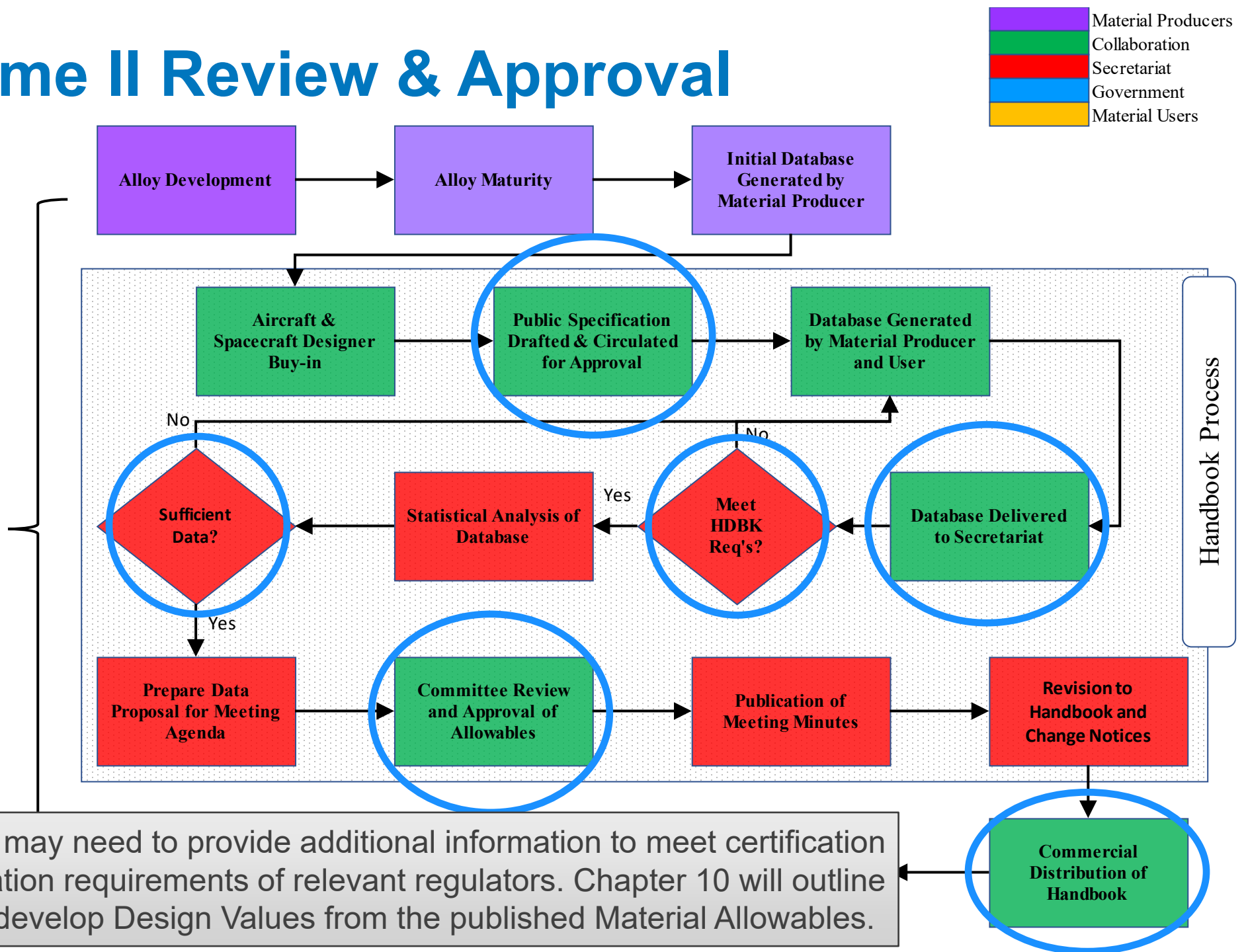
Working Groups:
Technical input from industry
Fatigue, Statistics, Welding
Volume 2

MMPDS Volume II Review & Approval

The Process is almost the same to publish values in Volume II.

Once a Material Allowable is published, the user must consider relevant influence factors to develop a Design Value.

AND convince their regulator or customer that they a making good material and good parts (“further showing”)



End-users may need to provide additional information to meet certification or qualification requirements of relevant regulators. Chapter 10 will outline a path to develop Design Values from the published Material Allowables.

9.2.2 Specification Requirements

- A material ". . . must be covered by a public, industry, or government specification that includes sufficient quality controls to ensure stable statistically valid mechanical properties. These controls shall include, but are not limit to, lot-release acceptance criteria for composition limits and mechanical properties, control of thermal-mechanical processing, sampling, and testing methodologies, and internal soundness/quality."
- "Test data meeting or exceeding requirements for S-Basis or better statistically based mechanical properties for properties included in the specification for lot-release shall be submitted to the MMPDS Secretariat for analysis."
- Additional requirements for Material Properties (9.2.2.1), Manufacturing and/or Processing (9.2.2.2), Feedstock (9.2.2.3), Recycling (9.2.2.4), Machine Qualification (9.2.2.5), Product Lot-Release Data (9.2.2.6)

Table 9.2.4 (1 of 3)

Table 9.2.4. Summary of Data Requirements within MMPDS Volume II

Mechanical or Physical Property	Customary Statistical Basis	Relative Importance in MMPDS Volume II	Extenuating Circumstances for Special Material Usage Requirements	Minimum Data Requirements				
				Sample Size	No. of Heats[a]	No. of Mfg. Lots	Machines[b]	Build Cycles
Bearing Yield and Ultimate Strength[c] (Direct)	S-Basis	Mandatory	Except for elevated temperature applications	30	3	3	3	3
Bearing Yield and Ultimate Strength[c] (Indirect)	C- and D-Basis	Strongly Recommended	Except for elevated temperature applications	20 indirect /20 reference	10	10	5	10
Coefficient of Thermal Expansion	Typical	Strongly recommended	Especially for anticipated range of usage	6	3	3	3	3
Compression Yield Strength[c] (Direct)	C- and D-Basis	Mandatory	Except for elevated temperature applications	30	3	3	3	3
Compression Yield Strength[c] (Indirect)	C- and D-Basis	Strongly recommended	Except for elevated temperature applications	20 indirect /20 reference	10	10	5	10
Creep and Rupture	Raw Data w/ Best-Fit Curves	Recommended	Especially for elevated temperature applications	6 tests per creep strain level and temp, at least 4 temps over usage range				
Density	Typical	Mandatory		3	3	3	3	3
Effect of Temperature Curves	Same as Room Temperature Properties	Recommended	Especially for elevated temperature applications	5[d]	2[e]	5	5	5
Effect of Thermal Exposure	Same as Baseline Properties	Recommended	Especially for elevated temperature applications	5[d]	2[e]	5	5	5
Elastic Modulus - Tension Compression Dynamic Shear	Typical	 Mandatory Mandatory Recommended Recommended	Dynamic modulus is strongly recommended for some engine applications	9	3	3	3	3
Elastic Modulus (T, C, D) - Elevated Temperatures	Typical	Mandatory	For anticipated usage temperature range	9	3	3	3	3

Continued on next page.

These tables are nearly identical to Table 9.2.4 in Volume I for conventional materials. Only the Machines and Build Cycle columns are new.

Table 9.2.4 (2 of 3)

Table 9.2.4. Summary of Data Requirements within MMPDS Volume II *(continued)*

Mechanical or Physical Property	Customary Statistical Basis	Relative Importance in MMPDS Volume II	Extenuating Circumstances for Special Material Usage Requirements	Minimum Data Requirements				
				Sample Size	No. of Heats[a]	No. of Mfg. Lots	Machines[b]	Build Cycles
Elongation	S-Basis	Mandatory	Two-inch gage length preferred	30	3	3	3	3
Fatigue-Load Control	Raw Data w/Best-Fit Curves	Recommended	Especially for high-cycle fatigue critical applications	6 test per stress ratio (R), 3 stress ratios, no minimum heat or lot requirements				
Fatigue-Strain Control	Raw Data w/Best-Fit Curves	Recommended	Especially for low-cycle fatigue critical applications	10 tests for R_ε = -1.0, 6 tests other strain ratios				
Fatigue Crack Growth	Raw Data w/Best-Fit Curves	Recommended	Especially for damage tolerance critical applications	Duplicate da/dN results for relevant stress ratios and stress intensity range				
Fracture Toughness - Plane Strain	Max., Avg., Min., Coef. Of Variance, S-Basis	Recommended	Mandatory for materials with spec minimum requirements for plane strain fracture toughness	30	3	10	3	10
Fracture Toughness - Plane Stress	Raw Data w/Best-Fit Curves	Recommended	Mandatory for materials with spec minimum requirements for plane stress toughness	f	2	5	3	5
Poisson's Ratio	Typical	Strongly recommended		6	3	3	3	3
Reduction In Area	Typical	Recommended		When tested, use same criteria as for elongation				
Shear Ultimate Strength[c] (Direct)	S-Basis	Mandatory	Except for elevated temperature applications	30	3	3	3	3
Shear Ultimate Strength[c] (Indirect)	C- and D-Basis	Strongly recommended	Except for elevated temperature applications	20 indirect/ 20 reference	10	10	5	10
Specific Heat	Typical	Strongly recommended	For anticipated usage temperature range	6	3	3	3	3
Stress Corrosion Cracking	Letter Rating	Recommended		Conform to replication requirements in ASTM G 47				

Continued on next page.

Table 9.2.4 (3 of 3)

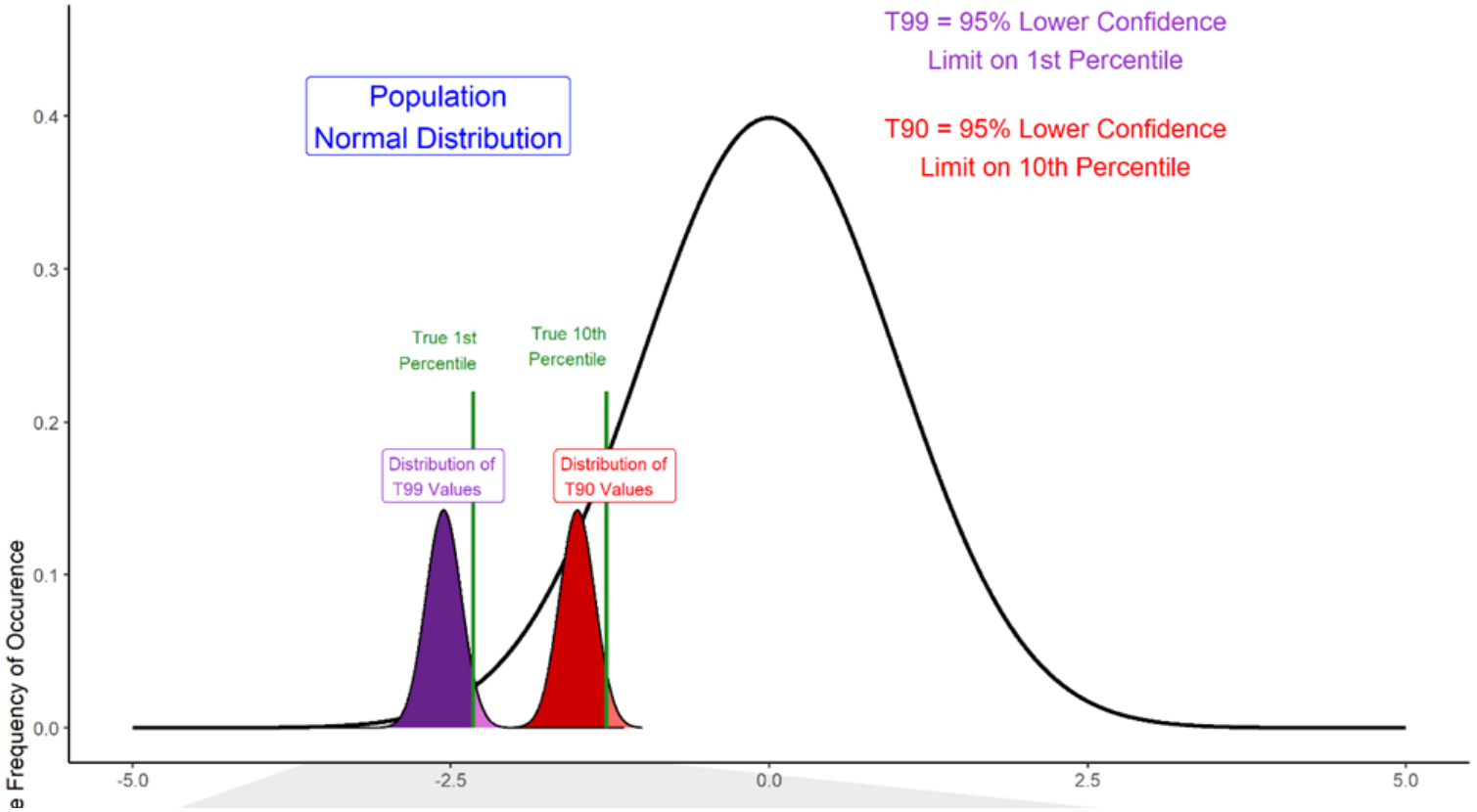
Table 9.2.4. Summary of Data Requirements within MMPDS Volume II *(continued)*

Mechanical or Physical Property	Customary Statistical Basis	Relative Importance in MMPDS Volume II	Extenuating Circumstances for Special Material Usage Requirements	Minimum Data Requirements				
				Sample Size	No. of Heats[a]	No. of Mfg. Lots	Machines[b]	Build Cycles
Stress/Strain Curves (To Yield) Tension and Compression	Typical	Mandatory	Desirable to have accurate plastic strain offsets from 10^{-6} to 3 x 10^{-2}	6	3	3	3	3
Stress/Strain Curves (Full Range) Tension	Typical	Mandatory	The strain rate should be constant through failure.	6	3	3	3	3
Tension Yield and Ultimate Strength (Direct)	S-Basis	Mandatory		30	3	3	3	3
Tension Yield and Ultimate Strength (Direct)	D-Basis	Strongly recommended	Especially for strength critical applications; a parametric representation of data is possible	100	10	10	5	10
Tension Yield and Ultimate Strength (Direct)	C-Basis	Strongly recommended	Especially for strength critical applications; a parametric representation of data is possible	100	10	20	5	20
Tension Yield and Ultimate Strength (Direct)	C- and D-Basis	Strongly recommended	Especially for strength critical applications; a parametric representation of data is not possible	299	10	20	5	20
Tension Yield and Ultimate Strength (Indirect)	C- and D-Basis	Recommended	For grain directions not required for lot release in specification	20 indirect/ 20 reference	10	10	5	10
Tension Yield and Ultimate Strength - Elevated Temps	Typical	Recommended	Mandatory for elevated temperature applications	g	2	5	5	5
Thermal Conductivity	Typical	Strongly recommended	For anticipated usage temperature range	6	3	3	3	3

a Heats refers to different input chemistries of the feedstock production process.
b Builds must be executed on the number of machines listed in the table or all existing machines if fewer machines exist.
c Optional direct property determination involves same minimum data requirements as tension yield and ultimate.
d Tests per temperature, at least 4 temperatures over usage range.
e 5 heats required for single form and thickness.
f Minimum sample size not specified, testing should be conducted at 6 or more panel widths to confidently represent trends over the panel widths of interest. Refer to ASTM E561 for testing details.
g Minimum sample size not specified, testing should be conducted at 6 or more temperatures to confidently represent trends over the temperature range of interest. Testing in regions where properties are expected to change rapidly with changes in temperature must be done at temperature intervals sufficiently small to clearly identify mean trends.

C-Basis (T99) – requires 20 builds. That means 20 manufacturing lots instead of 10 for A-Basis for conventional materials.
This is because there is a perception that build-to-build is a significant source of variations.

Volume II C-Basis, D-Basis, S-Basis: Material Allowables



T_{99} and T_{90} are one-sided lower tolerance bounds. Both are calculated from data.

C-Basis = the lower of the specification minimum or T_{99} value.

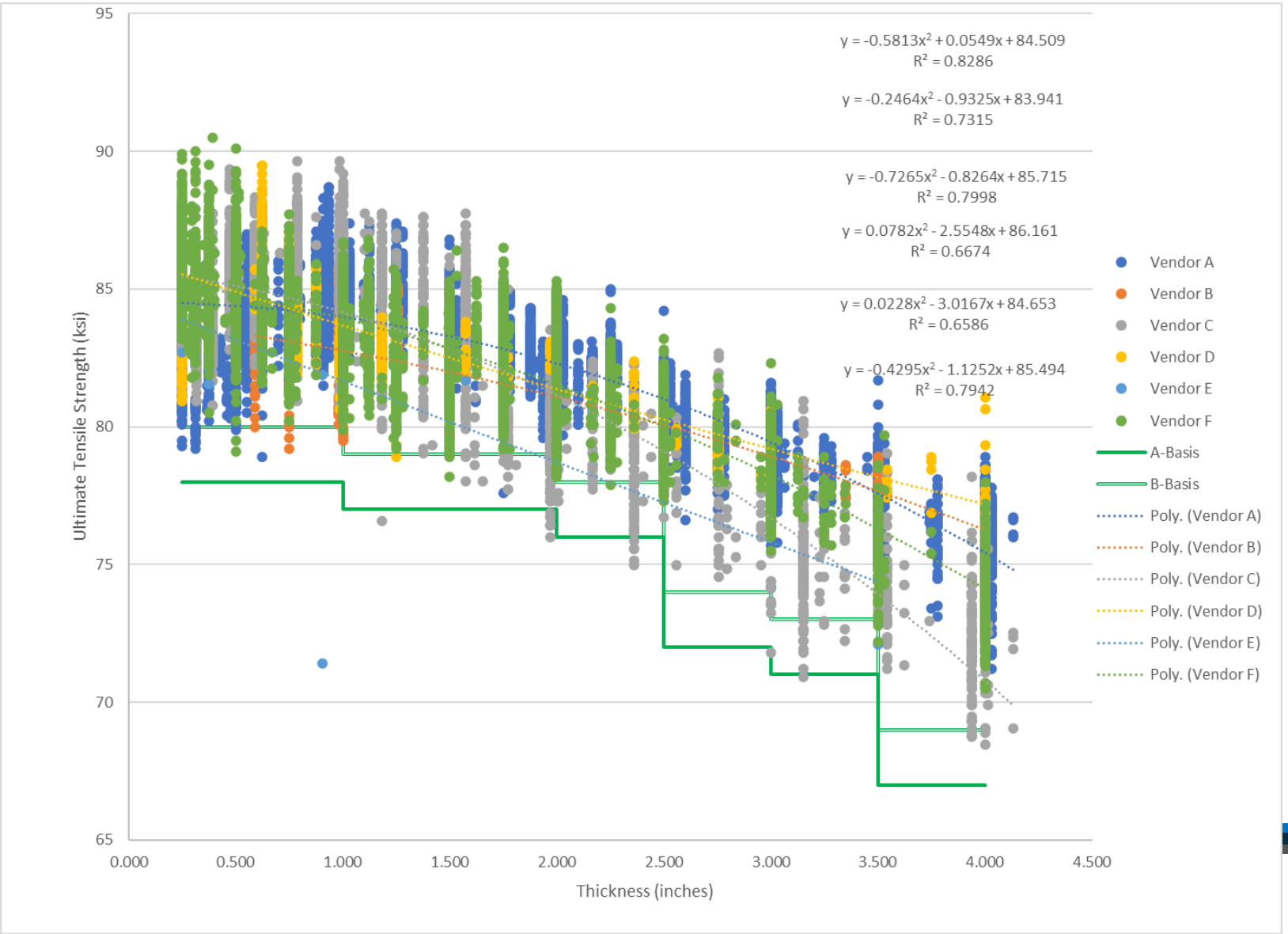
D-Basis = is the T_{90}. It is not related to the spec minimum.

S-Basis = is a T_{99} that does not meet C-Basis requirements for sample size or distribution fit.

Metallic C-/D-/S-Basis published in MMPDS Volume II require "further showing." A large sample is required.

MMPDS is the primary gov't approved source for A/B/C/D/S-Basis metallic material allowables. Proprietary values require extra effort by the CEO.

Conventional Material Legacy Alloy Review



- Four major aluminum producers, making plate & sheet in six separate factories
- All producers of 7075-T6 per AMS4045 are not making identical material
- The published A/B-Basis allowables are safe, at least for these producers.

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Next Steps

- At the request of the Government Steering Group, material allowables will not be published in Volume II before GCC approval of these Agenda Items
  - 21-20: Microstructural Submittal Requirements
    - Micrographs are required.
    - Details are being ironed out with input from government and industry.
  - 21-46: MMPDS Vol 2, Certification & Qualification “Further Showing”
    - OEMs and their customers requested introductory information about this process.
    - This will not be a checklist guaranteeing approval.
    - Material producer quality requirements are imposed on the owner of the machine.
  - 22-13: V2, 10.8 Considerations for Development of Design Values
    - MMPDS publishes bulk material allowables.
    - The user is responsible for applying influence factors for their application.
    - Many existing rules of thumb may no longer apply.

Phase 2 – Populate Volume II & Expand Guidelines

- Expand & Revise Guidelines†
  - 21-02: Section 9.5 & 9.6 for Volume II – data analysis methods
  - **21-20: Microstructural Submittal Requirements** ††
  - **21-46: MMPDS Vol. 2, Certification & Qualification "Further Showing"** ††
  - 23-04: V2, 10.3 Overview of Qualification
  - 23-11: Section 10.6 Consensus Standards
  - **22-13: V2, 10.8 Considerations for the Development of Design Values** ††
  - 23-19: Review of 9.7 for Volume II – fastening technologies
  - 23-20: Section 9.8 & 9.9 for Volume II – example problems
  - 21-46: MMPDS Vol 2, Certification & Qualification "Further Showing"
- Populate Volume II
  - 21-53: Analysis of 718 Laser Powder Bed Fusion per AMS 7038 – test plan approved at 40th
  - 23-22: 6061-RAM2 per AMS 7054 – test plan approved at 41st
  - 23-48: Ti-6Al-4V per AMS 7004/7005 – test plan approved at 42nd

† - a summary of significant open items covering Volume II.

†† - **Bold items** required to publish entries

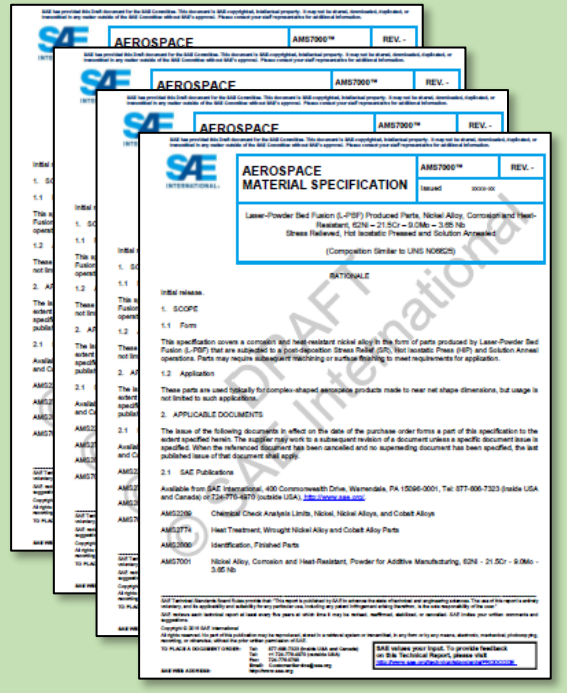
Coordination with SDOs & Other Organizations

- America Makes
  - AMSC WG5 Finished Material Properties - Co-Chair w/Rachael Andrulonis
  - Team member for JMADD, GAMAT, & Delta Qual projects
- ASTM International
  - F42 membership
- FAA-EASA AM Workshops
  - WG1 - Discussing S-Basis as an acceptable material allowable for low criticality parts.
- NIAR
  - JMADD - Air Force/FAA funded project to develop a specification and allowables for PBF Ti 6-4.
- NIST
  - NIST team defining data management standards. FAIR guiding database modernization project.
- SAE AMS
  - Advisory Group & Metals Committee
  - Additive Manufacturing Data Consortium – Battelle is a Liaison member
  - SAE AMS AM Metals Committee
    - Update to the AM Data Submission Guideline – Andrew Steevens (Boeing) sponsor
    - Multiple specs being developed. Battelle analyzes data to establish lot-release values.
      - Currently analyzing data for AMS 7024, 7030, 7036, 7038, 7039.
    - AMS 7032 (Machine Qualification) – reporting requirement to send data to Battelle to support MMPDS

SAE AMS-AM Material Properties for Spec Mins and Design Values

- Additive Integrated Specification Ecosystem (AISE™)*

➢ AM Standards Generation	SAE INTERNATIONAL	➢ SAE AMS-AM
➢ AM Data Generation	SAE AMS-AMDC Additive Manufacturing Data Consortium	➢ SAE AMDC
➢ AM Data Storage	MMPDS / NIAR	➢ MMPDS, NIAR
➢ Audit/Oversite	Nadcap Administered by PRI	➢ Nadcap
➢ AM Testing/Inspection	ASTM INTERNATIONAL	➢ ASTM
➢ Operator/Process Qualification	AWS American Welding Society	➢ AWS/SAE
➢ Supplier Pre-Qual Registry	PRI PERFORMANCE REVIEW INSTITUTE / ASPQP Aerospace Standards Part Qualification Program A Program of SAE ITC	➢ PRI/ITC p-QML*
➢ Supplier/Part Registry	PRI PERFORMANCE REVIEW INSTITUTE / ASPQP Aerospace Standards Part Qualification Program A Program of SAE ITC	➢ PRI/ITC QSL/QPL*



*PROPOSED – UNDER DEVELOPMENT

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Biography

Doug Hall

Doug Hall joined Battelle Memorial Institute in 2017 as the MMPDS Program Manager. Before that, he spent 30 years at Honeywell Aerospace as a stress and material allowables data analyst supporting safety and mission critical engine and airframe components for military and commercial programs. Doug began using MIL-HDBK-5D in 1987 and CMH-17, Rev G in 2011 to develop material allowables and design values both metals and composites used in critical applications. From 2011 to 2017, he supported approximately 150 stress analysts and 350 materials engineers at Honeywell offices around the world.

His current role at Battelle includes technical management of the MMPDS program and supporting material characterization, stress analysis, and life prediction on a variety of projects.

Doug has a bachelor's degree in Mathematics and a master's degree in Engineering Mechanics from Ohio State University.