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Metallic Materials Properties Development and Standardization (MMPDS): Continuation and Replacement for MIL-HDBK-5

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Abstract
The Metallic Materials Properties Development and Standardization (MMPDS) document is essentially a continuation of and replacement for the military handbook entitled “Metallic Materials and Elements for Aerospace Vehicle Structures” (MIL-HDBK-5). MIL-HDBK-5 is a source of statistically based material and fastened joint design allowables that are generally accepted for meeting aircraft certification and continued airworthiness requirements because of its rigorous standards. It also contains extensive information and data for other material properties and characteristics, such as fracture toughness, fatigue, creep strength, rupture strength, fatigue-crack propagation rate, and resistance to stress corrosion cracking. This paper details the government and industry transition of MIL-HDBK-5 to MMPDS. Examples will be included of recent technical initiatives to broaden the range and usability of the handbook’s statistically based design allowables and its supporting guidelines.

Background
The handbook entitled “Metallic Materials and Elements for Aerospace Vehicle Structures,” (MIL-HDBK-5), is considered the primary source of statistically based design allowables for metallic materials and fastened joints used in the design of aerospace vehicle structures in the United States (U.S.). The handbook has been in existence for over 50 years and has been reviewed and updated by industry and government on a consensus basis. MIL-HDBK-5 has evolved significantly over the years. Its predecessor was first published in 1937 as Army-Navy-Commerce Handbook 5 (ANC5). The United States Air Force (USAF) took over the primary responsibility of continuing development in 1954 and, subsequently, the name of the book was changed to MIL-HDBK-5 in 1956. The handbook has continued to incorporate new methodologies, add new material properties, and update existing ones. This continuing effort has enabled the handbook to keep up with technology development and maintain up-to-date information for materials being used by industry.

In 1971, detailed guidelines for statistical analysis of data were incorporated into the handbook establishing standardized procedures for data requirements and data reduction. The statistical procedures were further developed in 1984 to properly treat skewed data. As part of its continuing development, a major update of fracture toughness was completed in 1987. As digital information technology has become available and increasingly simple to use, the handbook was distributed on CD-ROM in 1997.

For over 40 years, the USAF Materials and Manufacturing Directorate at Wright-Patterson Air Force Base, OH, has been the lead government agency for this effort with ancillary support from the Federal Aviation Administration (FAA) and other Department of Defense (DoD) agencies. However, after several years of budget reductions to the Air Force Science and Technology accounts starting in 1997, and the move away from military specifications, alternative sources of funding were required to sustain the MIL-HDBK-5 process.

In 2000, it was agreed to transition responsibilities and custodianship of the MIL-HDBK-5 from the USAF to the FAA. Because MIL-HDBK-5 was critical to commercial aircraft certification and continued airworthiness, the FAA committed to taking the lead for the federal government for the continued development and maintenance of the handbook. An interagency agreement was established in 2001 transitioning the primary responsibility of maintaining the MIL-HDBK-5 process for establishing statistically based material allowables from the USAF to the FAA. In the transition, MIL-HDBK-5 will be replaced with the FAA document entitled "Metallic Material Properties Development and Standardization (MMPDS)."

Handbook Significance

The handbook is recognized internationally as a reliable source of aircraft materials data for aerospace materials selection and analysis. Consistent and reliable methods are used to collect, analyze, and present statistically based material and fastener allowable properties. The handbook is the only publicly available source in the U.S. for material allowables that the FAA generally accepts for compliance with Federal Aviation Regulations (FAR) for material strength properties and design values for aircraft certification and continued airworthiness. Moreover, it is the only publicly available source worldwide for fastener joint allowables that comply with the FARs. The only other publicly available source that complies with the FARs for material allowables is the Engineering Science Data Unit (ESDU) Metallic Materials Data Handbook, ESDU 00932, recognized primarily in Europe.

The handbook benefits government personnel who develop, regulate, repair, modify, or certify critical aircraft and aerospace systems since it helps improve safety and increase operational readiness. The use of handbook allowables precludes further showing and FAA review to find compliance to the FAR. Allowables from other sources require an FAA review of large amounts of data for each allowable being considered, which would be a significant effort for both industry and the FAA with respect to time and technical resources required. The handbook provides a level playing field that has been defined and agreed to as part of an industry-government collaborative effort. The use of the handbook results in uniform levels of safety regarding structural approvals within all FAA Aircraft Certification Offices.

Industry benefits because the handbook avoids redundancy and reduces cost when defining minimum design properties for critical structural materials used in different aircraft and aerospace systems. Thus, aircraft manufacturers support the handbook because it helps them operate profitably when designing, repairing, and building certified safe airplanes. Material and fastener suppliers support the handbook since it helps them operate profitably while broadening the safe usage of their products.

Handbook Contents

The handbook contains design minimum properties in terms of tensile ultimate and yield (F_{tu}, F_{ty}), compression (F_{cy}), shear (F_{su}), and bearing ultimate and yield (F_{bru}, F_{bry}) for the most widely used metallic materials for aerospace applications. It provides standardized design values and related information for metallic materials and structural elements used in aerospace structures. Figure 1 shows the typical format of design mechanical properties displayed in the handbook.

Table 3.2.9.0(b). *Design Mechanical and Physical Properties of Alclad 2524-T3 Aluminum Alloy Sheet and Plate*

Specification	AMS 4296						
Form	Sheet and Plate						
Condition	T3						
Thickness, in.	0.032-0.062	0.063-0.128		0.129-0.249		0.250-0.310	
Basis	S	A	B	A	B	A	B
Mechanical Properties:							
F_{tu}, ksi:							
L	59	61	62	62	62	62	63
LT	59	61[c]	62	62	62	62	63
F_{ty}, ksi:							
L	44	45	47	45	46	45	46
LT	39	40[d]	42	40	41	40	41
F_{cy}, ksi:							
L	38	39	41	39	40	39	40
LT	42	43	45	43	44	43	44
F_{su},[b] ksi:	40	41	42	42	42	42	43
F_{bru},[a] ksi:							
(e/D = 1.5)	93	97	98	98	98	98	100
(e/D = 2.0)	117	121	123	123	123	123	125
F_{bry},[a] ksi:							
(e/D = 1.5)	65	67	70	67	69	67	69
(e/D = 2.0)	76	78	82	78	80	78	80
e, percent (S-basis):							
LT	15	15	...	15	...	15	...
E, 10^3 ksi							
Primary	10.3						
Secondary	9.8						
E_c, 10^3 ksi							
Primary	10.5						
Secondary	10.0						
G, 10^3 ksi	---						
μ	0.35						
Physical Properties:							
w, lb./in.^{3}	0.100						
C, K, and a	not available						

[a] Bearing values are "dry pin" values per Section 1.4.7.1. See Table 3.1.2.1.1.
[b] Determined in accordance with ASTM B831-93.
[c] A-basis value is 62 ksi.
[d] A-basis value is 41 ksi.

Figure 1. Example of design allowable data in the handbook

The handbook also contains extensive information and data for other material properties and characteristics, such as elongation, reduction of area, elastic modulus, fracture toughness, fatigue strength, creep strength, rupture strength, fatigue-crack propagation rate, and resistance to stress corrosion cracking.

Materials included in the handbook are steel, aluminum, magnesium, and titanium. The handbook also includes information on heat-resistant materials, hybrid materials, and structural joints, e.g., mechanically fastened and metallurgically connected (welding and brazing) systems. In addition, detailed guidelines of data analysis procedures are included for determining design allowables. Based on the standardized procedures, requirements for adequate test data have been established to ensure a high degree of reliability for allowables published in the handbook.

Tensile design minimum allowables F_{tu} and F_{ty} are determined from one-sided lower-tolerance limits, T_{99} and T_{90}, by direct or indirect statistical procedures. The T_{99} value represents a lower-tolerance limit in which 99% of the population of the values is expected to equal or exceed the T_{99} value with 95% confidence. Likewise, the T_{90} value represents a lower-tolerance limit in which 90% of the population of the values is expected to equal or exceed the T_{90} value with 95% confidence. Direct statistical procedures can be used if the sample can be described by a Pearson or Weibull distribution in which a minimum sample size of 100 must be considered, including data from at least ten production heats and ten lots. If the sample cannot be described by a distribution (as described above), a minimum sample size of 299 must be used, including data from at least ten heats and ten lots.

Design minimum shear, compression and bearing allowables are typically determined through the indirect method. At least ten data points from three heats and ten lots are used in combination with paired direct properties to compute a design minimum value. In this indirect method, the compression, bearing, and shear strengths are paired with tensile values determined in the same region of the product to produce a ratio. Statistical analyses of these ratios are conducted to obtain lower-bound estimates of the relationship between the primary property and the ratioed property. These ratios are then multiplied with the appropriate F_{tu} or F_{ty} in the handbook to obtain the F_{su}, F_{cy}, F_{bru}, and F_{bry} values for shear, compression, and bearing (ultimate and yield), respectively. The material property data in the handbook can be categorized in the following four types, based on the statistical confidence of their values:

Typical Basis: Average value having no statistical assurance associated with it.

S-Basis: Minimum value determined by appropriate industry or government specifications. The minimum number of data sets (observations) is 30 and must come from at least three heats and ten lots.

B-Basis: Equals the T_{90} lower-tolerance limit as described earlier.

A-Basis: The lesser of S-basis or the T_{99} lower-tolerance limit as described earlier.

Handbook Process

A rigorous process has been established to ensure that data entered in the handbook is properly screened, analyzed for goodness, and reliable. Handbook additions, modifications, and deletions are made on a consensus basis by the General Coordination Committee (GCC) at coordination meetings held on a semi-annual basis.

General Coordination Committee

The GCC is a voluntary group led by the Government Steering Group (GSG), Figure 2. The GCC consists of approximately 150 members from various government agencies, including the

FAA, USAF, Army, Navy, NASA, etc., and is open to interested industrial companies such as airframe manufacturers, material producers, suppliers, and fastener manufacturers. An unbiased third party acts as the GCC secretariat for the planning, facilitating, coordinating, and implementing activities necessary to develop and maintain the handbook. Data reduction,

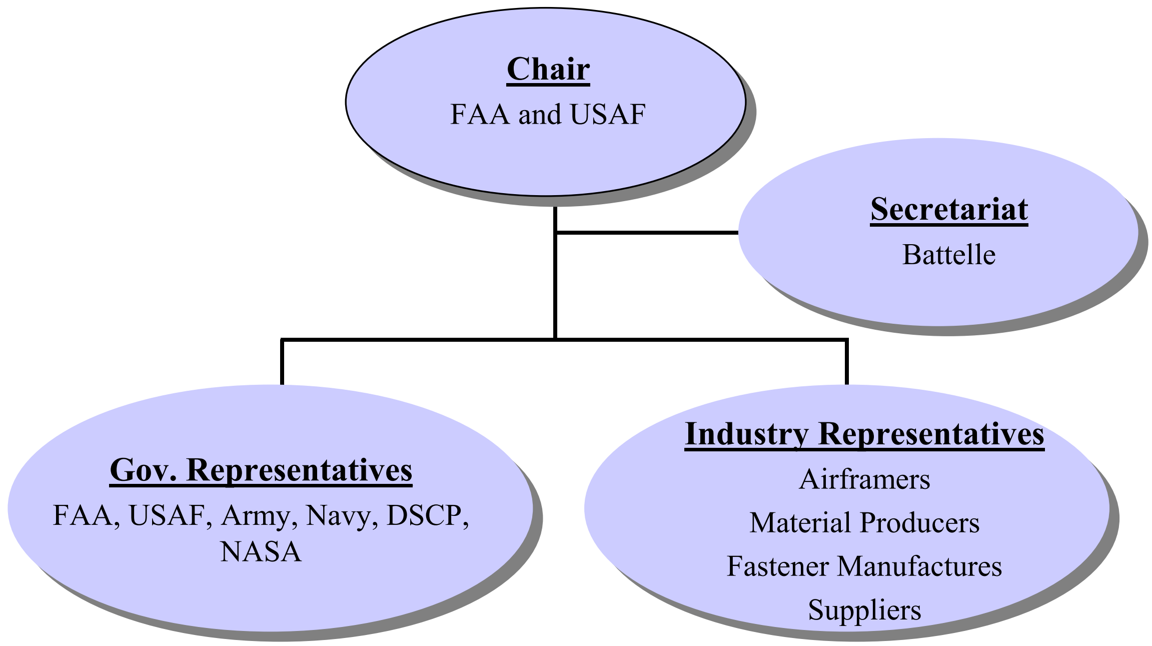

Figure 2. Government Coordination Committee (GCC)

presentation of statistical and characteristic properties, and compliance with handbook requirements are all functions of the secretariat. Over the past 40 years, the USAF served as the chair and Battelle Columbus Laboratories served as the handbook secretariat. During the current transition, the GCC is co-chaired by the FAA and USAF with Battelle as the secretariat. Under the current GCC, there are seven working or task groups, which are listed below and shown in Figure 3:

1) Airframer Steering Group (ASG), which is restricted to airframe manufacturers only. Members of ASG currently include Boeing, Lockheed, Northrop-Grumman, Cessna, Raytheon, Gulfstream, Bell, and Sikorsky
2) Fastener Task Group (FTG), which excludes fastener suppliers so that requirements and critiques of fastener systems can be openly discussed between users of these systems
3) Fastener Industry Working Group (FIWG), which is open to all GCC members
4) Materials Task Group (MTG), which is open to all GCC members
5) Guidelines Task Group (GTG), which is open to all GCC members
6) Statistics Working Group (SWG), which is open to all GCC members
7) Laser Additive Manufacturing Working Group (LAMWG), which is open to all GCC members

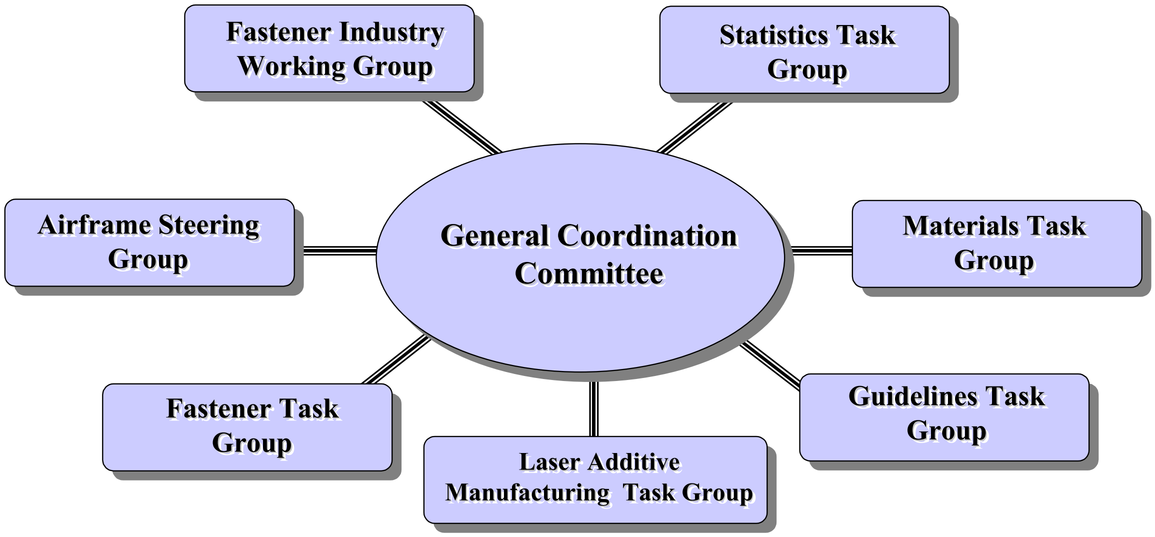

Figure 3. Working and steering groups of the GCC

Each group will address specific technical issues as tasked by the GCC. For example, the SWG will evaluate statistical procedures and submit its recommended changes to the GCC for approval. Similarly, the FTG will review fastener analysis procedures and recommend changes to the GCC. The LAMTG is newly formed and will determine if it is appropriate to include process-dependent materials in the handbook.

The GCC coordination meeting is held twice a year, typically in April and October. The secretariat acts as the meeting facilitator, providing agenda and meeting minutes. The meetings generally take about 4 days with the first 3 days for group meetings before the GCC meeting on the fourth day. The agenda is normally mailed by the secretariat to attendees 4 weeks prior to the meeting date and normally includes:

1) A review and approval of data proposals (in general, 20-30 data proposals are reviewed and approved at each meeting).
2) A review and approval of S-, A- and B-basis material properties for inclusion to the handbook.
3) An approval of change notices on changes and updates as well as revisions (each of the change notices approved at the coordination meeting consists of 300-500 pages).
4) A review and approval of updates and/or modifications of guidelines and methodologies.
5) A review of status reports on ongoing data analysis and methodology development.

At each meeting, the GCC acts upon proposed changes and additions to the document submitted in writing to the secretariat before the meeting. The approved changes are entered into the meeting minutes, which are compiled and mailed by the secretariat to attendees 4 weeks after the meeting. The meeting minutes are then recognized as approved data for entry into the subsequent handbook release.

Data Entry Requirements

Inclusion of material property data into the handbook is a rigorous and lengthy process that requires GCC final approval after an independent and thorough statistical analysis is performed by the unbiased secretariat. Data proposals need to be reviewed and approved by the GCC. For a product to be considered for inclusion in the handbook, the following criteria must be met:

1) It is a production material, i.e., standard manufacturing procedures must have been established for its fabrication and processing.
2) It is covered by an industry specification (an AMS issued by SAE Aerospace Materials Division or an ASTM standard published by the American Society for Testing and Materials), or a government specification (military or federal).
3) A sufficient number of production heats and lots have been tested to meet handbook requirements.

Once a data proposal is accepted for further analysis, data will be sent to the secretariat for independent examinations and analyses. Data will be first evaluated for quality and quantity acceptance. Standard statistical procedures, as specified in the handbook, will be applied to evaluate data quality and its statistical distribution to determine which basis (A-, B-, S-, or typical) the data fits into. In most cases, the material producers begin to work with the secretariat while the material specifications are being drafted and reviewed. Figure 4 shows the handbook review and approval process.

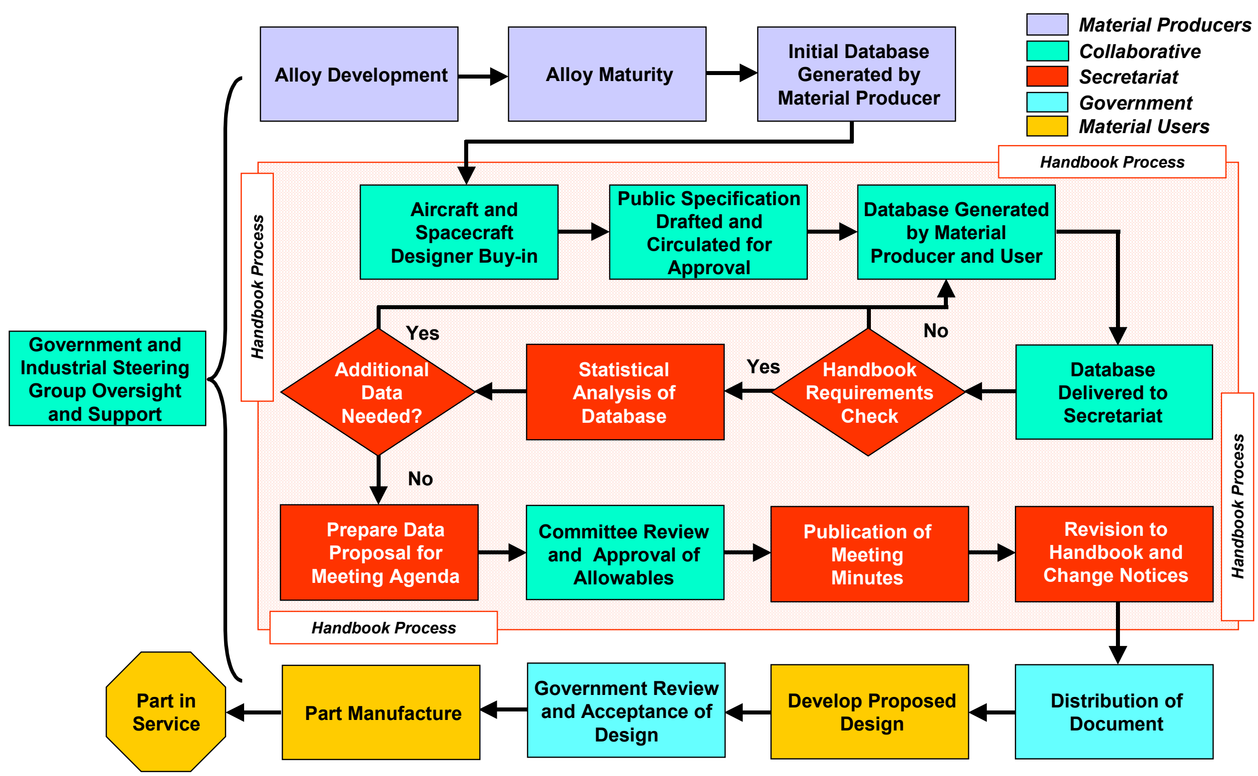

Figure 4: Handbook review and approval process

Industry Collaboration

Industry has been and continues to be a strategic partner in the development and maintenance of the handbook. In recent years, suppliers and manufacturers have been the primary source for information entered in the handbook. Industry is responsible for registering new materials and fastening systems to appropriate organizations and for developing specifications per Society of Automotive Engineers (SAE) Aerospace Material Specifications (AMS) guidelines. Moreover, industry is responsible for the testing required to generate the raw data used to develop material and fastening system allowables. Suppliers invest a large amount of resources to introduce a new material into the handbook; including material registration, developing specifications, and generating test data for developing material allowables. In addition, industry representatives are active participants of the handbook process and activities. At GCC meetings they help render decisions for the entry, deletion, or modification of handbook contents. They provide review, feedback, and input to agenda items and meeting minutes from GCC meetings. Industry absorbs the cost to participate in these activities, including travel costs.

In 1997, the Industry Steering Group (ISG) was formed by Battelle Memorial Laboratories in response to a sharp cutback in DoD funding. The ISG is a consortium comprised of major aerospace original equipment manufacturers and supplier companies. The current ISG membership is shown in Table 1. The ISG was formed to develop technologies that meet industry needs while indirectly benefiting the handbook. Battelle acts as the ISG treasurer, secretary, meeting facilitator, and archivist. As treasurer, Battelle is custodian of ISG consortium funds, supervising receipts and expenditures and providing an annual statement on the financial condition of the ISG to all members. As secretary, Battelle records and maintains meeting minutes of all meetings and activities; is in charge of all papers, archives, records, and property; issues all notices of meetings; and provides periodic reports on the activities of the organization. The ISG meets at the same time the GCC working and task groups meet.

Table 1. Current MIL-HDBK-5/MMPDS Industrial Steering Group Membership Roster

Company	Membership Status
Alcoa	Continuous
Bell Helicopter	Continuous, except for one year
Boeing	Continuous
Cessna	Continuous
Corus Aluminum	Continuous, except for one year
Howmet	Continuous
Lockheed Martin	Continuous, except for one year
Northrop Grumman	2 years of membership to date
PCC Structurals	1 year of membership to date
Pechiney/McCook	Continuous
Textron Aerospace Fasteners	2 years of membership to date
Universal Alloy	Continuous, except for one year

The ISG funding is used to complement the development of products that benefit members of the ISG and aerospace industry. These products include an ISG member's only website that contains information such as electronic, hyperlinked access to current and prior handbooks, meeting agendas, handouts, and minutes. An example of an ISG web-based product is shown in

Figure 5. A Technical Interchange Forum was developed to promote dialogue between aircraft material users, suppliers, and certifying bodies. A CAD-compatible relational database of MIL-HDBK-5 static strength, fatigue, fracture toughness, and corrosion design properties is included. In addition, a suite of analysis tools have been developed by the ISG and is available through the website with the following capabilities:

- Determine direct and indirect static design allowables in accordance with current guidelines
- Normal and Pearson estimation of upper and lower tail design allowables on small samples
- Obtain statistically based fatigue strength values for all materials and conditions covered by MIL-HDBK-5 S-N curves
- Construct typical and full-range stress-strain curves in accordance with handbook guidelines
- Determine temperature-specific, coordination group-verified design allowable properties

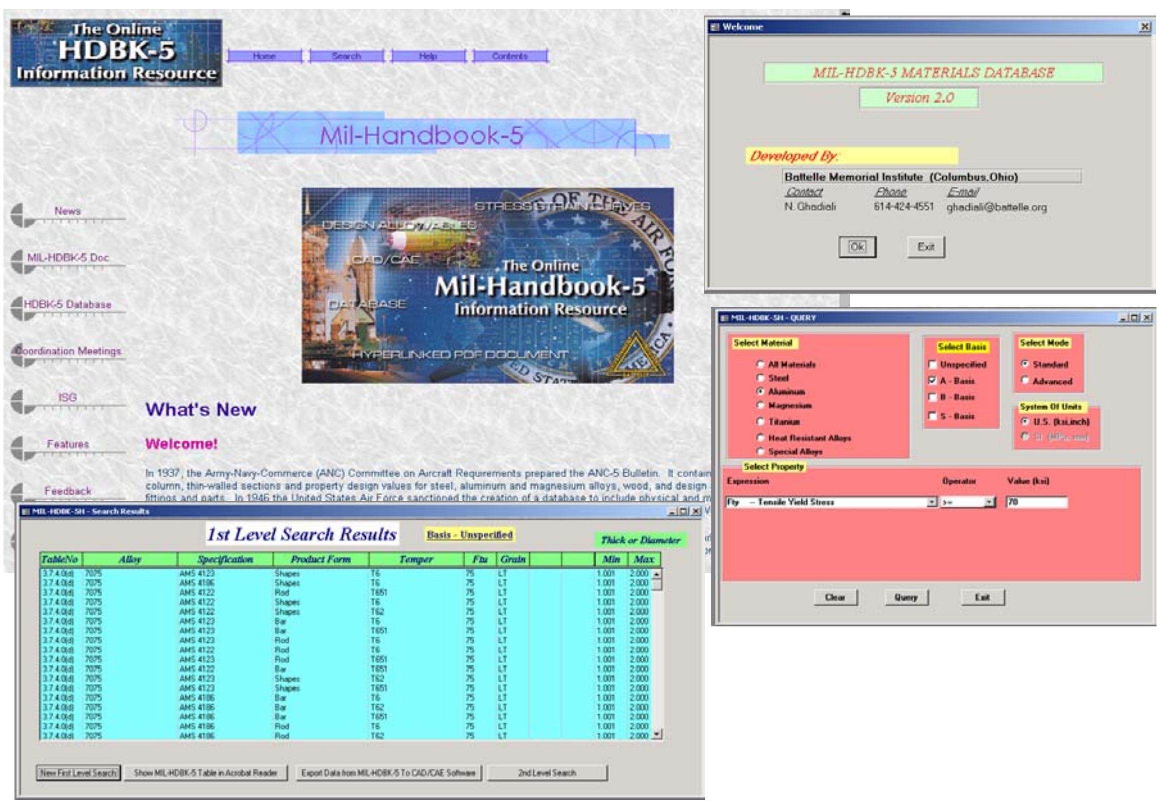

Figure 5. ISG web-based products

The ISG products are continuously reviewed, updated, and modified for improved usefulness and benefit to the member companies. The sponsoring government agencies (FAA and USAF) also have full access to these ISG web-based products.

Handbook Transition

A plan has been developed to transition custodianship of MIL-HDBK-5 from the USAF to the FAA. The legacy of the MIL-HDBK-5 process of establishing statistically based design allowables for material and fastener systems will be maintained in the transition. The FAA and USAF will continue teaming closely with industry and other government agencies to develop a replacement handbook entitled "Metallic Materials Properties Development and Standardization" (MMPDS).

The new MMPDS document will be updated on a regular basis and ultimately replace MIL-HDBK-5 as the aviation industry standard for statistically based design properties of metallic materials. The final version of the MIL-HDBK-5 document, MIL-HDBK-5J, is scheduled to be published in the February 2003 time frame. The first edition of the MMPDS will be published at the same time. The MMPDS will be distributed through the National Technical Information Service (NTIS). For a nominal fee, the MMPDS will be available in four formats: (1) download a portable document format (PDF) at a cost of $8.95; (2) microfiche at $12.00 plus shipping; (3) on a CD for $18.95 plus shipping, and; (4) paper copy, $29.50 plus shipping, based on a 100-page document.

The primary goal of the transition plan is to maintain the MIL-HDBK-5 process for establishing statistically based material and fastener system allowables that are required for aircraft certification and continued airworthiness. As part of this process, government and industry coordination is essential to maintain the integrity of both the design allowable and guideline development processes.

As part of the transition plan, a broader base of government and industry support is being cultivated to ensure the long-term health of the MMPDS. Currently, the FAA is the sole government agency funding this effort. The risk level is too high to have a single government agency funding this effort over a long period of time, during which unforeseen budget cuts and restrictions could again occur. Alternative funding sources are required to maintain the prolonged existence of the MMPDS. The custodianship and sponsorship of the handbook must be shared by multiple organizations. The current GSG and ISG are working towards that goal and are becoming more broad-based and institutionalized groups. There are plans to develop procedures to improve efficiency and accountability. Government agencies benefiting from MMPDS will be encouraged to participate with GSG members receiving benefits consistent with their level of participation. Some of the benefits being explored are free copies of the electronic or hard copies of the handbook, access to the ISG website databases, and data analysis tools (e.g., A- and B-basis determination, equivalent strain and stress fatigue analysis, and statistical crack growth analysis).

As discussed previously, industry plays a key role in handbook activities and recently stepped up its efforts through the development of the ISG. Through the auspices of the ISG, web-based products and tools have been developed that complement handbook activities. The ISG exemplifies industry's willingness to participate and collaborate. The ISG recognizes the potential to draw increased support from industry by promoting a more broad-based international membership with foreign airframe and supplier companies.

It is estimated that over 1000 copies of MIL-HDBK-5 have been issued each year by the Defense Area Printing Services. To take advantage of demand and circulation of the handbook, the idea of selling the MMPDS handbook at a nominal fee to nonpaying GSG and ISG members will be explored. Profits from sales could provide supplemental funding for handbook activities. Currently, there are several commercial ventures independent and outside of the handbook process that are profiting from the sale of MIL-HDBK-5 information raising several concerns. Of primary importance is maintaining the integrity of the MIL-HDBK-5/MMPDS information being sold. Commercialization of the handbook within the current process will ensure the integrity of the data and could provide supplemental funds to support the handbook activities. As a starting point, a commercialization plan will be developed, including a market survey, feasibility study, appropriate timelines, and marketing strategies.

Handbook Enhancements

Several recent enhancements have been made to broaden the range and application of the handbook's statistically based design properties and its supporting guidelines. A complete restructuring of the Chapter 9 guidelines for improved handbook usability was completed and approved for the next release. Chapter 9 provides detailed guidelines for judging adequacy of data, procedures for analyzing data in determining property values, and formats for submitting results of analyses to the GCC for approval.

Revised analytical techniques were established for the analysis of fastened joints. The past analysis method was used for over 3 decades, based on a trilinear fit to the test data. Changes were made because of concerns that the approach was inconsistent with techniques used for static properties and without a statistical basis. The new approach is based on the development of a B-basis lower-limit curve below the average design curve. Figure 6 shows a comparison of the joint ultimate design curve using the new B-basis approach and the traditional trilinear approach. Using the new approach, new fastener joint allowables will be reported in the handbook as B-basis properties.

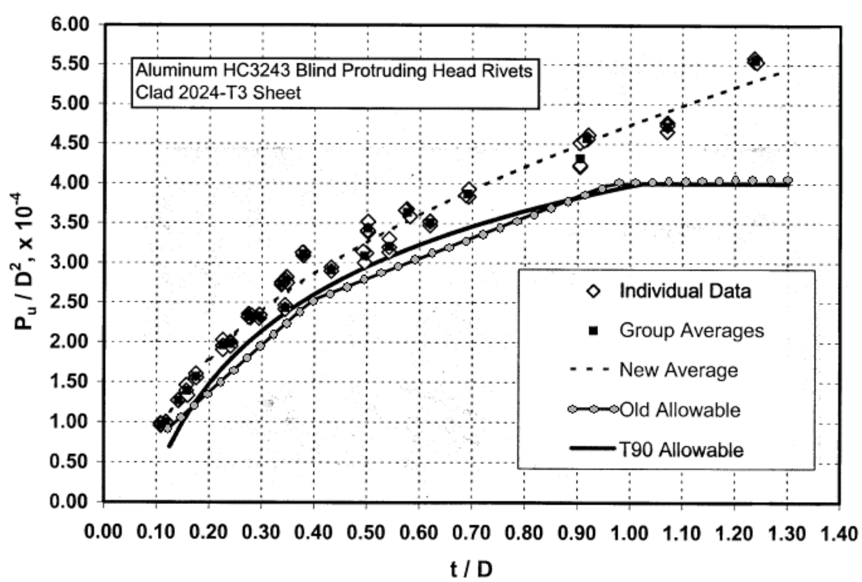

Figure 6. Joint ultimate load design curve

Alternative techniques for statistical characterization of fatigue crack growth properties are currently being considered for incorporation into the handbook guidelines. For example, Figure 7 shows a large collection fatigue crack growth data for Ti-6Al-4V HIP and annealed castings for stress ratios ranging from –0.50 to 0.80. This data was analytically modeled with an inverse hyperbolic tangent function and represented as mean and 2σ (standard deviation) upper- and lower-bound curves in the figure.

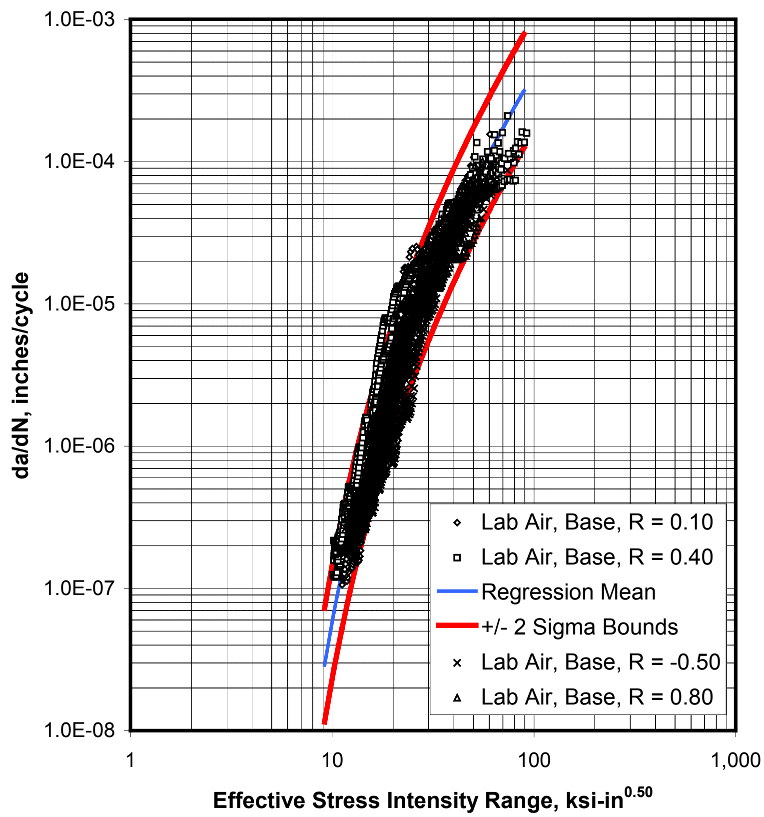

Figure 7. Mean and upper- and lower-bound crack growth properties of Ti-6Al-4V HIP and annealed castings

Average and minimum plane strain fracture toughness properties of various aircraft structural materials have been included in the handbook for over 20 years. These properties have traditionally been considered as constant for a given alloy, heat treatment, and product form; however, more recent work on large collections of valid plane strain fracture toughness data have shown that the properties often vary significantly over a range of product thicknesses, as shown in Figure 8, for a 7000 series aluminum plate alloy.

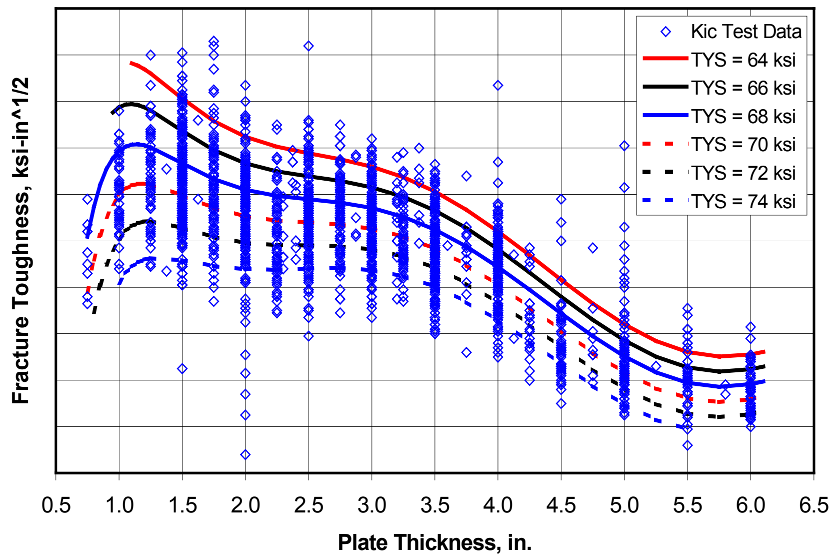

Figure 8. Variation in plane strain fracture toughness as a function of yield strength and plate thickness in a 7000 series aluminum alloy

Widespread problems with stress corrosion cracking in aging aircraft are being addressed in the handbook through the development of design allowables on new strength aluminum alloys and tempers that provide greatly improved resistance to stress corrosion cracking, with very little loss in strength properties, as shown in Figure 9.

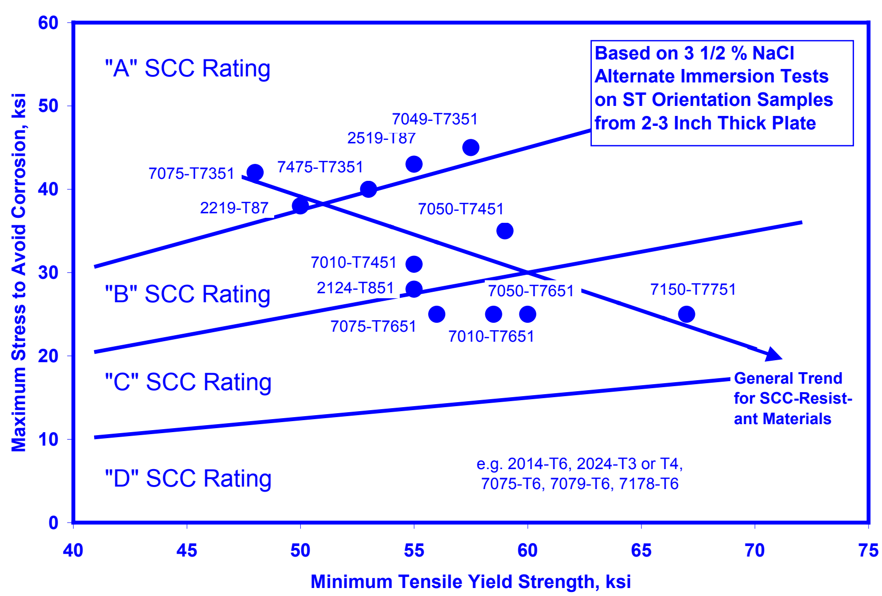

Figure 9. Resistance to stress corrosion cracking as a function of yield strength for aluminum alloys

Summary

The Metallic Materials Properties Development and Standardization (MMPDS) document will be a continuation of and replacement for the military handbook for metallic materials entitled "Metallic Materials and Elements for Aerospace Vehicle Structures" (MIL-HDBK-5). These handbooks are sources of statistically based material strength properties and design values that are generally accepted as meeting the Federal Aviation Regulations for material strength properties requirements because of its rigorous standards. As with MIL-HDBK-5, the MMPDS will also contain extensive information and data for other material properties and characteristics such as fracture toughness, fatigue, creep strength, rupture strength, fatigue-crack propagation rate, and resistance to stress corrosion cracking. The legacy that has evolved over the past 50+ years will be continued through this new document, providing users with a robust database of statistically reliable data.