Development of MMPDS Handbook Aircraft Design Allowables

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Abstract
This year, 2003, marks the first year of publication of the Metallic Material Properties Development and Standardization (MMPDS) Handbook and the final year of publication of MIL-HDBK-5. For this year only, MMPDS-01 and MIL-HDBK-5J will be technically equivalent. In the spring of 2004, when the 1st Change Notice of MMPDS-01 is published, MIL-HDBK-5 will be designated noncurrent and MMPDS will become the only government recognized source in the U.S. of published design allowable properties for commercial and military aircraft structures and mechanically fastened joints. In this way, the 65-year legacy of MIL-HDBK-5, and its predecessor Army-Navy-Commerce Handbook 5, will be maintained.

This paper will review technical activities in four key focus areas of the MMPDS coordination committee:

- Development of Statistically Based Design Allowables for Aircraft Mechanical Fasteners
- Determination of Minimum Design Properties for Skewed Distributions Using the Pearson Method
- Improvement of the Consistency Between Specification Minimum Properties and MMPDS T_{99} (A-Basis Minimums) for Aircraft Materials
- Facilitation of Worldwide Coordination of Aircraft Material Design Allowables

This paper will also briefly review two potential research topics of interest to many within the aging aircraft community:

- Improved interpretation and statistical representation of notch effects on fatigue life
- Development of statistically based design limits on crack growth data

This paper will conclude with an update on other current and near-term initiatives of the MMPDS Government and Industry Steering Groups.

Background

The handbook traditionally known as MIL-HDBK-5 has, for over 50 years, been 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.). Throughout this period, the document has been reviewed and updated by industry and government on a consensus basis. Its predecessor was first published in 1937 as Army-Navy-Commerce Handbook 5 (ANC5). The United States Air Force (USAF) changed the name of ANC5 to MIL-HDBK-5 in 1956. From 1956 to 2003, under USAF leadership, over 95 industry/government coordination meetings were held to review the usefulness and accuracy of proposed Handbook changes and additions; over 35 major revisions of the Handbook resulted over that time period. Details regarding the coordination and approval process may be found in Reference 1.

In 2002 the FAA took over formal U.S. Government responsibility for coordination of this document and renamed it the Metallic Material Properties Development and Standardization (MMPDS) Handbook. Under the Federal Aviation Administration's (FAA) guidance and oversight the MMPDS Handbook will continue the longstanding MIL-HDBK-5 legacy through ongoing development, review and incorporation of state-of-the-art analysis methodologies and reliable statistically based material properties on all widely used metallic aircraft structural materials. Continued government coordination of the Handbook will also ensure that the analysis methods and design allowable data remain useful and unbiased for certification of new aircraft and efficient repair/maintenance of the existing fleets of military and commercial aircraft throughout the world.

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. 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 and rupture strength, strength, fatigue crack propagation rate, and resistance to stress corrosion cracking. The handbook also includes design allowables for mechanically fastened joints.

Detailed guidelines for determining design allowables are also included in the Handbook [2]. Two levels of conservatism in tensile design minimum allowables are computed for F_{tu} and F_{ty}. The T_{99} value, which is commonly required for use on nonredundant, critical aircraft structure, represents a 95% lower confidence limit on the 1st percentile of the distribution, as illustrated in Figure 1. Similarly, the T_{90} value, which is commonly used on redundant, but critical structure, represents a 95% lower confidence limit on the 10th percentile of the distribution. Direct parametric statistical procedures can be used if the sample contains at least 100 observations (from at least ten heats and lots) and can be described by a Pearson or Weibull distribution. If the sample cannot be described parametrically, nonparametric procedures must be used, which almost triples minimum sample size requirements, to a minimum of 299 observations. Some of the reasons why these large sample sizes are required in MMPDS for determination of design allowables will be reviewed later in this paper.

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. It is important to keep in mind that the reliability of these derived design allowables is dependent on the validity of the underlying assumption that the statistical variability of the properties being ratioed is similar. Although this assumption cannot be validated with high statistical confidence with small sample sizes, it has been found to be a realistic assumption with a variety of metallic materials when larger sample sizes of these secondary properties have been available.

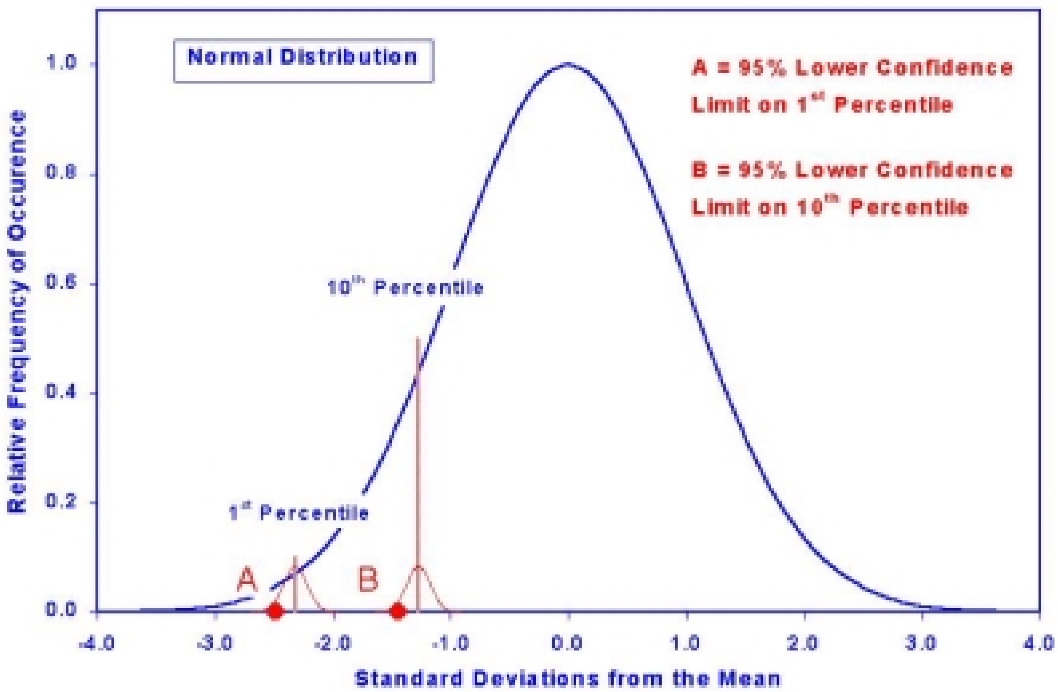

Figure 1. Illustration of A- and B-Basis Design Allowables for a Normal Distribution

In summary, the material property data in the handbook can be categorized in the following four types, based on their statistical confidence:

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 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 Code of Federal Regulations (CFR) 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 CFRs. 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. At the present time ESDU 00932 is recognized primarily in Europe. Some differences in analysis procedures used to compute material design allowables also exist between these two documents. Recently initiated efforts to resolve and/or reconcile these differences between the MMPDS and ESDU 00932 coordination groups will be discussed later in this paper.

The MMPDS/MIL-HDBK-5 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 by applicants demonstrates compliance to the CFR. Allowables from other sources require an in-depth 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 also 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. Since 1997, the collective Handbook interests of several metallic aircraft material suppliers and users (Alcoa, Bell Helicopter, Boeing, Cessna, Corus Aluminum, Howmet, Lockheed, McCook, Northrop Grumman, PCC Structurals, Pechiney, Textron Aerospace Fasteners, and Universal Alloy) have been represented through the Industrial Steering Group (ISG). Representatives of ISG member companies meet prior to each Handbook coordination meeting to review ISG-specific activities and to work with the Government Steering Group in setting priorities for future Handbook guideline and design allowable development activities.

Development of Statistically Based Design Allowables for Aircraft Mechanical Fasteners

Methods and techniques to establish design allowables for fasteners were first published in 1971 in MIL-HDBK-5B. The earliest published reference to this methodology dates back to 1943 [3]. These methods were based on a subjective interpretation of a carefully controlled, consistent set of tests performed to characterize the shear-bearing interaction behavior of a fastened joint. The average strength curves for a fastener system were developed based upon a trilinear visually best fit representation of the nondimensional transformation of these test data. Strength allowables were then determined by prescribed offsets from these average trends.

In 2002 the MMPDS coordination group approved a new quantitative regression procedure for development of a B-basis lower-limit design curve below the average yield and ultimate load curves. The form of the regression expression is as follows:

$$\frac{P}{D^2} = A_0 + A_1\left(\frac{t}{D}\right) + A_2 \ln\left(\frac{t}{D}\right)$$

where P = test load,
D = fastener diameter
t = sheet thickness
ln = natural logarithm
A_i = constant coefficients

A quadratic regression of the average test loads is fitted to the following parameter:

$$x_i = \ln\left(\frac{t}{D}\right)$$

The regression model then becomes

$$\overline{y_i} = a + bx_i + cz_i$$

where $\overline{y_i}$ = average of replicate tests
x_i = ln of i^{th} t/D level
z_i = $\exp(x_i)$

Detailed procedures for calculating the regression parameters are given in Reference 4. Figure 2 shows the computed joint ultimate design curve using the above quantitative approach. Using the new approach, new fastener joint allowables will be reported in the handbook as B-basis properties.

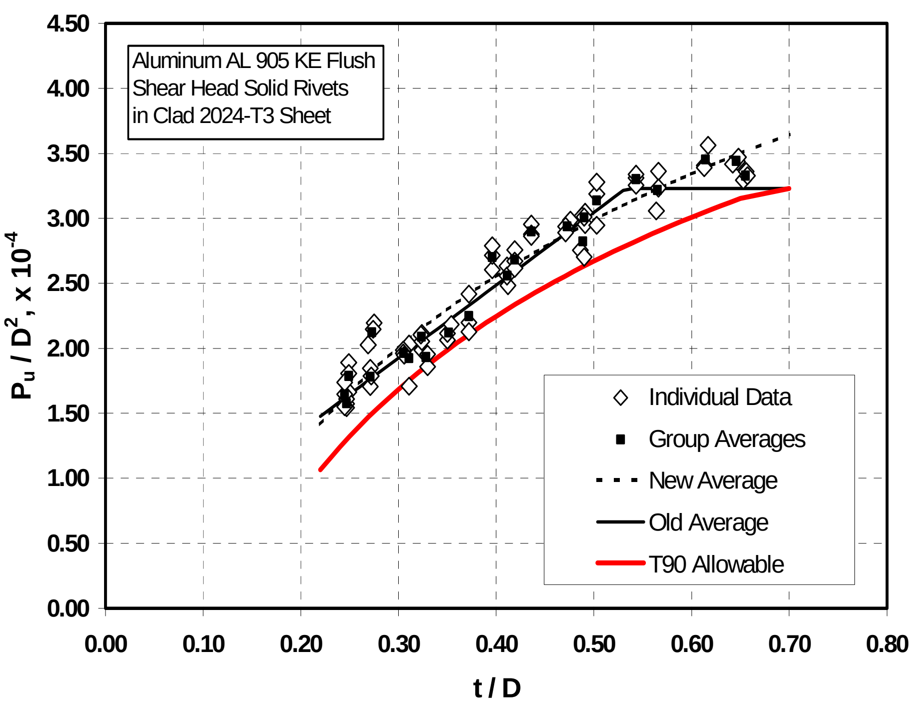

Figure 2. Joint Ultimate Load Design Curve

Figure 2 illustrates another distinction between the old and new fastened joint design allowable analysis procedures. The former analysis procedure did not allow individual observations to fall below the estimated trilinear design allowable. If an observation fell below a segment of the trilinear estimate of the design allowable, that segment had to be lowered to account for this low value. The net result was that there was a built-in incentive to generate as little data as possible, because generation of more data tended to increase the number of low observations and, thereby, tended to decrease the calculated design allowable. This methodology was counter-intuitive, because generation of more data should allow the definition of more precise, and often higher design allowables. The new analysis procedure (as shown in Figure 2) does allow the possibility of individual observations falling below the design allowable curve, and it does introduce a positive incentive to generate additional data to possibly increase the estimated design allowable.

Determination of Minimum Design Properties for Skewed Distributions Using the Pearson Method

In the early 1980s the MIL-HDBK-5 coordination group performed an examination of 57 metallic material tensile and yield strength data sets ranging in size from 25 to over 8000 observations. Results revealed sample skewness levels ranging from as low as -1.0 to as high as 1.0 [5]. Only 26% of these data sets displayed insignificant skewness. The remaining 74% of these data sets were significantly skewed with either a long lower tail (negative skewness) or a long upper tail (positive skewness). Note that the possible effect of secondary variables, such as thickness on the material properties, was eliminated before performing these calculations. This was necessary because tensile strength properties for a material often vary significantly with thickness, and analyses performed on these data sets without regard for the effect of thickness can make the property distributions look skewed, when in fact the variation in properties over small ranges in thickness are not.

Figure 3 illustrates the dramatic difference in the nature of strength property distributions spanning this range in skewness. All of the statistical distributions shown were computed based on a set of variable-skewness distributions, each with a mode (most frequent observation) of 100 and a standard deviation of 5. Of particular importance with regard to a material design allowable is the widely varying difference between the minimum portions of these curves relative to the mode of the sample.

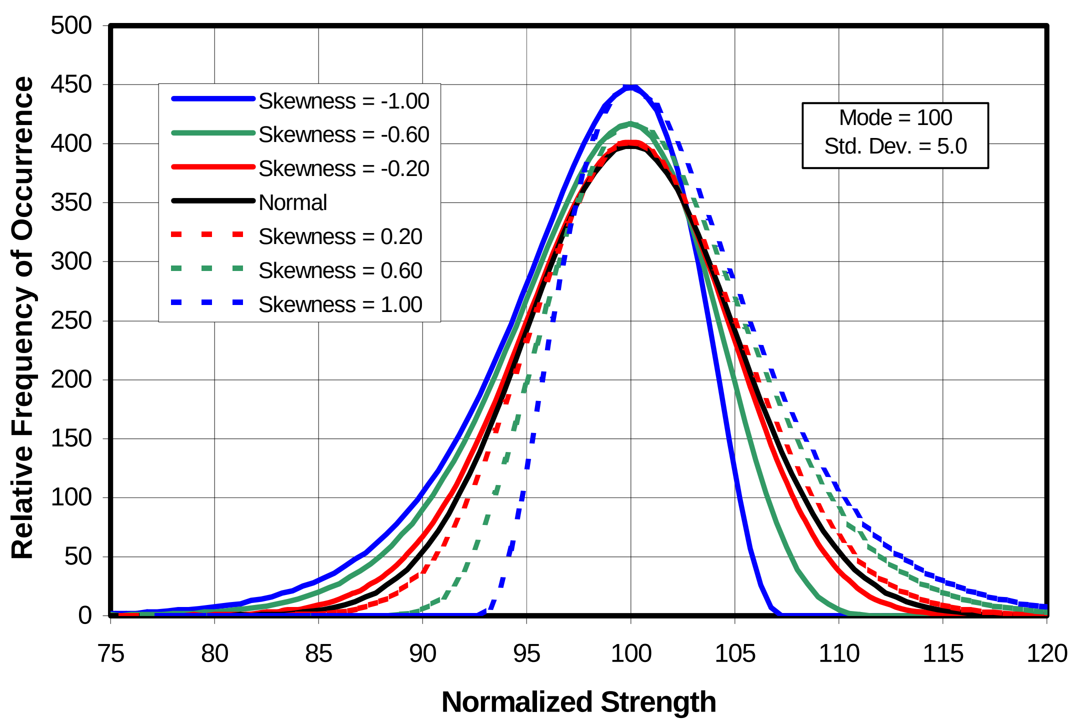

Figure 3. Probability Distributions for Skewness Levels Ranging From -1.0 to 1.0

This means that the use of normal statistics on fundamentally skewed strength properties can lead to significant errors in computed A-Basis properties, especially with small sample sizes. This point is illustrated in Figure 4, where the percent error in A-basis properties computed using normal statistics is estimated for true skewness values ranging from -1.0 to 1.0. Computation of design allowables using normal statistics on negatively skewed data sets will tend to lead to an overestimation of the true A-basis value. Conversely, computation of design allowables using normal statistics on positively skewed data sets will tend to lead to an underestimation of the true A-basis value. The errors can be substantially larger with small data sets because significant uncertainty regarding the true mean and standard deviation of the true strength distribution remains.

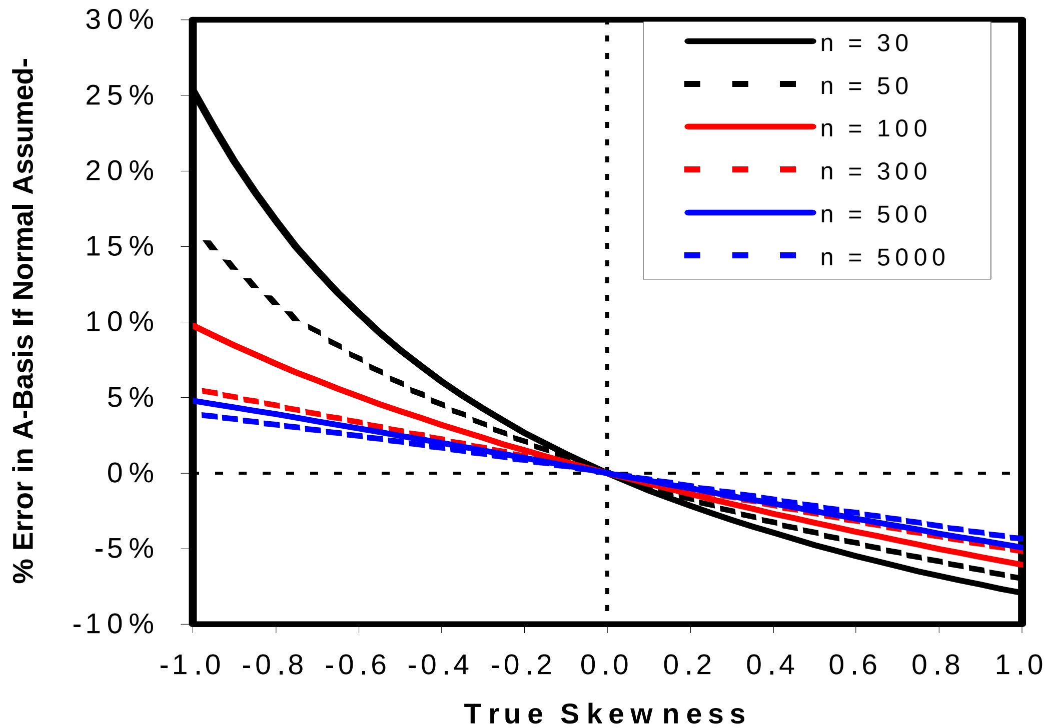

Figure 4. Potential Error in Computed A-Basis Properties if the True Skewness is Significant; But Assumed to Be Insignificant (Normally Distributed)

For over 15 years, the effect of skewness on design allowables has been taken into account in MIL-HDBK-5 using a 3-Parameter Weibull distribution. However, the methodology required to identify optimum shape, scale, and threshold parameters for a 3-Parameter Weibull distribution is relatively complex and difficult to program. Accurate estimates of the 3-Parameter Weibull threshold value are also difficult to establish with fewer than 50 test results.

This dilemma was addressed in the late 1990s through the development of design allowable analysis procedures based on a Pearson, Type III distribution. This distribution has the distinct advantage over the 3-Parameter Weibull distribution where design allowable properties can be estimated through knowledge of only the sample size, along with the sample mean, standard deviation, and skewness. Details of the algorithms necessary to compute design allowables using the Pearson Type III distribution are included in the guidelines of MMPDS-01 and MIL-HDBK-5J.

Practical experience has shown that some data sets do not conform to either a Weibull or Pearson distribution. Adaptations of the standard Weibull and Pearson approaches have been developed to allow computation of realistic design allowables for data sets that deviate only slightly from one or both of these parametric distributions; these so-called back-off methods are also described in detail in the guidelines of MMPDS-01 and MIL-HDBK-5J. Assuming these deviations from standard statistical distributions are not attributable to nuisance variables (e.g., mixed grain directions, tempers, or product forms), design allowables must be computed through use of a nonparametric ranking procedure.

Improvement of the Consistency Between Specification Minimum Properties and MMPDS T_{99} (A-Basis Minimums) for Aircraft Materials

All materials included in MMPDS must be covered by a public specification to ensure that the requirements for production of the material do not change over time. As a result, most materials in the Handbook are covered by Aerospace Material Specifications (AMS) published by the Society of Automotive Engineers (SAE). However, as mentioned earlier, the S-basis value defined in a public specification for an aerospace material does not have a strict statistical significance. At the same time, this specification limit typically represents a lot-release strength level, above which a supplier may sell that lot of material to a user. As a result it has been standard practice within MIL-HDBK-5 for many years to define an A-basis design allowable as the lowest of either the statistical T_{99} value or the S-basis value. This sometimes has led to a situation where the A-basis value shown in the Handbook has fallen well below the statistically computed T_{99} value. However, in these same situations the estimated B-basis design allowable has not been downgraded, creating an artificially large statistical difference between the published A- and B-basis values.

This approach has led to two possible scenarios, neither of which is particularly desirable. In the first scenario, where material properties remain constant over time, the airframe designer must use an artificially low A-basis value in nonredundant primary structure, which translates into excess weight in the aircraft. In the second scenario, the disparity between the A- and S-basis value could allow degradation over time in actual T_{99} values from the old T_{99} value to the S-basis value. If this second scenario actually occurred it would likely mean that the true T_{90} value would also decrease and not be documented in the Handbook, which would lead to unconservative design allowables for redundant primary structure.

The solution to this problem is being addressed in two ways. First, over the past 20 years the interaction and commonality in statistical analysis procedures between the MIL-HDBK-5/MMPDS coordination committee and the SAE/AMS group has been increased. The SAE/AMS has adopted several basic changes proposed by the MIL-HDBK-5/MMPDS coordination committee to their statistical procedures for establishing S-basis values. These changes have resulted in more stringent sample size and heat requirements for establishing S-basis values. All proposed S-basis values must also be verified by an independent party prior to their acceptance by the applicable SAE/AMS committee. Second, in cases where a significant disparity between calculated T_{99} values and published S-basis values are still found, the MIL-HDBK-5/MMPDS and SAE/AMS groups have agreed to work together to modify or replace the existing specification.

Worldwide Coordination of Aircraft Material Design Allowables

As mentioned earlier, there are only two widely accessible approved sources of design allowable properties for aircraft and aerospace materials; these are MMPDS/MIL-HDBK-5 and ESDU 00932. The first of these is the de facto standard in the United States, while the second is the de facto standard in Europe and Great Britain. Recent examinations of these two documents have shown significant differences in the guidelines for collecting and analyzing strength data for computation of design allowable properties. This has raised concerns about the possibility of different design allowables being published in the two documents for the same material, temper, and product form. This has been of particular concern for airframers building aircraft in both the United States and Europe.

In the short-term, the problem is limited because representatives of both coordination groups have found only a small number of cases where design allowables are published in both documents for identical alloys, tempers, and product forms. In the long-term, both groups have agreed to increase their interaction to eventually resolve or reconcile differences in approaches between the two documents.

Improved Interpretation and Statistical Representation of Notch Effects on Fatigue Life

Although the primary emphasis of design allowables work within the Handbook has always been on static strength properties of metals and mechanical fasteners, there also has been a need within the aircraft community to develop similar design allowable information for other material properties such as fatigue, fatigue crack growth, and fracture toughness.

Load-control fatigue data have been included in MIL-HDBK-5 for over 40 years. Initially this information was included in the Handbook in the form of constant life diagrams, which were subjectively derived from collections of load-control fatigue data developed over a wide range of stress ratios and/or mean stress levels. These constant life diagrams were replaced in the 1980s by maximum stress versus life plots displaying the actual fatigue data along with the best-fit analytical representations of mean fatigue life trends. The equivalent stress procedures that were adopted allowed the quantitative definition of mean trends and statistical variability in these data. However, since comprehensive procedures have not been available to consolidate load-control fatigue data generated on unnotched and notched specimen geometries, separate analyses and data presentations have been made for unnotched data and each available notch concentration. These separate data presentations for individual notch concentrations have limited the usefulness of the information for actual notch concentrations different from those represented in the Handbook. In a few cases it has also led to inconsistencies where longer fatigue lives have been predicted for more severe notch concentrations.

The local strain approach to fatigue life assessment is based on the premise that the mean and cyclic stresses seen at the root of a notch will nucleate fatigue cracks in the same number of cycles it takes to produce a fatigue failure in an unnotched specimen tested at the same mean and cyclic stresses. This means that the number of fatigue cycles needed to nucleate a crack at a specific nominal mean and cyclic stress should decrease as the notch concentration increases. Linear elastic fracture mechanics essentially represents a limiting condition of this trend where a crack is viewed as an infinitely sharp notch requiring no fatigue cycles to initiate it. The net result, and physical observations have supported this conclusion, is that load-control fatigue tests on sharply notched specimens represent essentially crack growth experiments, with only a small percentage of the total life spent in crack nucleation.

Only a very small fraction of load-control fatigue tests on notched specimens have been monitored carefully enough to document the number of fatigue cycles required to nucleate a dominant fatigue crack relative to the total cycles to failure. This means that the vast majority of notched specimen fatigue data shown in the MMPDS Handbook and elsewhere represent an unknown combination of fatigue cycles to crack nucleation and fatigue cycles to propagate that crack to failure. This uncertainty has traditionally been handled by the calculation of K_f factors, or effective notch concentration factors for different materials and types of notches. Invariably the K_f factor is found to be less than K_t, or the theoretical notch concentration factor, especially for very sharp notches. All of this confusion about the number of fatigue cycles required to nucleate a crack in a notched structure versus the number of cycles required to propagate that crack to failure has led most analysts to ignore one or the other. In most aircraft structures that contain a large number of mechanical fasteners, where the nominal stresses are relatively low compared to the local stresses at the fastener holes, fatigue cycles to crack initiation are ignored through the introduction of an equivalent initial flaw that is propagated analytically to failure through a damage tolerance analysis.

Recent analytical efforts to improve the interpretation and statistical representation of notch effects on fatigue life have produced promising results, as shown in Figures 5 and 6 for 2024-T3 sheet. Figure 5 shows the predicted cycles to crack initiation based on a local strain analysis at the notch tip using previously documented cyclic stress-strain properties for the material. A Neuber analysis [6] was used to estimate local stresses and strains from nominal stress conditions, wherein it was assumed that

$$K_t^2 = K_\sigma K_\varepsilon$$

where K_t = theoretical stress concentration factor

K_σ = local stress concentration factor

K_ε = local strain concentration factor

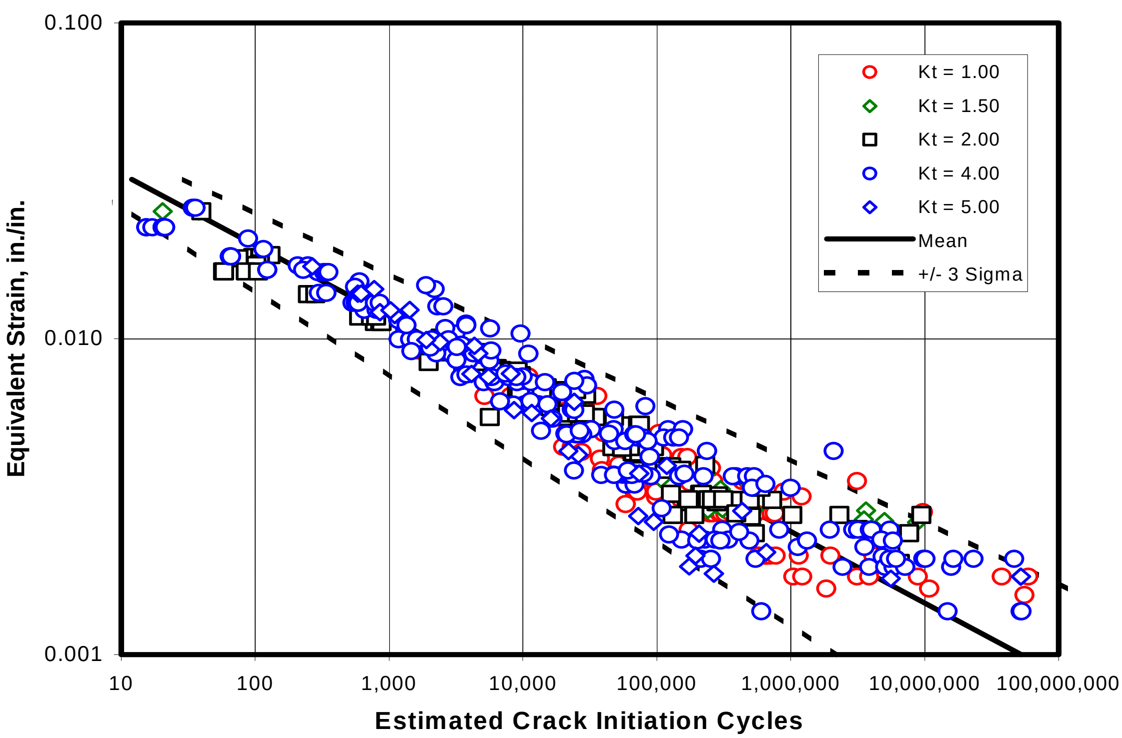

Figure 5. Estimated Fatigue Cycles to Crack Initiation for 2024-T3 Sheet Based on Specimens Tested in Load Control with Notch Concentrations Ranging from 1.0 to 5.0

The equivalent strain parameter was formulated as follows:

$$\varepsilon_{eq} = \left(\frac{\Delta\varepsilon}{2}\right)^{m}\left(\frac{\sigma_{max}}{E}\right)^{1-m}$$

where $\Delta\varepsilon$ = estimated local strain range,
σ_{max} = estimated maximum local stress,
E = elastic modulus, and
m = optimized parameter between 0.0 and 1.0, typically in the range of 0.50.

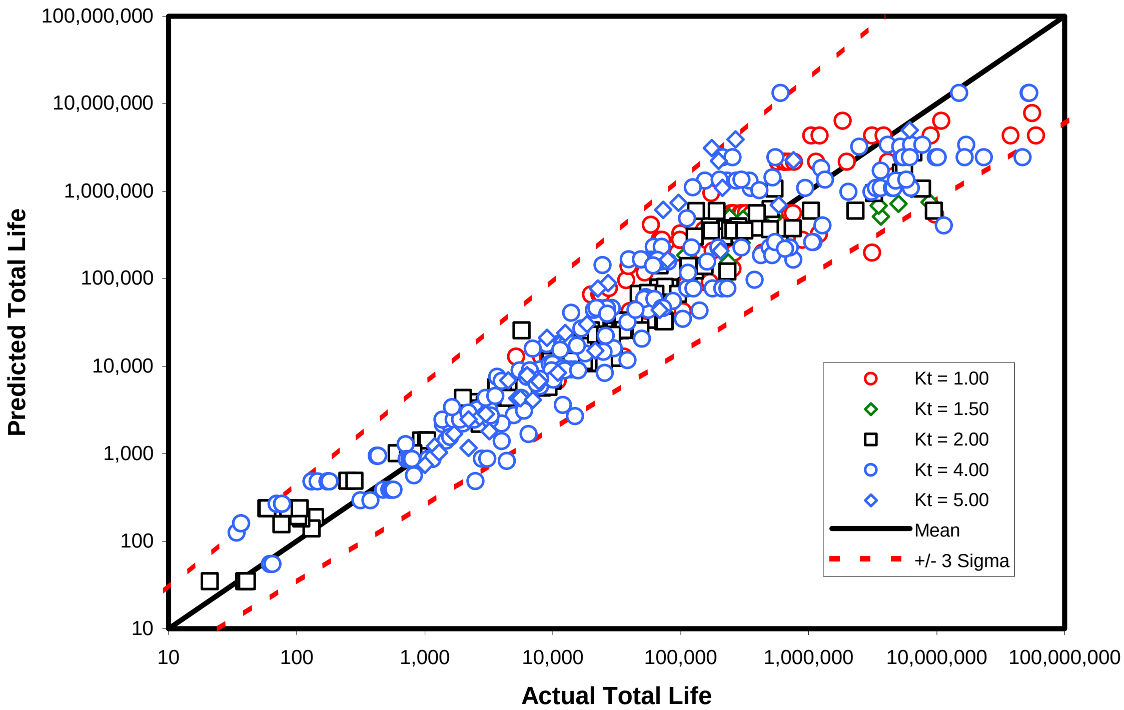

Figure 6. Predicted Versus Actual Fatigue Cycles to Failure for 2024-T3 Sheet Based on Specimens Tested in Load Control With Notch Concentrations Ranging from 1.0 to 5.0

The predicted total life was based on predicted fatigue cycles to failure, N_t, which were calculated as follows:

$$N_t = N_i + N_p$$

where N_i = cycles to initiate a crack 1/10 as long as the notch root radius
N_p = cycles to propagate the initiated crack to failure

These figures include over 545 test results on five different notch geometries, spanning seven orders of magnitude in total fatigue life, with nominal stress ratios ranging from -1.0 to 0.85. Computed ratios of cycles to crack initiation versus cycles to failure (N_i/N_f) ranged from 0.8% to 99.9%. Life predictions based only on crack initiation or crack growth were in error by as much as three orders of magnitude.

Development of Statistically Based Design Limits on Fatigue Crack Growth Data

Crack growth data shown in MMPDS/MIL-HDBK-5 are currently represented only by visually best fit mean curves that have no quantified statistical significance. It has been recognized for a number of years that it would be advantageous within MMPDS/MIL-HDBK-5 to identify mean crack growth trends as a function of stress ratio and associated scatter about those mean trends through quantitative procedures, and in sufficient detail, that individual organizations could construct their own statistically based design limits (much like the current statistical treatment of load and strain control fatigue data in the Handbook). However, there has never been agreement on the methodology that should be used to construct these mean curves and to define the statistical variability about those mean trends.

It is understood that no method will ever provide a perfect representation of overall crack growth trends over a broad range of stress ratios and stress intensity ranges. The tradeoff clearly is one of high accuracy of representation of crack growth trends at individual stress ratios, with no overarching model to relate crack growth trends between those stress ratios versus a somewhat less precise overall representation of crack growth trends at all stress ratios, with an attendant ability to easily predict crack growth trends at intermediate stress ratios where no experimental data exists.

A potential for statistical representation of crack growth trends spanning a wide range in stress ratios and crack growth rates is an approach proposed over 30 years ago by Collipriest [7]. This approach is based on the use of an inverse hyperbolic tangent model to represent crack growth rates for stress intensity ranges from near threshold to near-fracture instability. The model is formulated as follows:

$$\log \frac{da}{dN} = C_1 + C_2 \tanh^{-1}\left[\frac{\log[K_c K_o / (K_{\max}(1-R)^m)^2}{\log(K_o / K_c)} \right]$$

where K_O = lower asymptote,
K_C = upper asymptote,
K_{max} = maximum stress intensity,
R = stress ratio (with stress ratios less than zero set equal to 0),
m = optimized exponent between 0 and 1 (to account for stress ratio effects, and
C_1, and C_2 = regression coefficients.

The results of such an analysis on a large collection of Ti-6Al-4V HIP and annealed casting crack growth data are shown in Figure 7. This analysis included over 4400 crack growth rate values generated on 36 test specimens at stress ratios ranging from -1.0 to 0.80.

This topic remains an open issue within the MMPDS/MIL-HDBK-5 coordination committee. No further work is planned at this time. If and when any further work is undertaken by the Handbook committee in this area, it will be done in close coordination with Committee E08 of the American Society of Testing and Materials (ASTM), in particular with Subcommittee E08.06, which is responsible for maintenance of ASTM E 647, the applicable crack growth rate testing standard.

Other Current Initiatives of the MMPDS Government and Industry Steering Groups

In addition to the technical items already discussed, there are a number of other technical issues being addressed by the MMPDS committee. Some of the other technical issues include:

- Determination of the effect of processing changes on design allowables
- Evaluation of the stability of design allowable properties of widely used “legacy” alloys introduced in the Handbook several decades ago
- Consideration of a “sunset clause” for old tables of design allowables on mechanically fastened joints
- Detection of lower-tail censoring and its impact on computed design allowables
- Consideration of the introduction of design allowables in the Handbook on “tailored” materials, such as laser additive manufactured Ti-6Al-4V
- Total revamping of the largely out-of-date section of the Handbook on metallurgical joints to address design allowables for new joining procedures such as friction stir welding
- Redefinition of guidelines in the Handbook for analysis and presentation of statistically based design properties for plane-stress fracture toughness
- Definition of quantitative design limits to avoid stress corrosion cracking and exfoliation damage

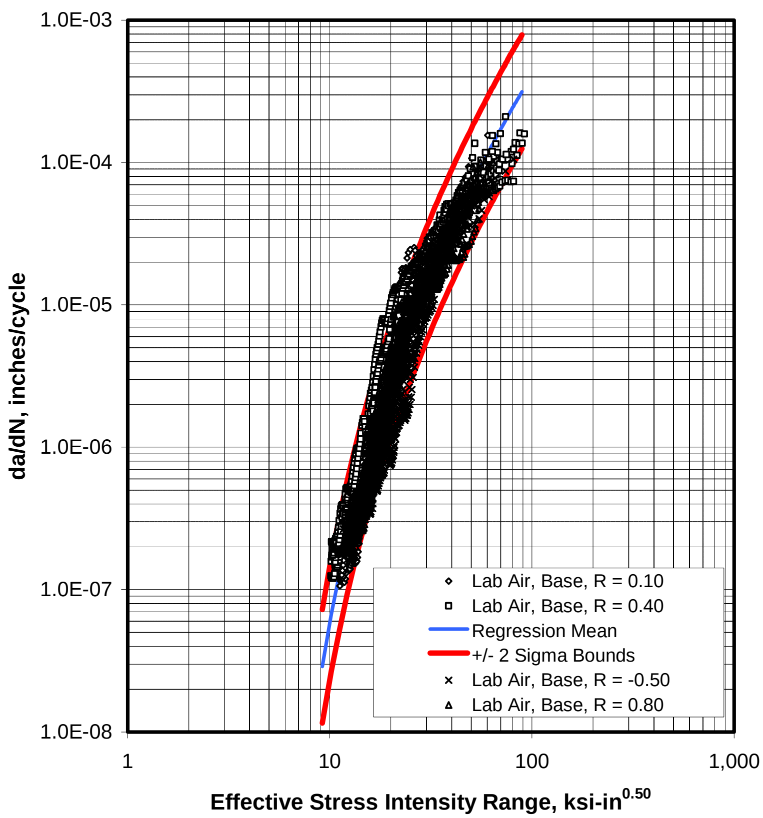

Figure 7. Mean-, Upper-, and Lower-Bound Crack Growth Properties of Ti-6Al-4V HIP and Annealed Castings

Summary

The Metallic Materials Properties Development and Standardization (MMPDS) document will be a continuation of and replacement for the military handbook for metallic material properties entitled "Metallic Materials and Elements for Aerospace Vehicle Structures" (MIL-HDBK-5). The MMPDS/MIL-HDBK-5 is a valuable source 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.

The continued long-term viability and credibility of the MMPDS will depend on the ongoing collaboration of all of the government agencies, material and fastener suppliers and aircraft and aerospace manufacturers that either use the Handbook for design purposes or supply metallic materials or fastened joints represented in it.

References

1. Bakuckas, J.G., Thompson, S.R., and Rice, R.C., "Metallic Materials Properties Development and Standardization (MMPDS) Continuation and Replacement for MIL-HDBK-5," Proceedings of the USAF Aircraft Structural Integrity Program (ASIP) 2002 Conference, December 9-12, 2002, Savannah, GA.
2. "Metallic Materials Properties Development and Standardization (MMPDS)," *Department of Transportation Report DOT/FAA/AR-MMPDS-01,* January 2003.
3. Holback, G.E., "Detail Aircraft Structural Analysis," Supplement Pamphlet No. 8, Glenn L. Martin Company, 1943.
4. See agenda package for 2nd MMPDS and 102nd MIL-HDBK-5 Coordination Meeting, held October 7-10, 2002, Item 99-27, "Revised Analytical Technique for Analysis of Fastened Joints", pp. 197-200.
5. Rice, R.C., "Investigation of Skewness in Mechanical Properties," Presentation in support of Item 80-1, 66th MIL-HDBK-5 Coordination Meeting, October 1983, Dayton, OH.
6. Neuber, H., "*Theory of Notch Stresses: Principle for Exact Stress Calculations*," Edwards, Ann Arbor, Michigan, 1946.
7. Collipriest, J.E., "An Experimentalist's View of the Surface Flaw Problem", *The Surface Crack: Physical Problems and Computational Solutions*, ASME, 1972, pp. 43-62.