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Replacement Document for MIL-HDBK5

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16. Abstract

The Metallic Material Properties Development and Standardization (MMPDS) Handbook is the replacement document for MIL-HDBK-5. It 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 Federal Avaiation Administration 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.

This edition, MMPDS-01, incorporates the additions and changes to aircraft metallic material design properties and analysis guidelines approved at the 1st and 2nd MMPDS government/industry coordination meetings.

This year, 2003, marks the first year of publication of the 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 metallic commercial and military aircraft structures and mechanically fastened joints. In this way, the 65-year legacy of MIL-HDBK-5, and its predecessor ANC-5, will be maintained.

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FOREWORD

This handbook is approved for use by the Federal Aviation Administration (FAA) and all Departments and Agencies of the Department of Defense. MMPDS-01 is equivalent to MIL-HDBK-5J, the last edition of the Metallic Materials and Elements for Aerospace Vehicle Structures Handbook that was maintained by the U.S. Air Force. The FAA plans to publish annual updates and revisions to the MMPDS. MIL-HDBK-5J is scheduled to be reclassified as noncurrent in the Spring of 2004.

Beneficial comments (recommendations, additions, deletions) and any pertinent data that may be of use in improving this document should be addressed to: Chairman, MMPDS Coordination Activity (609-485-4784 voice or 609-485-4004 fax), AAR-450, Materials and Structures Branch, FAA William J. Hughes Technical Center, Atlantic City International Airport, Atlantic City, NJ 08405.

This document contains design information on the strength properties of metallic materials and elements for aerospace vehicle structures. All information and data contained in this Handbook have been coordinated with the FAA, the Air Force, the Army, the Navy, and industry prior to publication and are being maintained as a joint effort of the FAA and the Department of Defense.

The electronic copy of the Handbook is technically consistent with the paper copy Handbook; however, minor differences exist in format, i.e., table or figure position. Depending on monitor size and resolution setting, more data may be viewed without on-screen magnification. The figures were converted to electronic format using one of several methods. For example, digitization or recomputation methods were used on most of the engineering figures like typical stress-strain and effect of temperature, etc. Scanning was used to capture informational figures such as those found in Chapters 1 and 9. These electronic figures were also used to generate the paper copy figures to maintain equivalency between the paper copy and electronic copy. In all cases, the electronic figures have been compared to the paper copy figures to ensure the electronic figure was technically equivalent. Appendix E provides a detailed list of all the figures in the Handbook, along with a description of each figure's format.

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EXPLANATION OF NUMERICAL CODE

For chapters containing materials properties, a deci-numeric system is used to identify sections of text, tables, and illustrations. This system is explained in the examples shown below. Variations of this deci-numerical system are also used in Chapters 1, 8, and 9.

Example A — 2.4.2.1.1

General material category (in this case, steel) 2

A logical breakdown of the base material by family characteristics (in this case, intermediate alloy steels); or for element properties 4

Particular alloy to which all data are pertinent. If zero, section contains comments on the family characteristics 2

If zero, section contains comments specific to the alloy; if it is an integer, the number identifies a specific temper or condition (heat treatment) 1

Type of graphical data presented on a given figure (see following description) 1

Example B — 3.2.3.1.X

Aluminum 3

2000 Series Wrought Alloy 2

2024 Alloy 3

T3, T351, T3510, T3511, T4, and T42 Tempers 1

Specific Property as Follows X

Tensile properties (ultimate and yield strength)	1
Compressive yield and shear ultimate strengths	2
Bearing properties (ultimate and yield strength)	3
Modulus of elasticity, shear modulus	4
Elongation, total strain at failure, and reduction of area	5
Stress-strain curves, tangent-modulus curves	6
Creep	7
Fatigue	8
Fatigue-Crack Propagation	9
Fracture Toughness	10

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NOTE: Information and data for alloys deleted from MMPDS may be obtained through the Chairman, MMPDS Coordination Activity.

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CHAPTER 1

GENERAL

1.1 PURPOSE AND USE OF DOCUMENT

1.1.1 INTRODUCTION — Since many aerospace companies manufacture both commercial and military products, the standardization of metallic materials design data, which are acceptable to Government procuring or certification agencies is very beneficial to those manufacturers as well as governmental agencies. Although the design requirements for military and commercial products may differ greatly, the required design values for the strength of materials and elements and other needed material characteristics are often identical. Therefore, this publication provides standardized design values and related design information for metallic materials and structural elements used in aerospace structures. The data contained herein, or from approved items in the minutes of MMPDS coordination meetings, are acceptable to the FAA, the Air Force, the Navy, and the Army. Approval by the procuring or certificating agency must be obtained for the use of design values for products not contained herein.

This printed document is distributed by the National Technical Information Service (NTIS). It is the only official form of MMPDS. If computerized third-party MMPDS databases are used, caution should be exercised to ensure that the information in these databases is identical to that contained in this Handbook.

Copies of the document can be obtained from the NTIS at the US Department of Commerce Technology Administration as follows:

US Department of Commerce Technology Administration
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 605-6000
http://www.ntis.gov

1.1.2 SCOPE OF HANDBOOK — This Handbook is primarily intended to provide a source of design mechanical and physical properties, and joint allowables. Material property and joint data obtained from tests by material and fastener producers, government agencies, and members of the airframe industry are submitted to MMPDS for review and analysis. Results of these analyses are submitted to the membership during semi-annual coordination meetings for approval and, when approved, published in this Handbook.

This Handbook also contains some useful basic formulas for structural element analysis. However, structural design and analysis are beyond the scope of this Handbook.

References for data and various test methods are listed at the end of each chapter. The reference number corresponds to the applicable paragraph of the chapter cited. Such references are intended to provide sources of additional information, but should not necessarily be considered as containing data suitable for design purposes.

The content of this Handbook is arranged as follows:

Chapter(s)	Subjects
1	Nomenclature, Systems of Units, Formulas, Material Property Definitions, Failure Analysis, Column Analysis, Thin-Walled Sections
2-7	Material Properties
8	Joint Allowables
9	Data Requirements, Statistical Analysis Procedures

1.2 NOMENCLATURE

1.2.1 SYMBOLS AND DEFINITIONS — The various symbols used throughout the Handbook to describe properties of materials, grain directions, test conditions, dimensions, and statistical analysis terminology are included in Appendix A.

1.2.2 INTERNATIONAL SYSTEM OF UNITS (SI) — Design properties and joint allowables contained in this Handbook are given in customary units of U.S. measure to ensure compatibility with government and industry material specifications and current aerospace design practice. Appendix A.4 may be used to assist in the conversion of these units to Standard International (SI) units when desired.

1.3 COMMONLY USED FORMULAS

1.3.1 GENERAL — Formulas provided in the following sections are listed for reference purposes. Sign conventions generally accepted in their use are that quantities associated with tension action (loads, stresses, strains, etc.), are usually considered as positive and quantities associated with compressive action are considered as negative. When compressive action is of primary interest, it is sometimes convenient to identify associated properties with a positive sign. Formulas for all statistical computations relating to allowables development are presented in Chapter 9.

1.3.2 SIMPLE UNIT STRESSES —

f_t = P / A (tension) [1.3.2(a)]
f_c = P / A (compression) [1.3.2(b)]
f_b = My / I = M / Z (bending) [1.3.2(c)]
f_s = S / A (average direct shear stress) [1.3.2(d)]
f_x = SQ / Ib (longitudinal or transverse shear stress) [1.3.2(e)]
f_x = Ty / I_p (shear stress in round tubes due to torsion) [1.3.2(f)]
f_s = (T/2At) (shear stress due to torsion in thin-walled structures of closed section. Note that A is the area enclosed by the median line of the section.) [1.3.2(g)]
f_A = Bf_H ; $f_T = Bf_L$ (axial and tangential stresses, where B = biaxial ratio) [1.3.2(h)]

1.3.3 COMBINED STRESSES (SEE SECTION 1.5.3.4) —

$f_A = f_c + f_b$ (compression and bending) [1.3.3(a)]

$$f_{s\,max} = \left[f_s^2 + \left(f_n/2\right)^2\right]^{1/2}$$ (compression, bending, and torsion) [1.3.3(b)]

$f_{n\,max} = f_n/2 + f_{s\,max}$ [1.3.3(c)]

1.3.4 DEFLECTIONS (AXIAL) —

e = δ / L (unit deformation or strain) [1.3.4(a)]
E = f/e (This equation applied when E is obtained from the same tests in which f and e are measured.) [1.3.4(b)]
δ = eL = (f / E)L [1.3.4(c)]
= PL / (AE) (This equation applies when the deflection is to be calculated using a known value of E.) [1.3.4(d)]

1.3.5 DEFLECTIONS (BENDING) —

di/dx = M / (EI) (Change of slope per unit length of a beam; radians per unit length) [1.3.5(a)]

$i_2 = i_1 + \int_{x_1}^{x_2} [M/(EI)]dx$ — Slope at Point 2. (This integral denotes the area under the curve of M/EI plotted against x, between the limits of x_1 and x_2.) 1.3.5(b)]

$y_2 = y_1 + i(x_2 - x_1) + \int_{x_1}^{x_2} (M/EI)(x_2 - x)dx$ — Deflection at Point 2. [1.3.5(c)]

(This integral denotes the area under the curve having an ordinate equal to M/EI multiplied by the corresponding distances to Point 2, plotted against x, between the limits of x_1 and x_2.)

$y_2 = y_1 + \int_{x_1}^{x_2} i dx$ — Deflection at Point 2. (This integral denotes the area under the curve of x_1(i) plotted against x, between the limits of x_1 and x_2.) [1.3.5(d)]

1.3.6 DEFLECTIONS (TORSION) —

$d\varphi / dx = T / (GJ)$ (Change of angular deflection or twist per unit length of a member, radians per unit length.) [1.3.6(a)]

$\Phi = \int_{x_1}^{x_2} [T/(GJ)]dx$ — Total twist over a length from x_1 to x_2. (This integral denotes the area under the curve of T/GJ plotted against x, between the limits of x_1 and x_2.) [1.3.6(b)]

$\Phi = TL/(GJ)$ (Used when torque T/GJ is constant over length L.) [1.3.6(c)]

1.3.7 BIAXIAL ELASTIC DEFORMATION —

$\mu = e_T/e_L$ (Unit lateral deformation/unit axial deformation.) This identifies Poisson's ratio in uniaxial loading. [1.3.7(a)]

$Ee_x = f_x - \mu f_y$ [1.3.7(b)]

$Ee_y = f_y - \mu f_x$ [1.3.7(c)]

$E_{biaxial} = E(1 - \mu B)$ — B = biaxial elastic modulus. [1.3.7(d)]

1.3.8 BASIC COLUMN FORMULAS —

$F_c = \pi^2 E_t (L' / \rho)^2$ where $L' = L / \sqrt{c}$ — conservative using tangent modulus [1.3.8(a)]

$F_c = \pi^2 E (L' / \rho)^2$ — standard Euler formula [1.3.8(b)]

1.3.9 INELASTIC STRESS-STRAIN RESPONSE —

$e_{total} = f / E + e_p$ (elastic strain response plus inelastic or plastic strain response) [1.3.9(a)]

where

$e_p = 0.002 * (f/f_{0.2ys})^n$, [1.3.9(b)]

$f_{0.2ys}$ = the 0.2 percent yield stress and

n = Ramberg-Osgood parameter

Equation [1.3.9(b)] implies a log-linear relationship between inelastic strain and stress, which is observed with many metallic materials, at least for inelastic strains ranging from the material's proportional limit to its yield stress.

1.4 BASIC PRINCIPLES

1.4.1 GENERAL — It is assumed that users of this Handbook are familiar with the principles of strength of materials. A brief summary of that subject is presented in the following paragraphs to emphasize principles of importance regarding the use of allowables for various metallic materials.

Requirements for adequate test data have been established to ensure a high degree of reliability for allowables published in this Handbook. Statistical analysis methods, provided in Chapter 9, are standardized and approved by all government regulatory agencies as well as MMPDS members from industry.

1.4.1.1 *Basis* — Primary static design properties are provided for the following conditions:

Tension	F_{tu} and F_{ty}
Compression	F_{cy}
Shear	F_{su}
Bearing	F_{bru} and F_{bry}

These design properties are presented as A- and B- or S-basis room temperature values for each alloy. Design properties for other temperatures, when determined in accordance with Section 1.4.1.3, are regarded as having the same basis as the corresponding room temperature values.

Elongation and reduction of area design properties listed in room temperature property tables represent procurement specification minimum requirements, and are designated as S-values. Elongation and reduction of area at other temperatures, as well as moduli, physical properties, creep properties, fatigue properties and fracture toughness properties are all typical values unless another basis is specifically indicated.

Use of B-Values — The use of B-basis design properties is permitted in design by the Air Force, the Army, the Navy, and the Federal Aviation Administration, subject to certain limitations specified by each agency. Reference should be made to specific requirements of the applicable agency before using B-values in design.

1.4.1.2 *Statistically Calculated Values* — Statistically calculated values are S (since 1975), T_{99} and T_{90}. S, the minimum properties guaranteed in the material specification, are calculated using the same requirements and procedure as AMS and is explained in Chapter 9. T_{99} and T_{90} are the local tolerance bounds, and are defined and may be computed using the data requirements and statistical procedures explained in Chapter 9.

1.4.1.3 *Ratioed Values* — A ratioed design property is one that is determined through its relationship with an established design value. This may be a tensile stress in a different grain direction from the established design property grain direction, or it may be another stress property, e.g., compression, shear or bearing. It may also be the same stress property at a different temperature. Refer to Chapter 9 for specific data requirements and data analysis procedures.

Derived properties are presented in two manners. Room temperature derived properties are presented in tabular form with their baseline design properties. Other than room temperature derived properties are presented in graphical form as percentages of the room temperature value. Percentage values apply to all forms and thicknesses shown in the room temperature design property table for the heat treatment condition indicated therein unless restrictions are otherwise indicated. Percentage curves usually represent short time exposures to temperature (thirty minutes) followed by testing at the same strain rate as used for the room temperature tests. When data are adequate, percentage curves are shown for other exposure times and are appropriately labeled.

1.4.2 STRESS — The term "stress" as used in this Handbook implies a force per unit area and is a measure of the intensity of the force acting on a definite plane passing through a given point (see Equations 1.3.2(a) and 1.3.2(b)). The stress distribution may or may not be uniform, depending on the nature of the loading condition. For example, tensile stresses identified by Equation 1.3.2(a) are considered to be uniform. The bending stress determined from Equation 1.3.2(c) refers to the stress at a specified distance perpendicular to the normal axis. The shear stress acting over the cross section of a member subjected to bending is not uniform. (Equation 1.3.2(d) gives the average shear stress.)

1.4.3 STRAIN — Strain is the change in length per unit length in a member or portion of a member. As in the case of stress, the strain distribution may or may not be uniform in a complex structural element, depending on the nature of the loading condition. Strains usually are present also in directions other than the directions of applied loads.

1.4.3.1 *Poisson's Ratio Effect* — A normal strain is that which is associated with a normal stress; a normal strain occurs in the direction in which its associated normal stress acts. Normal strains that result from an increase in length are designated as positive (+) and those that result in a decrease in length are designated as negative (-).

Under the condition of uniaxial loading, strain varies directly with stress. The ratio of stress to strain has a constant value (E) within the elastic range of the material, but decreases when the proportional limit is exceeded (plastic range). Axial strain is always accompanied by lateral strains of opposite sign in the two directions mutually perpendicular to the axial strain. Under these conditions, the absolute value of a ratio of lateral strain to axial strain is defined as Poisson's ratio. For stresses within the elastic range, this ratio is approximately constant. For stresses exceeding the proportional limit, this ratio is a function of the axial strain and is then referred to as the lateral contraction ratio. Information on the variation of Poisson's ratio with strain and with testing direction is available in Reference 1.4.3.1.

Under multiaxial loading conditions, strains resulting from the application of each directional load are additive. Strains must be calculated for each of the principal directions taking into account each of the principal stresses and Poisson's ratio (see Equation 1.3.7 for biaxial loading).

1.4.3.2 *Shear Strain* — When an element of uniform thickness is subjected to pure shear, each side of the element will be displaced in opposite directions. Shear strain is computed by dividing this total displacement by the right angle distance separating the two sides.

1.4.3.3 *Strain Rate* — Strain rate is a function of loading rate. Test results are dependent upon strain rate, and the ASTM testing procedures specify appropriate strain rates. Design properties in this Handbook were developed from test data obtained from coupons tested at the stated strain rate or up to a value of 0.01 in./in./min, the standard maximum static rate for tensile testing materials per specification ASTM E 8.

1.4.3.4 *Elongation and Reduction of Area* — Elongation and reduction of area are measured in accordance with specification ASTM E 8.