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STRENGTH OF AIRCRAFT ELEMENTS

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CHAPTER 1

GENERAL

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1.0 PURPOSE AND USE OF HANDBOOK

1.00 INTRODUCTION

Since many aircraft manufacturers supply airplanes for both commercial and military use, standardization of the requirements of the various Governmental procuring or licensing agencies is of direct benefit to the manufacturer. Although the types and purposes of military airplanes often differ greatly from those of commercial airplanes, necessitating certain differences in the structural requirements, the requirements for strength of materials have for some time been nearly identical. This publication has therefore been prepared to eliminate the necessity for referring to different handbooks and bulletins in calculating the allowable stresses or minimum strength of typical structures. With a few exceptions (which are noted in the appropriate places) the material contained herein is acceptable to the Army Air Corps, Bureau of Aeronautics of the Navy, and the Civil Aeronautics Administration

1.01 SCOPE OF HANDBOOK

Only the most commonly used materials are included in this publication. Until a structural material has been used for some time and in considerable quantities, the strength properties will probably vary considerably as manufacturing processes are improved and modified. In such cases special rulings should be obtained by the manufacturer from the procuring or licensing agency. These rulings will be based upon specimen tests and will eventually form a basis for standard accepted strength properties.

In addition to the strength of the materials themselves, there are contained herein the most commonly-used methods and formulas by which the strength of various structural components are calculated. In some cases the methods presented are empirical and subject to further refinement. Likewise, it is expected that additional material can be added from time to time as the methods of handling new problems become more uniform and reliable.

Engineers making use of the material contained herein are invited to submit comments and suggestions as to the expansion and improvement of the handbook. Such comments should be submitted directly to the committee in charge of this publication.

1.02 USE OF STRENGTH SPECIFICATIONS

As the materials commonly used in aircraft construction are more or less standardized as to composition and physical properties, it is customary to assign standard values to the strength properties for specification purposes and for strength calculations. The values so assigned represent the minimum values which will be accepted under a given specification. Conversely, they represent the maximum values which may be used in substantiating the strength of a structure or component part built of material of that specification. In this handbook the latter interpretation applies; that is, the values stated herein or obtained from specified formulas represent the <u>maximum</u> values which are acceptable for strength calculations. Changes in procurement specifications will, of course, require corresponding changes in the maximum allowable strength properties.

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The manner in which the values specified herein are to be used will depend on the type of structure being investigated and will be definitely specified in the detailed structural requirements of the procuring or licensing agencies. For example, it will be found that several different strength properties may be given for a certain material: such as the ultimate tensile stress, yield stress, and proportional limit stress. The use of these different values and the factors of safety to be associated with them will not be taken up in detail in this handbook, information of this sort being in the nature of specific requirements which do not affect the material properties as such.

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1.1 STANDARD STRUCTURAL SYMBOLS

A - area of cross section, sq. in.

B - slenderness ratio factor (See Eq. 1:28).

C - circumference.

D - diameter.

E - modulus of elasticity in tension.

E_c - modulus of elasticity in compression.

E_s - secant modulus.

E_t - tangent modulus.

F - allowable stress.

F_b - allowable bending stress, modulus of rupture in bending.

$F_{b_{cr}}$ - critical bending stress for buckling of rectangular panels.

F_{be} - endurance limit in bending.

F_{br} - ultimate bearing stress.

F_c - allowable compressive stress.

a - subscript "allowable".

b - width of sections; subscript "bending".

br - subscript "bearing".

c - fixity coefficient for columns; distance from neutral axis to extreme fiber; subscript "compression".

cr - subscript "critical".

d - depth or height; mathematical operator denoting differential.

e - unit deformation or strain; eccentricity; subscript for Euler's formula; subscript "endurance".

f - internal (or calculated) stress.

f_b - internal (or calculated) primary bending stress.

f_b' - internal (or calculated) precise bending stress.

f_{br} - internal (or calculated) bearing stress.

f_c - internal (or calculated) compressive stress.

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F_{cc}	- allowable crushing or crippling stress. (upper limit of column stress for local failure)		
$F_{c_{cr}}$	- critical compressive stress for buckling of rectangular panels.		
F_{co}	- column yield stress. (upper limit of column stress for primary failure)		
F_{cp}	- proportional limit in compression.		
F_{cu}	- ultimate compressive stress.		
F_{cy}	- compressive yield stress.		
F_n	- allowable normal stress.	f_n	- internal (or calculated) normal stress.
F_s	- allowable shearing stress.	f_s	- internal (or calculated) shearing stress.
$F_{s_{cr}}$	- critical shear stress for buckling of rectangular panels.		
F_{se}	- endurance limit in torsion.		
F_{sp}	- proportional limit in shear.		
F_{st}	- modulus of rupture in torsion.		
F_{su}	- ultimate shear stress.		
F_t	- allowable tensile stress.	f_t	- internal (or calculated) tensile stress.
F_{tp}	- proportional limit in tension.		
F_{tu}	- ultimate tensile stress.		
F_{ty}	- tensile yield stress.		
G	- modulus of elasticity in shear, (modulus of rigidity).	g	-
H	-	h	- height or depth; especially the distance between centroids of chords of beams and trusses.

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I	- moment of inertia.	i	- slope (due to bending) of neutral plane of a beam, in radians. (1 radian = 57.3 degrees).
I_p	- polar moment of inertia		
J	- torsion constant (= I_p for round tubes).	j	- stiffness factor = $\sqrt{EI/P}$.
K	- a constant, generally empirical.	k	-
L	- length; subscript "lateral".	l	- (not used, to avoid confusion with numeral 1).
M	- applied moment or couple, usually a bending moment.	m	-
M_a	- allowable bending moment.		
N	-	n	- subscript "normal".
O	-	o	-
P	- applied load (total, not unit load).	p	- subscript "polar"; subscript "proportional limit".
P_a	- allowable load.	psi	- pounds per square inch.
Q	- static moment of a cross section.	q	-
R	- stress ratio = $\frac{f}{F}$.	r	- radius.
S	- shear force.	s	- subscript "shear".
T	- applied torsional moment, torque.	t	- thickness.
T_a	- allowable torsional moment.		
U	- factor of utilization.	u	- subscript "ultimate".
V	-	v	-
W	-	w	- specific weight, lb/cu.in.
X	-	x	- distance along elastic curve of a beam.
Y	-	y	- deflection (due to bending) of elastic curve of a beam; distance from neutral axis to given fiber; subscript "yield".

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Z - section modulus, $\frac{I}{y}$.

Z_p - polar section modulus, $= \frac{I_p}{y}$. (for round tubes)

z -

δ (delta) - deflection.

Φ (phi) - angular deflection.

ρ (rho) - radius of gyration.

μ (mu) - Poisson's ratio.

' (prime) - in general denotes an "effective" or "precise" value.

1.2 COMMONLY USED FORMULAS

1.20 The formulas of the following sections are listed for reference purposes. The sign conventions generally accepted in their use are that quantities associated with tensile action (load, stress, strain, etc.) are considered as positive, and quantities associated with compressive action are considered as negative. When compressive action is of primary interest, however, it is sometimes convenient to consider the associated quantities to be positive.

1.21 SIMPLE UNIT STRESSES

1:1 $f_t = \frac{P}{A}$ (tension).

1:2 $f_c = \frac{P}{A}$ (compression).

1:3 $f_b = \frac{My}{I} = \frac{M}{Z}$.

1:4 $f_s = \frac{S}{A}$ (average direct shear stress).

1:5 $f_s = \frac{SQ}{Ib}$ (longitudinal or transverse shear stress).

1:6 $f_s = \frac{Ty}{I_p}$ (shear stress in round tubes due to torsion).

1:7 $f_s = \frac{T}{2At}$ (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).

1.22 COMBINED STRESSES

1:8 $f_n = f_c + f_b$ (compression and bending).

1:9 $f_{s_{max}} = \sqrt{f_s^2 + \left(\frac{f_n}{2}\right)^2}$ (compression, bending, and torsion).

1:10 $f_{n_{max}} = \frac{f_n}{2} + f_{s_{max}}$.

1.23 DEFLECTIONS (AXIAL)

1:11 $e = \frac{\delta}{L}$ (unit deformation or strain).

1:12 $E = \frac{f}{e}$ (This equation applies when E is to be found from tests in which f and e are measured).

1:13 $\delta = eL = \frac{f}{E} L = \frac{PL}{AE}$ (This equation applies when the deflection is to be calculated using a known value of E).

1:24 DEFLECTIONS (BENDING)

1:14 $\frac{di}{dx} = \frac{M}{EI}$ (change of slope per unit length of beam, radians per unit length).

1:15 $i_2 = i_1 + \int_{x_1}^{x_2} \frac{M}{EI}\, dx$ = slope at point 2. (The integral denotes the area under the curve of M/EI plotted against x, between the limits x_1 and x_2).

1:16 $y_2 = y_1 + i_1 (x_2 - x_1) + \int_{x_1}^{x_2} \frac{M}{EI} (x_2 - x)\, dx$ = deflection at point 2. (The integral denotes the area under a curve having ordinates equal to M/EI multiplied by the corresponding distances to point 2, plotted against x, between the limits x_1 and x_2).

1:16a $y_2 = y_1 + \int_{x_1}^{x_2} i\,dx$ = deflection at point 2. (The integral denotes the area under the curve of (i) plotted against x, between the limits x_1 and x_2).

1:25 DEFLECTIONS (TORSION)

1:17 $\frac{d\phi}{dx} = \frac{T}{GJ}$ (change of angular deflection or twist per unit length of member, radians per unit length).

1:18 $\phi = \int_{x_1}^{x_2} \frac{T}{GJ}\, dx$ = total twist over a length from x_1 to x_2. (The integral denotes the area under the curve of $\frac{T}{GJ}$ plotted against x, between the limits x_1 and x_2).

1:18a $\phi = \frac{TL}{GJ}$ (Used when torque T is constant over length L).

1.26 TRANSVERSE DEFORMATIONS

1:19 $\mu = \frac{e_L}{e} = \frac{\text{unit lateral deformation}}{\text{unit axial deformation}}$ (Poisson's ratio)

1:20 $Ee_x = f_x - \mu f_y$

1:21 $Ee_y = f_y - \mu f_x$

1.27 BASIC COLUMN FORMULAS

1:22 $F_{c_e} = \frac{c\pi^2 E}{(L/\rho)^2} = \frac{\pi^2 E}{(L'/\rho)^2}$ (Euler formula for long columns)

where $L' = \frac{L}{\sqrt{c}}$

1:23 $F_c = F_{co}\left[1 - K\left(\frac{L'/\rho}{\pi\sqrt{E/F_{co}}}\right)^n\right]$ (General parabolic formula)

1:24 $F_c = F_{co}\left[1 - \frac{F_{co}(L'/\rho)^2}{4\pi^2 E}\right]$ (2.0 parabola - Johnson formula)

1:25 $F_c = F_{co}\left[1 - .3027\left(\frac{L'/\rho}{\pi\sqrt{E/F_{co}}}\right)^{1.5}\right]$ (1.5 parabola)

1:26 $F_c = F_{co}\left[1 - \frac{.385(L'/\rho)}{\pi\sqrt{E/F_{co}}}\right]$ (1.0 parabola - straight line formula)

1.28 BASIC COLUMN FORMULAS (NON-DIMENSIONAL).

1:27 $R_a = \frac{F_c}{F_{co}}$ (Allowable stress ratio)

1:28 $B = \frac{L'/\rho}{\pi\sqrt{E/F_{co}}}$ (Slenderness ratio factor)

1:29 $R_a = \left(\frac{1}{B}\right)^2$ (Euler formula)

1:30 $R_a = 1 - KB^n$ (General parabolic formula)

1:31 $R_a = 1 - .25B^2$ (2.0 parabola - Johnson formula)

1:32 $R_a = 1 - .3027B^{1.5}$ (1.5 parabola)

1:33 $R_a = 1 - .385B$ (1.0 parabola - straight line formula)