TECHNICAL NOTES

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The practice most used in assigning load factors to new airplanes has been an arbitrary specification based primarily upon experience. The chief consideration in determining the factor has been the intended use of the airplane. It has long been recognized that the dimensions and performance of an airplane have a profound influence upon the load factor in flight but no satisfactory formula is now in use for accurately considering these influences. For instance, since the World War, fighting airplanes have improved greatly in performance due, chiefly, to improved engine power to weight ratio with the result that experience has led the principal military services to adopt design load factors greatly in excess of those found satisfactory during the war.

Obviously, any formula for determining the proper load factor for design must check actual experience but it must be fundamentally rational in order to merit replacement of arbitrary factors.

The first case considered in deriving a suitable formula will be a heavy load carrier of large size and practically no reserve power. An airplane flying at the stalling speed could not, theoretically, be maneuvered and the maximum load on the wing structure would be unity. Since the load to be designed for is a working load and not an occasional load, the true factor of safety should be higher than is usual with airplane structures. The formula should, therefore, be written in such a way that the theoretical minimum load factor will exceed 1.75. The first term of the formula will be a constant K_1 equal to 1.75.

Any constant in excess of 1.75 should depend upon maneuverability and performance. Maneuverability is an inverse function of size and the factor will tentatively be assumed to vary inversely as the square root of gross weight. Highly maneuverable airplanes are at present limited to a gross weight of approximately 3000 pounds and less. It seems rational, therefore, to modify the maneuverability factor in such a way as to reduce the effect of size for airplanes within the 3000-pound class. Assume that a 500-pound airplane should have a constant 20 per cent higher than a 3000-pound airplane.

$$1.2\sqrt{500 + K_2} = \sqrt{3000 + K_2}$$

$$K_2 = 5200; \text{ let } K_2 = 5000$$

Then, neglecting performance:

$$F = 1.75 + \frac{K}{\sqrt{5000 + W}}$$

The performance factor is ordinarily neglected in so far as differentiating between airplanes within a class is concerned. Its importance, however, is very generally recognized. An airplane with a great deal of excess power naturally inspires confidence and will be maneuvered more than an airplane of less power. Theoretically, the load factor developed in a zoom extending over the burble point depends upon the square of the ratio of air speed to stalling speed. A pilot soon becomes accustomed to flying an airplane at its maximum horizontal speed. Attainment of a speed greater than the maximum horizontal speed requires prolonged diving flight, a very uncomfortable attitude, and the pilot is instinctively cautious in maneuvering at the finish of a dive. The maneuverability factor should, therefore, be a function of the square of the ratio of the maximum horizontal speed to stalling speed.

The formula may now be written:

$$F = 1.75 + \left(\frac{V_m}{V_s}\right)^2 \frac{K}{\sqrt{5000 + W}}$$

where F = load factor

V_m = maximum horizontal speed

V_s = stalling speed

W = gross weight

K = a constant

The value of the constant K, must ultimately be checked by practical experience, but a tentative value may be assigned through semitheoretical considerations. The true safety factor for an extremely maneuverable fighting airplane would be based on an ultimate load which is occasional and not a working load. It may, therefore, be rationally somewhat less than 1.75, say 1.5. Making allowance for the constant first term of the formula, the value of $\left(\frac{K}{\sqrt{5000 + W}}\right)$ should equal less than 1.5, say 1.25. Assume that the gross weight equals 3000 pounds: Then,

$$\frac{K}{\sqrt{5000 + W}} = 1.25$$

$$K = 1.25 \times \sqrt{8000}$$

$$= 111.7$$

For simplicity, let K = 112. Then the complete formula may be written:

$$F = 1.75 + \left(\frac{V_m}{V_s}\right)^2 \frac{112}{\sqrt{5000 + W}}$$

The best class of airplanes with which to check a load factor formula seems to be those which have experienced structural failure. Table I comprises a list of the airplanes which have experienced failure in flight definitely traceable to the wing structure. The load factor by formula is observed to be greater than the designed strength in each case, without a single exception. Table II compares the load factor by formula with the designed strength of a number of well-known service types. The formula indicates that, by far, the majority of these have ample structural strength. Of the exceptions it may be said that all of the thin ice which a skater negotiates without breaking through is not necessarily safe.

One important point well demonstrated by the formula is the fact that overloading is not nearly so serious as an increase in power. No case comes to mind where overloading has led to structural failure. The maximum load on the wings in a maneuver equals the speed squared, times the wing area, times the maximum lift coefficient. If maneuvers are confined to the horizontal speed range of the airplane, the maximum loading in a maneuver is definitely limited and is really reduced by overloading because the maximum speed is reduced. The <u>working</u> stresses are, however, increased by overloading.

The ultimate test of a load factor formula is experience. The chief advantages of a semirational formula over arbitrary factors are that it fairs in between points of experience and it differentiates according to variables within a type. Structural failure of an airplane apparently safe according to the formula would call for a specific change in the formula. Failure of an extremely large airplane or of an airplane of small speed range would call for an increase in the constant 1.75. Failure of an airplane of large speed range would call for an increase in the constant 112. Failure of an extremely small airplane would call for a decrease in the constant 5000.

The factor given by the formula refers to the high incidence condition. It is believed practical to assign factors for other flight conditions by proportion. The constants derived for the proposed formula are based upon experience with military airplanes. It is probable that commercial airplanes would require a slightly higher true factor of safety but the basic loads would be generally lower. The constant 1.75, should be increased and the constant 112, reduced. A suggested value for the former is 2.00, and for the latter, 100.

TABLE I.

Structural Failures.

Model	V_m	V_s	$\frac{V_m}{V_s}$	Gross weight	L.F. by formula
DVII (300 HP.)	143.5	54.5	2.63	2462	10.75
PW-7	156.2	57.0	2.73	3269	10.95
R-6 Racer	224.4	75.0	2.99	2230	13.55
R2C-1 Racer	247.0	75.0	3.30	2151	16.18
MB-3A	160.9	58.0	2.77	2485	11.69
UO-1	122.0	55.5	2.20	2508	8.02

Model	L.F. by SD-24B	Design L.F.	L.F. by static test	Remarks
DVII (300 HP.)	12	-	(8.45)	Static test L.F. by proportion
PW-7	12	8.5	9.00	Partial failure in flight at 7.8 g
R-6 Racer	12	8.5	11.50	
R2C-1 Racer	12	10.6	-	
MB-3A	12	8.0	10.3	
UO-1	7.5	7.0	(6.8)	

Average strength/L.F. by formula = .828

TABLE II.

No Known Structural Failure.

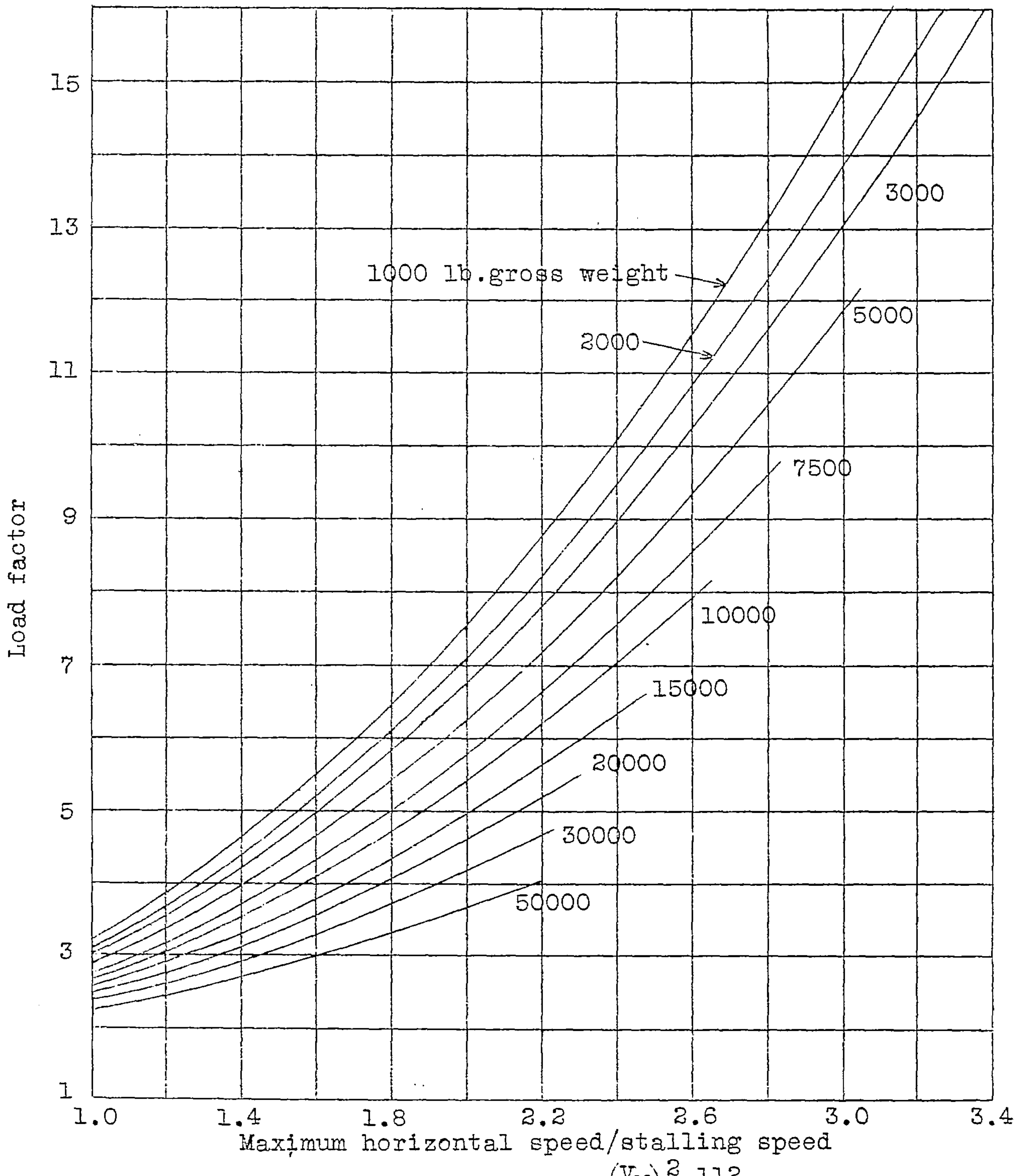
Model	V_m	V_s	$\frac{V_m}{V_s}$	W	L.F. by formula	L.F. by SD24B	Probable strength
F5L	89.7	52.3	1.715	13,600	4.17	4.5	4.7
H-16	95.0	52.7	1.805	10,900	4.74	4.5	4.8
SC-2	100.7	55.0	1.83	9,352	4.88	5.0	5.2
DT-2	99.5	51.2	1.94	7,291	5.54	5.0	4.7
N9-H	80.0	44.5	1.80	2,765	5.87	7.5	5.9
JN4H	93.0	44.4	2.09	2,017	7.53	7.5	8.0
NB-1	97.6	47.7	2.04	2,840	7.01	7.5	8.0
DH4B	120.0	55.7	2.15	3,876	7.25	7.5	6.5
VE-7	118.5	52.2	2.27	2,175	8.58	7.5	8.0
OL-2	121.3	57.0	2.13	5,010	7.82	7.5	7.0
F6C-3	165.0	61.5	2.68	2,941	10.76	12.0	12.3
FB-5	170.0	60.0	2.83	3,130	11.70	12.0	12.0
TS-1	122.8	50.2	2.45	2,123	9.73	12.0	7.0
D-VII (160 HP.)	115.0	53.0	2.17	2,005	8.07	12.0	10.7

Average strength/Load factor by formula = 1.023.

TABLE III.

New Service Types.

Model	V_m	V_s	$\frac{V_m}{V_s}$	W	Load factor Formula	Load factor SD-24B	SD-24A
PB-1	125	69.2	1.81	26,822	3.80	4.0	4
PN-10	114	64.3	1.77	19,029	4.01	4.5	5
TB-1	118.7	59.5	2.00	10,265	5.39	5.0	5
TN-1	121.6	59.4	2.04	10,535	5.59	5.0	5
T3M-2	121	57.4	2.11	10,110	5.80	5.0	5
F6C-4	162	58.0	2.79	2,582	11.75	12.0	7
FU-1	124	52.5	2.36	2,452	8.97	12.0	7
F3W-1	162	56.6	2.86	2,128	12.61	12.0	7
OD-1	150	60.0	2.50	4,253	9.05	7.5	6
O2U-1 Fighter	149	50.0	2.98	3,097	12.81	9.0	6



$$\text{Load factor} = 1.75 + \left(\frac{V_M}{V_S}\right)^2 \frac{112}{\sqrt{5000 + W}}$$

Fig.1