NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL MEMORANDUM NO. 718

# DEVELOPMENT OF THE RULES GOVERNING THE STRENGTH OF AIRPLANES*

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## PART III. LOADING CONDITIONS IN FRANCE, ITALY, HOLLAND AND RUSSIA - AIMS AT STANDARDIZATION

### 8. French Loading Conditions

The French strength specifications originally avoided all numerical data and left the test decision open for each individual case. Aroused by the rapid development of pursuit and acrobatic airplanes toward the end of the war, the assumption of sudden pull-out at high angle of attack from a vertical nose dive, formed the basis upon which to analyze wing strength. On the premises that the drag coefficient of the whole airplane in a nose dive is approximately equal to the drag coefficient $c_{w_h}$ for maximum horizontal flight $v_h$ at ground level, the S.T.Aé. prescribed the classical formula

$$n_A = k \frac{F}{N} (0.036\ v_h)^3 = 0.007 \frac{k\ \eta}{\rho_o\ c_{w_h}} \qquad (50)$$

for the load factor of case A.

The center of pressure was at one third of the wing chord.

In 1922 (reference 61) the k factors were prescribed:

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*"Die Entwicklung der Festigkeitsvorschriften für Flugzeuge von den Anfängen der Flugtechnik bis zur Gegenwart." Luftfahrtforschung, June 21, 1932, pp. 38-52. (For Parts I and II, see N.A.C.A. Technical Memorandums Nos. 716 and 717.)

| | | |
|---|---|---|
| Pursuit single-seat monoplane, | k = 15 | ($m^4/kg\ s^2$) |
| " " multiplane, | 10 | |
| Other military monoplanes, | 11 | |
| " " multiplanes, | 7.5 | |
| Nonmilitary monoplanes, | 9 | |
| " multiplanes | 7.5 | |

The inclination of the resultant of the air loads toward the wing chord shall be 4:1 in case B. The point of application shall be determined from the wing polars. In case C the stress of the wings is investigated by its internal drag. The load factor in cases B and C is a stated fraction of the A-case load factor. In case D the load factor shall be $n_D = 0.5\ n_A$ for all airplanes.

Niles, after critically comparing formula (50) with the U. S. load factor, came to the conclusion that according to it some of the newer pursuit airplanes would be of inferior strength, whereas commercial airplanes, which practically never get into a nose dive, would become excessively strong.

Breguet and Devillers (reference 63) also criticized this formula and adduced the empirical breaking load factor, especially for commercial airplanes, from the stress in a vertical gust. Starting from the reasoning that a sharp pull-out at high speed is an unduly vitiating loading condition for commercial types, and that such a maneuver was not at all executable, particularly with large airplanes, they analyzed the motion of an airplane flying into a gust roller with sinusoidal distribution of the vertical velocity under the assumption of steady lift coefficients. The maximum stress is reached in the case of sudden rise of vertical velocity

$$n = 1 + \frac{\rho}{2} \frac{d\ c_a}{d\ \alpha} v_h\ w \frac{F}{G} \qquad (51)$$

With

$$\frac{\rho}{2} \frac{d\ c_a}{d\ \alpha} \sim 0.25\ kg\ s^2/m^4$$

gust velocity $w = 3\ m/s$, safety factor 2.5 of static quota and 5 as that of the dynamic quota, the breaking load factor becomes

$$n_{Br} = 2.5 + 3.75 \frac{v_h F}{G} \qquad (52)$$

The breaking load factor by this formula deviates for different commercial airplanes only slightly from 6 as contrasted with formula (50) which, even with the minimum $k = 7.5$ yields unnecessarily high load factors in some cases. It was therefore believed that a constant load factor of 6 was perfectly sound for commercial aircraft. But this no longer holds true to-day, where the number of airplane types has increased consistently.

The Permanent Commission for Aeronautical Research, with which the S.T.Aé. and the International Commission for Air Navigation were affiliated, came to the conclusion in 1925 (reference 64) that formula (50) rendered the preliminary static analysis difficult, because the speed $v_h$ was determinable only after test flights. Moreover, since the arbitrary $k$ factors were simply empirical, a determination of the load factors independent of the speed but dependent upon the gross weight of the airplane, was preferable.

The load factors set up by the two Commissions are given in

Table XXIX. French Load Factors, 1925

| | | Total weight G (t) | $n_A$ ⩽ 1 | $n_A$ ⩾ 5 | $n_C$ |
|---|---|---|---|---|---|
| Civil | CINA | Normal purposes | 7 | 5 | 1.5 |
| | | Records and special purposes | 5 | 4 | 1.2 |
| | | Acrobatics | 9 | 7 | 2.5 |
| | S.T.Aé. | Normal purposes | 8 | 6 | 2 |
| | | Records and special purposes | 6 | 6 | 1.5 |
| | | Acrobatics | 12 | 9 | 3 |
| Military | S.T.Aé. | Heavy bombers, training and ambulance airplanes | 8 | 6 | 2 |
| | | Multiseaters, day bombers | 9 | 7 | 3 |
| | | Pursuit and observation airplanes | 13 | 10 | 4 |

(t × 2204.62 = lb.)

These load factors were based in part upon acceleration measurements made by Huguenard, Magnan, and Planiol (reference 65).

For case B (c.p. position corresponding to that for maximum horizontal flight), the load factor is $n_B = 0.75\ n_A$.

Case C shall be analyzed for a nose dive with terminal velocity; the load factor, better called safety factor in this case, is given in table XXIX.

For wheel landing from normal flight attitude (pancaking), the impact factor is 6 for all airplanes except for the special group, where it shall be 4.5.

As vertical component of the landing shock for the landing gear 5 times the gross weight of the airplane shall be assumed (3.5 times for special group). The resultant slopes $27^\circ$ forward and $9^\circ$ sidewise against the vertical. For the rest, the specifications were similar to those found in the 1927 edition of the Bureau Veritas.

The CINA, originated in France, began in 1925 with the promulgation of "minimum requirements for obtaining an airworthiness certificate." The loading conditions contained therein had, in May 1929, progressed to the following stage:

General Specifications for Stress Analysis and Testing

The tests or stress analyses are subject to the following rules:

a) For the successively assumed flight attitudes or movements on the ground the loads produced under these conditions and which the different parts of the airplanes have to carry, are determined and, except for the forces set up by the propeller, multiplied by the load factor cited in the subsequent chapter.

b) The forces produced by the propeller are introduced in actual magnitude when computing the airplane speed. In case of fatigue stress of the airplane, thrust and propeller torque shall be multiplied by the load factors given in the subsequent section if these load factors are less than 2.5; but in any other case, with 2.5.

When static strength tests are required, it must be proved during these tests whether the total stress assumed according to the above data, produces forces which actually cause failure in some part of the structure.

Granted sufficient design data, they may be referred to breaking limit or elastic limit; but in all cases the different assumed load factors must be such as to give assurance of an identical factor of safety as the static strength tests with the load factors (given in the next section) would reveal.

Analysis and Strength Test of Wings

Case I: Flight with c.p. far forward. This case corresponds to pull-out from a nose dive and to horizontal flight in a vertical up-gust.

It shall be assumed that the airplane flies horizontally at the angle at which the center of pressure of the air loads is farthest forward. The forces impressed hereby on the different parts of the airplane shall be analyzed and the following breaking load factors applied thereto:

| Gross weight of airplane | $< 1$ t | 1 to 5 t | $> 5$ t |
|---|---|---|---|
| Class 1 (normal) | 7 | 7 " 5 | 5 |
| " 2 (special) | 5 | 5 " 4 | 4 |
| " 3 (acrobatic) | 9 | 9 " 7 | 7 |

The load factors for airplanes having a total weight of from 1 to 5 t change linearly.

Case II: Flight at maximum speed.

The airplane shall be assumed to fly horizontally at its top speed $v_h$ without the power and r.p.m. of the engines exceeding their respective internationally accepted figures. The loads impressed thereby on the individual parts of the airplane shall be analyzed and the pertinent load factors applied; they are three fourths of the value of case I.

Case III: Nose dive (c.p. farthest to the rear).

The airplane shall be assumed to dive at its limiting velocity with power off. The loads impressed hereby upon the individual parts of the airplane shall be analyzed and the following load factors applied:

| | |
|---|---|
| Airplanes of class 1 (normal) | 1.5 |
| " " " 2 (special) | 1.2 |
| " " " 3 (acrobatic) | 2.5 |

Case IV: Rough landing.

The airplane shall be assumed to be in horizontal attitude and drop vertically when touching the ground, after which the weight of the different members of the structure shall be multiplied as follows:

| | |
|---|---|
| Airplanes of class 1 (normal) | 6 |
| " " " 2 (special) | 4.5 |
| " " " 3 (acrobatic) | 6 |

Aside from the four main cases, there are the following special cases:

a) It shall be assumed that the airplane attains to attitudes 1 and 2 successively; hereby half of the above-cited load factors for analyzing the produced forces are assumed, and it must be proved whether, after failure of one bracing or fitting, any part of the cellule is under greater than its breaking load.

b) The loads on the wings shall be analyzed for the case that the airplane taxies or that the engines rotate on the ground separately or collectively, whereby the highest permissible torque shall be assumed and a unit load factor of 2.5 applied.

## Analysis and Test of Control Surfaces

The vertical tail surfaces of the airplanes of class 1 (normal) and of class 2 (special) shall be designed to withstand a mean test load perpendicular to their surfaces, which is defined according to the formula $Q = 3.6\ v_h$, but which in no case must be less than 70 $kg/m^2$.

The distribution of this mean load over the fin surface shall be uniform, triangular over the rudder. The apex of the triangle shall lie over the outer edge, its base over the axis in unbalanced, and over the leading edge in balanced, elevators.

The strength of the fin attachment to the fuselage and of the rudder must be at least equal to the applied loads.

Fin and rudder and fittings must, without abnormal fatigue, sustain the stresses set up by control forces in flight or on the ground.

These regulations were revised July 1931, and amended as follows:

Elevators and stabilizers shall be analyzed with that of the following loads which produces the greatest stress:

a) A steady load equal to that specified for the vertical tail surfaces.

b) The loads resulting from the equilibrium equations for the first three flight attitudes with the same load factors as for the wings.

c) The load set up when the part of the elevator lying on one side of the line of symmetry of the airplane is loaded separately. If not amenable to direct analysis it may be assumed that the corresponding load is for the time being half of the loads found under a) and b).

For the investigation of the equilibrium equations in case b), the c.g. of the airplane yielding the maximum load on the control surfaces shall be assumed.

The load distribution over top and bottom of wing on one hand, and over span and chord on the other, depends upon the results from full-scale or model tests. When such are not available, officially recognized publications may be consulted. The fin attachments on the fuselage and of the elevator must be designed to withstand at least the stresses produced by the loads on the tail surfaces.

Ailerons shall be analyzed for the loads accruing from the second load case, the ailerons shall be assumed to be displaced 3° downward, and the load factors for the wings shall be applied; intensity and distribution of the loads to be taken from experiments or, lacking these, from officially recognized publications. Aileron fittings shall be designed to withstand at least the stresses impressed by the aileron loadings.

## Landing Gears

For landing-gear design, three conditions must be complied with:

1. With an airplane in flight attitude, it shall be assumed that only the wheels touch the ground. The total weight shall be multiplied by a load factor 4.

2. The airplane attitude is as above, but the resultant of the loads is no longer vertical but shall be assumed inclined in a plane perpendicular to the longitudinal axis of the airplane so that the horizontal component equals 0.7 times the gross weight of the airplane.

3. The airplane is in the same attitude and subjected to the same loads as in the first case. But the resultant of the loads shall be assumed to be inclined in a vertical plane through the longitudinal axis of the airplane, so that the horizontal component is equal to one fourth of the resultant.

The stresses of the parts supporting the fuselage shall be analyzed as follows:

a) The airplane rests with the wheels and the support on a horizontal plane and its weight shall be multiplied with the load factor set up for the landing gear.