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SAFETY FACTORS IN AVIATION.

By Louis Bleriot.

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As the speed of airplanes has increased and the stresses have become more severe, the safety factor required by the S.T.Aé. (Technical Section of Aeronautics) has been raised until it is about 18 for pursuit monoplanes.

$$n = K \frac{s}{T} \left(\frac{Vo}{100}\right)^3$$

The above formula, which has rendered real service to aviation by giving it a degree of safety seldom attained before, now seems to have a tendency to stifle, by requiring of new airplanes a form of construction perhaps too heavy and burdensome. The question of speed comes in, with the exponent 3, though, with present speeds of 150 to 250 km/hr (93.2 to 155.3 mi/hr), an exponent of 2 - 2.5 would seem to be nearer the reality. Moreover, simply from the physiological standpoint, it may be asked whether aviators can withstand the rapid variations in speed which engender such stresses.

When an airplane is in normal rectilinear flight, its cell is subjected, by definition, to a stress of 1, i.e. it undergoes stresses due:

1. To its own weight;

2. To the weight of the fuselages or hulls (including all weights other than that of the cell, i.e. engine, fuel, passengers, the hull itself, etc.) and in direct proportion to these weights.

* From L'Aerophile, October 1-15, 1922, pp. 305-6.

Under these conditions, and inversely, if, in a severe shock, the wing or the cell undergoes a stress of 18 times the normal stress (i.e. if the force causing the normal stress has been increased 18 times), the pilot's inertia generates a stress on the cell and on the pilot himself (according to the law of action and reaction) equal to 18 times his weight.

If we now consider a pilot of average weight $P = 80$ kg (176.4 lbs) and if, in order to exert on him the stresses he would be subjected to during the course of a flight, we make him fall freely in a sitting posture from increasing altitudes, his velocity in m/s will be given by the formula

$$V = \sqrt{2\,gh} \qquad (1)^*$$

in which h denotes the altitude in meters and g the acceleration due to gravity = about 10 m/s (32.81 ft/sec).

The stress undergone by the pilot at the end of the fall will be equal to one-half the kinetic energy developed.

$$T = \frac{1}{2}\ m\ V^2 \qquad (2)$$

in which m is the mass of the man = P/g, whence, according to equation (1),

$$T = \frac{1}{2}\ m\ V^2 = \frac{1}{2}\,\frac{P}{g} \times 2\ gh = P\ h = 80\ h.$$

We may accordingly sum up the results of this elementary calculation in the following table:

* On account of the small velocities, the resistance of the air is considered negligible.

Distance fallen in meters		1	2	3	4	5	10
Velocity at end of fall	m/s	4.50	6.30	7.75	8.95	10.00	14.00
	(ft/sec)	14.76	20.67	25.43	29.36	32.81	45.93
	km/hr	16.20	22.60	27.80	32.20	36.00	51.50
	(mi/hr)	10.07	14.04	17.27	20.01	22.37	32.00
One-half kinetic energy in	kg	80	160	240	320	400	800
	(lbs)	176.4	352.7	529.1	705.5	881.8	1763.7
Physiological factor of safety		2*	3	4	5	6	11

It is perfectly evident that a man cannot withstand beyond certain limits. What are those limits? In the absence of accurate data, we will content ourselves with examining clearly established facts.

During the war, it was assumed that the vertical landing velocity in a parachute drop could not, with impunity, exceed the velocity attained by a man in falling freely four meters = 8.95 m/s (29.36 ft/sec) or 32.2 km/hr (20.01 mi/hr). In this case, however, the man lands under favorable conditions, having the unhampered use of his limbs, which can serve as shock absorbers and therefore cannot be compared with the case of a man sitting. When, for instance, the stress is 320 kg (705.5 lbs) or four times the weight of the man, with a safety factor of 5, we can affirm that a sitting man will have a physiological factor of safety of considerably less than 5.

What speed variation of an airplane will produce such a

* In fact, the man supports his weight plus 80 kg (176.4 lbs), hence the factor 2.

stress? Let us apply the theorem of kinetic energy:

$$d \frac{1}{2} m (v^2 - v'^2) = d T$$

to the case of an airplane with a speed of 360 km/hr (223.69 mi/hr), or 100 m/s (328.08 ft/sec) and to a pilot of 80 kg (176.41 lbs), working at the coefficient 5.

$$\frac{1}{2} \frac{80}{10} (100^2 - v'^2) = 320$$

v' = 99.5 m/s (326.4 ft/sec) or about 358 km/hr (222.45 mi/hr). Hence, an instantaneous change of speed of only 2 km/hr (1.24 mi/hr) would cause the pilot to experience a shock equal to four times his own weight.

Fortunately, no change of speed can take place in zero time. In spite of all, there were registered, during trial flights in France, Italy and England (by means of a dynamometer, a Maret capsule, a Brinnel instrument or a Lindemann and Searle's glass filament), stresses of 3 to 4 which were withstood by the pilot in every instance, without inconvenience. Why?

First, because the coefficient 4 was not exceeded and, secondly, because there seems to come in, for both airplane and pilot, the elasticity of the airplane itself (especially the wings), of the seat and of the cushion (if there is one), of the pilot's muscles, etc.

Injuries resulting from violent landings or falls do not consist simply of broken bones (notably the sixth vertebra of the spinal column), but especially and much oftener, of lesions of the soft parts, such as the displacement of the viscera (heart, stomach, kidneys, liver, etc.), hemorrhages, etc., all of which are included in the vague and general term of internal injuries.

Where one person can, perhaps, endure a factor of 5 or 6, another will experience serious lesions from a factor of 3, due to his organs, for some reason or other, being in a condition of less resistance.

We cannot therefore expect precise results from experiments, however accurate and numerous they may be. We may, however, hope for approximations and maximum limits. It cannot be affirmed that, in such a position, a person will die at the factor of 5, and that, below that, he runs no risk, but it may be affirmed that, above the factor 5, there is danger for an average man.

If experiments tried on apes, for example, should show that accidents with the factor 5 are usually fatal, we would be forced to conclude that the less supple human body could not withstand it.

Is it therefore useless to require a safety factor of 18 of airplanes, if the human body can stand only 5? Is it required of an automobile to withstand a sudden turn at 150 km (93.21 mi) per hour? Have we any right to require of an airplane an automatic safeguard not required of any other means of locomotion? It may be replied that shock-absorbing seats can be used which will absorb a large part of the shocks experienced by the pilots, but to what extent?

The displacements being necessarily very limited, since the pilot cannot let go of his controls, it seems that we cannot expect very much from this expedient. We arrive at the conclusion that accurate experiments can further establish, not the resistance or strength of the materials which shall limit the acrobatic performances of the artificial bird, but rather the physical resistance of the man, who is its brain.

Translated by the National Advisory Committee for Aeronautics.