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FACTORS OF SAFETY AND INDEXES OF STATIC TESTS.

By Le Bailly.

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By Le Bailly.

In the October number, L'Aerophile published an article by Louis Bleriot which considered the conditions of mechanical strength required by airplanes from a particular point of view. Mr. Bleriot asks whether account should not be taken of the physical resistance of the passengers themselves for establishing an upper limit to the strength of airplane cells which it would be of no advantage to exceed. This manner of considering the question is interesting, since it is evident that it would be absolutely useless to build airplanes capable of withstanding formidable stresses, if the existence of still weaker stresses would necessarily cause the death of the passengers.

Mr. Bleriot presented the problem without attempting to solve it, confining himself to the presentation of certain figures and suggesting certain conclusions. In connection with this question, which is of the greatest importance for the future of aviation, it may not come amiss to present a few arguments and to recall certain experiments which would seem to be of such a nature as to remove all fears.

1. Man's physical resistance.- Certain data are lacking for establishing the acceleration limits capable of being with-

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* From L'Aerophile, December 1-15, 1922, pp. 361-3.

stood by the human organism. The computation example given by Mr. Bleriot does not seem, however, to be absolutely accurate. It is quite certain, in fact, that a man throwing himself from a third-story window would run a great risk of being killed, but, in such event, death would be due to the shock at the point of impact with the ground. Moreover, if the ground were perfectly solid and it should be a bone to receive the first shock, the acceleration of this part would be, properly speaking, infinite. As to the viscera, the muscles and membranes supporting them act as shock absorbers and diminish the acceleration to a certain degree. If insufficiently absorbed, however, this acceleration may still be great enough to cause internal injuries.

The stresses which airplane passengers have to withstand in acrobatic flights, are of quite a different character. Under these conditions, there is no localized shock, as in the case of a fall, but some sort of a stress uniformly distributed throughout the whole body. It is permissible, as we shall see, to assume that, under these conditions, the body can withstand very great accelerations, up to 8 or 10 times that of gravity.

There is no need of considering exceptional evolutions, like looping. As demonstrated by Dr. Adolf Rohrbach in a treatise on the factors of safety in curving flight, airplanes undergo in making turns, stresses entirely comparable with those encountered in looping. With very swift airplanes, pursuit or racing planes, calculation based on experience shows that a turn may cause great acceleration.

Without considering the record airplanes of the Deutsch cup race and the impressive turns made by Sadi Lecointe and Lasne, it has been found that the pilot of the Gourdou pursuit airplane C_1, for example, can turn at 230 km.(143 mi.) per hour in 1.5 sec. A simple calculation shows that the acceleration holding the pilot on his seat exceeds ten times that of gravity.

Similar results would be obtained by timing the turns of Sadi Lecointe, Lasne, Casale, or any other pilot of a swift airplane. We see therefore that these men, evidently of superior physical qualities, can withstand great variation of acceleration. It has never been questioned, however, that pursuit pilots must have physical qualities superior to those required by pilots of commercial airplanes.

For the benefit of those who are not satisfied with the calculation, it is only necessary to recall the experiments made during the war by Drs. Garceaux and Broca for the purpose of ascertaining whether high indexes of static tests were incompatible with the physical resistance of living beings. The experiments were performed on dogs placed in a centrifugal machine and subjected to accelerations of 50 to 100 times that of gravity. It was found that dogs subjected to accelerations of 40-50 times that of gravity for one minute and thirty seconds recovered within a few minutes. One of them underwent an acceleration of 80 g. for more than half a minute without dying.

Although these experiments were performed on dogs, do they not enable us to conclude that man can withstand a stress of 10 g. for the few seconds occupied by a stunt? Such, indeed, was the conclusion of Dr. Garceaux.

2. Safety factors.- Whatever acceleration limit the human organism can be subjected to with impunity, we must not forget what a safety factor is. The safety factor of any part is the ratio between the breaking strength of that part and the maximum stress to which it is liable to be subjected in actual service. The static test indexes required by the French departments are not safety factors. They are what the English term "load factors," i.e. if an airplane is designed to withstand a certain stress under normal flight conditions, it is calculated (or tested) to be able to withstand n times this stress, n being computed by the formula

$$n = K \frac{S}{T_o} \left(\frac{V_o}{100} \right)^3$$

In order to compute from this formula the true safety factor, it would be necessary to know, for all the evolutions, the maximum stress withstood by the airplane. If this stress reaches n' times the normal stress, the true safety factor is only n/n'. In default of sufficient experiments, the calculation goes to show that the figure n computed by the above formula corresponds to a true safety factor of rarely more than 1.5 or 2. Obviously, a smaller figure could hardly be allowed.

Now, there can be no question of considering any safety factor for a man. Particularly, in a military airplane, which Mr. Bleriot chose for illustration, the pilot will fly to the limit of his forces and will risk any stunt for conquering his adversary, even if it may cause his own death. What must not happen, however, is for the airplane to give out first by suffering a rupture during flight. Even the fear of a rupture should not be possible. It is therefore necessary, independently of the mechanical strength it should possess by reason of the stresses which its characteristics enable it to withstand, that the airplane have an additional true safety factor with respect to the maximum stress the pilot can withstand himself. More exactly, if the evolutions which the airplane is capable of performing may produce stresses near the strength limit of the man, the airplane must be given a safety factor with respect to this strength limit.

Considering the hazards of quantity production, the wear of the airplanes, etc., the factor 2 is a minimum and it follows that, since a man can withstand accelerations of 8 to 10 times that of gravity, static test indexes of 16 to 20 are not unreasonable.

Independently of any computation based on any particular kind of evolution, there is a simple method of determining the order of magnitude to be required for static test indexes.

Let us assume that, considering the nature of the tasks of a given type, an airplane may be required to withstand, in flight, stresses of $\underline{p}$ times its weight. If $\underline{n}$ is the desirable true factor of safety, the airplane should be calculated for stresses equal to $n\ p$ times its weight.

On the other hand, if we assume that aging may entail a 25% loss of strength and if we also take into account the fact that it is desirable never to stress the parts beyond their limit of elasticity, we find that the static test index must be of the order of

$$\frac{n\ p}{0.75 \times 0.7} :$$

For a commercial airplane, which never attempts stunt flying nor sharp turns, we may take $n = 2$ and be satisfied with a true safety factor of $p = 1.5$. This gives 6 as the minimum static test index desirable.

For a pursuit airplane or racer, it is customary to adopt $n = 4$ and $p = 2$, which again leads to the conclusion that test indexes of the order of 16 are reasonable.

The application of the formula giving this index sometimes gives larger figures in the special case of pursuit monoplanes for which $K = 15$ and it may be assumed that this formula, though reasonable within certain limits, should not be carried too far. It should be noted, however, that modern pursuit airplanes do not conduce, in general, to figures above 18, because of their heavy wing loading and their small load per HP, which make the ratio $\frac{S}{T_o}$ very small. Nevertheless, for pursuit monoplanes, it would perhaps be possible, in consideration of the present thick wing construction, to adopt the factor $(k = 10)$ as for biplanes, but there is no reason for changing, as Mr. Bleriot suggests, the exponent 3, under which the speed enters into the formula.

This formula, in fact, only serves to express the drag of the airplane, while V^3 varies proportionally to T_O, so that their ratio remains constant for a given airplane. This is so true that, if the engine of a given airplane is changed, the application of the formula gives the same figure, to within the range of experimental errors, when based on the performances of any one of the engines tested.

If, therefore, experience should show beyond the shadow of a doubt that the figures given by the formula were excessive, they would have to be corrected by means of the factor k and not by changing the exponent of V.

3. Commercial airplanes.- Generalizing the conclusions of his discussion, based on the example of a pursuit monoplane, Mr. Bleriot entitles his article "Les coefficients de securite et l'avenir de l'avion" (Safety factors as related to the future of aviation), seeming to assume that the static test indexes required in France are of such a nature as to compromise the future of our aeronautic industry.

Such fears, however, are doubtless uncalled for. The future of French aviation, like that of all other countries, does not depend, let us hope, on military aviation alone and, after the years we have just passed through, perhaps we may be allowed to hope that the intensive development of commercial aviation holds in store for us a less tempestuous future.

If, therefore, we consider the question from the purely commercial point of view, we find there is no occasion to fear incompatibility of the respective powers of resistance of the airplane cells and of the passengers. The coefficient $K = 15$, in fact, no longer enters into the formula, but only, according to the cases (biplanes or monoplanes), $K = 7.5$ or 9.

Whether the formula is applied to some existing commercial airplane or to research, it is found that the static test index n oscillates between 6 and 10, according to the airplanes. It is obvious therefore that, taking into consideration the true factor of safety, the maximum stresses to which airplanes can be subjected are from 3 to 5 times the normal stresses and therefore of the order which the human organism can withstand without danger and that we need have no fear of seeing an airplane, after a violent shock, flying intact loaded with dead passengers.

Moreover, the regulations of the different countries are practically the same as regards the construction of commercial airplanes and will doubtless soon be made perfectly uniform. Our industry therefore incurs no risk of being handicapped as compared with foreign construction by too severe regulations. We still labor, however, under one disadvantage. In France we require static tests of sample airplanes, while in England, for example, the simple calculation of the stresses is adjudged sufficient. It must be confessed that the static test is a great source of anxiety for the constructor. But, for a few hours of uneasiness, a great service is rendered! Calculation determines, indeed, the principal stresses in the spars, struts, stays, etc., but how many unknown factors there are in the parts designed to withstand these stresses! The testing enables the improvement of the secondary bracing, the local rigidity and other possible causes of rupture, which can be discovered in no other way. Moreover, nearly all French constructors are convinced of its utility. As for the pilots, they seem to attach special importance to it.*

Doubtless the time will come when the progress of the science will enable the elimination of static tests without danger, but it would be imprudent to do so before emerging from the period of experimentation, which does not appear likely to be very soon.

On the other hand, it seems rather strange to find that, in spite of the prudence of the French regulations, French commercial airplanes generally have a smaller wing loading than foreign airplanes. French airplanes (without engine) have an average wing loading of 13 to 14 kg/m² (2.66 to 2.86 lb/ft²), Italian airplanes a little more and English airplanes as high as 18 to 20 kg/m² (3.69 × 4.10 lb/ft²).

These results are all to the credit of French constructors and their engineers, but, on the other hand, they render it impossible to lay to the difficulties of construction the defects, doubtless temporary, which now seem to characterize our airplanes

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* As an illustration of the insufficiency of calculation, in the Daily Mail soaring contest, the De Haviland glider suffered a rupture of the wings, in spite of its having been calculated with a factor 3.

on lines where they are competing with foreign makes. The reason for this is both very serious and very simple: very serious, because, if certain French lines are very irregular, it is due to too frequent failures of the engines employed; very simple, because many travellers would return to French airplanes, if the latter were fitted out with the care for comfort which characterizes the English and German airplanes. French constructors, therefore, do not need to be disturbed regarding the static test indexes, for they are not what is now handicapping our airplane industry.

Let them rather give a little more attention to the comfortable equipment of the cabins, where the passengers should not be bothered with spare propellers and wheels, and, above all, let them turn to engine builders to demand of them reliable engines, without which even multi-engine airplanes can never render satisfactory service.

Table of commercial airplanes now in use.

Airplane	Engine	Wing area		Dead load	
		m^2	ft^2	kg	lb
Breguet-Limousine	1 Renault 300 HP	49	527.43	1145	2524.29
Salmson-Latécoère	1 Cu-Z-9 230 HP	39	419.79	935	2061.32
Berline-Blériot 33	1 Cu-Z-9 230 HP	43	462.84	1050	2314.85
Goliath-Farman	2 Cu-Z-9 230 HP	161	1732.97	2500	5511.55
Potez-Limousine 9	1 Lorraine 370 HP	45	484.37	1260	2777.82
Vickers-Vimy	2 Lorraine 370 HP	119	1280.89	3340	7363.43
De Haviland D-18	1 Napier 450 HP	57	613.54	1900	4188.78
Handley-Page	2 Napier 450 HP	135	1453.11	3990	8796.43
Fokker Sidney	Sidney Puma 240 HP	42	452.08	1200	2645.54
Junkers-Limousine	B. H. W. 185 HP	39	419.79	1030	2270.76
Ansaldo	Fiat 300 HP	44	473.61	1400	3086.47

Table of commercial airplanes now in use (Cont.).

Airplane	Engine	Wt. without engine.		Wing loading.		Average wing loading
		kg	lb	kg	lb	
Breguet-Limousine	1 Renault 300 HP	640	1410.96	13	28.66	French 13.5 kg 29.76 lb
Salmson-Latécoère	1 Cu-Z-9 230 HP	550	1212.54	14	30.86	
Berline-Blériot	1 Cu-Z-9 230 HP	665	1466.07	15.5	34.17	
Goliath-Farman	2 Cu-Z-9 230 HP	1730	3813.99	10.5	23.15	
Potez-Limousine 9	1 Lorraine 370 HP	660	1455.05	14.5	31.97	
Vickers-Vimy	2 Lorraine 370 HP	2140	4717.89	18	39.68	English 20.0 kg 44.09 lb
De Haviland D-18	1 Napier 450 HP	1250	2755.78	22	48.50	
Handley-Page	2 Napier 450 HP	2690	5930.43	20	44.09	
Fokker-Sidney	Sidney Puma 240 HP	760	1675.51	18	39.68	German 17.25kg 38.03lb
Junkers-Limousine	B. H. W. 185 HP	650	1433.00	16.5	36.38	
Ansaldo	Fiat 300 HP	900	1984.16	20.0	44.09	Italian 20.0 kg 44.09 lb

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