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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 464

DISCUSSION OF PROBLEMS RELATING TO THE
SAFETY OF AVIATION

By J. Sabatier

PART I

From "Bulletin Technique" No. 42, of the "Service Technique
et Industriel de l'Aéronautique," June 18, 1927

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

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DISCUSSION OF PROBLEMS RELATING TO THE SAFETY OF AVIATION.*

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PART I.

The question of safety in aviation has called forth an exceptional number of articles in France during the past year.

The "Commission Permanente d'Etudes Aéronautiques" (Permanent Commission for Aeronautic Research), presided over by Mr. Rateau, has long been investigating the strength of airplane cells in flight and calculation methods for guaranteeing it.

The "Commission d'Aviation de l'Aéro-Club de France" (Aviation Committee of the Aero Club of France), presided over by Mr. Soreau, has discussed, with all the fullness they merit, the safety-contest programs, which the Guggenheim Fund in the United States submitted for its examination. The discussions bore more especially on loss of speed (stalling) and on the qualities required by the cells when the engines are stopped or the controls are abandoned.

More recently, the "Comité de Propagande pour l'Aéronautique" (Aeronautic Propaganda Committee) has organized a series of sub-committees, both for investigating some of the problems relating

*"Examen d'Ensemble des Principaux Problèmes Concernant la Sécurité de la Navigation Aérienne," "Bulletin Technique" No. 42, of the "Service Technique et Industriel de l'Aéronautique," June 18, 1927.

to safety in flight and also for discovering means to solve them. The efforts of this committee are devoted especially to the functioning of the engine-propeller groups, to protection against fog and to the stability of airplanes in flight.

The "Société de Navigation Aérienne" (Aerial Navigation Society) has undertaken an extensive technical investigation, in which most of the questions pertaining to the safety of aviation have been discussed. By offering its services to the engineers who design and inspect aviation materiel, to the pilots and representatives of the companies using it and to the navigators and meteorologists, this society has demonstrated the various aspects of the problem and has enabled the envisagement of the possible solutions.

Lastly, the technical departments of the government have endeavored to assist all these instrumentalities by coordinating them, so as to avoid gaps or overlapping. Their laboratories, statistics and test results have been held at the disposition of inquirers and have contributed to the common cause. Many direct investigations, relating especially to static tests and protection against fire, have yielded good results.

The object of the present treatise is to review all these efforts and to examine the present status of aerial safety.

General Remarks on the Problem of Safety

It is important to state first just what the problem of safety in aviation really is. The airplane will not find many users, if its functioning is not sufficiently reliable; nor will it find many more, if this reliability is obtained at the expense of excessive sacrifices in speed and carrying capacity or, to speak more generally, in economy of operation. In brief, it is not a question of producing an absolutely safe airplane by subordinating all the other requisite qualities. On the contrary, it is necessary to meet these requirements with the maximum degree of safety permitted by the present status of the art of aviation. A safety device may therefore be excellent in principle, but it will not be finally adopted, if it is excessive in weight, bulk, aerodynamic resistance, or complexity.

Two examples will suffice to illustrate this idea, which is disregarded by many inventors. If an airplane had a great reserve of engine power, it would avoid most of the stalls, which cause a large proportion of the accidents. Similarly, if the landing speed did not exceed 40 km (25 miles) per hour, the hazards of forced landings would be considerably reduced. No technical difficulty prevents the production of airplanes with superabundant power or with a very low landing speed, but the excessive dead weight of the former and the insufficient cruising speed of the latter reduce these advantages to almost nothing.

Moreover, it is not enough to meet the conditions imposed

by safety and economy of operation. It is also necessary to take measures for avoiding every kind of accident, so as not simply to shift the danger and modify its nature, with no ultimate gain in safety. For example, many inventors, impressed with the danger from the continued flow of gasoline into the carburetor, in case of fire, have proposed devices for automatically cutting off this flow as soon as the temperature of the engine compartment rises ever so little. Such devices, if adopted would, in many instances, deprive the pilot of his only means of maneuvering at the very moment when he is most in need of them. Such devices would replace the fire hazard by that of stalling, and generally with no increase in safety.

Lastly, the measures to be taken vary according to the type of airplane and the use for which it is intended. Thus, parachutes are indispensable on military airplanes, where they have already saved many lives. On the other hand, their use on commercial airplanes is more questionable, because the passengers generally have neither the experience nor the presence of mind to profit by their use, in case of need. On the other hand, commercial aviation companies, whose personnel is stable and experienced, can profit from delicate safety devices of functioning or upkeep, while military formations, with a young personnel of short term of service, would derive much less benefit from such devices.

The above considerations demonstrate the complexity of the

problem of aerial safety. We cannot expect to solve it as certain writers have proposed, by adopting the most effective preventive for each category of possible accidents and by installing on one and the same airplane all the corresponding devices. Such an airplane, were it realizable, would certainly not be able to fly. The possible solutions are neither simple nor uniform. It is only by a thorough analysis of each type of airplane, of the particular service for which it is designed and of the consequent possibilities, that we can improve them and gradually develop their efficacy.

Statistics and Their Results

The study of the statistics of accidents form the basis of researches relating to progress in safety. Particularly valuable information in this connection has been supplied by the "Société de Navigation Aérienne."* The statistics concerning the civil aeronautics of the different countries are known in their entirety. This is not true, however, of accidents in the military and maritime aeronautics of the various countries for obvious reasons. For the latter we are therefore restricted to incomplete data taken from official publications and parliamentary documents.

Nevertheless, the study of accidents in military aviation

*See Brunat, II, III, and IV (The Roman numerals refer to the bibliography at the end (Part II) of this treatise.

is of great value to civil aviation. In fact, the service conditions for military aircraft are generally severer than those for commercial aircraft. Stunt and night flying and landing on all kinds of fields are of constant occurrence. Accidents are therefore much more frequent. The technical lessons drawn from them can, however, be almost always applied to commercial aviation. From this viewpoint, military aviation constitutes a veritable experimental laboratory for civil aviation.

It would therefore be particularly beneficial for the civil statistics in each country to be accessible to technicians, for them to be tabulated for comparison according to a uniform model and, lastly, for them all to be compiled in a single publication.* It would also be desirable for this publication to contain all the military statistics which may have been published in each country. There could be no objection on the part of the respective authorities, because it would be only a repetition of data already known.

However that may be, the results of the statistics known in France can be analyzed as follows: During 1923-1925 there have been three deaths in French civil aviation for about 100,000 hours of flight, which is only one-third of what it was in 1920. Recent mortality statistics per hours of flight, for the British, American and French military air services, differ but little from

*The "Commission Internationale de Navigation Aerienne," at the request of French experts, has just laid the foundations for such a publication.

one another. They are about six times as great as in civil aviation. For the past five years, there has been a regular decrease in the mortality rate per hours of flight, as shown by statistics, both in France and in the United States. There has therefore been systematic progress in safety, for military airplanes as well as for commercial airplanes. If, instead of the number of deaths, we take the number of serious accidents, we find that, in the military air services of Great Britain and of the United States, there are five to six accidents for one death. The proportion was the same in France from 1923 to 1925. There has been the same decrease in the number of accidents per hour of flight as in the number of deaths (from three to one between 1920 and 1925 in French civil aeronautics). Here also the statistics, although taken from various sources, confirm the progress made.

On the other hand, military and civil statistics, compiled in England, the United States and France, from 1923 to 1926, and covering about 2000 cases, ascribe 50-55% of the accidents to errors in piloting. The same documents ascribe 20-25% to engine failures and 6-7% to the cells. Lastly, atmospheric disturbances and miscellaneous causes, determined or not, cause about 20% of the accidents. Although the discrepancies in the same column are appreciable between one set of statistics and another, they are small enough on the whole for the above averages to be considered accurate. It is remarkable that the statistics for military and civil aviation do not differ more from each other.

On passing from the number of accidents to the seriousness of their consequences, we find, at least in France (for all branches of aviation from 1923 to 1925), that errors in piloting cause 54% of the accidents, entailing 62-63% of the deaths and injuries. These errors are therefore relatively the most serious. Engine troubles, on the contrary, are relatively less dangerous, since they cause 22% of the accidents but only 5% of the deaths and 19% of the injuries. As to the accidents (24%) ascribable to other causes, they represent a medium seriousness (33% killed and 18% injured). Thus it is seen that the errors in piloting are the most serious. To reduce their number is therefore a matter of prime importance.

Errors in Piloting

What constitutes an error in piloting? The statistics are often not explicit enough on this point. A flat turn or a spiral take-off certainly constitutes one. The case is not so clear, however, when, for example, the pilot, feeling his engine weaken, begins a turn, in order to avoid an obstacle which looms up in front of him. Should the consequent stall be ascribed to the faulty functioning of the engine, which was the original cause, or to an error in piloting, simply because the pilot considered the fall less dangerous than the collision? The conclusions will vary considerably, according to how this question is answered.

It is doubtless true, however, that the accidents ascribable to errors in piloting, without previous defect in the airplane, are very numerous. The statistics compiled in France in civil aeronautics for 1924-1925 show, in fact, that out of a total of 370 more or less serious accidents entailing injuries to the personnel or materiel, 200 are ascribable to errors in piloting, as follows:

Accidents due to bad landings	120;
" " " " take-offs;	20;
" " " navigation errors	20;
" " " stalling	40.

It is seen that bad landings account for nearly one-third of the total number (370) of accidents. The latter are themselves due, in most cases, to excessive landing speed and to poor judging of the nature of the ground, of the neighboring obstacles, or of the prevailing wind.

To what must we attribute the frequency of these errors in piloting? Must we agree with one of our officer pilots (Cousin, V), perhaps too modest, that "men are inferior to machines"? Must we believe, on the contrary, that airplanes should be made easier for average men to operate? In the former case, the education of the pilots and navigators should be improved. In the latter case, the quality and design of the airplane should be improved. Obviously, aviation could not develop very far, if only men endowed with exceptional qualities could serve as

pilots. It is of vital importance, therefore, to make airplanes less difficult to operate, and especially to diminish the dangers from the failure of the human organism, which is always possible. Progress in this direction may render exceptional skill on the part of the pilots less essential, but it will never eliminate the importance of their task. It may even be claimed that technical improvements, by rendering it possible to build airplanes capable of carrying several tons of passengers or merchandise long distances, increase the responsibilities of the pilots and render it obligatory to require of them superior professional qualifications. Hence the selection, instruction and suitable training of the navigating personnel largely determine the safety and the development of aviation.

Education of the Navigating Personnel

The navigating personnel includes not only the pilots, but also the navigators and mechanics, who are their natural aids. We will therefore consider successively the improvements to be made in the education of each of these three classes of specialists. The task of educating pilots differs according to whether they are to be civil or military pilots. The requisite qualifications differ widely and it is probable that the differences will become more pronounced as the two branches of aviation become more specialized. However, since nearly all the present civil pilots received their training in the army or navy,

the methods employed in educating military pilots play a preponderant role.

Sometimes these methods are criticised for their special adaptation to the physical characteristics of the pupil (Devaluez, VII). Future pilots will doubtless be taught the things which are essential for them to know, but they must also be taught the technical principles underlying them. It is only by understanding the reasons that the pilot can appreciate the value of the prescribed maneuvers and can acquire the philosophy of his calling. If the education of the pilot is too empirical, he runs the risk of sooner or later encountering circumstances differing from those in which he has been instructed. He is then liable to make a wrong maneuver, unless he possesses exceptional skill and experience. Unfortunately, the shortness of the military service and the high cost of the hours of flight are obstacles to the attainment of these qualifications. In France, the candidates for the public carrier's license in 1921 had an average of 1000 hours of flight to their credit, while the 1924 candidates did not have over 150 hours, including their school flights (Devaluez, VII).

This situation can be remedied by appealing more to the intelligence of the apprentice pilots and especially by teaching them better to use the instruments of control, with which their airplanes are provided (speedometer, inclinometer, and turn indicator) (Cousin, VI). We often hear it said that these instru-

ments are more cumbersome than useful and that a good pilot can dispense with them; that nothing can take the place of his "aerial sense." Such a theory, if adopted, would preclude all possibility of improvement in piloting and of the consequent improvement in safety. It is true that a pilot should be able to maneuver his airplane without recourse to instruments, the observation of which requires time and which are susceptible of injury, but this does not signify that he should systematically neglect their indications.

In the first place, instruments of control are absolutely necessary for flying by night or in foggy weather. Even in ordinary daytime flights, it is important for the pilot to compare the sensations or reflexes, which the airplane produces on his organism, with the indications of the instruments. These indications are independent of the degree of training or the physical condition of the pilot. They enable him to verify and to "calibrate" continually his own impressions. They thus constitute a means of education and of improvement of the very first order.

The instruments of control are no less important for helping a pilot get into form again, after he has stopped flying for a long time. The methods of using and of interpreting their indications can, in fact, be much more easily learned than the empirical rules or the reflexes to which the present methods so often appeal. In brief, it seems desirable to teach apprentice

pilots first to use the instruments of control and only after they have acquired the habit of doing so, to teach them how to be able to dispense with the instruments.

For such a method to be efficacious, it is necessary to have instructors who thoroughly understand the principles involved. This amounts to saying that it is necessary to raise the standards both for instructors and for their pupils. We can first seek to increase the number of candidates in both branches (military and commercial) and thus facilitate their selection by an active propaganda and by the institution of more or less important advantages. The range of these measures, however, will be seriously limited. It is necessary to establish a school where pilots may receive the theoretical instruction they need and where the principles of piloting can be learned. Only pilots graduated from this school can become instructors in the schools of commercial piloting. Attention has often been called to the importance of such a school not only for pilots but also for navigators which will now be needed (Devaluez, VII and VIII).

It has already been mentioned that about 10% of the accidents in French civil aviation, attributed to errors of piloting, were due more particularly to errors of navigation (errors of route, collisions, etc.). Most of these errors, as also some of those ascribed to other causes, are due to the multiplicity of maneuvers, which the pilot must execute alone in difficult cases, and to his fatigued condition, especially at the end of a journey,

and, lastly, to his inadequate knowledge of navigation properly so-called, especially as regards keeping his course when he can not see the ground.

In order to reduce the number of accidents, it is therefore necessary to improve the instruction of the pilots in the art of navigation and, whenever the size of the airplane permits it, to give them the assistance of licensed navigators. The best solution, from this viewpoint, is to provide all multiplace airplanes, military and commercial, with dual control. The pilot holds the position of chief control, but can be immediately replaced by the navigator or (for lack of the latter) by the mechanic. This device, which is gradually coming into general use, is only a step toward the solution long since adopted on ships, which consists in reserving to the commander the general charge of the navigation, of freeing him from all actual operation, and of requiring him to operate in person only in case of an emergency. On this plan, the present navigator would be in line to become the future pilot of the airplane. (It is interesting to note that the tasks assigned to each member of the crew of Commander Byrd's transatlantic airplane, corresponded quite exactly to the above.)

It is therefore desirable to educate navigators properly so-called and to give pilots instruction in navigation when their education is deficient in this respect. The task is urgent because the length of individual flights is constantly increasing, thus increasing the importance and danger of errors in navigation.

The difficulties are great, however. When the navigator has many and precise means of finding his bearings (compass, radiogoniometry, radio signals, sounders, etc.), these often make very great demands on his technical knowledge (Franck, XI). Such devices can be used only by specialists with a sound general scientific education.

This leads us therefore, for navigators even more than for pilots, to the necessity of establishing a school where only pupils already provided with a good scientific education will be admitted and where it will only be necessary for them to complete their education by courses in the various special branches of aerial navigation. In brief, this school would bear the same relation to the schools for instructors and pilots, as the schools for deep-water captains bear to the schools for the captains of coasting vessels.

It will be noted that the school for pilots and navigators, although intended principally for commercial aeronautics, is capable of rendering great service to military and even maritime aviation. The latter could send probationary officers to it for instruction, just as it now does to the "Ecole Supérieure d'Aéronautique." It will also be noted that it deals with long-distance night flights, field observations over inhospitable regions, and sanitary or governmental missions in pacified colonies, where technical navigation methods are more and more needed.

The question of the mechanics remains to be considered, both

on the ground and on the airplane. The mechanics have a double task. They must reduce, by careful upkeep of the engines and accessories, the considerable number of accidents due to their poor functioning. Moreover, they must also relieve the pilot of his cares in the surveillance of the power plant, thus enabling him to give his whole attention to the maneuvering itself. The professional ability of an airplane mechanic is therefore an important factor of safety, which increases with the power and especially with the number of the engines.

The problems involved in the creation of a body of good mechanics are easier to solve, at least in France, than those pertaining to the pilot and navigator. They hardly exist aside from military aviation, where the shortness of the service period is a serious obstacle to the creation and to the maintenance of the necessary elements. Nevertheless, real efforts have been made in France to overcome these difficulties (Ramat, XVI). Of course, it would be foolish to suppose (as has sometimes been claimed) that it is possible to give young men, in a few months of schooling, all the theoretical and practical instruction they need but, by a combination of recruiting in industrial centers, preparatory courses in the service and premiums favoring long-term enlistments, a corps of skilled mechanics can gradually be built up, without which an efficient air service cannot be maintained.

Accidents in Landing

We have just seen how to improve the professional ability of the navigating personnel. We will now consider how the airplanes can be modified so as to render aviation accidents less numerous and less serious. Bad take-offs and, more especially, bad landings are among the most frequent causes of damages. Some of the accidents would be avoided by a better preparation of the aviation fields and their approaches, especially by draining off all moisture which softens the ground. This is particularly important for fields used by large airplanes, because of their great weight and long take-off distance.

Although airdromes are generally quite clear when first created, their approaches soon become encumbered with obstacles (power-transmission lines, factory chimneys, etc.), which constitute real dangers. It is important therefore to maintain the greatest possible aerial access to the airdromes. Should it be impossible or too expensive thus to protect the whole peripheral zone of an airport, the most important approaches should, at least, be kept clear, thus preserving veritable aerial avenues, comparable to the channels of seaports, where navigation would have the maximum safety (Report to the "Commission d'Etudes Permanentes" XVII).

How can airplanes be improved so as to reduce the number and gravity of landing accidents? The operation of returning to the ground comprises two phases, each corresponding to conditions

which must be met. In the first phase the pilot, after stopping his engine, lets the airplane glide to the ground. In the second phase the airplane, having reached the ground, rolls to its final stop. At the end of the first phase, it is important to touch the ground at a reduced speed and at a small angle of incidence. He tries therefore to prolong the glide, but is quickly limited in this attempt by the need of retaining control of his maneuvers. On the other hand, after clearing the obstacles at the edge of the field, he must leave a sufficient length of clear field for stopping his airplane.

The condition of being able to maneuver is the most important and therefore controls the other aspects of the problem. From this viewpoint, the first phase is executed with a security in proportion to the margin between the chosen gliding speed and the limiting speed below which the airplane ceases to be maneuverable. But the greater the gliding speed, the greater the shock of landing and the greater the danger of capsizing. On the other hand, the landing run of an airplane is a function of its remaining speed. The greater it is, therefore, the greater the braking force required to reduce it.

In order to increase the landing safety, it is therefore necessary:

- To reduce as much as possible the limiting speed below which the airplane loses its maneuverability;
- To land at speed sufficiently above this limit;

To dimension adequately the landing gears and shock absorbers;
To brake the airplane during its period of rolling.

These conditions have been particularly investigated for airplanes designed to land on the decks of ships. These airplanes have special airfoils enabling them to increase their lift at low speeds. Their control surfaces are large, so as to be effective at the same speeds. Lastly, the ships themselves have, on their landing decks, braking devices which enter into action as soon as the airplane makes contact with the deck. Unfortunately, the employment of these devices involves conditions which are acceptable only for the airplanes embarked, by reason of their special characteristics, but very difficult for ordinary airplanes. Hence their use has not yet become general. Nevertheless, it seems possible to improve the present situation in the three following ways:

By equipping the wheels with brakes to supplement the action of the tail skid (Some constructors have recently utilized a combination of two skids, the ordinary skid and a supplementary one. The latter points forward and can be operated at will by the pilot so as to form a plowshare and brake the airplane very energetically);

By employing shock absorbers capable of distributing the landing shocks better and especially of absorbing their energy better;

By increasing the speed range.

It has often been remarked that the airplane, being the swift-

est vehicle, is the one most in need of brakes, though actually having the least provision in this respect. Its means of arrest are, in fact, limited to the tail skid and to the resistance exerted by the air on its airfoils at large angles. This fault should be remedied by the use of aerodynamic brakes and of mechanical brakes acting in particular on the wheels. Aerodynamic brakes would be especially effective during the first part of the rolling, when the air speed is still high and when any premature braking of the wheels might incur the danger of capsizing. The unfolding of auxiliary surfaces or the use of reversible propellers would correspond to these conditions.

Wheel brakes are more easily installed (Several types are already used in the United States) and offer, moreover, the advantage of enabling the pilot to maneuver the airplane on the ground, without external aid, by differentiating the effect on the two wheels. Lest a too sudden stop might capsize the airplane, the wheel brakes should be provided with a very gradual control, braking very slightly at first and increasing toward the end of the course. Moreover, all devices reducing the risk of capsizing would facilitate the use of wheel brakes, notably the adoption of low landing gears placed far forward with respect to the center of gravity of the whole airplane. Several special anti-capsizing devices have been invented. Unfortunately the only efficacious ones are heavy, air-resisting and relatively complex. Their use cannot yet be recommended.

As regards the shock absorbers, their improvement is to be desired from the viewpoints of both safety and comfort. Despite the services rendered by the "sandows" (rubber-cable shock absorbers), which are still most generally used, they are difficult of upkeep and relatively fragile, especially when poorly protected from dust and mud. The distance reserved for their extension is generally inadequate. Lastly, though the sandows distribute the stresses well, they do not absorb them. This is done only by the pneumatic tires. It should be possible to make liquid or gas shock absorbers with a long stroke, which would remedy these faults without excessively increasing the weight.

There still remains the problem of increasing the speed range. Although it has been the object of much research ever since the beginning of aviation, it has never been definitely solved. Perhaps the use of lifting propellers, of revolving wings, or something of the kind, will facilitate its final solution. At present, however, these devices are under investigation and their practical application cannot be immediate.

The only devices which have been the object of adequate experimentation are slotted wings and wings with variable camber and area. They call for the following observations. In order to reduce the gliding speed of an airplane, we must increase its lift or its wing area. The latter is generally effected by telescoping auxiliary surfaces, which the pilot extends at the moment of landing, thus forming a prolongation of the trailing edge of

the wings. Increase in lift is effected either by the introduction of slots in the leading or trailing edge of the wings, or by warping the wings, or by simultaneously lowering both ailerons.

Since the second power of the speed enters into the flight equation, while the lift and area occur only in the first power, it is necessary, in order to obtain any appreciable reduction in speed, to effect a simultaneous variation of the area and lift, or a much greater variation in either one of these factors alone. The simultaneous variation of both area and lift is possible, but it is mechanically complicated and runs the risk of making the wings either too fragile or too heavy. The variation of only one of the two factors is much easier, but is generally less efficacious, due to the difficulties encountered in giving it the necessary amplitude.

In order to compare the results obtained under these conditions, we must define exactly what is meant by "speed range." Although the maximum speed of an airplane near the ground V_M is easily determined, the same is not true of the landing speed, which varies quite widely according to the pilot and to the maneuvers he executes. Hence we cannot introduce it directly without running the risk of obtaining results hardly comparable with one another. It is better, from this viewpoint, to introduce the stalling speed (v_m) corresponding to a gradual reduction of the rotational speed of the engine. This speed is derived from the value of the speed at the ceiling by the formula $v_m = v_p \sqrt{\mu}$.

The actual landing speed, in some cases, will be lower than the stalling speed, but it will vary in the same direction. Under these conditions the speed range is represented by the expression $\frac{V_M - v_m}{V_M}$. For existing airplanes, this expression has values generally included between 30 and 45%, with an average of about 40%.

The use of a variable-camber device, investigated in France in 1923, made it possible to increase the speed-range ratio of the corresponding airplane from 47.5 to 52.5%, or a relatively small increase of five points. The employment of a device for simultaneously changing the wing area and camber, tested at the same time, made it possible to obtain, on the contrary, the very large gain of 17 points (from 39 to 56%). This figure represents a reduction of 26 km (16 miles) per hour, as compared with the minimum speed of a normal airplane. The airplane itself was found to attain a final maximum speed of 153 km (95 miles) against a minimum speed of 67 km (42 miles), or an absolute speed range of about 86 km (53 miles) per hour. It would be interesting to compare these results with those obtained in other countries under similar conditions, especially with slotted wings. In any case, the above figures show the possibility of appreciably improving the speed range. The efforts already made should therefore be continued.

Of course the advantages resulting from an increased speed range will be utilizable only when the airplane is manageable at its minimum speed and at the corresponding landing speed. This

amounts to saying that the areas of the control surfaces must be increased to correspond to the reduction in the minimum speed.

For a given speed range, the airplane will have a landing speed just so much greater and consequently more dangerous, as its normal flight speed is higher. Therefore, in order to have the same relative safety, the speed range should be as much greater as the speed of the airplane is greater. Unfortunately this condition is not realizable in the present state of the art. In order to obtain the desired safety, some writers have thought simply to limit the landing speed without regard to the effect on the normal flight speed. It would appear difficult to accept this view, because speed is not only of obvious value in its utilization, but is also a very important factor of safety.

There are many kinds of accidents whose causes are a function of the time. Their probability is therefore diminished if the speed renders it possible to shorten the time required for the trips. Injuries to the engine accessories, especially failure of the lubricating system or of the piping, the fatigue of the pilot and the difficulties due to an imperfect knowledge of the meteorological situation, come under this head. On the other hand, a high speed diminishes the relative importance of errors with respect to the wind and the drift and makes it easier to avoid tempests or squalls. It also diminishes the danger from strong head winds. We should not therefore seek to improve the landing qualities of an airplane at too great a sacrifice in its flight speed.

We have just reviewed the means now available for reducing the frequency of landing accidents. We must also try to diminish the seriousness of their consequences. The following are the most important measures to be taken in accord with this viewpoint.

Padding the pilot's cockpit and, in general, all parts of the airplane against which the pilot or passengers are liable to be thrown in the event of a hard landing;

The elimination, on passenger airplanes, of all seats at the extreme front end of the fuselage and their replacement by a shock compartment similar in principle to those on ships and special railway cars;

Precautions against fire on the ground, the details of which will be considered farther on.

Stall or Loss of Speed

Public opinion attributes a very large proportion of aviation accidents to the stall or loss of speed. Nevertheless, this opinion is not borne out by the statistics given above for French civil aeronautics, which ascribe to the stall only about 10% of the accidents due to errors in piloting, or only 5-6% of all the accidents listed. This contradiction, however, is more apparent than real, first because stalls are more numerous in military than in civil aviation. Moreover, although stalling is not always the original cause of the accidents, it often contributes indirectly toward increasing their seriousness. This is the case of

an airplane which, on the failure of the engine, does not recover and crashes to the ground. The statistics naturally ascribe the accident to the failure of the engine, though it is really the resulting stall which converts the incident into a catastrophe.

What then is meant by the term "stall"? According to some writers, a stall is characterized by the softness and inefficacy of the controls, but this definition is not entirely satisfactory. It is obvious that an airplane will respond to its controls less readily at a low speed than at normal speed. However, when its control surfaces are properly dimensioned, they will always enable the pilot to remain master of the maneuvers down to and including the minimum speed of sustentation or the stalling speed. In short, the controls should not limit the speed at which an airplane can maintain flight. If, as the abovementioned opinion would seem to imply, there are airplanes whose controls prove inadequate under these conditions, this defect should be remedied by enlarging the control surfaces.

The phenomenon of stalling may be analyzed as follows (Lepere, XIII). While an airplane is flying, there is equilibrium between the attraction of gravity, the propeller thrust and the aerodynamic resultant. Any accidental circumstance, due either to a wrong maneuver or to some defect in the airplane, suddenly destroys this equilibrium, leaving the resisting forces preponderant. The speed decreases, entailing a diminution in the lift. The relative increase in the drag is ascribable either to a reduc-

tion of the engine speed which diminishes the propeller thrust, or to a spiral climb which increases the retarding component of the weight, or to a sudden turn or other equivalent maneuver. The pilot, wishing to avoid the loss of altitude resulting from the decrease in lift, increases the angle of attack instead of letting his airplane go into a glide. This maneuver may succeed, if the propeller thrust is still greater than the minimum drag of the airplane. Otherwise it only aggravates the situation. In fact, the drag increases faster than the lift and the retardation of the airplane is thus accentuated. The pilot then has only one resource, namely, to recover his speed by diving and thus resume horizontal flight. If he is too near the ground for diving, or if for any reason he fails to do so, a crash under the worst conditions is inevitable. The situation will become still more critical if the pilot operates the ailerons in order to flatten out his airplane laterally. This maneuver increases the drag of the lowered wing and tends to throw the airplane into a spin.

From the foregoing it follows:

1. That a stall is not dangerous at an altitude such that the pilot can dive to regain speed;
2. That the airplane must, however, be strong enough to withstand the abnormal stresses produced by diving;
3. That the control surfaces must be large enough to enable

the pilot to retain the mastery of his airplane down to the stalling speed;

4. The pilot must not lose time before trying to prevent a descent which circumstances may render inevitable. He must unhesitatingly attempt the necessary maneuvers, but must avoid too sudden action on the rudder and especially on the ailerons.

How can the accomplishment of these various maneuvers be made easier for the pilot? It has already been mentioned that a stall is less dangerous at a high altitude, which gives the pilot a longer distance to dive in the effort to regain sufficient speed. He will also have a broader zone in which to choose a landing place if, after regaining control, he cannot maintain horizontal flight. From this viewpoint, airplanes with little reserve power and a consequent low ceiling are obviously dangerous.

It does not suffice, however, for the airplane to be able to fly high. It is also necessary for the pilot not to hesitate to do so, especially when fog conceals most of the landmarks, which ordinarily help him to keep his course. This again illustrates the importance of pilots being able to navigate by dead reckoning.

The question of the strength to give the framework of an airplane, in order to enable it to dive and flatten out without danger of failure, will be examined farther on. As to the efficacy of the control surfaces, it is a function not simply of their

areas but also of their shapes and their positions with respect to the cell, to the fuselage, and to the propellers.

Many experiments have been tried, especially in the United States and in England, with normal cells and with slotted wings, in order to determine the types of ailerons giving the highest relative flattening-out couples. It is important to continue these experiments and to draw general conclusions from them.

It remains to consider the instruments and devices whose adoption may reduce the frequency and seriousness of stalls. It has been remarked (Bramson, I) that the premonitory indications of a stall are little apparent and may escape the notice even of very cautious pilots. If a pilot is preoccupied with the functioning of his engine or the following of his route, he is liable not to consult in time the instruments which would warn him of the danger. Any gain, of even a few seconds, in executing the maneuver of recovery, is then of vital importance. It is therefore important for the instruments intended to be read to be supplemented by warning signals which will automatically draw the attention of the pilot in case of danger.

The warning may consist of a visual or audible signal or even of a supplementary resistance to the control stick, which the pilot can readily perceive. Many such devices have been proposed. A thorough investigation of their functioning is certainly worth undertaking. Independently of warning devices, there have long been installed on airplanes many instruments

whose indications suffice to prevent a pilot who knows how to interpret them, from going into an involuntary stall. Such are the air-speed indicators, turn indicators and even inclinometers.

The chief objection which pilots make to the use of these instruments, is the time required to consult them, to compare the readings of the different instruments and, lastly, to deduce the maneuvers to be attempted. Of course the pilot, when in difficulty, has much to do and can afford to lose no time. On the other hand, multiplying the indications does not always render them easier to interpret. With these reservations, the prejudice of many pilots with respect to the instruments, is certainly exaggerated. In particular, the methodical observation of the air-speed indicator is susceptible of rendering very great service in taking off and in landing. The recent transatlantic flight of Commander Byrd is a striking example of the advantages resulting from the methodical use of instruments of control. The airplane had to be navigated for more than six consecutive hours in a dense fog with no external visibility. In the opinion of the crew, the dangers of stalling and of flying in an abnormal position to which the atmospheric conditions exposed them, could not have been overcome without constant observation of the instruments.

Thus far it has been assumed that the pilot has possession of all his physical and intellectual powers. Otherwise, the risks incurred would be tremendously increased. Hence all means for lessening the fatigue of the pilot and the consequences of even

a temporary indisposition are of very great importance. These means will now be considered.

Comfort - Maneuverability - Stability

Obviously the fatigue of the pilot will be lessened in proportion to the comforts of his post, namely, a large adjustable padded chair, instruments easily read and conveniently arranged, extensive views of the territory flown over, and complete protection against the violent current of air due to the speed of the airplane. The use of windows similar to those of airship cars or of Lindbergh's transatlantic airplane is important in this connection. The realization of these conditions presents no technical difficulty. It is only necessary for the constructor to understand their importance and give them the careful attention they deserve. Much improvement can and must be made in this respect.

The pilot's fatigue will likewise be less in proportion to the maneuverability and, in some degree, to the stability of his airplane. In other words, the airplane must, at the same time, be able to maintain steady flight, without appreciable exertion of the pilot, and to alter its altitude or direction without the application of excessive or prolonged force to the controls. The condition of performing evolutions without great effort presents no particular difficulty, at least for light or medium-weight airplanes. It is almost always possible to give to their

control surfaces the suitable area and balance. It is also important to see that the respective forces required for operating the rudder, elevator and ailerons are of the same order of magnitude. It is difficult, for example, to maneuver an airplane well, whose rudder and elevator work hard and whose ailerons work very easily.

Facility of evolution is more difficult to obtain for large airplanes with more than one engine and with a large carrying capacity, because the distribution of the mobile loads may vary sufficiently during the flight, or from one flight to another, to change the location of the center of gravity and the manageability of the airplane in altitude. In like manner power variations, especially if the engines are outside the central axis of the airplane, affect the manageability in direction. These disadvantages are generally remedied by making the vertical and horizontal stabilizers adjustable during flight. This method is entirely satisfactory when employed judiciously. Many accidents have happened, however, because the pilot had changed the adjustment of the stabilizers to meet certain exceptional flight conditions and failed to restore them to their original positions after these conditions had disappeared, thus profoundly disturbing the stability of the airplane. This further illustrates how important it is for the aviators to have a thorough knowledge of the principles governing the mechanics of flight. Thus far we have succeeded in controlling very powerful airplanes without

intermediary devices, but we will probably soon reach the limit, beyond which servo-motors will be necessary. Such airplanes have already been built, but their testing needs to be continued.

On passing from the facility of evolution to the stability in horizontal rectilinear flight, it is found that these qualities are partially opposed to one another. Moreover, stability in altitude is the most important and the most difficult to regulate (Grimault, XII. Cousin, V). If an airplane is too stable in horizontal flight, its movements of recovery are difficult and its behavior is bad in rough weather. If, on the contrary, the stability is relatively poor, the pilot must be constantly regulating it and it is at the mercy of any inattention or wrong maneuver. In order to obviate these disadvantages, recourse must be had to stabilizers capable of automatically keeping the airplane at an altitude determined by the pilot. Such stabilizers exist and function, notwithstanding their relative complexity. Their investigation and use should be encouraged. Finally, stability in normal flight should not be sacrificed to maneuverability, as is sometimes done. The stability should be marked, although not excessive.

We still have to consider what measures can be taken to reduce to a minimum the danger resulting from a momentary failure of the pilot. We have already seen the advantages in this regard of a dual control, enabling the management of the airplane to be transferred at any instant, without interruption, from one

pilot to another. Many recent flights in which the pilot was either injured or thrown overboard and where the passengers were able to escape death only by operating the controls, somehow or other, confirm the desirability of the dual control. It should therefore be made obligatory on all airplanes designed to carry more than one person.

It may happen, however, even with a dual control, that the pilot momentarily loses control of the airplane, which then assumes a dangerous position. A serious accident is then imminent, if the pilot does not regain control quickly enough. It is therefore very desirable for an airplane to be so constructed that, when abandoned in any position of flight, it will tend to resume its normal flight position without the aid of the controls. It is desirable, moreover, for the airplane to be stable not only in horizontal flight at normal power, but also under the various flight conditions encountered, according to the speed of its engines, down to and including gliding flight. Experience proves that these conditions are realizable because there are already many airplanes capable of flying several minutes with no one at the controls and of thus modifying their flight position without abnormal movements according to the variations in the speed of their engines (Program of the Guggenheim Fund contest).

All these considerations demonstrate the importance of the researches regarding the stability of airplanes at various

speeds. These researches require the combined application of theoretical calculations, wind-tunnel experiments and flight tests. It is highly desirable for the investigators to continue their researches in this direction, since an important part of the possible progress depends on their eventual success. A contest of essays on this important question has just been organized by the "Comité français de propagande pour l'Aéronautique."

In the same order of ideas, the technical descriptions, which should furnish the users of each type of airplane with all the necessary information, should be much more explicit regarding the stability at the various engine speeds and for the various loads. The analogous information, furnished for ships in the form of curves or scales giving the longitudinal and transverse straightening moments, can serve as a model. The regulations now proposed by the "Commission Internationale de Navigation Aérienne" anticipate, moreover, the furnishing of documents of this nature which, by obliging constructors and inspectors to investigate thoroughly, for each type of airplane, the various elements affecting its stability, will surely help to elucidate the details of the problem.

(To be followed by Technical Memorandum No. 465 containing the translation of the rest of this article.)

Translation by Dwight M. Miner,
National Advisory Committee
for Aeronautics.

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