TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 465

DISCUSSION OF PROBLEMS RELATING TO THE SAFETY OF AVIATION

By J. Sabatier

PART II

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

Washington
May, 1928

1

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL MEMORANDUM NO. 465.

DISCUSSION OF PROBLEMS RELATING TO THE SAFETY OF AVIATION.*

By J. Sabatier.

PART II**

Structural Strength

The accidents attributed by the statistics to the cells and their accessories represent but a small fraction (6-7%) of the total. Their number should be reduced, however, to almost complete disappearance. In fact, the elements which share in the fatigue of the various parts of an airplane are relatively well known and there is no insurmountable difficulty in dimensioning the framework and accessories accordingly.

It is, of course, the "stunt" airplanes which pay the heaviest tribute to structural defects. It must not be forgotten, however, that, although ordinary airplanes are not expected to indulge voluntarily in acrobatic stunts, they may sometimes be forced to do so. Such is the case, for example, when an airplane dives suddenly in order to avoid stalling.

In order to solve, as a whole, the problem of the minimum strength to be given the structural elements of airplanes, it

*"Examen d'Ensemble des Principaux Problèmes Concernant la Sécurité de la Navigation Aérienne," "Bulletin Technique" of the "Service Technique et Industriel de l'Aéronautique," June 18, 1927.
**For Part I, see N.A.C.A. Technical Memorandum No. 464.

is necessary:

1. To know, as exactly as possible, the stresses to which these elements would be subjected under the most unfavorable circumstances;

2. To know, as exactly as possible, the mechanical properties of the materials which receive these stresses;

3. To be sure that the fatigue or wear, resulting from long use, will not dangerously affect the magnitude of the stresses and the original strength of the new material.

The stresses, supported by the constituent elements of the airplane, vary greatly, not only from one type of construction to another, but even for one and the same airplane, according to the circumstances of flight and especially according to the accelerations produced by the more or less rapid evolutions. Nevertheless, all agree the three following cases are the most important ones to study (Various Reports, XVIII and XIX):

1. Flight at the extreme forward position of the center of pressure;
2. Flight at the maximum speed;
3. Vertical dive.

The first case corresponds to the maximum fatigue of the front wing spar; the second and third, to the fatigue of the rear spar and to the maximum stress of drag. The two latter give, in fact, interesting data on the fatigue of the front struts and spars when subjected to aerodynamic stresses directed downward.

The three principal cases must be supplemented by the study of several secondary cases, such as: inverted flight for stunt airplanes; flexure of the wings in landing, for airplanes a part of whose load is located in the cell; the dissymmetric result due to the action of the ailerons.

The study of the aerodynamic characteristics of an airplane gives accurately enough the magnitude of the direct stresses for each of the three typical cases. These stresses must be increased to make allowance for the overloading caused by the atmospheric disturbances and the forces of inertia developed in the evolutions. The values obtained are then multiplied by the factor of safety adopted for the type of airplane under consideration, which factor is generally 2-2.5.

Lastly, the stresses, which the various elements of the airplane must withstand before breaking, are found by multiplying the direct stresses by an inclusive factor, which is the load factor for the case under consideration. There has been much discussion concerning what values the load factors should have. If they are too high, the structure is too heavy and the efficiency of the airplane is impaired. If too low, failures are liable to occur during flight.

Finally, the determination of the load factors brings us back to the determination of the acceleration which the corresponding airplanes must withstand under the diverse circumstances of flight. These accelerations can be quite easily determined for a few typical airplanes, which has been done through several series of experiments undertaken in France and in other countries. It is not so important, however, to know the absolute values of the accelerations, as to know their variations according to the dimensions of the airplane, the area of its control surfaces and the energy with which the latter are put in operation. It is, in fact, necessary to determine with a fair degree of accuracy the accelerations which a projected airplane will have to support from the measurements of accelerations on a somewhat similar airplane. These measurements could be profitably supplemented by researches:

1. On the braking effect of the propellers, which plays an important part in determining the conditions of diving flight;

2. On the variations in the lift and drag for angles of attack attaining or exceeding the angle of zero lift (These variations are important to consider for diving, stunt flying and inverted flight);

3. On the distribution of the aerodynamic pressures along the chord for most of the wing sections actually used.

Regarding this distribution, it may be questioned as to whether the wing sections, which undergo large displacements of the center of pressure between the angle of maximum lift and the angle of zero lift, do not present serious disadvantages for the structural strength of the cell. These wing sections, in fact, almost exclusively load the front spar in flight at large angles, and the rear spar in flight at small angles. In the latter case, moreover, they sometimes develop downward stresses on the spar, which greatly fatigue the struts and their fittings. They render it necessary, therefore, to give each spar more strength than would be required if the displacements of the center of pressure were more moderate.

In addition to the cell, the fuselage and the tail planes, particular attention must be given the ailerons. Accidents to the latter are relatively frequent. It seems probable that the aerodynamic loads supported by the ailerons, when deflected downward in flying at small angles of attack, are much greater than is generally assumed and greater than the simple consideration of the lateral balancing couple would lead one to suppose. On the other hand, at high speeds, the ailerons sometimes develop vibrations so intense as to dislocate the rear portion of the wing and violently agitate the control stick. Many serious accidents have been caused by these vibrations and it would be very important to determine their true cause through methodical researches.

There is no occasion to renew here the discussions concerning the static breaking tests and their guaranties of safety, as compared with those of the strength calculations. So long as technical progress does not furnish more solid bases for structures as complex as those of airplanes, static tests will be the only ones capable of furnishing indisputable elements of valuation. Unfortunately, these tests are very costly and can not be made for each of the principal flight cases to be considered. They have to be limited to the most unfavorable case of fatigue, or to the one whose calculation will be the most hazardous. The importance given to static tests sometimes tempts constructors to base their calculations on the breaking strength, instead of on the elastic limit of the corresponding materials. This is regrettable because for aeronautic structures, as well as for all others, it is the passing beyond the limit of elasticity which marks the real beginning of danger. It is therefore desirable that, while deriving from the static tests the data they must furnish, the constructors should depend more, in their calculations, on the consideration of the proportionality limit of the deformations to the stresses.

It is not enough, however, for the tests and calculations relative to the original model to be satisfactory, but it is also necessary to be assured that the quantity-produced airplanes will have the same guaranties as the model from which they are derived. It is possible to have such guaranties only when the quality of the materials used remains as good and when they are fashioned with equal care.

The general adoption of metal for the framework of airplanes constitutes real progress. It would be better, however, for the methods, employed in different countries for verifying the quality of the metallurgical products, to be more uniform and to enable more accurate comparisons. The adoption of a standard test piece in the different countries would be particularly desirable (Reports to the C.I.N.A., XX). Moreover, the researches undertaken in the different countries for improving the properties of the light alloys and for rendering them more immune to moist or salt air, should be continued.

Lastly, aeronautic structures are still too fragile and delicate to leave them free to develop without any safety control, as regards their execution and their aging in service. Every control or restriction disturbs and retards. The control must therefore be reduced to a very strict minimum, but it would be no favor to aeronautics to allow accidents to happen, as this would be disastrous for the advertising. It is better to require both constructors and users to adopt a few indispensable safety measures. There is nothing more demoralizing for pilots and more destructive of public confidence than the failure of an airplane cell in flight, because it is without recourse.

Defects in the Functioning of the Engines

Next to errors in piloting, these cause the most accidents, representing, in fact, 20 to 25% of all the cases confirmed. Nevertheless, accidents due to engine defects are, on the average, less serious than those due to other causes. This is because an engine rarely fails instantaneously, so that the pilot often has time to take measures for lessening the seriousness of the results.

A tabulation, covering 1570 cases of engine failure in French military and maritime aviation, shows about

285	cases	or	18%	involving	the	fuel system,
260	"	"	17	"	"	ignition,
230	"	"	15	"	"	installation,
215	"	"	14	"	"	distribution,
200	"	"	13	"	"	cooling system,
160	"	"	10	"	"	lubrication,
115	"	"	7	"	"	carburetion,
105	"	"	6	"	"	other or indeterminate causes.

The above cases did not all cause accidents. The relative seriousness of their consequences varied considerably from one line to another. Nevertheless, it is possible to draw the following general conclusions. The accidents involving the installation often originate in defective lubrication, which is more or less easily detected. We are thus led to conclude that failures ascribable to defective lubrication have a percentage almost as high as those connected with the fuel system, or about 20%. Aside from the two preceding defects (which together make about 40%), failures of the carburetion and distribution are the most important, not only because of their still high rate (21% together), but also because of the fire hazards entailed. On the other hand, the defects of the fuel and cooling systems, of the lubrication and, to some extent, of the carburetion, which all together constitute nearly half the cases, are generally due themselves to a poor design or to insufficient attention to the pipes and their connections. Lastly, the importance of the good functioning of the engine accessories (fuel pumps, magnetos, spark plugs, radiators and carburetors) is demonstrated by the high percentage of the failures which involve them more or less directly (fuel system, ignition, cooling system, carburetion).

The frequency of these failures can be reduced (Martinot-Lagarde, XIV. - Brunat, II, III, IV): by improving the endurance of the engines themselves; by a better installation of the pipes and accessories; by facilitating the inspection and repairs on board; and lastly, by dividing the power plant so that failures will remain partial instead of affecting all the available power.

The endurance of the engines has been undeniably increased during the last ten years, but it can and must be still further increased. The prescribed acceptance tests which are now 50 hours, should be gradually increased to 100 hours, if not to 150 hours. Moreover, the tolerances which are still allowed during these tests for injuries, or the replacement of secondary parts, should be gradually reduced in number and quality. These results can probably be attained by the gradual improvement of the details, rather than by important innovations.

It is not possible to enumerate here all the points which should receive attention. The following, however, are specially important:

Very careful supervision of the quantity and of the treatment of the metals used. Both the constructor and the user must be sure that the engine parts, which are subject to very severe stresses, have the requisite characteristics. Uniformity of the quality is almost preferable to its absolute value.

Improvement of the lubrication.- The use of oil radiators and purifiers and, if necessary, of two oil pumps, is especially recommended.

Heating the carburetors.- It is important for the carburetion not to be disturbed by the modifications of the atmosphere and especially by sudden changes in temperature or humidity. These disadvantages can be avoided by suitably heating the intake air. It is best to resort as little as possible to the exhaust gases for this purpose, because of the fire hazards when inadequate precautions are taken. It is better to do the heating with the water or oil circulation.

Thorough cooling of the valves, especially of the exhaust valve and increasing the durability of the valve springs.

Reference has already been made to the large number of engine failures due to defects in the connections, pipes and accessories. It is necessary, at any cost, to improve their installation and functioning. This point cannot be too strongly emphasized for the safety of aviation. The pipes and accessories are the intermediate parts between the cell and the engine, so that they are often unfortunately neglected by the constructors of both, each specialist leaving their installation to his colleagues.

It is difficult to make the pipes perfectly tight and yet sufficiently flexible to withstand the vibrations of the engine. The shorter the pipes and the fewer the connections, the easier it is to obtain tightness. On the contrary, the need of withstanding the vibrations leads to the consideration of sinuous pipes interrupted from place to place by elastic connections. In order to be sufficiently flexible, these connections consist of rubber tubes, which age rapidly and which are quickly impaired by the gasoline. The particles from the disintegration of these connections stop the pipes, filters and spraying nozzles and cause a large proportion of the failures in the alimentation and carburetion. Many failures are also caused by leaks due to defective joints.

There are two ways to avoid these disadvantages. The first consists in very carefully designing the principal fuel pipes in advance instead of applying them, hit or miss, after the engine is completed. This method would often render it possible to lessen the number of joints, while leaving the pipes with sufficient flexibility. The second way consists in making the necessary connections flexible without the use of rubber or, if rubber is used, in protecting it from all direct contact with the gasoline. Various devices, utilizing accordion-plaited tubes or metallic linings, or goldbeater's skin, have been tried. These should be tested on a larger scale (A contest is now open in France, under the auspices of the "Comité de Propagande," for the invention of flexible joints for gasoline pipes).

Among the engine accessories, whose functioning should be improved, are the fuel pumps, magnetos and spark plugs. It would be very useful to make, as far as possible for each type of engine, standard models of these accessories and avoid changing them afterwards.

In order to save trouble and the need of carrying so large stocks, the air services, both civil and military, try to make the various accessories interchangeable between different engine types. Without wishing to completely eliminate this procedure, which rests on a legitimate economical conception, it may be said that the disadvantages entailed by its too general adoption more than offset its possible advantages. In principle, the accessories with which the engine should continue to be provided are the ones with which it made its official endurance tests, and these accessories should be installed during the tests, under the same conditions as they are to be used in service.

Of course the power and the rotational speed for which the engine is tested in the factory, should never be exceeded in service. This is so obvious that it would seem needless to proclaim it if experience had not demonstrated the infractions to which it is exposed. Such infractions are particularly dangerous with supercharged engines. These engines are not designed to function at full intake at sea level and can support full intake without abnormal fatigue only at the altitude corresponding to the equivalent power. The pilot who exceeds, on the ground, the authorized intake limit, in order to facilitate the take-off or to accelerate the climb, runs the risk of a serious accident. Automatic intake controls (Dorand, IX) and recording instruments making it possible to control constantly the R.P.M. developed during flight, are capable of rendering valuable service by preventing the pilots from committing such errors.

The measures to be taken to improve the conditions of upkeep and of speed of the engine-propeller groups, vary too much on different airplane types for them to be determined in advance. Two general methods can be recommended, however. The first consists in mounting each group, complete with all its accessories, on a removable engine bed. In order to make any important repairs or replace the engine, the whole assembly is removed from the airplane. This operation requires only a few minutes and renders it possible to make all the necessary changes under the best conditions. Many constructors have adopted this type of mount, which should become more general. The second method consists in providing an engine room on the airplane, where the mechanic can remain and from which he can have access to the principal organs of the engine groups. This room is particularly easy to provide when the engines are arranged in tandem with sufficient space between them for the engine room.

The question of dividing the power remains to be considered. There has been much discussion on the advantages and disadvantages of multi-engine airplanes and on the number of independent groups which it is best to adopt. The first idea to present itself is that an injury to an engine group will be less dangerous in proportion to the smallness of the fraction of the total power represented by the group. The most favorable case, from this viewpoint, is the one in which horizontal flight can be maintained with one engine stopped. If horizontal flight, under these conditions, is possible only by lightening the airplane of a portion of the fuel, arrangements should be made to effect this as instantaneously as possible, so as to reduce the loss in altitude corresponding to the intervening time. If the loss in power is too great for the flight to remain horizontal, the airplane can still utilize the remaining power to prolong its flight and thus have a larger region in which to select a landing place, thus greatly increasing the chances of a safe landing.

It remains to consider whether increasing the number of engines does not also increase the chances of engine trouble in a proportion to offset, or more than offset, the abovementioned advantages. The statistics, analyzed above, show the high percentage ascribable to the engine accessories and to the piping. The failures from these causes are naturally increased by increasing the number of the engines. If the pipes and accessories are arranged so as to serve several independent groups, there is danger that any injury to the common parts may simultaneously paralyze all the available power and thus eliminate the very advantages it is desired to obtain. On the other hand, the division of the power does not diminish the fire hazards, but rather increases them, because it increases the number of the tanks and fuel pipes and scatters them more widely, and because it increases the number of carburetors and the consequent possibilities of backfiring. Lastly, it makes more work for the pilot, when his airplane is in difficulty, to maneuver four or five engines simultaneously and to stop them all in time, when necessitated by a forced landing or the breaking out of a fire.

The conclusions drawn from these opposing arguments are that the multi-engine airplanes afford incontestable guaranties against stalls and forced landings, but that these advantages are offset by risks of another nature, which have to be combatted in their turn. Among the principal precautions which enable this, are the following:

To limit the division of the power to three groups at the most. As long as the state of the art does not enable a more complete decentralization of the engine control and the transfer of an important part of it to the mechanic, there is danger that a larger number of engines would make it impossible for the pilot to watch them during flight and would overburden him in making the necessary maneuvers.

To obtain, on the contrary, the complete independence of each group and of all its accessories, including tanks, with respect to the other groups.

To arrange the controls in as clear a manner and as well grouped as possible. To provide a single maneuver to stop all the engines simultaneously in case of accident.

To give special attention to the arrangement of the fuel tanks and pipes. Oversights, which would be of no great consequence on single-engine airplanes, become dangerous on multi-engine airplanes, through the development and dispersion of these accessories.

To take all possible precautions against fire.

It was probably due to the neglect of all or of some of these precautions that several large multi-engine airplanes had serious accidents in 1926.

Precautions against Fire

We have just seen the increasing importance which the use of multi-engine airplanes gives to precautions against fire. The instantaneous violence of the fire, the frequent inadequacy of the means for fighting it and its destructiveness contribute to make the danger of fire one of the chief obstacles to the development of aviation. Fire may break out either during flight or on the ground. In the latter case, it may occur either during take-offs or normal landings or after a landing accident. Fires on the ground, during normal maneuvers, are more frequent than is generally supposed. In 1925-1926 there were two or three such fires a month, all due to back-firing to the carburetor. Damages resulted, however, from only 10% of the cases. The fire was almost always overcome by extinguishers, kept on board or on the field. Fires on the ground or during ordinary maneuvers are of no special interest to consider here, excepting so far as they furnish information concerning the causes of the fire and the means of fighting it. Such fires should be completely eliminated by locating the openings of the air intake pipes clearly outside the cowling and by keeping the engine compartments free from deposits of fuel and oil.

The analysis of fifteen recent fires in military aviation, during flight, show:

3 due to back-firing,

4 " " leaks or breaks in the pipes,

3 due to injuries to the engine parts,

5 " " unknown causes.

The causes of ten recent fires in civil aviation, during flight, were:

7 failures of engine parts,

1 break in pipe,

2 not determined.

In military aviation there are relatively more cases due to back-firing without previous injury to engine than in civil aviation. These cases are similar to the abovementioned fires on the ground and should be eliminated by the precautions indicated for the latter.

Except the back-firing, the causes in the above two categories are the same, although in different proportions, namely, injuries to the engine parts and leakage of the pipes. The large proportion of injuries to the engines, in civil aviation, is explained by the fact that the civil cases of fire extend over several years, while the military cases cover a much shorter period. The above 25 fires during flight caused the destruction of 18 airplanes (72%) and four deaths (16%).

For the same periods, the statistics show 27 fires on the ground after landing accidents. These 27 cases caused the destruction of 26 of the 27 airplanes with 14 deaths (54%). It is obvious that, although the ground fires after accidents are hardly more frequent than fires during flight, they are much more serious both for the personnel and for the materiel. The causes of these 27 cases were as follows:

Capsizing and landing on the nose	4
Stalls, etc., generally preceded by injury to engine .	16
Collision with an obstacle	3
Miscellaneous	4

Capsizings and collisions caused nearly a fourth of the most serious fires. We have already seen they can be avoided (better education of the pilots, maneuverability of the airplanes and better airports), so that it is not necessary to revert to them here. Every measure increasing the reliability of the engines and their accessories will reduce the number and gravity of the fires, since forced landings are almost always caused by injuries to these organs.

But, however efficacious such measures may be, they can only reduce the frequency of engine troubles, without entirely eliminating them. The investigation of precautions to be taken against fire is therefore more necessary than ever. It is sufficient, moreover, to limit the investigation to the case of a forced landing after an injury to the engine, not only because this is the most dangerous case, but because it is the most difficult one to combat, by reason of the dislocations entailed in the gasoline or electric conduits, in the fuel tanks and throughout the whole airplane.

It is in this connection that a remarkable series of experiments has been undertaken in the United States during the past few years. Old airplanes, with their engines running, have been launched on an inclined plane, at the end of which there was a wall against which the airplanes crashed. Thanks to this device and to the numerous motion pictures* taken during the tests, it has been possible to observe the development of many fires. The principal conclusions, deduced from these experiments by the American authorities, are as follows:

"The tanks should be capable of being cast off. They should be separated from the engine by a fire wall. In so far as avoidable the tanks should not be placed directly behind and above the engine, so as not to incur the risk of their being broken by the force of the landing shock and spilling their contents on the hot parts of the engine.

"Three-fourths of the fires, after the crash, are attributable to the heating of the exhaust pipes, and the fire hazard is greater in proportion to the length of these pipes. It is advisable therefore, to test with care every new exhaust device; in particular to run the engine at reduced intake and slight advance, so as to heat the exhaust pipe to the maximum; to make several injections of gasoline and of oil into the proper pipes and to make sure that no combustion results.

"Lastly, great precautions must be taken for isolating the ignition conduits and the gasoline and oil pipes. The attach-

*These pictures, obligingly lent by the military attaché of the United States in France, were shown, at the beginning of 1927, to the Société de Navigation Aérienne," and to the "Service Technique de l'Aéronautique."

ments of the latter must be disposed in such a manner that, in case of shock, a slight displacement of the pipe with respect to the cowling shall be possible, without break or leak. In every way, the gasoline and oil should be prevented from coming in contact with the electric wires or with the hot parts of the engine."

In these conclusions, we find most of the precautions actually required in France. The test with the exhaust pipe, which which is not customary in France, would be worth trying, though it may be questioned as to whether the conclusion relative to the preponderant role played by the exhaust in ground fires, is generally applicable, or whether it is not rather due to the particular conditions of the American experiments.

In these experiments, the airplane crashed against a wall, after a run at low speed. The exhaust pipe was therefore poorly cooled. On the other hand, the ignition remained on, while the propeller stopped immediately on striking the wall. On the contrary, in the case of an ordinary fall, the pilot generally has time to switch off the ignition, and the propeller makes a few more revolutions before stopping. The exhaust gases are thus expelled into the atmosphere and the hot portions of the valves and pipes may cool so as to be no longer incandescent. In the American experiments, there was no time for the gases to be expelled, the incandescent parts remained so and, when the gasoline left the tanks, it was vaporized in the atmosphere, came in contact with the incandescent parts and ignited in a body. The pictures of the experiments show this phenomenon very clearly. Lastly, the airplanes tested had only single exhaust pipes of various lengths, without mufflers or spark screens. The use of these devices, properly installed, would reduce the fire hazard, even on the ground. At any rate, there are plenty of fires, both in flight and on the ground, on airplanes without exhaust pipes, to demonstrate the need of seeking other remedies than the improvement or removal of these accessories.

For the gasoline to ignite and produce a general conflagration, there must be a combination of two circumstances, namely, an injury or leak of some pipe or accessory, scattering the gasoline outside, where it vaporizes, and the ignition of the carbureted air by contact with a spark or with a red-hot part of the engine.

In the case of back-firing, the explosive mixture is not due to a fuel leak, but consists of the carbureted air contained in the cylinders and intake pipes. Due to some defect in the fuel system or in the functioning of the engine, this mixture comes in contact with the spark from a spark plug while the intake valves are still open. The flames thus produced are propagated to the carburetor and thence to the air intakes and the rest of the airplane.

The analysis of these phenomena indicates the following remedies. The carburetor air-intake pipes should extend far enough outside the fuselage, so that the flames produced by back-firing cannot come in contact with any combustible substance. It is generally much better for the air-intake pipes to open at the side of, rather than underneath the engine, so that any gasoline, leaking from the pipes, cannot encounter the hot gases of the back-fire. Lastly, the use of special valves or devices can help to reduce the frequency or the violence of the back-fires themselves.

Although it is relatively easy to prevent fuel leaks in normal flight, it is much more difficult to avoid them in case of serious injury to the engine or in case of a hard landing. Leaks, without ruptures, especially at the joints or connections, are then almost inevitable. They can be reduced by several precautions, including the following ones: Dimension the attachments of the pipes to the fuselage so that the attachments will always break before the pipes themselves; make the attachments sufficiently flexible, so that the pipes held by them can shift or bend appreciably before any break occurs; use copper tubing, rather than duralumin, because the former metal is more flexible and less brittle than the latter.

Above all, it is important to prevent any escaping gasoline from coming in contact with hot parts of the engine. The engine and its principal accessories should therefore be separated from all fuel and oil tanks of any considerable capacity. This wall must be impervious to gasoline and to the flames. It must not only be complete transversely, but it should be extended along each side of the fuselage far enough so the flames issuing from the engine cannot get around it and carry the fire to the rest of the airplane. Of course, the fuel and oil pipes must be provided with quick-action stopcocks outside the fire wall.

If all airplanes had fire walls satisfying the above conditions, probably most of the fires during flight would be prevented and ground fires after hard landings would be less numerous. There are two cases, however, where the efficacy of this device will remain uncertain. The first case is when the engine, driven violently backward in landing, rams the fire wall and shatters it more or less completely. The other case is when the fuel tanks are too near the fire wall and are not fastened securely enough to the fuselage. The attachments then give way, when the airplane lands on its nose, and the tanks are hurled against the fire wall and burst, spilling their contents. In order to combat this double danger, the fire wall must be made as strong as possible, so that it will remain intact, even under a violent shock. This method is limited, however, by the question of weight. The safety may be increased by leaving a distance of 15-20 cm (6-8 in.) between the fire wall and the rear end of the engine, on the one hand, and between the same wall and the fuel tanks, on the other hand. At any rate, the tank attachments should be calculated to withstand the longitudinal stresses of inertia produced by landing on the nose. Lastly, although the presence of the fire wall is a great safeguard, it is preferable for the fuel tanks to be placed outside the axis of the engine, so they will not be directly exposed to being rammed by the latter, in the case of telescoping.

Other precautions to be taken are as follows: thorough ventilation of all places where gasoline vapors can accumulate; direct drainage, to the outside of the airplane, of all drippings of fuel and oil; adoption of special devices to prevent the fuel from spilling out through the orifices for the admission of air, in the event of a sudden motion of the airplane; use of protecting flanges for the ignitiom wires, which, coupled with the above-mentioned precautions for the protection of the electric conductors, will prevent short-circuiting and sparks.

We have just enumerated the precautions against fire. These must be supplemented by means for combatting fires after they have started. These means are of two kinds, one of which consists in getting rid of the fuel as quickly as possible, so it cannot feed the fire. The other consists in using fire extinguishers.

Dropping the fuel tanks meets the first of these requirements. This is often done on military airplanes where, in addition to the ordinary fire hazards, there is the danger from the incendiary bullets used by the enemy. It remains to be seen whether commercial airplanes, in times of peace, will be always allowed, evèn in case of immediate danger, to release several hundred kilograms of inflammable liquid wherever they may happen to be. Aside from this disadvantage, it is not always possible to install, under good conditions, tanks which can be dropped. It has been proposed to substitute for them a device for the rapid emptying of the tanks. Experience has shown, however, that the shower of gasoline (which is very difficult to direct outside the zone of danger for the airplane) incurs serious risks. We can therefore only indicate the dropping of the tanks as being very desirable, without making it mandatory. It may, for example, be assumed that if the tanks are far enough from the engines to make the flames traverse a large portion of the airplane before reaching them, it is of no real importance to drop them during flight.

As to fire extinguishers on board, their efficacy cannot be doubted. French statistics show that, two times in three, their use extinguishes the fire or greatly retards its progress. Every airplane should have at least one fixed extinguisher installed in the engine group. On large airplanes this should be supplemented by one or more portable extinguishers. Moreover, the fixed extinguisher should be provided with an automatic fire alarm for warning the pilot, as soon as the temperature near the engine comes abnormal, so that the fire cannot be smoldering without his knowledge, only to burst forth later with a violence impossible to overcome.

An alarm which allows the pilot to decide when to use the extinguisher, is preferable to an automatic extinguisher, which is often heavy and complicated and which is liable to function at the wrong time. In any case, the pilot should be able to stop the extinguisher as soon as he thinks best. He may need to do so, because the emitted vapors become dangerous, or in order to reserve some of the liquid for use in the event of another fire. Since the extinguisher attacks the effect without always destroying the original cause, it is not surprising that the fire, after being extinguished, starts again of itself. In such an event the pilot is left without protection, if his reserve of liquid has been imprudently exhausted.

It may be remarked that the action of the extinguisher is more effective in an inclosed space. From this point of view, well-cowled engines are safer than engines left uncovered for observation or cooling. Lastly, extinguishers have been much criticised for the relative toxicity of the substances used. This can be restricted, however, by certain precautions and is more than offset by the increase in safety.

Thus far we have assumed that the engines were supplied with ordinary fuel. It is obvious that the safety would be considerably increased by the use of a less volatile fuel. Many researches have been undertaken in different countries, either in the hope of inventing new aviation engines capable of burning existing heavy fuels, or of inventing new fuels capable of being used in existing engines. These researches have not yet met with industrial success. Engines, of the Diesel or other types, capable of using heavy fuels, now have too great a weight per horsepower for their use in aviation to be anticipated very soon. It is hoped, however, that further progress will eventually render it possible.

As to so-called "safety" aviation fuels (Dumanois, X), great hopes have been based on them. Inventors and scientists have proposed several, whose first tests were encouraging. It is often far, however, from the preparation of a few liters of a new liquid in the laboratory to the industrial production of a stable homogeneous fuel of uniform quality. Assuming that these difficulties will be overcome and that the product will be comparable with gasoline, as to power, price and quality of conservation, its use will necessitate a reinvestigation of all the factors of the problem of carburetion. It is only necessary to recall the long researches required for perfecting the carburetors now used for aviation gasoline, in order to comprehend the new difficulties presented. These difficulties should not discourage investigators, however, though it is well to recognize and take account of them in the interest of further improvements it is hoped to make.

Accessory Installations Affecting Safety

We have just reviewed the accidents attributable to the pilots, to the cells and to the engines. These accidents are about 80% of the total number. The remaining 20% include a certain number of cases whose causes were not definitely determined and which, if better known, would doubtless increase the above proportion. There still remain, however, about 10% of the accidents, whose causes are different and must be fought by other means than the ones we have just been considering.

A better knowledge of meteorology and a more rapid and accurate forecasting of the weather will diminish the accidents due to inclemencies. These improvements are all the more urgent because nonstop flights are increasing in frequency and length and cover regions whose atmospheric conditions are more varied. Among the inclemencies, there are few more feared by aviators than fog or even low clouds. This is because, despite the use of special instruments, flight in fog or clouds is difficult and the landing dangerous. Low clouds, moreover, tempt pilots to fly close to the ground and too near to obstacles. A good sounder, enabling the aviators to measure with precision the distance between the airplane and the ground rendered invisible by fog, would be of great service.*

The radio, by rendering it possible to keep continually in touch with the ground and to call for help in case of need, is an indispensable instrument for long voyages. Lastly, the various processes of radiogoniometry, tall beacons and signalling devices all contribute to the common cause by reducing the errors of navigation and easing the task of the pilot. Unfortunately, many of these methods require, on the part of those who use them,

*A contest for such sounders, endowed with large prizes, has been recently inaugurated by the "Comité de Propagande pour l'Aéronautique."

a technical knowledge which is relatively rare and which therefore limits their possibilities.

It remains to consider the question of parachutes (Mazer, XV). These have saved life too often for their efficacy to be denied. They should be obligatory on all airplanes whose occupants know how to make use of them. It is desirable, moreover, for the parachutes to have a double releasing device, i.e., so they can be opened at will by a motion of the passenger or by means of a cord attached to the fuselage. The only reservation that can be made concerns their adoption on public passenger airplanes. The passengers on these airplanes are many and they are inclosed in the fuselages from which they cannot escape quickly. They are ignorant of the necessary precautions for the parachute and the harness, both in launching and in landing. Under these conditions, it is to be feared that an order given the passengers by the pilot to jump overboard with their parachutes would only create a panic and would cause accidents at least as serious as the ones it is desired to avoid. Commercial aviation companies do not provide parachutes for the passengers and it can hardly be required of them to do so at present. Perhaps this problem will sometime be solved by the use of a detachable cabin provided with a parachute similar to the basket parachutes for captive balloons, but nothing practical has yet been invented in this line.

Conclusions and Summary

We have considered in rapid review the principal problems relating to the safety of aerial navigation and have seen how varied, numerous and complex these problems are. Their solution is facilitated, however, by the endeavor to understand them better. For each particular problem, we have indicated its present status and the direction in which researches should be made. The following points seem to be the ones most in need of serious attention:

Raising the standards for the education of pilots; creation of a special school of aerial navigation;

Improvement of the maneuverability of airplanes at very low speeds;

Increasing the speed range;

Methodical use of instruments to avoid stalls; warning devices;

Methodical investigation of flight stability for various loads and engine speeds; flight without using the controls;

Extension of the dual control; increasing the comfort of the pilots' posts;

Experimental measurements of the stresses sustained in flight by the various airplane parts, especially by the ailerons;

Methodical improvement of the conditions of functioning and of installation of the engine accessories;

Stronger, more flexible and better installed pipes and connections;

General adoption of removable engine beds;

Improvement of multi-engine installations;

Development and strengthening of the fire walls;

Thorough investigation of the best relative positions to give the fuel tanks and engines, with the necessary precautions to be observed in each case;

Methodical development of fire extinguishers and alarms;

Research on the use of safety fuels.

From now on, these problems will be the objects of intensive research in most countries. All technicians know that the future of aviation depends on their gradual solution.

B i b l i o g r a p h y

Bramson .... Technique Aéronautique, No. 65, March, 1927. "Sur la perte de vitesse."

Brunat.......... Technique Aéronautique, (No. 55, May, 1926.
(On safety in general) (" 56, June, 1926.
N.A.C.A. T.M. 438 (" 63, Jan., 1927.

Cousin .... Technique Aéronautique, No. 64, Feb., 1927. "Qualités de maniabilité des avions." (Lecture of April 6, 1927.)

Devaluez .... Technique Aéronautique, No. 39, Jan., 1925. "Recrutement du personnel navigant." Report No. 3 to the Commission permanente d'Études Aéronautiques," Jan. 14, 1925.

Dorand .... Technique Aéronautique, No. 67, May, 1927. "Limiteurs automatiques d'admission."

Bibliography (Cont.)

Dumanois .... Technique Aéronautique, No. 66, April, 1927. "Combustibles de sécurité" (N.A.C.A. T.M. 451).

Franck .... Technique Aéronautique, No. 67, May, 1927. "Méthodes de navigation."

Grimault .... Technique Aéronautique, No. 64, Feb., 1927. "Sur la stabilité."

Lepere .... Report to the Commission d'Aviation de l'Aéro-Club, Dec., 1926. "Sur la perte de vitesse."

Martinot-Lagarde..Technique Aéronautique, Nos. 65 and 66, March and April, 1927. "Moto-propulseurs."

Mazer .... Technique Aéronautique, No. 65, March, 1927. "Les engins de sauvetage."

Ramat .... Technique Aéronautique, No. 64, Feb., 1927. "Sur les Écoles de Mécaniciens."
Report No. 5 to the Commission permanente d'Études Aéronautiques, May, 1926. "Servitudes à imposer au voisinage des aérodromes."
Report No. 4 to the Commission permanente d'Études Aéronautiques, "Conditions de fatigue des avions en vol."
Reports of the "Sous-Commission d'Exploitation et du Matériel de la C.I.N.A.," "Règles de calcul et d'essai des cellules."
Ditto, "Unification des méthodes d'essai des matériaux."

Verdurand .... Technique Aéronautique, No. 60, Oct., 1926. "Nécessité d'une école de Navigateurs Aériens."

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