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SAFETY IN AIRPLANE FLIGHT

By H. Brunat

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By devoting its first sessions to the investigation of suitable means for increasing the safety of airplane flight, the "Societe Francaise de Navigation Aerienne" emphasized the importance of this question. This is the first time that technical men belonging to all lines of aviation have met to exchange their views on safety and discuss the results of their studies, observations, and experiments. This cooperation will enable all the aspects of the problem of safety to be investigated as completely as can be done at the present time.

The present report is intended to give an accurate idea of each of the problems arising from accidents. In this report I shall repeat certain statements which I have already made in previous reports. I apologize for this repetition, although I believe it is useful, since all the profit has not yet been derived from the lessons taught by experience.

*Communication by H. Brunat of the "Service de la Navigation Aérienne" to the "Société Francaise de Navigation Aérienne," November 10, 1926.

Enlistment and Training of Aviators

It was pointed out at one of the earlier conferences, held in this place, that 54% of the accidents in French aviation (civil, military, naval and colonial), were due to professional and piloting errors. These accidents are extremely grave, being the cause of 62% of the deaths and 63% of the injuries in aviation. Professional and piloting faults result from errors of judgment which in most cases are due to a lack of general and technical knowledge.

Although the development in aeronautical construction is marked every year by the creation of swifter aircraft which carry heavier loads and have a longer radius of action, thus calling for a steadily increasing professional knowledge on the part of the crew, the methods of enlisting pilots have not changed since the end of the war. Upon close examination, it appears that the previous instruction of most of our student pilots has been quite inadequate, so that they are unable to acquire the necessary professional and technical knowledge for safely piloting modern aircraft, particularly commercial airplanes and seaplanes.

In my opinion, the best way to improve this state of affairs would consist in starting a campaign, exclusively among young men having a thorough general education (college students and pupils of high schools), for enlisting student pilots. Attempts have already been made along this line, but without much success. This failure is probably due to a bad method. Students were expected to take up work at aviation schools, thereby almost entirely abandoning their regular studies. This plan was naturally opposed by their families.

Still the interests of all concerned could be easily provided for. Instead of having flying schools scattered aimlessly all over the country, they should be concentrated in the vicinity of university towns. The students should not be expected to abandon their studies, but the aviation courses should be so arranged that they can be attended by students during their free time. In case of necessity, agreements could probably be made with the universities for changing the hours of certain lectures. The training of students enrolled under such conditions would necessitate a longer period of instruction which, however, should not exceed a year. I do not believe there is any serious objection to such a method of recruiting, which would provide high-grade aviators capable of receiving the special technical instruction required for air navigation. In order to make sure that the application of the above method of enlistment will result in an increase of safety, an adequate training method for pilots should be worked out and standardized in our schools. This would require the education of special licensed pilot trainers. In addition to being an excellent pilot, the trainer must also be a good teacher.

Likewise the training airplanes must be adapted to school purposes. These airplanes should be adapted to all conditions of flight, in order to give the trainer a chance to show the pupil, without danger, the maneuvers required to correct a spin, to regain lost speed and to land from different altitudes and different directions with regard to the landing field. Of course the student should be trained on intermediate airplane types, before piloting the airplane which he is expected to fly in regular service, when he should again familiarize himself with all the maneuvers mentioned above.

Suitable methods of recruiting and training pilots should produce a considerable reduction in the number of accidents. But this alone would not provide our air force with the number of commanders and long-distance pilots which it is now beginning to need and which will be absolutely necessary in the near future, as soon as we possess airplanes of greater capacity and longer radius of action.

We are in urgent need of a high school for aviators. Unless such a school is created within the near future, we may not have enough trained aviators with sufficient experience for piloting our large civil, military, and naval airplanes. Difficulties are already being encountered by civil aviation in securing the requisite personnel. The idea of this school is not new. In 1924, following a communication from Mr. Devaluez, the "Société Francaise de Navigation Aérienne" considered this question. It consulted the air transportation companies and leading men of the aeronautical world, who seemed to regard the idea with particular interest. Mr. Laurent Eynac, who was then Under-Secretary of State for Aeronautics and Air Transportation favored the idea. The matter was dropped, however, and must now be taken up again on an entirely new basis. An especial effort must also be made as regards mechanics.

The only schools, which at the present time have an excellent organization, are those which train mechanics for military aviation. The apprenticeship of young soldiers of around twenty years of age, who work as mechanics, does not exceed one year. This period is obviously too short to make expert mechanics. This view is justified by the difficulties encountered by air transportation companies in securing competent mechanics, although there is no lack of candidates.

In many instances engine troubles during flight are due to lack of watchfulness by the mechanics. They are the cause of approximately 5% of the deaths and 19% of the injuries in aviation, in addition to important material losses. It is manifest that the number of accidents would be reduced and human lives saved, if the air services had better-trained mechanics. In my opinion the trouble with the present system is that a military mechanic is prevented from being promoted to a higher rank which would enable him to earn a good living for himself and family. This is the reason why mechanics leave the army as soon as they are through with their terms of enlistment; that is, when, owing to acquired experience, they begin to be more useful.

The creation of a corps of airplane mechanics similar to the corps of naval mechanics, might remedy this state of affairs. Good results have already been obtained in the navy where a mechanic with a good education, such as a graduate of "L'Ecole des Arts et Metiers," might become an officer-mechanic and reach a comparatively high rank. Military aviation would be thus provided with a permanent staff of engineers and foremen-mechanics (commissioned officers and noncommissioned officers) duly qualified to insure the best conditions of upkeep and repair. The creation of such a corps would be no actual expense to the state. The economies of materiel would rapidly make up for the investment. The fact that excellent reserves for civil aviation are formed by demobilized officers and noncommissioned officers of the corps of mechanics, must also be borne in mind.

Improvements of the Airplane Proper

The numerous accidents referred to above, which were attributable to wrong maneuvers, are partly accounted for by imperfect construction. Except for certain types, existing airplanes lack inherent stability. The speed range is too small, the efficiency of the tail group insufficient in stalled flight and the position of the ailerons dangerous when their action is exerted at the minimum critical speed.

The problem of stability has already received considerable attention and satisfactory results have been obtained by some designers. Airplanes fly at a determined engine speed, without the pilot having to touch the controls. On losing speed, these airplanes flatten out automatically after the strictly necessary glide to regain the lost speed. Starting from any normal position of flight they flatten out without the aid of the pilot and take up a line of flight corresponding to the engine speed. Their maneuverability is good and the action of their controls instantaneous.

Some designers and technicians have devoted their efforts to the problem of stability, whereas the importance of this question is denied by other constructors, who consider that its solution would necessarily be detrimental to other qualities of the airplane. Although this may be true, inherent stability is such an important factor of safety that it must be developed even if performances are reduced which, however, has never been demonstrated.

In a recent accident a student pilot owed his life to the excellent inherent stability and maneuverability of his airplane. Owing to a wrong maneuver, he stalled at 30 or 40 meters (98 or 131 feet) above the ground. The airplane slipped but flattened out before striking the ground. The airplane could not have been righted after such a short drop, if it had not possessed the qualities referred to above, and the accident would have had more serious consequences.

Investigation should be made of the action of the control surfaces and ailerons at the critical speed for sustentation. It is quite evident that if, by some device, the rudders could be made effective at the critical speed, means would at last be provided for correcting the instability which precedes stalling, thus avoiding a spin and consequently re-establishing the stability of the airplane more quickly. Also it seems that the spin could be prevented by the ailerons if they were designed and arranged for exerting a sufficient moment around the axis passing through the center of gravity of the airplane. These problems remain to be solved.

A differential aileron control has already been invented. By operating this control, one aileron can be sharply raised, while the other is only slightly lowered, thus straightening the airplane laterally and bringing it into a gentle glide. Under these conditions a maneuver of the ailerons cannot reduce the speed of the airplane and cause stalling. Another advantage of this aileron control is the resulting smoothness of the maneuver, which causes less fatigue to the pilot. The general adoption of this control is desirable.

An enormous increase in safety could be obtained by reducing the take-off and landing speeds to 40 or 50 km/h (24.9 or 31 mi./hr.). On the other hand, this advantage should not be counterbalanced by an excessive reduction of the cruising speed, as the airplane would then be of no practical use. This important question may yet be solved by means of a device which we are now unable to conceive. Its discovery, however, may still be in the distant future, and it would be unwise to rely on it for a solution of which we are now urgently in need.

A simple device, the Handley Page slotted wing, is available and gives satisfactory results. By means of this wing the pilot is able to increase the lift or drag at his convenience. It is like a speed gear applied to the airplane. I believe that investigations ought to be based on this idea and directed first toward devices designed to create a zone of negative pressure on the upper surface of the wing to support the airplane at cruising speed.

Except for the remarkable De La Cierva autogiro, the improvements and applications of which it is difficult to anticipate, the easy method outlined above will take precedence over the method of reducing landing and take-off speeds by means of variable wing camber and wing area, owing to the difficulties involved in the practical application of the latter method. However, the problem of simultaneous variation of camber and area should not be neglected as a very considerable speed range might be obtained by its solution.

Designers should be recommended to build comfortable cockpits, although this point may at first appear to be of less importance. Accidents attributed to wrong maneuvers are sometimes due to excessive fatigue of the pilot, whose physical fitness has become impaired toward the end of a long flight, owing to lack of comfort. It should be attempted to obtain the maximum smoothness of the controls by reducing the number of pulleys, carefully calculating the length of the horns, and the position and dimensions of the balancing surfaces. Airplanes should be designed so as to be easily flown by the average pilot.

The danger of stalling can also be diminished by special devices suitably adapted to the airplane. I recall the fact that the adaptation of a special device was suggested in 1923, this device to act automatically on the elevator control when the airplane reached its minimum critical speed. Constantin and Bramson have since developed different types of this device. A report dealing with their inventions will probably be submitted by each of them. Without any doubt, the safety will be considerably increased by these devices, which act automatically on the elevator control as soon as the airplane reaches its critical angle of attack.

Fortunately, only a very small number of accidents is due to failure of the cell in flight. Still such cases do occur and there is no apparent reason for them. Strange as this may seem, old airplane types are less subject to failure than modern ones. Old airplanes are all provided with thin wings. The effects of air pressure on such wings have become sufficiently known for different cases of flight, to enable the determination of a method of static tests for discovering the weak points of the aircraft. On the other hand, these airplanes are prevented by their considerable drag from reaching very high speeds. Thus the pilot is able to flatten out, even at the maximum diving speed, without imposing excessive stresses on his airplane. This means that the failure of a wing on an airplane of an old type might be attributed to the failure of some poorly assembled part, fitting, bolt or joint, or to some inherent defect overlooked by the inspection service. Certain failures might also be attributed to the excessive tension of the brace wires having absorbed, at rest, part of the factor of safety of the airplane. Careful and frequent inspection should further reduce the number of accidents. There appears to be another cause for failures on modern airplanes. They do not seem to be due to local defects, but rather to the stresses which, in certain cases of flight, exceed the stresses anticipated in the static tests and in the calculations of the designer.

Airplanes of great fineness ratio (L/D) are particularly subject to failure at their maximum diving speeds. These airplanes can actually reach very high diving speeds so that the stresses may exceed the factor of safety, particularly if the airplane is pulled out of a dive too suddenly. A few months ago an investigation of the failure in flight of an airplane having a high fineness ratio showed that the failure occurred after pulling out of a long dive. The rear wing strut was bent at right angles by compression while the front strut was torn from its fittings by traction. The rear member of the landing-gear V-strut, broken by the shock of the cell dropping backward, was found near the spot where the wing had fallen to the ground. It is evidenced by all these facts that the position of the center of lift must have been aft of the wings when the break occurred. It is therefore probable that the airplane gave way while being pulled out of the dive, it being possible for its angle of attack at that moment to reach a considerable value. The details of this accident are given to show that the loads imposed on the rear spar may under certain conditions, exceed the loads which the front spar can support in other cases.

In any case it follows from these accidents that calculations and static tests, for the determination of airplane characteristics, must be based on the results of full-scale tests involving measurements, at high speeds and under all conditions of flight, of the magnitude, direction and distribution of pressure on the given wing sections. Such tests may reveal lack of strength of some structural parts in certain cases of flight, thus putting the constructors under the obligation of reinforcing the weak parts of the wings. In order to avoid the increase of weight which might result from these reinforcements, wings with a slight displacement of the center of lift should be designed. This solution would enable the concentration in one point of all the elements determining the strength of the wings.

However, at the present time it would be well to equip all aircraft of great fineness ratio with air-speed indicators graduated for very high speeds. Moreover, the attention of the pilots should be called to the maximum critical speed not to be exceeded and at which the airplane can still be flattened out without danger of rupture. A device might also be designed for controlling automatically the flattening out maneuver when the airplane is about to reach its maximum critical speed. The production of such a device based on the air speed of the airplane would appear to be quite simple.

Improvement of the Power Plant

Safety in flight largely depends on the proper functioning of the engine. Next to fog, engine trouble is what the pilots fear most, since it may force a landing when no suitable landing place is in sight. According to statistics, 22% of the accidents are attributed to engine failures. As a matter of fact, this figure is really much higher, since engine failures followed by partial crashes without injury to the crew are not always reported to the department in charge of collecting information regarding causes of accidents. The reported breakdowns are due to the following causes given in order of their frequency: failure of one of the engine parts; poor circulation of water; lack of lubrication of some part; imperfect carburetion; deficient ignition.

The parts most frequently subject to failure are: valves and controls, springs, valve rockers, and valve-rocker pins.

Next come failures due to piston troubles. In this connection, the new engine types represent real improvements. Connecting rod breaks come last and are constantly decreasing in number. They are mostly due to deficient lubrication. On old engine types, failures were often due to small cracks in the water jacket. These accidents may be attributed to unequal expansion of the different engine parts.

Poor water circulation is due to vibration, deficient upkeep of the radiators, to leaks in loose or neglected joints, and sometimes to failure or bad functioning of the water pump in which the pump vane is separated from its axle after failure of the rivets. Forced landing brought about by bad water circulation might often be avoided by an increased volume of reserve water to replace a slight loss of water in flight.

Failures due to poor oil circulation occur when a pipe is stopped up by some foreign substance. Similar conditions are produced by poor carburetion, which is mostly due to a partial stopping of the rubber tubing by disintegrated particles of rubber at the joints. Forced landing caused by deficient ignition is generally due to neglect of the magnetos.

It appears from the above statements that most breakdowns are due to lack of inspection and care of the engines, so that one might be tempted to throw all the blame on the mechanics. They have, however, some excuse in the complicated arrangement of the power plant, which renders the inspection of certain parts particularly difficult. On some airplanes the engine is mounted in such a way that the removal of a magneto is exceedingly difficult. It is easily understood how a mechanic, pressed for time, might neglect some important detail.

Such relations between airplane and engine illustrate the importance of close cooperation of the airplane and engine constructors with the aviator. This cooperation might be obtained by the adoption of a "rent-and-sale" system, according to which the user would rent an airplane for a certain period, after which he agrees to buy it, if the conditions of the contract are fulfilled. The airplane and engine constructors would thus be kept more closely in touch with their products and would be enabled to design new airplane and engine types better adapted to the needs of the user. With reference to engine improvements, the number of failures to which they are subject could be reduced by the elimination of valves and of water cooling. Sample engines should be submitted to longer endurance tests on the ground, this being the safest and most practical way to detect defects and determine the value of the improvements.

The rotary engines of training airplanes should be equipped with automatic carburetors in order to increase their safety. Every year several accidents are caused by student pilots inadvertently turning the mixture handle while absorbed in maintaining the equilibrium of their airplane. This chokes the engine and causes it to stall. These accidents might be avoided by using automatic carburetors.

Multi-engined airplanes, able to fly with one engine stopped, are gradually coming into use on air transportation lines. This leads us to hope for the practical elimination of forced landings, provided the engines are made easily accessible during flight, thus enabling the mechanics to make the necessary repairs.

In view of the fact that serious accidents due to fire have recently been reported, all the available information as to their causes and the efficacy of protecting devices is given below. As I have already pointed out in previous reports, the number and seriousness of conflagrations in flight and on the ground have increased, notwithstanding the protective means employed, since powerful engines are being more extensively used.

In 1923, when airplanes were not equipped with fire extinguishers, 12.09% of the deaths in French aviation were due to conflagrations in flight. In 1924, efficient means of protection were provided and the percentage immediately dropped to 1.30%. Since 1924 the deaths have increased and the percentage has risen from 3.67% for 1925, to 13.23% for 1926, from January 1st to the present date (November 10). The deaths are increasing in the same proportion for conflagrations on the ground. In 1923 they amounted to 16.07%. In 1924 the adoption of protective measures reduced the percentage to 11.76% which, however, rose to 17.27% in 1925, and 22.46% in 1926.

An examination of the causes of conflagrations in flight shows that 28% are due to back-firing into the carburetor, thereby setting fire to the gasoline escaping from the float chamber or flowing back into the intake pipes or flowing from a broken pipe or loose joint, or igniting the residues of oil and gasoline accumulated in the cowling or between the rows of cylinders; 24% to connecting-rod breaks entailing either back-firing, setting fire to the gasoline flowing through the broken pipes, or setting fire, through the broken piston, to the oil contained in the broken crank case; 6% to engine troubles usually caused by defects of the valves or of their distribution members; 4% to poor functioning of the engines (without further details); 2% probably to rupture of an ignition wire near a spark plug of a rotary engine, the wire coming into contact with the engine bearer soaked with gasoline and oil; 2% to rockets catching fire. It was not possible to determine the causes of the remaining 34% of the fires.

Notwithstanding the fact that certain causes of fire may have escaped our attention, we have gathered enough information to show that most conflagrations in flight were caused by back-firing and failures of connecting rods. Under these conditions, it is reasonable to conclude that there is no danger of conflagration if the flames bursting forth in the engine cowling do not come into contact with inflammable materials, such as gasoline and oil.

Efforts should be directed along this line. The presence of oil tanks, filters, decanters or fuel-pump damping devices should not be tolerated inside the engine cowling. Preference should be given to those engines in which the crank case is not used as an oil tank. The development of devices capable of preventing back-firing from reaching the carburetor should be continued. The use of special carburetors which are proof against back-firing is particularly recommended. As stated above, conflagrations due to back-firing were caused by leakage which resulted in deficient delivery of fuel to the engine. Leakage is therefore particularly serious, as it may cause back-firing and at the same time create most favorable conditions for the further development of the conflagration.

The greatest care is recommended with reference to fuel and oil pipes and to the tightness of the connections. Two types of connections are now available: rubber connections and flexible metal connections. The trouble with the former is that they are combustible and may stop up the pipes when they are in bad condition. The latter are not flexible enough and cause the breaking of the pipes to which they are attached by their additional weight. Both types are therefore objectionable, and a third one should be sought, which will remedy the above-mentioned defects. Instead of using these connections which may cause serious accidents, it would be better to use jointless pipes integral with the device, flexibility being obtained, after annealing, by several coils arranged in different planes.

Back-firing may cause fire in the carburetor for the following reason: In general, the air-intake scoops on the outside of the cowling are neither firmly secured nor sufficiently strong. Consequently, they are separated from the tubing or are blown off by violent back-fire. I was personally present at engine tests when air scoops, which appeared to be well secured, were hurled several meters away by an explosion. Of course the air scoops on this company's airplanes were immediately reinforced, with the result that no more conflagrations occurred which could be attributed simply to back-firing.

Back-firing, which might be considered negligible on low-powered engines, may, if no precautions are taken, entail serious consequences on modern engines. The great amount of gas contained in the tubing of powerful engines may produce quite a serious deflagration, wherefore the air scoops must be strong and solidly attached. Flames produced by back-firing may set fire to the fuel falling back into the air-intake pipes, since the fuel passing through the spraying nozzle is not all drawn in by the engine. Very often the delivery of the carburetors is unequal, so that some of the gasoline falls back into the air pipes. Apparently this trouble is due to bad design and bad location of the air scoops.

In general, the air scoops are of equal length and directed toward the front of the airplane. They are struck at a certain angle by the propeller slip stream. Owing to the fact that one of the air scoops slightly overlaps the other, the air is drawn in differently by each scoop, notwithstanding the action of the engine. This was confirmed on a twin-engine airplane in flight, where a moist air scoop could be seen. It was again confirmed by consumption tests during which each carburetor was supplied with fuel from a different tank. For a 300 HP. engine, the consumption varied from 10 to 15 liters (2.6 to 4 gallons) per hour for an absolutely identical adjustment of the carburetors. To avoid these troubles the air scoops should face the propeller slip stream and be placed in different planes to prevent overlapping.

Conflagrations during stunts are most liable to occur when the pilot suddenly opens the throttle valve. It is possible that this sudden opening, which alone is sufficient to entail deficient delivery and consequent back-firing, has coincided with a maneuver of acceleration, which would have reduced the quantity of fuel delivered to the carburetor. On certain airplanes where the pipes entered the carburetor from the back, a partial emptying of the float chamber was noted shortly after the pilot opened the throttle wide to reach the take-off speed. Back-firings occurred and the pilot had to start over again. Attention was finally given to the inertia of the fuel in the pipes, which were then modified by being first extended to the front of the engine and then led back to the carburetor. At the present time the delivery is perfect under all conditions of acceleration of the airplane. Owing to the fact that deficient delivery may entail back-firing, the above arrangement of the pipes is particularly advisable for pursuit airplanes.

One modern engine type has air-intake pipes leading from a single air scoop. Although this engine has not yet been subject to conflagrations in flight, attention is called to the danger involved by this arrangement in case of back-firing. Flames breaking forth from one of the pipes will undoubtedly set fire to the gas contained in the other pipes. Hence there should be a separate air scoop for each carburetor.

Cleanness of the engine is a good guaranty against fire. This is well known by aviators who try to keep their engines as clean as possible. In fact, the engines are clean at the start, but not after half an hour of flight, because the oil becomes too thin at the high temperatures and leaks through all the joints. A number of conflagrations having been caused by the oil catching fire, means should be sought to obtain sufficient viscosity to insure good mechanical tightness. There is only one way to achieve this result, namely, to cool the oil. Recent tests showed that, owing to slow circulation, the oil leaving the engine reached a temperature of 90° as soon as the engine was started. Since many airplane engines are subject to this trouble, it is particularly important to study the circulation of the oil, in order to prevent it from reaching temperatures which will appreciably reduce its viscosity. Moreover, the snifting valves should connect directly with the external air in order to avoid the projection of oil or the formation of carbureted gases inside the engine cowling.

Only 2% of the conflagrations on airplanes equipped with rotary engines were ascribed to the contact of an ignition wire with the engine bearer covered with fuel and oil residues. On the other hand, since the causes of 34% of the conflagrations on airplanes equipped with fixed engines are unknown, it may be assumed that some of them are attributable to deficient ignition.

Attention is called to the following precautions against fire: good insulation and strength of the ignition wires, insulation of the spark-plug-wire connections on their outer surface, adoption of an ignition distributor which will reduce the length of the insulated wires to a minimum and, lastly, tightness of the magnetos. Owing to the fact that these precautions have not always been taken, I will also mention that fuel pipes should not lie above magnetos or ignition wires, since a drop of fuel, falling at the instant when a spark is produced, may set fire to the airplane.

After having enumerated all the causes of fires which have occurred in flight since 1923, means of preventing them from spreading and becoming dangerous, will now be considered. Of course fire would not spread if it had nothing to feed on. The means indicated for avoiding fire, such as the removal of all tanks and strainers containing fuel and oil from the engine cowling, would likewise prevent it from spreading. In addition to these precautions, no wooden parts should be placed inside of the engine cowling, as they easily get soaked with fuel and oil.

In a great number of accidents the fire was fed by fuel and oil flowing from a broken pipe, a loose connection, or one which had actually burned. In addition to researches for finding a suitable connection, a check valve should be invented which, being placed in the fuel tank, would automatically cut off the supply from the fuel pipe if it or any of its connections should break. The problem is very difficult, but its solution does not appear impossible. The operation of the check valve above referred to might depend on the speed of the fuel flow. Its presence on airplanes would be of great service.

Nearly all conflagrations in flight resulted in the death of the crew when the flames, breaking forth from the engine cowling, reached the fuel tanks. In some cases the fall was precipitated by the instantaneous dislocation of the tanks produced by the explosion of gasoline vapors, which had collected in the vicinity. The fireproof bulkheads used at the present time are not sufficient to protect the tanks efficiently, when they are located immediately behind the engines. Although the flames cannot melt the bulkheads, they easily pass by them and reach the fuel tank, which gives way at a joint and allows its contents to escape.

The problem has two possible solutions: Either the fuel tank should not be placed immediately behind the engine, or it should be efficiently protected. The first solution can be easily realized on modern commercial airplanes. The second also appears to be quite easy and might be obtained, not by placing a simple protection wall in front of the tank, but by actually enclosing the tank in a fireproof housing. A sufficient air layer might be provided between the fireproof housing and the tank, good circulation of the air being insured by a great number of openings covered with wire gauze. The weight of such a wall would be insignificant. The wall could be made of sheet asbestos covered on both sides with sheet duralumin and fine wire gauze.

Emptying the tanks, in order to avoid the spreading of the fire was considered, but experiments showed that gasoline discharged in flight was splashed over the fuselage and the tail planes. After these tests, the idea of draining the tanks was abandoned. The trouble with the draining devices was that they discharged the gasoline through the bottom of the tanks. Therefore, the results were not surprising and would probably have been the same if the gasoline had been conducted to the bottom of the landing gear. A possible solution would consist in exerting sufficient pressure inside the tanks to drive the gasoline into a pipe opening at the rear end of the fuselage. Tanks now in use could stand the requisite pressure. Tank-dropping devices were installed on various types of airplanes and proved to be an important means of preventing fires from spreading. In 20% of the cases the pilots escaped injury when the tanks were dropped.

The causes of fires on the ground were not so accurately determined as the causes of fires during flight, the crew being either killed or unable to account for the accident. The information gathered on this question indicates that: 47% of the conflagrations on the ground followed crashes due to stalling; 33.33% were caused by collisions in flight or by striking obstacles in taking off or in landing; 15% were caused by partial or total crashes due to bad landings; 1.5% were caused by falls due to defects in the construction materials; 1.5% occurred on seaplanes and were due to the shock of phosphorous flare buoys on the water after capsizing; 1.5% were due to circumstances concerning which no information was received; 7.54% of the conflagrations on the ground occurred on airplanes after flat landings or landings on the nose, and it was found that they were due to a sudden increase in the engine speed following the breaking of the propeller. In these accidents the tanks were not burst open by the shock and no gasoline was splashed on the mufflers.

These observations, in addition to those which I was able to make for myself, and the fact that the number of conflagrations on the ground increases and decreases in proportion to the number of conflagrations in flight, indicate that the most frequent cause of conflagrations on the ground is back-firing coincident with the breaking of the air scoops against the ground, the breaking of the pipes and sometimes the bursting of the gasoline tanks. Measures for avoiding conflagrations in flight would therefore also reduce the danger of conflagrations on the ground. However, it is probable that some of the fires were also due to the crushing of the gasoline tanks against the mufflers at the moment when the carbureted mixture exploded in them. This danger could be avoided by not placing the tanks immediately behind the engines and by using long exhaust pipes to conduct the gases as far aft as possible.

In both cases fire is produced on the ground because the engine makes a few more revolutions. This is clearly proved by the way in which the propellers were broken. Back-firing can only be produced when there are burning gases in the cylinders. Therefore, no fire can be produced if the ignition is switched off. Pilots know the importance of switching off the ignition to prevent conflagration on the ground and they do so whenever they consider it advisable. It may happen, however, that after the ignition is off the engine continues to revolve by self-ignition. This very serious disadvantage, which considerably increases the danger of accident, is due in most cases to the spark plugs which, for some unknown reason (defects of the electrodes, excessive accumulation of calamine deposits) maintain a sufficient temperature to ignite the fuel mixture. Tests were made with different types of spark plugs, and it appeared that with some of them the engine continued to revolve after the ignition had been switched off, whereas with others the engine, maintained at a strictly constant temperature, stopped as soon as the ignition was off. The choice of spark plugs is very important with regard to conflagrations on the ground.

In order to further reduce the danger of such accidents, a device might be invented to stop the engine in the shortest possible time. It would seem that this result might be obtained by introducing a neutral gas into the intake pipe. Thus the pilot would be provided with a safe means for stopping the ignition during a fall or a landing on bad ground.

A considerable number of incipient fires occur on the airport while the engine is being started or stopped. The ratio between these two cases is 25 : 1. 98% of them were attributed to back-firing and 2% to the ignition of gases in the muffler. In one of these cases a pilot was badly burned, who was unable to escape quickly enough to avoid an explosion which took place near the tanks where gasoline vapors had collected. In another instance, a mechanic was repairing the storage batteries in an airplàne, when a spark jumped between two wires. At the same time an explosion took place, this spark having set fire to gasoline vapors between the lower part of the cockpit and the bottom of the fuselage. These accidents demonstrate the advantage of providing the lower parts with outlets and of ventilating all parts of the airplane where even small amounts of oil or gasoline might accumulate. Before turning to the operation of fire extinguishers, it should be noted that all the measures outlined above will lose much of their importance when we use heavy-oil engines or a noninflammable fuel.

50% of the fires which occurred on the airport, while starting or stopping the engines, were put out by means of engine fire extinguishers alone. Their action was supplemented in 46% of the fires by the hangar fire extinguishers. In the remaining 4% of the cases, the extinguishers failed to stop the conflagrations and the airplanes were burned. The extinguishers were less efficient in flight, where only 7.5% of the conflagrations were stopped by engine fire extinguishers; 5% by means of engine and hand extinguishers; 2.5% by means of hand extinguishers alone; 30% spread more slowly after the functioning of the engine extinguishers and the airplanes could land in most cases, but were burned on the ground; 2.5% stopped of themselves; 2.5% occurred near the ground and were put out by means of hangar extinguishers; in 12.5% of the cases the attempts to use the extinguishers failed; in 12.5% of the cases the extinguishers were operated without benefit; in 12.5% of cases the extinguishers were not used. No information is available in 15% of the cases.

The above figures show that in 42.5% of the cases the extinguishers were useful, but that the airplanes were burned in most of the cases. When conflagrations occurred on the ground after the airplane had crashed, the fire extinguishers were of no use. The time required to start an extinguisher was often too long to enable the pilot to use it. On the other hand, the design of the carbonic acid gas containers, which supplied the pressure to the carbon tetrachloride tank, was defective in some cases. Some extinguishers are operated by turning a handle which opens the valve of the carbonic acid gas container. It sometimes happened that the pilot was unable to give the handle a sufficient number of turns to operate the extinguisher. Moreover, the container was sometimes found to be empty, owing to the fact that the valves were not absolutely tight. These two defects can be avoided by using quick-release containers closed by simple tin caps. Lack of efficiency was often due to slow action of the extinguishers and bad arrangement or direction of the jets when the currents created in the neighborhood of the engine were not taken into consideration. Besides, the carbonic acid gas containers were sometimes partly empty.

The pilot was often unaware of the fact that an engine had caught fire, one of its sides being hidden from his view. A fire alarm should therefore be used. The installation of this alarm is now compulsory on civil airplanes.

The position of the sprays or jets can be easily improved, since a simple inspection would show whether their position might be changed so as to improve the efficiency of the extinguisher.

Several pilots were seriously inconvenienced by carbon tetrachloride vapors after using the extinguisher. Means should be provided for expelling these vapors, in order to protect the crew. Tightness of the pilot cockpit would seem to be the first step toward achieving this result. Owing to the inconvenience referred to, the use of tetrachloride extinguishers is prohibited inside of passenger cabins.

Reducing the Seriousness of Accidents

The number of accidents should be reduced by providing means for avoiding them. Notwithstanding the degree of safety obtained, accidents will always occur, owing to unforeseen causes. Therefore, efforts should be simultaneously directed toward reducing the seriousness of accidents. In this connection valuable suggestions are furnished by experience and some improvements can be immediately made.

It appears from several accidents, one of them being particularly serious, that the troubles were due to the location of the cabin on most multi-engine airplanes. On such an airplane the cabin, partly projecting beyond the wings, is in the front part of the fuselage, whereas the luggage and freight compartment is located aft. Thus, in case of an accident or a violent landing, the passengers are more exposed than the baggage since the front end of the airplane always strikes the ground first. In the accident just alluded to, the passengers who occupied the front part of the cabin, projecting beyond the wings, were killed, while those in the rear end escaped without injury. The passengers in the central portion of the cabin were either seriously or slightly wounded, according to whether they were seated forward or aft of the center. The baggage and freight showed no sign of damage.

The advantage of the unobstructed view afforded passengers by a cabin located in the extreme front should be disregarded, owing to the increased safety obtained by placing the baggage room in the front end of the fuselage and the cabin farther aft. This change should be made. At the same time, all projections inside the cabin should be eliminated and careful consideration given the shape and arrangement of the seats in view of reducing the seriousness of accidents. The seats should be firmly secured and provided with handles, and the floor should be provided with foot rests so that the passengers may have a good hold and brace themselves firmly when landing on bad ground. Straps would serve the same purpose, but the trouble would be to get passengers to use them.

Special accommodations should be provided for a mechanic if the airplane has three or more engines. In normal flight the pilot could look after the engines alone, but in case of emergency, such as fire, his attention would be absorbed by the great number of maneuvers to be attended to within a short period of time. On multi-engine airplanes it is advisable to arrange the engine and fire-extinguisher controls in such a way that they may be reached either by the pilot or by the mechanic, who should always be ready to obey any command.

If this plan is not adopted, the number of maneuvers to be performed by the pilot in case of fire should be reduced to a minimum by grouping in a single ordinary or automatic control for each engine the gasoline cock, the gas throttle, the ignition switch, the cock of the extinguisher pipe, and the cock of the carbonic acid gas container. If the pilot has to make all the additional maneuvers required in case of fire, while busy with piloting a heavy airplane, looking for a good landing place and perhaps maneuvering to land safely, he is liable to be unable to take all the required safety measures and thus run the risk of an accident which might have been avoided, had the airplane been provided with a mechanic or with a single fire control.

The airplanes which cross the British Channel every day are not equipped with floats. Under these conditions, engine trouble over the water may become dangerous, unless immediately remedied. During the crossing, the airplanes are flown as high as possible, thus having a chance of either reaching the coast or alighting near a ship. But in a fog an airplane may alight without being noticed. In this case help is immediately dispatched if requested by radio or if the air-survey stations on the French or British coasts signal that an airplane flying over the Channel has not reached its destination on time.

In spite of the rapidity with which help is dispatched, some accidents have happened. In the beginning of this year, one of our single-engine airplanes was wrecked near the Varne bank. Help arrived too late, although it was sent as soon as the accident was reported. Quite recently a British airplane sank. Fortunately the passengers were rescued by a fishing-boat which reached the place of the accident quite by chance. The accidents show that the measures taken (such as life-belts for each passenger and relief organization) were useful, but not sufficient to reduce to a minimum the dangers of the Channel flight. It would seem that this can only be done by providing airplanes with floating devices capable of keeping them above the water for several hours until help arrives.

Attempts to keep an airplane afloat by inflating, when alighting, air bags placed on both sides of the fuselage, have as yet given no convincing results. This question should receive further attention. Meanwhile, and until a better solution is found, the problem might be solved by placing a few water-tight compartments in the fuselage of each airplane designed to cross the sea. This is not a very satisfactory solution as it means considerable additional weight, but an immediate increase of safety would be obtained.

The solution would be simpler, if only the safety of the passengers were considered. The fuselage of an airplane might be provided with a detachable top, so designed as to constitute an excellent buoy to which the passengers might hold or attach themselves while awaiting rescue. The top of the fuselage might actually be given the form of a light nonsubmersible boat to be detached in case of emergency. This buoy or boat and the airplane itself should be painted a color which would be very visible on the water, in order to facilitate discovery. This remark also applies to seaplanes.

While speaking of accidents on the water, attention should be called to the importance for a seaplane of a radio antenna enabling it to call for help and to indicate its position after alighting. The antennas now in use are of the most primitive type and cannot be mounted when the sea is rough. In case of a forced alighting, the crew and the passengers of seaplanes may fail to be rescued, owing to the lack of a suitable antenna which, however, could be easily designed.

Another measure for reducing the danger of a forced alighting would consist in equipping a seaplane with a pump having a large output. At present many seaplanes have no means for removing the water which may get into the hull through a crack or through the port holes. A pump might delay the sinking until the arrival of help.

I shall now end this report on the means for diminishing the seriousness of accidents by considering the question of parachutes. One might be surprised that parachutes, which have now been brought to a high degree of perfection, have not played a more important part in the serious accidents, conflagrations, and failures in flight which have occurred during recent years. The simple explanation of this fact lies in these few words: "Parachutes have not yet been perfectly adapted to the requirements of airplanes."

On French airplanes with open pilot and passenger cockpits, back and seat parachutes are used. The parachutist must stand on the seat and then jump overboard. This maneuver is difficult to perform when the airplane is not in normal flight, as is often the case during an accident.

On airplanes with passenger cabins it was decided to supply parachutes to the passengers upon their request. In order to make use of the parachute, the passenger must reach the door of the cabin and then jump off. This way does not seem very satisfactory, since the passengers may be prevented from reaching the door, should the airplane lose its equilibrium, which may be the case if the passengers become panic-stricken and all move simultaneously.

The plan has also been considered of providing the floor and the walls of the cabin with openings. The first plan has been tried on an airplane, but it is far from being satisfactory, when it is considered that the trap-door may be accidentally opened in normal flight by an absent-minded passenger. The second plan is more reasonable although not quite perfect, since each passenger must open a door and jump out. It is doubtful whether all passengers of different ages will have the necessary self-control to jump in time. Besides, parents may hesitate to throw their children overboard. Even if it is assumed that passengers will have the necessary self-control and decision, they may be prevented from reaching the exits by the successive accelerations and changing positions of the airplane, of which the wings or control surfaces may be broken.

A parachute with sufficient area to support the airplane and its occupants has been designed abroad. Tests were even made with it but, although it might be useful in case of a failure in flight, it would be absolutely useless in case of a conflagration, when the parachute would burn with the airplane.

There seems to be only one solution capable of doing away with the disadvantages just mentioned. It was suggested by me in 1923, and consists in first throwing out the parachute which, after filling with air, is supposed to lift the passenger from his seat. This result could be, for instance, obtained on open airplanes (with cockpits) by placing the parachute in the fuselage behind the head of each occupant inside of a closed housing which could be opened by the pilot. The cover of the housing could be so designed as to throw the parachute out. It could, moreover, serve as a guide for the parachute cords, to prevent the pack from unfolding before getting clear of the rudder and out of danger of catching. To this end, the cover could open backward in such a way that its upper edge would extend above the top of the rudder.

The same solution could be applied to commercial airplanes of the closed-cabin type, the only difference consisting in the arrangement of the parachutes inside of a housing located between the cabin roof and the top of the fuselage, behind and above the head of each passenger. Each housing, after the release of the parachute, might form the opening through which the passenger would be lifted from the airplane by the parachute and guided by the back of the seat. In case of danger, the passengers would be simply notified to attach the belts, and the commanding officer, as sole judge of the situation, would liberate the parachutes at the proper time. The equilibrium of the airplane would be preserved by liberating the parachutes in the proper order. Parachutes might be used which would lift several passengers together, or even parts of the cabin.

In order to keep this report within reasonable limits, I shall not discuss accidents resulting from bad ground organization or errors of navigation in the fog. Their number is comparatively small and will automatically decrease. In fact, questions relating to ground organization are always given the most careful attention by countries proposing to participate in international air traffic, these matters being attended to as soon as an air line is projected. The question of increasing the safety when flying in a fog depends on the training of the crew, on the navigation instruments, and on other suitable devices. Nearly all the requisite instruments and devices are now available, though they may be further improved. Means for rendering airports visible in a fog are still to be invented. I have therefore confined myself to the study of only such serious accidents as may happen again with the same frequency if suitable means for their prevention are not adopted. It has been shown that, although some difficult problems are presented, other problems can be easily and quickly solved, if the necessary means are provided.

In addition to the air services in especial charge of airplanes, engines and accessories, it would be of great benefit to organize a service exclusively in charge of questions relating to safety. This service should investigate accidents, study their causes, suggest remedies, provide for the inspection of materials, etc. Of course this service alone could not be expected to solve all the problems which call for the attention of specially qualified technicians. For extensive researches it would therefore be necessary to resort to a "Committee of Safety," which would work out a program of investigation for the different problems submitted to it by the above service. This committee might call a conference of experts on the particular question under investigation, who would doubtless feel honored to respond to such a call.

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