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*See also
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FIRE PREVENTION ON AIRPLANES

By J. Sabatier

PART I *See also Part II*

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PART I.

Fear of fire certainly contributes to the turning away of
many people from aviation. The violence of the fire, its immedi-
ate effects, the difficulty of giving efficient help, strike the
imagination of those who are, or believe themselves to be, ex-
posed to these dangers. Why does fire threaten airplanes more
than any other vehicle? Because they carry large amounts of
gasoline which, in contact with the surrounding air, produces
explosive mixtures, and because of the relatively great risk of
leakage and spilling of gasoline on airplanes.

Chapter I.

Problem of the Elimination of Gasoline

The idea which immediately comes into one's mind for reme-
dying the above danger, is to eliminate gasoline and to replace
it by a less dangerous fuel. Numerous attempts have been made
in this connection during the last five or six years, along the
following two principal lines.

a) The search for new fuels, less inflammable than gasoline, but still enough like it to be used in existing engines, without necessitating any great changes in them.

b) On the other hand, the adoption of the heavy fuels already on the market and the construction of engines capable of using them.

Special Fuels and the Results Obtained with Them

The former method consists in first choosing a suitable "safety fuel" and then adapting the engines (particularly the carburetors) to it. This method has been the subject of numerous investigations. Before analyzing the results, it is well to consider how to characterize the relative degree of safety of a fuel.

In this connection, one usually has recourse to the notions of the flashing point and of the burning point. The flashing point is determined by means of the so-called Luchaire closed-cup test. The fuel to be tested is placed in the cup. The cup is covered by a lid with a funnel, and the temperature is measured to which the fuel must be raised in order to cause the emitted mixture of air and vapor to be ignited by a flame placed at the mouth of the funnel. The burning point, the measurement of which is less accurate than that of the flashing point, is determined by the open-cup test. The temperature is then measured to which the fuel must be heated in order to catch fire when its open surface is brought into contact with a flame, and in order

that the fire continue as long as any fuel remains to feed it. In short, the flashing point indicates the temperature at which a liquid fuel begins to emit inflammable vapors, while the burning point denotes the temperature at which the liquid itself begins to burn.

Aviation gasoline is known to burn in either the gaseous or liquid state at much lower temperatures than $0^\circ C$ ($32^\circ F$). On the other hand, the flashing points of the proposed safety fuels vary according to their nature, but lie mostly between 20 and $35^\circ C$ (68 and $95^\circ F$), while the burning points lie between 30 and $40^\circ C$ (86 and $104^\circ F$). In this respect, their superiority over gasoline is undeniable. However, the fuels with the lowest flashing and burning points (and, to a certain extent, all other fuels) necessitate precautions in use, which cannot be neglected without real danger.

In fact, temperatures of $25^\circ C$ ($77^\circ F$) are common in our country in summer, while 30 and $35^\circ C$ are often exceeded in tropical countries. Of course the confined air which surrounds the engines inside the cowlings is much hotter than the outside air. But it is inside the cowlings that fuel leaks are most to be feared. Hence, on many occasions, accidentally spilt fuel will be hot enough to emit vapors, which may catch fire in contact with a spark or flame. Hence it is essential, especially in hot countries, that precautions against leaks and flames be taken with respect to these fuels, as well as with gasoline.

It will be observed, however, that under similar conditions, the vapors emitted by safety fuels are much less abundant and spread less rapidly than gasoline vapors. Hence, if they catch fire in spite of precautions, the resulting conflagrations are less violent and more localized. Moreover, the consequences of such conflagrations are not so terrible, even if the flames spread far enough to reach the principal fuel reserve. In the case of liquid gasoline with a burning point far below that of the surrounding temperature, the ignition of this reserve is instantaneous. In general, it is even violent enough to cause actual explosions. In the case of fuels, however, with a burning point of the order of 30 to 40°C the temperature of the principal fuel reserve may reasonably be expected to lie considerably below the danger point. If a fire is started under these conditions, it will generally spread slowly or go out of itself.

Moreover, the degree of safety will depend on the elevation of the burning point of the fuel above that of the surrounding atmosphere, on the reduction of the temperature of the fuel contained in the tanks, and on the distance between these tanks and the point of emission of the hottest flames. This means that, in order to attain the highest degree of safety, the fuel tanks must be protected by fireproof bulkheads and kept comparatively cool (especially in hot climates) by means of an air circulation which keeps the temperature of their contents below the burning point.

Lastly, it should not be forgotten that the flashing point drops with decreasing pressure. Thus, the S.T.I.Aé. (Service Technique et Industriel de l'Aeronautique) recently found that a fuel with a flashing point of 28 to 29°C (82.4 to 84.2°F) on the ground, did not exceed 21°C (69.8°F) at 3500 meters (11,500 feet).* Hence, if the temperature of the surrounding air, and especially the temperature of the fuel in the tanks, does not decrease during the climb of an airplane, so as to keep below 21°C, the actual degree of safety in flight is much smaller than appears from observation at ground level.

Of course, the above considerations do not lessen the superiority of safety fuels over gasoline as regards fire hazards. This superiority is undeniable. They give a good idea, however, of the guaranties afforded by these fuels and of how they can be used to the best advantage. Besides, it will be shown subsequently, in the chapter on mufflers, how safety fuels behave with respect to their hot spots.

The safety fuels hitherto tried in France were derived either from crude petroleum or from coal tar. The suitable distillation of crude petroleum renders it possible to eliminate the light, highly inflammable fractions which they contain and to retain only the fractions distilling within narrow limits of temperature, e.g., between 130 and 180°C (266 and 356°F). We thus obtain fuels quite similar to "white spirits" with a mean

*These figures are similar to those indicated by M. Aubert, "Les combustibles liquides" (Liquid fuels), Paris, 1924.

flashing point of about 38°C (100.4°F), and a mean burning point
of about 40°C (104°F). The composition and hence the character-
istics of the tested coal derivatives vary considerably, the
flashing point being 25 to 26°C (77 to 78.8°F), and the burning
point 33 to 36°C (91.4 to 96.8°F). It will be noted that these
points are lower than those of petroleum derivatives and hence
afford a smaller guaranty against fire.

The following general results have been obtained by testing
safety fuels, derived from coal, both on the bench and in flight.
These fuels require thorough heating of the carburetors. Even
with such heating, the engines do not pick up easily and are
difficult to start cold. It is often necessary to use gasoline
to start them. At temperatures below 0°C, the tested mixtures
become turbid and, if the cold increases, solid ingredients are
precipitated which may obstruct the pipes. Owing to the preheat-
ing required, these fuels give a smaller power output than gaso-
line, even when used under otherwise similar conditions and on
the same engine. On the other hand, owing to the presence of
aromatic hydrocarbons, they can be used, without risk of detona-
tion, at much higher compression ratios than gasoline or other
petroleum derivatives. This feature permits increasing the com-
pression ratio and thus compensating to a certain extent for the
loss of power due to preheating. In addition to reducing fire
hazards, these fuels present, for France, the advantage of being
extracted from native raw materials.

In brief, the interesting properties of the fuels derived from coal fully justify the expectations. Their disadvantages, as regards loss of power, are not prohibitive, especially on ordinary airplane types. On the other hand, the difficulties of starting and of picking up are very serious and must be overcome before these fuels can come into general use on airplanes. Lastly, unless some way is found to prevent the turgidity and deposits observed in cold weather, the use of these fuels will have to be confined to climates and seasons, where the temperature at normal altitudes of flight is above 4 or $5^{\circ}C$ (39.2 to $41^{\circ}F$).

The fuels obtained from the distillation of petroleum, as tested in France, usually have less pronounced defects of the same order, such as the necessity of using specially heated carburetors, irregularities in the carburetion and loss of power. On the other hand, there is no turgidity nor precipitation in cold weather.

As shown above, we may seek to reduce the loss of power by increasing the compression ratio. In this respect, however, we are limited by the tendency of petroleum derivatives to detonate prematurely (at least when they do not originally contain a considerable proportion of aromatic compounds). These premature detonations, in addition to fatiguing the whole engine by the shocks they produce, also heat internal parts, such as the pistons and valves, thus causing them to wear out more rapidly.

The detonations can be avoided or reduced by the introduction of antidetonants, such as tetraethyl lead. By these expedients, the loss of power due to the use of petroleum derivatives is made passable (6 to 7%). The difficulties of starting and picking up still remain to be overcome.

Lastly, it should be considered that, for France, safety fuels derived from petroleum are products of foreign origin. On the other hand, they are obtained by distillation between very narrow temperature limits, which reduces the chances of industrial production at economical prices. The researches and tests carried on in France, in connection with safety fuels, are well under way, without however, being yet fully satisfactory. The difficulties are both technical and industrial.

From the technical point of view, the task of the designers of airplane engines was greatly facilitated by the abundant and accurate data on the fundamental arrangement of carburetors and accessories, due to the development of automobile engines. Thus, they were able to devote their efforts to the solution of specific aviation-engine problems and especially to the maintenance of a good carburetion at all speeds, temperatures and pressures in flight. However, the carburetion problem is again raised when it comes to discontinue using gasoline on aviation engines and turning to new fuels which are not used in other industrial engines. If the demand on an engine, running on the new fuel, is confined to constant speed under uniform conditions of temper-

ature and pressure, experience shows that a suitable adjustment can be easily found. However, the difficulties increase as soon as the speed varies, and especially under the influence of all the elements which affect carburetion in flight.

In addition to the technical question, the invention of a new fuel involves a difficult industrial problem. It is comparatively easy to obtain a few liters of a substance, the nature and composition of which are accurately known, while it is often much more difficult to produce the same substance on a large scale. It is not always possible to apply industrial methods to the economical production of substances of uniform quality with the original sample. Uniformity, perhaps even more than quality, is an essential feature of aviation fuels. Lastly, some of the proposed new fuels require raw materials which cannot be found on the market in sufficient quantities to meet the demands of aviation.

Special Engines and the Results Obtained with Them

All these considerations account for the fact that the second of the methods indicated above has practically necessitated greater efforts than the first one. It consists in using known fuels, produced on an industrial scale, and in creating an extralight engine capable of using them. These fuels can be either gas oils, with flashing point of 80°C (176°F) and a burning point of 90 to 100°C (194 to 212°F), or oils from the (French) colonies, or else heavy oils with flashing points of over 100°C (212°F),

thus being almost absolutely fireproof.

The satisfactory utilization of the above fuels calls for very high compression ratios, e.g., of the order of 30 kg/cm² (426 lb./sq.in.), the engines used for this purpose being similar to the industrial Diesel or semi-Diesel. On the other hand, in order to reduce the weight of these engines, their revolution speed must be greatly increased, thus producing a cycle closely resembling that of ordinary explosion engines. Hence, the engine type suitable for aviation purposes is intermediate between a Diesel and an ordinary gasoline engine. This new type must be thoroughly investigated from both the mechanical and the thermal points of view. The first question is whether the two-stroke or four-stroke cycle should be adopted. The two-stroke type pleases by its relative simplicity, by the uniformity of torque and by the turbulence of the scavenging, which is favorable to a good utilization of the fuel in the cylinders.

In Germany, Professor Junkers is known to have paid particular attention to this solution. His heavy-oil truck engine is of the opposed piston type with triple connecting rod. Each engine cylinder has a scavenging pump in its upper part, coaxial with the cylinder, the piston of which forms one piece with the upper piston of the engine proper. The height of this mechanical device is cumbersome, but it permits of a more flexible adjustment of the distribution phases than is possible on standard engines. Besides, the equicurrent trajectory of the scavenging

air facilitates the complete expulsion of the burned gases. Starting from this solution, Professor Junkers has built an aviation engine with six cylinders in line, the bench tests of which are now under way. This engine is said to have a power of 800 hp and a weight slightly exceeding 1000 kg (2205 lb.). Besides, the fuel consumption is said to be very low. We must, of course, wait for the results of this engine in operation, before giving a definite estimate of its value.

On the other hand, the investigations and tests carried on in France* in connection with light two-stroke heavy-fuel engines, demonstrated the following points. Unless we adopt special devices, as Junkers did, we are led by general arrangement considerations to provide a scavenging pump for each row of engine cylinders. This pump being of the high-speed type, like the engine itself, must be given very large dimensions in order to supply the required volume of air, since the scavenging speeds are of the order of several hundred meters per second, and the losses of pressure head in the pump and in the scavenging manifold are very high. The necessary exhaust output and pressure can nevertheless be attained, but it is then found that the distribution of the air among the different cylinders is no longer uniform. Each variation causes a decrease in engine power and knocking in the cylinders. It actually happens that part of the exhaust gases of a cylinder passes into the scavenging manifold, which is thus filled with burned gases. These gases in

*Most of the information regarding the following investigations and tests was given me by Mr. Clerget of the S.T.I.Aé.

turn get into the other cylinders and disturb their operation.

An attempt to remedy these conditions and to increase the scavenging action by raising the pressure of discharge (e.g., from .250 to .500 kg (.55 to 1.1 lb.), may fail by causing an excessive loss of pressure head and of the power absorbed by the pump. The losses, thus incurred, exceed the advantage derived from the improvement of the internal working conditions. Finally, reaching too high speeds, the jets of scavenging air cut actual gaps in the burned gases inside of the cylinders, thus preventing the complete expulsion of these gases. We may, of course, resort to valves, in order to improve the distribution of the scavenging air. In this case, however, we are again limited by the mechanical complication and by the losses entailed.

Aside from these difficulties, the application of the two-stroke cycle to aviation engines meets with two fundamental objections. It is less favorable than the four-stroke cycle to the balancing of the inertia forces, which are of material importance in multicylinder high-speed engines. It does not easily lend itself to supercharging, which is the only means of enabling the engine to maintain its power at high altitudes.

The effect of the decrease in air density on the output of the scavenging pump can be remedied by adopting greater dimensions than are actually required on the ground, or by compressing the air during the suction stroke, by means of a special compressor. This makeshift, however, does not prevent the decrease

in pressure which takes place at the end of the scavenging period
with increasing altitude. This decrease results in a reduction
of the air pressure in the cylinders at the moment of the fuel
injection. Under these conditions, an excessive decrease may
prevent the ignition of the fuel. For all these reasons and in
consideration of the present state of technical development,
the adoption, for aviation purposes, of the two-stroke cycle
in preference to the four-stroke cycle is not advisable. Be-
sides, the efforts of English and American designers (Beardmore,
Sperry) are concentrated on the four-stroke engine.

The problem which dominates the construction of engines of
this type, is that of the introduction of fuel under pressure
into the cylinders and the atomization required for satisfac-
tory combustion. This problem may be solved by a blast of com-
pressed air or by pump injection. At first thought, compressed
air would seem advantageous owing to the simplicity of its use
and to the atomization of the fuel brought about by the blast.
Unfortunately, great difficulties are encountered in building
high-speed compressors capable of producing pressures up to 70
kg/cm² (996 lb./sq.in.).

Mechanical injection remains, however. In order to effect
it, we must have pumps capable of delivering fuel, in accurately
determined quantities, at high pressures (up to 250 kg/cm² (3556
lb./sq.in.). Considering, moreover, that for an engine turning

at 1800 r.p.m., the injection period of each cylinder is only
1/360 of a second, we can appreciate the practical difficulties
to be overcome in order to build satisfactory pumps. These dif-
ficulties, however, do not seem insuperable, and the tests car-
ried out for several years lead to the belief that they are
being overcome.

There is the question of atomizing the fuel delivered by
each pump, when it reaches the corresponding cylinder. This
can be achieved by an experimental study of the form, the size
and the distribution of the jets, and also by their adaptation
to the shape of the upper surface of the pistons to produce good
turbulence. Besides, the following special conditions must be
taken into consideration. The injectors wear quickly under the
abrasive action of the liquid projected at high speed and of the
impurities which it contains. Hence, they must be accurately
calibrated in order to be easily interchangeable. The risk of
the orifices becoming clogged with dirt contained in the fuel
and with combustion residues should be reduced. The drops of
fuel which may adhere to the injector at the end of the normal
combustion period and lead subsequently to premature ignition,
should be eliminated. Lastly, it is necessary to prevent the
combustion residues from gradually fouling the piston rings and
polluting the lubrication oil. These conditions, although com-
plicated, can be complied with. It seems, in particular, that
we can expect to build engines, the fundamental principles of

which have already been tested and which do not weigh more than
2 kg (4.34 lb.) per hp. However, only prolonged tests will
enable a final decision regarding their adoption and regarding
the results obtainable in operation.

If, as may be expected, these engines prove satisfactory,
there remains to be overcome the difficulty of starting them
without using too heavy starters. Compressed-air starters,
which first occur to one's mind, require heavy and cumbersome
containers. On the other hand, the air driven into the cylin-
ders cools them, while they should be heated to facilitate com-
bustion and to increase the tightness of the rings. These ob-
jections do not apply to starting by means of an auxiliary gas-
oline engine (Beardmore) which, however, is also comparatively
heavy. Besides, it presents a serious disadvantage in necessi-
tating a reserve of starting fuel to be carried, although in a
compact form. Hence, aviation engines, running either on safety
fuels or on heavy oil, must be further improved, before the
elimination of gasoline can be contemplated. Technical efforts
in this field should be pursued with great perseverance, since
they are now apparently nearing a successful solution.

Chapter II.

Fuel Leakage and Back-Firing

Until the above problems are solved, aviation engines must continue to use gasoline. Therefore, efforts should be first directed toward reducing the dangers inherent in this fuel. Two conditions are necessary to bring about the burning of the fuel. It must come in contact with the surrounding air and be vaporized. The air, thus carbureted, must come in contact with something hot enough to ignite it. Fire hazards will be reduced by avoiding these two conditions. If one of them cannot be avoided, one should seek to prevent its coincidence with the other. In normal flight, dangerous mixtures of gases are produced by leakage from the tanks or fuel pipes, or by the poor functioning of the carburetors. We shall, therefore, consider in turn the requirements to be satisfied by these accessories in order to avoid the above defects.

Fuel tanks.- These must satisfy the following conditions: Resist, without failure nor abnormal deformation, general accelerations imparted to the airplane in flight, shocks caused by surging of the liquid contents, and engine vibrations; be attached to the fuselage by fittings capable of withstanding the same stresses, without fatigue nor local deformation of the tanks; remain perfectly tight in spite of the fatigue or deformation; lastly, be able to withstand satisfactorily, and with-

out bursting, the impact resulting from a partial crashing of
the airplane on striking the ground. As to whether these con-
ditions are satisfied can be verified as follows.

1. Mechanical resistance.- The framework of an airplane,
with a safety factor of 2 to 2.5 is designed to withstand the
stresses due to its weight plus the additional load resulting
from accelerations in flight. The most intense and important
ones to be considered in this connection, are the centrifugal
accelerations during a turn or a leveling off after a dive.
Hence, letting R denote the total load under which the struc-
ture will collapse, and P the weight of the airplane in flight,
and assuming the maximum accelerations to be ng, we obtain the
fundamental equation

$$R = 2.5 \, nP = fP,$$

in which 2.5 n = f, the load factor of the airplane considered.

The order of magnitude of the centrifugal accelerations to
which the tanks are subjected during the preceding evolutions,
differs but little from those of the airplane as a whole. Under
these conditions, their mechanical resistance must satisfy the
above equation.

However, since the strength of the tanks is usually verified
by pressure tests which are not carried to the point of destruc-
tion, it is convenient to introduce the elastic limit rather
than the breaking load. Besides, owing to the metal structure

of the tanks, we can assume the load limit of the elastic deformation to be about 2/3 of the breaking load. Under these conditions the test pressure of the tanks can be expressed by the formula $E = \frac{2}{3} f p$, in which

E represents the load withstood by the tank without appreciable permanent deformation, this load being measured at the bottom of the tank and expressed in kilograms per square centimeter;

p represents the liquid load supported by the full tank while the airplane is at rest, the load being measured at the bottom and expressed in kg/cm^2;

f represents the load factor of the airplane for which the tank is designed, this factor corresponding to the case of flight with the center of lift in the extreme forward position (first case of flight of the C.I.N.A.).

The above formula has been adopted by the British Government for the delivery of airworthiness certificates to transport airplanes (D.3, September, 1928), it being understood, however, that the test pressure must in no case be less than .150 kg/cm^2 (2.13 lb./sq.in.). In the case of a normal airplane, with a load factor 6, and a tank containing gasoline (S.G. 0.7) to a depth of 0.60 m (1.97 ft.), this formula gives a test load of 170 kg/cm^2 (2.42 lb./sq.in.), which is increased to .280 kg (.62 lb.), if the airplane is designed to perform stunts (f ≮ 10). These figures compare with those of the 1921 French specifica-

tions (Art. 18) of uniformly 200 kg/cm² (2.84 lb./sq.in.). They
prove that a test pressure of .200 kg (.44 lb.) is insufficient
for very deep tanks (especially when designed to be used on air-
planes for stunt flying), and should be increased. This view is
confirmed by a study of the regulations adopted in other coun-
tries. In the United States (1925) the minimum test load was
.280 kg (.62 lb.), while in Germany it reached the very high
value of .750 kg (1.65 lb.). The Italian specifications for
1924 required a test pressure equal to the normal load at the
bottom of the tank, increased by .300 kg (.66 lb.) which, in
the case of the already considered model of 60 cm (23.6 in.)
depth, corresponds to about .340 kg (.75 lb.).

2. Tightness.- Hitherto we have only considered the condi-
tions of mechanical resistance of the tanks to centrifugal accel-
erations. We must also satisfy ourselves that they meet the
conditions required for the maintenance of perfect tightness in
service. The conditions of tightness, as specified in the various
above-mentioned regulations, are usually confined to requiring
the absence of leaks during the pressure test. It is easily
seen, however, that this simple test does not furnish, from the
viewpoint of tightness, such complete guaranties as for the me-
chanical resistance. As a matter of fact, the formula
$E = \frac{2}{3} f \times p$ has been based on an assumed safety factor of from
2 to 2.5 (with respect to rupture). Hence, provided the pres-
sure test proves satisfactory, there will be available a wide

resistance margin as a protection against the hazards and unfore-
seen stresses which the tank may have to withstand in operation.

On the contrary, the tightness of the tank may prove excel-
lent during the same test, but fail nevertheless for a load
slightly in excess of that previously supported. In certain
cases, experience has shown that tanks, after successfully pass-
ing the .200 kg (.44 lb.) pressure test, leak at lower liquid
pressures after installation on airplanes. These phenomena are
attributable to the fact that tightness is not only a function
of general fatigue and over-all deformations of the tank, but
also of certain local conditions, such as secondary deformations
in the seams due to defective riveting and welding, to which no
precise rule can be applied. In other words, the pressure test
at $\frac{2}{3}$ f p, does not provide a safety margin of the order of 2.5
for the tightness, as it does for the mechanical resistance, but
only a margin of $\frac{2}{3}$ × 2.5 = 1.6.

Considering the danger which even the slightest fuel leakage
entails, we are warranted in asking whether the coefficient 1.6
is not too small, and whether it would not be better to require
for the tightness of the tanks a safety factor of the same order
as for the strength of the airplane proper, i.e., 2.5. In this
case, the test pressure would no longer be given by the formula
$E = \frac{2}{3}$ fp, but by $E = fp$. Reverting to the example of a tank
of 0.60 m (23.6 in.) depth, installed on a normal airplane
(f = 6), this new formula would call for a test load of .250 kg

(.55 lb.) (instead of .170 kg (.37 lb.)). In the case of the
same tank mounted on a stunting airplane (f = 10), the test
load would be .420 kg (.93 lb.) (instead of .280 kg (.62 lb.)).
These figures are very acceptable and approximate those specified
in the above-mentioned American and Italian regulations.

Whatever the pressure, the following precautions must be
taken during the tests. All fuel and oil tanks must be tested
before being installed on airplanes. Besides, they must carry
during the test all the accessories included in the standard
service equipment. If compressed air is used for the test, it
is well to plunge the tank in a tub of water, since leaks are
then revealed by air bubbles. In this case, however, the coun-
terpressure exerted by the water on the walls of the tank should
be taken into account and the air pressure increased according-
ly. Besides, since the air pressure is constant over the whole
height of the tank, the air test is relatively more severe than
a water test. The test pressure must be exerted during a suffi-
ciently long period of time to enable the general and local fa-
tigues to make their influence felt on incipient deformations
and defects in tightness. A duration of 15 minutes would seem
sufficient.

There likewise arises the question of whether the tank
walls would also be subjected to deflection measurements, in ad-
dition to the strength and tightness tests. The French regula-
tions of 1921 (Art. 18) contain a statement to the effect that

deformations, produced during a test, should be neither permanent nor marked. The latter condition is essential. Unless contradictory results are obtained in practice, this condition may be defined as in the American regulations, according to which deflections not exceeding 5/1000 of the length, are considered allowable.

3. Fittings.- Lastly, a brief reference may be made to the fittings for securing the tanks to the fuselage. Considered from the viewpoint of mechanical strength, they should withstand, without permanent deformation, a total load equal to $\frac{2}{3}$ f P_r, P_r being the weight of the full tank. It should also be ascertained that the points of the tank, which carry the fittings, can withstand the above load without fatigue or loss of tightness.

According to considerations analogous to those arising in connection with the pressure tests, these tightness conditions should be satisfied not for a load of $\frac{2}{3}$ f P_r, but for f P_r. Since, however, as in the present case, we may content ourselves with testing a single unit of each type of tank or fitting, instead of testing all the tanks, it may be sufficient

a) To see that the fittings and the corresponding portions of the tank develop no leak nor permanent deformation under a load of $\frac{2}{3}$ f P_r;

b) To see that, under the load f P_r, the tank remains tight in the vicinity of its fittings, whatever its deformations (permanent or not).

In any case, this experimental work requires special testing devices, since the above-described pressure test cannot afford the necessary indications. For this purpose, Commander Lamé, of the Service Technique et Industriel de l'Aeronautique, has recently had a device made which renders it possible to investigate the surging action of the liquid, to be considered farther on. It consists in a platform to which is secured the tank to be tested. By means of a set of cams, a series of oscillations can be imparted to the platform, which thus receives either horizontal or vertical accelerations, capable of attaining three to four times the force of gravity. They are measured by means of recording accelerometers rigidly secured to the platform. Under these conditions, the tanks need only to be attached to the platform by means of the fittings intended to secure them to the fuselage, and to be filled with fuel or water (taking into account the difference between the density of the two liquids), in order to produce the accelerations and the fatigues to which the fittings and the tank itself would be subjected in flight. The first tests made with the S.T.I.Aé. device show that it can give us important information. Hence, these tests should be continued and developed. When they have yielded more exhaustive information, it will be time to consider whether corresponding tests should be compulsory and under what conditions.

4. Vibrations.- Turning now to the effect of vibrations on the tightness and resistance of tanks, we find it very difficult

to anticipate the conditions under which it is manifested. The
position of the tanks in the cell or fuselage, their relative
distance from the engines, their method of suspension, the ratio
between their natural vibration period and that imparted by the
engines, and lastly, their degree of fullness, are all elements
which affect this problem. It should be noted, however, that
the liquid mass usually contained in the tanks constitutes a
very efficient vibration absorber. Hence the latter seem to be
less dangerous to the tanks than to the pipes and other accesso-
ries. However this may be, recent reports indicate that the
Bureau of Aeronautics in Washington is considering the question
of rendering a 25-hour vibration test compulsory for all new
tank models. It would be interesting to obtain full particulars
regarding the vibration device employed and to study the experi-
mental results already obtained.

5. Surging.- There remains to be examined the question of
tank resistance to surging and horizontal impacts, especially
in hard landings. In calculating the above-described pressure
test, the accelerations were assumed to be practically perpen-
dicular to the airplane and to act so that the stressed liquid
remained in a state of relative pressure equilibrium. This
assumption corresponds to the case of a turn or of a leveling
off after a dive. There are evolutions, however, in which the
accelerations are tangential instead of being centrifugal, and
are not expressed by a general increase in the internal pressure

of the tank, but by water impacts on the front and rear walls.
This occurs when the airplane stops short, passes rapidly from
a horizontal to a steeply banked position of flight or makes
strong pitching motions.

The analysis of the motions of the liquid produced by these
accelerations is complicated and varies much according to circum-
stances. It is therefore difficult to make a general investiga-
tion. Thus, in studying the fatigue of the front wall of the
tank during a sudden dive, it is found to depend:

On the rapidity of the change of attitude;

On the final inclination of the airplane and on the result-
ing static pressure, when the new speed in the diving position
is reached (For long flat tanks this pressure may be rather high
in comparison with the normal pressure on the bottom);

On the distance between the center of gravity of the liquid
mass and the wall against which the liquid strokes either di-
rectly or in reflux, when the attitude of the airplane is changed;

On the fullness of the tanks and on the braking action
which the baffle plates in the tanks oppose to the motion of
the liquid or to the transmission of pressures.

For lack of general information, it will be interesting to
resort to a few direct experiments and to use for this purpose,
the acceleration platform referred to above. One can, for in-
stance, rate the maximum horizontal accelerations of the air-
plane in flight at 1.5 to 2 g, and demonstrate, by several

successive impulsions given to each new type of tank on the plat-
form, that no permanent deformation nor loss of tightness are in-
curred by the stresses undergone. The test may be made first
with the tank full and then with it half full or filled to the
level at which the free surface of the liquid may be expected
to develop the most unfavorable motions.

In any case, it will be necessary to determine with great
care during the tests, the deformations of the baffle plates and
the tightness of their attachments to the walls of the tank.
These baffle plates withstand liquid impacts, the strength of
which is directly proportional to the efficacy of their braking
action. These impacts may eventually loosen the rivets of their
attachments and impair their external tightness. It is also
probable that the fatigue of the tanks, after undergoing these
tests, will be smaller, in general, than that resulting from the
static pressure test, especially when there is a large number of
baffle plates. The French regulations of 1921 stipulate one
baffle plate every 50 cm (19.7 inch).

6. Landing shocks.- The above considerations form a natur-
al preamble to the study of the conditions under which the
tanks withstand the shock produced by the impact of the airplane
with the ground. Unfortunately, experience shows that, when
such accidents happen, the tanks almost always burst open, there-
by immediately spilling the fuel in floods. Fire danger is then
imminent. It can be avoided by building tanks which are more
resistant to dynamic stresses. Besides, their installation on

airplanes should fulfill certain conditions which are dealt
with in Chapter IV, of N.A.C.A. Technical Memorandum No. 537
(Part II of this report).

The analysis of the accelerations imparted to an airplane
which strikes the ground hard, shows that they can reach many
times the intensity of gravity. For example, if an aitplane
strikes the ground perpendicularly (Fig. 1) to its surface at a
speed of 120 km (74.6 mi.) stopping in 2 meters (6.56 feet) by
penetrating the obstacle or being itself deformed, the average
acceleration will be of the order of 50 to 60 g. The formula,
however, given above for the calculation of the test pressure of
tanks, assumed that accelerations which entail failure, without
leaving any margin for safety, would be only of the order of 5
to 10 g, according to the category of the airplane. However,
an airplane landing on its nose generally strikes the ground at
an appreciable angle (e.g., 15 to 20°) with the vertical (Figs.
2 and 3). Moreover, the tanks may not be full at the time of
the crash, thus reducing the liquid mass, the inertia of which
produces the destructive impact.

However the shock is transmitted to the tank, what are the
actual stresses engendered? During the dive preceding the land-
ing, the front wall of the tank withstands a static pressure,
expressed by a liquid column equal to the length of the tank.
The attachments of the tank to the fuselage are stressed hori-
zontally with respect to the normal line of flight of the air-
plane. They must be designed to support safely the weight of

the full tank under these new conditions.

When the airplane strikes the obstacle, the liquid tends to pursue its motion and exerts a dynamic pressure on the front wall of the tank, the effect of which is added to the initial static pressure. If the tank has no baffle plates, the liquid mass forms a single block and exerts on the front wall a unitary pressure roughly expressed by $l \, d \, ng$, l being the length of the tank, d the density of the fuel and ng the maximum acceleration of the airplane during the crushing and stopping periods.

On the other hand, if the tank is divided into transverse compartments, the liquid mass is cut in sections, separated by baffle plates, which prevent the instantaneous transmission of dynamic pressures from point to point. The resultant pressure on the front wall and on the adjacent side walls, is thus regularized, if not reduced in absolute value. Besides, this double effect becomes more pronounced with decreasing deformation of the baffle plates under the action of pressure and with the reduction in the width of the openings provided in the plates for the passage of the liquid from one compartment to the other. Eventually, the momentary loads supported by the baffle plates, will be transmitted through their fittings to the external walls of the tank, which will thus be made to participate in the resistance of the whole.

The reduction in general fatigue, obtained with baffle

plates for different tank types, cannot be estimated in advance. It actually depends on the number of baffle plates, on their own resistance and on that of the fittings by which they are secured to the outer walls. In this connection we will confine ourselves to the following observations. In order to be efficacious, baffle plates must be solid over nearly their whole surface. It is advisable to reduce the size of the passages between the compartments, so as to increase the braking effect. Each baffle plate must be strong enough to withstand, without serious damage, the difference in the momentary pressures exerted on its two surfaces. Lastly, it is advisable not to distribute the baffle plates uniformly over the length of the tank, but to reduce the intervals between them in approaching the front wall. Thus the action of the baffle plates will be more effective, especially if the destructive shock occurs when the tank is partly empty.

We can try to obtain a general idea of the pressures at which tanks provided with baffle plates should be tested, in order to prove fully satisfactory as regards their resistance to landing impacts. Taking, for example, a tank of 1 meter length, divided into two sections by a transverse baffle plate at 0.35 m (13.8 in.) from the front wall, the tank is assumed to be half empty at the moment of the impact, when the airplane strikes the ground at an angle of about 20° to the vertical. Lastly, the action of the baffle plate is assumed to be sufficient to permit of substituting, in the load calculation, the

mean acceleration for the maximum acceleration due to the impact.

The probable order of magnitude of this mean acceleration has been roughly estimated above at 50 g. Under these conditions the dynamic pressure on the front wall of the tank will be 0.50 m × 0.7 × 50 cos 20, or approximately 1.6 kg/cm² (22.8 lb./sq.in.). If the tank is to be designed to withstand this pressure limit without collapsing, it needs to support, without permanent deflection, only about 2/3 of this pressure, or roughly, 1.0 to 1.1 kg/cm² (14.2 to 15.6 lb./sq.in.). The difference between this figure and the test pressure adopted, for example, in Germany, - 750 kg (1.65 lb.) - is smaller than might have been feared. Hence, in a considerable number of cases, it may still be possible to build strong enough tanks, without making their weight prohibitive.

Besides, it would be of particular interest to test experimentally the accuracy of the assumptions on which the preceding calculation is based, namely:

By letting several old reclaimed airplanes crash against the ground in order to determine the maximum and mean accelerations imparted to the fuselage and its accessories;

By subjecting tanks of different types to accelerations of the same order and by determining the ratio of the pressures supported by the front and adjacent side walls, according to whether the tank is provided with baffle plates or not;

Lastly, by testing different types of baffle plates with

their attachments, in order to determine the best compromise be-
tween the qualities of strength, lightness and tightness.

Moreover, although reinforced tanks do not always fully
resist the shock of a crash, they nevertheless materially dimin-
ish the fire hazards. Above all, it is necessary to prevent
the fuel from immediately flooding the engine. As a matter of
fact, any delay in the spilling of the fuel and any reduction
in the size of the leaks diminishes the chances of the carburet-
ed air coming in contact with points hot enough to cause detona-
tion. Even if fire should break out, the crew would have more
time to leave the damaged airplane and to use all available
means to combat the fire. Hence, if the tank, instead of burst-
ing wide open, leaks only through a few small cracks, the fire
hazard will be greatly reduced.

The liquid, issuing from a broken tank, does not generally
have much kinetic energy. Hence, only a comparatively light
but necessarily tight dam is required to stop its flow. It will
be seen subsequently how such a dam can be made by extending the
fire wall laterally along the fuselage. It would also be impor-
tant to investigate the possibility of building, in agreement
with space and weight requirements, double-walled safety tanks,
the inner wall being strong and tight and the outer wall designed
to prevent leakage from the inner tank from getting into the
fuselage or engine cowling.

7. Resistance of attachment fittings to impacts.- We have already seen that during a dive stresses are exerted on the fittings which secure the tanks to the fuselage, their mean direction being parallel to its longitudinal axis. If the dive ends in a crash, these stresses suddenly increase and assume great values, the magnitude of which may be estimated from the abovementioned calculations. The effect of the impact on the tank varies according to the strength of its fittings. If they cannot take up the stress without breaking, the tank will be suddenly freed from all connection with the rest of the airplane. It will be thrust forward against the walls and accessories in its way. It is very liable to dislodge them and to be smashed against them. In any case, it may tear off the pipes and cocks which connect it with the engine. Thus, very considerable leaks will occur, even if the tank is built to withstand high pressures.

If, on the other hand, the fittings absorb the shock and keep the tank in position, its intrinsic resistance will lose none of its value. We will still have to make sure that the tank portions to which these fittings transmit their reactions, can withstand them without damage. Although it is not very difficult to make strong fittings and supports, it is more difficult to prevent the thin sheets of the tanks from being deformed under the action of the local stresses exerted by the fittings. The following suggestion is made in this connection. Place in

close contact with the front wall of the tank a metal lattice consisting of thin aluminum strips crossed and secured to the fuselage by a rigid frame. During a dive, the tank is supported by this lattice without entailing excessive local fatigue.

Whatever device is adopted, particular attention is called to the necessity of satisfying the conditions considered above. In this respect, most of the installations now used on airplanes are far from satisfactory. The tank is usually suspended in a cage consisting of four small angle-iron struts, the chief purpose of which is to guide the tank when it is dumped overboard in flight. These struts can hardly be expected to keep the tank in place in the case of a crash. On the other hand, when stronger supports are used, their bearing surface is seldom wide enough to distribute the reactions over the walls of the tank without damaging them. The above considerations apply alike to fuel and oil tanks. There is a more urgent need, however, for the application of the suggested precautions to fuel tanks.

In addition to these precautions there are those dealing with tank accessories, especially the fuel and air inlets. The cross section of the air inlets should be as small as possible and they should be so located that even jerky maneuvers and flight in rough weather cannot cause the fuel to spill. The air intake and tank-filling pipes must furthermore lead outside the airplane, to prevent accidentally spilled fuel (e.g., during a hurried re-fuelling) from getting inside the engine cowling or fuselage.

The latter precaution applies particularly to seaplanes, with tanks located in water-tight compartments, and to airplanes with tanks located in the confined atmosphere of the wings.

To sum up, we have pointed out the unexplored regions upon which experimental activity should be concentrated in order to produce better tanks with a minimum increase in weight. Until this result is achieved, the regulations now in force should be revised and defined, especially as regards the test pressures of tanks and the requisite resistance of their supports to horizontal stresses. More complete and strict regulations would probably contribute greatly toward protecting airplanes against the danger of fire.

Pipes.- Fuel and oil pipes on airplanes are exposed to three principal causes of leakage and damage, namely, vibrations, unequal expansion, and shocks of all kinds. Vibrations attack simultaneously the mechanical resistance of the pipes and the integrity of the joints and connections. Their effect is reduced by increasing the number of the fittings which connect the pipes to the stationary portions of the engine block and fuselage. In a general way (and except for the limitations given below) the danger due to vibrations decreases with increasing stiffness of the whole arrangement. Fatigue due to unequal expansion is, on the contrary, more pronounced when the corresponding pipes are less flexible. We can try to reduce it by a layout of the pipes which will enable them to compensate auto-

matically, by slight changes of shape or curvature, for the variations in length due to changes in temperature. These changes of shape must, of course, remain elastic. They must neither tend to open the joints nor to loosen the pipe connections.

In order to reconcile these contradictory requirements, designers have usually recourse to the following makeshift. They use rigid pipes with flexible connections. The pipes are firmly secured to the fuselage or to the engine block and the flexibility of the joints is relied upon to absorb the unequal expansions and damp the vibrations or render them harmless. The connections usually consist of rubber tubes reinforced by fabric. The tubes are secured by special clamps to the pipes which they connect. This method has the advantage of requiring the least effort. It is simple and enables overcoming most of the difficulties arising in connection with the piping system, by increasing the number of connections.

These advantages, however, are outweighed by very serious disadvantages. However good such connections may be originally, they soon lose their elasticity and tightness. They loosen in the long run. The rubber, of which they are made, hardens and crumbles or disappears in the fuel. The particles, thus detached, obstruct the pipes or nozzles. Hence they constitute one of the most dangerous causes of failure in flight. Lastly, it is not unusual, under the action of impacts, for pipes to separate from their connections and cause serious fuel leaks.

Therefore, it seems highly advisable to reduce the number of flexible pipe joints to a minimum and to prohibit the use of rubber-tubing connections and replace them by something better. It will be possible to reduce materially the number of flexible joints now generally used by adopting the following principles.

As regards vibrations of the piping, the airplane is divided into two distinct masses, the power plant and the fuselage, linked up with the tanks and their accessories. These two masses have quite different elasticities and vibration periods. Hence the portions of the pipes attached to the engine and those which, on the other hand, are attached to the fuselage, will simultaneously tend to acquire periodical motions of different amplitudes. At the same time, the intermediary elements will be stressed oppositely. Hence, flexible connections will have to be used at the junction of the two groups of pipes, attached respectively, to the engine and to the fuselage. On the other hand, it will usually be best to eliminate the flexible joints within each group and to increase the number of fittings by which the pipes are secured to their respective elements, thus bringing them into the closest possible union with the latter.

Although additional joints are required to facilitate assembly and maintenance work, there is no reason why they should be particularly supple. It is, on the contrary, better to use metal connections, entirely devoid of rubber, with its inherent defects. In other words, there must be two types of connections

or joints, according to the part they have to play. One type
is designed to assure the requisite elasticity. Only a very few
joints of this type will be used, and they will be made of rub-
ber, which is the only material having the requisite elasticity.
The other type is designed to facilitate dismounting and in-
spection. It must be absolutely tight, highly resistant and
free from rubber.

Thus far, we have considered only the resistance of pipes
to vibration. Hence, we may fear that a reduction in the number
of flexible joints will impede free expansion and entail danger-
ous fatigue of the too firmly strapped pipes. However, these
apprehensions are not justified, provided special attention is
given this point in laying out the piping system. Running pipes
in straight lines, especially over any considerable length,
should be particularly avoided. They should preferably be bent,
in order to leave a margin for slight deflections without strain-
ing terminal fittings and intermediate connections. Lastly,
provision should be made for free longitudinal sliding of the
pipes in their attachment fittings, in the event of marked tem-
perature variations. However, the portion of the airplane where
such variations occur is usually quite limited.

All these measures should greatly reduce the number of con-
nections and the danger of leakage. It is particularly impor-
tant to achieve this result on multi-engined airplanes, where
the very extensive fuel and oil pipes sometimes cover the greater

part of the wing span or fuselage. It is actually shown by experience, that such airplanes often suffer injuries to the pipes, which partly offset the additional safety afforded by the larger number of engines. Obviously, for such airplanes, the suitable layout of the piping system is a necessary corollary of the multi-engine and multi-tank problem.

The problem of how to construct the few flexible joints, which cannot be eliminated, still remains to be considered. This problem has received the special attention of the Service Technique de l'Aeronautique, on the occasion of the "Concours de Raccords" (Joints Competition), organized in 1928 under the auspices of the Comité de Propagande Aéronautique. Keeping in mind the lessons learned from that competition, a new one is now being organized by the S.T.Aé.

The program proposed to the competitors may be summed up as follows. The connections, once mounted on the pipes, must be able to withstand without fatigue nor leakage, test pressures of 2 kg/cm² (28.4 lb./sq.in.) for fuel and of 10 kg/cm² (142.2 lb./sq.in.) for oil. They must also be able to withstand a longitudinal pull of 25 kg/cm² (355.6 lb./sq.in) for 10 seconds, without leaking nor showing any tendency to separate.

In order to test the effect of the vibrations on the joints, they will be subjected to two tests of 25 hours each, separated by a complete disassembling and reassembling. The vibrations, to which the joints are subjected during these tests, may vary

between 1000 and 2000 per minute. The vibratory motion will be
imparted to the joints by a cam with return spring. It will
involve a simultaneous translation of 5 mm and a rotation of 5°
amplitude. The joints will be under an internal pressure of
1 kg/cm² (14.2 lb./sq.in.). They should show neither leak nor
wear, fatigue nor appreciable slackening.

Lastly, it will be ascertained whether the materials, of
which these joints are made, can withstand the solvent action
of gasoline and benzol (benzene), and the destructive effect of
flames in the case of a fire. A fifteen-days immersion test of
a joint fully assembled and of another joint in parts will ren-
der it possible to test the first of these qualities. As to non-
inflammability, it will be tested by dipping a pipe with its
joint in gasoline and immediately exposing it to a flame. The
fire should go out as soon as the gasoline on the outside of
the pipe is consumed, without igniting the gasoline inside the
pipe.

It will also be ascertained whether the joints are too
heavy or too bulky or too expensive to construct. Lastly, it
will be determined whether they can be assembled and dismounted
without   special tools and without requiring too much free
space for worker.

We may hope that these conditions, despite their relative
severity and complexity, will be gradually satisfied. In any
case, our designers will be expected to make a serious effort in
this line.

Fuel and oil pipes and their accessories are subjected to more or less dangerous impacts in service, the possible destructive effects of which can be reduced by the following measures. The pipes (especially those running from the tanks to the engines which are most exposed in the case of landing accidents) are made of copper, annealed after shaping. The use of brittle metals, unannealed copper and particularly duralumim, should not be authorized. The fittings, which connect the pipes to the power plant and to the fuselage, must be designed to yield first under the action of an impact and to release the pipes before they break. Protective sheet-metal guards should be provided wherever pipes are liable to be crushed or damaged.

Lastly, in order to prevent all the fuel contained in a tank from flowing into the fuselage, in the case of the accidental rupture of a pipe, each pipe will be provided with a stopcock. These cocks must have readily accessible quick-closing controls. They should, if possible, be operated by the pilot or else by the mechanic. It was seen above, that when a tank is not held horizontally by very strong supports, it may be thrust violently forward in a landing on the nose, thereby tearing off and breaking the pipes. Thus, from the viewpoint of protection against fire, it is of capital importance that the ruptures take place back of the stopcocks, which will thus provide means of stopping the leaks as soon as they occur.

Carburetor air intakes.- Fuel and oil leaks are not danger-
ous of themselves, but become so, as soon as the vapors which
they produce encounter flames capable of igniting them. The
phenomenon most to be feared in this connection is back-firing,
which takes place as follows: The air sucked in by the engine
passes through the carburetor, becomes charged with fuel vapor
and enters the cylinders. Owing to a trouble which may come
from various causes (jamming of the valve, irregular feed, etc.),
the mixture introduced into the cylinders is still burning at
the moment the intake valves are open. The escaping flames re-
turn in part to the carburetor, ignite the fuel which it con-
tains, and burst forth through the air intakes. These flames
may set the whole airplane on fire. Naturally, the best means
of avoiding the danger is to prevent bad functioning of the en-
gine, which causes it. Since, however, this cannot be fully
achieved, measures should be taken to stop the flames before
they reach the carburetor, and also to render comparatively
harmless the flames which nevertheless succeed in breaking out
through the air intakes. This can be done best by extending
the air intakes to the outside of the fuselage or cowling to
prevent the burning gases from coming into contact with any of
the combustible elements of the airplane. Besides, it is advis-
able to have the air-intake pipes open on the side, rather than
at the bottom of the engine bed, so that fuel sinks or pools
due to accidental leaks within the fuselage or cowling will not

be directly in the path of the return gases.

Particular attention is called to the danger involved by these sinks since, owing to the different inclinations of the airplane in flight; it is often difficult to anticipate the point where they will eventually empty into the atmosphere. This recently occurred on an airplane, in the cowling of which there had gathered a small amount of fuel. In spite of precautions, the motions of the airplane in flight finally brought the fuel into contact with the opening of the air intake, where it was ignited by the flames of a back fire. Fortunately, the quantity of spilled fuel was small and the fire stopped of itself. But the incident caused a crash in which the airplane was damaged and the pilot hurt.

The necessity of running air intakes to the outside has its disadvantages, especially during flights in damp and cold weather. In the first place, snow or ice may accumulate in the end of the air intake pipe and obstruct it, thus causing serious trouble. It is probable, however, that if the pipe is properly designed to avoid pockets and depressions where fuel or oil can collect, it will usually prevent snow or ice deposits.

On the other hand, the air being taken directly from the surrounding atmosphere, it cannot become warm and dry in contact with the engine, as it formerly did, when the intake opening was inside the engine cowling. Hence, it is drawn damp and cold into the carburetor where it tends to form frost. Since frost or rime

seriously jeopardizes the regular functioning of the engine, it must be prevented by all means. In other words, the use of external air intakes presents the problem of heating the carburetor and its pipes. This special problem is dealt with in Chapter III, N.A.C.A. Technical Memorandum No. 537 (Part II of this report).

In spite of this disadvantage, the necessity of running the air-intake pipes to the outside of the fuselage or cowling is undeniable. It applies not only to the air intakes of the main engines, but also to those of the auxiliary ones (starter, electricity, wireless) which may be carried by the airplane without always receiving due consideration. Thus, several fires which occurred in France in 1927-28, were due to faulty installation of the air intakes and tanks of starter engines.

Devices for the prevention of back-firing.- The above precautions, which apply to air intakes, reduce the dangerous effect of back fires, but do not eliminate them. Accordingly, several inventors have submitted special devices, designed to prevent flames issuing from the engine from reaching the carburetor. These devices are based on greatly differing principles.

One of them, recently tested in France, divides the carburetion into two separate processes. The first process takes place as in an ordinary carburetor, but the carbureted mixture is given a large excess of fuel. This mixture, after leaving

the carburetor, passes through a long pipe, at the end of which
there is an auxiliary air intake which determines the final com-
position of the carbureted air before its introduction into the
cylinders. Thus, any flames escaping accidentally through the
intake valve encounter, aft of the auxiliary air intake, the gas
current from the carburetor. Since this current contains excess
fuel, it does not burn and extinguishes the flames coming in
contact with it. This device is ingenious and efficacious
against back fires. Besides, it makes it possible to put the
carburetor chamber farther from the engine and thus protect it
against the injuries usually entailed by a rupture of the crank
case of a connecting rod. On the other hand, its adjustment is
difficult, owing to the condensation of fuel between the carbu-
retor and the engine.

Other devices, based on quite different principles, have
been tested in France. Some of them stop the flames by means
of non-return valves, which remain open as long as the air flows
from the outside toward the cylinders, but close as soon as the
flow reverses its direction. The other methods consist in op-
posing cooling surfaces to the flames. Hitherto non-return
valves have not given conclusive results, since the conditions
they must satisfy are partly contradictory. These conditions
comprise: very small inertia of the valve, enabling it to close
at the slightest back fire and to remain/under normal conditions;
open
ability to function in any position of the airplane during flight;

resistivity to deformation by shocks, and good gas tightness
when closed; sufficiently large air-intake pipe, guaranteeing
the engine against appreciable loss of power and preventing ir-
regularity of carburetion in the case of flapping of the non-
return valve. As a matter of fact, the valve models thus far
tested have proved ineffective and have presented more disad-
vantages than advantages, especially as regards saving power.

The use of cooling surfaces is obviously preferable. It
consists in placing a very large-surfaced metal screen between
the engine and the carburetor which it is desired to protect.
This screen consists of thin steel sheets or corrugated duralu-
min cylinders. The general direction of the screen is parallel
to the flow of the intake gas, to which it opposes only a very
slight resistance. Tests carried out on the ground and in
flight proved the loss of power caused by this protecting screen
to be practically negligible.

When the flames, coming from the engine, pass through the
cooling screen, their temperature is reduced by the contact sud-
denly enough to extinguish them. Many tests made on different
types of engines and with various kinds of protecting screens,
actually proved the latter to stop back fires created artifi-
cially by deliberately causing ignition or intake-valve irregu-
larities. The proportion of flames which pass in spite of these
precautions, varies according to local conditions, but is very
small (from 0 to 3 or 4%).

On the other hand, the weight of these devices is quite acceptable (only a few kilograms), especially if their supporting envelope is used for the installation of the usual intake-gas heating system. Their use is therefore strongly recommended.

For Part II, see N.A.C.A. Technical Memorandum No. 537, which follows.

Translation by
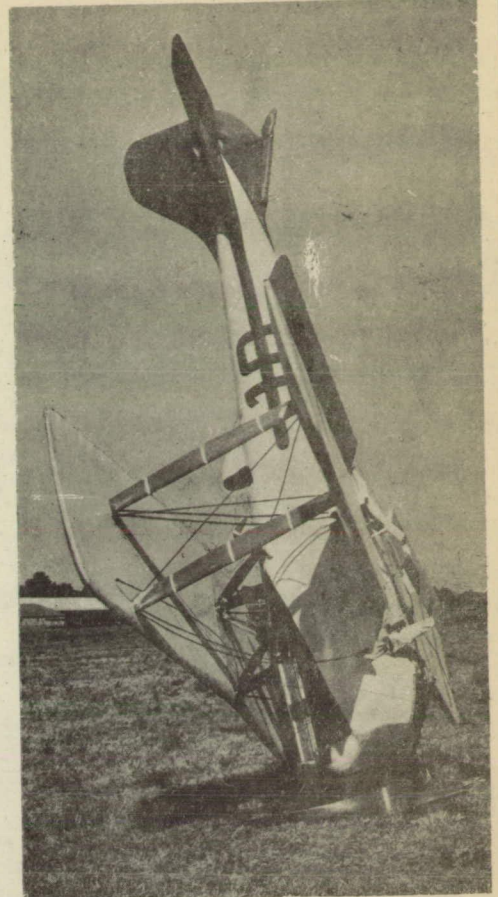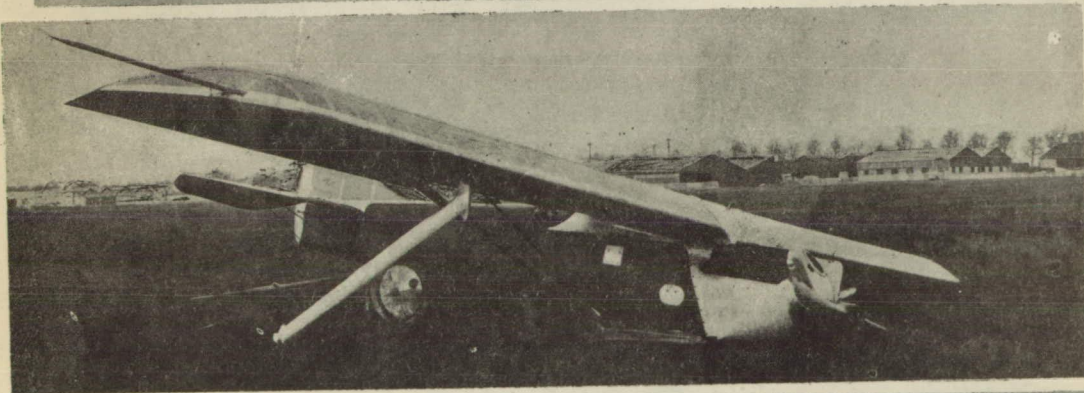National Advisory Committee
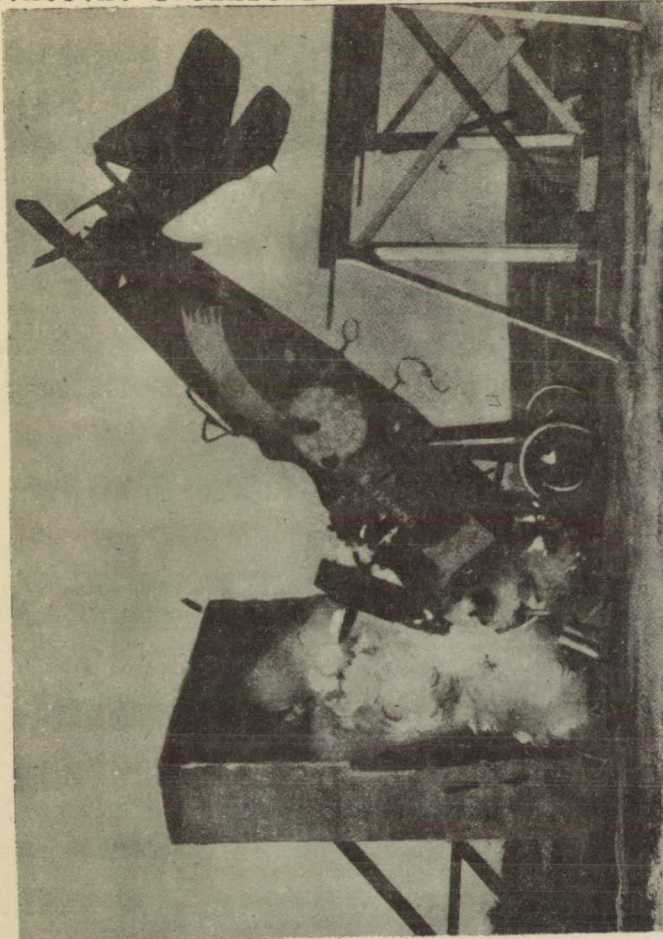for Aeronautics.

Fig.4 Crashing test made in the United States.

Fig.1   Landing on the nose.

Fig.2

Hard
landing
at an
angle.
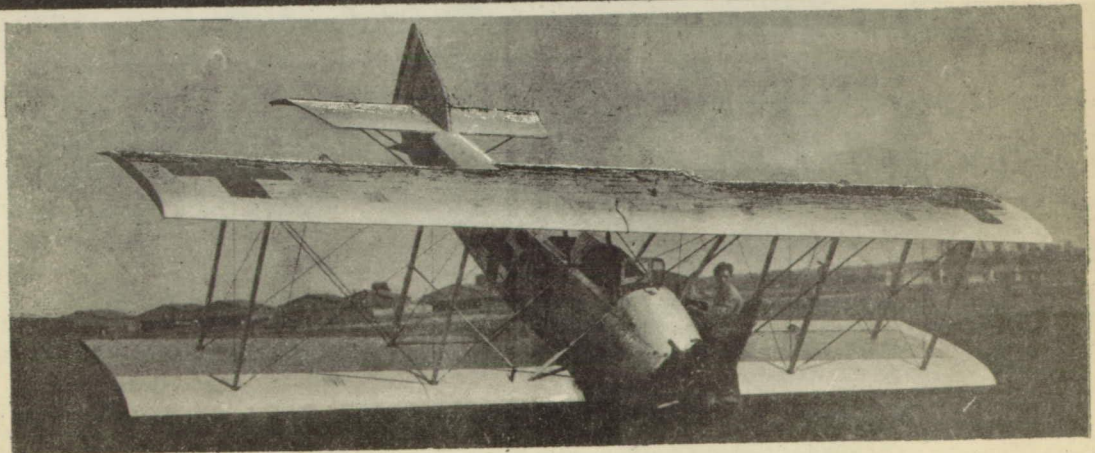
Fig.3

Hard
landing
at a
greater
angle