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No. 345

THE PREVENTION OF THE ICE HAZARD ON AIRPLANES

By William C. Geer and Merit Scott

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By William C. Geer and Merit Scott.*

The Formation of Ice on Airplanes

The reasons for the ice hazard and the ice forms have been reported in Technical Notes of the National Advisory Committee for Aeronautics (References 1 and 2). The weather conditions under which ice forms have been discussed by Wesley L. Smith (Reference 3).

For the purposes of the present report it is sufficient to say that the major risk** due to the formation of ice upon the airplane arises when the aircraft is operated through an atmosphere of mist, fog, or cloud, the temperature of which may range from 0°C to at least -20°C and when the relative humidity is high, usually 90% or above. When flown in such an atmosphere the leading edges of the various exposed surfaces, wings, struts, wires, etc., become coated with ice. The study of ice formation

*Research Chemist and Guggenheim Research Physicist, respectively. The laboratory work herein reported was performed principally at Cornell University, Ithaca, N. Y., under a grant from The Daniel Guggenheim Fund for the Promotion of Aeronautics, Inc.
The practical constructions were made by the B. F. Goodrich Co., of Akron, Ohio, and flight tests were performed by the National Air Transport, Inc., at Cleveland, Ohio.
This publication is authorized by the Committee on Aeronautic Research, of the Department of Physics at Cornell University, consisting of F. Bedell, Chairman, W. C. Geer, E. Merritt and C. C. Murdock.
**A more technical discussion of the process of ice formation upon a moving airfoil may be presented in a forthcoming paper by one of the authors.

as reported in this note indicates that the major risk comes from the undercooled fine particles of liquid water in the atmosphere.

In order to obtain an intimate picture of the way in which ice is formed on an aerodynamic form due to droplets in the atmosphere, let the case of a strut with the flow lines be held in mind (See Fig. 1). A droplet is imagined to approach the strut coming down one of the tubes of flow. The forces which act upon the drop are the following: (1) a force arising from the pressure gradient normal to the lines of flow; (2) a viscous force due to the air which tends to drag the drop along with it. As the drop approaches the strut force (1) tends to hold the drop away from the surface, where the curvature of the tube is convex toward the strut, and to force it on where the curvature is concave toward the strut; while force (2) tends to constrain it to a tube of flow and hence to carry it by without deposition.

An examination of these forces shows that the smaller drops are accelerated from the stagnant point S (See Fig. 1) much faster than the larger drops. The result, therefore, is a separation of the drops according to size, the smaller ones being carried farther from S. As Figure 2 indicates, actual formations under suitable conditions show a solid hard cap symmetrically located over S with a scattering of crystalline rime at its borders which appears very much like little prisms standing up into the wind. Such deposits have been obtained many times at the leading edge of wings and struts upon airplanes in flight

as well as upon the strut sections in the wind tunnel as will be referred to later.

Adhesion of Ice

As these fine water droplets strike the moving airplane they are deposited upon it, forming ice. Since at the time of contact, the water is liquid, it naturally tends to fill up all the small irregularities of the surface with which it is in contact and clings to it with a degree of adhesion that is natural to the adhesion of ice to the particular solid. The reasons for high adhesion of the ice to the exposed parts of the airplane, are probably (a) the solubility of water in these substances which when frozen is anchored in them; (b) the action of the force known as adsorption, assuming this to be a purely interfacial force existing between any two substances; and (c) the specific interfacial adhesion tension which may be peculiar to two different substances. If one assumed that interfacial adhesion tension is a characteristic of two different substances then it is logical to believe, with ice as one of them, that another may be found the adhesion tension of which toward ice is zero. It is therefore logical to undertake an investigation of a variety of different substances which can be applied to an airplane part in the form of a thin film or put on as a varnish to which it may be expected that the ice will not adhere.

Experimental Apparatus for Observation of the Formation and Adhesion of Ice upon Small Airfoils

In order to study ice formation and its prevention or removal, a small wind tunnel was set up in the laboratory. It was designed to permit of experimentation with the formation of ice from vapor but could be used in the study of ice formed from droplets. To meet without too great difficulty the requirement of obtaining high humidities and even supersaturations of a high order, the tunnel was, necessarily, small. When one considers the area of a tunnel, all of which is subject to deposition, he realizes that water must be fed to the air stream very rapidly. Also the tunnel must be kept free of nuclei, that is, hygroscopic particles upon which the vapor may condense, otherwise supersaturations may not be obtained. Calculation of the different quantities involved lead to the construction of a small tunnel of 7-inch by 7-inch cross section with a 3-inch circular throat. The diagrammatic sketch is shown in Figure 3.

The tunnel was designed so that an aspirator could be mounted in the channel at B. An additional thermojunction was added at E just out of the air stream in order that a better control of conditions might be possible, and a vessel for water was located within the evaporator. No temperature control has yet been incorporated into this vessel but the temperature was maintained as desired by the addition of ice. Thermojunction A was mounted at the intake of the aspirator at F.

The miniature struts were mounted in a holder at D and the formation under varying conditions was studied. The factors under control are temperature of air, temperature of water, and air speed. Evidently when the air temperature is close to 0°C, and the water above 0°C, the case corresponds to that of a temperature inversion. Under these conditions the ice is observed to be hard, clear, and of mushroom form with many icicles lying back on the strut or trailing to the rear. As the temperature of the water approaches 0°C, the ice formation becomes milky, takes the wedge-shape form predicted, with the ice due to the finer drops away from the stagnant point and making a fringe to the harder, clearer central ice (See Fig. 2). This deposit, obtained in many tunnel tests, seems definitely to confirm the mass separation of the droplets by the viscous force. As the air temperature becomes lower the ice becomes more cloudy and snowy white, is very hard and has the wedge-shape form at the leading edge. At the lowest temperatures obtainable in the tunnel without too great difficulty, ice still forms, is white and very hard and the adhesion to any surface is firm. This temperature has been as low as -20°C or -4°F. The air speed apparently has little effect upon the character of the ice formation.

A further observation was made: Although the ice becomes cloudy and more snowy in appearance as the temperature is lowered, the hardness of it does not decrease appreciably, and its adhesion to any given surface certainly increases. This result

might not be the case if the undercooled drops fell upon a surface at their own temperature and not upon one at a lower temperature, as may be the case in the tunnel. The greater adhesion seems to be related to the greater rate at which heat is withdrawn from the droplets.

Possible Means of Preventing Ice

1. Many different arrangements have been suggested whereby the exhaust engine heat might be used to warm the wing surfaces. All of these conduct the hot gases either directly through the wings to exit ports at the wing tips or at the trailing edges or through special ducts located along the leading edge of the wing or distributed throughout the wing. To prevent ice the outer surface of the entire wing must be maintained at 0°C or above, and it seems doubtful if the arrangements employing inside ducts will absorb sufficient heat to warm the entire wing surfaces without too much cumbersomeness and weight and without offering too great back pressure to the engine. It is certain that an exhaust gas sheath at the leading edge will not be successful unless the heat of the gases maintains the whole wing at 0°C or above, for experiment has shown that if the leading edge only is warm the melted ice runs back and freezes again upon the airfoil surface. Also in this connection the question arises as to what shall be done to protect the struts and wires.

It should be remarked that in view of present construction

the danger of corrosion is severe enough, to avoid an increase of which, special ducts to convey exhaust gases would seem to be needed - a problem of high difficulty within reasonable weight limits.

With those biplanes which are complicated by many wires and struts, the use of heat as an ice preventative seems impossible because of the lack of any light weight means of distribution of the heat to these several parts. As airplanes of simpler design come into general use, the employment of heat to prevent the formation of ice may become a simpler problem.

2. Analysis of this problem would not be complete without taking into consideration the possibility of the use on the airplane surfaces of substances (Reference 4) which are soluble in water and which have the effect of lowering the freezing point of water. Such substances theoretically should prevent the formation of ice so long as the quantity used in proportion to a quantity of ice formed upon the airplane at any one time, be such that the freezing point of the solution is below the prevailing air temperature. The choice of such substances may be from those which in eutectic proportions with water show such lowered freezing points. A considerable number have been tried: (a) using rubber in the form of unvulcanized smoked sheets as a vehicle, the one under test was mixed into it on a mixing mill and the mixture subsequently dispersed into an organic solvent and applied upon the airplane parts in the form of a paint;

these substances were glycerine, ethylene glycol, ferric chloride, calcium chloride, triethanol amine sodium chloride; (b) Using glue as a vehicle and water as a solvent, the following were tried: potassium oleate, sodium oleate, glycerine, ethylene glycol, dextrose.

These substances all retarded the formation of ice, but the effect was but temporary, and no soluble substances have been tested which prevented ice formation save when the temperature was very close to 0°C. This method of attack is not a practical one when one considers that the airplane may fly through rain before reaching an ice-forming region. The rain would be effective in washing off these water soluble materials and leaving the airplane unprotected in the ice region. Furthermore, the quantity of soluble substance required to protect the airplane for a flight of reasonable duration is excessive and would reduce the pay load by that amount. Any idea, therefore, in this category may be considered impractical.

3. Means of lowering the interfacial adhesion tension. One might believe that those substances which resist water, namely, which are good waterproofing materials, would be useful in reducing the adhesion of ice, but such is not the case. It does not follow that because a material, such as paraffine is so excellently water-resistant at ordinary temperatures, that it will show resistance to ice at temperatures at or below the freezing

point. Indeed, in some instances, the precise reverse is the case, although not in all instances.

The following substances were tested: nitrocellulose in the form of the dope usually used, ice adheres; rubber in the form of a vulcanized pure gum rubber sheet, ice adheres, but less so than to aluminum; deproteinized rubber as a vulcanized sheet, ice adheres, but less than to aluminum or to the smoked sheets of rubber vulcanized; deresinized balata, gutta siak and gutta-percha were tried, but they are difficult to put into solution except hot and upon cooling they formed a rough surfaced film, and therefore were impractical; a sheet of deresinized balata was found to reduce the adhesion of ice to a considerable degree; an isomer of rubber known as thermoprene, dissolved in benzol reduced the quantity of ice formed, probably because of the heat insulating properties of the substance; but the adhesion was relatively high; films of vinylite and metastyrol show a fairly high adhesion.

Various hydrocarbons other than rubber were tried, having dissolved them in solvents and applied as a varnish to the airfoil. In order to obtain fairly good films it was necessary to dissolve most of these in hot solvents, turpentine being the most usual one used. The use of hot solvents is in itself not as practical as that of cold solvents, but the following were tried: candelilla wax, montan wax, carnauba wax, paraffine. The ice formed and adhered strongly to all of them.

The adhesion of ice toward various fatty acids and their salts in the form of greases, waxes, etc., was observed. Cocoa butter rubbed on as grease, stearic acid dissolved in turpentine, goose grease, ice adheres strongly to these. The adhesion is higher to the greasy substances, due apparently to the fact that even though slippery at ordinary temperatures, these substances became sticky at lower temperatures and held the ice. No more ice is formed because of these substances, however, and the adhesion is no higher than to aluminum.

Of the various salts of the fatty acids which were tried, the following may be listed: magnesium stearate, barium stearate, potassium oleate, aluminum oleate, aluminum palmitate, calcium stearate, aluminum stearate, zinc stearate, zinc palmitate, lead stearate, copper oleate, lead oleate, calcium oleate. These salts of the fatty acids were difficult to put into solution. In the majority of instances it was necessary to dissolve them hot and apply them hot to the airfoil. Upon cooling and before the evaporation of all the solvent, usually the salt would precipitate in the solvent and there would then be formed upon the airfoil merely a dust or at best, a weak film. It was found preferable therefore to search for vehicles which would serve to retard the rate of precipitation on cooling, or hold the salt in solution in the cooled solvent free film.

Summing up a large number of experiments, the best results were obtained by the use of calcium stearate and calcium oleate

dissolved in hard gum damar resin and hot turpentine. For calcium stearate the proportions were two of calcium stearate to one of gum damar; the ice adhesion to this film was definitely lower than to aluminum. Better results were obtained by the use of calcium oleate in the proportions of calcium oleate 10, gum damar 5 parts by weight, hot turpentine 50 parts by volume. This solution required a long boiling for its proper preparation, and then filtration. The adhesion to this film was low. However, for some reason that we have not determined the duration of the effectiveness of this film upon the airfoil was not long. The calcium oleate is superior to the calcium stearate in that it remains in solution when cold.

It is a general conclusion from all the experimental work that even if the adhesion of ice to these films be lower than to either aluminum or the "nitrodoped" surface, the rate of the formation of the ice upon these low adhesion surfaces is no different from that upon those surfaces to which this varnish has not been applied. In other words, low adhesion does not change the rate of formation.

Some tests were run using very thin, highly polished films. In testing out the theory that perhaps the character of the surface so far as absolutely colloidal uniformity is concerned, might have some effect upon adhesion, we tried the use of a mixture of carnauba wax, Japan wax and calcium stearate in the form of a grease which was rubbed upon a wood airfoil and then highly

polished. This seemed to indicate a definite lowering of the adhesion.

4. It had been evident that the principle of lubrication of the surface would be a most effective means of lowering the adhesion of ice to such a lubricated surface. This has been suggested by others (Reference I). The previous work, however, indicated that these oils were scrubbed off in the air stream and since they were removed from the leading edges by the wind forces they had no effect at the place where most needed. Our experiments have confirmed this conclusion. However, two factors required further study in the field: (a) the choice of oils, and (b) the selection of a vehicle for the oils, the latter to be of a character that would hold the oil at the surface of the leading edge of the airfoil. Obviously, whatever vehicle would be used, would determine to a certain extent the choice of the oil. The various vehicles which have been tried are: unvulcanized rubber, vulcanized rubber, paper, nitrocellulose, either in the form of a film applied from a "nitrodope" or as a sheet of nitrocellulose added, and leather. Nitrocellulose possesses a characteristic of absorbing certain well-known oils which are used in the nitrocellulose lacquer industry as plasticisers. The majority of these, however, render the nitrocellulose film sticky, and our experiments indicated that when the plasticisers are used upon a nitrocellulose film in sufficient quantity to be effective, the film is far too sticky to be

practical and so the adhesion of ice would be higher instead of lower. We therefore eliminated the nitrocellulose from consideration, as a vehicle for oils.

Leather, paper, or any fibrous material would serve to hold oil well, but, on the other hand, rain would emulsify the oil and displace it from the fiber, therefore causing the adhesion to be higher. This was proved by experiments. Further tests, however, were run on a waterproofed paper, oil-soaked. Although the adhesion was less, it was too temporary an expedient to be considered. So we chose the one most practical substance, vulcanized rubber.

Unvulcanized rubber was discarded for the same reason mentioned above in respect to nitrocellulose, viz., those oils which would be soluble in unvulcanized rubber usually dissolve it into the form of a very sticky cement.

On the other hand, a vulcanized rubber sheet has the property of absorbing large quantities of various oils without becoming sticky. For our special purpose a most valuable property is that when oils are dissolved in it they show upon standing, a decrease in solubility with temperature and consequently an exudation of the oil from the body of the rubber to the surface. In order to prove the principle involved and whether the adhesion would be reduced sufficiently, the oils which were first tested were chosen regardless of the effect upon the quality of the vulcanized rubber sheet as to swelling and deterior-

ation of tensile strength.

An oil to be used in connection with a vulcanized rubber sheet must show certain characteristics, namely, (a) It must absorb into the rubber in appreciable quantity; (b) Its freezing point must be below any temperature at which ice may form; (c) Its viscosity at any ice-forming temperature must not be high enough so that when in thin film upon the surface it would be sticky rather than fluid. We may arbitrarily choose -25°C as the desired freezing point as this temperature is below any ice-forming conditions. In other words, properties (b) and (c) must be a freezing point of -25°C, or below; and a high fluidity at temperatures down to that one; (d) Its vapor pressure must be low, that is, its boiling point must be sufficiently high so that it may be called a permanent oil. It must not evaporate readily, even when one considers the speed of the airplane, and the rate of air flow over an airplane when at full cruising speed. It must be absorbed rapidly into rubber so that the oil may be painted upon the protected part frequently. One may choose, therefore, an arbitrary figure for the duration of the effectiveness of the oil to be absorbed into rubber as that of not less than 48 hours, to allow for a long flight. So far as mail planes are concerned running between Cleveland and New York, or Cleveland and Chicago, it would be quite possible to use an oil successfully which would need reapplication at periods of four hours. These latter comments indicate another

characteristic, namely: (e) The oil cannot be a drying oil which will become hard upon oxidation in the air. This excludes many vegetable oils. It would be preferable if the oil could be one known technically as nondrying oil, although it may be semidrying.

The oils which are absorbed into rubber, the freezing points of which are -25°C and below, and the boiling points of which are 180°C and above, include the following:

	Melting point	Boiling point
Diethyl benzene	-20°C	181°C
Tetrahydro naphthalene	-25°C	206°C
Decahydro naphthalene	-125°C	193.3°C
Pine oil	-25°C	--
p-cymene	-73.5°C	176.5°C
A chosen petroleum lubricating oil of a melting point as low as -20°C and a boiling point unknown		

Out of the large number of oils tested the pine oil and low freezing point petroleum lubricating oil when soaked into a vulcanized rubber sheet of the so-called pure gum type showed the most pronounced lowering of adhesion.

The adhesion of the ice in the refrigerated wind tunnel tests to the rubber so treated was so low that it was very easy to push the ice off. Repeated tests in the wind tunnel of oiled rubber sheets showed that the adhesion remained low and within a practical range. However, the rubber swelled, as it is well

known that it will do when these oils are soaked into it, and when swollen it was irregular upon the surface. It rapidly deteriorated upon exposure.

In order to render the oil-soaked rubber a practical one for airplane use, it became necessary to find an oil mixture which would not deteriorate the rubber. To solve this problem, a large number of mixtures of oils were tried and a two-component mixture was conceived, namely, that of an oil soluble in rubber mixed with an oil insoluble in rubber, each chosen from those which had the thermal and viscosity characteristics desired. Each of these two oil components in mixture would be absorbed into rubber and its swelling and deterioration reduced, forming a three-component mixture such that each of these components would be miscible in some proportion. Pine oil was chosen as the oil soluble in rubber, and into this pine oil was mixed an equal quantity of a liquid insoluble in rubber. Generally speaking, this group was taken as the nitrocellulose solvents and plasticisers.

Out of a large number of mixtures examined, an equal mixture of pine oil and diethyl phthalate seemed to be a good one, but these liquids were not miscible as was the case with a good many of the others which were tried. In order to eliminate the two-phase mixture, just enough castor oil, which in itself was not soluble in rubber, was added to bring the other components into solution. This oil mixture, known as JA52, was composed

of pine 4, diethyl phthalate 4, and castor oil 1, parts by volume.

To determine the effect of this oil mixture upon rubber a pure gum composition consisting of smoked sheets of rubber, sulfur, zinc oxide and accelerator enough for vulcanization was cured and cut into test strips. These strips were tested for tensile strength before soaking in the oil and other strips were soaked in this JA52 mixture for 24 hours and then removed and tested. The following figures are typical: the composition showed a weight increase of 18.8%, volume increase of 7.55%, tensile before 4915 (lb./sq.in.), tensile after 4310 (lb./sq.in.), a decrease in tensile strength of 12.3%. Another composition showed a weight increase of 17.4%, volume increase of 6.2%, tensile before 4487 (lb./sq.in.), tensile after 4010 (lb./sq.in.), a tensile decrease of 10.6%. Long continued soaking of the rubber test strip even in this oil mixture shows a slowly decreasing tensile strength. However, for purposes of use upon an airplane, the 20% increase in weight may be considered as the maximum which would be absorbed into the rubber at any one time. In point of fact, due to syneresis and the fact that the ice as removed would continually take away small amounts of the oil, this 20% weight increase would probably decrease and would need therefore to be built up by the process of painting the oil upon the rubber part.

To duplicate here the data from all of this work on the

rubber composition and the oils to be used, would extend this note far beyond reasonable bounds. Suffice it to say that the rubber mixture, its coefficient of vulcanization, and the oil mixtures and the proportions of the oils used, all play vital parts in both the adhesion and the maintenance of the rubber in a proper degree of quality. In the wind tunnel this oil mixture has shown a degree of adhesion which is low enough and shows the characteristic of exuding to the surface and maintaining the surface in an oily condition at the temperature at which ice forms. Without further addition of the oil a rubber sheet has repeatedly been coated and the ice removed without an apparent decrease in effectiveness. There is some number of times that the ice can be formed and removed after which the oiled rubber sheet will lose its effectiveness, but this point has not yet been determined.

Even though the adhesion of ice to this oiled rubber is very low, the ice does not remove itself during the flight of the airplane and no sideslipping or other attempts of the pilot have succeeded in eliminating it. Such failure of the ice to be displaced from a low adhesion surface is probably due to three contributing causes. First, while the adhesion has been decreased, it still remains a small positive quantity. Second, due to the process of the ice formation, the contact between the ice and the surface is so perfect that the atmospheric pressure tends to maintain this contact. Third, the aerodynamic

forces, arising from the flight speed of the airplane, act in such a way upon the ice as to hold it in place (See Fig. 4). Compared with these forces, the weight of the ice is inappreciable so far as accomplishing the removal of the ice is concerned.

The Ice-Removing Overshoe

In order to overcome the forces which hold the ice upon even a low adhesion surface, several methods were tried out in the wind tunnel. The most successful consisted in the use of an expanding rubber sheet about the leading edge of the airfoil. When this sheet was so fastened as to permit expansion by air pressure the ice was lifted and loosened.

A pure gum rubber sheet was wholly unsuccessful in practical trials because of irregularity of expansion or "ballooning." So a fabric-strengthened member was designed, called for convenience the "ice-removing overshoe."

This detachable rubber-covered overshoe* was placed over the leading edge and back toward the lines of maximum ordinate. It was made of light fabric, in the center of which and parallel with the leading edge, is a rubber tube reinforced by elastic stockinet fabric. The rubber tube is capable of expansion by air delivered under pressure. Over this tube and elastic stockinet is a thin rubber sheet, the whole being vulcanized together into one piece. The edges are reinforced and along the reinforcement are applied grommets of the type used upon automobile

*These devices were constructed through the courtesy and cooperation of the B. F. Goodrich Company, of Akron, Ohio.

side curtains with the usual pin, over which these grommets are to go, being permanently set into the wing structure. This overshow may be applied and detached quickly, and to avoid the deteriorating action of sunlight upon rubber, the overshoe is intended to be attached to the airplane only when needed. The overshoes surround struts and wires, being laced or clipped at the trailing edges. The tube upon inflation expands evenly along its length, the ice is lifted, the vacuum tends to be relieved, and the ice becomes a foreign body upon the airplane and to be removed by the air forces. The diagrams (Fig. 5) show the essential principle of the structure of the overshoe, and Figure 6 indicates schematically a fully equipped airplane, except for wires which are too small to show well in a small drawing.

In the practical tests which were tried late in March and early in April, upon an airplane of the National Air Transport, Inc., and piloted by Mr. Wesley L. Smith, Eastern Division Superintendent, we used (a) a test section upon a wing, the section being 36 inches long and 15 inches wide. Two tubes were in the leading edge, each of which was 2 inches wide. Photographs of this overshoe, not inflated, partly and fully inflated, are shown in Figures 7, 8, 9. On one of the six-foot supporting struts there was an overshoe 8 inches wide with one 4-inch tube. This overshoe was laced around the strut and was probably larger

and heavier than would be necessary in practice. This overshoe which was comprised of only one inflation tube, is shown uninflated as Figure 10, and inflated in Figure 11. The radio mast was protected with a laced-on overshoe carrying two 2-inch tubes along the leading edge. These were also probably larger than necessary. One of the flying wires was protected with a very light weight simple single tube expansion overshoe, the tube extending practically around the wire and the little overshoe was sewed on behind.

The airplane carrying these parts was flown in ice conditions. The ice formed on the leading edges of all parts of the airplane including the overshoes and was removed from the expansion members upon their inflation. A ground examination after the airplane returned to the hangar showed all leading edges of the airplane carrying a coating of ice in the usual way, but there was no ice upon any of these overshoes. Ice was formed upon the wing from the fuselage to the overshoe, no ice upon the overshoe, and ice continuously from the edge of the overshoe on to the end of the wing. Three practical tests have been run and in each case inflation of the previously oiled expansion members removed the ice.

Recapitulation

1. The adhesion of ice to a surface may be reduced somewhat by the application of certain waxes and varnishes. In the experiments described, the varnishes containing calcium stearate and

calcium oleate gave the best results. In wind tunnel tests, the adhesion was further reduced by the application of these waxes and varnishes to a thin, heat insulating layer of rubber.

2. The adhesion of ice is greatly reduced when the surface consists in a vehicle which carries an oil in sufficient quantity so that the surface of the vehicle is self-lubricating. The oil must be fluid at the ice-forming temperatures and should be permanent. The vehicle is vulcanized rubber of a suitable composition.

3. Ice may be removed from the wings, struts, wires and other parts of an airplane during flight by the inflation of properly constructed pneumatic rubber members, providing these members have previously been treated with a suitable low adhesion oil as described in (2). These rubber parts or overshoes contain one or more expansion tubes or compartments which are strengthened by extensible fabric. These parts are readily detachable so that they may be used only when needed.

Further Immediate Technical Developments

Further developmental work is necessary in order to perfect the design of these ice-removing overshoes, both as to manufacturing problems and to give to it the least effect upon the aerodynamical characteristics of the airplane. So it is proposed to study different designs in their effect upon lift and

drag; the size of the air tubes; the weight of the overshoe, its durability, by repeated inflation tests in a refrigerated wind tunnel; and of no less importance is the design of the air pump, distributing system and automatic air valve so as to give the pilot the minimum of care when flying through an ice-forming area.

Cornell University,
June, 1930.

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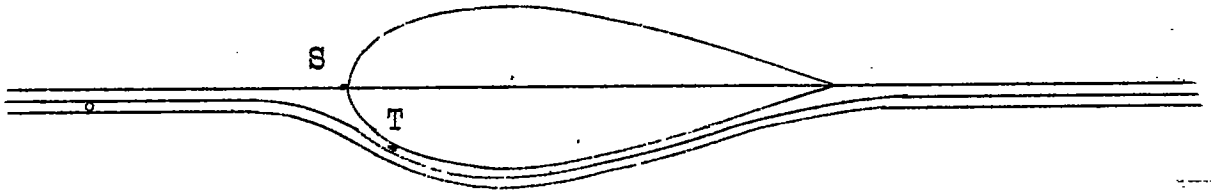


Fig.1

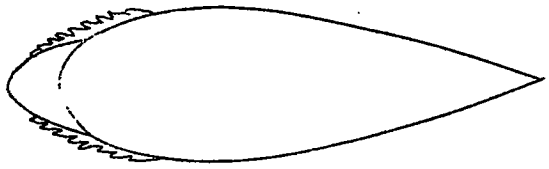
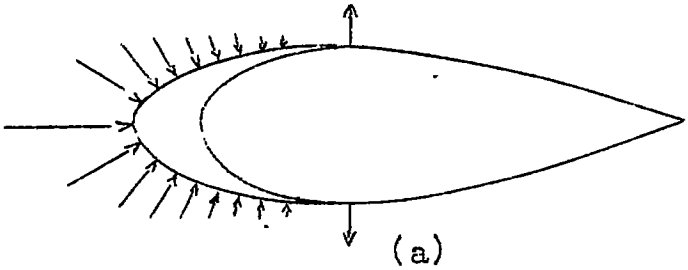
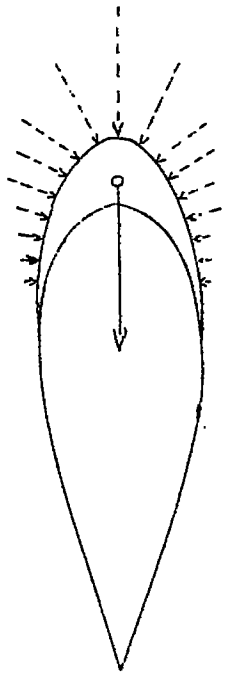


Fig.2



(a)



(b)

Fig.4 The aerodynamic forces are replaced by their resultant R in this mechanical analogue to show the stable equilibrium of the ice cap.

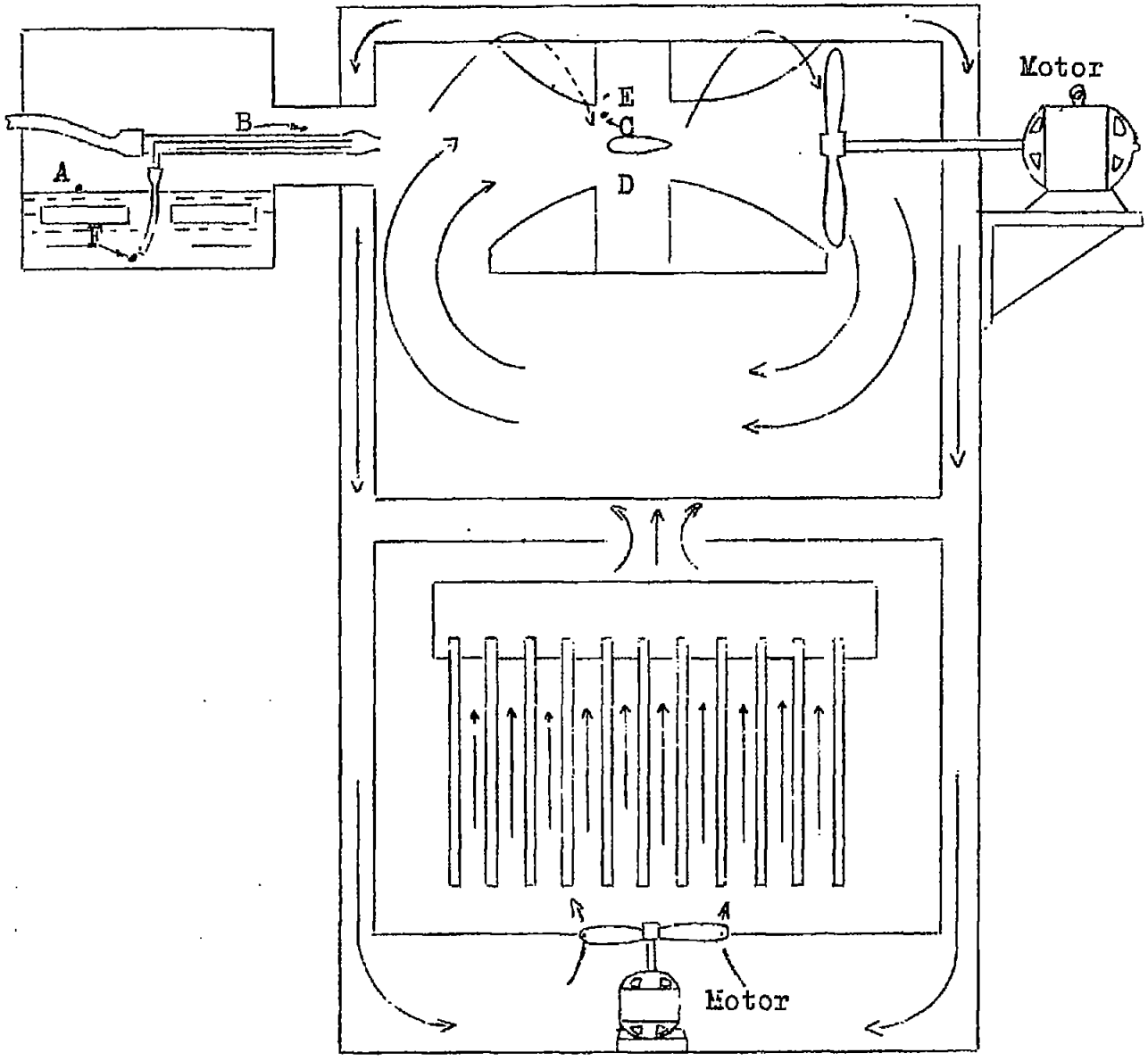
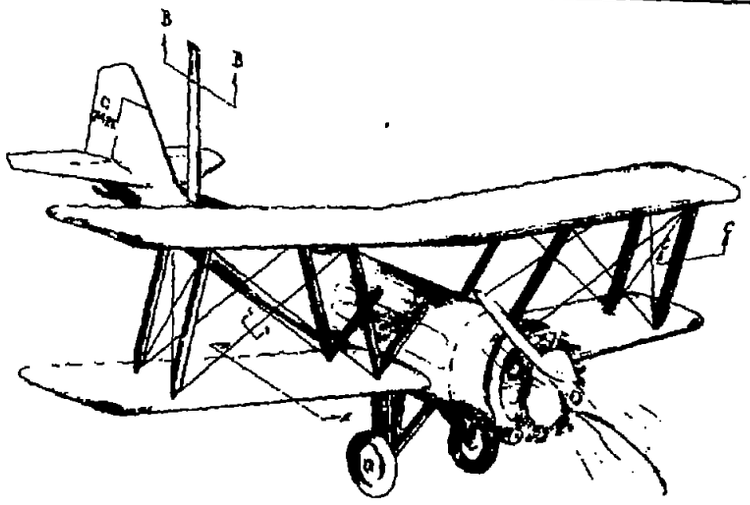
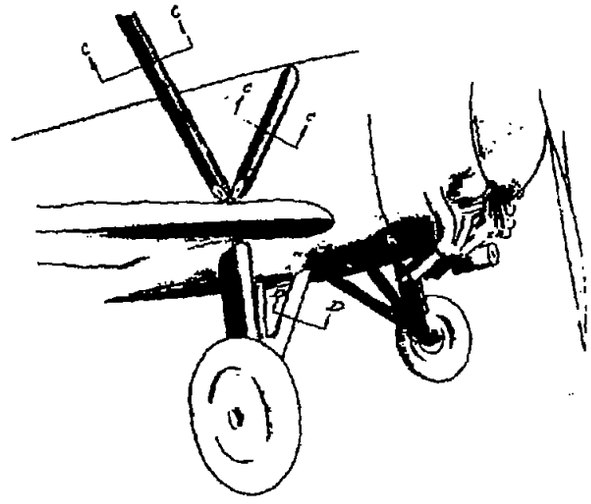
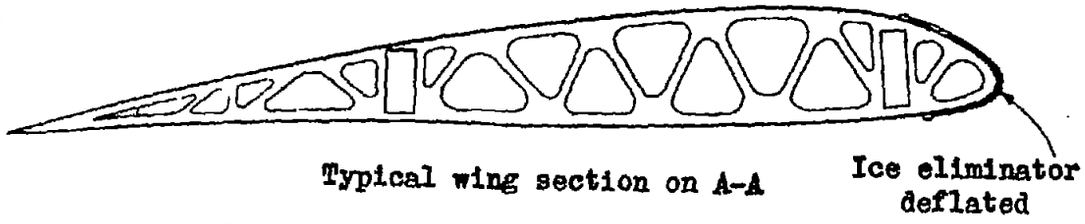


Fig.3

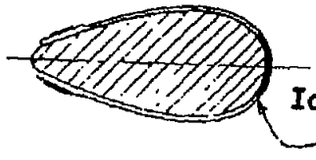
Fig.3



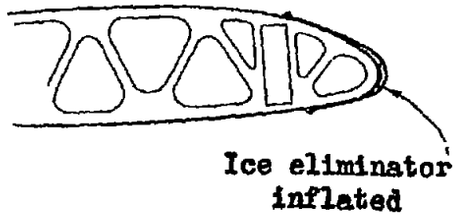


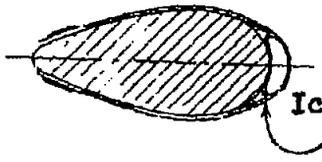


Typical wing section on A-A

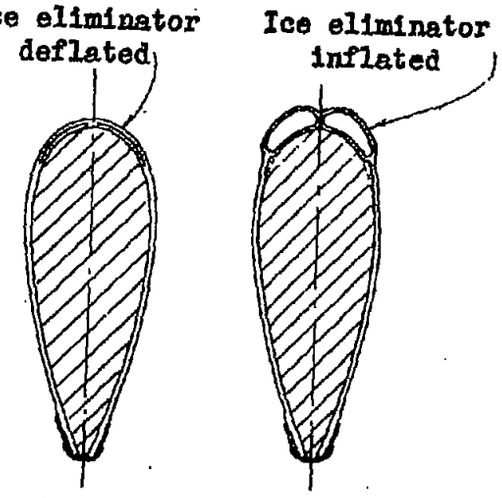


Typical strut section on C-C or D-D





Typical flying wire section E-E



Typical radio mast section on B-B

Fig. 5

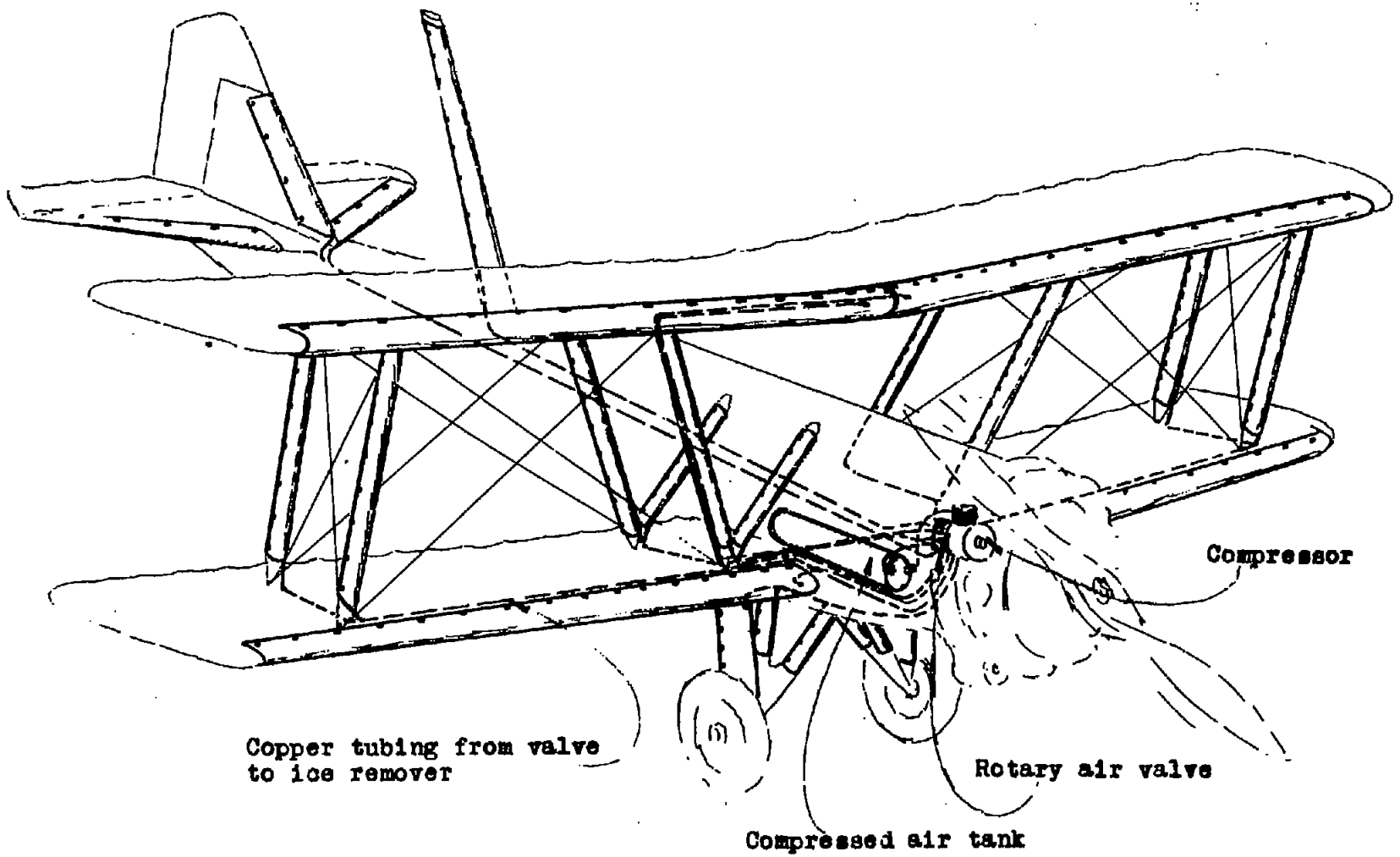

Compressor
Copper tubing from valve
to ice remover
Rotary air valve
Compressed air tank

Fig.6

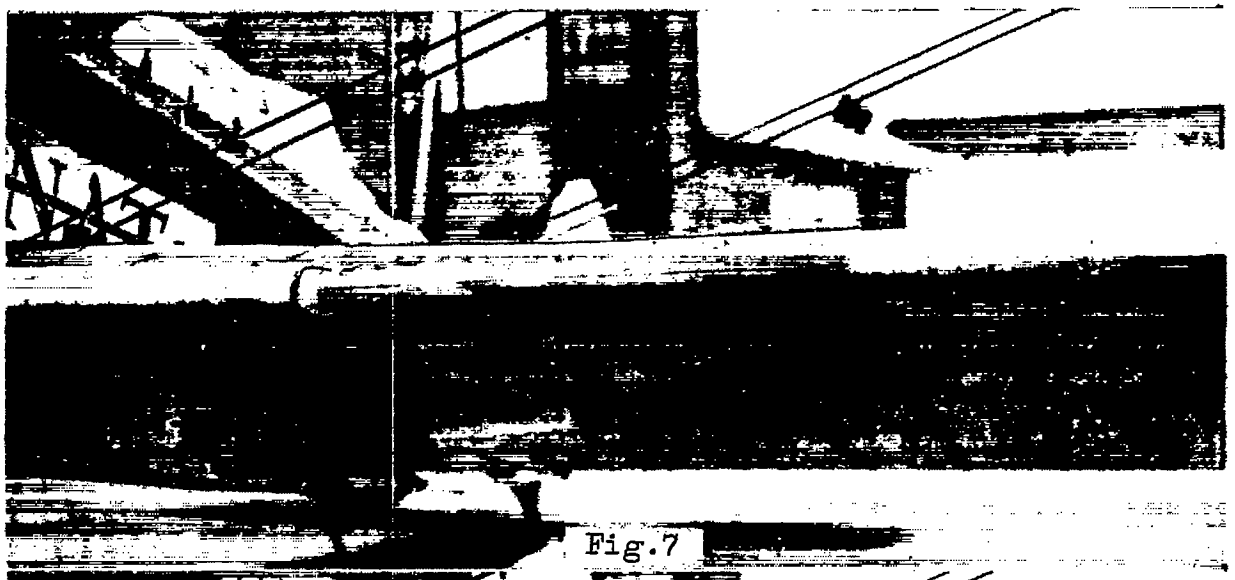


Fig.7

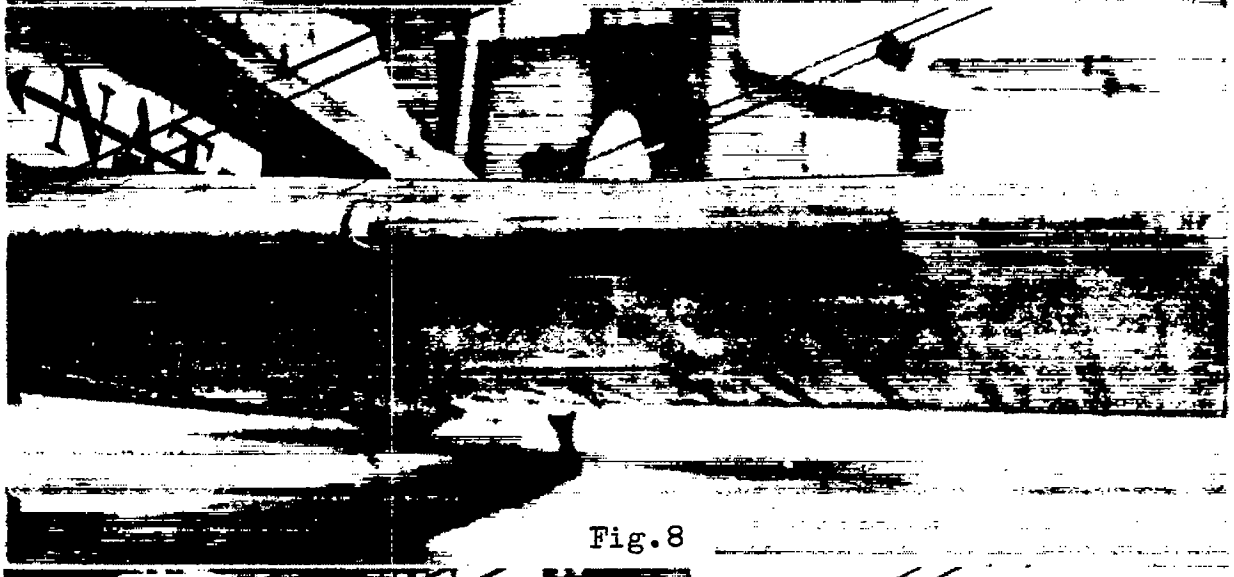


Fig.8

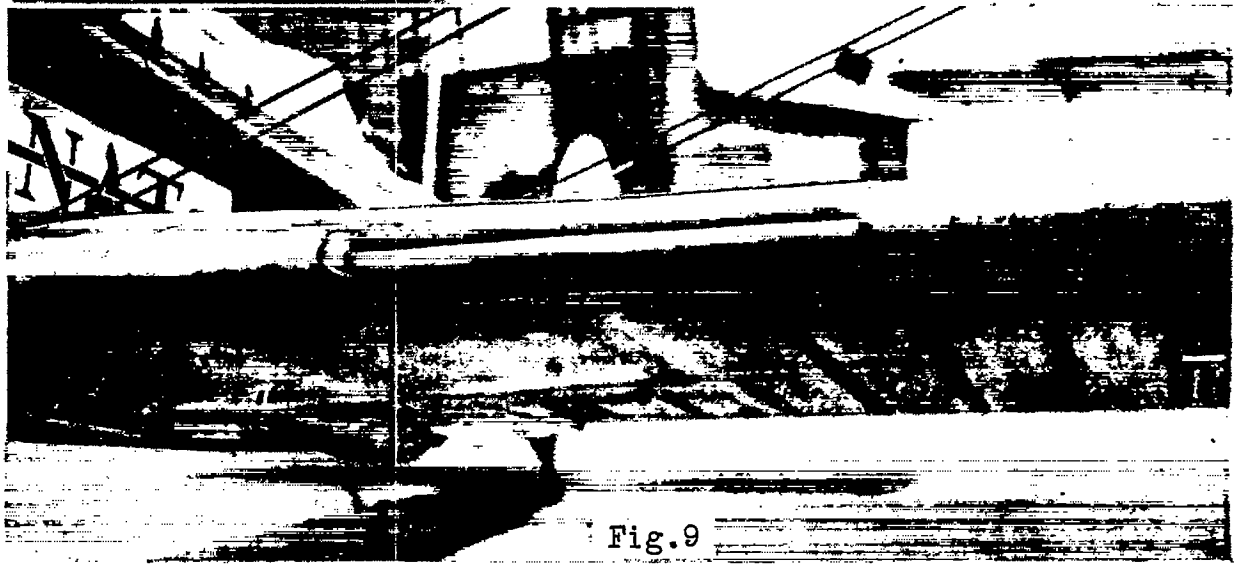


Fig.9

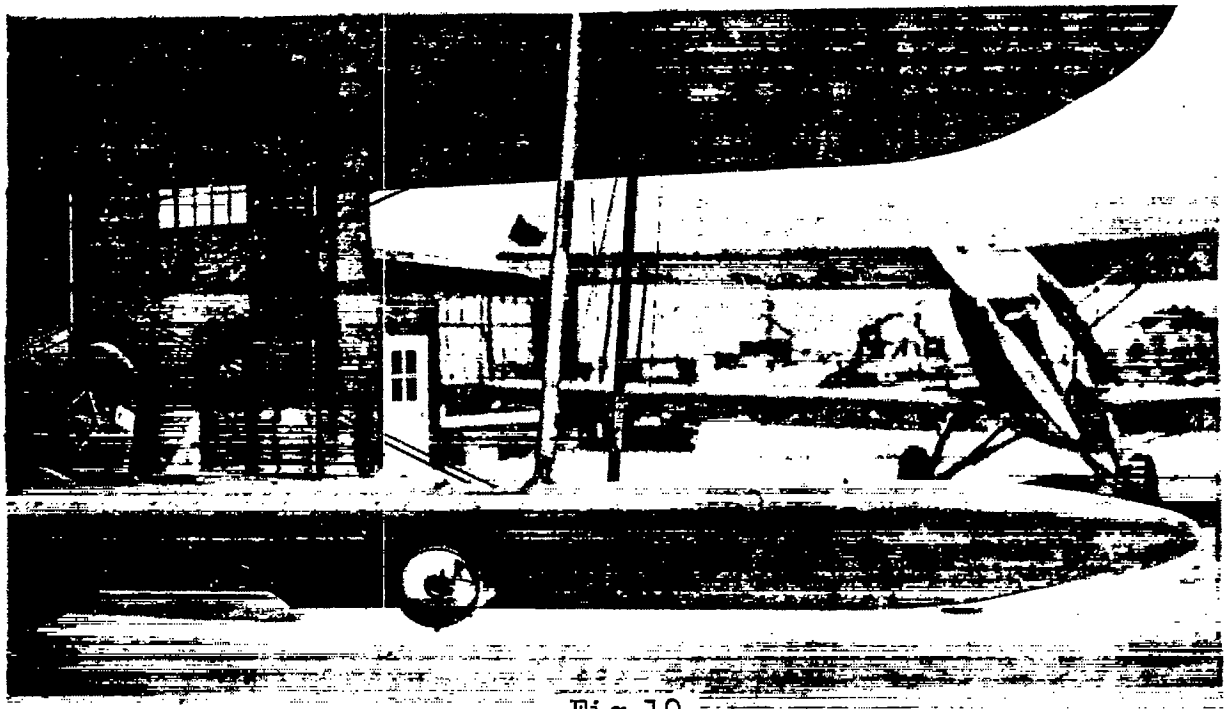


Fig.10

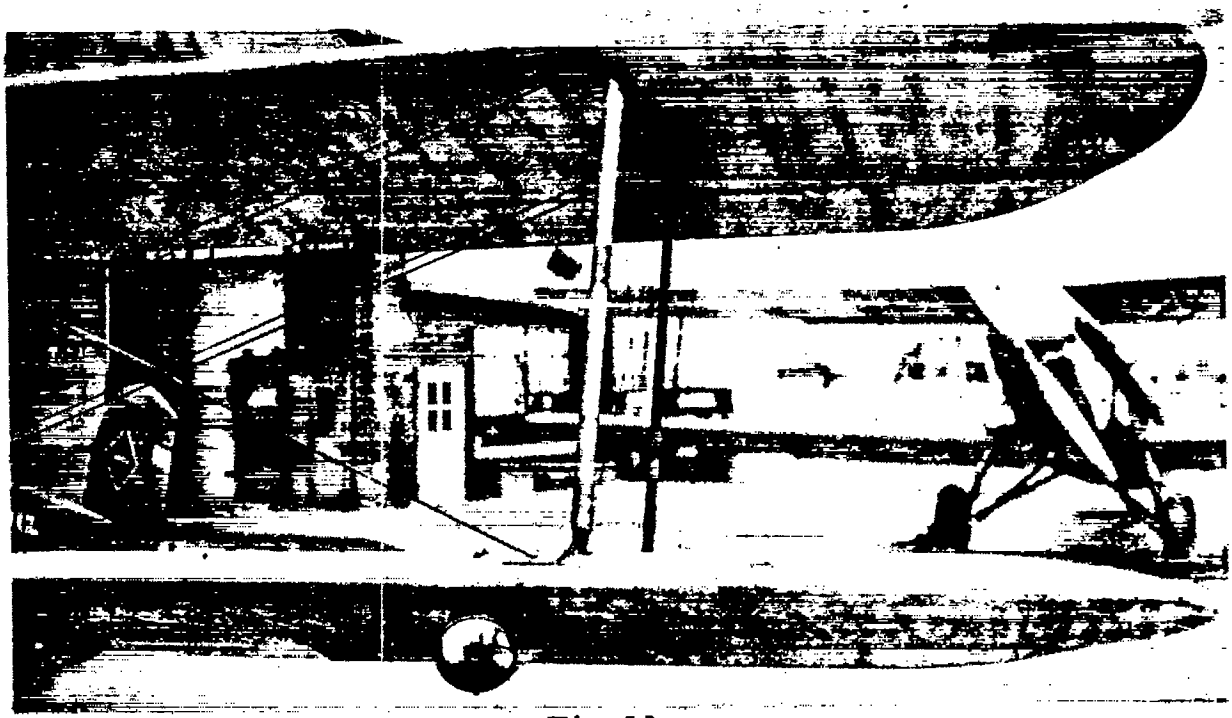


Fig.11