C.P. No. 223
(17,993)
A.R.C. Technical Report

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MINISTRY OF SUPPLY

AERONAUTICAL RESEARCH COUNCIL
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Report of the Third Year's Flying on the Development of Flight Testing Techniques for Finding and Measuring Natural Icing Conditions

By

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LONDON HER MAJESTY'S STATIONERY OFFICE

1956

THREE SHILLINGS NET

C.P. No. 223
Report No. A.A.E.E./Res/285

AEROPLANE AND ARMAMENT EXPERIMENTAL ESTABLISHMENT

18th January, 1955

Report of the third year's flying on the development of flight testing techniques for finding and measuring natural icing conditions

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Summary

This report covers the third year's search for natural icing conditions together with some results for the whole three year period. Various forms of unserviceability limited this year's flying to approximately four months. For the three year period only half the icing forecasts for layer type cloud over U.K. yielded icing conditions sufficiently continuous to allow an anti-icing system to be tested. A number of these were too limited to allow more than one test run. By limiting testing to the best synoptic conditions yet found, forecasts will probably be completely correct although very limited in number. A good coating of ice was obtained from almost all forecasts for cumulus clouds. Occasions on which icing severity was overestimated during the past two years are double those in the first year, presumably due to the smaller number of upper air soundings available. The technique of photographing the leading edge of the tailplane has produced several interesting studies of ice formation. Due partly to the limited flying time no great advance in instrumentation has been achieved this year.

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ERRATA

Page 5. Last word "Included" should be "Including".

Page 6. Line 4. "larger" should be "layer".
Para. 5.2, line 9. the "i" from dying has been omitted.

Page 11. Ref. 4, line 2. "ellipsord" should be "ellipsoid".

Table I. Columns 13, 14, 16 and 17 should contain the following additional figures.

Flight No.	Columns Nos.				
	13	14	16	17	
60		16.53	-	-	
61	0.02	16.55	-	-	
62		16.55	-	-	
63		16.58	0.19	0.17	The date should be 8.7.53. Not 3.7.53.
64		17.08	0.17	0.11	
65		17.43	0.21	0.06	
66		17.43	-	-	
67		17.43	-	-	
68		17.54	0.06	0.04	
69		18.21	0.14	0.09	The date should be 2.2.54. Not 2.2.59.
70		18.36	0.09	0.06	
71		18.48	0.11	0.04	
72		19.13	0.22	0.10	
73		19.31	0.15	0.06	
74		19.41	0.14	0.07	
75		19.59	0.30	0.12	
76		20.08	0.27	0.16	
77		20.13	-	-	"Depression" should be inserted in Col. (4).
78		20.28	-	-	
79		20.33	0.26	0.23	

In Table 2 flight 72, line 3, column (6) "-775" should be "-7.5".

1. Introduction

Work has now been proceeding at the A. & A.E.E. for three years on a joint programme with the R.A.E. and the Meteorological Office designed to discover more about aircraft icing.

The aspects of the problem on which work has been concentrated have been:

(1) Correlating the occurrence of icing conditions with the Met. Office forecasts.
(2) Developing instruments to measure the parameters on which icing conditions depend.
(3) Studying ice formation on aircraft and its effects.
(4) Developing water sprays to produce ice in flight in clear air.

The first two years work has been reported in references 1 and 2. The present report deals with items 1 - 3 for the period from June 1953 to May 1954.

2. Details of test aircraft and its instrumentation.

2.1. Aircraft. As described in reference 1 the aircraft used was a Viking, a twin engined aircraft designed to carry 24 passengers.

2.2. Instrumentation. The majority of the instrumentation was the same as described in reference 2 but the micro camera had been redesigned and repositioned to bring all the major instruments, with the exception of the rotating cylinders, under the control of one operator. This operator controlled the auto observer, the two rotating discs, the fixed cylinder which was seldom used mainly due to lack of time because of other commitments when in icing conditions, the balanced bridge thermometer, the Hussenot A20 recorder and the redesigned micro camera and the oiled slide sampling equipment. Details of the changes made to the instrumentation are given below:-

2.2.1. Oiled slide sampling equipment and micro camera. To enable samples to be photographed at a temperature below freezing the micro camera had been modified to allow the oiled slide to be brought straight into the position in which it was photographed, immediately after sampling. The microscope stage was kept cold as before by air from outside the aircraft. A diagrammatic sketch of how this was achieved is given in Figure 4. A tube was fitted through the micro camera with a gap at the microscope stage for photography and a slide carrier was mounted on the end of a flexible cable running through this tube. On the inboard side of the micro camera there was a gap in the tube to allow a fresh slide to be fitted to the slide carrier, while beyond the gap the tube was slotted to control the angle at which the slide was held. On the outboard side of the micro camera the tube ran inside an outer tube which in turn was inside a streamlined outer cover. This outer cover with the two tubes in it passed through the skin of the aircraft and projected some two feet into the airstream. An air intake on top of this outer cover directed an air flow into the micro camera to maintain the temperature at the microscope stage below freezing. As before the lens and the stage were shielded from the direct blast of the air to prevent water droplets from contaminating the sample when flying through cloud. The inner tube was fixed so that its outboard end coincided with the end of the outer cover but the second tube could be pushed out into the air stream and withdrawn again by means of a rod which also passed through the micro camera to the inboard side.

The method of sampling was to insert an oiled slide into the slide carrier on the inboard side of the micro camera and then to push it outboard by means of the handle projecting through the slot in the inboard tube. The slide passed through the micro camera stage and through the aircraft skin until it was near the outboard end of its guiding tube. After a short interval to make sure that the oil was below freezing temperature, the outer tube

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would be pushed beyond the end of the outer cover, the slide would be turned from horizontal to vertical by passing the controlling handle through the appropriate part of the slot in the inboard tube and then would be pushed out to the end of its travel. The slide would then be beyond the end of the outer cover but was still shielded from the airstream by the outer tube. To make the exposure the outer tube was retracted into the outer cover and then pushed out to cover the slide again. The slide was immediately withdrawn into the photographing position and photographed as quickly as possible while the outer tube was retracted into the outer cover to prevent ice from building up on it. After photography was complete the slide was brought to the inboard side of the micro camera and removed. The whole sequence could then be repeated.

2.2.2. Tail camera. An F73 35 mm camera was mounted at the rear window for photographing the ice formation on the leading edge of the tailplane. A thin 2" graduated rod was mounted from the leading edge to show the thickness of the ice formation, the outer half of the rod was marked in $\frac{1}{2}$" but the inner half was marked in $\frac{1}{4}$". The camera was operated by a T35 control which could be set to take photographs at intervals of from 2 - 55 seconds.

2.2.3. Electrolytic windscreen. A small test electrically heated windscreen approximately 8" square was mounted in front of the flight engineer. Heat was produced by passing an alternating current through an electrolyte while the temperature was measured by thermocouples mounted between the two pairs of glass laminations that made up the front and rear faces of the screen.

2.2.4. Thermal ice detectors. Several forms of thermal ice detectors were fitted for various periods throughout the year but no final production model was made available for test.

2.2.5. Rotating discs. Two rotating discs were fitted, one half way back in the original position on the starboard side while the other was well forward on the port side.

3. Method of test

3.1. Period of tests. The aircraft was grounded for several long periods so that the time available for test flying was only about four months in the whole year. The first two periods of unserviceability which were separated by a week were in June and early July and were due to modifications to the main spars that were general to all Vikings. In July the aircraft was unserviceable for one week but was then available till the 10th August when some modifications were made to the instrumentation. Very shortly afterwards it was decided that the fin and tailplane must be investigated by the Contractor for possible corrosion. Although a replacement fin was not available the fin and tailplane were sent to the firm and the aircraft did not fly again till the 11th December after the original fin had been returned. Various radio snags, bad weather and the Xmas break prevented any test flying until the 31st December. From then till the beginning of April there was an accumulation of only about one week's unserviceability and four days when the airfield was unserviceable because of snow, so the majority of the years' flying was concentrated in this period. On the 5th April one engine failed and could not be replaced before a major inspection fell due. A C. of A. inspection was performed concurrently with the major inspection and some modifications were also made. The inspections and modifications were not completed before the beginning of June.

3.2. Normal tests. The normal method of test was in general the same as in previous years. The Met. forecast was obtained each morning and when icing conditions were forecast a search was made in the area. After ice was found measurements were made with all the available instruments and photographs were taken of the ice formation. Measurements were normally continued until no further worthwhile icing condition could be found, or tests had to be abandoned due to the accumulation of ice on the aircraft. Owing to the very limited period over which the aircraft was available some flights were made when the forecast was less promising than the forecasts used in previous years.

4. Results

4.1. Success in finding ice. Table 1 shows the conditions under which ice was found compared to the conditions that were forecast by the Met. Office. There were 19 encounters with ice in 17 flights while on 3 flights no ice or only very slight icing was found. One of the successful encounters was obtained by using information from other aircraft that were experiencing icing conditions while all the others were obtained by following the Met. forecast. Of the 3 failures one was due to cumulus cloud not having built above freezing level by the time the aircraft was searching the area. It is possible that it may have built up later on in the day. The chances of finding ice forecast for the flight on which the second failure occurred were not very good but seemed to justify a flight to test a modification to a new ice detector. The front in which the icing was expected was actually found to be lying along an air lane where a search could not be made. The third failure was only partial but only very slight ice was found as the main body of cloud was below freezing level with only small peaks above. In this case there was a broken layer of cloud above, in which it was just possible icing conditions might have been found but, owing to the inexperience of the observer in charge, it was not tried.

4.2. Icing conditions missed due to unserviceability. During the eight months of unserviceability there were 40 odd forecasts of icing that would have been investigated if the aircraft had been available. They were fairly evenly divided between layer type clouds and cumulus type clouds, the layer type being more numerous during the winter period. They did not, however, contain any with an extremely low freezing level.

4.3. Type of ice formation. With the addition of the tail camera more information on ice formation is becoming available. Figures 1 - 3 show interesting sequences taken by this camera. Figure 3 shows the ice formation on the tailplane after the aircraft had landed. A piece has been broken off to give a better view. It is interesting to estimate the thickness at the break. (see discussion in para. 5.3.). Figure 3 also illustrates some different ice formations on other parts of the aircraft.

4.4. Instrument readings. The results from the instruments are given in table 2. They include all cases when the value of liquid water content exceeded 0.1 grams per cubic metre for any appreciable time. For both the rotating discs the average liquid water content is given for each period where the reading was greater than 0.1 grams per cubic metre together with the peak reading achieved during the period. Where the readings are not given the disc was unserviceable or its results were unreliable for one of the reasons given in paragraph 5.4.2. Only a comparatively small number of oiled slide results are given due mainly to troubles experienced from the cooling system.

4.5. Electrolytic windscreen. The results obtained from the electrolytic windscreen are outside the scope of the general programme and will be reported separately.

5. Discussion of results

5.1. Conditions suitable for testing aircraft de-icing or anti-icing systems. Of the 20 flights made 3 were made primarily to test instruments and 4 others were not successful in finding a really useful icing condition. Of the remaining 13 flights 8 achieved their success mainly from cumulus clouds although these were embedded in a layer of strato cumulus in two cases. This leaves 5 flights in layer type cloud which might well have been satisfactory had an icing system been under test. Against these 5 flights a further 4 were attempted on forecasts from which it was hoped that an adequate quantity of ice would be found. Two of these 4 were rather inconclusive as conditions were such that it is possible that a more experienced observer might have been able to achieve greater success but at least 2 of the 9 forecasts did not lead to suitable conditions for testing an icing system.

Including the flights made in the previous years there is a total of 20 flights on which a test on an icing system might well have been made, against a further 18 forecasts from which it was hoped to obtain good test conditions. This shows that, over the British Isles, the duration of ice in larger type cloud throughout the year is unlikely to be sufficient to allow even one satisfactory test on an icing system in nearly 50 per cent of the conditions forecast. The conditions suitable for several test runs on a system represent a still smaller percentage and are almost invariably confined to the winter season. The picture is not, however, quite so black as it appears as it represents layer type cloud from all types of synoptic conditions throughout the whole year and then only when the aircraft was serviceable. If testing is confined to the winter period and to the most promising conditions which so far seem to be an unstable airstream with a very low freezing level, it seems probable that almost all forecasts will be correct even though their total number will not be very great, possibly as low as 5 per year. Further experience may also allow flights in other synoptic conditions that should be nearly as suitable thereby increasing the number of possible forecasts that are almost certain to lead an aircraft to the required conditions.

The picture on cumulus cloud flying is very much better. For this year 8 out of 9 forecasts were successful while the figure over 3 years is 30 out of 34. The duration of icing conditions in cumulus clouds is too short to be of much value for testing anti-icing systems. A good coating of ice can, however, be built up and this might be used for testing some types of de-icing systems, particularly mechanical ones. In addition the behaviour of an aircraft with a coat of ice on is in itself important to allow for the case of the protection system failing. At the same time, unprotected items such as tank vents, for instance, may be checked for possible failure in ice.

5.2. <u>Severity of icing conditions.</u> Table 3 shows that the forecasts of the severity of icing conditions were not so good as in previous years. In only 12 out of 20 forecasts were the correct icing severities found. This is partly due to searches being made on forecasts that gave a smaller chance of finding ice than in previous years. In one such case a search could not be made in the condition associated with the forecast as the only active cloud was confined to an air lane. In another case the aircraft did not take off till so late that it is doubtful if the forecast severity still applied. In yet another case the frontal activity was dying out more rapidly than had been expected so that by the time the aircraft reached the condition only light icing could be found. On one occasion the search had to be curtailed after a late start due to lack of daylight although it is believed that the full forecast severity was present in the condition, while once the search may have been made a little too early. On the remaining three forecasts on at least two occasions there did not appear to be any cloud above freezing level capable of sustaining more severe conditions than these found. It seems probable that with more recent upper air data, cloud conditions could have been forecast more accurately. This theory is borne out by the fact that over the past two years the number of occasions on which icing severity was underestimated is double that of the first year when more soundings were available.

As in previous years the values of Rg, the rate of build up on a standard ice collector, have been calculated from the rotating cylinder results and compared with the severities observed on the flight. This comparison made in table 4 fits in exactly with previous years results that the values of Rg above between 4 and 6 were obtained for severe icing while values of Rg below about 2 - 3 indicated light icing.

5.3. <u>Ice formation.</u> The camera photographing ice formation on the tail-plane has produced several interesting sets of results, including some unusual formations caused by runback. The first photograph in figure 1 shows the formation on the leading edge of the tailplane on flight 69 when the temperature and liquid water content were both fairly low and the droplet size was small (about 10 - 12 microns). The photograph was taken after the last reading for this flight given in Table 2. It will be seen that the main ice formation is confined to between the two T.K.S. strips, a distance of no more than $1\frac{1}{2}$" while there is subsidiary build up from the upper T.K.S. strip. The interesting

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feature is the way in which the ice has built up in small, almost unconnected, columns each pointing in a direction that clearly shows the trajectory of the super cooled water droplets that froze to form them. The trajectories must have been almost parallel to the wing surface, except close to the stagnation point, showing that the water droplets were very small. Indirect conformation of how small the droplets were, can be obtained from the shape of the ice that has grown from the end of the 2" measuring rod projecting from the leading edge. This is very narrow by comparison with the corresponding formation shown on the other photographs in the same figure. This narrow type of formation is due to each droplet freezing on impact before the next droplet is caught and without having time to flow any appreciable distance. This only happens with low temperature, in this case -12°C, and with low water contents which are normally associated with small droplets. The larger wide formation on the other photographs was caused by more and larger droplets caught at a higher temperature so that drops took an appreciable time to freeze after impact and during that time they flowed and amalgamated with adjacent drops. In addition subsequent drops arrived beforethe initial drop had completely frozen so that a well knit ice film was formed. This is the classic difference between the method of formation of rime and glaze ice. The last four photographs in the figure were taken on flight 75 at intervals of 6½, 10 and 5 minutes respectively. The first photograph was taken 1½ minutes before the start of the results given for this flight in table 2. The last photograph was taken at 16.01 at the end of the period of icing starting at 15.56. The air temperature was from -7°C to -9½°C during the sequence while the droplet size reached 20 microns or over. There were two peak values of liquid water content of over 1 gm. per cubic metre but the averages over periods of approximately 2, 2 and 5 minutes respectively were of the order of 0.4 gms. per cubic metre. Earlier in the flight the aircraft had flown through an icing cloud at approximately freezing level in which it had picked up a small quantity of ice, much of which had been formed after running back a few inches behind the leading edge. This formed the foundation for the scattered nodules that can be seen in the first photograph an inch or so above the upper T.K.S. strip and also below the lower T.K.S. strip. Rivulets of water that froze while running back to these areas also formed a foundation for some of the ice formation that can be seen on and above the upper T.K.S. strip. The ice thus built up on the earlier deposit over a wider area than it would have if this deposit had not been present. The nodules further back on the upper and lower surfaces grew on the foundation of the earlier deposit to such a size that, as can be seen from the last photograph, they started to break off again. In the meantime the single lump of ice on the top of the measuring rod built up till, on the last photograph, it had almost reached its maximum size before breaking off. Even though the thickness of the ice on the leading edge of the tailplane did not exceed ¼" its rough, wide character affected the elevator controls although not quite far enough to cause overbalance, and increased the drag of the aircraft. Another undesirable feature of this type of ice formation was that it affected the engine cooling to such an extent that even with the gills fully open the aircraft had to increase speed by descending to prevent the engine temperatures from reaching limitations.

A similar effect was produced on flight 78 by the ice formation shown in figure 2. Here all the ice formed very close to freezing level. The distance to which the water ran back before freezing was considerable. In the first photograph it can be seen freezing as far back as the third black line on the upper surface. As the lines are an inch wide this means at least six inches. Later on the ice was observed to have formed as far back as 12" from the leading edge. It can be seen that during the first 6 photographs ice is gradually freezing on the upper surface although not much has formed on the T.K.S. strips. On the seventh photograph a 2" deep area has practically cleared itself although the amount of ice on the leading edge has increased. In the last two photographs the clearance has progressed considerably. The de-icing system was not operated during this time so clearance was caused by flying first just below then just above freezing level and finally descending a little below it during the last part of the sequence. Readings from a thermocouple near the measuring rod on the leading edge show that for the first three photographs and the last two the temperature on the leading edge was +2°C. Thermocouple readings were not taken at times corresponding to the remaining photographs but over this period the air temperature reduced from about -1.5°C to -4°C. As the temperature was so close

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to freezing the ice accretion instruments gave unreliable results so the true values of droplet size and liquid water content are unknown. The physical effects of the ice formation were similar to those experienced during flight 75.

Figure 3 shows several different points about ice formation. The first two photographs which were taken on flight 76 at an interval of 4 minutes show that the ice formation of an aircraft is not always confined to ice formed from supercooled droplets. In the first photographs a number of frozen particles have been caught in the film of ice formed from the supercooled droplets with which they were mixed in the cloud. In the second photograph the same particles can be identified well covered with a layer of glaze ice and with further particles added. This type of formation is not uncommon in cumulus clouds, particularly if they are well developed, and it clearly demonstrates how ice accretion instruments for measuring liquid water content may give inaccurate results. The second pair of photographs show two views of the ice formation on the leading edge of the tailplane obtained on flight 65, taken after the aircraft had landed. Part of the ice had been broken off to measure the thickness and to make it easier to see the formation. As in flight 75 later ice formation grew on this foundation to almost the same extent as that on the leading edge. One further point of interest is the thickness of the ice at the leading edge. Various estimates made from the photograph by casual observers were all considerably higher than the truth which was that the ice was only $\frac{1}{2}$" thick. This shows how easily inexperienced observers may be in error so that normal pilot's reports of the thickness of ice formation on an aircraft must be treated with reserve. The remaining two pairs of photographs are of the ice formation on flights 73 and 75 on parts other than the tailplane. The first in each set shows the ice formation round the engine cowling and on the air intake. In each case the formation was enough to upset the flow of cooling air so that even with the gills fully open the engine temperature was still rising towards its limitation. This was more the case on flight 75 where it can be seen from the spinner that there was considerable runback as the ice formed. On flight 73 the ice formation on the spinner, although not visible from the photograph, covered only the tip and the area of the first dark ring seen on the flight 75 photograph, showing that although, there may have been a little run back, there was not much. The smaller photographs show the ice on Rebecca aerials and the roughness of the formation on flight 73 shows up well against the much smoother mushroom shape on flight 75. The drag caused by the roughness of the ice on flight 73 was such that even using climbing power it was only possible to maintain level flight at an indicated speed of 125 knots, which is of the order of 50 knots lower than would be expected for the clean aircraft. It was found necessary to descend below freezing level to shed the ice. A record from this flight is given in figure 5. It shows how the speed dropped off, even though power was increased, until it had fallen almost 50 knots. Unfortunately the heater on the rotating disc strut did not prevent ice building up until it covered the front of the disc and stopped it from recording after 6 minutes. The Smiths ice detector continued to operate and the times between its pulses show the continuing severity of the conditions.

5.4. Readings of individual instruments

5.4.1. Rotating cylinders. Readings from the rotating cylinders follow the same general tendency as last year in that all the values of liquid water content over 0.3. grams per cubic metre come above the theoretical Ludlam limit from the largest cylinder and so must be subject to some doubt. The amount of error is rather indeterminate but can be quite large at larger values of liquid water content with high sub freezing temperatures. For lower values of liquid water content and lower temperatures the error should not be excessive so the rotating cylinders still give a fair indication of the true liquid water content in this region.

/5.4.2....

5.4.2. Rotating discs. The rotating discs were both of a production pattern which had not been in use for long. During the year several small faults were found, most of which were finally eliminated. Apart from the inadequacy of the heater under severe icing conditions mentioned above, the two main faults arose from the adjustment of the feeler and the scraper. The feeler tensioning spring had to be reduced in size to give more adjustment at low tension and the friction of the feeler bearings had to be improved. The scraper was found to be ineffective on some types of ice and the tension of its spring had to be increased. Lastly the feeler and the disc being of the same metal, a groove was worn in the feeler which was not noticed at first but which made calibration difficult. The feelers are being replaced by new feelers of a harder steel. The other failures that were experienced were of a minor form such as broken electrical connections and were not attributable to the design of the disc. Now that the teething troubles have been overcome the discs are giving very useful measurements of liquid water content. Typical records of both discs are given in figure 6, for a small part of flight 71. This illustrates one of the early failings in that the feeler on the port disc pushed off the first piece of ice formation and so did not start to measure until some six seconds after the starboard disc. The starboard disc gives a lower liquid water content than the port of the order of 0.1 grams per cubic metre. This happened fairly generally as can be seen from figure 7 where the values of liquid water content obtained from each disc are plotted against one another. The port disc was sited much further forward than the starboard disc and it is to be expected that it would give a higher reading due to the effect of the fuselage on the droplet trajectories. This point is clearly illustrated in reference 4 where the liquid water concentrations round an ellipsoid are compared with the conditions in undisturbed air.

5.4.3. Oiled slide sampling equipment and micro camera. Troubles were experienced with the cooling system of the micro camera due to drops of water depositing on to the slide both before and after sampling. The various apertures through which these drops penetrated were gradually traced and eliminated but, although under certain flight conditions this contamination was cured after a few flights, it was not until the end of the period that the difficulty was completely overcome. This accounts for the very limited number of successful measurements made by this method this year.

5.4.4. R.A.E. - Smiths icing indicator. Figure 8 shows a calibration of the Smiths indicator results against the amount of ice as measured by the port rotating disc. It will be seen that the points do not agree with the line from last years' results. This was not discovered until after the points had been plotted when, on investigation, it was found that the indicator head had been knocked and bent back through an angle of 4°. This brought the internal heater much closer to the inside of the four pressure holes, particularly the lowest one, so that the head was partially converted to a baffled type similar to the Canadian type described in reference 4, while the effective area of the holes was reduced. The new formula for liquid water content with the head bent back became $m = \frac{590}{V(T+\frac{150}{\theta})}$ gms per cubic metre as opposed to $m = \frac{400}{V(T+\frac{228}{\theta})}$ before the head was damaged. This is closer to the corresponding formula for the Canadian type which was $m = \frac{590}{V(T+\frac{88}{\theta})}$ V is the true air speed in knots (T is the off time between indicator signals in seconds and θ is the air temperature in °C). The main difference in these formulae is that with the damaged head the constant that is divided by θ is smaller so that the time between signals can be shorter before the denominator of the fraction becomes so small that it makes the value of m ridiculously large. This allows more reasonable results to be obtained at temperatures only a few degrees below freezing.

6. Conclusions

6.1. Over the past 3 years the duration of consistent icing conditions found in layer type clouds over the British Isles has been too short for even one satisfactory test on an aircraft protection system on nearly 50 per cent of the layer type icing conditions forecast. The icing encounters found to be suitable for several tests represent a still smaller percentage and were almost

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invariably confined tothe winter months. Although some ice was usually found as a result of the other forecasts it was too scattered to be of value for tests on the aircraft systems. The most suitable type of synoptic condition for ice can be forecast with considerable accuracy but it occurs only very seldom, possibly of the order of five times per year. Good testing conditions can be obtained in other synoptic conditions but experience is still too limited to give any special guidance on them.

Forecasts of icing conditions in cumulus clouds have been very good and, although too short for testing most systems, a good coating of ice can be built up by flying repeatedly through such clouds.

6.2. Occasions on which icing severity was overestimated during the past two years are double those in the first year, presumably due to the smaller number of upper air soundings available.

6.3. The technique of photographing the leading edge of the tailplane has produced several interesting studies of ice formation including examples of "run back" ice. The danger of icing conditions at temperatures near to the freezing point has been emphasised due to the greater area over which the ice may form thus giving a foundation to subsequent formations.

6.4. Comparison of the records of the two rotating discs shows that, allowing for positioning on the aircraft, this instrument gives a clear and reliable indication of the variation of liquid water content throughout the icing conditions. The existing heater on the supporting strut is inadequate for prolonged severe icing.

6.5. The modified oiled slide sampling equipment has now reached a stage where samples can be photographed almost immediately after being taken but its full possibilities have not yet been tested.

7. Further Developments

7.1. Further experience must be gained in the synoptic conditions giving the most continuous icing. These are more complicated than most of the situations mentioned in reference 2 and the most suitable combinations will be watched for during the coming winter.

7.2. The photographs of various types of ice formation will be used for comparison with the artificial ice obtained in flight by means of water sprays.

7.3. The oiled slide sampling technique needs further testing while the rotating disc requires an improved heater.

7.4. Improved thermal ice detectors and rotating discs are still needed while an improved version of the Smiths type of indicator should also be investigated.

8. References

1.	AAEE/Res/272.	Report of the first year's flying on the development of flight testing techniques for finding and measuring natural icing conditions. C.P. 221.	G.C. Abel
2.	AAEE/Res/278.	Report of the second year's flying on the development of flight testing techniques for finding and measuring natural icing conditions. C.P. 222.	G.C. Abel

3.	N.A.C.A. T.N.3153.	Variation of local liquid water concentration about an ellipsoid of fineness ratio 5 moving in a droplet field.	R. G. Dorsch R. S. Brun.
4.	N.A.E. Canada LR.-71.	Characteristics of an orifice type icing detector probe.	D. Fraser.

Flight No.	Date	Meteorological Forecast				Found in Flight				Flying time hrs. mins.		Time in measurable ice hrs. mins.		No. of Rotating cylinder measurements made	Rate of ice build up ins. per minute		Remarks
		Type of Cloud	Synoptic Condition	Icing Severity	Freezing level	Type of Cloud	Icing Severity	Height at which ice was found	Air Temp. °C.	Flight	Total on which ice was found	Flight	Total		Peak	Average	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
60	16.6.53	Cumulus	Unstable W'ly Airstream	Moderate Severe	7,000	Cumulus	Moderate with some severe	10,000	-5	1.40	148.15	0.03		6			Very short duration of ice in each of 8 clouds.
61	17.6.53	Cumulus	Unstable SW'ly Airstream	Moderate	6,500	Alto Cumulus	Light	12,000	-8	1.00	149.15			0			Most cumulus clouds had subsided by the time of the flight.
62	18.6.53	Cumulus	Unstable SW'ly Airstream	Moderate	6,500	None above freezing level	Nil	-	-	-	-	-		-			Flight may have been too early.
63	3.7.53	Cumulus	Unstable W-WNW Airstream	Severe	6,000	Cumulus	Severe			1.40	150.55	0.03					Mainly test of Sangamo Weston ice detector. 6 clouds flown through.
64	9.7.53	Cumulus	Unstable WNW-NW'ly. Airstream	Severe	6,500	Cumulus	Moderate with a little severe	9,000	-4	1.30	152.25	0.10		2			
65	6.1.54	Alto Cumulus	Occlusion	Moderate	1,500	Alto Cumulus	Light with a little moderate	6,500 - 8,000	-5 - -9	1.45	154.10	0.35		2			Over ½ inch build up on tail-plane. But cloud not all continuous.
66	21.1.54	Alto Cumulus	Occlusion	Light	8,500 - 7,000	No icing Clouds	Nil	-	-	-	-	-		-			Forecast was not good but a check on instrument modification was needed. The search was hindered by the presence of air lanes.
67	22.1.54	Strato-Cumulus	Occlusion	Light - Moderate	7,000 - 6,000	Strato-Cumulus	Only very slight icing	8,000	-5	-	-	-		0			Only a little of the main cloud layer above freezing level.

/Continued.....

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16	(17)	(18)
68	25.1.54	Strato-Cumulus	Complex Frontal Trough	Moderate-Locally Severe	7,000 - 1,500	Strato-Cumulus	Light	6,000	-7	2.10	156.20	0.11		2			Time of search limited by late take-off. Severe icing was later found in this system by a Washington which was forced down.
69	2.2.59	Strato-Cumulus	Occlusion	Light-Moderate	500	Strato-Cumulus	Light	4,000 - 5,000	-12 - -13	3.05	159.25	0.27		2			Cloud not continuous except in one small area.
70	11.2.54	Strato-Cumulus	Occlusion	Moderate	3,000 - 4,000	Strato-Cumulus	Light	7,000	-7	3.00	162.25	0.15		2			Main cloud tops below freezing level. Air drying out above.
71	18.2.54 a.m.	Strato-Cumulus	Warm Front	Moderate	5,000 - 7,000	Strato-Cumulus	Light	8,500 10,000	-6.5 - -11	1.50	164.15	0.12		1			Main cloud layer was below freezing level.
72	18.2.54 p.m.	Strato-Cumulus	Warm Front	Light	4,500	Strato-Cumulus	Light	8,000 - 7,500	-7.5 - -7	2.20	166.35	0.25		3			Cloud not continuous but reasonably thick.
73	19.2.54	Alto-Cumulus	Occlusion	Moderate	4,500 - 3,000	Alto-Cumulus Cumulus	Light Severe	10,000 4,500	-11 -6	3.30	170.05	0.18		1			Severe icing found from aircraft reports. Heavy build up very rough ice Speed reduced by 50 knots.
74	26.2.54	Cumulus	Unstable WNW'ly Airstream	Moderate	2,000	Cumulus	Light with a little moderate	7,000	-9	1.00	171.05	0.10		1			Main object of flight to obtain samples of ice crystals so clouds were past their prime for normal icing.
75	1.3.54	Strato-Cumulus and Cumulus	Frontal Depression	Moderate	1,000 - 1,500	Cumulus Strato-Cumulus	Light with some moderate	6,000	-9	2.20	173.25	0.18		1			Considerable run back although ice not thick. Loss of speed and engines tended to overheat.
76	4.3.54	Cumulus	Unstable NW-N'ly Airstream.	Moderate	2,500	Cumulus	Moderate	8,000	-11	1.45	175.10	0.09		4			Icing conditions of short duration only.

/Continued.....

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
77	23.3.54	Strato-Cumulus		Light	4,000	Strato-Cumulus	Light	8,500	-6	2.20	177.30	0.05		3			Cloud not continuous and only the tops were high enough to find ice.
78	29.3.54	Alto-Cumulus	Warm Front	Moderate	6,000	Alto-Cumulus	Light	8,500 - 9,500	-4	3.00	180.30	0.15		3			Extensive runback, 12 ins. of upper surface of tailplane covered with ice.
79	31.3.54	Cumulus	Unstable W'ly Airstream	Severe	3,000	Cumulus	Severe	9,000 - 10,000	-12 - -13	1.35	182.05	0.05		5			7 clouds flown through

Table 2.....

Flight No.	Date	Time of day	Height (feet)	I.A.S. (Knots)	Static O.A.T. °C	Liquid Water Content (Grams/Cubic Metre)								Med. drop dia. (Microns)		Remarks
						Rot. Cyls.	Port rot. disc.		Stbd. Rot. Disc.		Time over which ave. taken (secs)					
							Peak	Ave.	Peak	Ave.	Rot.Cyls.	Port Disc.	Stbd. Disc.	Rot.Cyls.	Oiled slide.	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
60	16.6.53	14.48	10,600	144	-6	1.00					17			17		
		14.57	10,600	129	-5	0.7					15			9		
		15.07	10,700	130	-5	0.45					41			20		
		15.22	11,400	150	-5	1.20					13			8		
63	8.7 53	14.47	10,000	150	-5		1.00	0.55	0.85	0.40		18	18			
		14.51	9,600	151	-4		0.55	0.30	0.45	0.25		16	16			
		14.55	9,600	150	-4		0.45	0.20	0.35	0.25		18	18			
64	9.7.53	11.45	9,300	133	-3.5		-	-	0.40	0.30		-	94			
		11.56	9,900	142	-5		-	-	0.80	0.50		-	29			
		11.59	10,100	135	-5		-	-	0.90	0.55		-	57			
		12.00	10,100	138	-4	1.05	-	-	0.70	0.70	32	-	32	11		
		12.07	9,600	134	-4.5		-	-	0.71	0.40		-	47			
		12.14	9,000	136	-3.5		-	-	0.45	0.25		-	176			
		12.20	9,400	130	-4		-	-	0.50	0.40		-	13			
		12.25	9,500	138	-4	0.3	-	-	-	-	100	-	-	7		
65	6.1.54	12.07	6,000	157	-10.5		-	-	0.45	0.15		-	185			
		12.14	7,000	149	-8	0.45	-	-			90	-		16		
		12.15	7,350	153	-8		-	-	0.40	0.15		-	348			
		12.21	6,800	133	-7		-	-	0.40	0.15		-	296			
68	25.1.54	14.50	7,800	181	-8		-	-	0.20	0.15		-	89			
		14.51	7,600	180	-8	0.05	-	-	0.25	0.15	148	-	148	17		
		15.17	6,000	174	-7		-	-	0.20	0.10		-	67			
		15.23	6,000	165	-7		-	-	1.00	0.30		-	56			
		15.24	6,000	163	-7		-	-	0.25	0.10		-	78			
69	2.2.54	14.52	4,000	126	-12		-	-	0.45	0.20		-	65		11	
		14.55	4,400	135	-11		-	-	0.35	0.25		-	32			
		15.01	4,500	130	-12.5		-	-	0.30	0.20		-	43			
		15.02	4,200	140	-12.5		-	-	0.40	0.20		-	330			
		15.09	4,300	135	-12		-	-	0.30	0.20		-	63			
		15.12	4,300	130	-12		-	-	0.25	0.15		-	35			
		15.14	4,200	130	-13		-	-	0.50	0.40		-	471			
		15.17	4,800	130	-13	0.3	-	-	0.50	0.35	300	-	300	12		
		15.22	4,800	130	-12		-	-	0.75	0.55		-	320			
		15.28	4,700	134	-11.5		-	-	0.40	0.25		-	82			

/Continued....

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
70	11.2.54	11.27	7,700	170	-8		0.20	0.10	-	-		45	-			
		11.29	7,700	168	-6		0.15	1.10	-	-		15	-			
		11.30	7,700	164	-8		0.45	0.25	0.40	0.25		529	555			
		11,31	7,700	160	-8	0.30	0.45	0.20	0.40	0.20	250	247	247	11		
		11.46	7,000	163	-7		0.35	0.25	0.30	0.10		157	198			
		11.51	7,200	159	-8	0.05	-	0	-	0	180			8		
71	18.2.54	10.24	9,300	163	-9		0.55	0 15	-	-		22	-			
		10.25	9,300	160	-9		0.25	0.10	-	-		21	-			
		11.07	10,000	143	-10.5		0.15	0.10	-	-		139	-			
		11.14	10,000	150	-11		0.35	0.20	-	-		14	-			
		11.16	10,500	156	-11.5		0.50	0.15	-	-		100	-			
		11.17	10,500	163	-11.5	0.15	0.50	0.20	-	-	65	65	-	14		
		11.21	9,400	169	-9.5		0.35	0.15	-	-		66	-			
72	18.2.54	15.00	8,000	164	-7		0.75	0.45	-	-		43	-			
		15.01	8,000	155	-7.5		0.80	0.45	-	-		67	-			
		15.02	8,000	147	-775	0.35	1.10	0.55	1.05	0.35	120	120	127	17		
		15.04	8,000	165	-7 5		1.15	0.55	1.05	0.35		91	98			
		15.15	7,900	155	-7		0.20	0.10	0.10	0.10		18	14			
		15.24	7,900	160	-7.5		-	-	0.10	0.05		-	57			
		15.26	7,800	160	-6.5		-	-	0.20	0 10		-	40			
		15.27	7,800	163	-7		0.20	0.15	0.15	0.10		30	44			
		15.28	7,700	160	-7		0.20	0.10	0.15	0.10		39	48			
		15.31	7,900	156	-7		0.50	0.25	0.35	0.10		75	75			
		15.32	7,800	155	-7		-	-	0.25	0.05		-	49			
		15.33	7,800	156	-7		-	-	0.20	0.15		-	136			
		15.47	7,900	147	-7		-	-	0.35	0.25		-	194			
		15.51	7,900	145	-7		-	-	0.20	0.15		-	78			
		15.54	8,100	143	-7	0.05	-	-	0.10	0.05	100	-	100	19		
73	19.2.54	15.06	9,000	169	-9		0.15	0.10	0.15	0.05		11	20			
		15.08	5,400	165	-5.5	0.10		0		0	262			20		
		15.13	8,500	136	-9		0.35	0.20	0.25	0.15		31	31			
		16.07	5,000	163	-5.5		0.70	0.30	0.65	0.25		361	361			
		16.37	5,200	140	-6.5		-	-	0.60	0.25		-	32			

/Continued.....

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(12)	(12)	(13)	(14)	(15)	(16)	(17)
74	26.2.54	15.16	7,000	125	-9	0.45	-	-	-	-	265	-	-	10		
		15.18	7,600	140	-9		-	-	0.40	0.15			198			
		15.22	7,300	145	-8.5				0.55	0.25			102			
		15.28	7,300	133	-9				0.35	0.25			112			
		15.30	7,700	131	-10				0.55	0.35			77			
		15.37	7,600	136	-9		0.50	0.25	0.45	0.20		64	64			
		15.40	7,200	140	-8.5		0.55	0.30	0.50	0.25		69	69			
		15.42	6,800	134	-7		0.80	0.40	0.75	0.30		27	27			
75	1.3.54	15.41	6,400	142	-9		1.35	0.45	1.40	0.40		127	123			
		15.42	6,400	142	-9.5		0.25	-	0.25	-					24	
		15.46	6,100	150	-8		1.05	0.50	0.85	0.30		120	134			
		15.47	6,100	154	-8	0.40		0.40		0.40	94	94	94	20		
		15.50	5,500	144	-7.5		-	-	0.10	0.05		-	49			
		15.56	5,300	139	-8		0.80	0.35	0.60	0.35		317	317			
		16.27	5,500	146	-8.5		0.40	0.20	0.20	0.15		136	136			
76	4.3.54	14.30	6,500	173	-7.5	0.20	-	0	-	0	35			8		
		14.43	7,400	146	-10	0.30	-	0	-	0	75			16		
		14.47	7,600	148	-10										24	
		15.06	8,500	138	-12		0.90	0.45	-	-		14	-			
		15.07	8,500	131	-12		0.35	0.10	-	-		21	-			
		15.08	8,500	138	-12		0.60	0.30	-	-		16	-			
		15.09	8,500	140	-12		1.95	0.90	-	-		60	-			
		15.11	7,500	140	-10	0.90	1.50	0.85	-	-	79	79	-	13		
		15.11	7,500	135	-10		1.55	0.70				99	-			
79	31.3.54	14.57	10,000	137	-12.5	0.20	-	-	-	-	90	-	-	11		
		15.08	10,000	130	-12.5		1.90	0.90	-	-		26	-			
		15.10	9,900	133	-12.5	0.55	1.40	0.75	1.35	0.55	36	27	36	16		
		15.19	10,000	131	-13	0.70	1.15	0.60	-	-	34	34	-	18		
		15.23	9,500	143	-12	0.35	1.05	0.55	-	-	43	36	-	11		
		15.28	9,700	143	-12		0.85	0.60	0.95	0.50		14	16			
		15.36	10,200	141	-13.5	1.0	1.90	1.30	-	-	30	29	-	17		
		15.39	11,500	139	-13.5		1.80	1.15	-	-		39	-			

/Table 3.....

Table 3

Comparison of severity of icing forecast with severity of icing observed

Observed / Forecast	Correct forecasts			Overestimated forecasts		
				Degree of overestimation		
				1		2
	Light	Moderate	Severe	Nil	Light	Nil
Light	2			1[*]		
Light-moderate	2	-				
Moderate		4			5[⊛]	1
Moderate-severe		-	1		1	-
Severe			3			
Totals	4	4	4	1	6	1
	12			7		1
				8		

[*] This flight was made primarily to test instruments so the forecast was not very promising. The main cloud formation lay in an airlane and may well have contained the severity forecast.

[⊛] A very late start was made on one of these flights and it is doubtful that the forecast severity applied.

Table 3

Comparison of severity of icing forecast with severity of icing observed

Observed / Forecast	Correct forecasts			Overestimated forecasts		
				Degree of overestimation 1		2
Forecast	Light	Moderate	Severe	Nil	Light	Nil
Light	2			1*		
Light-moderate	2	-				
Moderate		4			5⊙	1
Moderate-severe		-	1		1	-
Severe			3			
Totals	4	4	4	1	6	1
				7		1
	12			8		

---

* This flight was made primarily to test instruments so the forecast was not very promising. The main cloud formation lay in an airlane and may well have contained the severity forecast.

⊙ A very late start was made on one of these flights and it is doubtful that the forecast severity applied.

Table 4

Values of Rg* calculated from the rotating cylinder measurements compared with observed icing severity

Flight No.	Liquid water content (gms./metre^3)	Median droplet diameter (microns)	Rg* (gms/cm^2/hours)	Observed wing severity	Type of Cloud
60	1.0	17	12	Moderate and severe	Cumulus
"	0.7	9	2.3		
"	1.2	18	15		
"	0.45	20	6.5		
64	0.3	7	0.35	Moderate and severe	Cumulus
68	0.05	17	0.5	Light	Strato Cumulus
69	0.3	12	2.0	Light	Strato Cumulus
70	0.3	11	1.7	Light	Strato Cumulus
"	0.05	8	1.0		
71	0.15	14	1.6	Light	Strato Cumulus
72	0.35	17	4.0	Light	Strato Cumulus
"	0.05	19	0.8		
73	0.1	20	1.4	Light	Strato Cumulus
74	0.45	10	2.0	Light with a little moderate	Cumulus
75	0.4	20	6.0	Light with some moderate	Cumulus
76	0.2	8	0.4	Moderate	Cumulus
"	0.3	16	3.0		
"	0.9	13	7.0		
79	0.2	11	0.8	Severe	Cumulus
"	0.55	16	0.5		
"	0.7	18	9.0		
"	0.35	11	2.0		
"	1.0	17	12		

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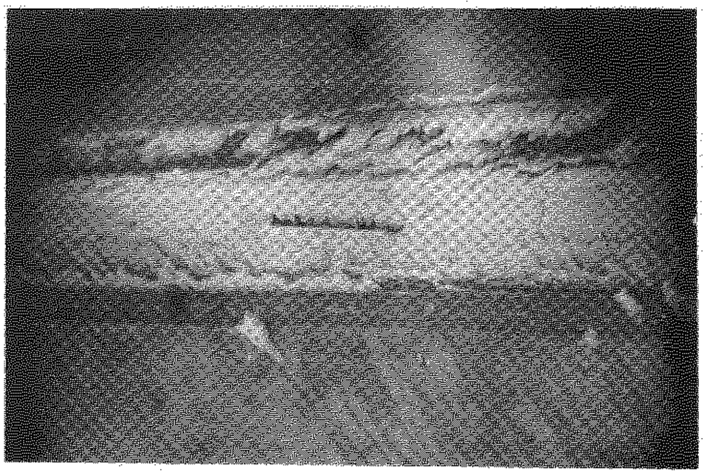
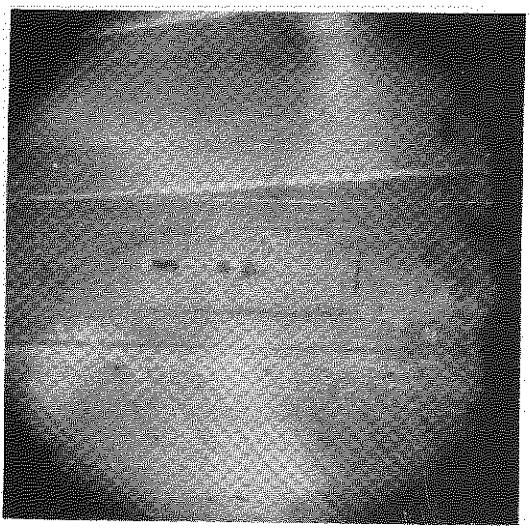
* Rg is the rate of ice accretion on a 3" diameter cylinder flying at 200 m.p.h. at a height of 3 kilometers (nearly 10,000 feet) in the international standard atmosphere.

FIG.1.



FLIGHT 69.



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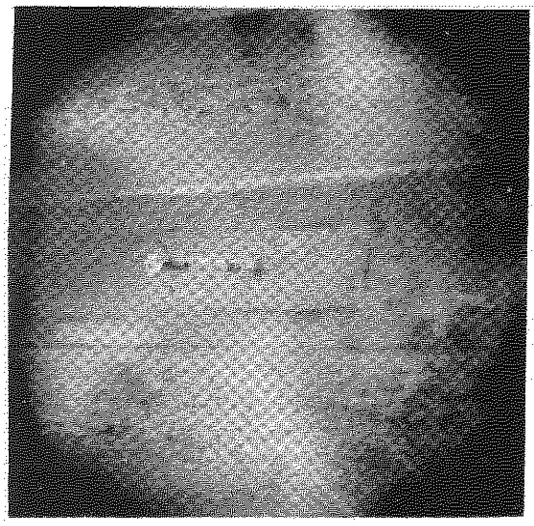

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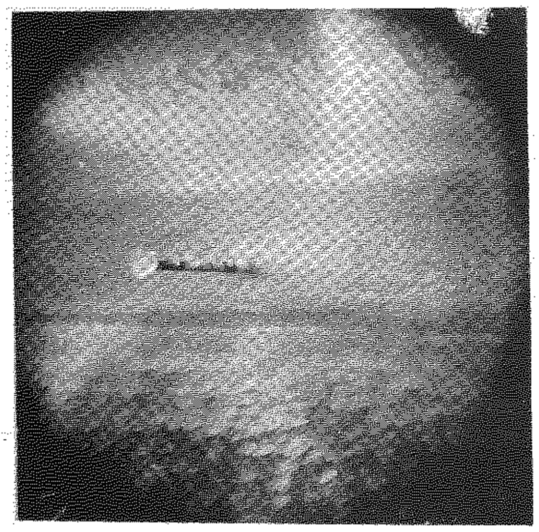
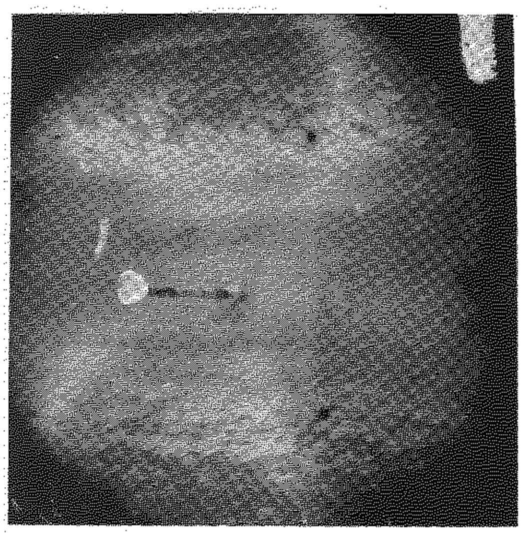


3

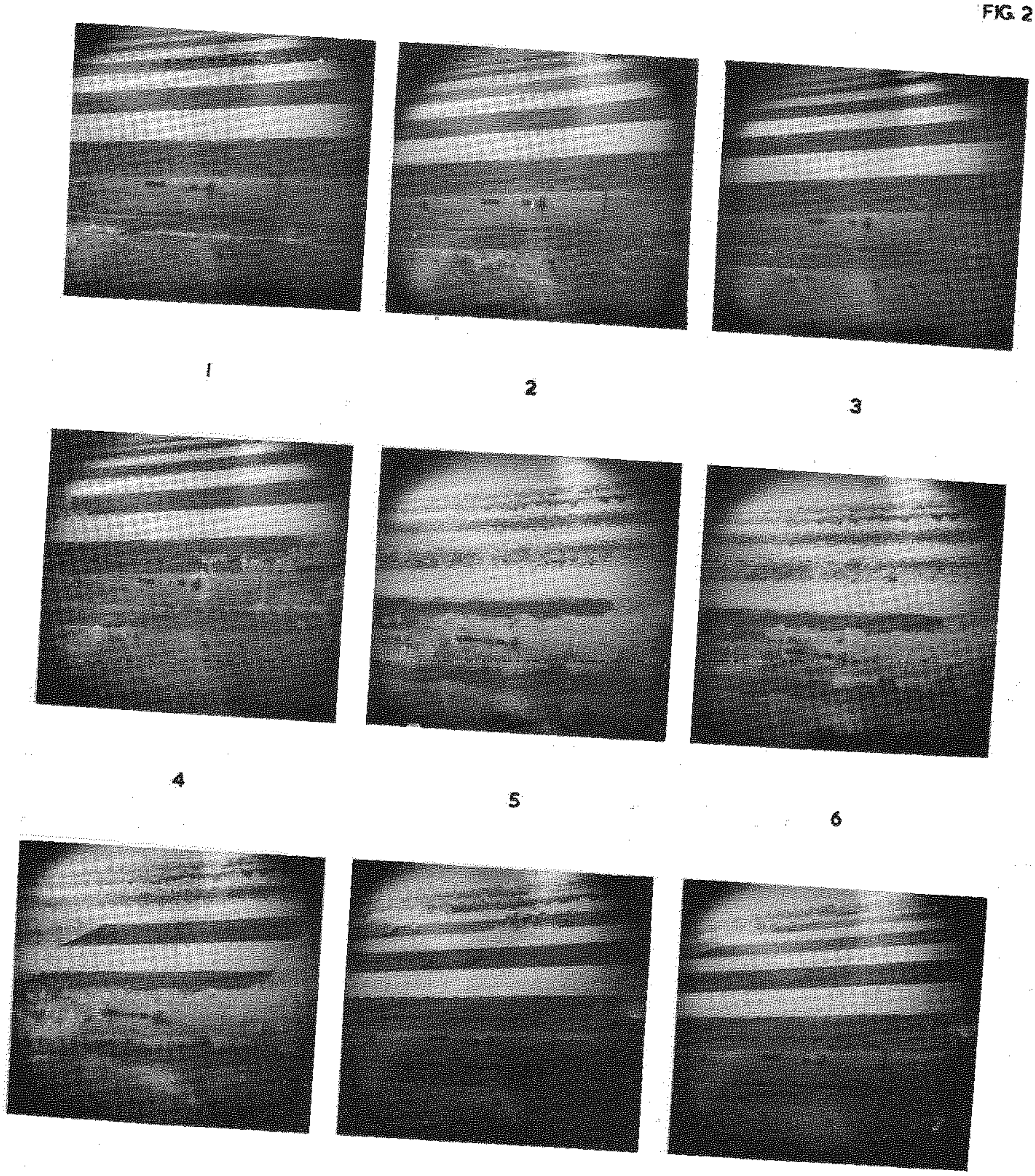


4

FLIGHT 75

ICE FORMATION ON LEADING EDGE OF TAILPLANE.

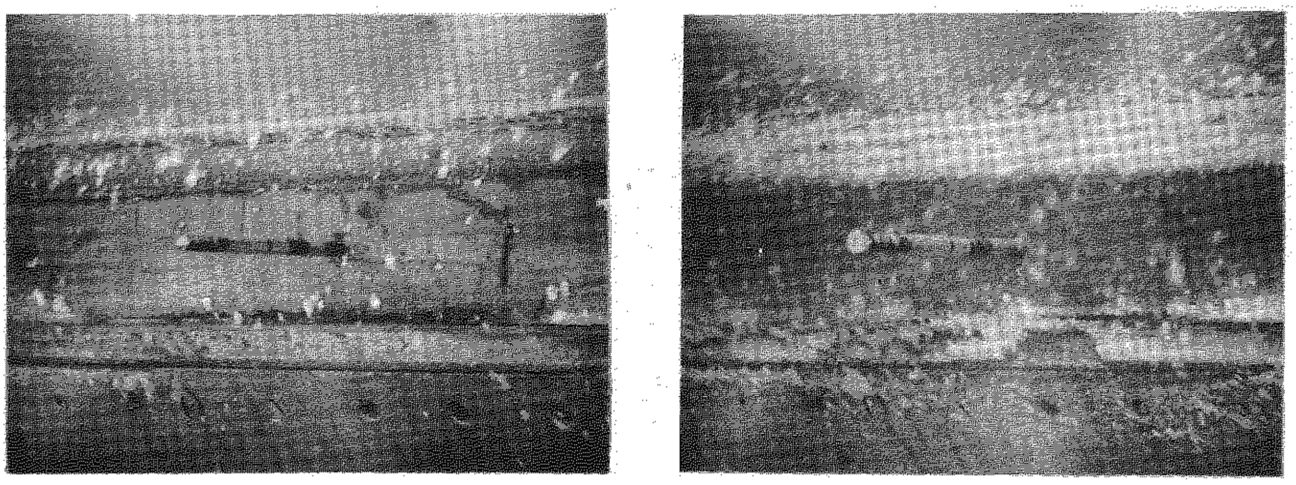
FIG. 2


1 2 3 4 5 6 7 8 9

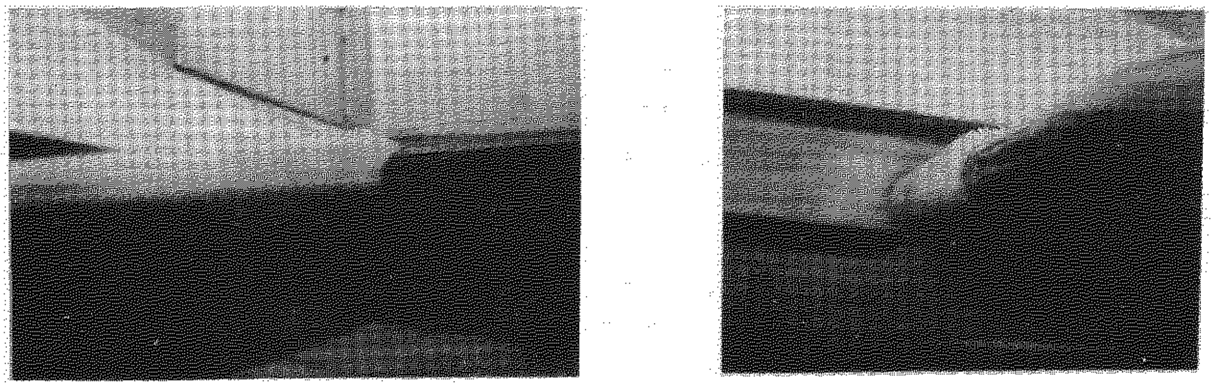
FLIGHT 78

ICE FORMATION ON LEADING EDGE OF TAILPLANE.

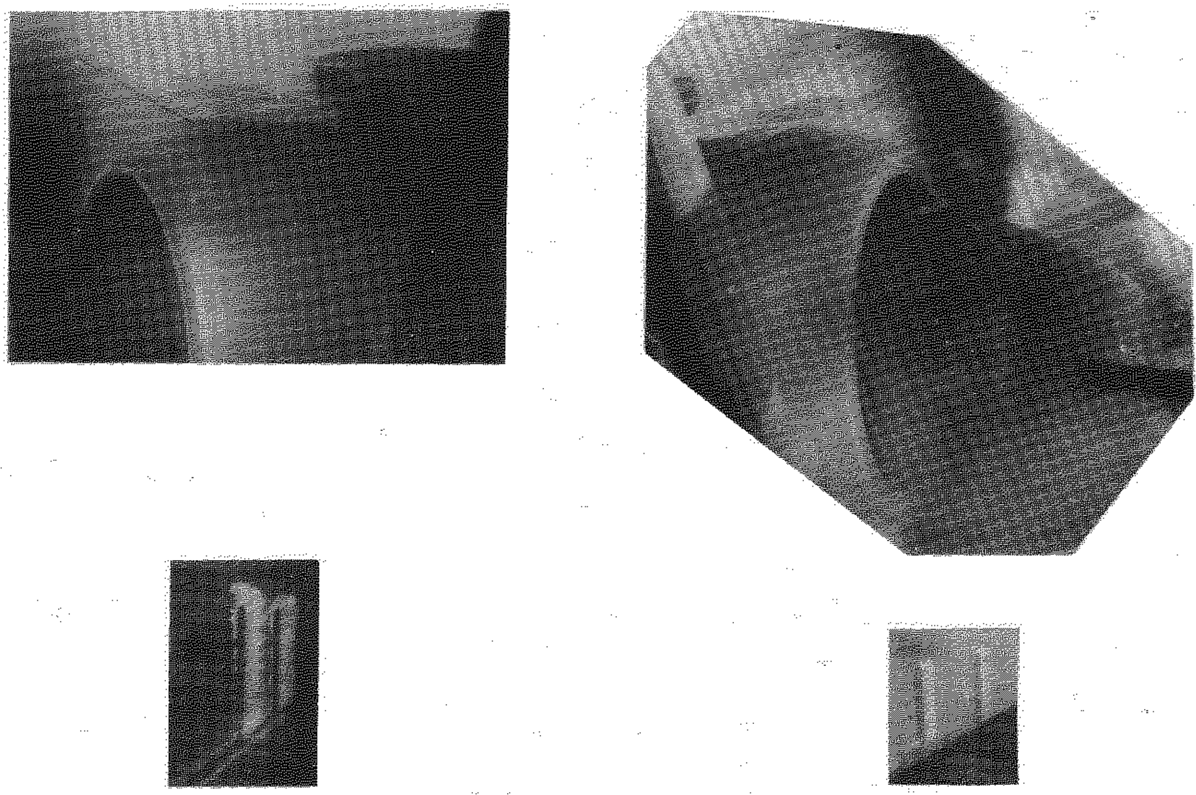
FIG. 3.



FLIGHT 76



FLIGHT 65

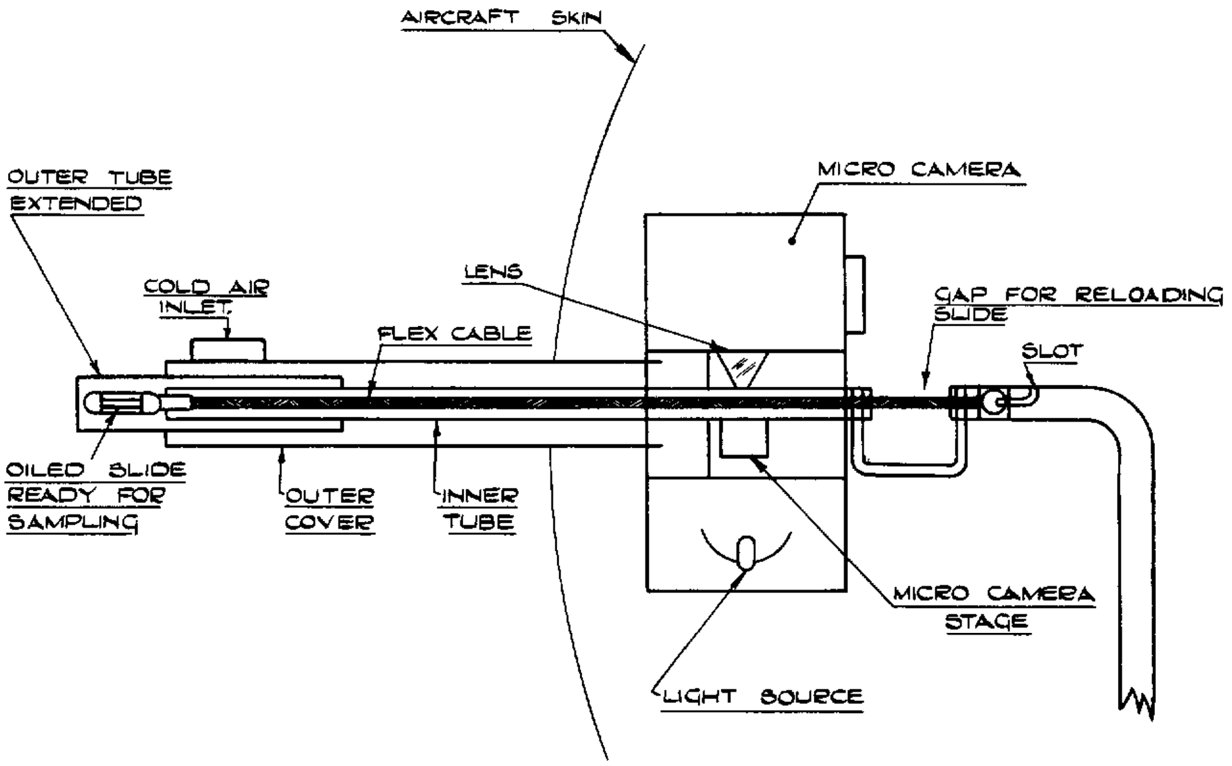


FLIGHT 73

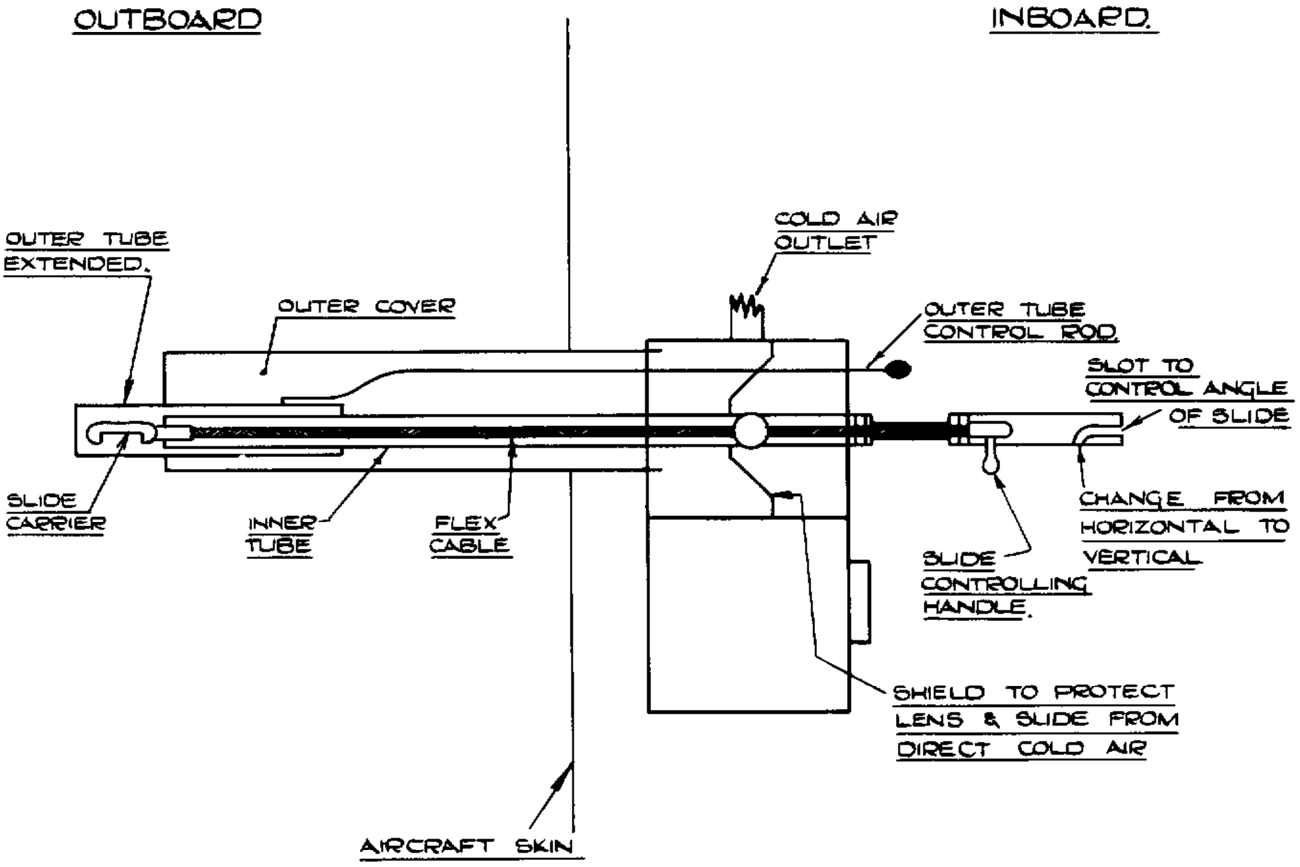
FLIGHT 75

ICE FORMATION ON THE TAILPLANE AND OTHER PARTS OF THE AIRCRAFT.
PARTS OF THE AIRCRAFT.

FIG.4.



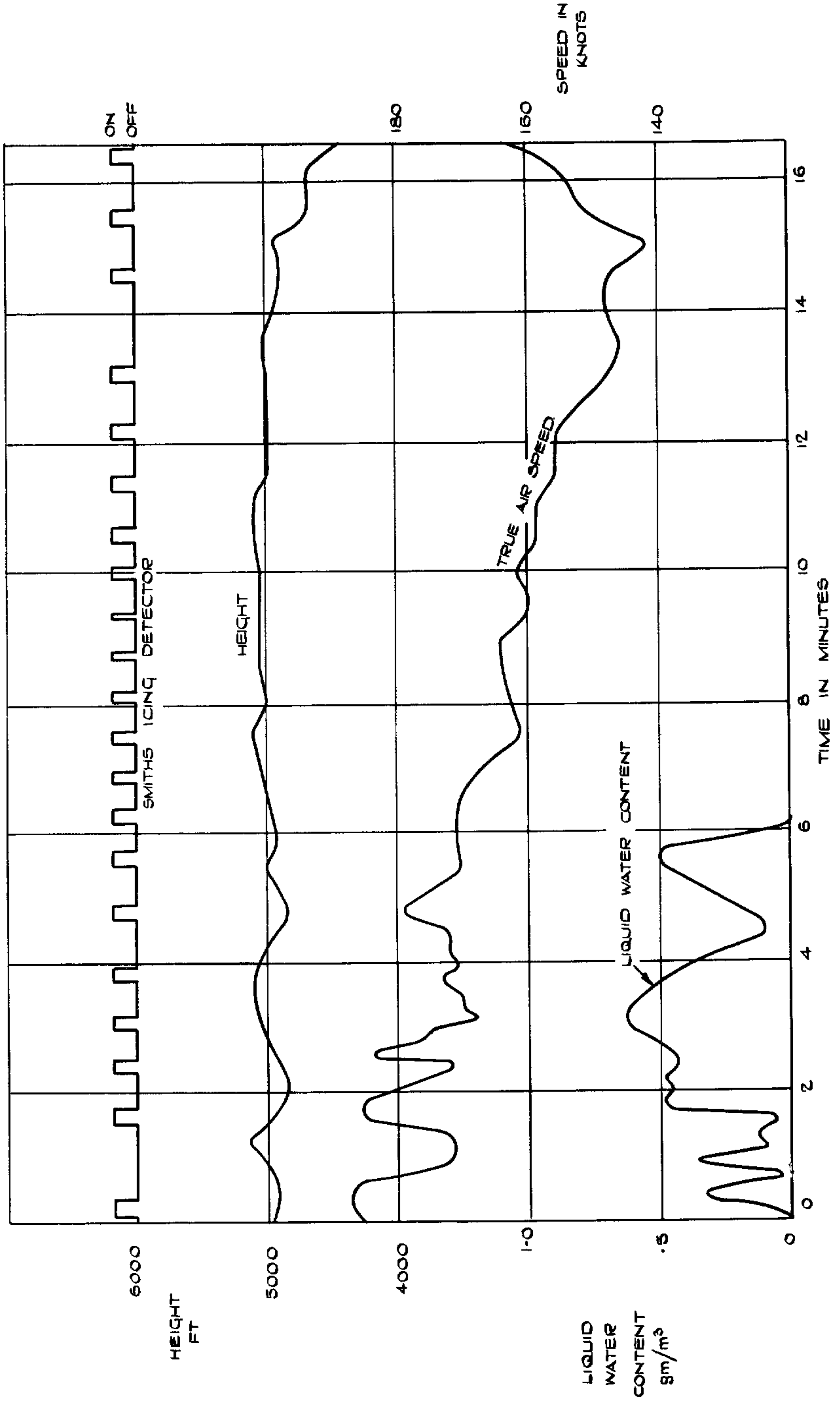
SIDE VIEW



PLAN VIEW

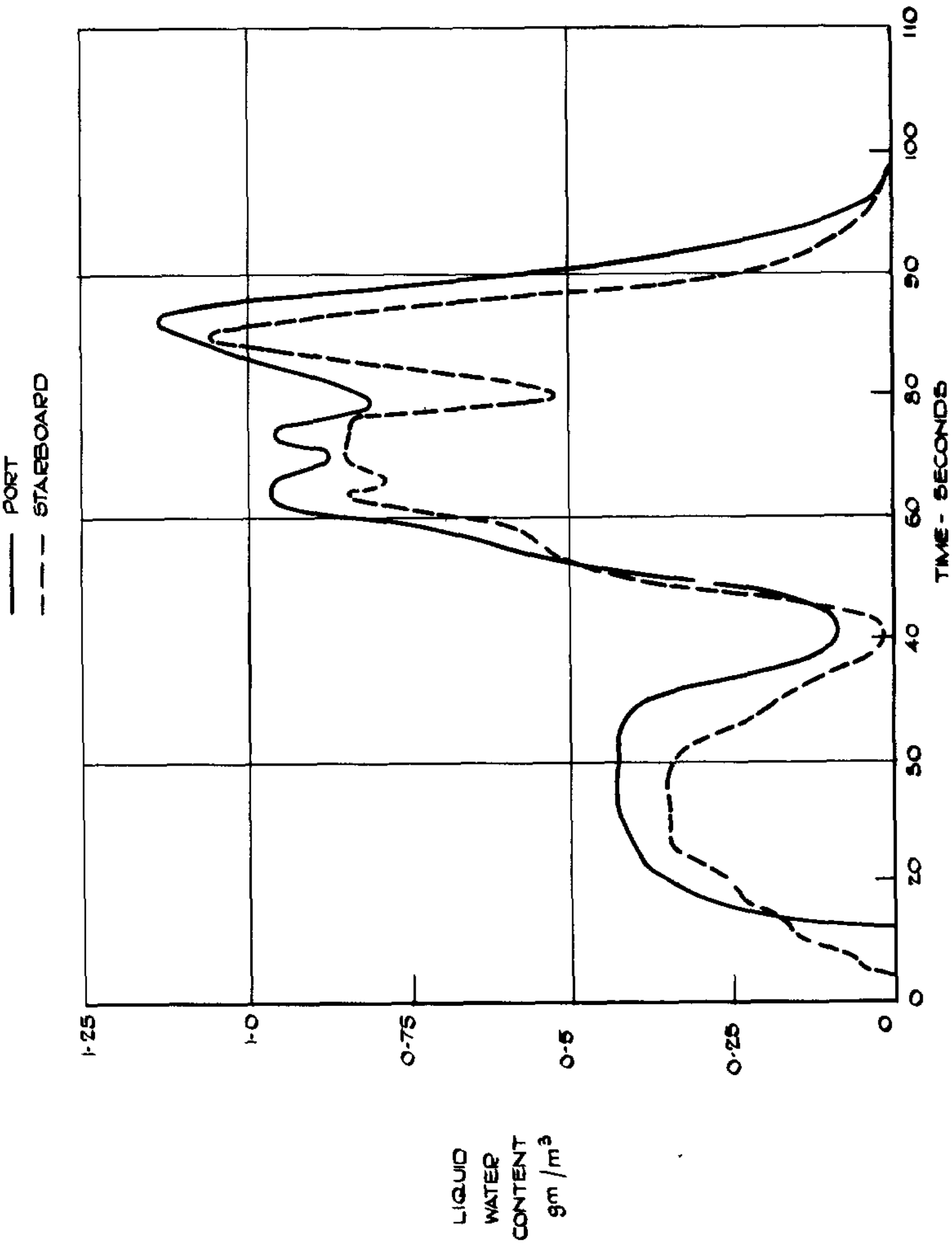
DIAGRAMMATIC LAYOUT OF MODIFIED OILED SLIDE SAMPLING EQUIPMENT AND MICRO CAMERA.

FIG. 5.



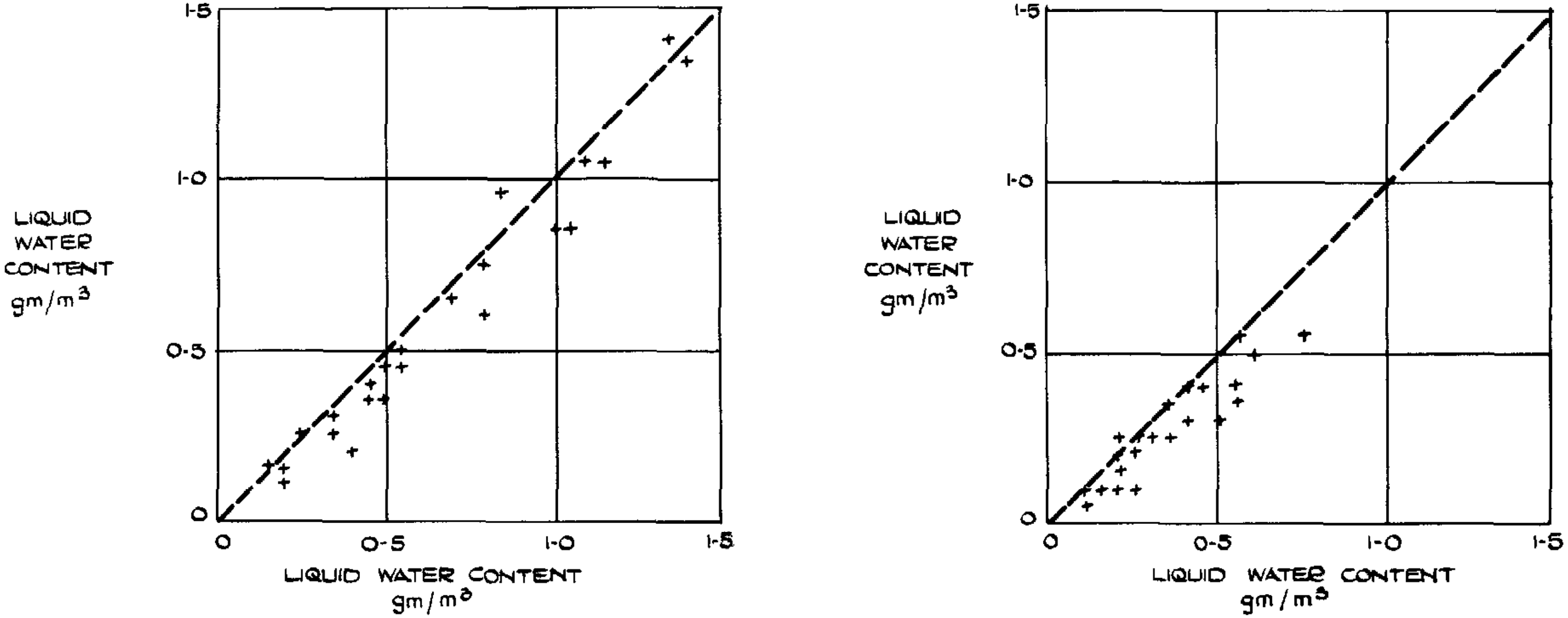
RECORD OF HEIGHT, SPEED & ICING INDICATIONS DURING SEVERE ICING ON FLIGHT 73.

FIG. 6.



COMPARISON OF PORT & STARBOARD ROTATING DISC RECORDS.

FIG. 7.

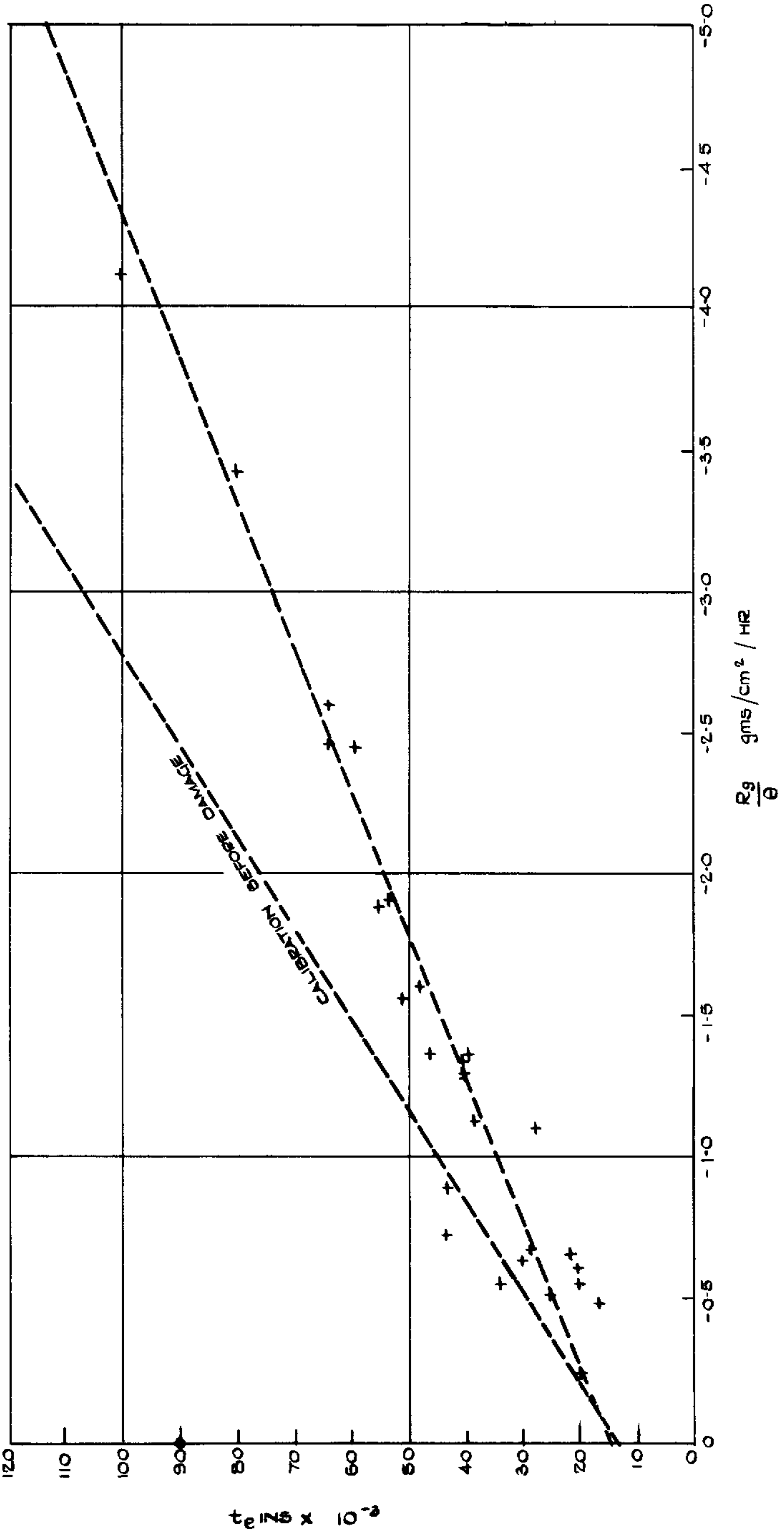


PEAK VALUES

AVERAGE VALUES

COMPARISON OF PORT & STARBOARD ROTATING DISC RESULTS.

FIG. 8.



CALIBRATION OF SMITHS ICE DETECTOR AGAINST ROTATING DISC.

C.P. No. 223
(17,993)
A.R.C. Technical Report

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To be purchased from
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