C.A.P. 167

MINISTRY OF AVIATION

CIVIL AIRCRAFT ACCIDENT

Report of the Reviewing Body appointed to consider and report upon certain matters connected with the Accident to the Elizabethan Aircraft G-ALZU at Munich on 6th February 1958

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REPORT

OF THE REVIEWING BODY APPOINTED TO CONSIDER AND REPORT UPON CERTAIN MATTERS CONNECTED WITH THE ACCIDENT TO THE ELIZABETHAN AIRCRAFT G-ALZU AT MUNICH ON 6TH FEBRUARY 1958

PRESENTED TO THE MINISTER OF AVIATION ON

THE 18TH DAY OF AUGUST 1960

3, PAPER BUILDINGS,
TEMPLE, E.C.4.

Sir,

On behalf of my colleagues, Captain R. P. Wigley and Professor A. R. Collar, and myself, I have the honour to present our Report upon the matters referred to us by your predecessor, the then Minister of Transport and Civil Aviation, in connection with the accident to the aircraft G-ALZU at Munich on 6th February 1958.

The transcript of the evidence given at the public hearing, and a volume of documents placed before us, are available if required.

We wish to express our appreciation of the excellent arrangements made by the Treasury Solicitor for the public hearing of the representations made to us under our Terms of Reference.

I have the honour to be, Sir,
Your obedient servant,

E. S. Fay

The Rt. Hon. Peter Thorneycroft, M.P.
Minister of Aviation.

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REPORT OF THE REVIEWING BODY

PART I - INTRODUCTION

1. On the afternoon of the 6th February 1958 the British European Airways aircraft G-ALZU crashed while taking off from the airport at Munich. A Commission of Inquiry appointed by the Federal Republic of Germany duly inquired into the causes of the accident and issued a Report dated 31st January 1959; the English translation of this Report was subsequently published by Her Majesty's Stationery Office for the Ministry of Transport and Civil Aviation (C.A.P. 153). As will amply appear hereinafter, both the captain of the Aircraft, Captain James Thain, and the British Airline Pilots' Association (B.A.L.P.A.) disagreed with certain of the findings of the German Commission of Inquiry, and your predecessor, the then Minister of Transport and Civil Aviation, on 10th June 1959 appointed us to be an independent reviewing body with the following terms of reference:-

> "To consider the representations made by and on behalf of Captain Thain with regard to the accident to BEA Elizabethan G-ALZU at Munich on 6th February, 1958: and, having regard to those representations and to the Report of the German Commission of Inquiry on the said accident, to report to the Minister whether or not in their opinion Captain Thain took sufficient steps -
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> (a) to satisfy himself that the wings of the aircraft were free from ice and snow;
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> (b) to ascertain whether or not in the conditions prevailing at the time the runway was fit for use; and
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> (c) to ascertain the cause of the difficulties encountered on the first two attempts to take off before making a third attempt."

2. As soon as Captain Thain's representatives were ready to meet us, we held a preliminary meeting with them, which took place on 16th July, 1959 and at that meeting it was decided to commence the hearing of the representations on 28th September 1959. In the meantime, however, certain fresh evidence had been submitted to the German Commission of Inquiry with the request that they re-open their proceedings. In consequence of information received from Germany, Captain Thain's solicitors on the 8th September 1959 asked us to adjourn the proposed hearing to a date to be fixed, and this we did. On 17th February 1960 we were requested to fix a fresh date for the hearing and accordingly we announced that this would commence on 4th April 1960. At the same time, Captain Thain through his solicitors expressed a preference for a public as opposed to a private hearing, and as this accorded with our own views, we decided to hold our inquiry in public. Before this commenced, the German Commission determined not to re-open their own proceedings and their detailed reasons for so doing, dated 14th March 1960, were before us in translation. The hearing took place on 4th, 5th, 6th and 7th April 1960

at 10 Carlton House Terrace, London, S.W.1. Captain Thain was represented by Mr. James Comyn of Counsel, instructed by Messrs. Evan Davies & Co., Solicitors.

3. The purpose of the hearing was to enable Captain Thain to make the representations which it was our duty to consider. The representations so made took the form of (a) a body of documentary evidence placed before us, (b) the oral evidence of a number of witnesses, and (c) the submissions of counsel. It is important here to emphasise that we were in no sense a Court of Inquiry into the causes of the disaster, nor had we any statutory powers as regards evidence or otherwise. Our function was to consider and to test the representations made to us on behalf of one party alone. The absence of any party charged with the duty of presenting an opposite view upon controversial matters might have rendered the hearing difficult, but Captain Thain and his counsel took the course of putting before us all the facts in their possession, whether they told for or against the representations; this greatly facilitated our task and we wish to pay tribute to the objectivity and sense of public duty evidenced by this course of action.

4. While not required to find the causes of the accident, we could not judge Captain Thain's actions, as our terms of reference require us to do, without ascertaining the surrounding circumstances. There was no dispute as to the majority of the relevant facts but, as will appear, considerable controversy over some which were most material. In the following Part of this Report, we set down, as the necessary background to dealing with the matters put to us, the facts so far as they are not in controversy.

PART II - THE FACTS IN OUTLINE

5. The aircraft G-ALZU was an Airspeed Ambassador, a type assigned the class name of "Elizabethan" by British European Airways. It had been constructed in 1952. The Elizabethan is a high-winged monoplane powered by two Bristol Centaurus 661 engines; it has a tricycle undercarriage. Since no question arises as to any defect in the aircraft, no further details need be given save to mention that the port engine was fitted with a Peravia Recorder; this is a power-driven roll of waxed paper used to record, against a time base, data as to altitude, engine speed, and manifold pressure. The Peravia recording was recovered after the crash and throws some light on the course of events.

6. The aircraft was on the return stage of a charter flight between Manchester and Belgrade, carrying the Manchester United football team and journalists and others, the total number of occupants, including the crew, being 44. It landed at Munich in order to refuel. The captain in charge of the aircraft was Captain Thain and his First Officer was Captain K. G. Rayment, who was fatally injured in the crash. On the outward journey to Belgrade Captain Thain had flown the aircraft; on the return, including the attempted take-offs from Munich, Captain Rayment flew the aircraft and Captain Thain acted as co-pilot. In fact, Captain Rayment was senior to Captain Thain; he came to be serving under him owing to the fact that a First Officer originally rostered to accompany Captain Thain on the flight had dropped out and Captain Rayment came in as his substitute.

Captain Thain had in the past flown with Captain Rayment but on those occasions Captain Thain's rank was that of First Officer and he had flown under Captain Rayment's command. The aircraft had flown from Belgrade at a height of between 14,500 and 16,500 feet at temperatures in the region of -21^{o} to $-25^{o}C$. During the descent to Munich through cloud, the wing de-icing equipment was operated: this comprises a petrol-burning heater used to supply hot air to the interior of the leading edge of the wing, and is fitted with a device which automatically cuts out operation at about 90 knots and thus comes into operation on landing.

7. The aircraft arrived at 1417 hours, i.e. 2.17 p.m., local time. (In this Report all times given are local time, which was one hour in advance of G.M.T.) It was snowing at the time, and snow and slush were lying on the ground, including the runway; the screen temperature was in the vicinity of freezing point. The aircraft made a normal landing and after arrival at the apron Captain Thain went first to the Met. Office for briefing on the next leg of the flight, and next to the Air Traffic Control Office; Captain Rayment reported to the B.E.A. office. Meanwhile, refuelling commenced at 1425 hours; the aircraft's wing tanks had a capacity of 1,000 gallons and they were filled, 726 gallons being taken on in the process. Mr. W. N. Black, the B.E.A. Station Engineer assisted in the refuelling, which finished at 1438 hours. The wings were not swept or de-iced; Captain Thain's decision in this respect will be examined in detail later.

8. At 1519 hours, the aircraft obtained clearance to taxi to the runway, and at 1530 it commenced its first attempted take-off. The aircraft accelerated to approximately 105 knots when Captain Rayment abandoned take-off because the boost on both engines was fluctuating. Brakes were applied and the aircraft came to rest approximately 450 yards from the far end of the runway. It received permission to back-track, returned to the starting point, and at 1534 hours commenced its second run. On this occasion, the throttles were opened more slowly and the starboard engine boost was steady, but at about 85 knots the port boost gauge "fluctuated quite a lot" (Captain Thain's phrase) and went above the permitted maximum of 60 inches. Captain Thain thereupon ordered the take-off to be abandoned and decided to return to the apron for consultation with the Station Engineer. The aircraft rolled to the far end of the runway and taxied back to the Terminal Building, arriving at 1539 hours. Captain Thain took over the controls while taxying.

9. Mr. Black knew that boost surging was not an uncommon phenomenon on Elizabethan aircraft at Munich, owing to the airfield's height of 1732 feet above sea-level. He so informed the pilots, and advised that the normal way of dealing with it was to inch the throttles back to maintain the required 57½ inches of boost. The pilots thereupon decided to make one further attempt at take-off. The passengers had been off-loaded; they were recalled and the aircraft again cleared to taxi to the runway at 1556 hours. Neither pilot had left the cockpit during the aircraft's 20-minute wait on the apron.

10. The aircraft reported "rolling" on its third and last attempted take-off, by R/T at 1603.06 hours. It never became airborne. 54 seconds later, the radio operator called Munich control but before he had had time to complete his identification, the transmission was cut short. The aircraft had traversed the entire runway and the continuation stopway, broken through the boundary fence and struck a house, after which it broke up. The last R/T message ended with the loud noises associated with the collision with the house.

PART III - THE GERMAN REPORT

11. The German Commission of Inquiry was able to narrow down its search for the causes of the accident to a detailed investigation of three possible factors, viz:

(a) rolling friction caused by snow on the runway;

(b) the effect of slush on the free running of the wheels;

(c) alteration in aerodynamic efficiency caused by wing icing.

12. On the first factor, snow on the runway, the Commission found that the snow had subsided into a layer of slush not more than 1 cm.* thick and that this slush on the runway did not increase rolling friction to such an extent that the accident could be attributed to it.

13. On the second factor, the Commission found that there could have been no packing of the twin wheels with ice such as to exert a braking effect, basing themselves on the facts that nothing of the kind had been detected after the first two abortive take-offs, that no mark attributable to such a condition had afterwards been found on the one surviving tyre, and that other aircraft with similar undercarriages had taken off without difficulty from the airport that afternoon.

14. On the third factor, the Commission decided that the wings of the aircraft had, at the material time, acquired a layer of rough ice some 5 mm. thick, with a roughness height of 3 mm., and that this prevented the aircraft from attaining the lift coefficient required for unsticking within the length of the runway. This they therefore found was the decisive cause of the accident.

15. In view of the representations made to us, it is necessary to set out in some detail the evidence upon which the Commission based its findings upon the first and third factors. On the question of slush on the runway, the German Report (pp. 14 - 17 of C.A.P. 153) refers to the following sources of evidence:

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* It may be convenient for the reader to bear in mind that

1 cm. = 0.394 inches and 1 inch = 2.540 cm.

(i) Twenty-one reports of incidents involving slush together with five reports of such incidents submitted by B.E.A. were examined. "These reports may be summarised to the effect that the extent to which take-off is impeded depends on the thickness of the slush and the type of aircraft. Aircraft with nosewheels are affected to a greater extent than aircraft of tailwheel design, because, in slush, the nosewheel causes an increasing nose-heavy moment as the rolling speed increases and this must be overcome by the pilot by means of considerable force on the elevator control. All experience goes to show, however, that it may be assumed that take-offs can be made with nosewheel aircraft without danger up to a slush-depth of at least 5 cm."

(ii) The head of the aircraft meteorological office, Dr. H. K. Muller, showed "that on the basis of data concerning snowfall and temperature, established from the records, by 1600 hrs. a total of 4-5 cm. of snow must have fallen, which, on the runway, would have subsided to form a layer of slush approximately $\frac{3}{4}$-1 cm. thick."

(iii) Herr Kurt Bartz, Traffic Manager of the Munich-Riem Airport Company, had driven with a colleague along the runway immediately after the time of the first two abortive take-offs: "We found that the entire runway was covered with slush approximately $\frac{1}{2}$-$\frac{3}{4}$ cm. deep. None of it was snow, but it was a jellified, watery mass covering the entire runway. We began from the east and drove off the runway at the west end. We did not merely stop, but got out and established the fact that the tracks left by the aircraft consisted purely of water."

(It is convenient to add here that when, after the publication of the German Report, Captain Thain made further representation to the Commission of Inquiry, a further statement was taken from Herr Bartz in which he said, "We checked not only the middle, but also each side. We got out to make spot checks on both sides. I am certain that there were no accumulations of slush or water on the runway or on either shoulder, which might have constituted a state different from that of the rest of the runway. On the right of the runway there is a natural fall-away which quickly drains off the water. On the left side of the runway special drainage has been constructed.")

(iv) Captain E. R. Wright, who had landed a B.E.A. Viscount at Munich at 1558 hours on the day in question, estimated the slush depth at 1 to $1\frac{1}{2}$ inches in places and stated that parts were merely wet and free from slush. (The Report commented that as Captain Wright was judging from his pilot's seat during the process of landing, he could not have obtained a precise impression of the deposit of slush).

(v) Professor Dr. H. Schlichting presented a Report into the technical aspects of the matter, in which he showed that, assuming a rolling friction coefficient μ increased from 0.03 to 0.06, the rolling distance required for a normal take-off may be increased by approximately 110 m. (120 yards).

(vi) Sixteen aircraft landed and took off on the afternoon in question; none of their captains reported any impediment worthy of serious consideration.

(vii) Captain Thain, in his first statement, made two days after the accident, stated that he was satisfied with the condition of the runway.

16. Upon the question of wing icing, the Report refers to the following sources of evidence:

(i) The Chief Inspector of Accidents and his assistants inspected the wreckage shortly after their arrival in Munich at 2200 hours, or some 6 hours after the accident, during which time further snow had fallen. They found the aircraft covered with a layer of 8 cm. of powdery snow; on the wings this could be pushed or blown from the surface without difficulty, and underneath there was found to be a very rough layer of ice about 5 mm. thick. From numerous spot checks, they concluded that the entire wing surface was covered with such ice, save only behind the two engines over the width of the slipstream, where there was snow but no ice. The ice had not blended with the superimposed snow.

(ii) Two witnesses whose duties took them on to the wings during refuelling (Mr. Black, the Station Engineer and Robert Wiggers, employed by the petrol suppliers) had seen melted snow running off the wings; Wiggers saw snow lying on the wing outer sections. Captain Thain also saw water running from the trailing edges of the wings.

(iii) Two witnesses (Schombel and Wöllner) who watched the aircraft prior to its last departure from windows fairly high up in the Terminal Building, stated that on leaving the apron, the wings, outboard of the engines, were covered with a thick unbroken layer of wet snow.

(iv) Meteorological evidence showed that sufficient snow had fallen during the period between 1400 and 1600 hours to furnish a layer of ice 5 mm. thick, and that conditions of temperature and humidity were such that by 1600 hours the snow could have turned to ice.

17. Upon the data summarised above, the Commission found firstly that the 5 mm. ice layer could have formed before the accident. They then considered whether it could have formed after the accident. During this period, the temperature was below freezing, and falling snow would be dry

and would not blend with any ice on which it fell. If, however, it fell on a wing warmed by the fires generated by the crash, it would melt and, as time went on, would re-freeze. The Commission felt that the outbreaks of fire near the remains of the wing were too small and too quickly extinguished to have melted the falling snow, and that the major outbreaks were downwind and too far away to have had this result. They regarded as conclusive the fact that no ice was found on the wings immediately behind the engines, pointing out that if post-accident melting and re-freezing accounted for the layer of ice under the snow, such a layer must have been formed under the snow in this position.

18. We were provided with copies of the Technical Report prepared by Dr. Schlichting. This commences by setting out the basic facts as follows:-

> "The investigation at the site of the accident and the testimony of witnesses and persons involved in the accident of the British aircraft "Elizabethan" G-ALZU on the 6th February 1958 at the Airport of Munich-Riem have led to the following main conclusions:-
>
> (1) The aircraft did not leave the ground throughout the take-off run, i.e., at no time were all three wheels off the ground.
>
> (2) The engines worked satisfactorily.
>
> (3) The attitude of the aircraft, whilst traversing the second half of the runway, was as normally associated with un-stick (tail wheel touching the ground, angle of attack $\alpha = 8.3^{\circ}$ to 9.3°).
>
> (4) At the time of the accident the runway was covered with a layer of snow and slush from 2 to 4 cm. thick, furthermore it may be fairly certainly assumed that the major part of the wing was covered by a layer of ice of about 5 mm. thick."

It examines the course of a normal take-off run, and finds that the aircraft should in normal conditions reach the take-off speed of 119 knots in 1000 metres (1100 yards). It examines a number of factors affecting acceleration and unstick speed, of which we need concern ourselves only with slush and icing. As to slush, the Report states,

> "There are no data available about the way in which the coefficient of rolling friction μ is affected by the presence of slush on the runway . . . It is possible that, due to the displacement and scattering of the slush by the wheels, the coefficient μ is a function of the speed, although μ is normally independent of speed. In the absence of more certain information μ is assumed to be constant. Instead of $\mu = 0.03$ it is assumed that, with slush, the coefficient becomes either 0.06 or 0.10, i.e., the presence of slush is assumed to double or treble the rolling friction respectively."

19. The Technical Report finds that with normal rolling friction doubled, the rolling distance to un-stick is increased by 110 metres (120 yards),

and with it trebled, the distance is increased by 270 metres (300 yards). The drag effect of icing, it finds, increases rolling distance to a given speed only slightly, but its effect on the lift characteristics increases unstick speed from a minimum of 110 knots to 120 knots or more. The Report concludes with the following summary:

"Exact information about the take-off run of the crashed aircraft cannot be given, since the precise runway and wing conditions at the time of the accident are not known. Although the take-off calculations which were carried out are only based on more or less accurate assumptions and estimates, the following statements can nevertheless be made, based on the results of these calculations:-

(1) It is very unlikely that the slush on the runway alone could have resulted in an excessive rolling distance.

(2) Slush on the runway combined with icing of the wing could lead to an excessive rolling distance (about 1500 metres).

(3) The take-off run of the crashed aircraft may have approximately taken the following course:-

Because of the slush on the runway and because of the drag-increase due to icing of the wing the rolling acceleration was appreciably below the normal value. The change of speed with rolling distance was approximately as in Curve 6 . . . This led to the fact that when the safety speed V_1 of 117 knots had been reached, a distance of about 1500 metres had already been covered, so that the end of the runway had already almost been reached. Since, however, due to the icing of the wing, the un-stick speed had not yet been reached, the pilot could not lift the aircraft off the ground. As is shown by the tail wheel tracks the pilot evidently attempted to leave the ground right up to about 180 metres short of the end of the runway. Since no further distance in which to stop was available for abandoning the take-off the catastrophe could no longer be avoided."

20. Captain Thain made a written statement to the German authorities on 6th March 1958, which is reproduced as Appendix 2a to the Report of the German Commission. The portion of the statement dealing with the final run records that Captain Rayment opened the throttles to about 28" of boost with the brakes on, released the brakes and opened the throttles to full power. It continues:

"At about 85 knots the port boost started to surge. I called "Port surging slightly" and pulled the port throttle lever back until the surging was arrested, the reading was about 54" and then advanced the lever again until it was fully open and indicating 57½". The starboard indication had remained at 57½" throughout. I called "Full power again" and glanced at the temperatures and pressures.

I then looked at the Air Speed Indicator, the speed was 105 knots and I called "105", the boost remained constant at 57½". The needle of the ASI was flickering slightly and when it indicated 117 knots I called "V_1" and waited for a positive indication of more speed. Captain Rayment was adjusting the trim of the aircraft. (Up to this point, whilst I had not looked out of the cockpit, I had not experienced any feeling that the acceleration had been other than normal under the circumstances.) The needle hovered at 117 knots and then dropped 4 or 5 knots, I was conscious of a lack of acceleration, the needle dropped further to about 105 knots and hovered at this reading. Suddenly, Captain Rayment called out "Christ, we won't make it." I looked up for the first time and saw a house and a tree, all this time my left hand had been behind the throttle-levers, I raised it and banged the throttles but they were fully forward. I believe Captain Rayment was pulling the control column back, he called hurriedly, "Undercarriage up" and I selected up and then gripped the ledge in front with both hands and looked forward. The aircraft's passage was very smooth as if we had become airborne and it looked as if we were slowly turning to starboard, I remember thinking that we couldn't possibly get between the house and the tree. I lowered my head and then the aircraft collided."

21. It should be interpolated that as a safety measure the aircraft operated on the "variable decision take-off technique" which involved calculating in respect of any take-off, firstly a decision speed (described as V_1) at which the aircraft would be capable either of continuing and taking off with one engine inoperative or of being brought to a standstill within the distance available, and secondly a take-off speed (described as V_2) at which the aircraft should be flown off. In the circumstances of this take-off, V_1 was at 117 knots and V_2 at 119 knots.

22. The Commission accepted Dr. Schlichting's report, noting that "the error . . . according to which there were 2-4 cm. of slush on the runway, is of no account as far as the results are concerned, because the expert was referring to the quantity of snow that had fallen, and at the desire of the Commission, he had undertaken calculations based on various rolling-friction coefficients." They stated that, "General flying experience and aerodynamic calculations are thus in agreement about the fact that an aircraft with such a degree of ice accretion as the aircraft involved in the accident would not, in the conditions obtaining at Munich on 6th February, be capable of taking off and flying within the take-off area available." This, however, would not explain the deceleration which Captain Thain noted. As to this, their Report notes that Captain Thain could not indicate either the point along the runway at which he observed the decrease in speed reading or the point at which V_1 was attained, and continues:

> "Judging from the sequence of his whole account, however, the drop in speed can only have set in towards the end of the runway. Captain Thain stated that during the process of take-off he at first only watched the instruments and did not look out of the aircraft. Only when he perceived a drop in speed did he look out. He then saw that they were in alarming proximity to the aerodrome boundary. Captain Rayment's exclamation, made at about the same moment, "We won't make it", would naturally only have been made when they were

already in a zone of the runway where catastrophe was seen to be unavoidable. There is therefore much to suggest that the drop in speed occurred approximately at or beyond the 1,800 m. mark. According to Captain's account, the aircraft first attained V_1, maintained, for a while, the speed it had reached, and only then lost speed appreciably. A certain interval must therefore have elapsed between the attaining of V_1 and the drop in speed. At 117 kt. a rolling distance of about 400 m. is covered in 6.5 seconds and a rolling distance of about 200 m. in 3.2 seconds. The interval during which V_1 was maintained would probably have lain within these values. If we proceed from this, and assuming that the drop in speed occurred within the zone beyond the 1800 m. mark, then it is highly probable that V_1 was indeed attained between 1400 m. and 1600 m., as the expert has calculated. Captain Thain's statements thus provide a certain confirmation of the expert's calculations, as far as there can be any question of precise confirmation, considering the element of uncertainty in Captain Thain's reconstruction of what happened. Under these circumstances the Commission considers it amply certain that V_1 was attained between 1400 m. and 1600 m. and was maintained or exceeded at any rate to within the region of the 1800 m. mark. Nevertheless, although the nose was pulled up and the emergency tail bumper was at times on the ground, the aircraft could not be raised off the ground."

23. The Commission's Report notes that there may be some uncertainty about the objective accuracy of Captain Thain's observation of the Air Speed Indicator, having regard to the "unnerving catastrophe" which supervened. But, they say,

> "it is entirely possible that the drop in speed of which Captain Thain spoke so definitely did indeed occur. There is then the further doubt as to where it occurred and why it happened. There is much to suggest that the aircraft slowed down at the point on the runway at which the tracks of the locked wheels were visible after the accident. The loss of speed reported by Captain Thain would then have the perfectly natural explanation that, in the final section of the runway, Captain Rayment saw disaster approaching and braked the landing wheels sharply. All four landing wheels were locked, as could still clearly be seen during the Commission's inspection in Munich. A simultaneous locking of all the wheels, however, can hardly have occurred except as a result of braking. But if this were the case it is not out of the question that a misunderstanding between the two pilots played a part at this juncture, for, whereas Captain Rayment (probably) applied the brakes, Captain Thain, in the hope of averting the catastrophe at the last moment, did exactly the opposite, viz (as he stated during interrogation), pushed the throttle lever forward as far as possible. Thus the measures taken by the crew to avert the accident or make it less serious cancelled each other out."

24. The Commission summarised the results of the Inquiry as follows:

"During the stop of almost two hours at Munich, a rough layer of ice formed on the upper surface of the wings as a result of snowfall. This layer of ice considerably impaired the aerodynamic efficiency of the aircraft, had a detrimental effect on the acceleration of the aircraft during the take-off process and increased the required unstick-speed. Thus, under the conditions obtaining at the time of take-off, the aircraft was not able to attain this speed within the rolling distance available.

The decisive cause of the accident lay in this.

It is not out of the question that, in the final phase of the take-off process, further causes may have had an effect on the accident."

PART IV - EVENTS SUBSEQUENT TO THE GERMAN REPORT

25. The finding that the aircraft attempted to take off with its aerodynamic efficiency impaired by the formation of ice on its wings, constituted a serious criticism of the commander of the aircraft and pointed to a breach of article 17(2) of the Air Navigation Order, 1954, which provides:

"Before the aircraft flies or attempts to fly the person in command shall satisfy himself . . . (vi) . . . that the wings and control surfaces are free from ice and hoar-frost."

Neither Captain Thain nor B.A.L.P.A. accepted the above-mentioned finding. Among other moves, the Association, on Captain Thain's behalf, submitted certain arguments and fresh evidence to the German Commission and requested that it reopen the Inquiry. The gist of the submission was that the evidence did not establish the presence of ice on the wings and that the behaviour of the aircraft could and should be accounted for by the retarding effect of slush on the runway, and did not point to icing. The fresh evidence consisted of statements (a) by three persons who took part in rescue operations and stated that they saw no ice on the wings when, immediately after the accident, they took part in extricating Captain Rayment from the wreckage, and (b) by two air traffic controllers, Erich Laas and Kurt Gentzsch, who watched the last take-off from the control tower. The latter both spoke of the aircraft making a normal run for the first half of the runway; the nose-wheel then left the ground but after some distance it touched down again, leaving the ground, according to Laas, once more before the end of the runway. (Gentzsch did not speak of the nose-wheel again leaving the ground, but thought the aircraft rolled to the end of the runway and then unstuck). This was submitted as consistent inter alia with a nose-heavy pitching moment caused by running into deeper slush or by frozen slush retarding the free running of the wheels.

26. The German Commission on 14th March 1960 issued a written decision that the facts, evidence and other points to which their attention had been drawn, did not justify the reopening of the proceedings. To this was appended a detailed statement of their reasons, a translation of which was before us. We conceive this document, although subsequent in date to our Terms of Reference, to form part of the Report of the German Commission to which we ought to have regard and we accordingly now refer

to its contents.

27. The Commission first dealt with the fresh evidence of the rescuers; they pointed out that none of the three spoke of the part of the wings outboard of the engines since they were concerned with the part adjacent to the fuselage and their evidence did not conflict with the finding of the Court. They also dealt with an argument advanced by Captain Thain that the fire-extinguishing powders used after the crash would have lowered the freezing point of water and would account for the absence of ice on the slipstream portion of the wings when examined six hours later. This point, as developed before us, will be examined later; the Commission rejected the argument in the following passage:

> "These considerations put forward by Captain Thain are based on the assumption that the wings, at least in the region of the engines, were so heavily sprayed with extinguishing agents as to make it possible for the melting-point of the snow to drop to -3°C. at this spot. All available reports regarding the fires and the activities of the fire-fighting services, however, show that these parts of the wreckage lay outside the main centres of fire. In the vicinity of the aircraft only a few minor fires <u>on the ground</u> broke out and were fought with extinguishing agents. There is no indication that on the upper surfaces of the wings (particularly in the region of the engines) any extinguishing measures were necessary or extinguishing agents deposited."

28. They next dealt with a submission that slush or water might have collected on the outer edges of the runway on account of its camber and, as the aircraft's course was not down the centre of the runway, might account for increased retardation at some point. They said:

> "The fact that the runway has a slight camber is not new to the Commission. The effect of this camber is that any possible melted snow can drain off better from the runway. On one side of the runway the manoeuvring area shows a natural fall-away. On the other side special drainage has been constructed. Provision is thus made on both sides for the further draining-off of the water. Since the amount of precipitation which fell prior to the accident was by no means great, it appears out of the question that any quantities of water or melted snow worth mentioning should have collected anywhere. What is more, the witness Bartz stated that on the day of the accident he not only checked the condition of the centre of the runway but also made spot checks on both outer edges of it. He was therefore able to say with certainty that he did not find any slush or water collected there."

29. The Commission reported that the statements of Laas and Gentzsch had been before them from the outset and their observations from a considerable distance had been considered, together with the evidence as to tracks on the runway and the evidence of Captain Thain. B.A.L.P.A., however, had submitted in writing the argument that the evidence of Laas and

Gentzsch showed that the angle of attack necessary for unsticking, and the necessary speed for this, were never simultaneously attained throughout the entire take-off process, and that wing icing could not therefore have caused the accident; and that these witnesses' statements suggested rather inability to unstick owing to restriction of free running of the wheels. With regard to this submission, the Commission expressed the following views and reasoning:

(a) They had concluded, on the evidence of Captain Thain and others, that speed V_1 was attained between 1400 and 1600 m. and maintained or exceeded to 1800 m. The question to be considered was therefore whether between 1400 and 1800 m. the aircraft attained the necessary angle of attack for unsticking with clean wings.

(b) It was highly improbable that, so near the end of the runway, Captain Rayment would not have attempted to unstick.

(c) A witness named Meyer, whose statement was appended, observed the track of the emergency tailwheel up to about 100 to 150 metres short of the end of the runway - he had walked back about 40 metres along the runway and could not see the beginning of the tailwheel track, and:

"It is thus confirmed that before the 1800 m. mark (i.e. over the rolling distance on which V_1 was exceeded) the aircraft had the angle of attack otherwise necessary for unsticking, for a period not precisely ascertainable but at any rate ample."

(d) The evidence of Laas did not conflict with the above as he saw the unsticking of the nosewheel towards the end of the runway; Gentzsch was clearly wrong in thinking the aircraft unstuck, and if his statement negatived the unsticking of the nosewheel before the end of the runway, the track of the tailwheel showed him to be wrong. Of the statement that the nosewheel unstuck for a short time in the middle of the runway, they said "If we assume that this observation is correct (and the overall impression made by the statement as well as the witness's experience suggest this), then we must ask ourselves whether his statement really differs decisively from those of most of the other witnesses. According to the Commission's former and present opinion, this is not the case, for when this witness speaks of unsticking in the middle of the runway, it does appear that the nosewheel first left the ground for a short time at about 900 m. and very soon afterwards (Gentzsch says 60 - 100 m.) touched the ground again. Laas could not say exactly where the nosewheel afterwards left the ground again, but he stated that it occurred, at any rate, before the end of the runway was reached and that he had the impression that it was primarily only a question of putting the nose down in order to gain speed. This indicates that the second part of his statement tallies with the observations of the other witnesses and that they merely disregarded the first brief unsticking of the nosewheel at 900 - 1000 m. In other words, Laas and all the other witnesses are agreed in principle that the nosewheel unstuck within the second half of the runway, towards the end of the runway. All the statements, however, including that of Laas, are vague, inexact and mutually at variance concerning precisely for how long, on what section /_ of the runway_/ and at what angle of attack this occurred. The reason for this uncertainty would lie, on the one hand, in the fact that the aircraft was already at a considerable distance from the witnesses and, on the other hand, that in assessing all these statements it must be remembered that when watching the take-off the eye-witnesses did not yet know that it would culminate in an accident and they consequently did not pay conscious attention to every detail of the take-off process. If these points are taken into consideration, the statements of all the eye-witnesses can easily be brought into line with the conclusion in (b) and (c), viz. that the pilot tried to unstick the aircraft between 1400 and 1800 m."

(e) The Commission therefore concluded that the assessment of the witnesses' statements failed to show that the pilot did not try to unstick although between 1400 and 1800 metres V_1 was exceeded and V_2 almost attained.

30. The Commission further dealt with the evidence of Laas and Gentzsch as to the earlier unsticking of the nosewheel in the following passage. This is a matter to which we attach importance and the Commission's observations are given in full:

"The statements of the witnesses Laas and Gentzsch also fail to justify the further opinion advanced that restriction of the free rotation of the undercarriage /_ wheels_/ (Fahrwerkshemmung) (whether due to slush or other causes) might have been a contributory cause of the accident. The observation that the nosewheel left the ground for a short time at about 900 m. but soon afterwards touched down again can be explained by the fact that V_1 had not yet been attained and Captain Rayment was possibly reducing, for a while, an angle of attack which perhaps appeared to him somewhat excessive. Captain Thain's remark that a "nose-heavy pitching moment" might have come into play here, can, it is true, be accepted in theory. This is contradicted in practice, however, by the fact that any braking action which could have put the nose down against Captain Rayment's will must have occurred abruptly and Captain Thain would have been bound to have become aware of it physically, or, at any rate, from the speed reading. His statement, however, makes no mention of it. Another point telling against this is the fact that the aircraft afterwards gained speed normally, exceeded V_1 and almost attained V_2, as Captain Thain mentions in his statement. It is out of the question that the sinking of the nosewheel observed by Laas and Gentzsch at about 1000 m. should be identical with the drop in speed from 117 kt. to 105 kt. observed by Captain Thain, since from the sequence of events in his statement it can be seen that this drop in speed can only have occurred just short of the end of the runway."

31. The Commission finally dealt with a further submission by B.A.L.P.A. that, in the prevailing conditions, 5 mm. of ice could not have been produced on the wings by the snow which fell during the time the aircraft was at Munich. They said it was not relevant to inquire whether the snow and slush had turned completely to ice, as the aerodynamic assessment of the aircraft's performance did not depend on whether the layer was wholly, or only partially, ice. Moreover, the wings were supercooled by high altitude flight when the sleet fell upon them.

PART V - SUBMISSIONS AND EVIDENCE: OUTLINE

32. At the public inquiry it was submitted on behalf of Captain Thain that we should give an affirmative answer to each of the three questions posed in our Terms of Reference. Of these, the first (whether Captain Thain took sufficient steps to satisfy himself that the wings of the aircraft were free from ice and snow) occupied the greater part of the time spent in the hearing. Captain Thain's counsel accepted that if in fact ice had been present on the wings during the third and fatal take-off attempt, it would be difficult for us to say 'yes' to this question, and he led evidence and submitted arguments with a view to establishing that no ice was or could have been present on the wings at that time. This involved inviting us to say that the findings of the German Commission were wrong in this respect. We refer later to the question of the extent to which we feel our Terms of Reference enable us to disagree with those findings, but we say at once that this was clearly a relevant submission and was one properly put in the forefront of Captain Thain's case.

33. Counsel also appreciated that a finding by us of no ice would not conclude the first point in his favour, because theoretically circumstances might be such that although no ice formed, the prevailing conditions should have led a prudent pilot to take steps towards satisfying himself which might not have been taken. His submissions here were that Captain Thain had done all that a reasonable captain could have been expected to do in the material circumstances.

34. A similar submission was made with regard to the second question (whether Captain Thain took sufficient steps to ascertain whether or not in the conditions prevailing at the time the runway was fit for use). If the German Report was correct in finding that the slight depth of slush on the runway had so little retarding effect as not materially to have affected the take-off run, we would be unlikely to reach an adverse finding on this question, but the answer became much more debateable since it was submitted that both the state of the runway and the effect of that state were different from that found by the German Commission. This was, in part, derived from the cardinal submission that there was no wing icing, because that submission had necessarily to be accompanied by the argument that the unusual behaviour of the aircraft must be attributed to a cause or causes other than icing, and the cause suggested was the drag effect of

slush on the runway. If this submission were correct, the state of the runway was an effective cause of the accident and the submission made on the second question was that at the relevant date little was known about slush hazards and that in the then prevailing state of knowledge Captain Thain had acted reasonably in the steps he took as regards the runway although they led him to the belief, erroneous if his case were accepted, that it was safe to use. The submission, previously made, that ice had had a braking effect on the aircraft's wheels was not pursued before us, and we think it clear from the evidence of wheel-marks, given at paragraph 79 below, that this suggestion could not be supported: we refer particularly to the evidence that all the main wheels, after being locked, commenced to run freely at the same point, a fact consistent with brakes being released but quite inconsistent with retardation by ice packing the undercarriage.

35. On the third question (whether Captain Thain took sufficient steps to ascertain the cause of the difficulties encountered on the first two attempts to take off before making a third attempt) we were presented with evidence as to the course of events, and it was submitted that Captain Thain had correctly diagnosed the trouble and acted reasonably in deciding upon a third attempt.

36. The witnesses called before us were the following:

Captain E. R. Wright, captain of the B.E.A. Viscount which landed at Munich five minutes before the Elizabethan's final run.

Mr. W. N. Black, the B.E.A. station engineer at Munich.

Captain R. T. Merrifield, who gave evidence both as Chairman of B.A.L.P.A. and as captain of a B.E.A. Viscount which visited Munich two days after the accident.

Dr. H. L. Penman, Ph.D., M.Sc., F.Inst.P., head of the Physics Department of Rothampstead Experimental Station, as to ice formation.

Mr. R. F. Jones, a Principal Scientific Officer at the Meteorological office, Air Ministry, who attended the German Inquiry as meteorological adviser to the British accredited representative.

Mr. J. R. D. Kenward, Superintendent of Performance and Analysis, Engineering Department, B.E.A.

Mr. G. M. Kelly, a Senior Inspector, Accidents Investigation Branch, the British accredited representative at the German Inquiry.

Mrs. R. V. Thain, B.Sc., as to the effect of fire extinguishing powder on the freezing point of water.

Captain James Thain.

37. In addition we were furnished with a large number of documents, including statements of some of the witnesses before the German Inquiry and including two papers, one prepared by Captain Thain and one by B.A.L.P.A. setting out reasoned submissions on matters in issue. We find it convenient in considering the evidence to classify it by subject-headings, and mention will be made hereafter of such of the documents as contributed materially to the views which we have reached. We now turn to a detailed consideration of the relevant facts, as a necessary preliminary to answering the three questions.

PART VI - WING ICING

Section (1) - Meteorological Conditions at Munich.

38. Two reports of the Airport Meteorological Office at Munich, as furnished to the German Commission, are set out in Appendix 1. On comparison of these with the times of the aircraft's stay at Munich, (paras. 7 - 10 above), it will be seen that snow is recorded as falling continuously from arrival to last attempted departure, the fall being described as 'moderate' up to 1550 hours, 13 minutes before the last run started, and as 'slight' thereafter. The witnesses spoke of the snowfall as having practically ceased at the time of the third run. The screen temperature, it will be noted, fell from + 0.1°C. just before the aircraft's arrival to - 0.2°C. at 1600 hours, just before its final run; and was recorded as precisely zero at 1500 hours, or 19 minutes before clearance for take-off was first obtained. The snow was lying on the ground but melting. Its condition on the runway will be considered later; at the apron it was slushy and footprints became filled with water.

39. Mr. Jones informed us that radio sonde observations made at 1300 hours showed that at approximately 500 feet altitude above the airfield the temperature was - 0.2°C. and at approximately 2000 feet was - 3.2°C.; at that time the screen temperature (2 metres above the ground) was + 0.2°C. It followed therefore that falling snow would not, at the material time, have encountered an ambient temperature above zero and commenced to melt until at or very near the ground. The German observers had described the snow at about the time of the accident as "wet snow, with big flakes" but Mr. Jones thought it unlikely that there was any water content in the snow, saying "it is quite common to refer to big flake snow as being wet. It is also easy to imagine it as such, because it frequently falls on a surface which is itself just above nought and it melts on impact."

40. The amount of snow falling during the aircraft's stay can be judged from the fact (see Appendix 1) that in the seven hours ending at 2114 the recorded precipitation was 5 mm. (the measurement is of the water equivalent). This 7-hour period embraced 4 hours of 'moderate snow' and 3 hours of 'slight snow' and during the Elizabethan's stay of under 2 hours, most of it in 'moderate snow', Mr. Jones thought that probably not more than 2 mm. of precipitation could have fallen. We agree with his assessment, as regards the precipitation at the meteorological enclosure, which was 100 to 200 yards from the apron. Snowfall may vary in density

within relatively small distances, and this assessment may not hold good of the runway, some 1000 yards away from the apron. It is also important to note that temperatures may vary within short distances: Dr. Penman said "temperatures at the same level above ground can vary by several tenths of a degree quite easily . . . . . so that a temperature of 0°C. in the screen might be appreciably more or even appreciably less on the apron."

Section (2) - Factors Affecting the Temperature of the Aircraft Wings

41. The Elizabethan had flown from Belgrade at temperatures below - 20°C. and had the wings not been artificially heated they would have been substanially below zero on arrival. We accept Captain Thain's evidence that the wing heaters had been used on the descent to Munich, and indeed it would have been surprising if in the prevailing conditions they had not. During operation of the heaters the leading edges of the wings would have been well above zero, and probably substantial areas of the wing surface as well. The heaters cut out during landing (para. 6 above) and thereafter any residual heat would diffuse through the wings. We think it unnecessary to attempt further evaluation of the effect of the wing heaters in view of what we now have to say about the effect of refuelling.

42. The wing tanks of the Elizabethan are of integral construction. Shortly after arrival 3,300 litres of fuel were uplifted; this is 726 gallons, and the tank capacity is approximately 1000 gallons. Since, as we were informed, the aircraft was refuelled to full tanks, the balance of some 274 gallons had arrived with the aircraft and its temperature had been influenced by the super-cooling at high altitude and by the use of the wing heaters. This temperature is problematical, but the temperature of the 726 gallons uplifted can be assessed. The fresh petrol came from bowsers which had been standing in the open, and the German Commission had information from the fuel suppliers that its temperature was "not above about 0.0°C." The greater part of the volume of the wings consisted of petrol, in direct contact with the metallic structure of the wing, and of that petrol nearly three-quarters was at approximately the same temperature as the ambient air. Whatever the effect of super-cooling at altitude, and of the wing heaters, the temperature of the wings soon after refuelling can have differed only fractionally from the prevailing air temperature.

43. The refuelling commenced at 1425 hours and finished at 1438 hours. It was at 1500 hours that the screen temperature was recorded as precisely zero. It appears to us that in these circumstances the temperature of the upper surface of the wings must have then been in the vicinity of freezing point. Owing to the possibility of a fractional difference between air temperature at the screen and at the apron, and to the impossibility of assessing the exact temperature of the uplifted fuel, it is not possible to be precise to a tenth of a degree, but we do not think the wing can have differed from the screen temperature by more than half a degree.

Section (3) - The State of the Wings: Direct Evidence

44. Two of the witnesses at our inquiry, Mr. Black and Captain Thain, gave evidence relating to the state of the wings. We were furnished with the written statements made to the German inquiry by five further witnesses on this matter. A photograph of the aircraft taken from a window in the Terminal Building at 1550 hours was reproduced as Appendix 7 to the German Report, and a print of this photograph was supplied to us; it was taken from above and shows the starboard wing surface. This body of evidence falls into two groups, dealing respectively with the two periods when the aircraft was standing on the apron.

45. As to the first period from 1417 to 1519 hours, Mr. Black said that his duties in connection with refuelling took him on to the mainplane surfaces from shortly after arrival for about 25 minutes, during which he walked out as far as the wing lettering (registration letters on the starboard wing and corporation letters on the port wing) to check the ailerons. It was snowing lightly and the wings were wet with melted snow, but there was no trace of snow adherence at any point: "When I was up on the wing, the wing was quite clean and as the snow was contacting the wing the snow was melting immediately on contact." Captain Thain, on leaving the control office (para. 7 above), met Captain Rayment (para. 64 below) and afterwards walked towards the aircraft and, in his own words, "studied the snowfall on the starboard wing." His evidence continued: "I had to wait till I got fairly close before I could really identify any snow, and when I got close to the leading edge or to the wing, I saw a thin film of partially melted snow on the wing. It had thawed in places, and I could see the water from the melted snow running off the trailing edge right the way along. I continued walking towards the door, and found that two airport hands were trying to pump some water into the aircraft, but they had not got a suitable connection for the water hosepipe, and the chap could not stand up because of the slush on the ground. I stood there assisting him, and at the same time, with my face towards the direction of the trailing edge of the starboard wing. I suppose I stood there for about three minutes or perhaps four minutes." His position at that time, he added, was between the fuselage and the starboard engine nacelle, and during the three or four minutes he watched the thawed snow running off the trailing edge of the wing. Refuelling had then ceased. The third witness on this part of the matter was Robert Wiggers, a refueller employed by the fuel company, whose written statement to the German Commission said "Refuelling took place in driving snow. I noticed that the inner section of the wings was clear of snow, whereas there was snow lying on the outer sections."

46. During the second period when the Elizabethan was stationary on the apron (1539 to 1556 hours) it was observed from the second floor of the terminal building by three, perhaps four, persons attending the Air Navigation Services School at the airport. The three were Siegfried Schombel, Hubertus Wollner and Johannes Bogen; the fourth was Heinz Tismer, whose statement does not indicate his position. All four made statements that they observed the starboard wing from about 50 yards distance and saw snow lying on it. The German Commission attached

particular weight to the statements of Schombel and Wollner, who gave oral evidence before them. Schombel's written statement includes this observation: "after the mechanic had given the "all clear" signal for taxying, the snow remained lying on the wings, in spite of the slipstream. It was sticky wet snow." Wollner stated "I can testify with absolute certainty that there was wet snow on the outer section of the right wing, I cannot remember if there was any snow on the centre section." The photograph mentioned above (para. 44) was taken by another student at the Air Navigation Services School and the print, which we examined, is consistent with the above statements. The wing surface is of unpainted metal, with the exception of the lettering and of a narrow band of anti-corrosive paint behind the engine exhaust. The photograph shows a distinct change in the colour of the wing surface at the edge of the propeller slipstream, the outboard portion showing white while that behind the propeller is darker; moreover the registration letters do not appear in the print, either from some photographic effect of refracted light or because they were covered by snow. There were three ice indicator marks on the starboard wing, narrow black lines painted on the forepart of the wing, outboard of the propeller slipstream, and extending some distance back from the leading edge. These are visible in the photograph, plainly so at the leading edge but becoming less distinct as the eye proceeds across the wing surface.

47. Mr. Black did not examine the wing surface at this period. He walked round the aircraft but the wing surface was above his eye level. (As the German Report accurately stated, "from outside the aircraft the wing surfaces cannot be seen at all from the front unless one stands in a raised position, and from the rear they can be seen only from quite a distance.") When the aircraft taxied away and reached a sufficient distance for the wing surface to be seen Mr. Black observed, according to his recollection, that the mainplane was clear of snow except for the wing tips. He told us he could not explain why there should be snow on the wing tips and not on the rest of the wing.

48. Captain Thain did not leave the cockpit during this second visit. Speaking of Captain Rayment and himself, he said "We both looked out of our respective windows and studied our respective wings and we found that we had lost that very thin film of partially melted snow which I had observed walking out to the aircraft, and from my seat the wing appeared quite clean." The engine nacelle interrupted his view of the inboard portion of the wing, but he could see the ice indicator marks and further outboard; his eye level was below the wing level, but he could see the leading edge, and, because of the curvature of the wing, he could also see the upper surface for the first tenth or twelfth part of its width. He emphasised that of the part of the wing within his vision he could see the metal with no snow upon it.

Section (4) - The State of the Wings: Indirect Evidence

49. It may be possible to deduce the presence or absence of wing icing immediately prior to the accident from observed facts as to (i) the performance of the aircraft on its final run, or (ii) the condition of the wings after the accident. We deal later with the first of these sets of facts (para. 86 below) but can say at once that no useful conclusion as to icing can in our view be

drawn from them. The second however is of prime importance: the German Commission attached considerable importance to deductions from what was ascertained after the crash, and a large portion of our Inquiry was taken up in submissions and evidence designed to show that the German conclusions were in this respect erroneous.

50. The evidence of Captain Reichel, the West German Chief Inspector of Accidents, and his two assistants as given in the German Report, has already been summarised at para. 16(i) above. Their inspection of the wreckage was made by the light of arc lamps six hours after the accident, and of the intervening period slight snowfall was recorded in the first $1\frac{1}{2}$ hours and moderate snowfall thereafter. The temperature at 2200 hours was $-3.0^{\circ}C$. We were told by Mr. Jones and Mr. Kelly that the evidence of the German investigators was that they brushed powdery snow off the wings in places and exposed a layer of ice underneath. We inquired how the depth of that ice, stated as 5 mm., was measured, and we were informed that it was not measured. According to Mr. Kelly's evidence "Captain Reichel . . . described how he had swept the snow off with his hand and found a rough layer of ice. That was all he said to begin with. Later on . . . he was asked to give some estimate of the depth or thickness of the ice and he said 5 mm. . . . I understood Goetz to say he examined the wing at one or two places simply by pushing his hand underneath the snow and feeling about with his fingers and he said at certain parts of the wing there was a rough layer of ice under the snow." Mr. Kelly had seen a news film, which chanced to have been taken at the time of the inspection, showing Captain Reichel brushing powdery snow off the trailing edge of the wing; he said "it would be possible to state that there was a layer of rough ice there, but I should not think you could make any accurate assessment of its depth without taking some such action as digging a pin in it or scraping it off and measuring it, and I have not heard that that was done at all." No evidence was proffered to us to controvert the German finding that the ice layer had not blended at all with the superimposed snow. As to the finding that there was no ice under the snow in the place behind the engines, the only criticism offered was that the whole wing was not examined but that the findings were based on "spot checks" made, according to counsel, in seven different places, and that these might be insufficient for the formation of a true picture.

51. We think that the primary facts as found by the German Commission must be accepted, save that the depth of the rough ice layer is not established as 5 mm. and may have been substantially less. These findings of course relate to a time at or after 2200 hours. We also had the evidence, in written statements, of the three individuals who took part in rescue operations and whose testimony had been furnished to the German Commission after their Report (para. 25 above). Karl-Heinz Seffer, aircraft mechanic of the German Air Force, in the process of freeing Captain Rayment from the cock-pit, climbed first on to the fuselage and then on to the starboard wing between fuselage and engine; he crossed this wing to its trailing edge, near the fuse-lage, where he got down. He said "Whilst I was doing this I did not notice any deposit of ice on the fuselage or on this part of the wing. I was wearing rubber boots. I am particularly inclined to assume that there was no deposit of ice, because if there had been I would probably have slipped. I cannot say

whether there was any ice on the wings outboard of the engines, nor did I notice any snow on the wings." His father Otto Seffer, employed in the airport traffic service, stood on the upper surface of the fuselage: "there was no ice to be seen, if only because everything was smashed up." Gerd Skwirblies, P.A.A. aircraft engineer, opened the port side of the fuselage, near the pilot's seat, with an axe. "At the spot at which I opened up the fuselage, there was, for certain, no ice. My companions were wearing rubber boots and were moving about on top of the fuselage, near the cockpit, without slipping. From this I conclude that there was no ice on the top of the fuselage either. Whether there was ice or snow on the wings, I cannot say. I was not looking for that. But I seem to remember that the leading edge of the wing was free of ice." These statements tend to establish that there was no ice behind or inboard of the engines immediately after the crash, which is not in conflict with the findings of the investigation at 2200 hours.

52. We now turn to the deductions from the above facts, all of which were debated before us. It is an important preliminary to this matter to recall that a snowflake falling in a temperature below freezing point is "dry"; it is pure ice and contains no water; but that if it falls into an ambient temperature above freezing point its minute strands of crystalline ice begin to melt so that the snowflake then contains water and is "wet". Likewise if it falls on to an object itself above freezing point it commences to melt. If a dry snowflake falls on an object itself below zero it does not adhere to the object, but if a wet snowflake falls on such an object its free water re-freezes and causes it to adhere to the object. The binding element in wing icing is freezing water. Now the air temperature at Munich airport fell steadily from the - 0.2^{o}C. recorded four minutes before the last run to the - 3.0^{o}C. recorded at the time when the inspection commenced. Unless therefore there was an abnormal variation between the temperature at the airport screen and that at the point where the wings came to rest, perhaps 1,500 yards distant, the snow falling at all times between the accident and the investigation must have been dry. Such snow falling on an aircraft wing coated with ice and ex hypothesi below zero would not adhere to the ice because there would be no free water present to bind the two together by freezing. The finding, therefore, of a layer of ice outboard of the engines covered with powdery snow which had not blended with the ice is consistent with that part of the wing being ice-covered at the time of the crash. Is it also consistent with its being free from ice at that time? If the wing were then clean, the ice can only have been formed by the melting of the snow that fell thereafter, and its subsequent re-freezing as the temperature dropped. There are two objections to this hypothesis. Firstly there is the question whether the wing temperature was at that time high enough to melt the falling snow, (which was only "slight snowfall" until 1850 hours), bearing in mind not only the recorded temperatures but also the fact that the physical change from solid ice to liquid water or vice versa involves a heat transfer of 80 calories per gramme (cu.cm.) of water. If snow is melted by falling on a wing of a temperature above zero, the act of melting itself thus extracts heat from the wing and lowers its temperature, so accelerating the cooling which was taking place during the time in question. The second objection is that, according to the evidence, the melting and re-freezing process would not produce two disparate layers, one of clear ice and one above it of powdery snow, but would produce a blending between the

upper ice and the lower snow, or as Dr. Penman put it, "some degree of adhesion" between the two. That witness said "as it is described to me now" (sc. marked lack of cohesion between ice layer and superimposed snow) "there is obviously a discontinuity in the physical system and one feels there must be discontinuity in the history of the formation."

53. As to the first objection, we were not invited to consider the point, dealt with in the German Report, that the fires which broke out in parts of the wreckage raised the temperature either of the air or of the wing surface sufficiently to melt falling snow. Instead it was suggested to us, as it had been to the German Commission when the reopening of their Inquiry was sought (para. 27 above), that the use of fire extinguishing powder on the wing surfaces had the effect of lowering the freezing point of water. The powder, according to this submission, would lie more heavily in the area behind the engines and the difference in quantity, and in consequent effect on the freezing point, accounted for the difference in the conditions found behind the engines and elsewhere on the wings.

54. In support of this contention Mrs. Thain gave evidence of experiments with a sample of the fire extinguishing powder used at Munich airport. The powder contained sodium bicarbonate and although it also contained a water repellent to prevent caking, she found that it went readily into solution in water, even when merely dusted on to a water surface, and that the freezing points of different concentrations of solution were as follows:

Solution	1 in 1000, freezing point	-0.4°
	1 in 100,	-3.0°
	1 in 10,	below -3.0°

In addition, Mrs. Thain thought that the ice produced by the subsequent re-freezing would be thicker than that produced by the freezing of rainwater. Her reason was that different constituents in the powder would crystallize out of solution at different points, providing, as the temperature dropped, a combination of solid and liquid matter which would be more viscous than the slush of water in the process of freezing and would stand on a slightly sloping wing to a greater depth than would water. However she had made no comparative tests of the viscosity of the solution while in process of freezing compared with that of water at the like stage. Of what may have happened, she said "I visualise that this snow could be intermittent or not heavy continuous snow, and that the snowflakes would fall, and where they came in contact with the powder they would melt. I do not think they would melt sufficiently quickly to enable the snow to run off, to enable the solution to run off the aircraft, and as the temperature fell you would reach a point (because you do not need a very high concentration to lower the freezing point) and somewhere between 0° and -1° the majority of the ice would form and the thickness would depend on how much snow you actually trapped in your solution. I do not think you can be specific on exactly how much snow would fall on how much fire extinguisher powder." When it was suggested that her evidence did not account for the absence of ice beneath the dry snow behind the engines, she said "As I read the Report I visualised that Captain Reichel brushed it away from the engine and found there was no ice, and I think one could mistake snow on top of a thick body of slush as complete snow, and that if one did that one would automatically dismiss the lot as snow, whereas in fact it could have been possibly slush in contact with the engine which he brushed off."   In this connection Mr. Jones, had suggested that the area behind the engines must have been hot at the time of the crash, so that snow alighting there would melt, that the finding of snow lying here at 2200 hours showed that it had in the intervening time passed below freezing point, and that at the moment of freezing the melted snow lying on it must have turned to ice.   He could not understand why there was not at least a film of ice behind the engines under the snow.

55. Captain Thain said that the fire extinguishing powder was projected from a portable apparatus (seen in the left of a photograph (Fig. 2) printed in Appendix 8 to the German Report).   The apparatus delivered a powerful jet of powder and he saw it used to extinguish a fire under the starboard wing. The fireman started to move away to a house which was burning, but Captain Thain called him back as the fire under the starboard wing had reignited: "I stood there while the fireman put out the fire for the second time . . . . . there is no doubt that he gave the starboard engine a jolly good dousing."   He saw him hold the nozzle 6 to 10 feet from the starboard engine, round which he concentrated.   He did not see the fireman applying powder to any other part of the starboard side, nor sprinkling the starboard wing as a precautionary measure.

56. We accept Mrs. Thain's evidence as to the lowering of the freezing point of a solution containing the powder, and if there had been any evidence of a distribution of powder over the whole of both wings, this factor would explain some melting and re-freezing despite the prevailing temperature.   But in our view it does not explain the discontinuity between the rough ice and the superimposed snow, nor does it explain the absence of ice behind the engines. The last-named finding is a puzzling feature on any view of the matter.   If any substantial part of the wing was heated by the engines, either this must have cooled very rapidly at a time when no snow was falling, or there was inaccurate or insufficient observation.   It is here that we encounter a difficulty inherent in the nature of our inquiry.   Our function is to consider Captain Thain's representations and the German Report.   As already mentioned, Captain Thain's representatives furnished us with a great deal of the material which was before the German Commission, but they were not of course in a position to call Captain Reichel or his assistants, whose evidence is the foundation of this part of the case.   This evidence was accepted by the German Commission, of which Captain Reichel was a member, and it would be improper for us to speculate as to whether, for example, the number of spot checks taken was sufficient or whether the investigators had mistaken dense slush for dry snow.   We feel at liberty to criticise the reasoning of deductions set out in the German Report, where such criticism is relevant, but it is out of the question to criticise evidence of witnesses we have not seen or to speculate on what answers they would have given to questions on details of their observations.   These considerations lead us to say that we have insufficient information to enable us to decide whether or not, by reason of the prevailing temperatures, the ice found at 2200 hours could not have formed after the accident.

57. It was further submitted to us that 5 mm. must in any event be an overestimate since the snow equivalent of a maximum depth of only 2 mm. of water had fallen during the aircraft's stay at Munich (para. 34 above) and if the whole of this froze on the wing it could produce an ice layer only fractionally deeper than 2 mm. Furthermore some of the precipitation had been seen running off the wing by witnesses. This is in our view a convincing point: we discuss below how far pre-take-off conditions can have permitted ice formation, and we think it true to say that if the post-accident ice was 5 mm. thick it could not have been formed from pre-accident precipitation, and that if it was formed from pre-accident precipitation it could not have been 5 mm. thick

Section (5) - The Effect of Spray

58. It emerged during the evidence that during its last run the Elizabethan threw up clouds of spray. Mr. Black said "the aircraft went along the runway as if it were a snowplough" and later said "It just looked as though a flying-boat was taking off." He added that the unusually low fuselage of this type of aircraft seemed to be deflecting the spray. If this happened during the last run it would appear that it must have happened on the first two runs. Now, as we shall see, what was lying on the runway was melting snow, slush, or water, and <u>if</u> any of this spray landed on the wings and <u>if</u> those wings were at the appropriate temperature the wet spray would freeze and adhere. This point does not seem to have emerged until our Inquiry, and there are no experimental or other data to show the trajectory of spray thrown up by the wheels at the relevant speeds, but it seems not impossible that it should reach the wings, except perhaps in the propeller slipstream since the blades might intercept and scatter it. In considering the origin of the ice found at 2200 hours therefore there is a possible source other than natural precipitation which in our view merits investigation. It was not investigated before us because Captain Thain through his counsel did not wish to make a point of it.

Section (6) - The Effect of the Evidence

59. Having assembled the facts and supporting evidence, we have to see whether they lead, as was submitted, to the conclusion that at the time of the last attempted take-off the wings were free of ice. We see no reason to doubt the eye-witnesses who saw melted snow running off the wings at or shortly after the time of refuelling. This points to the wings at that time being appreciably above zero centigrade. The last person to note this was Captain Thain (para. 45) and no-one speaks of this happening after he had embarked, a fact consistent with our view that the wings were then at about zero. The time of Captain Thain's observation is not known but assuming it to be 1500 hours, there elapsed an hour between it and the final run, during which 20 minutes was spent in taxying, holding, making two abortive runs, and returning. During that hour the wings could have been at any temperatures between say + 0.5°C. and - 0.5°C. according to what local variations from screen temperature existed. It is impossible to assert that they must have been thawing or must have been freezing at this time. In one of the documents before us, Mr. Jones, starting with the assumption that

the wing had cooled from + 10°C. on arrival to zero in 30 minutes or less, proceeded as follows: "If the ambient temperature is 0°C. and the relative humidity very high (i.e. wet bulb temperature also very close to 0°C.) the wing when cooled to 0°C. in about half an hour will remain at 0°C. and there will be no further melting of snow as it falls and the freezing process, if any, will be very slow indeed. The wing will remain wet with a maximum of ½ mm. of water depth on it (from the half hour's melting although, of course, some water must have run off) and the subsequent snow will accumulate on the wing, i.e. snow equivalent to about 1 mm. of water, corresponding to the snow falling between 1447 (half an hour after landing) and 1550. At 1550 the snowfall became very light and at 1600 the temperature in the meteorological enclosure was - 0.2°C. and the relative humidity had fallen to 91 per cent. Slow freezing was then inevitable provided the air temperature in the meteorological screen was typical of the air over the whole aerodrome. When dealing with temperatures to one tenth of a degree C. no meteorologist could state positively that this was so. The small margin of temperature therefore makes it impossible to say with certainty that freezing was proceeding. All that seems reasonably certain is that there was snow on the wings and that beneath the snow there was a thin layer of water or ice. Freezing of the water film . . . would cause some of the snow above to be held and would lead to a rough surface to the ice. It could be argued, and no one I think could positively contradict it, that the freezing of the wet film containing embedded snow occurred after the accident since the temperature continued to fall after the accident."

60. That analysis demonstrates both the theoretical uncertainties of the situation and how crucial the prevailing meteorological conditions were to the aircraft's safety. Do the observations of the eye-witnesses during the second visit to the apron help to resolve the uncertainties? We accept, without attaching great importance to, Captain Thain's observation of the small portion of wing he could see from the cockpit. We think the witnesses who looked down from the terminal building, corroborated by the photograph, establish that snow was lying on the wing and not melting; whether there was ice under the snow they could not tell. It was submitted that the above-mentioned photograph showed some water lying under the starboard wing at 1550 hours and that this water must have dropped from the wing. We agree that the darkness on the ground, contrasting with the white track-marked snow elsewhere on the ground, is probably water; it lies beneath the inboard section of the wing, largely in the vicinity of the engine, where melting of any falling snow would certainly take place. Whether this water came from this aircraft or from another aircraft which, as the tracks show, had previously stood there, and whether it fell from the trailing edge of the wing or from the vicinity of the engine and ran into the position seen in the photograph, it is quite impossible to determine. We do not think the photograph helps us in this respect. Whether or not there was ice under the snow on the wing, and whether or not, if so, the snow was freezing to it and thickening the layer, depends upon a temperature variation within so small a compass that, in the light of the evidence of Dr. Penman and Mr. Jones (paras. 40 and 59 above), we are unable to find that the presence of ice is conclusively established, although on balance of probability we think it not unlikely that there was at least a thin film of ice present under the snow.

61. The German Report (p. 25) is in substantial accord with our reasoning as regards the position up to 1500 hours. It says "It is true that in the case of the first take-off at 1519 hours, at a temperature of approximately 0^{o}, the humidity of the air still amounted to 96%. Cooling by evaporation will thus still have been slight at this juncture. Only a film of ice will have formed on the cooled wing, under the layer of snow observed." However it goes on to say "When the last take-off was initiated, however, the air temperature was already - 0.2^{o}C, and the humidity of the air was 91%. Thus there existed conditions which point to the fact that by the time the aircraft taxied out for the third take-off and during the first phase of take-off, the cooling by evaporation had become so highly effective that the wet snowy mixture turned into the rough sheet of ice which was observed in the late evening of the same day." We were pressed to say that the reasoning in the latter passage was erroneous, and Dr. Penman was called expressly to deal with cooling by evaporation. We need not however comment upon his calculations since we differ from the view of the German Commission as to what happened after 1500 hours because we cannot accept the proposition, underlying their reasoning, that the air temperature at the wing was exactly the same as that at the screen. Moreover we think that factors other than evaporative cooling, such as the temperature of the uplifted petrol, could be at least as powerful in influencing the temperature of the wing.

Section (7) - Steps Taken by Captain Thain

62. It is well known to pilots that ice may form in critical meteorological conditions such as those outlined above, and it is common practice for precautions to be taken in such conditions. See for example Civil Aviation Information Circular No. 150 of 1954, "The Effect of Frost, Ice and Snow on Aircraft Performance, Precautions before Take-off", para. 4(b)(iv) of which states that snow "will also be liable to freeze to the surface if the temperature has fallen from just above freezing point during the snow. It is never safe to assume that snow, though apparently of the dry variety, will be blown off during take-off . . . . . . Particular care is necessary when the temperature is in the neighbourhood of freezing point and delay occurs between the removal of the snow and take-off." An example of the steps taken in the prevailing conditions is afforded by the evidence of Captain Wright. On arrival he inspected the wings of his Viscount. Asked whether this was a routine check he agreed but added "in those circumstances of temperature I would say a specific and special check". He climbed on a stand in order to inspect his wings: he found a little water and melted snow and if he had departed then he would not have de-iced the wings. (He had had his de-icing equipment switched on while descending through cloud but thought it had been switched off before landing). When about an hour later he was ready to embark his passengers he inspected again; heavier snow was falling and he found it freezing to the wings. He therefore had the aircraft de-iced. The Viscount took off at 1720 hours. Asked why he regarded his first check as special, he said "because of the temperature and the fact of the temperature dropping slowly with the length of time on the ground, getting dark, and temperatures obviously falling, and as a matter of interest with a slight precipitation forming of any frozen kind

I would always do that." He had ascertained the temperature from the Meteorological Office. His evidence continued:

"Q. Would you regard the temperature being at or about zero as being important in your consideration of de-icing?

A. Yes, obviously so. In relation to my first check on the wings, the amount of precipitation, melted snow, water, was the first consideration. If there had been more present at that temperature then I would have had it de-iced, but there was so little . . . . it was so very little as to be negligible."

63. The German Commission had evidence that similar precautionary action was taken by those responsible for the other aircraft taking off from Munich that afternoon. See p.23 of their Report: "In the case of all the other aircraft which took off that afternoon snow had, in fact, collected on the wings and in each case it had been removed by personnel of the air transport undertakings." This refers to four aircraft other than the Elizabethan and the Viscount, namely a DC-3 departing at 1408 hours, a DC-7C at 1433 hours, a Convair at 1544 hours and a DC-6B at 1554 hours. (The German Report appears to be inaccurate in stating at p. 17 that sixteen aircraft landed and took off in the course of the afternoon. We were supplied with a memorandum from the Station Superintendent, Munich, showing that after 1300 hours (midday G.M.T.) eight aircraft landed and the six mentioned above departed).

64. Captain Thain described his action in detail when giving evidence to us. On alighting at the apron he found the ground covered with watery slush and pools of water about an inch deep. Fifteen or twenty minutes later, after completing the flight plan, he met Captain Rayment and discussed the snowfall on the wings: "he told me that he had looked at the wings and in his opinion they did not need sweeping." He agreed with him. Asked why he agreed, he said "I could not think of a better authority than Captain Rayment, a senior captain in B.E.A. He had gone out and looked at the wing and he came back and told me he had done so." This conversation took place outside the Air Traffic Control Office, in view of the aircraft. Captain Rayment did not say how he had looked at the wings, nor did Captain Thain ask him, but Mr. Black was then on top of the wing and there would be a ladder in position for his use. Captain Thain said "I think there is every likelihood that Captain Rayment would have used that ladder."

65. After the conversation Captain Thain visited the B.E.A. office, signed the ship's papers, and returned to the aircraft, at this stage making the observations of water running from the wing already detailed in para. 45 above. Before he embarked he was approached by the Station Engineer, Mr. Black, who asked him if he required the aircraft to be de-iced. Captain Thain did not remember this conversation but accepted Mr. Black's evidence which was that in reply to the question Captain Thain said that he did not consider that the aircraft required de-icing at all. After embarking for the first attempted take-off, Captain Thain made no further observation of the wings from the cockpit. He said he had by then satisfied himself of the position. The following are his answers in this respect to his counsel:

"Q. Did you consider at that stage, just before the first take-off, that there was any need whatever to sweep snow off the wings?

A. It is always a possibility when you have got snow falling.

Q. But did you consider it necessary to do so?

A. No, there was insufficient; you have got to have snow to sweep off.

Q. And you had addressed your mind to it?

A. Absolutely, and I decided that, with the very very small quantity that was there, it was not necessary to sweep it off.

Q. And it was actually snowing at the time, was it?

A. Very lightly."

66. Later, before the final attempted take-off, Captain Thain again considered the question of snow on the wings. His observations from the cockpit window have been given in para. 48 above. He said he discussed the matter with Captain Rayment, who reported seeing the same conditions on the port wing, and formed the view that there was no necessity for the wings to be either swept or de-iced. By this time, he said, there was virtually no snow falling, only "a flake here or there."

67. Captain Thain was asked by us whether he had ascertained the ground (screen) temperature. He could not recall having been told this before landing, nor making inquiries about it when visiting the Meteorological Office. His evidence continued:

"Q. Did you think it important to make any inquiries about the temperature?

A. I think I was aware of the fact that the temperature was approximately zero.

Q. But in connection with any ice on your aircraft, that was the most critical temperature in the whole thermometer, was it not?

A. Yes, but at the same time I was aware of the fact that the temperature when I arrived at Munich was certainly not below zero, but was above it.

Q. What made you think that?

A. Perhaps by experience . . . There was snow falling at the time when we arrived there, and the snow which was falling was wet snow.

Q. You are saying it was wet snow, and therefore you thought the thermometer was above zero?

A. Yes . . .

Q. Did you change that view at any time up to the accident?

A. No . . .

Q. Did you give any thought to the possibility that it might be going below zero?

A. I did not think it would be going below zero.

Q. Why not?

A. At that particular time it was not far advanced in the afternoon. There was complete cloud cover . . . I did not expect the temperature to fall below zero, or to zero."

68. Captain Thain said he was well aware of the dangers of icing. He was familiar with Circular 150 of 1954 (para. 62 above) and with a B.E.A. Instruction that "Captains should . . . make absolutely certain immediately before take-off that the lift and control surfaces of their aircraft are clear of snow." He said that if he had thought that his wings had a temperature below freezing he would have had them de-iced. He agreed that on his second visit to the apron he took no steps to satisfy himself about wing conditions except to observe from the cockpit window, and that inside the cockpit he was not in a position to check the outside temperature (except by radio, which was not used). As to his decision before the last run, he was asked:

"Q. Is it fair to say you were going on general impression and general feeling rather than on any observation or any concrete information about temperature?

A. My opinion was based on what I had seen of the snow melting on the wing, and the general feeling that I had.

Q. Yes, of course that was some considerable time earlier, was it not?

A. It was earlier." . . . (He said it was about 40 minutes earlier)

Q. You did not think it right, in view of that lapse of time, to ask for specific information about temperatures, or have a look at your wings a bit closer to?

A. No, I was satisfied when I saw that the snow that had been on that wing had been blown away, the aircraft did not have any snow on it."

69. Shown the photograph referred to in para. 46 above, Captain Thain agreed that it gave the impression of a wing covered with snow outboard of the propeller slipstream but free of snow behind propeller and engine. He agreed that the alteration in colour at the edge of the slipstream could not be

accounted for by the band of anti-corrosive paint. Asked what could account for the change of colour, other than the edge of a covering of snow, he could offer no explanation.

70. Upon the evidence it was submitted on Captain Thain's behalf that he had acted correctly; that every indication which he had pointed to a thaw; and that a Captain could not be expected to have moment to moment reports of temperature changes. It was further urged upon us that the amount of ice which could have formed between the first and last departures was infinitesmal, and that we must consider the position of a Captain with a great deal on his mind. Our opinion on this part of the matter is given in Part IX below.

PART VII - RUNWAY CONDITIONS

Section (1) - The Runway: Direct Evidence

71. The runway at Munich has been lengthened since the accident. It was then 1908 m. long (2087 yards). It is 200 feet wide and lies at a compass bearing of 249°. At the material time aircraft were landing and taking off from E-N-E to W-S-W. At its nearest point (about two-thirds of its length, starting from the east) it was approximately 950 m. from the terminal building. The surface was concrete, slightly cambered.

72. The only witness, so far as we are aware, who examined the runway from the ground at the time in question was Herr Bartz, whose evidence to the German Inquiry is quoted in extenso at para. 15(iii) above. Direct evidence at our Inquiry was given by three pilots, Captain Wright, Captain Merrifield and Captain Thain.

73. Captain Wright landed his B.E.A. Viscount five minutes before the Elizabethan's last run; in fact the latter was holding at the end of the runway when the Viscount landed. Captain Wright, looking down from an eye-level height about 10 feet from the ground, observed the ruts made by aircraft wheels in the snow or slush covering the first two-thirds of the runway and from them estimated that the depth of cover was one to one and a half inches. The last third was covered in slush with large pools of water. He saw distinct banks at the edge of the runway, as though the snow had been swept earlier. The snow or slush on which he landed had a retarding effect, so that instead of having to brake, as he would have had to do on bare concrete in calm conditions, he had slowed to taxying speed by about the mid-point in the runway and thereafter applied power. While taxying he was asked by control to report on braking action; he applied his brakes and found that "a fair amount of braking could be applied without causing any sliding." When taking off again for London at 1720 hours the Viscount again experienced retardation attributable to the slush: it was the practice to time the run with a stopwatch; in ordinary conditions, with the aircraft lightly loaded as this was, the elapsed time to V_2 of 106 or 107 knots would be about 23 seconds, but to the best of Captain Wright's recollection it was on this occasion nearer 30 seconds and the aircraft used about two-thirds of the runway before unsticking.

74. On arrival at London Airport it was found that the nose-wheel of the Viscount had on the take-off accumulated a great deal of slush which had turned to ice: the back of the oleo and the steering jacks were covered with a thick coating of ice, estimated as varying between 2 and 5 inches in thickness: the steering jacks had disappeared in a ball of ice.

75. Captain Merrifield had landed another BEA Viscount at Munich two days later, on the 8th February 1958. By then a thaw had set in and from the air the runway appeared clear although the grass areas of the airfield were still snow-covered. About half way down the runway this witness found a large pool of water 200 to 300 yards long on the northern side of the concrete and extending to the half-way mark. He landed on the south side to avoid the pool.

76. That part of Captain Thain's evidence which dealt with the runway was as follows. "When we first touched down the aircraft was inclined to slide on what I thought to be some packed snow, it was slippery. When we got further down the runway we found that the precipitation or snow on the runway was rather different: it was watery, there were some bare patches and the braking effect was quite satisfactory. I reported this to the control tower." He did not recollect whether a special braking test was carried out, as in Captain Wright's case, but thought they would have braked in the normal way: it was Captain Rayment who operated the brakes. He did not remember his aircraft being retarded by slush as the Viscount had been. He recalled nothing special about the state of the runway. On the first abortive take-off the aircraft stopped and turned approximately 400 m. from the end of the runway, and on the second it taxied to the end in order to return to the terminal by the perimeter path. He did not see the banks of snow on either side of the runway spoken of by Captain Wright, nor anything unusual in the state of the runway. When taxying back after the second run he had difficulty in identifying the edge of the perimeter path owing to the snow: there were no tracks of other aircraft to be seen on this path, so far as he remembered.

77. We may summarise the direct evidence by saying that while Herr Bartz, who examined the runway at about 1535 hours both from a vehicle and on foot, gives a picture of a runway covered with slush of a uniform depth and consistency ("a jellified water mass" "approximately $\frac{1}{2}$ to $\frac{3}{4}$ cm. deep"), the two pilots noted a difference in condition between the easterly two-thirds and the westerly one-third, and one of them gave an estimate of the depth of the first part as five times greater than did Herr Bartz (one inch = 2.540 cm.) None of these witnesses observed any significant change in the depth of the cover nor did the pilots experience any increased drag at any particular part of the runway. With these considerations in mind we proceed to see what light can be thrown on the matter by the behaviour of the aircraft on its third and final run.

Section (2) - The Final Run: Evidence

78. The part of Captain Thain's written statement dealing with this run has been reproduced above at para. 20. In evidence he was asked what happened when the needle of the A.S.I. reached 117 knots and answered "The needle hovered at that speed; it was flickering. I waited for an increase in speed,

but it did not come forward, and after a few seconds at that speed the indication fell off about four or five knots. It was flickering quite a lot. It paused at about 112 knots, and then it fell off again to 105, flickering quite a lot. I thought I felt at that time - well, I certainly felt a lack of acceleration, but the thought passed through my mind about the accuracy of the instrument. I could not make up my mind. The next thing that happened was a cry of alarm from Captain Rayment." He had no idea how much runway they had used when V_1 was attained; he said the needle stayed at 117 knots for "several seconds" and at 112 knots for one or two seconds. While the speed was at 117 knots Captain Rayment was operating the elevator trimmer. He did not look up from the instruments until Captain Rayment's ejaculation: "When he uttered his cry of alarm, things happened very quickly indeed. I looked up, banged the throttles, and almost at the same time he called 'undercarriage up.'" He was "pretty sure" they had not then reached the end of the concrete. It was afterwards ascertained that the nosewheel retracted but the main wheels did not. He was not conscious of the nosewheel retracting, but "I was aware of a strange feeling of believing that I was airborne. We had at that time reached a very smooth passage." At this stage the nose of the aircraft was up, but he had no knowledge of the aircraft's attitude up to the time of his colleague's cry. He himself did not close the throttles.

79. Further evidence of this attempted take-off is provided by the observations of the two Air Traffic Controllers, Laas and Gentzsch, summarised at para. 25 above, and by the tracks of the aircraft's wheels. The evidence of the tracks was given in the German Report as follows:

> "From the point at which the aircraft had broken through the fence its tracks could clearly be discerned, extending back to the runway. The double track of the right side of the undercarriage could be followed back to the runway without difficulty. The left-hand wheel track was interrupted in places. Nowhere was there any nosewheel track to be seen.
>
> "From the end of the runway to the fence, in the direction of take-off, the wheel-tracks showed a slight swing to the right. Two days after the accident, when the snow had melted, the tracks were particularly clearly visible. On the runway, about 50 m. short of the end, a skidmark began. It was clearly visible on the concrete and from the strewn sand which the wheels had pushed aside . . . This mark showed that at this point all four wheels of the main undercarriage were locked. This skidmark continued for approximately a further 30 m. beyond the end of the runway. It then stopped and there remained the impression of the free-running wheels on the grass surface. The track of the right-hand twin wheels was strongly marked; that of the left-hand wheels was fainter and at times interrupted. The track of the right-hand wheels was uniformly clear throughout the whole length (250 m.) of the stopway as far as the point at which the aircraft crashed through the fence. The left-hand wheels had at times left the ground. The skidmark and wheel-marks were still clearly visible at the time of the survey of the scene of the accident by the

Commission of Inquiry on 30th April, 1958."

The track of the rear wheel was also visible in the snow at the end of the runway: see the statement of the witness Meyer, mentioned in para. 29(c) above.

80. The time taken by the run can be gauged with accuracy from the transcript of the tape recording of R/T communication between the aircraft and control (Appendix 1 to the German Report), in conjunction with the written statement of Mr. G. W. Rodgers, the radio operator of the Elizabethan. He reported "rolling" as the aircraft began to move, this being recorded at 1603.06 hours. He heard Captain Rayment call "undercarriage up" and immediately called control but "before I could do more than give the call sign the aircraft crashed." The tape records this message as commencing at 1604.00 hours.

81. Relevant data is also furnished by the Peravia recording of the port engine performance referred to in para. 5 above. On the recording the time scale is 2 minutes to about $\frac{1}{8}$ inch, so that precision as to seconds cannot be obtained, but Mr. Kenward, who interpreted it in evidence, thought he could certainly read it accurately to within 5 seconds. Two traces were recorded on the wax cylinder, one showing boost pressure, the other r.p.m. The boost pressure trace shows that from the opening of the throttle power was applied for approximately 50 seconds. After 20 to 25 seconds the recording fell from about 59 inches to about 54, presumably from throttling back, but after 10 to 15 seconds it returned to 59, staying at this pressure for a further 15 seconds approximately after which it fell abruptly below static pressure, indicating that the engine was throttled right back, remaining there until it reverted to static pressure, as it would when the engine stopped. The importance of the record lies in its corroborating Captain Thain's evidence about throttling back during the run, and in its demonstrating that the throttles were cut an appreciable time before the crash. Owing to the coarseness of the scale it is impossible to be precise about the length of this time or to say at what point on or after the runway it occurred, but Mr. Kenward thought it clearly corresponded to a point either near the end of the runway or on the overrun area. This, it will be recalled, is the vicinity where the skid-marks appeared, and as Captain Thain neither closed the throttles nor braked, it is not unlikely that the beginning of the skid-mark represents the point where Captain Rayment cut power as well as braked.

82. The outstanding feature of Captain Thain's evidence is his firm recollection of the airspeed dropping from 117 to 112 and then to 105 knots. The German Commission rightly pointed out that "for subjective reasons, statements by witnesses are subject to error precisely when it is a question of giving an account of what happened in an unnerving catastrophe." Memory plays strange tricks with the victims of shock. We do not doubt, nor did the German Commission, that Captain Thain was giving his honest recollection, but in the circumstances it may not be an accurate recollection. It is certainly a consistent recollection: Captain Thain mentioned the drop in speed when interrogated by Captain Reichel two days after the accident, according to the transcript of the interview furnished to us.

Section (3) - The Final Run: Inferences

83. It was submitted on Captain Thain's behalf that, accepting his evidence as accurate, the remarkable deceleration of which he spoke, could only be attributed to an increase in either the depth or the density of the slush or both. The German Report reconciled the evidence with their view of what happened by attributing the drop in speed to the applying of the brakes by Captain Rayment (para. 23 above) and by stating that the sequence of Captain Thain's account showed that the deceleration took place towards the end of the runway, (paras. 22 and 30 above). We find it difficult to follow this reasoning. Captain Thain's statement appended to the German Report (para. 20 above) does not, as it seems to us, necessarily indicate that there was little lapse of time between the deceleration and the witness looking up and seeing the house in front of him. Moreover, Captain Rayment's cry "Christ, we won't make it" can only indicate that up to then he had been trying to make it, and if that is so he cannot have applied the brakes until at any rate the moment of the cry. Yet this was after the deceleration first to 112 knots and secondly to 105 knots, according to the statement. If Captain Thain's recollection has transposed the order of events, it is unreliable and must be rejected. On the other hand it is honestly and consistently given and is entitled to consideration. If it is correct, we cannot accept braking as the cause of deceleration and must look elsewhere. Moreover even if Captain Thain's recollection has transposed the order of events we do not think braking can have caused the deceleration of which he spoke. The wheels were locked for 90 yards, which at 117 knots would be covered in $1\frac{1}{2}$ seconds. A deceleration of 12 knots in this time is nearly $\frac{1}{2}$g; this would be impossible in the conditions obtaining even if the wings were not lifting at all. Since the aircraft was at full incidence, such a deceleration is doubly impossible as a result of braking alone; the probable loss in the conditions obtaining would be 1 to 2 knots at the most.

84. The deceleration must be caused by either a diminution of power or an increase of drag. There has never been any question of the former and the cause of the deceleration must have been drag increase. We have considered possible causes and can find none save an increase in the depth or density of the slush. According to Captain Wright as well as Captain Thain the slush changed in character two-thirds of the way down the runway from being predominantly snow to being predominantly water, i.e. its density increased. This, if the depth remains constant, must increase its drag, and if the increased drag is applied to the main wheels, the nose wheel then being clear of the ground, the resultant pitching moment may return the nose wheel to the ground. Once that happens, drag increases further since it is applied to six wheels instead of four. It is in this connection that the evidence of Laas, mentioned above at para. 25, assumes significance. Laas's statement says "The aircraft gradually built up speed, the nose wheel leaving the ground approximately half-way along the runway, but the aircraft did not become airborne within a period which could be considered as normal. I then observed that the pilot pressed the nose of the aircraft down again, until the nose wheel touched the ground, as if he wanted to gain extra "play" in order to pull the aircraft off the runway, but I could not make out with the naked eye whether the aircraft actually became airborne."

This clearly accords with the possibility outlined anove. It is also consistent with Captain Thain's evidence that when the acceleration was checked at 117 knots Captain Rayment was operating the elevator trimmer. The question arises whether it is also consistent with scientific knowledge of the drag effects of slush of varying density.

85. At the time of the accident very little was known about slush drag, and Dr. Schlichting was driven to employ the assumption that this drag could be expressed as an increase in the coefficient of rolling friction, taking arbitrarily double or alternatively treble this coefficient for his calculations (paras. 18 and 22 above). Since that time, however, and partly because of this accident, more has become known on this subject, and it is now believed that slush drag increases with speed (as indeed Dr. Schlichting suggested: para. 18 above) whereas rolling friction decreases with speed as the weight is taken on the wings. One of our number, Professor Collar, has prepared a paper giving in Part I tentative conclusions based on data now available, and we attach this at Appendix 2. Part II of this Appendix gives an interpretation of Captain Thain's account of the aircraft's run in the light of these tentative conclusions.

86. We attach this Appendix in order to show that there is nothing improbable in Captain Thain's account, particularly of the deceleration. If it is correct, it leads to the conclusion that, just as Captain Rayment was about to lift his aircraft off the runway his nose-wheel came down and by the time he had lifted it off by elevator trim he had lost the minimum speed (110 knots) at which, with a clean wing, he could fly off. This interpretation explains the accident without postulating wing icing, although of course it does not disprove icing, and it is because we think this is a feasible explanation of the events that we have already stated that no firm conclusion as to ice can be drawn from the performance of the aircraft.

87. But we are far from saying that this is what must have occurred. We are not required to ascertain the causes of the accident, and if we were so required we should be unable to do so for lack of sufficient evidence. The reconstruction conflicts with the evidence of a number of persons whom we have not seen, for example Gentzsch, whose statement about the run is "It began rolling normally and built up speed until it was about half-way along the runway: the nose wheel left the ground, but touched down again after about 60 - 100 m. The aircraft continued to roll as far as the very end of the runway . . . ." Also Schombel, whose evidence on wing icing is referred to at para. 46 above, watched the run, and gave this account: "During the take-off it struck me that, approximately from half-way along the runway, the pilot was trying, with all his might, to get the aircraft off the ground, and I noticed the particularly large angle of attack. The nose wheel was high in the air, the emergency tail wheel, according to my observation, was on the ground. This attitude became slightly modified during the take-off process. The nose wheel remained off the ground." Bartz's evidence likewise, as to the uniformity of the slush, cannot be reconciled with this reconstruction. We have already indicated (para. 56 above) that it would be wrong to criticize persons who have not given oral evidence before us; it would be equally indefensible to pick out statements favourable to a theory and reject others.

The German Commission saw the witnesses, or such of them as they wished to see, and rejected the view canvassed above. We have neither the material nor the wish to say they were wrong. What we can say, however, is that their conclusion is not reconcilable with Captain Thain's evidence. We have already given our views on the suggestion that the deceleration was caused by braking: a further point is that the German Commission's reconstruction of the run takes the aircraft to 117 knots at between 1400 and 1600 m. (para. 22 above) whereas the deceleration by braking, as shown by the skidmark commenced at 1850 m. If the aircraft reached 117 knots by 1600 m. it should have reached a higher speed by 1850 m. unless indeed the slush drag was such as to render 117 knots the maximum obtainable speed. Professor Schlichting's curve 6 (para. 19(3) above) shows the aircraft reaching 117 knots at 1550 m. 120 knots at 1650 m. and 123 knots at 1800 m.

88. We may leave this part of the case by saying that the only evidence of deceleration during the run (apart from the braking at the end of the runway) is that of Captain Thain. We have no reason to reject it, and it is not inconsistent with much of the other evidence, including the time factor. It is however inconsistent with some of the evidence, as mentioned above, and if it is unreliable, its unreliability is accounted for, without the slightest criticism of Captain Thain, by the effect of shock. If one discards this evidence, the aircraft attained V_2 but failed to unstick owing to icing, or the slush was of sufficient depth to prevent V_2 being attained (Professor Collar calculates that on the basis of the data given in Appendix 2 an Elizabethan with a clean wing would require the whole runway to attain V_2 if there were uniform watery slush of a depth of 0.8 ins. whereas with the slush depth given by Bartz of $\frac{3}{4}$ cm. and a clean wing it would achieve V_2 at 1300 yards); or of course there may be a combination of the two factors. Therefore having considered fully Captain Thain's representations concerning the final run we are unable to make any useful deduction as to either the presence of ice or the degree of slush drag.

Section (4) - Steps Taken by Captain Thain

89. Captain Thain's description of the runway conditions has been recorded at para. 76 above. He did not regard it as in any way unusual or unfit for use. However, he had had no great experience of such conditions in the past; asked whether he had encountered similar conditions before, he said "I suppose I have at one time or another . . . My particular experience was probably less than average because I have been, since joining B.E.A., on flights operated down to the Mediterranean." Before the outward journey to Belgrade he had not been to Munich for "five years, may be three." Prior to the final run, the Elizabethan had twice that afternoon taxied over the western end of the runway, once on landing and once after the second run, and after the first run it had passed the halfway mark. We asked Captain Thain some questions regarding his observations on these occasions:

"Q. Did it occur to you on any of those three occasions when you were at the western end of the runway that in the conditions it was a matter of some importance to know what the runway was like throughout the whole of its length?

A. Yes.

Q. Did that lead you to take any special precautions by way of looking or gauging what the position was?

A. Well, I was not concerned at all by the deposit of slush on the runway.

Q. Why not?

A. It did not present a problem.

Q. Would you like to expand that answer?

A. Well, it just did not present a problem.

Q. You felt just as happy with it as you would have with a dry concrete runway?

A. I did not say that, but it did not strike me as a problem for taking off.

Q. Did it occur to you there might be differences in the depth of the snow or water on it?

A. No, it did not."

90. After Captain Thain had said that a Captain accepted responsibility for the safety of his aircraft, the evidence continued:

"Q. Including considering the problem of whether the runway surface is not safe enough to take off on?

A. I think that, including that, yes.

Q. You accept that as something which, in appropriate circumstances, he should address his mind to?

A. Yes.

Q. Have you yourself ever gone out on foot or in a vehicle to inspect a runway surface before taking off over it?

A. I cannot recollect having done that, no.

Q. Have you heard of it being done by other Captains?

A. In isolated circumstances, yes.

Q. Does it come to you as a surprising statement that other Captains may do that in some circumstances?

A. I think you would have to be awfully concerned about the state of the runway.

Q. Before you go and look at it yourself?

A. Yes, for this reason, that there must be a group of airport staff whose job it is to service and look after the airfield, and they cannot just sit back and do nothing about it; one expects it to be up to a certain standard."

91. Captain Thain said that he did discuss with Captain Rayment before the last run one aspect of taking off on slush, namely whether if throttling back to deal with boost surging produced a swing, it could be corrected by steering the nosewheel without slipping. No other aspect of runway conditions was discussed, and he was quite satisfied. He did not think the slush would retard the aircraft "to any large extent", nor did Captain Rayment mention such retardation. He had not noticed the retardation on landing, as Captain Wright had; he thought that although he was not at the controls he would have noticed it if it had happened.

92. There was no evidence that the Captain of any other aircraft departing from Munich that afternoon had experienced any difficulty with the runway or had thought it right to make a personal inspection of its surface or to take any other special steps. Captain Wright said that the conditions, though not unprecendented, were not often encountered and with his lightly-loaded Viscount he did not consider it necessary to inspect the runway, as he had done on some occasions.

PART VIII - THE FIRST TWO ATTEMPTS TO TAKE OFF

93. There is little that we need add to the recital of the facts set out in para. 8 above, as a preliminary to considering the third question put to us. The Peravia record shows that at the first attempt power was applied to the port engine for about 32 seconds and that it took about 14 seconds to reach full power. On the second attempt it took about 25 seconds to reach full power, corroborating Captain Thain's statement that the throttles were opened more slowly; power was applied for about 32 seconds. On both these occasions the boost is recorded as reaching somewhere between 59 and 60 inches. Mr. Black was so familiar with boost surging at Munich that on seeing the aircraft returning to the tarmac, he felt sure it had been encountered.

PART IX - THE THREE QUESTIONS

94. Having set out the relevant facts, and our views on Captain Thain's representations upon disputed questions of fact, we are now in a position to deal with the three questions upon which we are required to give our opinion. The first is whether Captain Thain took sufficient steps to satisfy himself that the wings of the aircraft were free from ice and snow. In forming our views on this question, we have to bear in mind that our task is to consider the steps which Captain Thain took up to the third and last attempted take-off. Had

the relevant time been that of the first take-off the considerations would have been different. The aircraft first asked for taxi clearance at 1519 hours, and at that time Captain Thain had had recent experience of conditions outside the cockpit. He had not ascertained the recorded temperature, nor himself inspected the upper surface of the wings, but he had had the report, made some 40 minutes earlier, from Captain Rayment, and he himself had seen the water running from the trailing edge. It may be that at that stage his decision not to have the wings swept or de-iced was correct; the decision accorded with Mr. Black's views, and Mr. Black had had the best opportunity to judge, having been upon the wings throughout refuelling. But the time we have to consider is not 1519 hours but 1556 hours, when the Elizabethan reported ready to taxi for the last time. It was then at least 40 minutes and probably longer since Captain Thain had watched the thawed snow falling from the wing, and 78 minutes since refuelling had ceased and anyone had inspected the whole upper surface of the wings. It was also 56 minutes since the screen temperature had reached zero and within 4 minutes of the time when the reading was taken as $- 0.2^{o}$. Since the previous decision the aircraft had taxied to one end of the runway, made two runs, and taxied back from the other end and, experiencing whatever temperature variations there might be in its path and having any evaporative cooling accelerated by the forced draught generated by its speed.

95. In these circumstances we have no doubt that Captain Thain ought to have made a personal inspection of the wings before reaffirming the decision neither to sweep nor to de-ice. Inspection means obtaining a ladder or stand and examining the top of the wings, not looking at the small portion visible from the cockpit. It is clear from the answers reproduced in paras. 67 and 68 above that Captain Thain's omission to take this or any other positive step originated in his ignorance of the ambient temperature, and his failure to acquaint himself with the available information on this subject was, in our view, a serious error. We find that he departed with some snow on his wings, in breach of the B.E.A. instructions; the factors making it impossible for us to say, positively, on the evidence before us whether there was ice under the snow, are factors emphasising the necessity for practical examination at the time. Captain Thain had then far less information than we have, and the greater the doubt the greater the necessity for precautions. The facts that he was unfamiliar with Munich, and had had no great experience of weather of the kind in question should also have led him to act with caution. We think it true to say that he had a great deal on his mind, in that he had been unexpectedly confronted with the boost surging; this is a matter which may help to explain his actions, but it cannot affect our finding that to the first question we must return a negative answer.

96. In approaching the second question, namely whether Captain Thain took sufficient steps to ascertain whether or not in the conditions prevailing at the time the runway was fit for use, we recognise that for a Captain to make a personal inspection of a runway is an extreme and infrequent action. Captain Thain found the runway being used without comment by arriving and departing aircraft, and regarded as safe by the airport authorities; these matters, as he accepts, did not absolve him from responsibility, but he was entitled to have regard to them. The duty upon him was perhaps higher than

in the case of Captains of some other aircraft using the runway that afternoon because of his long take-off run, lengthened by the necessity to correct the boost fluctuation; but, as he said in evidence, Munich was not a marginal airport, and he would have had no reason to suspect that he had not enough runway unless he had possessed a knowledge of the drag effects of slush which was not then available. Furthermore, had he made an inspection and found the conditions to be as described by Bartz he would have rightly accepted the runway as safe, whereas had he noted from the ground, as he had from his cockpit, a change in the character of the slush at the two-thirds point along the runway, he could not be expected, in the then prevailing state of knowledge of slush-effects, to have appreciated its significance. We find therefore that he did take sufficient steps to ascertain whether in the prevailing conditions the runway was fit for use.

97. The third question is whether Captain Thain took sufficient steps to ascertain the cause of the difficulties encountered on the first two attempts to take off before making a third attempt. This question presents no difficulty. We have no doubt that Captain Thain acted correctly in consulting with the Station Engineer and that the trouble was correctly diagnosed. We think he acted properly in deciding to make the third attempt.

PART X - CONCLUSION

98. In conclusion we think it right to emphasise that while we are unable, for the reasons given, to reach a firm finding upon Captain Thain's representations that there was no ice on the wings during the final run and that the accident was due solely to slush drag, this uncertainty does not affect our answers to the questions posed in our terms of reference. Had Captain Thain established that there was no wing icing, our answer to the first question would still have been "no", and had he established slush drag as the sole cause of the aircraft's behaviour, our answer to the second question would still have been "yes".

99. We therefore have to report that we have given full consideration to the representations made to us by and on behalf of Captain Thain with regard to the accident to the Elizabethan aircraft G-ALZU at Munich on 6th February 1958, that we have had regard to the Report of the German Commission of Inquiry into the said accident, including that Commission's reasons for refusing to reopen their inquiry, and that in our opinion Captain Thain did not take sufficient steps to satisfy himself that the wings of the aircraft were free from ice and snow, but that in our opinion he did take sufficient steps to ascertain whether or not in the conditions prevailing at the time the runway was fit for use and did take sufficient steps to ascertain the cause of the difficulties encountered on the first two attempts to take off before making a third attempt.

E. S. FAY

R. P. WIGLEY

A. R. COLLAR

APPENDIX 1

REPORTS BY THE AERODROME METEOROLOGICAL OFFICE OF THE GERMAN METEOROLOGICAL SERVICE AT MUNICH RIEM AIRPORT

1.

German Meteorological Service

Munich Airport
Munich 64

Aerodrome Meteorological Office

7.2.58.

Subject: Weather observations on 6.2.58

In accordance with a request made personally by Flugkapitän Reichel, Munich-Riem aerodrome meteorological office herewith supplies the following weather observations made on 6.2.58 (all times given in GMT).

1) Weather at time of accident

Time: 1504 hr. - Surface wind 300°/8 knots - Surface visibility 1.6 NM - slight snowfall - 8/8 stratus at 600 ft. (precipitation ceiling) - QNH 1004.0 mb/29.65 inches - QFE 942.7 mb/27.84 inches - Temperature - 0°C, dew point - 1.6°C.

2) The following observations (QNY) were made on 6.2.58

Snow + rain (mixed)	from 0320 - 0550 GMT
Rain only	" 0550 - 1020 "
Snow + rain (mixed)	" 1020 - 1050 "
Moderate snowfall	" 1050 - 1450 "
Slight snowfall	" 1450 - 1750 "
Moderate snowfall	from 1750 onwards

3) The following screen temperatures (2m. above ground level) and relative humidities were measured:

At 1300 GMT	+0.1°C	95%
" 1400 "	0.0°C	96%
" 1500 "	-0.2°C	91%
" 1600 "	-0.8°C	89%
" 1700 "	-0.9°C	91%

(Sgd.) Dr. H. K. Müller

German Meteorological Service
Aerodrome Meteorological Office
Munich Riem

Munich-Riem
9.2.58

Precipitation amounts and state of the ground on
6.2.58 at Munich-Riem

(observed and measured in the climatic enclosure of the aerodrome meteorological station)

1. Precipitation measurement at 06.14 hr. Z
(for the period 5.2.58, 2014 hr. to 6.2.58, 0614 hr. Z)

Precipitation amount:	13.7 mm
State of ground:	Ground partially covered with snow

2. Precipitation measurement at 1314 hr. Z
(for the period 06.14 - 13.14 hr. Z)

Precipitation amount:	3.7 mm
State of ground:	Ground covered with melting snow

3. Precipitation measurement at 2014 hr. Z
(for the period 13.14 - 20.14 hr. Z)

Amount of precipitation:	5.0 mm
State of ground:	Ground not frozen, but covered with snow of a depth of less than 15 cm

The snow cover (new snow) began to form at 1200 hrs. Z. The depth of the snow at the "snow board" (Schneebrett) near the temperature screen amounted to 7 cm at 1730 hrs. Z.

The snow fell on an unfrozen wet base and the lowest layers were slushy.

(Sgd.) Dr. Herb
For airport Meteorological Office

Notes: (1) Add one hour to obtain the local times used throughout the Report.

(2) The Reviewing Body was informed that temperatures after 1700 GMT were:

1800 GMT	-1.0°C
1900 "	-1.0°C
2000 "	-2.0°C
2100 "	-3.0°C

APPENDIX 2

New calculations on the take-off of the Elizabethan

PART I

Estimation of slush drag

A.2.1. A new basis of calculation. - There are, as yet, very few reliable experimental data from which slush drag may be calculated. When Professor Schlichting made the calculations referred to in paragraph 19 there were no data at all (see paragraph 18); it was therefore agreed that he should represent the effect of slush by additions (which were apparently arbitrary in magnitude) to the rolling friction drag coefficient. However, since those calculations were made, tests reported below in A.2.2.3, have demonstrated that slush drag is approximately proportional to the square of the aircraft ground speed. There is a profound difference between the two assumptions: an addition to a friction coefficient means that the drag is proportional to the load on the wheels, which decreases as the aircraft gains speed and wing lift develops. The state of affairs is illustrated diagrammatically in Fig. 1; curve A shows a drag increasing as the square of the speed, curve B a drag of the type implied by Professor Schlichting's assumption for a fixed aircraft attitude. In view of the new information, additional calculations were obviously desirable.

With the resistance proportional to the square of the (ground) speed v, it is natural to write the slush drag D_s of a wheel as

$$D_s = \tfrac{1}{2}\rho_w \sigma_w v^2 A C_s, \qquad \text{--------------------- (1)}$$

where ρ_w is water density (1.94 slug/cu.ft.) and σ_w the specific gravity of the slush, A is a reference area and C_s a dimensionless slush drag coefficient. Since the tests recorded in A.2.3. below show drag to be proportional to water depth d, this is chosen as one dimension defining A; the other is then naturally chosen as overall tyre width, or effective width b. Then with D_s in lb., v in ft/sec., d, b in ft., (1) becomes

$$D_s = 0.97\sigma_w v^2 b d C_s. \qquad \text{--------------------- (2)}$$

We proceed to an evaluation of C_s.

A.2.2. NASA tests. - In an investigation of slush drag, the National Aeronautics and Space Administration of the U.S.A. has recently conducted tests on an aircraft wheel propelled on a carriage through a trough containing water or artificial slush made from crushed ice. The results of these tests are as yet unpublished, but were communicated to the Air Registration Board of Great Britain in a preliminary form. Grateful acknowledgment is due to the N.A.S.A. for permission to quote their results here, and to the A.R.B. for their assistance.

Appendix 2, continued.

In a typical test, a wheel of width 10 in. was run through water of depth 0.65 in. at a speed of 180 ft/sec., a drag force of nearly ½ ton being measured. Hence, from (2), C_s may be found. The N.A.S.A. states that on the basis of formula (2) the tests give C_s a value between 0.7 and 0.75. We therefore assume for our calculations

$$C_s = 0.72 \qquad \text{--------------------- (3)}$$

A.2.3. Road Research Laboratory tests. - The data recorded here are extracted from the Road Research Laboratory Report RN/3565, an unpublished report communicated to us by the Director of Road Research.

A car weighing 3200 lb. was allowed to run in neutral gear through an artificial water puddle 128 ft. long: the tests were conducted at various initial speeds and water depths, and deceleration was measured in different ways. It was found, inter alia, that drag was closely proportional to depth. Now if (2) is correct, the equation of motion of the car will be (with $\sigma_w = 1$)

$$\frac{W}{g}\frac{dv}{dt} = \frac{W}{g}v\frac{dv}{ds} = 0.97\, v^2 bdC_s,$$

which on integration gives

$$C_s = \frac{W\, \ln(v_i/v_o)}{0.97gbds}, \qquad \text{--------------------- (4)}$$

where W is weight, v_i and v_o are speeds into and out of the puddle, and s is its length. In the present instance the constant ratio 1.62 was measured for v_i/v_o at a depth of 2¼ in.; there were four wheels each of width 6 in. With these data, (4) gives $C_s = 1.03$. This figure includes a small air drag contribution which may be estimated independently; after correction for this we find

$$C_s = 0.96$$

In commenting on the experiments the Laboratory observed that (i) the rear wheels were running 'dry', i.e. the displacement of water by the front wheels was such that there was virtually no depth at the rear (ii) much water thrown up by the front wheels was carried forward by the mudguards, so that water impinging on the body added to the drag. If this is so, we may deduce, using only two wheels

$$C_s \text{ (including mudguard effect)} = 1.92 \text{ --------- (5)}$$

On comparison with (3) it will be seen that 'mudguard effect' nearly trebles the drag of a wheel alone, at least for a car wheel.

A.2.4. An incident to a North Star aircraft. - There is a well-known case in which a North Star (DC4) aircraft attempted a take-off in about 5 in. slush; but a ground speed of 125 ft/sec. could not be exceeded and take-off was abandoned. Trans-Canada Airlines (to whom acknowledgment is due for permission to quote their calculated drag) estimated a slush drag of 12520 lb. in this incident. The DC4 has 5 wheels, of width nearly 16 in; hence in (2) D_S = 12,520, v = 125, b = 5 x 16/12, d = 5/12, whence

$$\sigma_W C_S = 0.30 \qquad (6)$$

If σ_W = 0.4, a figure that seems not unreasonable for slush of depth 5 in., C_S agrees closely with (3).

A.2.5. A Viscount incident. - We were also presented with evidence concerning an abandoned take-off of a Viscount: in no wind, and in a slush depth of $3\frac{1}{2}$ in., a speed of 125 ft/sec. could not be exceeded. A rough estimate of the forces is as follows:

Rolling drag (lb.)	1800
Air drag	600
Slush drag	11400
Thrust	13800

The Viscount has 6 wheels of $10\frac{1}{2}$ in. width; hence in this case

$$\sigma_W C_S = 0.49 \qquad (7)$$

If σ_W = 0.6, a figure not improbable here, C_S again agrees broadly with (3).

A.2.6. A Boeing 707 take-off. - Some details were presented to us in evidence concerning an unusually long take-off for a Boeing 707 in $1\frac{3}{4}$ in. slush. Acknowledgment is due to the firm for permission to refer to the incident here. Take-off was achieved at an airspeed of 250 ft/sec., and ground speed 200 ft/sec., roughly. The aircraft was still accelerating slowly. Very rough estimates of the forces are

Rolling drag (lb.)	7500
Air drag	5600
Acceleration force	12500
Slush drag	34400
Thrust	60000

The aircraft has ten wheels, of width 16 in. However, four of these are rear wheels on the main bogies, and will 'run dry'. As against this, the fuselage is very low and may provide some 'mudguard effect'; certainly there must have been much fuselage drag, in view of damage caused by the impact of slush during the run. If we double the nosewheels to take account of this we have effectively eight wheels, and

Appendix 2, continued.

$$\sigma_W C_S = 0.57 \qquad \text{-------------------- (8)}$$

With σw = 0.8, C_S is again near the value (3).

A.2.7. Summary. - Of the above attempts to determine C_S, the only unequivocal value is the result (3) in A.2.2. above, and it is adopted in what follows. The results of the car experiments described in A.2.3. are rather less certain, in view of the unknown contributions from rear wheels and mudguards; they imply, however, that mudguard effect can be very pronounced. As regards the three aircraft incidents described, there is an obvious degree of guess-work, and in particular, since the slush density is unknown, no firm value for C_S can be deduced. The most that can be said is that one would expect slush density to decrease as depth increases, and that if one assumes values in accordance with this hypothesis, a consistent value of C_S results.

The paucity of available information suggests that further careful experiments, if possible with aircraft, are most desirable, if the drag due to slush is to be properly evaluated.

A.2.8. Application to the Elizabethan. - The Elizabethan has six wheels, of width nearly 12 in. The fuselage is exceptionally low, and is therefore assumed to give a 'mudguard effect' which doubles the drag of the two nosewheels. With C_S = 0.72, equation (2) then gives the drag in lb. as

$$\begin{aligned} D_S &= 5.6\ \sigma_W d v^2 \text{ (nosewheels grounded)} \\ &= 2.8\ \sigma_W d v^2 \text{ (nosewheels raised)} \end{aligned}$$

A speed of 180 ft/sec. (105 knots ground speed) then gives, in water 1 in. deep, a drag of over 15,000 lb. with nosewheels grounded, or half this amount with the nosewheels raised. The former figure is of the order of the maximum thrust available.

PART II

A possible reconstruction

A.2.9. We begin by setting down in tabular form evidence as to the course of events in the final attempted take-off.

		Time (sec.)	Speed (kt.)	Distance (yd.)
(i)	'Rolling', throttles partly open, head-wind 6 kt., main wheels say 20 yds. down runway	0	6	20
(ii)	Throttles fully open, nosewheel still grounded	17	-	-
(iii)	Boost fluctuation begins	25	85	-
(iv)	'Full power again'	34	105	-
(v)	Nosewheel first lifted	-	-	1000
(vi)	Aircraft encounters wet (dense) slush: point assumed to be 2/3 of 2360 yd. Aircraft pitches on to nose, decelerates for about 5 sec., pilot applying trimmer	(t)	117	1570
(vii)	Nosewheel comes up, losing its drag: unbalanced aircraft goes to full incidence	(t+5)	105	1890
(viii)	Pilot (realising aircraft will not unstick) applies brakes, cuts throttles	50	-	2030
(ix)	Pilot calls 'undercarriage up', releases brakes	-	-	2120
(x)	Impact occurs	55-56	-	2382

In this Table, the time column derives from the Peravia and R/T records (except for the 5 sec. interval estimated by Captain Thain); the speed column (except for the first entry) from Captain Thain; the distance column from ground observers or from subsequent measurement.

Any interpretation of the take-off run of the aircraft should not be seriously at variance with these figures. In particular, the time to impact is fairly accurate; the skidmark distances are precise. Less accurate are the times (17, 25, 34 and 50 sec.) read from the Peravia record, and the distances (1000, 1570, 1890 yds.) estimated by various witnesses.

A.2.10. The equation of motion and its solution.

The equation giving the acceleration of the aircraft is

$$m\frac{dv}{dt} = T - D_R - D_A - D_S, \qquad (9)$$

where m is the aircraft mass, v its ground speed, t the time, T the thrust, and D_R, D_A, D_S, are the drag forces due to rolling, airspeed, and slush.

We can write, sufficiently nearly,

$$T = a(T_o - \tfrac{1}{2}\rho V^2 S C_T), \qquad (10)$$

where a is a fraction of full thrust due to throttling, and V is the airspeed (in general, different from v). Also

$$\left.\begin{aligned} D_R &= \mu(W - L) = \mu W - \tfrac{1}{2}\rho V^2 S \mu C_L, \\ D_A &= \tfrac{1}{2}\rho V^2 S C_D, \\ D_S &= \tfrac{1}{2}\rho_w \sigma_w v^2 d b_e C_S, \end{aligned}\right\} \qquad (11)$$

where b_e is the total effective width of all wheels touching the ground. Moreover, if w is the headwind component of velocity,

$$V = v + w,$$

and accordingly (9) becomes

$$\frac{dv}{dt} = P - 2vQ - v^2 R, \qquad (12)$$

where

$$\left.\begin{aligned} mP &= aT_o - \mu W - w^2 X, \\ mQ &= wX, \\ mR &= X + \tfrac{1}{2}\rho_w \sigma_w d b_e C_S, \end{aligned}\right\} \qquad (13)$$

and

$$X = \tfrac{1}{2}\rho S(aC_T + C_D - \mu C_L). \qquad (14)$$

The equation (12) is an ordinary differential equation for v in terms of t; when P, Q, R are constants it can be integrated in terms of standard solutions depending on the signs and magnitudes of P, Q, R. Moreover, a second integration yields the distance covered; this integral also has standard forms. When P, Q, R are varying (e.g. when a is a function of t, as when the throttles are being opened) the standard solutions are not applicable, and in general approximate methods, such as step-by-step solution, must be adopted.

A.2.11. Values assumed in the solution. - These are as follows:

(i) Headwind component - At 1502 hrs. the R/T record gave the wind as 10 kt., 300°. The runway direction is 249°; hence the headwind component is, sufficiently nearly

$$10 \cos 51^{\circ} = 6 \text{ kt.}$$
$$\text{or } w = 10 \text{ ft/sec.}$$

(ii) Air density - The relative density corresponding to 0°C., 943 mb. is σ = 0.982. Hence

$$\rho = 23.35 \times 10^{-4} \text{ slug/cu. ft.}$$

(iii) Aircraft mass - This, to correspond with an aircraft weight at the final attempt of

$$W = 54620 \text{ lb.}$$

is $m = 1698$ slug.

(iv) Aircraft thrust - The data assumed for the evaluation of (10) are as follows, and relate to conditions at Munich:

$$T_O = 15{,}600 \text{ lb.}$$
$$C_T = 0.080,$$

while the area S of the wing is

$$S = 1200 \text{ sq. ft.}$$

In addition, for the initial period of opening of throttles, it is assumed that

$$a = 0.712 + 0.018t;$$

thus at 'rolling' (t = O), just over 70% of full thrust is being applied, corresponding roughly to 28" boost. Full throttle is reached at t = 16 secs., when a = 1.

For throttles cut, a = 0.

(v) Rolling Friction - Values assumed for μ are

μ = 0.03 (wheels free)
= 0.3 (wheels locked)
= 0.2 (wheels braked in abortive take-off).

(vi) Airforce coefficients - For the reconstruction suggested above, three aircraft incidences are required: nosewheel grounded (2.1°), nosewheel lifted just off (3.0°) and tailwheel grounded (8.8°). Moreover, since wing icing was in question, a clean wing and a lightly iced wing are considered; the coefficients are based on the polars given by Dr. Schlichting and are as follows. It may be worth noting here that the sectioh of the Elizabethan wing

Incidence	Clean Wing		Lightly Iced Wing	
α^o	C_L	C_D	C_L	C_D
2.1	0.467	0.042	0.395	0.056
3.0	0.546	0.046	0.473	0.061
8.8	1.161	0.084	0.978	0.110

is of the laminar flow type, and will therefore be particularly sensitive to the addition of small asperities, even such as might be due to light icing.

(vii) Slush conditions - Much of our Inquiry was concerned with representations on the degree of wing icing and the effect of slush; accordingly, in addition to making calculations with differing degrees of icing, slush depth was also treated as a variable parameter, though it was assumed to be uniform over the runway.

On the question of slush density, it seems possible from the evidence of Captains Wright and Thain that there was an increase in density two-thirds of the way down the runway (see paragraph 77). It is therefore assumed (arbitrarily) in the calculations that the specific gravity of the slush increased by 50 per cent at that point, so that

$\sigma_W = 0.64,$ 0 - 1570 yds.

$\sigma_W = 0.96,$ 1570 - 2382 yds.

As regards depth, calculations were made with a number of different depths, in an attempt to obtain results conforming with the reconstruction of A.2.9. The best correlation obtained was with a depth

$$d = 0.67 \text{ in.}$$

This is rather more than twice the depth estimated by Bartz ($\frac{3}{4}$ cm = 0.3 in.) but only about half the depth estimated by Wright.

(viii) The first abortive take-off - In addition to the data for the final run, there was some information relating to the first abortive take-off, which must of course also be subject to calculation if the hypotheses are correct. We have, as in A.2.9.

Appendix 2, continued.

	Time (sec.)	Speed (kt.)	Distance (yd.)
(i) Rolling, etc.	0	6	20
(ii) Throttles open	14½	-	-
(iii) Nosewheel first lifted (the normal speed)	-	85	-
(iv) Take-off abandoned	32	105	-
(v) Aircraft halts	-	-	1650

The important item is (iv) where the Peravia record shows the power cut at 32 sec. and Captain Thain stated that the speed was 105 kt: the other figures are relatively imprecise.

(ix) Results - Some curves are given in Fig. 2 of the results of the calculations.

Curve A. - This is a basic curve, assuming no wing icing and no slush, i.e. a normal take-off. It will be seen that V_2 is achieved at point A in about 31 sec. and at 1070 yds. In this calculation the throttles are opened to full power in 0-16 sec. and the nosewheel is first lifted at the usual speed of about 85 kt.; clearly the curve is not sensitive to these figures.

CurveB. - Light icing is assumed, but no slush. This differs only from A in that the aerodynamic data used relate to the lightly iced condition. Take-off now requires 33 sec. and 1150 yd.

Curve C. - No wing icing, 0.67 in. slush are assumed. This curve shows the powerful effect of slush at the high take-off speed. V_2 is now achieved in 39 sec. and requires 1450 yds. - nearly 400 yds. beyond A.

Curve DE.- This is the calculation of the first abortive take-off after the throttles were cut; it is assumed identical with curve C as far as D. The throttles are assumed to be opened in 16 sec. instead of 14½ (clearly not an important difference). Throttles are cut and brakes applied at 32 sec. (point D). The calculated speed of 107 kt. is in very good agreement with Captain Thain's evidence. In addition, the point E at which the aircraft comes to rest, calculated to be 1690 yd., agrees well with the estimate of Herr Bartz.

This curve lends support to the assumptions concerning slush conditions: a smaller depth of slush (on interpolation between D and A) would raise the speed at 32 sec. and lengthen the distance to E.

Curve FGHJKLMN. - This curve is described in some detail, since it represents a calculation relating to the accident run; it should be compared with the Table in A.2.9. Light wing icing and 0.67 in. slush are assumed.

From F to G is the throttle opening period (0-16 sec.). From G to H the aircraft is at full throttle (no allowance made for the slight effects due to surging) with the nosewheels grounded. Normally the nosewheels would have been lifted at about 85 kt., but witnesses put the lifting at about half way down the runway, so 1000 yds. is assumed. (Since an engine was surging again, Captain Rayment may well have kept the nose down in anticipation of a third abandonment. If this is so - it is no more than guesswork - and Captain Rayment lifted the nose when Captain Thain called 'Full power again' it puts the speed at 100 kt.; Captain Thain shortly after called '105'). As regards the boost surge period, Captain Thain's evidence of 85 to nearly 105 kt. gives times of 24 to 34 sec., in very good agreement with the Peravia record. From H to J the nosewheel is raised.

At J the aircraft enters the denser slush assumed to begin at 1570 yd.; the additional main wheel drag pitches the aircraft on to its nosewheels so that further slush drag is added. The speed at J is 116½ kt., the time 42 sec.

With the added drag deceleration occurs; in 5 sec. K is reached, at 111 kt. At K it is assumed that by the use of trimmer the nosewheel is lifted; this is the point at which the track of the tailwheel appeared. The cessation of nosewheel drag causes the aircraft to pitch into a fully nose up attitude and the deceleration ceases.

At 111 kt., with the slightly iced wing at full (8.8°) incidence the lift is 48,300 lb. (the clean wing would give 57,300 lb.). The aircraft accordingly does not lift off with the assumptions made.

KL occupies 2 sec., in which 112 kt. is reached. At L it is assumed that Captain Rayment realises 'we won't make it' and applies brakes: the calculated point is very near the beginning of the skid mark. One second later (M) the throttles are cut and brakes released (to assist retraction). Impact occurs at N in 55½ sec.

The calculation matches the reconstruction of A.2.9. very well on the whole; the deceleration does not however reduce speed to 105 kt. before Captain Rayment's exclamation (point L). It does however show the 'hovering' at 112 kt. mentioned by Captain Thain, and at 52 sec. (2 sec. after throttles cut) the speed is down to 105 kt.

A.2.12. Comment. It must be emphasised that no claim is made that the above reconstruction is accurate, despite the very good agreement with the evidence. The degree of icing assumed is arbitrary, and the slush depth is chosen, not to accord with evidence (though it does lie within the limits set by evidence) but to give a curve matching those parts of evidence set out in A.2.9.

Nevertheless, it remains true that certain valid deductions are permissible.

(a) Slush drag is of vital importance, and in particular, slush density is of equal importance to slush depth.

(b) Wing icing is less important in its effect on drag than on lift, though this may be less true for wing sections other than laminar.

(c) No factor other than a sudden increase in slush drag could be found to account for a change from acceleration to deceleration; moreover, it was necessary to assume reimmersion of the nosewheels in the slush, with a 'mudguard' effect to obtain the curves given.

(d) Although it might be possible to reproduce the main curve F...J...N by assuming rather more slush and a clean wing, the aircraft would lift off at the point K; this is why both icing and slush were assumed. However, at this stage so many assumptions as to slush density, pilot's actions (trim, braking, cutting throttle, etc.) are made that the most that can be claimed is that the curve represents a possible state of affairs; no rigorous deduction as to either icing or slush can be made.

D 32525/1/Wt.4042 K3 3/65 XL

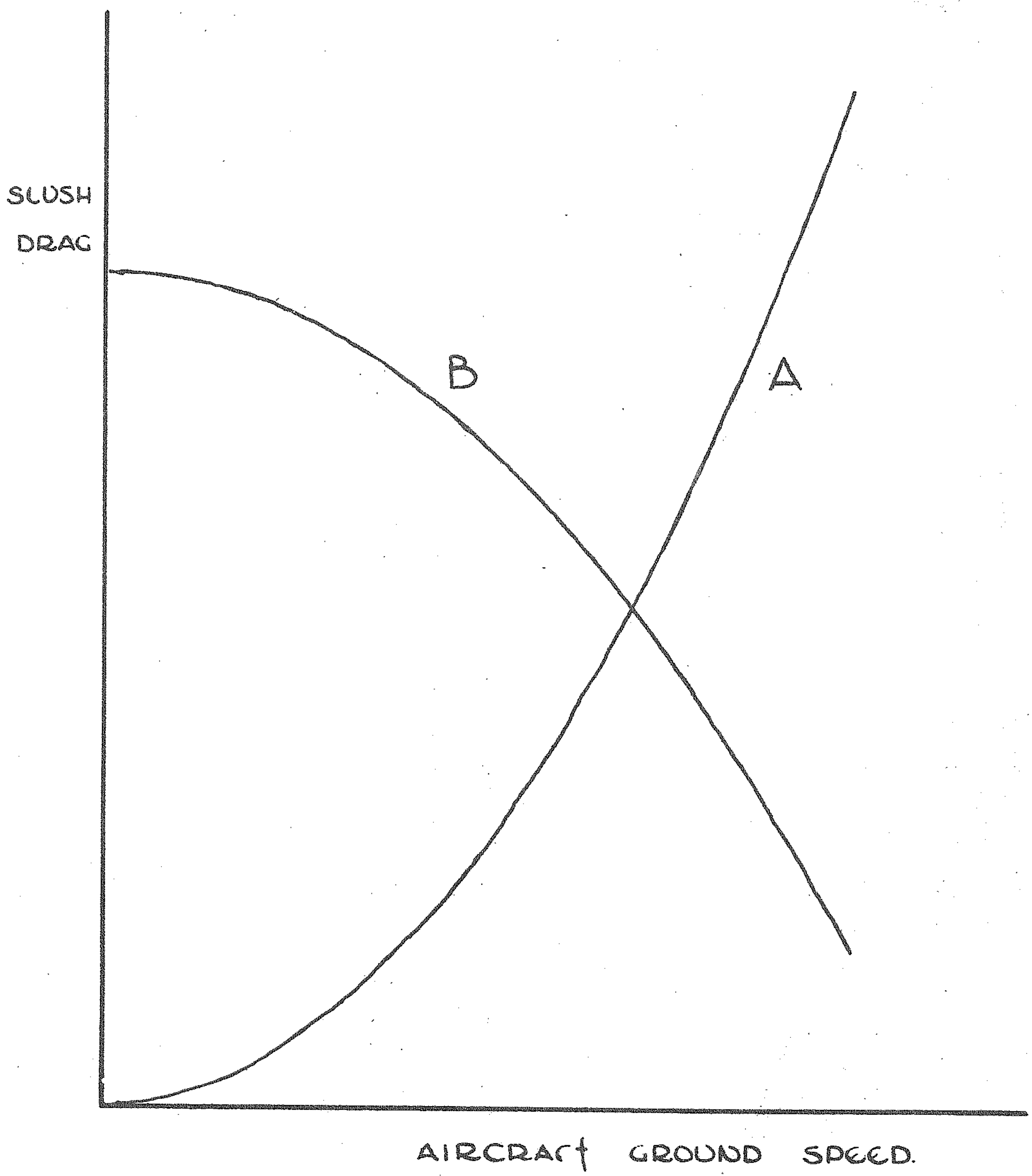
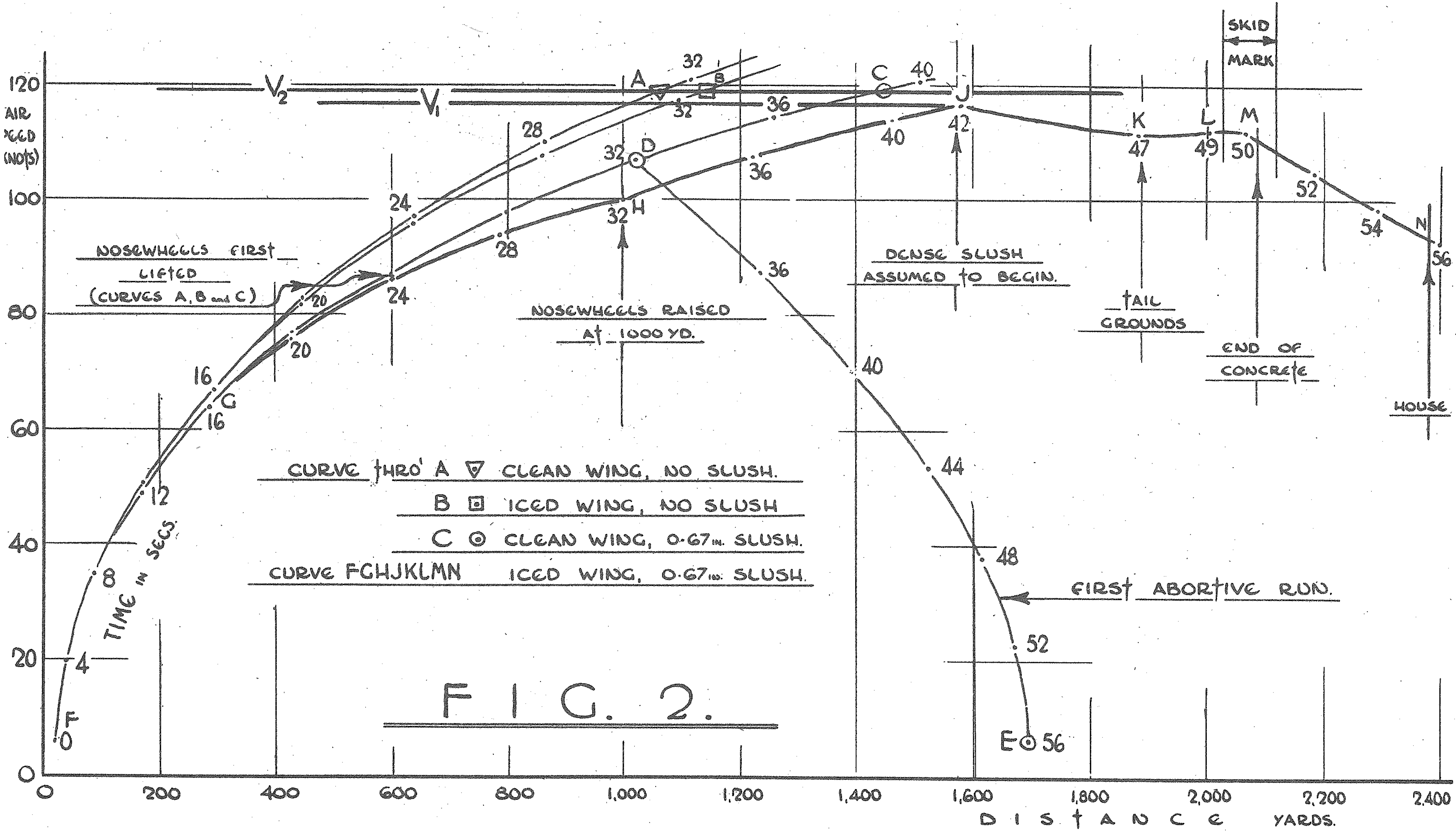


FIG. 1.



AIR SPEED (KNOTS)
120
100
80
60
40
20
0
V2
V1
DISTANCE YARDS.
0
200
400
600
800
1,000
1,200
1,400
1,600
1,800
2,000
2,200
2,400
TIME IN SECS.
NOSEWHEELS FIRST LIFTED (CURVES A, B and C)
NOSEWHEELS RAISED AT 1000 YD.
DENSE SLUSH ASSUMED TO BEGIN.
TAIL GROUNDS
END OF CONCRETE
SKID MARK
HOUSE
FIRST ABORTIVE RUN.
CURVE THRO' A ▽ CLEAN WING, NO SLUSH.
B ⊡ ICED WING, NO SLUSH
C ⊙ CLEAN WING, 0·67 in. SLUSH.
CURVE FGHJKLMN ICED WING, 0·67 in. SLUSH.

FIG. 2.

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