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CIVIL AIRCRAFT ACCIDENT

Report of the German Federal Office of Aviation relating to the re-opened Inquiry into the Accident to BEA Ambassador (Elizabethan) Aircraft G-ALZU on 6th February 1958 at Munich Riem Airport

and

Royal Aircraft Establishment, Farnborough, memorandum on "Application of the Results of Slush Drag Tests on the Ambassador to the Accident at Munich" submitted as evidence to the Inquiry

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B O A R D   O F   T R A D E

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C O N T E N T S

Report of the German Federal Office of Aviation relating to the re-opened Inquiry into the Accident to B.E.A. Ambassador (Elizabethan) Aircraft G-ALZU on 6th February 1958 at Munich Riem Airport

(Translated from the German)

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Luftfahrt-Bundesamt
(Federal Office of Aviation)
Commission of Inquiry

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REPORT

relating to the Re-opened Inquiry into the Accident to BEA Ambassador (Elizabethan) Aircraft G-ALZU on 6 February 1958 at Munich-Riem Airport

Brief Circumstances

Aircraft G-ALZU owned by British European Airways Corporation (BEA) landed at Munich-Riem Airport at 1417 h* on 6 February 1958 on a charter flight from Belgrade with a crew of 6 and 38 passengers among whom were the Manchester United football team. During the period 1425 to 1438 h the aircraft was refuelled with 3,300 litres of fuel and at 1519 h it was given clearance for take-off to continue its flight to Manchester. On this first attempt to take-off the aircraft accelerated normally up to about 100 kt on the airspeed indicator. When, however, the pilots noticed the boost pressure readings of both engines surging beyond the maximum figure the take-off was abandoned. The aircraft turned and taxied back to the beginning of the runway. During the second take-off attempt, begun shortly afterwards (1530 h), the port boost pressure reading again rose beyond the normal value and the take-off was again abandoned. The aircraft continued to roll until it reached the end of the runway and thence returned along the west taxiway to the terminal building. Here the BEA Station Engineer Mr. BLACK went on board and discussed the cause of the boost fluctuations (atmospheric humidity and the airfield elevation) with the two pilots, who stayed on board whilst the passengers disembarked. As the Station Engineer said that the boost fluctuations were not critical the pilots decided to make a third attempt. The passengers were re-embarked and at 1603 h the aircraft again began to take off. It never became airborne, ran off the end of the runway and across the 270-metre-long stopway with its engines at full power, broke through the aerodrome boundary fence and collided with a house, losing parts of its port wing and of its tail unit. Both aircraft and house caught fire. The aircraft skidded further and crashed into the concrete base of a wooden hut, the rear of the fuselage breaking off. The remainder of the wreckage slid on for about 70 m. more and came to a standstill the right way up.

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*All times local

Of the 44 persons on board, 21 were killed instantly in the accident, two died in hospital as a result of their injuries, and the remainder were injured, most of them seriously.

The first pilot of the aircraft was Captain Gordon RAYMENT, who was sitting in the left-hand seat and was shown in the aircraft documents as co-pilot, whilst Captain James THAIN, who was shown as commander, had taken the right-hand seat.

Captain RAYMENT died in a Munich hospital on 15 March 1958 from the serious injuries sustained in the accident. It had not been possible to interrogate him about the circumstances of the accident. Captain THAIN and the third man on the flight deck, Radio Officer RODGERS, were only slightly injured.

Full information about the circumstances of the accident, in particular the aircraft crew weather conditions and airport and the details of the accident, are contained in the Report of the Luftfahrt-Bundesamt Commission of Inquiry dated 31 January 1959 [1]* and in the Supplementary Report by the same Commission dated 14 March 1960 [2]. Reference is made to both reports.

Result of the first Inquiry

The first Commission of Inquiry stated in its Report of 31 January 1959:

"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 also have had an effect on the accident."

After the first Inquiry had been concluded Captain Thain submitted material which in his opinion proved that the ice deposit found on the wings had been formed by the action of the fire-extinguishing chemicals after the accident and therefore was not to be considered a cause of the accident. The first Commission of Inquiry examined this objection but did not find it valid, and gave the following decision in its Supplementary Report of 14 March 1960:

"The facts, evidence and other opinions which have been brought to the notice of the Commission since the Report of 31.1.59 was signed are not such as to justify the re-opening of the proceedings."

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*[ ] = See references

Re-opening of the Inquiry

In July 1964 the United Kingdom Ministry of Aviation sent the Federal Minister of Transport material concerning experiments, which had been carried out in the United Kingdom in the interim, to determine the effect of slush on the take-off process of aircraft [3] [4]. In these tests an aircraft of the same type as G-ALZU, the aircraft involved in the accident, was used. The British put forward the view that the results of these tests should be examined to see whether or not they tended to alter or supplement the findings of the first Inquiry. A preliminary examination of the material by the Luftfahrt-Bundesamt showed that they did. The Federal Minister of Transport thereupon ordered on 21.11.1964 that the Inquiry into the accident of 6.2.1958 be re-opened.

The Commission appointed to conduct the re-opened Inquiry consisted of the following:-

Chairman:	Regierungsdirektor Dr. Hermann RUPPRECHT Augsburg
Assessor presenting the case: (Berichterstatter)	Flugkapitän Hans-J. REICHEL Brunswick
Assessor aeronautical engineer:	Diplom-Ingenieur Hans WOCKE Hamburg
Assessor pilot:	Flugkapitän Josef FORSTER Frankfurt a.M.

The proceedings of the Commission of Inquiry took place on 18 and 19 November 1965 in the Small Council Chamber of the Government of Upper Bavaria (Oberbayern) in Munich.

The following were present:-

From Germany:

Oberregierungs-Baurat Dr. Ing. LEPKE	Federal Ministry of Transport
Regierungs-Baudirektor ENDRASS	Bavarian State Ministry for Economics and Transport
Flugkapitän BRANDENBURG	Luftfahrt-Bundesamt (Federal Office of Aviation)
Regierungsräte VIERHEILIG and KOLLE	Bundesanstalt für Flugsicherung (Federal Administration of Air Navigation Services)
Count zu CASTELL	Munich-Riem Airport Ltd.
Diplom-Ingenieur HERB	Feutsche Forschungsanstalt für Luftfahrt (German Aeronautical Research Institute)

From the United Kingdom:

Mr. G. M. KELLY	Accredited representative of the United Kingdom
Mr. J. B. VEAL	Head of the Accident Investigation Branch of the United Kingdom Ministry of Aviation, as observer
Mr. J. K. B. ILLINGWORTH	Royal Aircraft Establishment Bedford, as adviser
Mr. R. L. MALTBY	Royal Aircraft Establishment Bedford, as adviser
Mr. R. SZUKIEWICZ	Hawker Siddeley Manufacturers of G-ALZU, as adviser
Mr. A. V. PARKER	Civil Air Attache British Embassy Bonn.

The following were also present:-

British European Airways (BEA):

Capt. E. POOLE	Technical pilot
Mr. M. J. LESTER	Legal adviser
Mr. D. KENWARD	Performance analysis
Mr. D. BRINJES	Air safety
Mr. W. CHISHOLM	BEA Office Munich
Miss JACOBS	BEA Office Munich

British Air Line Pilots' Association (BALPA):

Capt. R. T. MERRIFIELD

Capt. D. F. O'SULLIVAN

Capt. E. R. WRIGHT

and Capt. James THAIN, commander of G-ALZU.

Amtsrat Walter BESSER of the Bavarian State Ministry for Economics and Transport Munich acted as secretary [5]. Two interpreters participated. Representatives of the German and British press, radio, and television services were admitted to the proceedings.

Task of the Commission

The task of the Commission in the re-opened Inquiry was to determine whether or not in the light of the material produced in the interval, viz. that brought forward by the British side, and new technical and scientific knowledge show that another or supplementary cause can be discerned with any certainty in addition to, or instead of, those given by the first Inquiry. The Commission's main interest was to find out whether snow or slush on the runway at Munich-Riem could be regarded as a cause of the accident in addition to, or instead of the wing icing which the first Inquiry found to be the main cause. After an exhaustive study of the voluminous records the Commission reached the conclusion that the facts of the case determined with great care by the first Inquiry could be taken as the basis for the re-opened Inquiry. In so far as it appeared necessary to supplement these facts by further evidence the Commission did so, as will be seen in the subsequent part of the present Report. In assessing the facts of the case the Commission's attention was directed primarily to the following three points: the actual course of the fatal attempt at take-off, the formation of ice on the aircraft on the ground, and the state of the runway.

The Course of the Fatal Attempt

No new factual information or evidence (other than that dealt with in the first Inquiry) was available during the course of the re-opened Inquiry. In reconstructing the course of the take-off therefore the Commission had to rely on the findings and the evidence recorded at the first Inquiry in partular the statements made at that time by the commander of G-ALZU, Captain Thain, who adduced nothing new at the re-opened Inquiry about the course of the take-off, merely referring back to the statements which he had made during the first Inquiry.

Captain Thain stated that after a slight initial fluctuation of the port boost-pressure gauge both engines continued to deliver full power. This statement agrees with the result of the engine test carried out by the United Kingdom manufacturers at the instigation of the first Inquiry. Captain Thain further stated that the aircraft had accelerated normally up to an indicated 117 kt (V_1) but that the speed had thereafter dropped 4 or 5 kt and then fallen to 105 kt. Whether or not Captain Thain informed Captain Rayment who was at the controls does not appear from Captain Thain's statement; nor could Captain Thain indicate the moment or the point along the runway at which the drop in speed occurred since during the take-off run he had concentrated on watching the instruments and had not looked out of the aircraft. Nor had he observed any attempt to unstick. He had not looked out until Captain Rayment exclaimed "We won't make it". He (Thain) had then pushed the two throttles fully forward, but they were already there. Captain Thain stated further that he believed that at the time Captain Rayment was now pulling the control column back; he had also called "undercarriage up" and Captain Thain had selected "Up". Shortly afterwards the aircraft had collided with the house.

In addition to Captain Thain's statements extracts from which are given above the following statements by eye-witnesses have an important bearing on the reconstruction of the take-off attempt:

On 9 February 1958 Mr. Black BEA Station Engineer at Munich-Riem made the following statement to Flugkapitän Reichel who was conducting the investigation:

"... the aircraft's nose lifted after it had covered approximately the first third of the runway and then continued in this normal attitude until approximately half or two-thirds of the runway had been covered. I was unable to see whether or not the wheels were on the ground all the time as the aircraft was enveloped in slush and spray during its whole run."

Mr. Black was watching from the apron. He had also watched the previous (abandoned) take-off attempt.

The following witnesses, who were all professionally connected with aviation and could therefore be considered as specialists, even if not as experts, watched the fatal attempt from various floors of the airport terminal building. Their line of vision was approximately 90° to the runway centre line and the aircraft would have been about 900 m. from them. The visual conditions were therefore entirely adequate.

Erich LASS, Air Traffic Controller, Munich-Riem Area Control Centre who had watched both the abandoned take-offs stated on 8 February 1958, inter alia:

"The aircraft gradually built up speed, the nose wheel leaving the ground approximately half way along the runway, but the aircraft still had not become airborne when the normal interval had elapsed. 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 unstick. The nose did in fact leave the ground once again before the aircraft reached the end of the runway, but I could not make out with the naked eye whether the aircraft actually became airborne. ... Whether or not during the attempted take-off the aircraft became airborne whilst still on the stopway I cannot testify, owing to the distance. My impression was rather that in the final phase, before the port wing hit the obstruction, the tail of the aircraft at any rate was dragging along the ground and crashed through the fence."

Kurt GENTSCH, Air Traffic Controller, Munich-Riem Area Control Centre who also watched the two first take-off attempts stated on 7 February 1958:

"... The aircraft 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. ..."

Peter POGGENDORFF, Air Traffic Controller, Munich-Riem Area Control Centre stated on 7 February 1958:

"... After reporting ready for take-off and being given clearance the aircraft began to move at 1504 GMT and gained speed rapidly. About half way along the runway the nose wheel left the ground for about 100 m. but then touched down again without loss of speed."

Gustav TARESCH, Air Traffic Controller, belonging to the same unit stated on 8 February 1958:

"After air traffic control clearance and take-off clearance had been given the aircraft began to move and built up speed. About half way along the runway the nose wheel lifted slightly. It touched down again about 60 m. further on. The aircraft continued to roll without any change in speed, along the full length of the runway, ran over the threshold lighting ..."

Siegfried SCHOMBEL, air navigation services trainee, stated on 17 December 1958:

"... During the take-off I noticed that the pilot was making every effort to get the aircraft off the ground and I noticed the particularly large angle of incidence. The nose wheel was high in the air and as far as I could see the emergency tail wheel was on the ground. This attitude became slightly modified during the take-off process. The nose wheel remained off the ground. ..."

Heinz Dieter TISMER, air navigation services trainee, stated on 17 February 1958:

"... During the take-off I noticed that the pilot was making every effort to unstick. The nose wheel was raised very high off the ground; the angle of incidence was very large. The tail appeared to be touching the ground. ..."

Reinhard MEYER, pilot informed the Luftfahrt-Bundesamt in writing on 16 April 1958 as follows:

"... I then went to the damaged house and thence direct through the gap in the fence on the QMS of Runway 07 in order to look at the wheel-tracks and so obtain some clues as to the cause of the accident. I went only about 40 m. along the runway and then came back immediately. I saw the following wheel-tracks. (Here follows a sketch showing the tracks of the main undercarriage wheels and the tail wheel.) The track of the tail bumper ceased about 100 m. to 150 m. short of the end of the runway; I could not see where it began ..."

It is established that towards the end of the runway all 4 main undercarriage wheels of G-ALZU were locked. The members of the first Commission of Inquiry saw this for themselves. The marks made on the runway by the locked wheels are shown moreover in Photographs No. 9 and 10 appended to the first Report. Of significance in this connection is the statement made by Mr. Harry GREGG one of the passengers in the aircraft during an interview in Munich on 8 February 1958:

"... I saw the wheels stop spinning as if the pilot had applied the brakes. ..."

The present Commission was no more able to gain an entirely clear picture of the course of the fatal take-off attempt than was the Commission which conducted the first Inquiry. From the statements of Captain Thain and the witnesses quoted above it appears to be fairly certain that the aircraft accelerated normally at the outset and that the nose wheel was raised for the first time about half way along the 1908-m.-long runway. It appears, moreover, to have been established by the statements of several witnesses that after a relatively short distance (60 to 100 m.) the nose wheel touched down again but within the last third of the runway was raised again and this time to such an extent that the emergency tail wheel was touching the ground. What is not clear on the other hand is the point on the runway at which the speed of 117 kt (V_1) was attained and when Captain Thain's drop in speed, first of 4 to 5 kt and then to 105 kt, took place. The first Inquiry assumed that V_1 was attained between 1400 and 1600 m. It may have been attained somewhat earlier but there are no certain grounds for assuming this. With regard to the moment and position at which the drop in speed occurred the Commission is convinced that this can have been only within the final third of the runway and more probably towards the end of it. If we assume that the drop in speed occurred considerably earlier then it is quite inconceivable that the take-off should have been continued in spite of the loss of speed.

The Commission considers that the drop in speed to 105 kt mentioned by Captain Thain is most likely to have occurred towards the end of the obviously forceful attempt to unstick at the end of the runway (emergency tail wheel on the ground) or at the moment when Captain Rayment applied the brakes. Captain Thain has not, it is true, stated whether he noticed any braking but the Commission is in no doubt about the fact that the brakes were applied (skid marks on the end part of the runway statement by the passenger GREGG). The best explanation for the fact that Captain Rayment tried to retract the undercarriage shortly before the accident occurred is that he expected an increase in braking effect, which was of decisive importance to him at this extremely critical stage of the take-off, when the aircraft dropped on to its belly. Captain Rayment would have known that the main undercarriage wheels cannot retract when there is any weight on them; but at this stage he was evidently trying to pull the aircraft off forcefully and in all probability assumed that with the vigorous pull on the control column the weight would be reduced enough to allow the wheels to retract. However the undercarriage down-locks had not operated.

The Commission has arrived at the opinion that a forceful attempt to unstick was made towards the end of the runway, since the track of the emergency tail wheel on the runway cannot otherwise be explained. Captain Thain's assertion that the pilot made no attempt to unstick during the entire take-off process until the aircraft had run off the runway is incomprehensible and opposed to all practical experience and procedure. Given the great experience of both pilots, in particular Captain Rayment on the Elizabethan type, and in view of the fact that Captain Rayment was regarded by the United Kingdom accredited representative as a very sound man and a capable pilot, failure to attempt to unstick would be as inexplicable as would failure to react to the negative information indicated by the instruments during take-off.

From the British side it was argued that the tracks of the nose wheel unit and of the emergency tail wheel had been confused and that the wheel tracks mentioned by the witness Meyer were those of the nose wheel unit not of the emergency tail wheel. In view of the big difference in design and size between the nose wheel unit and the emergency tail wheel this argument does not appear to the Commission to be valid. This view is supported by the photograph of G-ALZU taken before the fatal take-off attempt (Appendix 7 to the Report of 31.1.1959 [1]), in which the double track of the nose wheel unit stands out clearly even in the conditions obtaining on the day of the accident. Moreover the fact that when United Kingdom representatives inspected the runway two days after the accident no traces of white paint (such as would normally be left by the emergency tail wheel) could be found on the surface of the runway is not proof that the tail wheel was not on the ground. Between the time of the accident and that of the runway inspection snow had fallen and then thawed, hence it is quite within the bounds of possibility that any traces of paint would have been washed out by the effects of the weather.

Having reconstructed the course of the fatal take-off attempt, the Commission now turned to the question of whether ice had formed on the aircraft or not and if so in what way and to what extent.

Ice Formation on the Aircraft on the Ground

The first Inquiry considered it proven that during the stop of almost two hours in Munich, a rough layer of ice formed on the upper surface of the wings as a result of snowfall.

On the other hand, after the publication of the Report of the first Inquiry and the Supplementary Report, reference was made by the British side to correspondence conducted in 1963 between Herr Walter PAUSE of Frankfurt a.M. and the British authorities and with BALPA and Captain Thain in particular. It was claimed that Herr Pause's statements prove that the aircraft was not iced up at the time of the accident.

The Commission examined this evidence and does not consider that Herr Pause's statements invalidate what was determined by the first Inquiry concerning the question of icing. To begin with Herr Pause, who at the time of the accident was an air navigation services trainee at Munich-Riem, was not by his own statement an eye-witness of the accident. As he himself states he saw only part of the second attempt at take-off and how "the aircraft taxied again to the runway position" which can only mean taxying out for the third take-off (the fatal attempt). In his statement of 12 December 1962 Herr Pause claims that he remembered precisely that "the wings of aircraft G-ALZU were completely free of snow during its taxy-roll from the ramp to its third trial for take-off". According to Herr Pause the photograph at Appendix 7 to the Report of 31.1.1959, which shows the aircraft covered with snow, must have been taken earlier. This statement by Herr Pause, not made until 5 years after the accident, is diametrically opposed to the statements of a number of eye-witnesses who were heard immediately after the accident. The following is an extract from one of the statements:

Siegfried SCHOMBEL, air navigation services trainee, stated on 17 February 1958:

"I was engaged on ramp service at Hamburg Airport for three years and was working on the de-icing of commercial aircraft. I am fully aware of the importance of wing de-icing. I was able to see the upper surface of the aircraft distinctly from the second floor of the terminal building from a distance of not more than 50 m. In spite of the propeller slipstream the snow remained lying on the wings. I expressed my surprise to my colleagues over the fact that the aircraft was not de-iced before take-off. After the mechanic had given the signal to taxy out the snow remained on the wings in spite of the slipstream. It was sticky wet snow. The horizontal tail surfaces were clear of snow before the engines started up ...".

Dieter TISMER, air navigation services trainee, stated on the same date:

"The aircraft was standing in the immediate vicinity of the main building. I could see the upper surface of the wings clearly from a distance of about 40 m. I said to my colleagues: "They're not removing the snow from the wings". I thought that perhaps it was not very important. I also said to my colleagues that the snow was remaining in spite of the moving propellers - probably because it was so wet.

The aircraft taxied out to the take-off in this state. I also noticed that the snow was lying only on the wing surfaces either side of the fuselage and behind the engines. Only the part of the wing above the fuselage and the whole fuselage itself were clear of snow ...".

Oberleutnant (Lieutenant) Hans Georg BREHME who was in the Munich-Riem control tower as a visitor on the day of the accident stated:

"I had a clear view of the aircraft and saw that the wings were covered with snow. ..."

Robert WIGGERS, BP refueller, who took part in the refuelling of G-ALZU, stated on 17 February 1958:

"After landing, aircraft G-ALZU was stationed at Position 6 for refuelling. Refuelling took place in snow flurries. I noticed that the inner wings were clear of snow whereas there was snow lying on the outer wings. ..."

The view held by Herr Pause that the Photograph of the aircraft (Appendix 7 to the Report of 31.1.1959) must have been taken earlier has been proved to be incorrect. The photograph was taken by Klaus NEUMANN a member of the Air Navigation Services staff at Munich-Riem from a window in the terminal building a few minutes before G-ALZU taxied out for the fatal take-off. The photograph shows quite clearly that there was a deposit of snow or ice on the starboard wing, since otherwise the aircraft registration marking (G-ALZU) painted in black on the upper surface of this wing must have been discernible. In the photograph however there is no sign of the registration marking. The photograph also shows, even if not so distinctly, that like the starboard wing which was turned towards the photographer, the port wing was also covered. It can also be seen that the two engine nacelles and part of the fuselage were free from deposit.

As further proof that G-ALZU was not iced up before the fatal take-off BALPA submitted a statement by Herr Kurt RESCHKE of Munich-Pasing, made on 22.11.1965 in the presence of two reporters from a Munich newspaper.

Herr Reschke stated, inter alia, /here quoted in his original English - Tr./:

"The rescuers moved absolutely freely and definitely not in a way which suggested that they were hindered by ice or frozen snow in their ordinary shoes. I helped Dr. Huber to climb on to the wing. I cannot remember at which point of the wing it was, in the excitement of the moment I naturally didn't pay attention to that. Therefore today as well I can remember only vaguely, but I know definitely when I recall the situation, that it was somewhere between the engine and the wing tip. I can't remember either in which way I helped Dr. Huber, whether I supported his arm or lifted him up. In any case the wing was so low that he was on the surface in no time. There is another reason why I know that I helped Dr. Huber up somewhere in direction of the wing tip, but in no case close to the fuselage; he had to take several steps on the surface to reach the fuselage while I ran beside him on the ground.

Also the point at which I helped Dr. Huber up was so low that I could see the whole of the wing surface from the fuselage to the wing tip without any effort. Naturally it didn't occur to me at that time to note the condition of the surface, but I am definitely sure that even under those special circumstances I would have noticed traces of ice or frozen snow. I only remember a moist shining metallic surface.

When Dr. Huber ran on the surface towards the fuselage he too moved absolutely freely in his ordinary shoes. When he reached the fuselage I stopped below and asked him whether I could be of any more help. And in doing so I touched the back edge of the wing which was considerably higher than my chest about on the level of my neck. The metal of the wing didn't feel especially cold and - probably due to the falling snow which melted on the surface - moist. Under no circumstances did I feel ice or frozen snow. ..."

The force of Herr Reschke's statement is considerably impaired by the fact that as he himself says "naturally it didn't occur to me at that time to note the condition of the surface". The rest of his statement concerning the condition of the wing surface therefore constitutes little more than a statement of speculations he made now or at the time of the accident. This statement by Herr Reschke, who went to the scene of the accident at that time as driver of a Red Cross vehicle, was not made, moreover until eight years after the accident. Reschke's repeated comment to the effect that the rescuers did not slip on the wing points precisely to the presence of a deposit of rough ice which prevented their slipping.

The Commission does not consider therefore that Herr Reschke's statement invalidates the findings of the first Inquiry concerning the question of icing.

After a thorough examination of the evidence produced during the first Inquiry and after assessing the statements of Herr Pause and Herr Reschke the Commission has arrived at the conclusion that there was already ice on the aircraft G-ALZU <u>before</u> the fatal attempt at take-off began. As a result of super-cooling the precipitation (a mixture of snow and rain) which fell on the aircraft during its stop on the ground turned into a solid form. Rough ice about 5 mm. thick formed. There are no grounds for thinking that there was any change in this wing ice between the time of the accident and about 2200 h on the same day at which time the investigating officer (Untersuchingsreferent) noted the ice.

Whilst therefore the facts that there was ice and that it was rough ice 5 mm. thick have been determined with adequate certainty, it appears that the question of the extent of the ice i.e. what proportion of the total wing surface was covered has not been settled beyond all doubt. The report by

Prof. Dr. H. SCHLICHTING and Dr. Ing. K. GERSTEN dated 13.6.1958 (Appendix 10 to the Report of 31.1.1959 [1]) assumes that the greater part of the wings was covered with a layer of ice about 5 mm. thick. On the other hand, the photograph referred to several times above (Appendix 7 of the Report of 31.1.1959) shows clearly that there was no deposit on the engine nacelles, between the nacelles and the fuselage or on part of the fuselage. The wing leading edges and part of the wing in the region of the ailerons were probably also clear of ice. The ice thus extended mainly over the upper surface of the outer wings over the major part of the chord. On the basis of these views the Commission arrived with adequate certainty at the finding that at least 45% of the total wing upper surface of G-ALZU was covered with ice (figure 1). The discussions and calculations which follow are based on this value (45%).

The Commission had therefore to examine the effect of this amount of ice on the take-off process and hence on the accident.

Effect of Wing Icing on the Take-Off Process

On the second day of the re-opened Inquiry (19.11.1965) Mr. R. Szukiewicz Dip. Eng. Assistant Chief Aerodynamicist of the manufacturers of G-ALZU, who took part in the proceedings as adviser to the United Kingdom accredited representative, gave a detailed verbal report on the results of flight tests carried out with an Ambassador aircraft in icing conditions during the winter of 1951/52. At the request of the Commission Mr. Szukiewicz embodied his verbal statements in a written report which he submitted to the Commission after the proceedings.

This report [6] concluded, as did the verbal statements, that icing affected the take-off process either not at all or only negligibly, and that it thus cannot have constituted the cause of the accident.

The Commission has studied Mr. Szukiewicz's statements and report with particular care, but is unable to agree with the conclusions therein in respect of a number of significant points. The Commission's view is, rather, that the results of the tests carried out during the winter of 1951/52 have only a limited application to the present Inquiry and in some respects none at all. The flight tests referred to concerned a form of icing which occurred on various parts of the structure of the aircraft during flight and not while the aircraft was still on the ground. The ice formed chiefly on the leading edges of the wings, on the tail, on the propellers and on the forward part of the engine nacelles. When the de-icing system had been switched on the wing leading edges and wing upper surfaces became almost free of ice, and the melted ice re-froze mainly on the lower surfaces of the wings. In the case of G-ALZU, on the other hand, there was found to be a deposit of rough ice on the upper surface of the outer wings from about 15% of the mean wing chord, and the part covered with ice was at least 45% of the entire wing upper surface. This ice which formed whilst the aircraft was on the ground, is totally different both in form and in distribution from the ice which formed on the test aircraft during flight, and must therefore be appraised differently. These test results can, however, serve as a general confirmation of the fact known for some time that icing brings about very distinct and in some cases great changes in the lift and drag coefficients of a wing.

Mr. Szukiewicz's comment to the effect that the Elizabethan NACA 65_2-415 aerofoil section, in particular, is less sensitive to icing than the sections of older aircraft types doubtless applies to wing leading edge ice but not to the kind of ice which formed on G-ALZU.

The effect of icing on the flow round a section, and hence on drag and lift, is governed by the section shape and the corresponding pressure distribution. Owing to the special shape of the NACA 65_2-415 section it is probable that ice or any other protuberance at the leading edge has a small effect while ice accretion in the central region of the upper surface has an effect on drag and a particularly large effect on lift.

Figure 2 of the present Report gives a comparison of the ordinates of some sections on which basic tests concerning the effect of ice or other protuberance were carried out. Figures 3, 4, 5 and 6 show local pressure distribution on a number of sections. Figure 7 compares local pressure distribution on the Elizabethan section with that of NACA 0012 and NACA 23012 sections in respect of the particular lift coefficient at take-off.

Determination of Lift and Drag in Aircraft G-ALZU with Wing Surfaces partly iced while the Aircraft was still on the Ground

Taking into account the verbal reports given by Mr. Szukiewicz and Mr. Illingworth during the proceedings on 19.11.1965 and their written reports, and after making a thorough examination of the material, the Commission arrived at the opinion set forth below. It must be pointed out, however, that the following two circumstances render it impossible to determine with exactitude changes in lift and drag with regard to G-ALZU:

First, there is no absolute certainty about the extent of the wing ice on G-ALZU. The actual extent would hardly have been less than, far rather would have exceeded, the value of 45% of the wing upper surface assumed by the Commission after mature consideration.

Second, while according to the findings of the first Inquiry and the conviction of the present Commission the extent of the wing icing on G-ALZU is considered to have been determined with adequate certainty, no measurements have been made in wind tunnel or flight tests of its effect.

Information exists concerning systematic experiments dealing with the effect of protuberances on the upper surface of wings [7], [8], [9], [10]. The sections and protuberances used in these do not, it is true, correspond exactly with the conditions to be assumed in the case of the accident, but they can be used as a basis for estimating the magnitude of the lift coefficient C_L and the drag coefficient C_D and their dependence on angle of incidence for the given form of ice.

Effect on Lift

References [7] and [8] show that protuberances on the upper surface of a section have a much greater effect on lift and drag than do protuberances on the lower surface. This is understandable since the effect of protuberances on the aerodynamic characteristics of a wing is undoubtedly dependent on the local velocity (of the airflow) on the upper surface of the section. Figure 8 shows that according to measurements made on a NACA 0012 section a considerable loss of lift is noted on the suction side of the wing. This graph also shows that the detrimental effect of protuberances makes itself particularly strongly felt when the protuberances are at the leading edge i.e. within the first 10% of the wing chord.

The disturbances in the flow caused by ice accretion on the wing of the Elizabethan were not, it is true, located at the leading edge, but it should be noted that the section of this aircraft, NACA 65_2-415, has a thickness and camber which differ considerably from that of the sections with which the icing tests were carried out. In the case of the Elizabethan section, relatively high suction extends over the central region of the chord at take-off lift coefficients. This means that the local velocity on the wing upper surface of the Elizabethan section is relatively high over a large part of the chord and that the effect of protuberances may be correspondingly greater than with other sections. The table (Figure 2) comparing the leading data of the Elizabethan section with other sections which have been used in wind tunnel tests to obtain the effect of icing shows that, with the particular shape of section used in G-ALZU geometrical ratios were present which would lead to ice having a greater effect than would be the case with other sections.

As already explained, it is to be assumed that at least 45% of the wing upper surface was iced (Figure 1). On the basis of all the material, it appears justifiable to assume that the effect of wing icing on lift during the fatal take-off by G-ALZU was not as great as it would have been in the case of totally iced-up wings but was as shown in Figure 9.

Effect on Drag*

In order to assess the dependence of the coefficient of drag C_D on angle of incidence where there are protuberances on the upper surface of the section, use was made, inter alia, of a report on tests by Gray-Glahn [10]. The NACA 65_1-212 section used in these tests possesses, with the exception of the camber measurement and thickness ratio, ordinates which do not differ greatly from those of the NACA 65_2-415 section of G-ALZU.

It was therefore possible to use the results of the aforementioned report, in the absence of any more precise data, as an indication of the drag to be assumed for G-ALZU in an iced-up state. It can be assumed that, given ice on 45% of the wing upper surface, the drag increase is at least equal to half the drag increase occurring with an upper-surface roughness (height 5 mm.) corresponding to that in Figure 10 at approximately 15% of wing chord (Figure 11).

For an angle of incidence of 2.1 degrees there is an increase in the drag coefficient from $C_D = 0.0415$ to $C_D = 0.049$. This means a ΔC_D of 18%. With an angle of incidence of 8.8 degrees ΔC_D amounts to approximately 23.5%. The drag coefficient increases from $C_D = 0.085$ for the clean wing to $C_D = 0.105$ for an iced-up wing (Figure 12).

On the basis of the investigations set out in the report and assuming a degree of icing corresponding to that in Figure 1 and an ice thickness of 5 mm., variation of lift and drag with angle of incidence can be taken to be as shown in Figure 13; i.e. at the maximum unstick angle with icing, as

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* This section gives the impression that the drag estimates are derived almost exclusively from ref. 10, whose results on drag are confined to effects on profile drag and are in any case taken from earlier tests on an NACA 0012 aerofoil and not on the NACA 65_1-212 section. However in discussion with the Commission it was made clear that this was not the case, and that other references, in particular calculations by Schlichting and Young, were used to a large extent.

opposed to a clean wing, there is a decrease of about 11% in the lift coefficient and an increase of about 23% in the aerodynamic drag.

Some doubt was expressed about the applicability of the Gray-Glahn results. It was suggested that the walls of the tunnel might have affected the measurements, and the dimensions of the model were described as somewhat large in relation to the cross section of the tunnel. To this it can be replied that the maximum angle of incidence used during the tests, viz., 8 degrees, resulted in only a small change in the cross section of the tunnel, and that since the model was suspended on both sides the flow can be regarded as two-dimensional. The proportions lie entirely within normal limits and the results of the tests may therefore be approximately applied to the full-sized version.

From these considerations we arrive at an increase in drag caused by icing which is relatively small in the case of the angle of incidence obtaining during the take-off run (approximately 2 to 4 degrees) and is in practical agreement with the values calculated by Mr. Szukiewicz.

The Commission is inclined to set the increase in drag at larger angles of incidence somewhat higher than Mr. Szukiewicz does. It agrees with him that this particular increase in drag can have played no important part in the normal acceleration process, if we assume that there was an adequate margin of performance. This increase in drag could, however, be regarded - at least partially - as an explanation of the drop in speed after V_1 which Captain Thain mentions, if, owing to other influences, the margin of performance had dropped almost to zero in this phase of the take-off.

On the other hand, the Commission has arrived at the opinion that the reduction in lift caused by icing contributed substantially to the failure of the take-off and hence to the accident.

Discussion of the Slush Question

The Commission now turns to the examination of the second possible cause of the accident, namely, the effect of slush on the take-off process.

After detailed investigation, the first Commission of Inquiry made the following statement on this point in its report of 31.1.1959 (pp 16 and 17):*

"According to the reliable statements of the personnel responsible for inspecting the runway, the deposit of slush on the runway cannot have amounted, on an average, to more than 1 cm. at the most.

The Commission is convinced that the [rolling] friction caused by so thin a layer of slush cannot have been a cause of the accident."

Statements concerning Slush Depth

The Commission's task was to find out whether there were any indications that the depth of slush on the runway at Munich-Riem at the time of the accident was greater than that determined by the first Commission of Inquiry. The investigation was based in the first place on the meteorological data recorded by the aerodrome meteorological office at Munich-Riem and the comments of the head of that office (see p.15 of the Report of 31.1.1959 concerning the Inquiry into the accident).

*Pages are given for the published English translation CAP 153, 1959, reprinted 1965.

Since the question of the effect of slush on the take-off process constituted the real reason for the re-opening of the Inquiry the Commission paid special attention to ascertaining the actual depth of the slush on the day of the accident. The Commission therefore re-examined Herr Kurt BARTZ, who had already been heard twice during the first Inquiry, and interrogated his deputy Herr Alfred MEYER who was appearing for the first time. The statements of these two witnesses are given in detail in the records of the proceedings [5].

According to their very specific statements the witnesses Bartz and Meyer had measured the depth of the deposit on the runway (slush) with a ruler in three places 15, or at the most 20 minutes before the accident about 200 m. from the beginning of the runway, then half way down the length of the runway, and approximately 200 m. short of the end of the runway. At each of these three places three measurements were made: in the middle of the runway (on the centre line), and 15 m. to the right and left of the centre line. The witnesses were agreed that the depth of slush found by means of these measurements was $\frac{1}{2}$ to $\frac{3}{4}$ cm., the depth on the centre line being less than the depth towards the sides of the runway. The two witnesses also stated that the depth of the slush throughout the length of the runway must have been approximately constant since the runway at Munich-Riem was not at that time, nor is it now, noticeably uneven. They further stated that as they went on to the runway they did not have to traverse any accumulations of snow or slush at the edges of the runway.

The foregoing statements were confirmed in the course of the re-opened Inquiry by Herr ENDRASS, Regierungsbaudirektor (Superintendent of Works) of the Bavarian State Ministry for Economics and Transport, and by Count zu CASTELL the Airport Director [5]. Both had walked along the end part of the runway shortly after the accident.

The statements of the witnesses Bartz, Meyer, Endrass, and Count zu Castell are contradicted by the statement of Captain WRIGHT who said during the first Inquiry that the surface of the runway was covered with snow and slush to a depth of 1 to 1.5 inches (= 2.5 to 4 cm.), the first two-thirds of the runway being covered with snow and the last third mainly with slush, with a few bare wet patches in the centre of the runway and deeper snow at the sides. Captain Wright, who spoke at great length during the re-opened Inquiry [5], confirmed the statement which he had made during the first Inquiry concerning the nature and depth of the deposit on the runway at Munich-Riem.

Herr Walter PAUSE (see p. 9 of the present Report) declared in his statement of 12.12.1962 that "during dinner-time and afternoon on this date (= the day of the accident) the runway at numerous places was covered along both sides of the centre line by bigger sheets of water and - as I presume snow - slush 4 - 5 cm. high.*

Herr Pause's evidence is almost devoid of weight since he himself in his statement about the depth of slush says "I presume" and does not make a definite assertion. The conclusiveness of Captain Wright's statements is impaired by the fact that he merely observed and judged the state of the runway from the flight deck of his moving aircraft and did not go on to the

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*Text as given in English statement by Herr Pause. - Tr.

runway himself to ascertain the depth of the slush. His statements are thus based on estimates the accuracy of which is undoubtedly prejudiced by the fact that when they were made he was not only in a fairly high position above the runway but was also moving along it. Captain Wright's deductions from the nature of the edges of the wheel-tracks of other aircraft also fail to provide any certain clues concerning the actual state of the runway.

At 17.53 h on the day of the accident SAS aircraft OY-KLU (DC6) took off from Munich-Riem. Shortly before take-off the crew, accompanied by Herr Bartz, went on to the runway in order to inspect the state of it at various points. The state of the runway appeared to the crew to be suitable for take-off. As far as Herr Bartz could remember the maximum depth of the runway deposit was found to be 2 cm. From this, and from the indisputable fact that during the period between the accident to G-ALZU and the inspection of the runway by the SAS crew and Herr Bartz more snow had fallen as the temperature dropped, it can be concluded that the deposit on the runway at the time of the accident must have been less than 2 cm. and cannot in any case have amounted to 4 cm. (Capt. Wright) or 5 cm. (Herr Pause).

Summarising, then, with regard to the question of the slush depth, the statements of the witnesses Bartz and Meyer, which are based on precise measurements, provide the only certain basis for judging the state of the runway. The Commission therefore considers it to be proven that, at the time of the accident, the runway at Munich-Riem was covered with slush to a depth of 0.8 cm. No sufficiently definite indications of the presence of patches of deeper slush or water on the runway came to light.

It also appears necessary to draw attention here to the fact that none of the pilots of the aircraft which landed at (16) or took off from (5) Munich-Riem during the period 13.50 to 18.05 h on the day of the accident reported any difficulties worth mentioning in landing or taking off. Captain Thain had also decided that the state of the runway was suitable for take-off; he has always attached great importance to this fact.

The five aircraft which took off during the period referred to had all been de-iced; G-ALZU on the other hand had not.

Effect of Slush on Take-Off Process of G-ALZU

The Commission has made a thorough examination of the material available concerning the effect of slush on the take-off process, in particular the reports on tests forwarded by the United Kingdom Aeronautical Authority, which caused the inquiry to be re-opened.

The tests carried out by the Royal Aircraft Establishment at Bedford on an Elizabethan aircraft in November 1963 showed that the supplementary drag caused by slush during the take-off process could not be expressed by an increase in the rolling friction coefficient if the hitherto customary methods of calculation were used [4].

It was found that this drag was dependent upon the square of the rolling speed and that, as in the case of air resistance, the supplementary slush drag could be expressed by the equation

$$D^* = \frac{1}{2} \rho \cdot v^2 \cdot w \cdot d \cdot C_D^* ,$$

where ρ is the density of the slush, w.d the frontal area of the wheels in the fluid (w = sum of width of wheels, d = depth of water or slush) and C_D* a drag coefficient having no dimension.

It was also found that the total supplementary drag was further dependent upon the design of the aircraft, since spray or slush impacting on the various parts of the aircraft also produces a supplementary drag of varying magnitude.

Even if the scatter shown in the results is relatively high, which can be explained by secondary effects and the accuracy limits obtaining in tests of this kind, relatively clear trends in the effect of slush on rolling friction are nevertheless discernible. Figure 14 shows the results of the tests on the Elizabethan.

The results appear also to be in general agreement with tests and comments by the FAA in the U.S.A. [11]. Of most value for purposes of comparison are the tests on a Convair 880M. These were, it is true, carried out within a higher speed range, but they did confirm the basic effect on drag of the various parameters in particular that of the rolling speed and slush depth (Figures 15 and 16).

Application of the Results of the Slush Tests to the Accident to G-ALZU

When the results of the slush tests on the Elizabethan are applied to the accident to G-ALZU, a number of difficulties arise which preclude the making of any certain pronouncement concerning the drag actually exerted by slush during the fatal take-off, even if a specific depth of slush be taken as basis. The difficulties in the way of arriving at any certainty in the evaluation of the tests are dealt with in detail in the report by the Royal Aircraft Establishment [3]. The determination of the slush drag is particularly uncertain in the higher speed ranges since aquaplaning then occurs. The aircraft wheels slide on the slush and a decrease in drag occurs. According to the test results this process begins within a small, distinct transitional speed range of approximately 10 to 20 km/h., but is dependent on tyre pressure on the density and depth of the slush, and on tyre profile.

Also to be borne in mind is the fact that the tests carried out by the RAE at Bedford were conducted only in slush depths considerably greater than those determined in the case of the Munich accident (Munich 0.8 cm., Bedford 0.58 - 1.31 inches = 1.47 - 3.32 cm.). The effect of slush at small depths can, therefore, not be directly deduced from the results of the Bedford tests. All in all, then, the equation for the effect of slush on drag cannot yet be regarded as entirely solved, as can be seen from the recommendations of the FAA, which evidently does not regard slush depths of less than half an inch (= 1.3 cm.) as presenting any acute danger [12].

Moreover the Federal Aviation Agency (FAA) and the National Aeronautics and Space Administration (NASA) conducted joint tests at the National Aviation Facilities Experimental Center at Atlantic City NJ from 25.9 to 9.10.1961, in order to determine the effect of slush on the take-off process. The result is published in "Joint Technical Conference on Slush Drag and Braking Problems" dated December 1961 [11]. The tests were undertaken partly as a result of the accident to G-ALZU (page 3 of the FAA-NASA report). In Draft Release No. 61-1 FAA proposed to issue a rule dealing with the take-off of propellerdriven aircraft in snow and slush. This announcement of proposed rule-making was withdrawn on 22 January 1965, on the grounds that the information so far gained was not sufficient for any precise measures to be taken. The information available in the USA was set out in Advisory Circular AC 91-6 of 21.1.1965 in the form of rules for the operation of turbine-powered aircraft. The text of the FAA Notice of 22.1.1965 is attached to the present Report (in original and in translation) as Appendices 17 and 18. (Figure 17)

In the assessment of the question as to what supplementary drag actually did occur in the various stages of the take-off process during the accident to G-ALZU, the problem of aquaplaning presents special difficulties. If we take as a basis the slush depth of 0.8 cm. (equiv. water depth) considered to be proved, and accordingly assume that aquaplaning, and consequently, a reduction in drag set in at a speed of approximately 130 to 150 km/h. (70 to 80 kt) and, further, postulate full engine power, then a failure to take off cannot be explained without including the effect of other contributory factors. It is certain that acceleration to a speed of far more than 117 kt would have been possible and hence, with such a reserve of power, unstick would have been ensured in any event.

It must be assumed that aquaplaning did not occur. This assumption is supported by the fact that clearly visible skid-marks from all four wheels of the main undercarriage were found near the end of the runway.

Extrapolating slush drag in accordance with Figure 14 beyond 140 km/h. (75 kt), the margin of performance in the speed range above about 185 km/h. (100 kt), as shown in Figures 19 and 20 diminishes considerably.

In Figure 21* it is assumed that, approximately in accordance with BEA take-off procedures, the aircraft first rolled with its nose wheel on the ground at an angle of incidence of 2.1 degrees, that from a speed of approximately 150 km/h. (81 kt) the nose wheel was raised, and that the aircraft then continued the rolling process at an angle of incidence of 4 degrees. The slush drag decreased after the nose wheel was raised since the drag caused by the nose wheel had ceased. Finally it is assumed that at a speed of 117 kt an angle of incidence of 8.8 degrees was attained. If we take into account the effect of icing on this high angle of incidence, then we have an increase in the total drag which could have resulted in a reduction of the margin of performance and hence to a reduction in the acceleration of the aircraft.

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*Discussion with the Commission established that Figure 21 was not intended to be their reconstruction of the actual course of events. This is put forward on pp 5-9 of this translation. Figure 21 does not show, for example, the drop in speed to 105 knots which the Commission accepts, and the aircraft would in any case lift off before reaching 8.8 degrees incidence at 117 knots even with the (iced) lift curve of Fig. 9. The figure was intended to show that although a considerable reduction in acceleration would be caused by the amount of slush which the Commission concluded was present on the runway it would not by itself be sufficient to prevent take-off. Equally the reduction in performance and lift due to icing would not by itself prevent the aircraft taking off. However the two together, while again not preventing take-off, would reduce the acceleration to such an extent that some other undetermined factor, which by itself would not have been significant, in fact made the accident inevitable. The Commission's statement that icing was an essential cause of the accident was founded on the view that slush plus the undetermined third factor would not have caused the accident in the absence of icing.

Other secondary effects, such as increased effect of the spray at a high angle of incidence, or the vertical force exerted by the pilot's trimming the aircraft and operating the controls, may have contributed to increasing the total resistance.

Even with these slush effects, however, the aircraft would have been bound to be able to unstick on attaining a speed of 117 kt if reduction in lift caused by wing icing, had not resulted in an increase in the minimum unstick speed and thus, in the end, caused the failure of the unstick process. It has been shown on page 8 of the present Report that at least one attempt to unstick must have been made.

Not irrelevant in this connection are Mr. Szukiewicz's comments concerning the manoeuvrability of the aircraft in the unstick phase. According to him changes of trim caused by slush may have resulted in a certain reduction in the available elevator force required to produce the necessary rotation and hence, in addition, in a delay in the unstick process and a further loss of speed. Witnesses' statements show, however, that the maximum angle of incidence of the aircraft was nevertheless reached (tail bumper touching the ground).

<u>Summary</u>

Even taking into consideration the whole of the material available to the Commission (in particular the new experiments concerning effect of slush on the rolling friction of aircraft) it has not proved possible to clarify completely how the various causal factors combined to bring about the accident.

The wing ice that was present is still to be regarded as an essential cause of the accident. The wing ice did not, it is true, have an unduly great influence on acceleration, but did reduce lift substantially and bring about an increase in the required unstick speed.

Slush, however, must be regarded as a further cause, since it resulted in a reduction in performance during acceleration and may also have caused changes in trim, which, in combination with other secondary effect, had an unfavourable effect on the unstick process.

The fact that the command situation on board G-ALZU was not entirely clear-cut may also have had an unfavourable influence on the take-off process.

The Commission has arrived at the view that, in the runway conditions obtaining at Munich-Riem at the time of the accident, the aircraft G-ALZU <u>without ice</u> on the wing upper surfaces could have attained the required unstick speed and would have been bound to have done so. The failure to unstick, and hence the accident, are thus to be attributed to a series of inter-related causal factors viz.:

1. Decrease in the lift coefficient resulting from ice on the wing upper surfaces and a consequent increase in the minimum unstick speed;

2. Increase in drag caused by ice accretion, particularly at the higher angle of incidence during the unstick process;

3. Reduction by slush and spray of the margin of performance of the aircraft and effect of the slush on the trim.

The differing assessments of the situation by the two pilots during the final phase of the take-off to be inferred from Captain Thain's statements resulted in their acting in opposition which probably increased the severity of the accident.

Dr. RUPPRECHT

Hans-J. REICHEL

Hans WOCKE

Jos. FORSTER

(Stamp)

LUFTFAHRT-BUNDESAMT

Certified true copy:

(Sd) Fritsch

Brunswick 29 August 1966

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[1] Untersuchungsbericht über den Unfall des Flugzeuges G-ALZU AS 57 Ambassador "Elizabethan" am 6. Februar 1958 am Flughafen München-Riem vom 31. Januar 1959 (Luftfahrt-Bundesamt Braunschweig)*.

[2] Nachtrag zum Untersuchungsbericht vom 31. Januar 1959 über den Unfall des Flugzeuges G-ALZU AS 57 Ambassador "Elizabethan" am 6. Februar 1958 am Flughafen München-Riem vom 14. März 1960 (Luftfahrt-Bundesamt Braunschweig).

[3] Application of the Results of the Slush Drag Tests on the Ambassador to the Accident at Munich dated 24 June 1964 (Royal Aircraft Establishment Farnborough) (Original text and German translation)

[4] Technical Note No. AERO 2968 - Some Measurements of the Drag due to Slush on an Ambassador Aircraft, by R. L. Maltby and N. V. Slatter of RAE Bedford and J. K. B. Illingworth of ACT 1a Ministry of Aviation. April, 1964. (Original text and German translation.)

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[6] Comments on the Ambassador Accident at Munich on 6 February 1958, in the light of available flight test evidence in icing conditions by R. Szukiewicz Dip. Eng. AFRAeS, AFAIAA, Assistant Chief Aerodynamicist, Hawker Siddeley Aviation Limited, Hatfield.

[7] Hoerner - Einfluss der Oberflächenrauhigkeit auf die aerodynamischen Eigenschaften der Luftfahrzeuge. Ringbuch der Luftfahrttechnik IA9 (1937).

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Jahrbuch der deutschen Luftfahrtforschung, 1940, Teil I, S. 575-587.

[9] W. Gerhardt, Vereisung des Tragwerks. Deutsche Luftfahrtforschung, Forschungsbericht Nr. 1052 (1939).

[10] Gray-Glahn, Effect of ice and frost formation on drag of NACA 65-212 Airfoil for various modes of thermal ice protection, NACA TN 2962 (1953).

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*Translation: Ministry of Transport and Civil Aviation - Civil Aircraft Accident: Report by the Federal Republic of Germany relating to the Inquiry into the Accident to G-ALZU AS 57 Ambassador (Elizabethan) on 6 February 1958 at Munich-Riem Airport (HMSO, CAP 153,1959).

[11] Joint Technical Conference on Slush Drag and Braking Problems, FAA and NASA, Departmental Auditorium, Washington, D.C., December 19-20 1961.

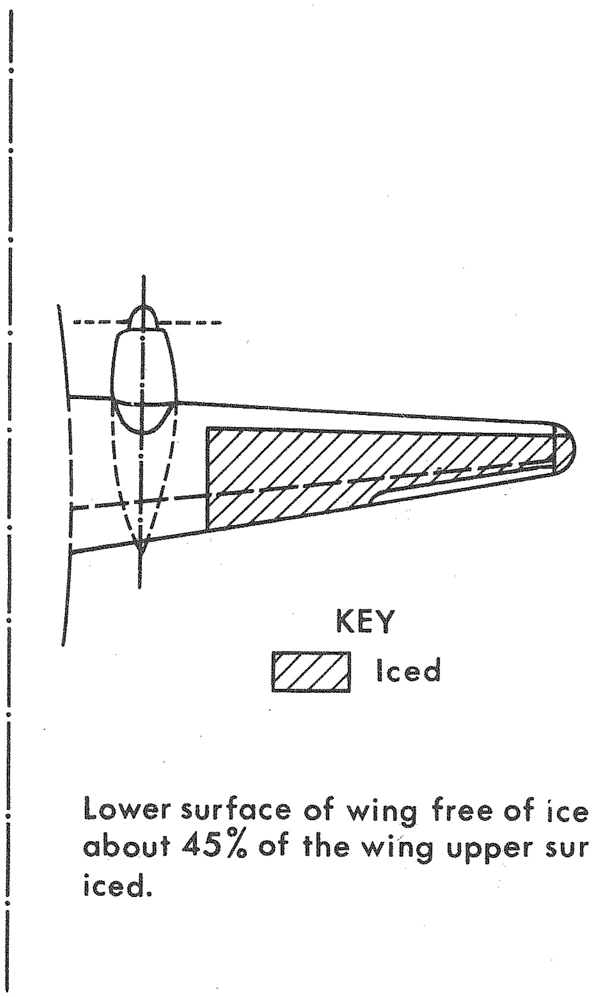
[12] FAA - Advisory Circular No. AC 91-6, General Operating and Flight Rules 1/21/1965 (Water, Slush and Snow on the Runway).

[13] Riegels F.W., Aerodynamische Profile, München 1958 (see also comments on Appendices 3, 5, 6).

List of appendices

FIG.1

ICING OF THE LIFTING SURFACES



Lower surface of wing free of ice, about 45% of the wing upper surface iced.

W I N G   S E C T I O N S

Comparison of the Geometric Data

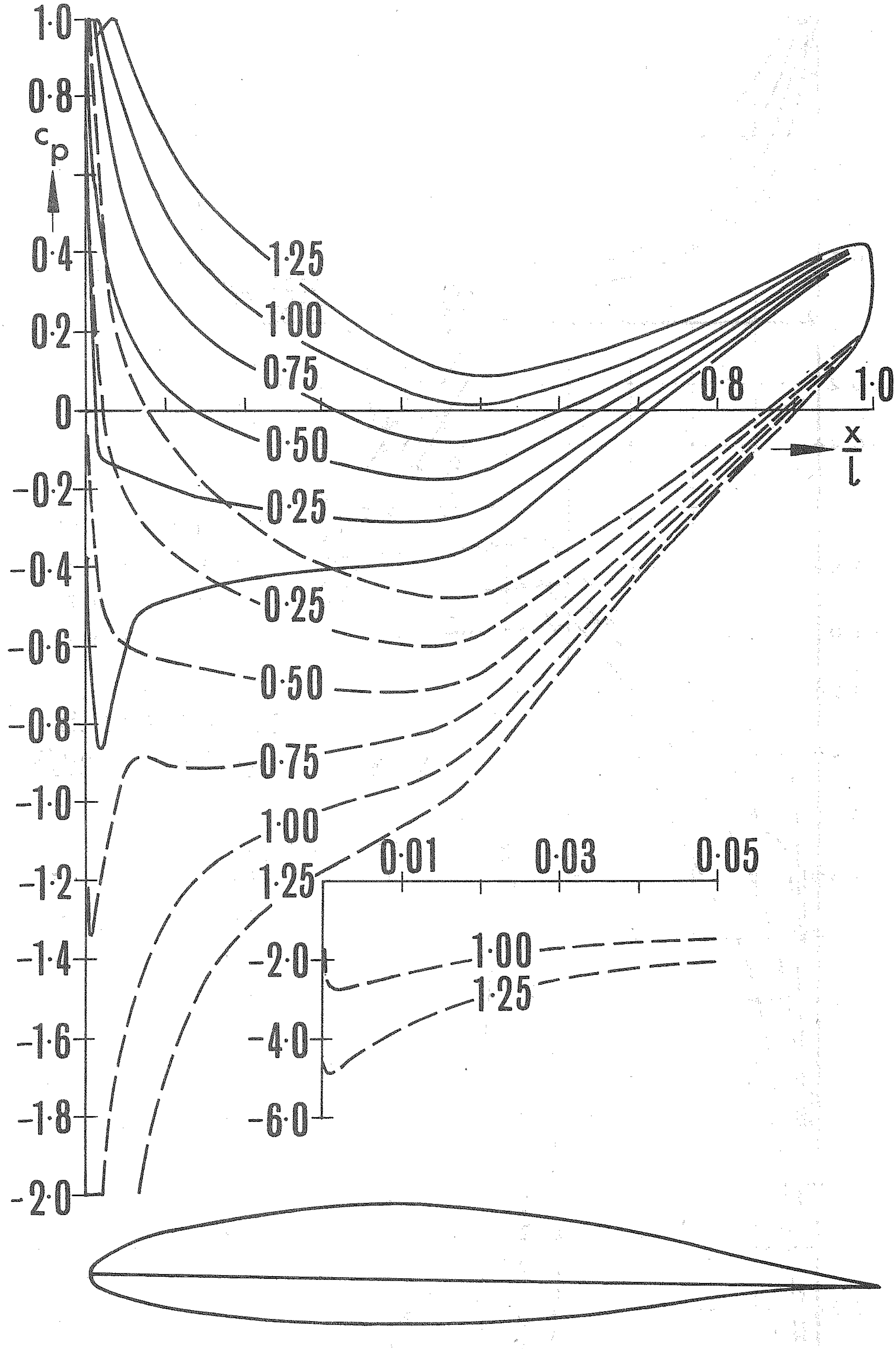
	NACA 65_2-415 (Ambassador Wing Section)	NACA 65_1-212 (Techn. N.2962)	RAF-34 (Prof. Young's Report)	NACA 2412 (AVA)	NACA 23012 (AVA)	NACA 001 (Hoerner
Nose radius	0669	0694	0800	1100	1100	1100
Camber	22	011	18	20	18	0
Position of Max. Camber	50	50	30	40	15	-
Maximum Thickness	15	12	12,6	12	12	12
Position of Max. Thickness	41	41	34	30	30	30
*Trailing edge shape parameter	53	54	115	113	113	113

*Ratio of $\frac{1}{2}$ ton. trailing edge angle to maximum thickness/chord ratio.

Figure 2

FIG. 3

PRESSURE DISTRIBUTION ON NACA 65_2-415 WING SECTION AT RE=3×10^6

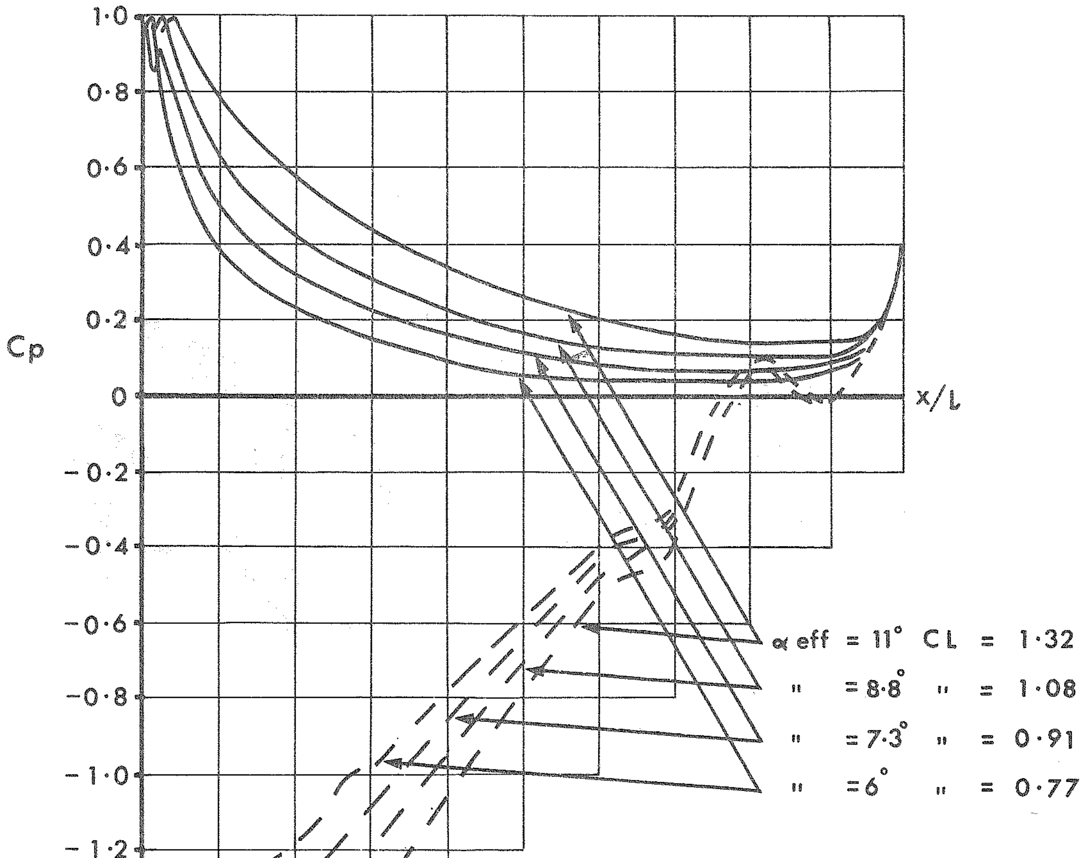


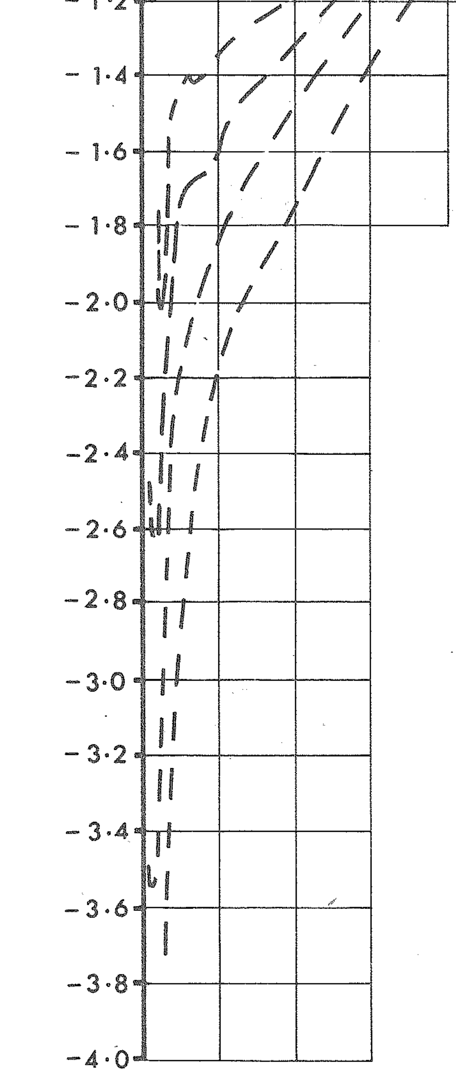
Taken from reference 13

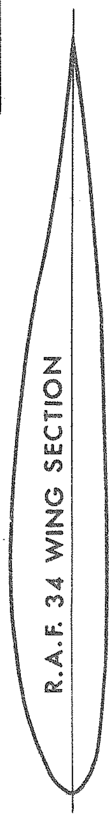
FIG 4

PRESSURE DISTRIBUTION ON R A F 34 WING SECTIONS

FROM PRESSURE DISTRIBUTION INVESTIGATION NO. 467 Z23







SECTION COORDINATES

x/l(%)	yo/l(%)	yu/l(%)
0	0	0
1·25	1·98	−1·62
2·5	2·82	−2·14
5	4·11	−2·81
10	5·83	−3·53
15	6·97	−3·91
20	7·72	−4·16
25	8·14	−4·26
30	8·32	−4·32
40	8·08	−4·32
50	7·21	−4·11
60	5·87	−3·69
70	4·31	−3·09
80	2·70	−2·30
90	1·26	−1·34
95	0·64	−0·76
100	0	0

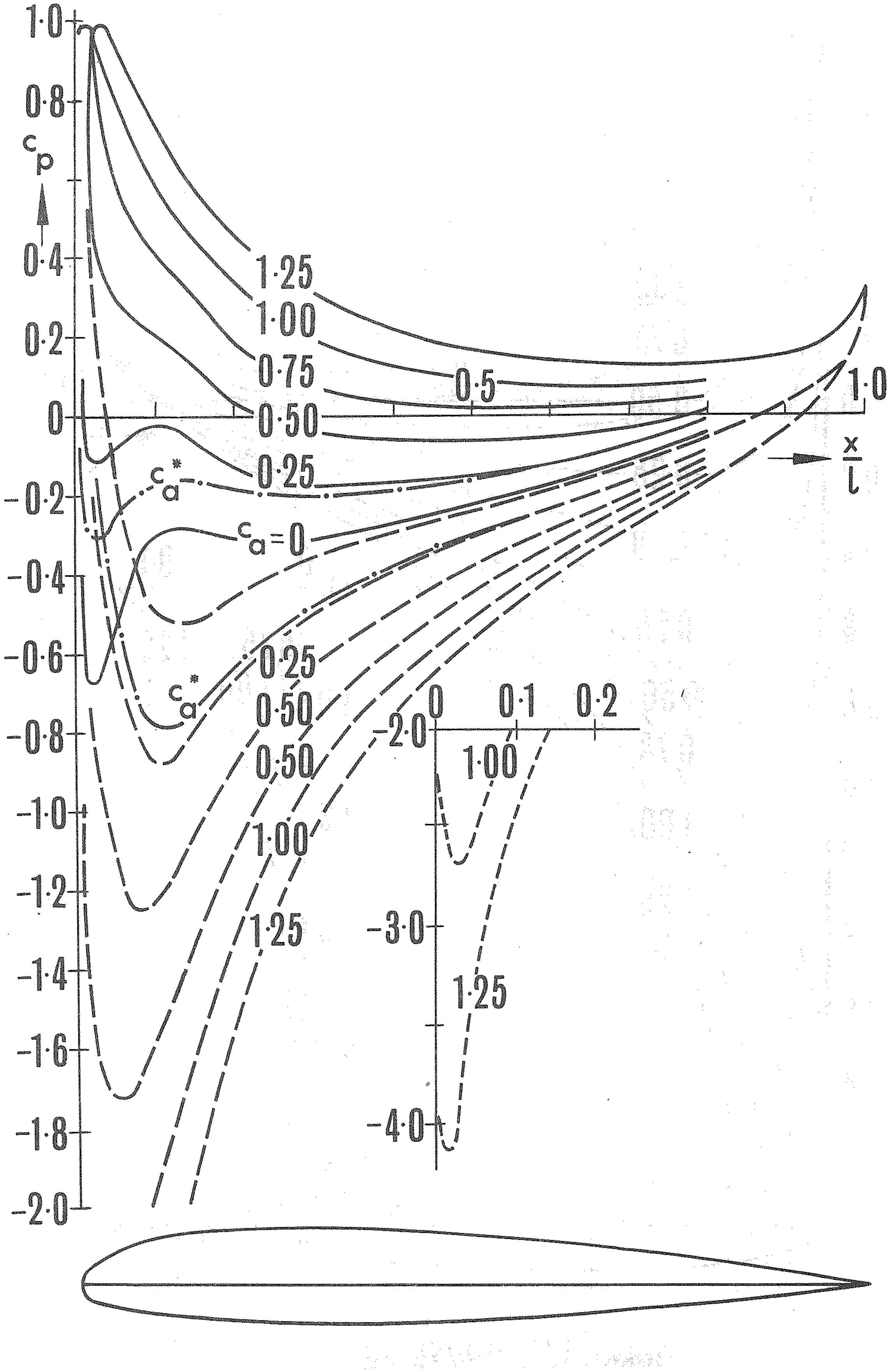
So = 1·29 (%)

d/l = 12·65 (%)   xd/l = 30 (%)

f/l = 2 (%)   xf/l = 30 (%)

FIG. 5

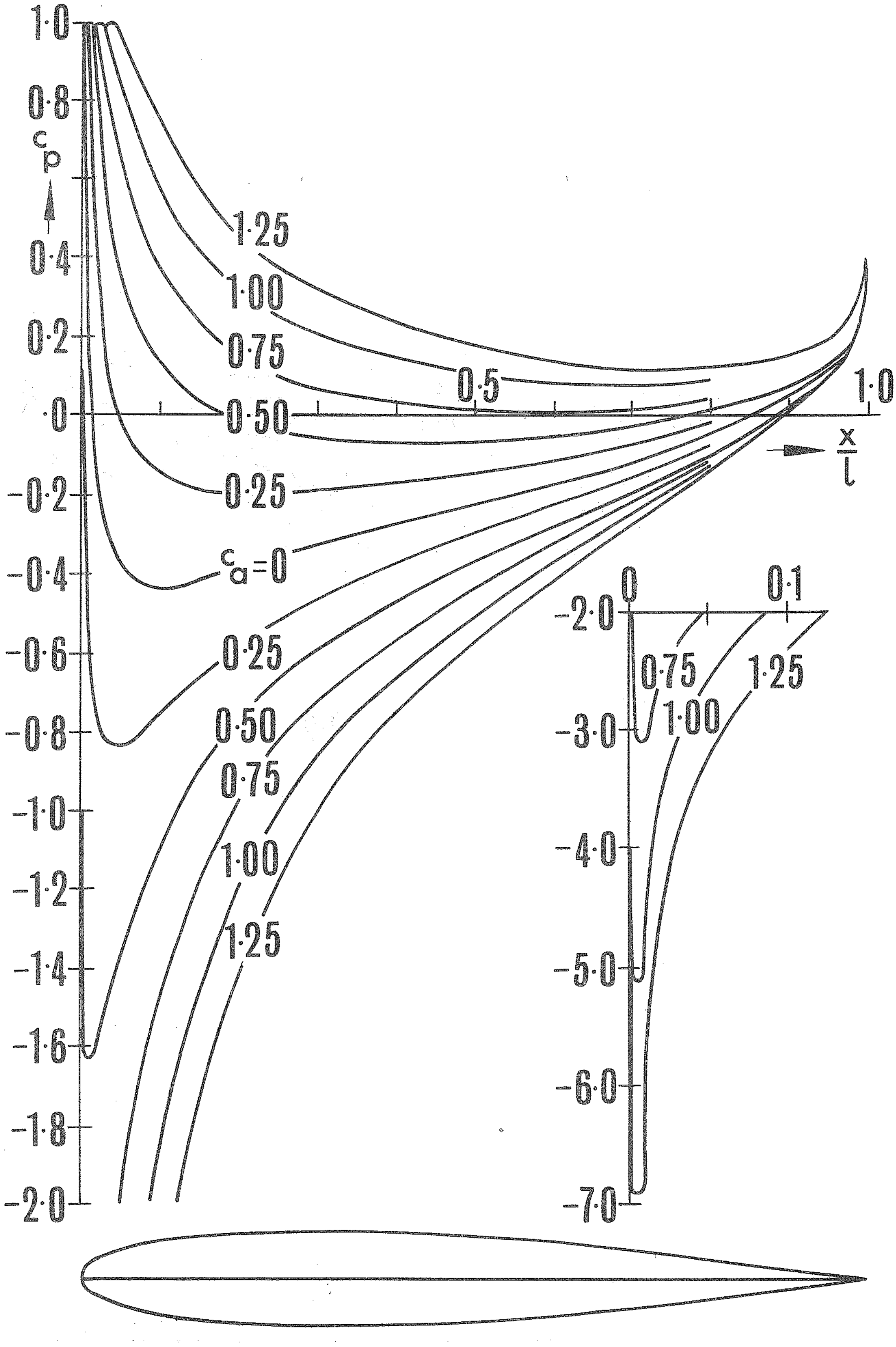
PRESSURE DISTRIBUTION ON NACA 2 30 12
WING SECTION AT RE=3×10^6



Taken from reference 13

FIG. 6

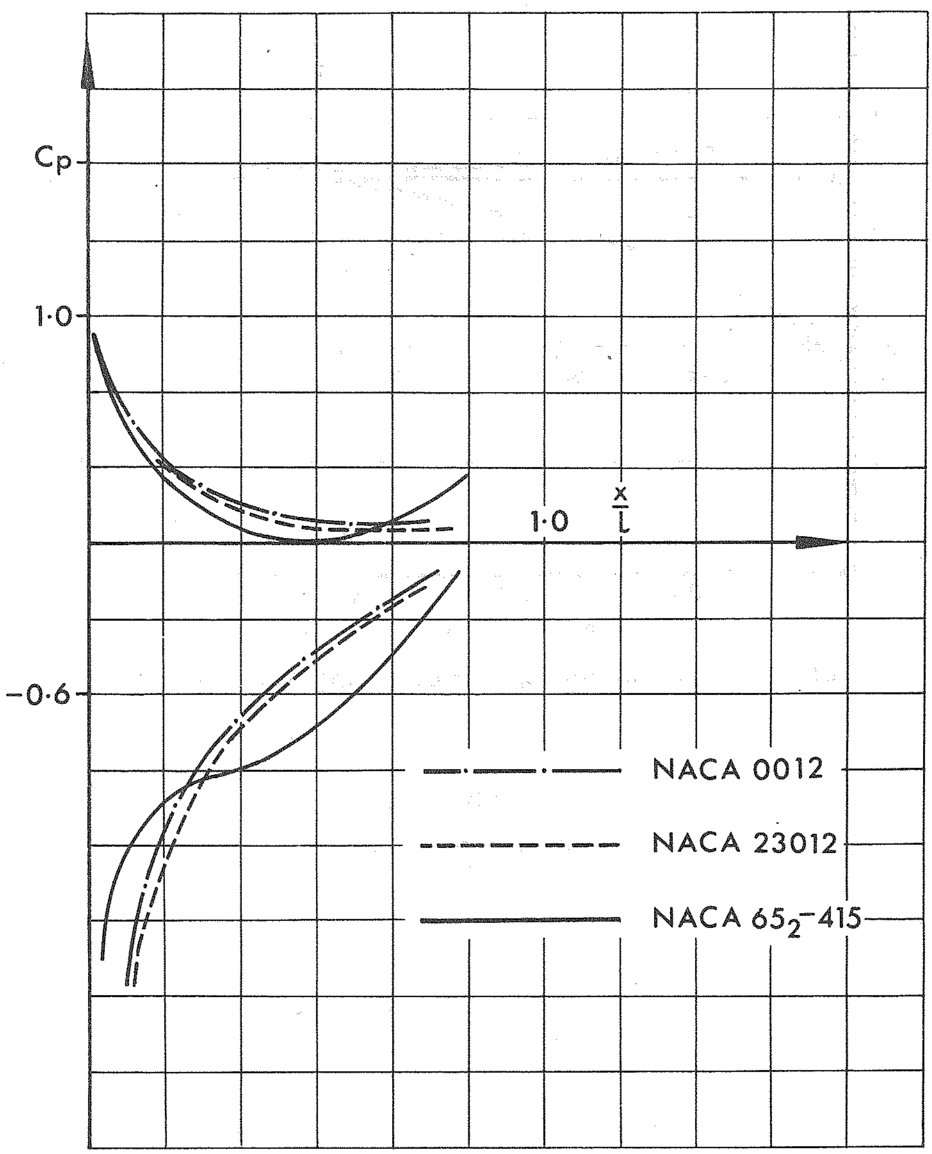
PRESSURE DISTRIBUTION ON NACA 00 12 WING SECTION AT RE = $2 \cdot 7 \times 10^6$



Taken from reference 13

FIG. 7

PRESSURE DISTRIBUTION AT $C_L = 1{\cdot}0$



Based on reference 13

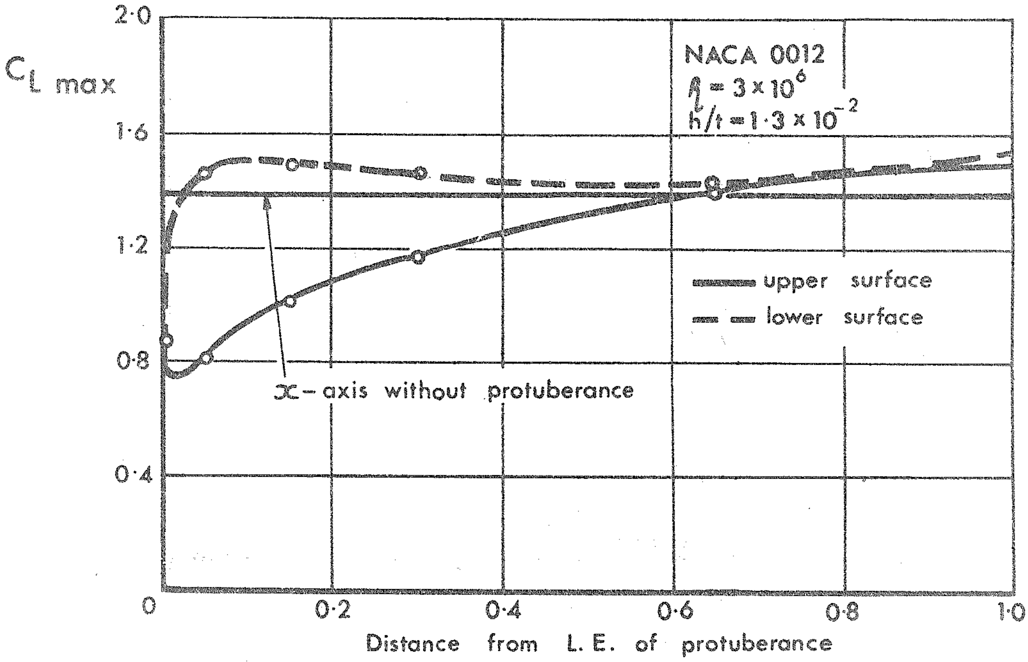


Abb. 12 Sensitivity of various wing sections to protuberances

FIG. 8
Taken from ref. [7]

VARIATION OF C_L WITH α

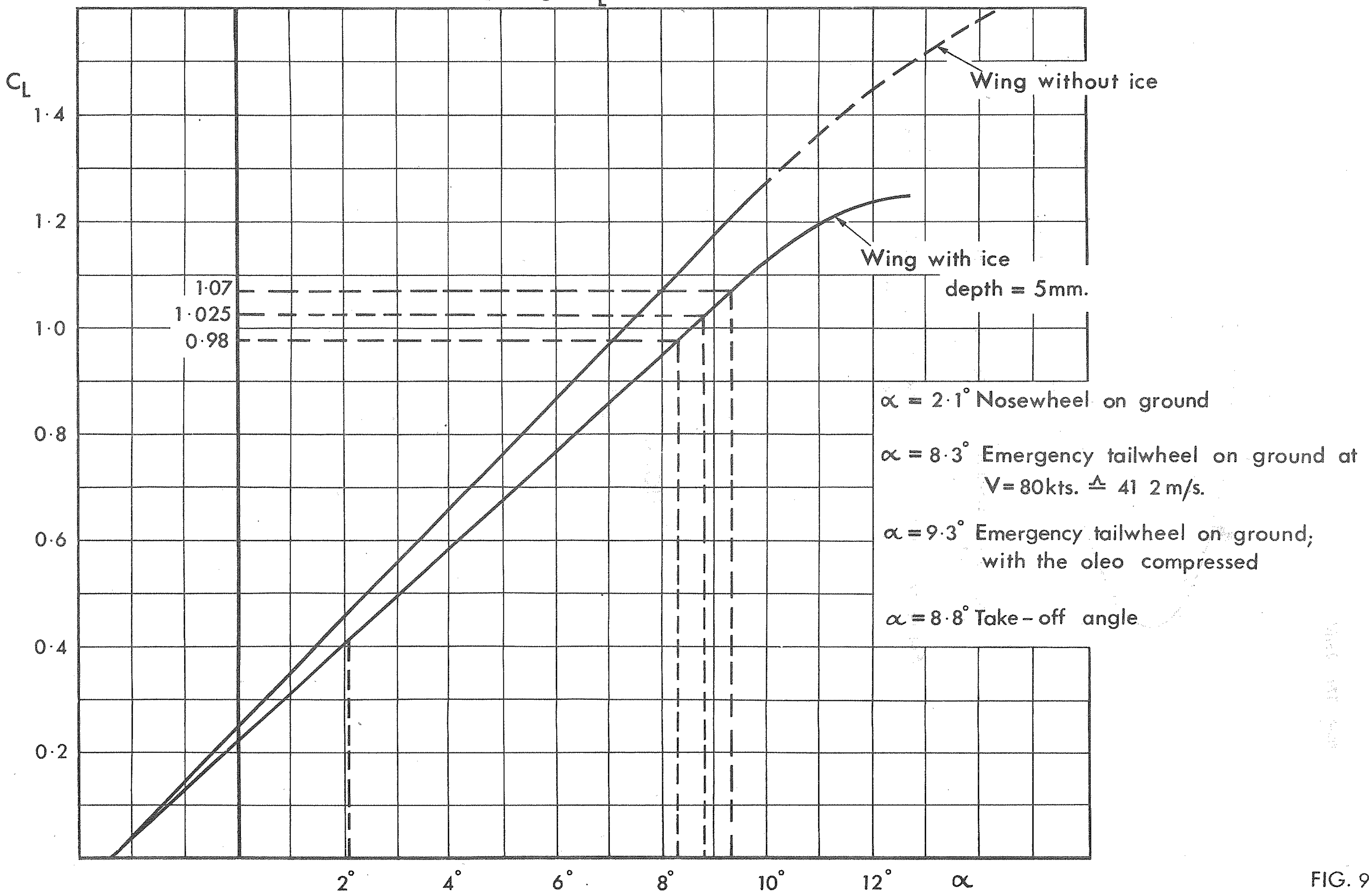
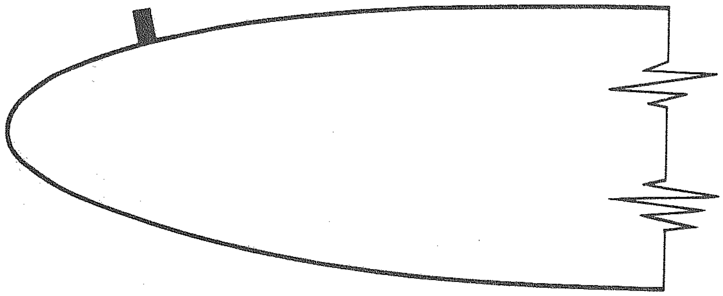


FIG. 9



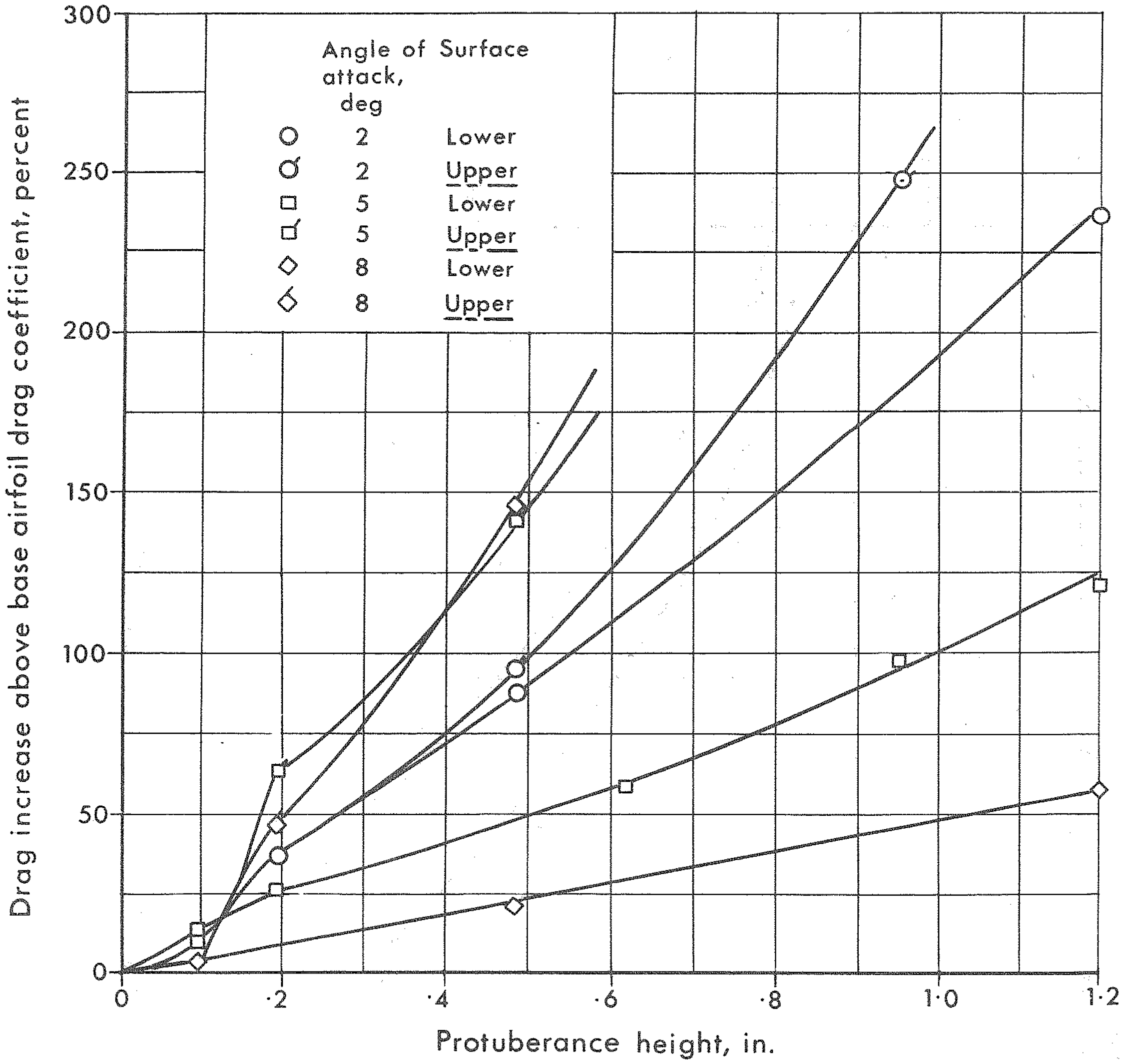
(a) Spoiler protuberance extending full span of airfoil model.

Figure 39. Sketch of protuberance types used in reference 4 to determine airfoil section characteristics.

FIG. 10

taken from ref. [10]

FIG. 11



(c) Protuberance location, 15–percent–chord station.

Figure 40.– Concluded. Percentage drag increase with protuberance height for several angles of attack at three chord stations (ref. 4). (Spoiler protuberance, fig. 39 (a).)

Taken from reference 10

FIG 12

VARIATION OF Cd WITH α

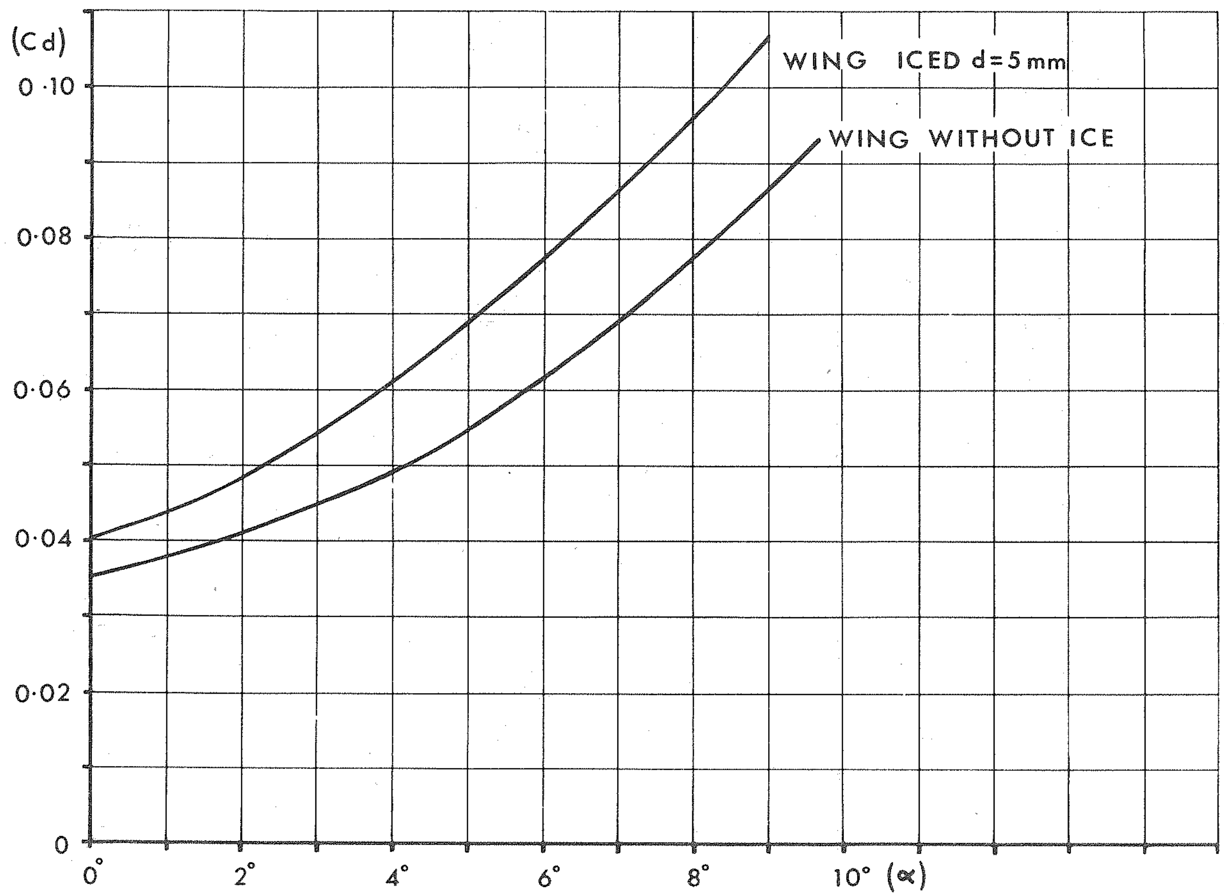


FIG 13

LIFT/DRAG POLARS FOR GALZU

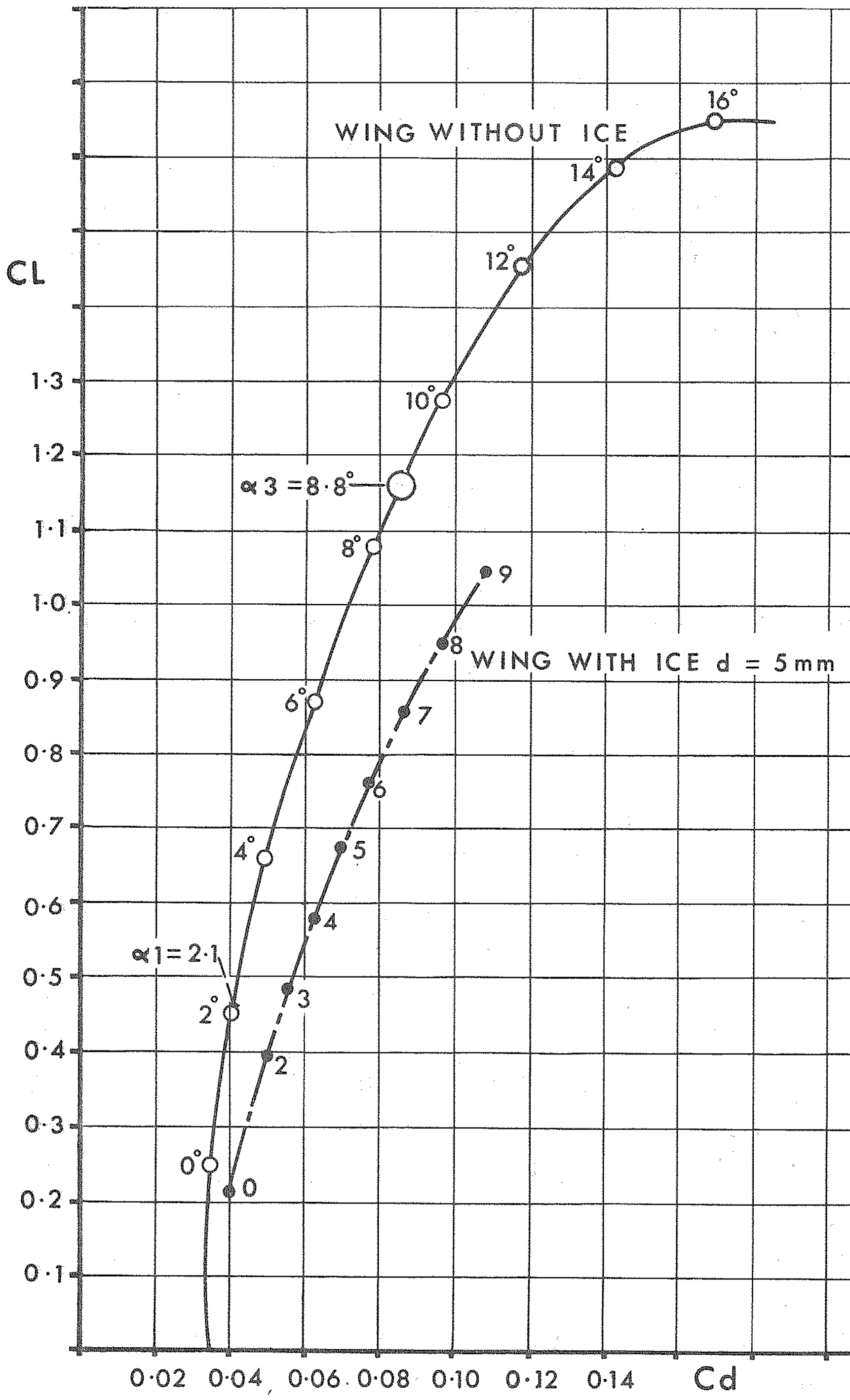
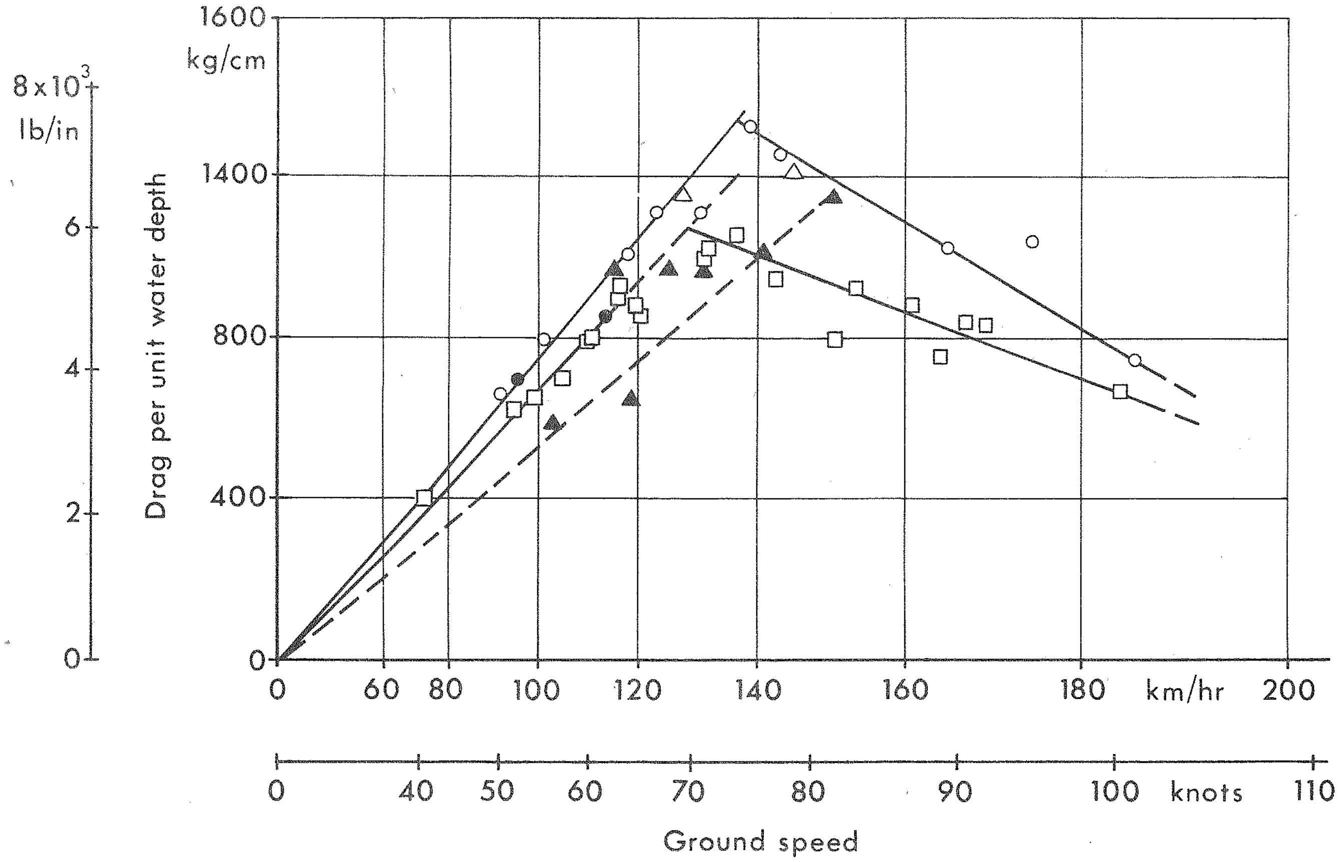


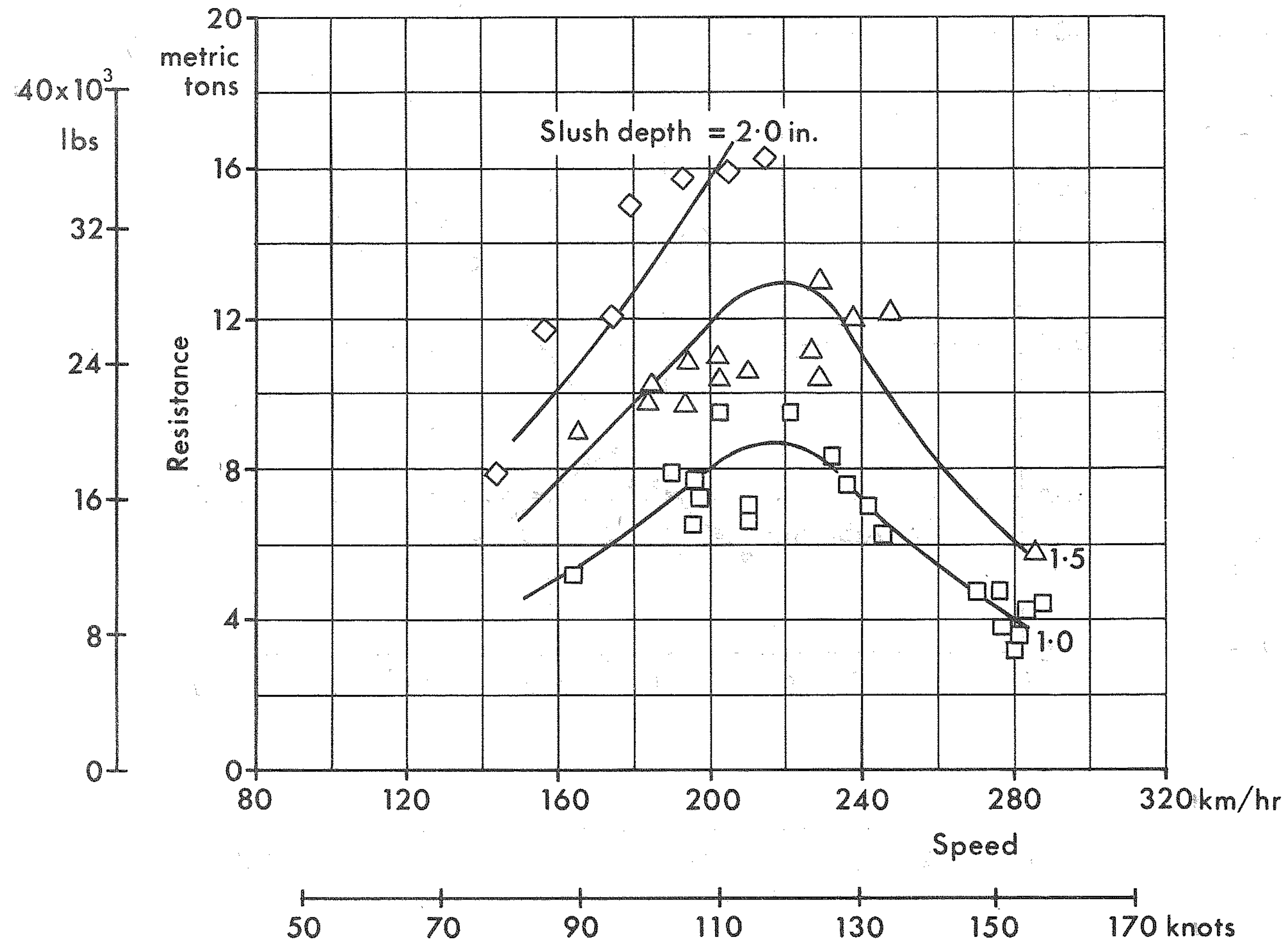
FIG. 14



Symbols	Condition of test	A/c weight		Tyre pressure	
		kg	lb	kg/cm²	psi
○ △ □	All wheels in water, water depth 14·7 to 33·2 mm.	24,100 24,100 20,000	53,000 53,000 44,000	6·0 5·3 3·3	85 75 75
●	All wheels in slush σ = 0·62 & 0·79 depth 22·2 & 25·4 mm.	24,100	53,000	6·0	85
▲	Main wheels only in water	24,100	53,000	6·0	85

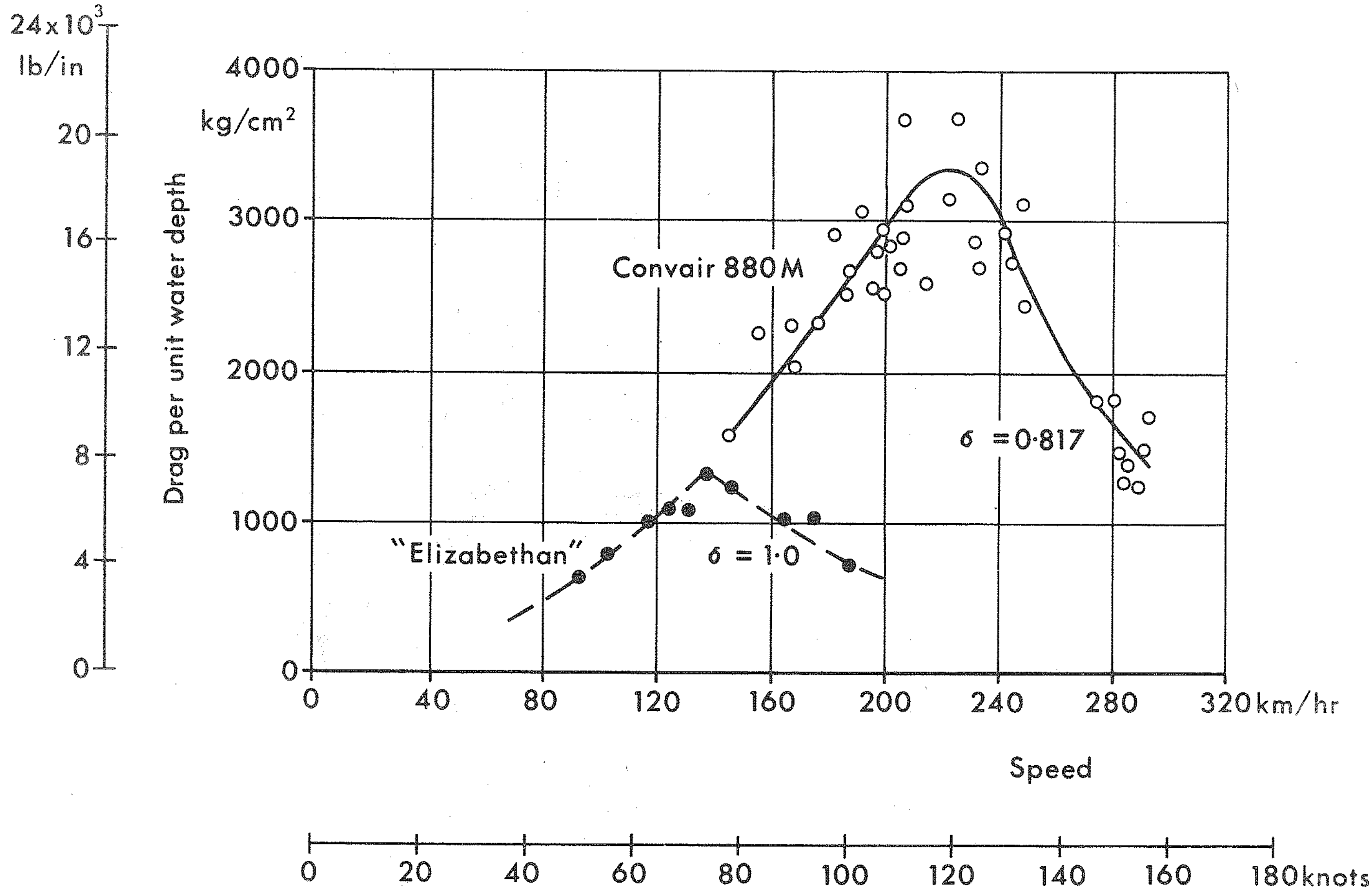
Variation of the drag of the Elizabethan with depth of water & speed

FIG. 15



Variation with speed of the drag of the Convair 880M at different slush depths.

FIG.16



Drag per unit water depth as a function of speed.

FEDERAL AVIATION AGENCY

[14 CFR Parts 4b, 10, 40, 41, 42, 91 [New]

SR-422, SR-422A, SR-422B]

[Docket No. 628; Reference Draft Release 61-1]

RUNWAY SLUSH ACCOUNTABILITY FOR TAKEOFF OPERATIONS OF TURBINE-POWERED TRANSPORT CATEGORY AIRPLANES

Withdrawal of Notice of Proposed Rule Making

The purpose of this notice is to withdraw Draft Release 61-1 (26 F.R. 757; January 25, 1961).

In Draft Release 61-1, the Agency proposed to require that the retardation and other effects of runway surface precipitation accumulations (i.e. wet snow, slush, and standing water) be taken into consideration in computing the takeoff performance of turbine-powered transport category airplanes. Included in the proposal were provisions that would have required each operator to determine the retardation effects of precipitation, and to measure precipitation depths and density by approved methods. Also included were provisions that would have required each operator to determine for each type of airplane operated by him, the precipitation depths above which impingement of precipitation spray during the takeoff run would cause critical engine ingestion or airframe damage, and that would have prohibited takeoff at depths in excess of those so determined.

After consideration of the numerous comments received in response to Draft Release 61-1 and as a result of information gained from studies of the runway precipitation problem since its issuance, including takeoff run tests in artificial slush that were jointly conducted by the Agency and the National Aeronautics and Space Administration, the Agency has concluded that presently available technical data provides an insufficient basis on which to develop the precise regulatory standards that would be required of any meaningful rule on the subjects, and that Draft Release 61-1 should therefore be withdrawn.

The proposal contained in Draft Release 61-1 was issued with only the retardation effects of runway surface precipitation accumulations on takeoff performance in mind. The joint NASA/FAA slush tests indicated that other factors, as well, influence the magnitude of total precipitation drag and must be taken into account if the influence of surface runway precipitation on takeoff performance is to be predicted accurately. However, accurate prediction in the present state of the art is not practicable since the exact relationship of these factors to each other, and their resultant effect on total precipitation drag, is unknown.

The data that the NASA/FAA tests did yield was derived from closely controlled conditions. In addition to bringing to light the foregoing problems, these tests also raised serious doubts as to the wisdom and practicability of any requirement to measure precipitation depth and density under normal air carrier operating conditions. The difficult problem of precipitation depth measurement also makes it impracticable to require establishment of a limiting depth for takeoff based on the possibility of airframe damage due to impingement of precipitation spray.

/Based

Based on the foregoing, the Agency has concluded that it cannot justify final rule making action at this time, and that the most appropriate course for it at this juncture is to disseminate as widely as possible the information that it has gained since the issuance of Draft Release 61-1 about the problem of runway surface accumulations of precipitation and the effects thereof on the takeoff performance and airframes of turbine-powered transport category airplanes. Accordingly, the Agency has issued concurrent with this withdrawal an advisory circular on this subject that will apprise operators of turbine-powered transport category airplanes of the problem, and set forth those courses of action that the Agency is able to recommend on the basis of present knowledge.

In consideration of the foregoing, the Notice of Proposed Rule Making published in the Federal Register (26 F.R. 757; January 25, 1961) and circulated as Draft Release 61-1, entitled "Runway Slush Accountability for Takeoff Operations of Turbine-Powered Transport Category Airplanes," is hereby withdrawn.

Notice 61-1 is withdrawn under the authority of section 313(a) of the Federal Aviation Act of 1958 (49 U.S.C. 1354).

(Signed) C. W. Walker
Acting Director
Flight Standards Service

Issued in Washington, D.C. on January 22, 1965

FIG. 19

VARIATION OF THRUST AND DRAG AT $\alpha = 2{\cdot}1°$

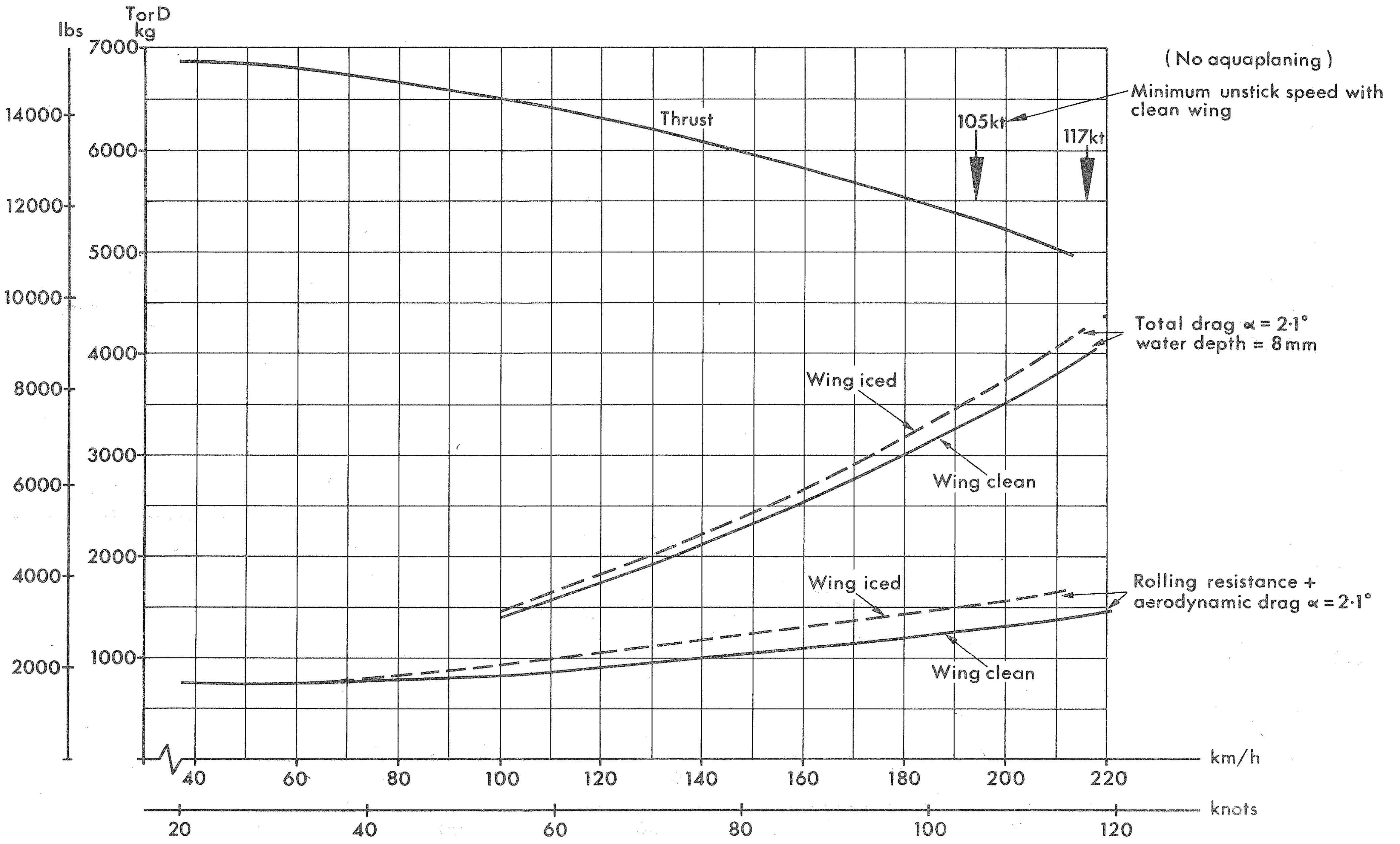


FIG. 20

VARIATION OF THRUST AND DRAG AT $\alpha = 8{\cdot}8°$

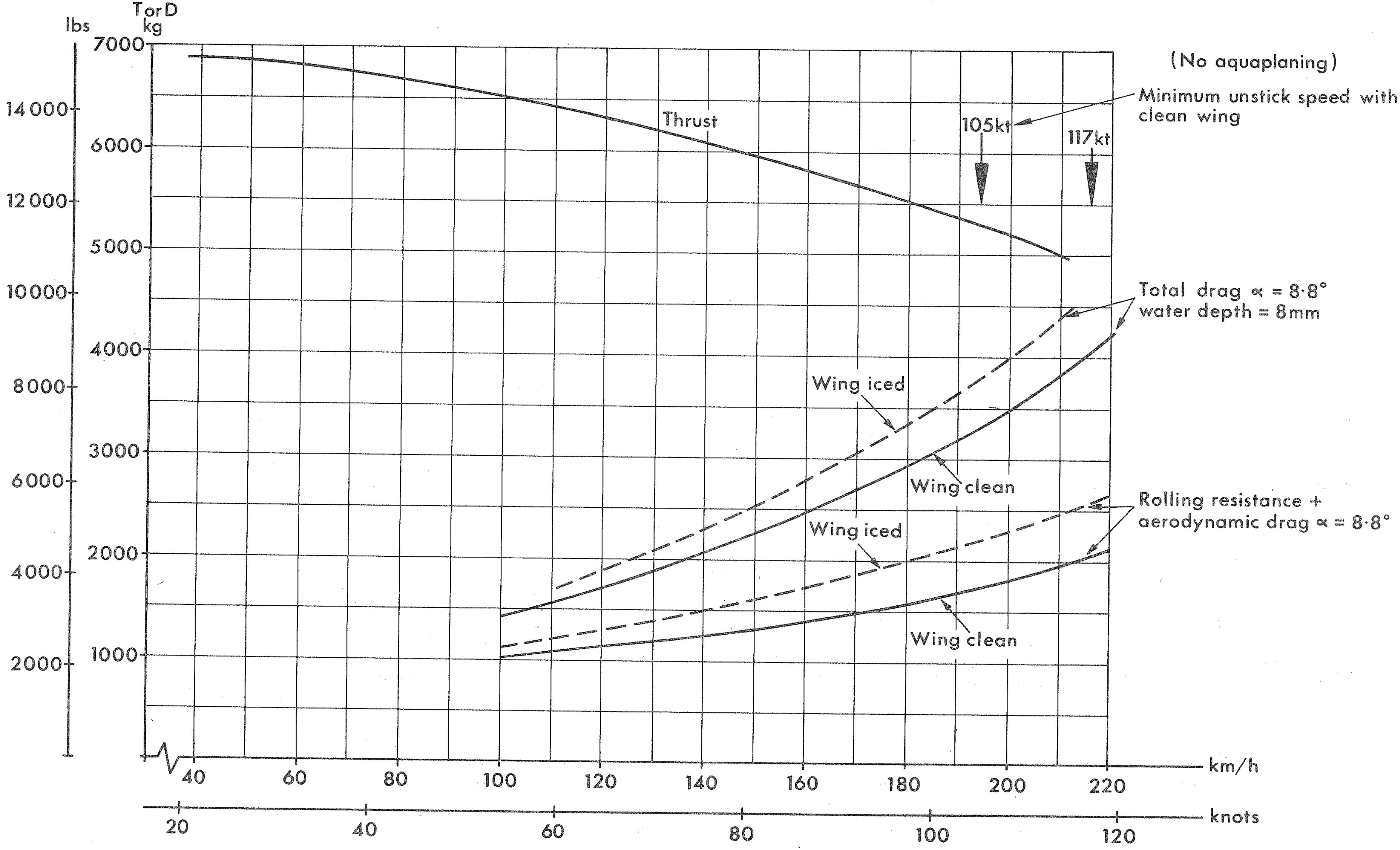
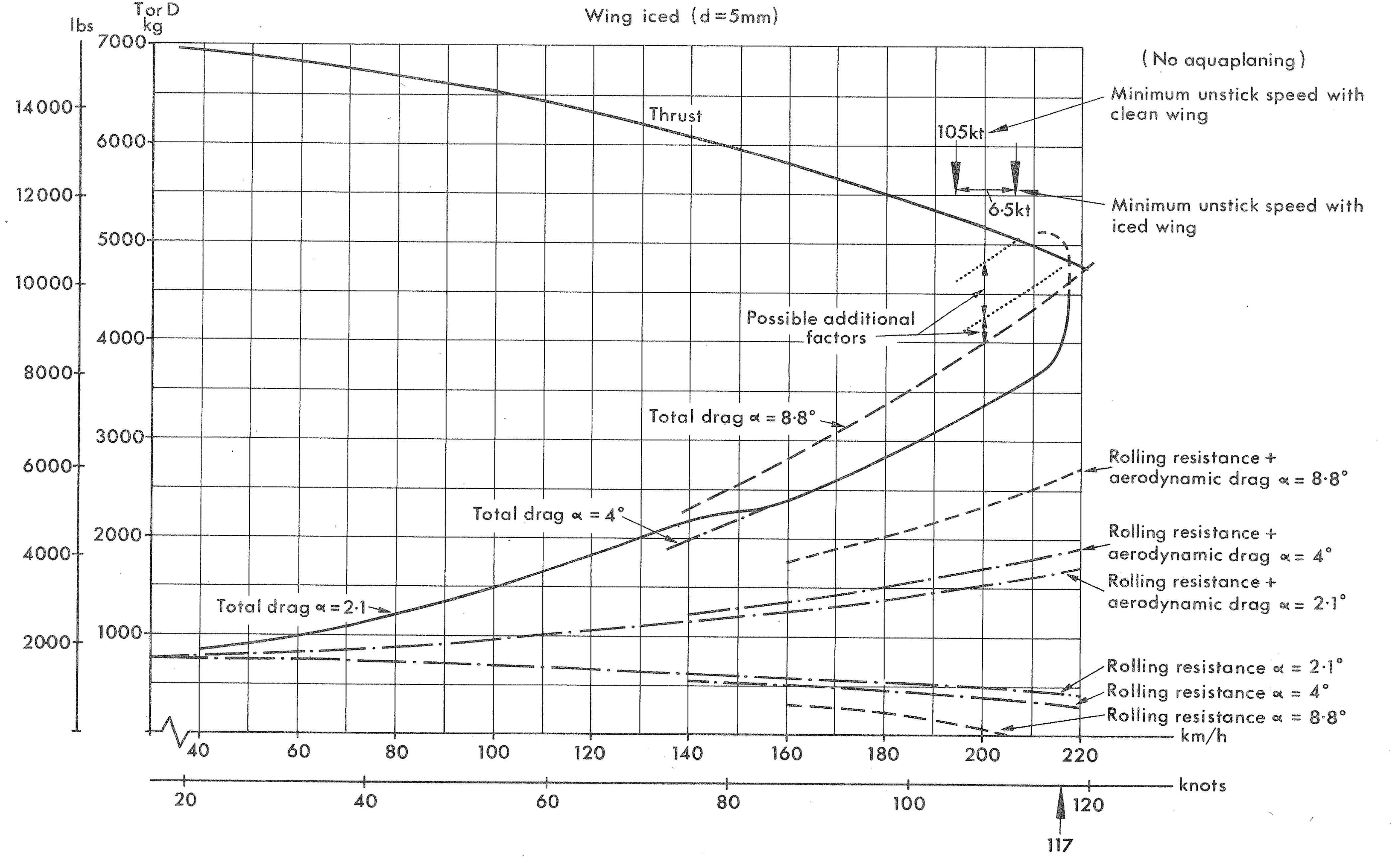


FIG.21

VARIATION OF THRUST AND DRAG

Wing iced (d=5mm)



Application of the Results of Slush Drag Tests on the Ambassador to the Accident at Munich

ROYAL AIRCRAFT ESTABLISHMENT, FARNBOROUGH

Application of the Results of Slush Drag Tests on the Ambassador to the Accident at Munich

1. Introduction

The tests described in R.A.E. Technical Note No. Aero 2968[4] make it possible to calculate the drag to which an Ambassador would be subjected under any given conditions of slush and water on the runway. It is therefore possible to estimate the depth and variation of slush required to produce the sequence of events during the attempted take-offs at Munich, as indicated by the evidence given in Refs. 1 and 2, and to see whether they are consistent with the other evidence available about the conditions prevailing at the time. However some degree of uncertainty is bound to remain since neither the sequence of events leading up to the accident nor the condition of the runway is known exactly.

2. Recapitulation of evidence

For the sake of convenience and clarity a brief recapitulation is included here of the parts of the evidence published by the German Commission of Inquiry[1] and in the report of the Fay Committee[2] which are relevant to this paper.

The Munich runway at the time of the accident was 6,260 feet long and the Ambassador made three attempts to take-off from it on 6th February, 1958. The first run started at 1530 hrs and the aircraft accelerated to about 105 knots indicated airspeed before the take-off was abandoned due to boost surge. The brakes were applied and the aircraft stopped about 1,350 feet from the end of the runway, after covering about 4,900 feet. The time-history of engine power output given by the Peravia record showed that the time taken before the take-off was abandoned was 32 seconds. After back tracking the aircraft began its second run at 1534 hrs, and this was abandoned at a speed of about 85 knots for the same reason as the first.

After returning to the Terminal Building, the aircraft started its third attempt to take-off at 1603 hrs, 33 minutes after the first attempt. On this run the aircraft weight was 54,620 lb, the decision speed, V_1, was 117 knots and the take-off safety speed, V_2, was 119 knots.* According to Captain Thain, who was acting as co-pilot, the airspeed indicator reached 117 knots, when he called 'V_1' to the pilot, before dropping back again to about 105 knots. Shortly after the drop in speed the aircraft ran off the end of the runway without taking-off and collided with a house.

---

* At V_1, the aircraft would be capable either of continuing the take-off with one engine failed, or of stopping within the distance available and consequently a take-off would not be abandoned in the event of engine failure after this speed had been reached. V_2 is the minimum speed at which a take-off can be safely initiated and is the normal take-off speed although, in these conditions of weight and power, the aircraft should have been capable of leaving the ground about 10 knots earlier.

During this take-off run there was slight boost surging on the port engine at a speed of about 85 knots. Otherwise the Peravia recorder on the engine showed that it had functioned correctly up to the point when the throttles were closed after 50 seconds. According to the R/T record the total time to impact was a little over 54 seconds. A further point affecting the take-off is the raising of the nosewheel, on which the evidence is conflicting. All the evidence given to the German Commission is not reproduced in detail in their report, but it appears that the nosewheel left the ground about half way along the runway for a short time (60 - 100 metres according to one witness) and then touched down again. According to most witnesses it left the ground again later before the end of the runway, and marks stated to be from the (emergency) tail wheel were observed in the snow near the end of the runway.

As far as conditions on the runway are concerned the main evidence is that of the Airport Traffic Manager, Herr Bartz, who stated that he had inspected the runway after the second attempted take-off and found the entire runway covered with a 'jellified, watery mass' of slush $\frac{1}{2}$ to $\frac{3}{4}$ cm deep. On the other hand Captain Wright, who landed a Viscount at 1558 hrs said that in parts the runway was merely wet and free from slush whereas in other places the slush was 1 to 1.5 inches ($2\frac{1}{2}$ to 4 cm) deep. The meteorological evidence was that 1.37 cm of precipitation (water equivalent) had fallen the night before and the ground was partially covered with snow at 0714 hrs. The runway was wet, but free from snow and slush up to 1120 hrs (having presumably been swept), and 0.37 cm precipitation fell between 0714 and 1414 and a further 0.5 cm up to 2114, some of this falling after the accident. The German enquiry concluded that "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 depth". A further piece of evidence concerning the state of the runway is available from the take-off of Captain Wright's Viscount[2]. He stated that in ordinary conditions his elapsed time to V_2 of 106 or 107 knots would have been about 23 seconds, but on this occasion it was "nearer 30 seconds" and the aircraft used about two-thirds of the runway before unsticking.

3. Performance calculations

3.1. Assumptions

The assumptions made in the performance calculations about basic aircraft aerodynamics and about propeller thrust are the same as those made by Dr. Schlichting in Ref.3. The conditions of temperature, pressure and wind assumed are the known conditions during the attempted take-offs at Munich. The drag assumed to be due to slush is based on that measured in Ref.4. However it is clear from Fig.5 of Ref.4 that aquaplaning has a marked effect on the drag due to slush of the Ambassador, and this figure also shows that with a slush specific gravity of 0.8 (consistent with Herr Bartz's description) and normal tyre pressures the aircraft would be expected to reach a maximum drag at a little over 80 knots. It would therefore be expected that the aircraft would have aquaplaned on all three runs and this point is considered in detail in para. 3.2.

Most of the calculations have been made for the clean aircraft, but some estimates have also been made assuming ice on the wing. Schlichting[3] estimated the changes in lift and drag due to ice on the wing having roughness heights of 0.03 cm and 0.3 cm, but he assumed that ice was present over the whole wing, whereas Ref.2 established that the areas behind the propellers and over the wing centre-section, comprising one half of the wing area, were certainly free from ice. In these calculations therefore the lift and drag changes assumed to be due to ice are half the changes estimated by Dr. Schlichting for ice of roughness height 0.3 cm. It may be observed that on Dr. Schlichting's estimates an increase of ten times in ice roughness height from 0.03 cm to 0.3 cm only increases the lift and drag effects of the ice by 60%. The effect of any possible increase in thickness above 0.3 cm is therefore likely to be small.

3.2. Aquaplaning

It was explained in para. 3.1 that aquaplaning would have been expected to take place on all three runs. However on the first attempted take-off, the aircraft accelerated to 105 knots indicated speed and stopped again successfully in a total distance of 4,900 feet. Had aquaplaning occurred there would have been no effective braking action until the ground speed had fallen below 80 knots, since aquaplaning continues to a lower speed than that at which it starts. Under these circumstances the speed would have not returned to 80 knots until about 4,500 feet of runway had been covered, and a further 1,300 feet would have been required to stop. The exact depth of the slush is not critical in this calculation: an increase increases the distance required to accelerate to 105 knots and decreases the coasting distance before the brakes become effective. An additional point is that no handling difficulty or lack of braking effort, such as are associated with aquaplaning, was reported at any time during the run. It is therefore accepted that the aircraft did not aquaplane for any appreciable period during the first attempt to take off.

Further, at the end of the final take-off attempt the aircraft left skid-marks on the runway when the wheels were locked by the application of brakes, which shows that it was not then aquaplaning in spite of a ground speed of at least 100 knots. Since the maximum ground speed achieved was about 111 knots and aquaplaning starting then would have persisted to below 100 knots it follows that the aircraft cannot have aquaplaned on this run either and that aquaplaning can be ignored in the performance calculations.

From this conclusion that the aircraft did not aquaplane, inferences can be drawn about the specific gravity of the slush, assuming it to be homogeneous. On the first run, when the tyre pressures were normal, lack of aquaplaning at 100 knots ground speed means that the specific gravity cannot have exceeded 0.5 by much except over the first third of the runway where the speed of the aircraft was less than 80 knots. On the final run the tyre pressures must have been appreciably higher than on the first run, since the aircraft had stopped from 105 knots and again from 85 knots and had taxied considerable distances in the previous half-hour. The evidence from Ref. 4 then indicates that, even in the prevailing low temperature, the tyre pressures must have been around 105 or 110 p.s.i. and the specific gravity of the slush must again have been no more than about 0.5 since aquaplaning did not occur on the second half of the runway. It is therefore concluded that over the majority of the runway the specific gravity of the slush cannot have been much greater than 0.5.

While this figure is on the low side for slush, it must be remembered that 'slush' is a complex medium and may be far from homogeneous throughout its depth. How lack of homogeneity, for example, would affect aquaplaning speeds is not known. Effects equivalent to slush with a uniform specific gravity of 0.5 could conceivably be obtained with other slush structures.

3.3. Effects of slush on acceleration

Calculations have been made on the assumptions already detailed of the distances which would have been required by the Ambassador to accelerate to various speeds with varying amounts of slush on the runway. In Fig.1 these distances are plotted against the depth of water equivalent to the amount of slush on the runway, that is the product of the slush depth and its specific gravity, this product being of course assumed to be constant in any take-off.

Curve 1 shows the distance required by the clean aircraft with its nosewheel on the runway to accelerate to its V_1 of 117 knots, this being the highest speed obtained on the final take-off attempt, and shows how the distance increases more and more rapidly as the slush depth increases.

Curve 2 shows the distance required to reach V_2, the minimum take-off speed of 119 knots, and the widening difference between Curves 1 and 2 shows how the acceleration of the aircraft in this speed range falls off as the depth increases.

Curve 3 for the iced aircraft is directly comparable with Curve 1 and the difference between them is the effect of the degree of icing assumed. This comparison shows that the effect of icing on the acceleration of the aircraft to a given speed is much less than the effect of slush and that icing reduces the equivalent depth of slush required to produce a given increase in distance to V_1 by only 0.08 cm.

Curve 4 shows the distance to V_1 if the aircraft nosewheel is raised at 100 knots and shows the favourable effect of doing so, particularly in slush equivalent to more than 0.8 cm of water. Curve 5 shows the distance to 105 knots, the maximum speed reached on the first run, and Curve 6 shows the distance to 100 knots, both on the assumption that the nosewheel is not raised.

These curves show the basic performance of the Ambassador in varying depths of slush. By using them in conjunction with the other data available about the take-off attempts it is possible to make further inferences about the state of the runway and the course of the accident.

3.4 Inferences from the first take-off attempt

A check on the mean depth of the slush over the first half of the runway can be got from the facts known about the first run. On this run the aircraft accelerated to 105 knots indicated airspeed in 32 seconds, and came to a standstill after a total of 4,900 feet. With a slush depth equivalent to 0.8 cm of water the estimated time to 105 knots is 32 seconds, and the distance 3,100 feet, which would allow the aircraft to stop again without difficulty at the known point. With a depth equivalent to 1.0 cm of water the time is up to 36 seconds and the distance is 3,550 feet, which does not allow sufficient distance for stopping, while with 0.6 cm the time is down to 29 seconds and the aircraft would probably although not certainly have stopped earlier than 4,900 feet. It is concluded that the depth must have been equivalent to 0.7-0.8 cm water. A slush depth equivalent on the average to 0.8 cm of water agrees well with the meteorological evidence, and the quantity is consistent with the evidence of Herr Bartz. However since aquaplaning did not take place we have to assume that over the last two thirds of the runway, the actual slush depth would have been about $1\frac{1}{2}$ cm assuming the slush to be homogeneous.

There is a real conflict of evidence between Herr Bartz and Captain Wright in the records of the inquiry[1] as to the depth and uniformity of the slush. Moreover, experience at R.A.E. Bedford is that snow and slush are not normally uniformly distributed over the runway although it is substantially level and exposed. Drifting nearly always takes place and a large number of observations are needed to establish the quantity of snow or slush present. In addition, of course, under thawing conditions, some drainage of the watery slush to low parts of the runway would take place.

The uncertainty of the exact state of the runway is such that it is not thought that the slush conditions deduced above (namely about 0.8 cm of water equivalent with an effective specific gravity, from the aquaplaning point of view, of about 0.5) can be regarded as unlikely.

3.5 Inferences from the final take-off attempt

Fig.1 shows that with slush equivalent to 0.8 cm of water on the whole of the runway, the take-off run of the aircraft would have been nearly or quite as long as the runway. If Captain Thain's evidence about the speed drop were supposed to relate to the period after Captain Rayment had decided to abandon the take-off (as suggested in Ref. 1 but rejected in Ref. 2) it would then be possible to explain the aircraft's inability to reach take-off speed within the length of the runway on the basis of little more than this amount of slush. However, if the aircraft was rotated until the tail bumper touched the runway at a speed of 117 knots, it would require an extreme degree of icing on the wing to prevent it lifting off. Even ice with a roughness height of 0.3 cm over half the wing area would not prevent the aircraft from lifting off at 117 knots according to the calculations of Ref.3. In a condition of heavy icing sufficient to prevent the aircraft lifting off at 117 knots the aircraft would reach V_1 after $46\frac{1}{2}$ seconds and the end of the runway after 48 seconds, while the impact would occur after about 53 seconds. These times would be rather (2-3 seconds) low compared with the Peravia and R/T records, but not impossibly so.

It should be observed that even on this hypothesis slush would be the principal cause of the failure to lift off. The aircraft would still have lifted off at V_2 (119 knots) if rotated to the maximum possible extent, and Fig.1 shows the slush to be the major cause of the lengthened run and therefore of the failure to reach V_2. Ref.1 suggested that the aircraft reached V_1 after about 1,500 metres and maintained or exceeded this speed at least to the 1,800 metre mark. To prevent acceleration above V_1 would require slush equivalent to about 1.1 or 1.2 cm of water, and an actual depth of about 2.3 cm, over this portion of the runway. The times taken for such a run would be slightly less than those given above and would therefore also be low.

A considerably greater depth of slush than 0.8 cm is needed to explain Captain Thain's observation of a drop in indicated speed from about 117 knots to about 105 knots. It is estimated that the equivalent of about 2.1 cm of water would cause this speed to be lost in 6 seconds, while about 1,100 feet distance would be covered.

The calculation assumes that all the aircraft's wheels were on the runway during the deceleration period. If the nosewheel was assumed to be raised during this time a further increase in the depth, to the equivalent of about 2.9 cm of water, would be necessary for the same deceleration to continue (induced drag being taken into account). On the other hand the raising of the nosewheel at 105 knots in 2.1 cm water equivalent would leave a slight excess of thrust over drag and prevent the aircraft losing further speed. However at 105 knots the aircraft could not lift off even assuming no icing and with the tail wheel touching the ground.

With this distribution of slush, that is with the equivalent of 0.8 cm of water up to V_1, increasing to 2.1 cm, the aircraft would reach V_1 after about 4,500 feet, and decelerate to 105 knots after about 5,600 feet with insufficient runway length left to reach lift-off speed. The time required to reach V_1 would be 41 seconds, the speed would have dropped to 105 knots after 47 seconds and the end of the runway would be reached after 51 seconds: the impact would then occur after about 56 seconds. These times agree very well with the Peravia and R/T records. This amount of slush, combined with a specific gravity of about 0.5 would mean a maximum total slush depth of 4.2 cm ($1\frac{2}{3}$ in). This quantity, which would have to be explained by drifting, is consistent with the evidence of Captain Wright but not of Herr Bartz. This conflict of evidence has already been discussed.

3.6 The Viscount take-off

Since no slush drag measurements have yet been made on the Viscount it is not at present possible to make much use of the information available from the take-off of Captain Wright's aircraft. However if the same slush drag coefficient is used for the Viscount as for the Ambassador, it is estimated that slush equivalent to 1.2 cm of water would raise the time to unstick to 29 seconds, and the distance to 3,050 feet. This is rather less than Captain Wright's recollection of using about two-thirds of the runway, given in evidence to the Fay Committee. All that can really be inferred from this calculation, is that it is unlikely that slush equivalent to 0.8 cm of water would have had anything like as serious an effect on the take-off of the Viscount, which was lightly loaded, as on the take-off of the Ambassador. Further the Viscount would take-off before reaching the deeper slush required to explain the drop in speed of the Ambassador.

4. Conclusions

It is concluded that there must have been on the average, slush equivalent to about 0.8 cm of water on the first half of the Munich runway at the time of the accident. Since aquaplaning did not take place, either the specific gravity of this slush must have been about 0.5-0.6 or the slush must have had some other characteristic to suppress it. The evidence that "the entire runway was covered with a jellified, watery mass of slush $\frac{1}{2}$ to $\frac{3}{4}$ cm deep" is not consistent with this conclusion. In any case slush is rarely uniformly distributed and accurate mean depths are difficult to judge.

In order to explain the whole of Captain Thain's evidence of a drop in speed from 117 knots to 105 knots it is necessary to assume that deeper slush had accumulated over most of the final third of the runway to an equivalent of 2.1 cm of water and an actual depth of about 4.2 cm ($1\frac{2}{3}$ in.). On these assumptions the calculated course of the take-off agrees closely with the evidence available. In this case it is not necessary to assume the presence of ice on the wing to explain the accident, because the tail wheel marks in the snow at the end of the runway make it probable that the aircraft was not rotated until the speed had dropped to 105 knots.

If however Captain Thain's evidence about the speed drop is rejected, it is not necessary to assume the accumulation of slush at one end of the runway since the equivalent of 0.8 cm would make the take-off run of the Ambassador nearly as long as the runway length, and any further increase in depth over the second half or ice on the wing would render the aircraft unable to reach its normal take-off speed. However the presence of extremely heavy icing would be required to prevent the aircraft taking off when it was rotated near the end of the runway after reaching its V_1 of 117 knots. On these assumptions the calculated times do not agree as well with the known course of the take-off as on the previous assumptions given above, and even on this hypothesis slush is still the principal cause of the reduced take-off performance which led to the accident.

Ref: BAF/9/01

24th June, 1964

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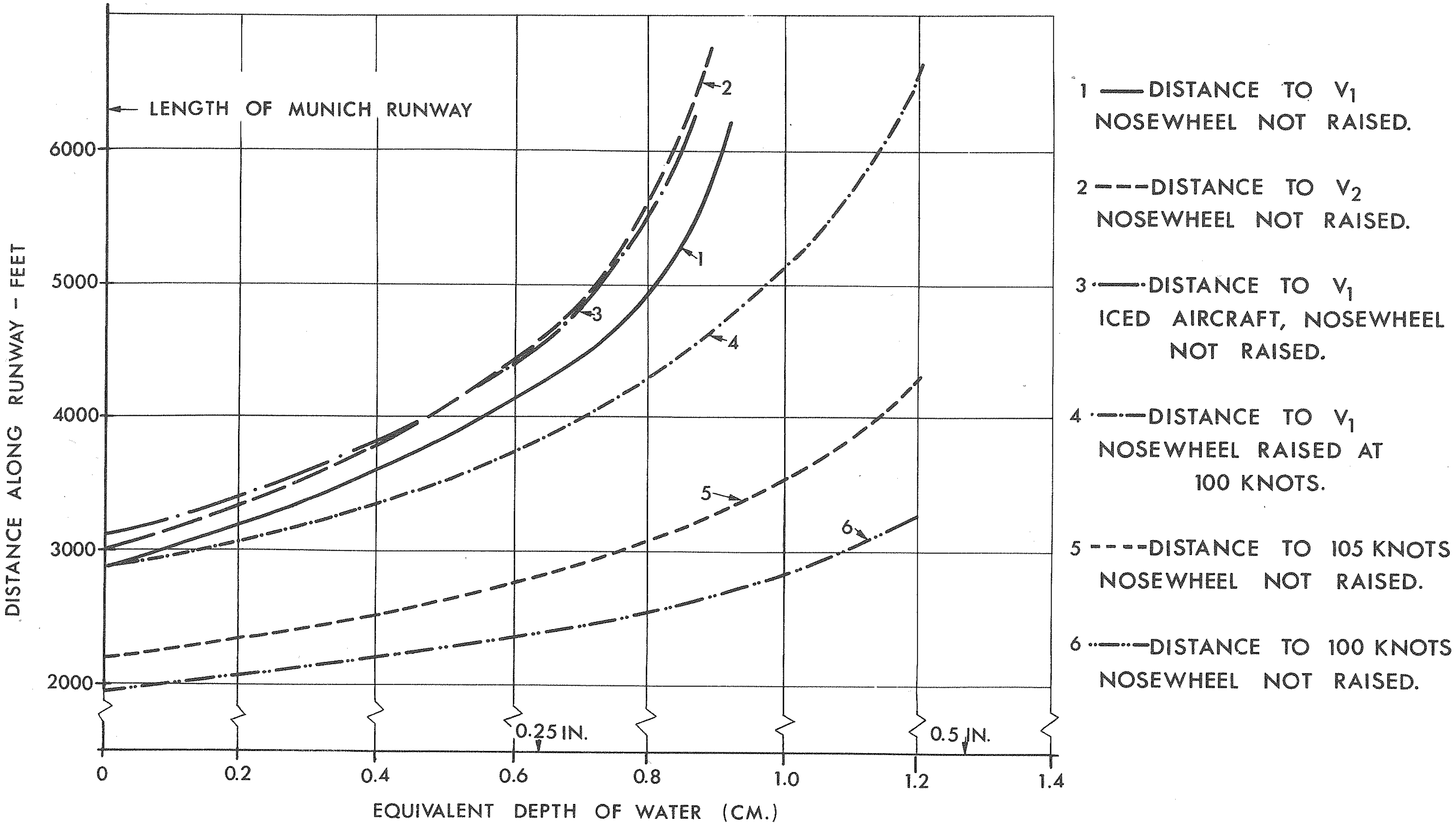

FIG. 1 EFFECT OF SLUSH OF VARYING DEPTH ON THE TAKE-OFF OF THE AMBASSADOR AT MUNICH

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