# ICAO CIRCULAR

CIRCULAR 60-AN/55/2

1968

# OPERATIONAL MEASURES FOR DEALING WITH THE PROBLEM OF TAKING OFF FROM SLUSH- OR WATER-COVERED RUNWAYS

Prepared by the Airworthiness Committee and published by authority of the Secretary General

Second Edition - 1968
Supersedes Circular 60-AN/55

INTERNATIONAL
CIVIL AVIATION
ORGANIZATION
MONTREAL • CANADA

*Published in separate English, French and Spanish editions by the International Civil Aviation Organization. All correspondence, except orders and subscriptions, should be addressed to the Secretary General of ICAO, International Aviation Building, 1080 University Street, Montreal 3 (Quebec), Canada.*

Orders for this publication should be sent to one of the following addresses, together with the appropriate remittance (by bank draft or post office money order) in U.S. dollars or the currency of the country in which the order is placed or in a freely convertible currency:

**Australia:** Robertson and Mullens, 107 Elizabeth Street, Melbourne, C. 1.

**Canada:** Department of Public Printing and Stationery, Ottawa (Ontario).

**France:** Représentant de l'OACI, Bureau Europe, 3bis, villa Émile-Bergerat, Neuilly-sur-Seine (Seine).

**India:** Oxford Book and Stationery Co., Scindia House, New Delhi *or* 17 Park Street, Calcutta.

**Japan:** Japan Civil Aviation Promotion Foundation, No. 38 Shiba Kotohira-Cho, Minato-Ku, Tokyo.

**Mexico:** Editorial Hermes S.A., Ignacio Mariscal 41, México 4, D.F.

**Peru:** Representante de la OACI, Oficina Sudamérica, Apartado 4127, Lima.

**Senegal:** Représentant de l'OACI, Bureau Afrique, Boîte postale 2356, Dakar.

**Sweden:** C. E. Fritzes Kungl. Hovbokhandel, Fredsgatan 2, Box 16356, Stockholm 16.

**Thailand:** ICAO Representative, Far East and Pacific Office, P.O. Box 614, Bangkok.

**United Arab Republic:** ICAO Representative, Middle East and Eastern African Office, 16 Hassan Sabri, Zamalek, Cairo.

**United Kingdom:** Her Majesty's Stationery Office, P.O. Box 569, London, S.E. 1.

**International Civil Aviation Organization** (Attention: Distribution Officer), International Aviation Building, 1080 University Street, Montreal 3 (Quebec), Canada.

---

## TABLE OF CONTENTS

| | Page |
|---|---|
| FOREWORD | 3 |
| 1. Introduction | 5 |
| 2. Engine Ingestion Problems | 6 |
| 3. The Effect of Slush on Take-off Performance | 6 |
| 4. Clearance and Prevention of Build-up | 8 |
| 5. Measurement | 8 |
| 6. Reporting and Notification | 9 |
| APPENDIX I.- Estimation of Performance Effects and Influence of Parameters | 10 |
| APPENDIX II.- Methods for Measuring Aeroplane Behaviour in Slush | 20 |
| APPENDIX III.- Airworthiness Requirements Relating to Operations in Slush, published in the United States and the United Kingdom | 23 |

THIS PAGE INTENTIONALLY LEFT BLANK

## FOREWORD

1. At its Fourth Meeting, held in Montreal in October-November 1960, the Airworthiness Committee studied, among other subjects, the effect on aeroplane performance of characteristics of the runway surface. It recognized that the problem posed by the presence of slush or water on runways was an important one. The information available on this subject was not then considered to be sufficient to establish new specifications for inclusion in the PAMC on Aeroplane Performance (Circular 58-AN/53); however, it was considered that such information would be very useful to airworthiness and operations authorities, operators and pilots, for guidance. To this end the Committee developed an appropriate text which the Air Navigation Commission, at the Twenty-ninth Meeting of its Thirty-fifth Session, on 15 December 1960, authorized for issuance as an ICAO Circular. In due course Circular 60-AN/55 - Operational Measures for Dealing with the Problem of Taking off from Slush - or Water-covered Runways - was issued.

2. At its Fifth Meeting, held in Montreal in May-June 1962, the Airworthiness Committee briefly examined, in the light of new information made available, the subject of drag due to slush on runways, and accordingly developed an Addendum No. 1 to Circular 60-AN/55. The Air Navigation Commission, at the Second Meeting of its Forty-first Session on 23 October 1962, approved the issuance of Addendum No. 1 to Circular 60-AN/55.

3. The subject was further studied at the informal meeting of the Members of the Airworthiness Committee, held in London in September 1966, and at the Committee's Seventh Meeting, held in Montreal in November-December 1966, because it was evident that the guidance material currently contained in Circular 60-AN/55 and Addendum No. 1 had been outdated by subsequent knowledge and research. At the Seventh Meeting, an ad hoc Working Group was formed to study and examine fully the performance aspects of the subject.

4. An interim report of this ad hoc Working Group, including a first draft of a revised Circular, was submitted to the Fifth Air Navigation Conference, held in Montreal in November-December 1967, and was the subject of Recommendation 5/33 of that Conference. This recommended that the text be further developed and that consideration be given to including operational measures for dealing with the problem of landing on slush- or water-covered runways.

5. At the Eighth Meeting of the Airworthiness Committee, held in Amsterdam in April-May 1968, a draft revision of the Circular 60-AN/55, prepared by the ad hoc Working Group, was examined and a corrected draft was agreed. As amended, the Eighth Meeting recommended to the Air Navigation Commission the issuance of this revised Circular. The Air Navigation Commission authorized issue of this revised edition of Circular 60-AN/55 at the Eighteenth Meeting of its Fifty-eighth Session on 26 June 1968. It is to be noted that, in so doing, the Air Navigation Commission did not pass judgement on, or endorse, the technical contents recommended by the Airworthiness Committee.

6. In addition to completing action on the operational measures for dealing with the problem of taking off from slush- or water-covered runways, the Eighth Meeting of the Airworthiness Committee took into account the views expressed at the Fifth Air Navigation Conference and considered the operational aspects of the effect on landing performance of such contaminants on runway surface. Here, however, it was agreed that information

on the effect of available braking friction should be included in the Aeroplane Flight Manual rather than in the revised Circular 60-AN/55/2, although it was recognized that at that time practical methods suitable for international standardization were insufficiently developed.

7. States are invited to use the specifications contained in Circular 60-AN/55/2 and to notify ICAO of the extent to which they are being applied. Should any State find it desirable or necessary to adopt any significant variations from the specifications, that State is invited to notify the Organization of these differences.

# PROVISIONAL ACCEPTABLE MEANS OF COMPLIANCE - OPERATIONAL MEASURES FOR DEALING WITH THE PROBLEM OF TAKING OFF FROM SLUSH- OR WATER-COVERED RUNWAYS

*Introductory Note.- Throughout this circular the term "slush" is used to cover the whole range of precipitation densities from that of dry snow to that of free standing water.*

## 1.- INTRODUCTION

1.1 There are a number of problem areas in the operation of civil transport aeroplanes which, although they existed for piston-engined types, have become acute only with the introduction of turbine-engined aeroplanes. Not the least of these is associated with operations from slush-covered runways.

1.2 There are three operational problems which arise when operating from slush-covered runways; first, that relating to take-off where the distance required for take-off is increased due to slush drag; second, that relating chiefly to take-off where slush spray thrown up by the wheels enters engine intakes causing serious loss of thrust or even complete stoppage of the engine, with consequent loss of performance; third, those relating to both take-off and landing where, due to reduced friction between tires and runway, there is reduced directional control and also reduced braking friction causing increased distances required for landing and for abandoned take-off. The purpose of this circular is chiefly to deal with the first of these problems although some mention is made of the second.

1.3 In determining the effects of slush on an aeroplane during take-off, there are a number of aspects of the problem to be considered:

(a) The effect on aeroplane performance due to:

(i) retardation effects on aeroplace wheels running through the slush layer, and

(ii) drag due to impingement on the aeroplane of spray thrown up by the wheels;

(b) The possibility of structural damage due to spray impingement;

(c) The possibility of power loss or system malfunction due to spray ingestion;

(d) The possibility of jammed landing gear due to filling of wheel wells with slush followed by freezing;

(e) The possibility of wing flaps becoming inoperative due to accumulated slush.

1.4 The characteristics of turbine-engined aeroplanes which tend to make the problem more acute than for piston-engined aeroplanes are:

(a) Higher take-off ground speeds mean that the presence of slush on the runway is much more significant from drag and damage considerations;

(b) Increased sensitivity of take-off performance to drag increments due to:

(i) the greater proportion of the take-off distance being spent on the ground, and

(ii) the marked diminution in excess thrust which results from any attempt to lift off at speeds below the normal values;

(c) Lower wing and engine height in relation to aeroplane length increase susceptibility to ingestion and impingement damage;

(d) A tendency to operate from runways of critical length on a higher percentage of occasions.

1.5 The need to minimize ingestion effects and impingement damage will tend to impose upper limits on slush depths, whereas considerations of performance will tend to permit take-off in a range of slush conditions depending on take-off distance available.

1.6 It is the purpose of this circular to collect any currently available data which leads to a more complete understanding of the problem, and to suggest procedures in both the airworthiness and operations fields which will lead to effective control of the risk level associated with take-off from precipitation-covered runways.

## 2.- ENGINE INGESTION PROBLEMS

Considerable attention has been paid to the problem of ingestion of slush during take-off by manufacturers, operators and airworthiness authorities.

The consequence of this activity has been that most recent transport aeroplanes have either been demonstrated to be free of ingestion troubles or operating techniques developed which avoid any serious difficulty.

*Note.- See Appendix III for extracts from U.S. and U.K. Airworthiness Requirements.*

## 3.- THE EFFECT OF SLUSH ON TAKE-OFF PERFORMANCE

3.1 Typical increments to the take-off ground roll of a jet transport aeroplane are given in Table 1.

TABLE 1

| Percentage increase in ground roll | | | |
|---|---|---|---|
| Thrust/Weight Ratio | | 0.3 | 0.2 |
| Slush Depth | 10 mm (0.4 in) | 18 | 22 |
| | 20 mm (0.8 in) | 48 | 64 |

The assumptions made in the estimation of these increments are discussed in Appendix I which indicates a method for estimating effect of slush on take-off performance.

*Note.- While the method of Appendix I allows the estimation of these effects at any slush depth or density, some operators may prefer in view of the difficulties of assessing the values of the depth or density accurately, to calculate the effects for only one or two critical values, for example:*

*Depth: For the limiting depth of slush or water for the aeroplane under consideration; this effect might then be used for all lesser depths.*

*Density: For one density in the dry snow range of possible densities, and one density in the slush/water range of possible densities. In each case, the worst density in the particular density range would have to be determined and used. Owing to the effects of aquaplaning, this might not be the highest density in the range of possible densities.*

3.2 The discussion in Appendix I will illustrate the marked effect that a number of parameters can have on the performance effects of slush. Thus the figures quoted in Table 1 should be treated as a rough guide only.

3.3 Although Appendix I gives an outline of methods which can be used for estimating the effect of slush on take-off performance, operators may have difficulty in obtaining the basic aerodynamic data of their aeroplanes in sufficient detail of enable them to make performance estimates.

In the United States a Federal Aviation Agency Advisory Circular* states that: "the operations manual should include specific instructions showing the gross weight reduction and/or additional runway length required for the conditions described." The United Kingdom British Civil Airworthiness Requirements* specify requirements for the determination and scheduling in the Flight Manual of the effect of precipitation on take-off performance.

Thus, in cases where an aeroplane is manufactured or operated in either the United States or the United Kingdom, it may be possible to obtain suitable information on slush performance effects from the operators or manufacturers in those countries.

* See Appendix III for extracts from U.S. and U.K. Airworthiness Requirements.

3.4 Clearly the most accurate information which can be given for the performance effect of slush is that which has been accurately measured on the particular aeroplane. Appendix II gives an outline of test methods which have been used for this purpose.

## 4.- CLEARANCE AND PREVENTION OF BUILD-UP*

4.1 The goal of aerodrome authorities should be the complete removal of precipitation from runways. To some extent a build-up of precipitation can be "designed out" by adopting appropriate runway construction techniques such as grooving, porous top surface, adequate crossfall, good drainage, etc. Where this has not been done or where the rate of precipitation is so high that some accumulation still occurs, rapid clearance action should be taken, particularly in the case of snow or slush. Since it is now thought that aquaplaning and hence braking and control problems can occur in slush or water depths as low as 1 mm (0.04 in), it is desirable that aerodrome equipment should be capable of clearing the runway down to black top. To achieve this, speed is essential since it is particularly important to prevent snow becoming impacted by traffic. Consequently, there appears to be a need for equipment that can move rapidly in sufficient numbers to clear an adequate width of runway in one operation. The equipment should be in action during the snowfall as frequently as traffic permits.

4.2 Clearance should be carried out over the complete length of the runway to a width of at least 30 m (100 feet) for runways up to 2 100 m (7 000 feet) long in conditions of favourable winds and visibilities. For longer runways and less favourable conditions the clearance width should be at least 36 m (120 feet). In both cases, the area of clearance should be increased to 45 m (150 feet) as soon as possible after initial clearance.

4.3 Experience has shown that the most effective equipment for clearing down to the runway surface is that having a brush in combination with a blower. Some research into the use of a mechanical squeegee is being undertaken and this could prove useful for clearing small depths of water or wet slush.

4.4 The clearance procedure must not result in any significant walls at the side of the swept area in view of the hazard to aeroplanes which this will create if the surface is slippery, and particularly when crosswinds exist. Aerodrome authorities should be provided with advice on the maximum acceptable heights of snow banks which may be permitted for the most limiting type using the airfield.

## 5.- MEASUREMENT*

5.1 It may be many years before the ideal of completely cleared runways is achieved in all States. Those States who have not the facilities to achieve cleared runways will need to provide a measuring and reporting service to enable compliance with Chapter 5 of Annex 6. This calls for account to be taken of the effects of snow, slush, ice and water on aeroplane performance.

---

* It should be noted in respect of both paragraphs 4 and 5 that, at the time of developing this text (1968), an ICAO Study Group on Snow, Slush, Ice and Water on Aerodromes was in process of developing detailed advice on measurement and reporting precipitation on runways. This work included descriptions of the various measuring devices available and recommended reporting procedures.

5.2 In the case of snow and slush, operators will require information on depth and density of the precipitation. At present, measurement of snow and slush depth is largely made by using a calibrated dip stick and a subjective assessment of density is also given. Because of variation in depth along runways, it is usual to take measurements at about 300 m (1 000 feet) intervals along the runway on either side of the centre line. A more sophisticated equipment, which has been undergoing operational trials, provides a mean drag figure for the usable length of runway. To overcome variations due to depth, density and properties of the precipitation, the equipment has been calibrated to indicate the equivalent depth of water so as to provide measurements in terms of a medium of known density and physical properties. It is hoped to develop a further refinement which will provide the actual depth of the deposit and so enable a realistic density to be determined. At present this information is only available by subjective assessment.

5.3 In the case of water, some estimate of depth will be required by operators. This information should also take account of significant ponding on otherwise dry runways.

5.4 For water depth measurement, trials are being conducted in one State with precise depth gauges let into the runway surface. Depths as low as 1 mm (0.04 in) can be recorded with this device which automatically reports and records in the control tower. Where precise methods of water depth measurement are not used, a subjective assessment of the degree of wetness on the runway should be provided, together with general advice on precipitation rates, i.e., heavy rain, drizzle, etc.

5.5 Ice depth is not measured since the effects on performance of such contamination does not vary with depth.

## 6.- REPORTING AND NOTIFICATION

6.1 In the EUM Region of ICAO, a procedure* has been developed and accepted by the States concerned for the reporting of runway state and significant changes thereto. Notification is made by SNOWTAM and the action required is described in Annex 15. It is not normal for rainfall, i.e., water depth information, to be included in such report.

6.2 It is desirable that the depth of snow or slush should be reported. The report should be indicative of the situation on the runway as a whole.

*Note.- When the influence of density on take-off performance is known (see Appendix I, Figure 5A), aerodrome authorities are encouraged to report density, even if only in subjective terms.*

6.3 The presence of ice or ice patches should be reported.

6.4 Information on water depth should be given in subjective terms if actual depth measurement is not available, i.e., damp, very wet, etc. Ponding where present should also be notified. In order to give pilots some indication of the likely change of runway state, broad information on rainfall rate or expected rate should be provided.

---

* This procedure has now been incorporated in Annex 15 and as such applies on a world-wide basis.

## APPENDIX I

### ESTIMATION OF PERFORMANCE EFFECTS AND INFLUENCE OF PARAMETERS

It is now well established that the drag due to slush may be expressed by the relationship[1/]:

$$D_S = C_{DS} \frac{\rho_w \sigma_s}{2} V_g^2 d_s b$$

where

$D_S$ = total aeroplane retardation force due to slush

$\rho_w$ = density of water

$\sigma_s$ = relative density of slush

$V_g$ = aeroplane ground speed

$d_s$ = slush depth

$b$ = chord length of tire cross-section at slush surface

$C_{DS}$ = slush drag coefficient.

The product $d_s \sigma_s$ is frequently termed the "water equivalent depth" (W.E.D.) of slush.

The chord length of tire cross-section at the slush surface may be expressed approximately[1/] as:

$$b = 2w \left[ \frac{\delta + d_s}{w} - \left( \frac{\delta + d_s}{w} \right)^2 \right]^{\frac{1}{2}}$$

where

$w$ = maximum tire width

$\delta$ = vertical tire deflection.

The slush drag coefficient of an isolated single aeroplane wheel has been established by experiment[1/] in both slush and water as close to 0.75. There is some evidence that in dry snow there is a significant reduction in drag coefficient due to the fact that the wheel does not remove all the snow from its path,as is the case for slush and water.

The presence of an undercarriage leg or additional wheels considerably modifies the isolated single wheel drag coefficient[2/]. For example, a dual-tandem (four-wheel-bogie) wheel arrangement enjoys reductions in drag from the favourable interference effect of side-by-side wheels and from the slush clearing effect of the leading wheels but suffers considerable losses due to spray impingement drag on the undercarriage leg.

Drag is generated by spray impingement on areas other than the undercarriage leg. Full scale tests have shown that the spray from nose wheels impinging on the airframe, notably the flaps, can contribute a significant part of the total retarding force on the aeroplane[4/]. Where aeroplane geometry poses a spray impingement problem, some relief may be obtained by spray deflection using "chined" tires or spray drag alleviators[2/].

The assumption that slush drag is proportional to (ground speed)$^2$ is valid until the aquaplaning speed is approached when the wheels begin to rise to near the top of the slush layer, supported by hydrodynamic forces[5]. The aquaplaning speed is a function of a number of slush, tire and runway surface parameters but to a first approximation may be expressed, for water,[5] by:

$$V_p = 34\sqrt{p}$$

where $V_p$ is aquaplaning speed in kt;

$p$ is tire inflation pressure in $kgcm^{-2}$;

or: $$V_p = 9\sqrt{p}$$

where $p$ is tire inflation pressure in psi.

If slush may be treated as an incompressible fluid, it is reasonable to assume that the aquaplaning speed in slush is given by:

$$V_p = 34\sqrt{\frac{p}{\sigma_s}}$$

where $V_p$ is aquaplaning speed in kt;

$p$ is tire inflation pressure in $kgcm^{-2}$;

$\sigma_s$ is relative density of slush;

or: $$V_p = 9\sqrt{\frac{p}{\sigma_s}}$$

where $p$ is tire inflation pressure in psi,

but test confirmation of this relationship is incomplete.

The onset of aquaplaning of main or nose wheels is accompanied by the start of a progressive reduction in the associated slush drag[6] [7]. This reduction is approximately proportional to (ground speed)$^2$. The small amount of full-scale testing at speeds well above the aquaplaning speed suggests that the slush drag coefficient reduces to zero at about 160% to 180% of the aquaplaning speed[3] [6] although the controlling parameters are not well understood.

A somewhat idealized representation[6] of the slush drag or speed relationship for a typical large jet transport aeroplane is shown in Figs. 1A and 1B.

FIGURE 1A

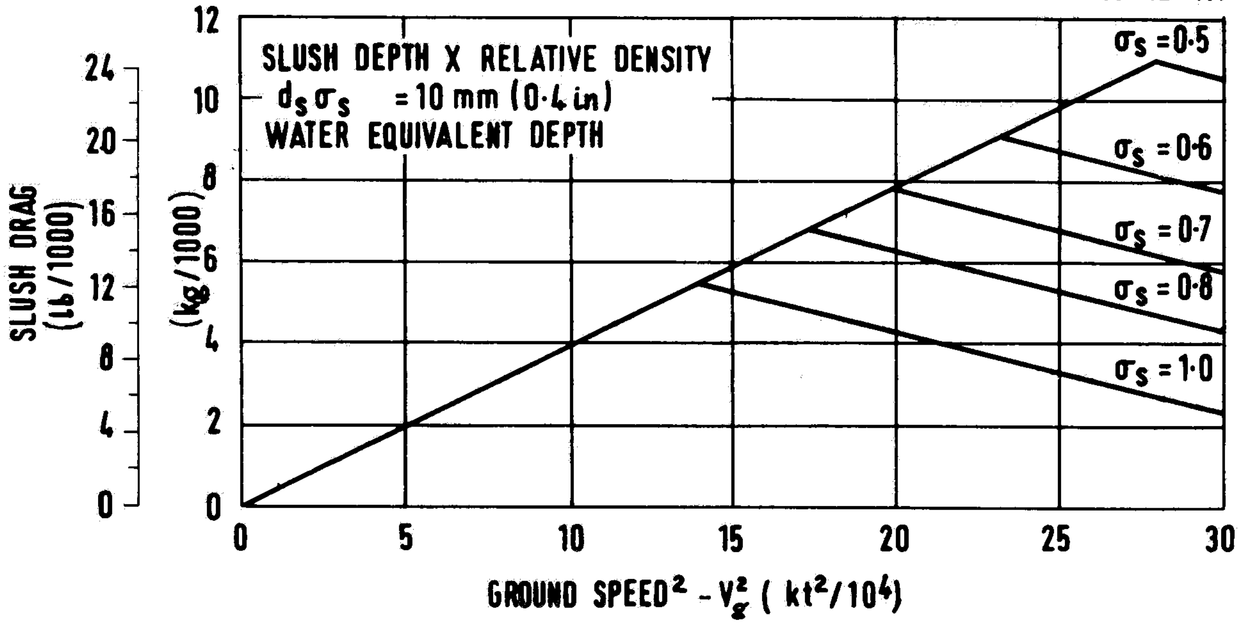
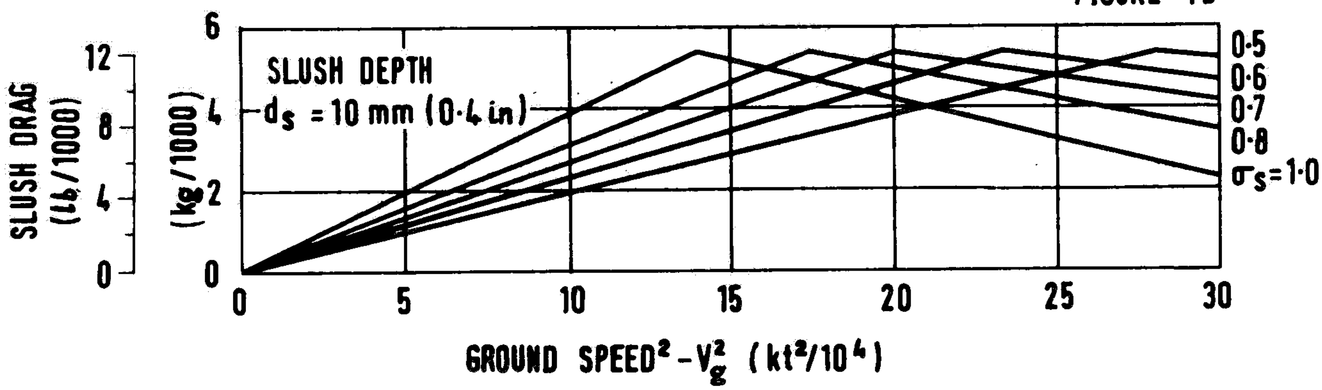



FIGURE 1B



In order to illustrate the effects on take-off performance of a number of aeroplane and slush parameters, estimates of take-off ground roll for the typical jet transport aeroplane of Figs 1A and 1B have been made for ISA, sea-level, zero wind and level runway conditions. Other assumptions are as follows:

1) Net accelerating force in the absence of slush approximated by:

$$T\text{-}D = 27\ 200 - 0.388\ V_g^2$$

where T and D are thrust and drag, respectively, in kg;

$V_g$ is aeroplane ground speed in kt;

or: $$T\text{-}D = 60\ 000 - 0.854\ V_g^2$$

where T and D are thrust and drag, respectively, in lb.

2) Lift-off speed:

$$V_{LOF} = 161\sqrt{\frac{W}{136\ 000}}$$

where $V_{LOF}$ is lift-off speed in kt;

W is aeroplane all-up weight in kg;

or: $$V_{LOF} = 161\sqrt{\frac{W}{300\ 000}}$$

where W is aeroplane all-up weight in lb.

3) Aquaplaning speed:

$$V_p = \frac{118.5}{\sqrt{\sigma_s}}$$

where $V_p$ is aquaplaning speed in kt;

$\sigma_s$ is relative density of slush.

4) Maximum aeroplane all-up weight:

$$W_{max} = 136\ 000\ \text{kg}$$

or: $$W_{max} = 300\ 000\ \text{lb.}$$

Ground roll distances to lift-off have been estimated by step-by-step integration of:

$$\Delta S_g = \sum_{0}^{V_{LOF}} \frac{W\Delta V^2}{2g(T-D-D_s)}$$

The extent to which aeroplane take-off performance is modified by the presence of slush is a function of four major parameters:

1) The thrust/weight ratio of the aeroplane.

2) The aquaplaning speed of the tires in relation to the lift-off speed.

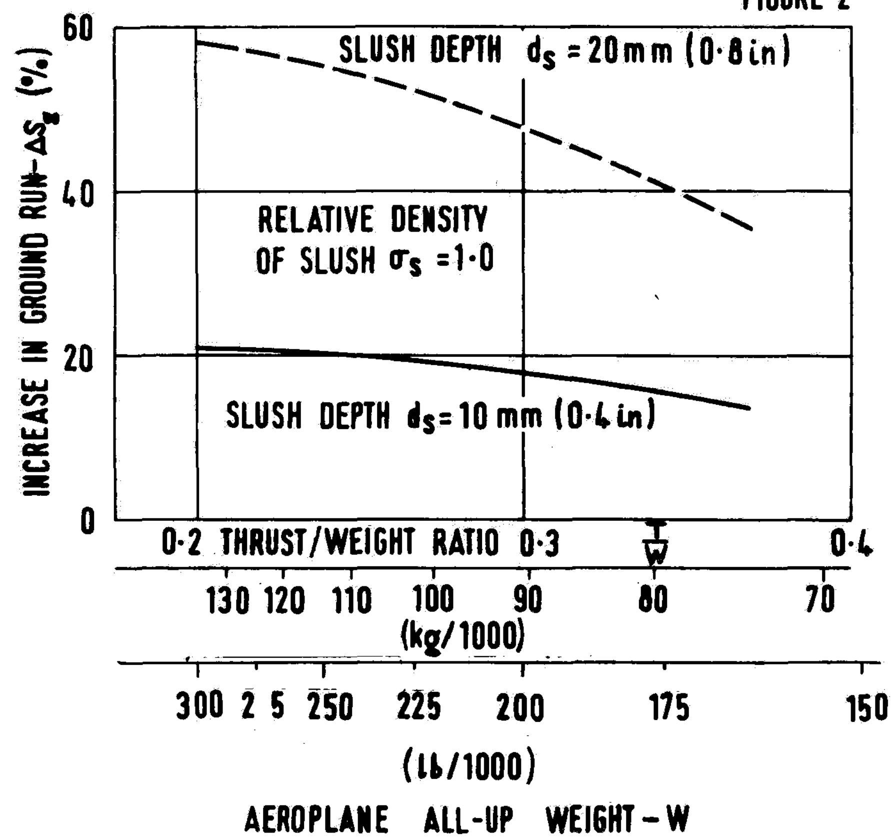
3) Slush depth.

4) Slush density.

Thrust/Weight Ratio

Figure 2 illustrates that an increasing thrust/weight ratio, achieved in this example by reducing the aeroplane all-up weight, leads to a reduction in ground roll increment associated with given slush condition. This effect is particularly marked at the greater slush depths where take-off performance is becoming marginal.

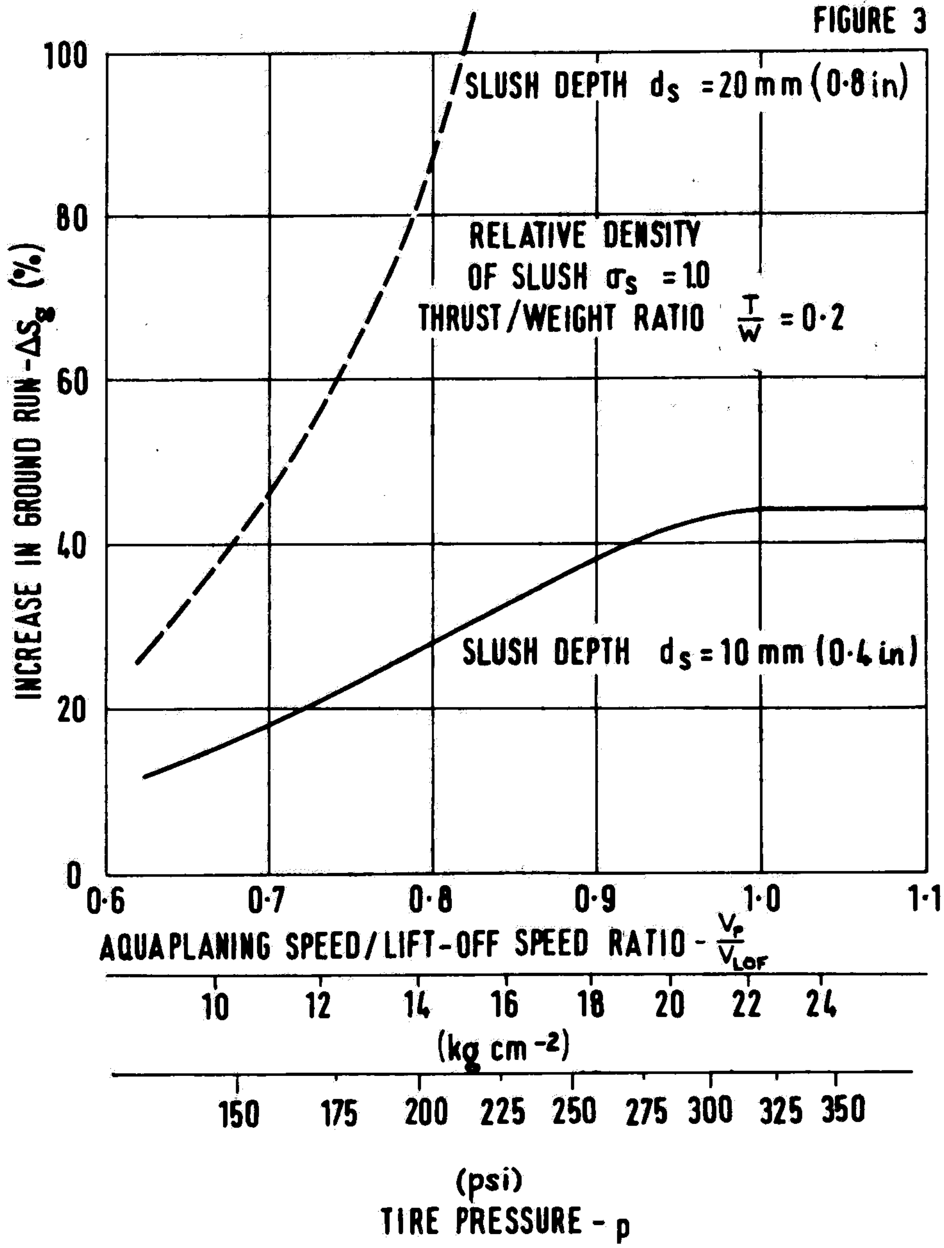
FIGURE 2



Aquaplaning Speed

Peak slush drag occurs at or near aquaplaning speed and any displacement of this peak towards higher speeds and hence to areas of lower excess thrust has an adverse effect on the performance penalty associated with a given slush condition. Figure 3 illustrates the marked rise in ground roll increment resulting from a displacement of aquaplaning speed towards lift-off speed. It is evident that relatively high tire pressures and hence aquaplaning speeds severely curtail an aeroplane's ability to operate satisfactorily in significant quantities of slush.

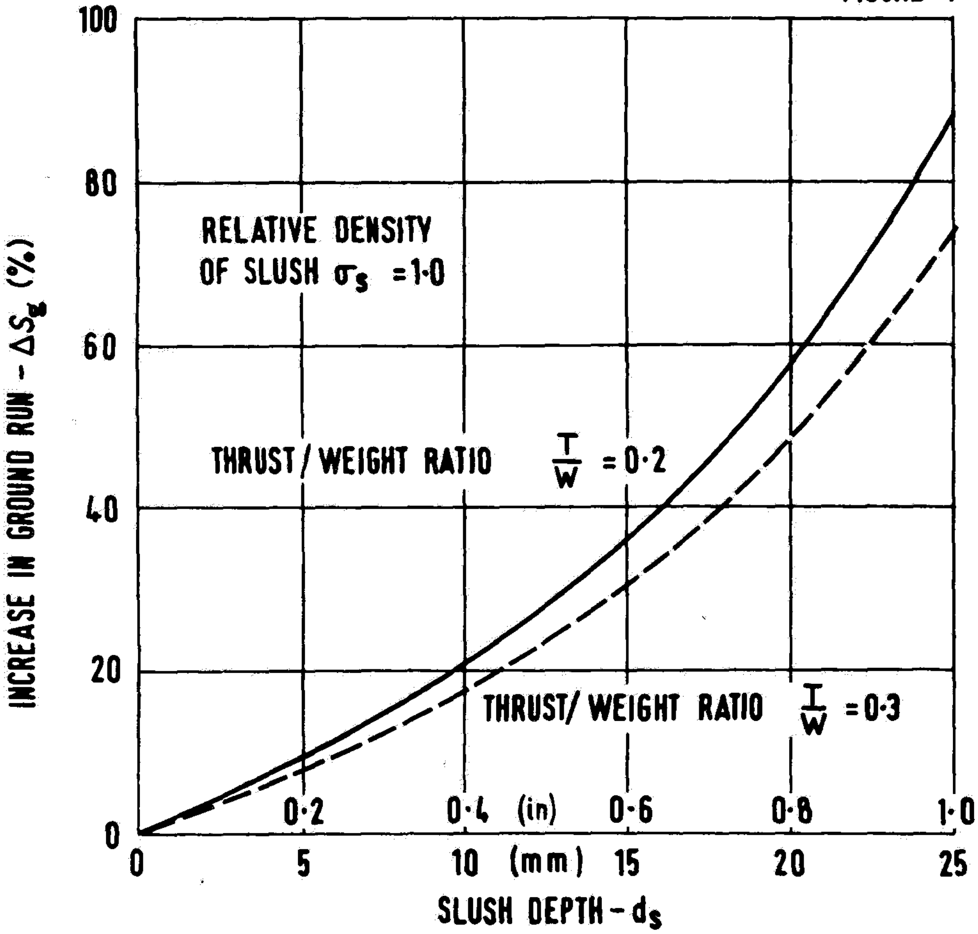
FIGURE 3



Slush Depth

Figure 4 illustrates the high sensitivity of ground roll performance to slush depth which occurs at significant slush depths. Even if sufficient runway is available to permit a particular operation with a 60% ground roll increment, a sensitivity of 5% distance per 1 mm (0.04 in) depth poses severe measurement problems.

FIGURE 4



Slush Density

Figure 5A shows that the ground roll increment associated with a particular slush depth is relatively insensitive to slush density over the usual range encountered in operation. It is important to note that the greatest performance penalty is not in fact associated with the highest value of slush density.

If the measure of slush depth is "water equivalent depth" any reduction in slush density is accompanied by an increase in actual depth. The sharp rise in performance penalty as slush density reduces from 1.0 to 0.6 is due to a progressive delay in the onset of aquaplaning and the achievement of higher and higher peak drags. (See Fig. 1A). No further penalty occurs at slush densities below those for which $V_p = V_{LOF}$ ($\sigma_s = 0.54$ in this example).

FIGURE 5A

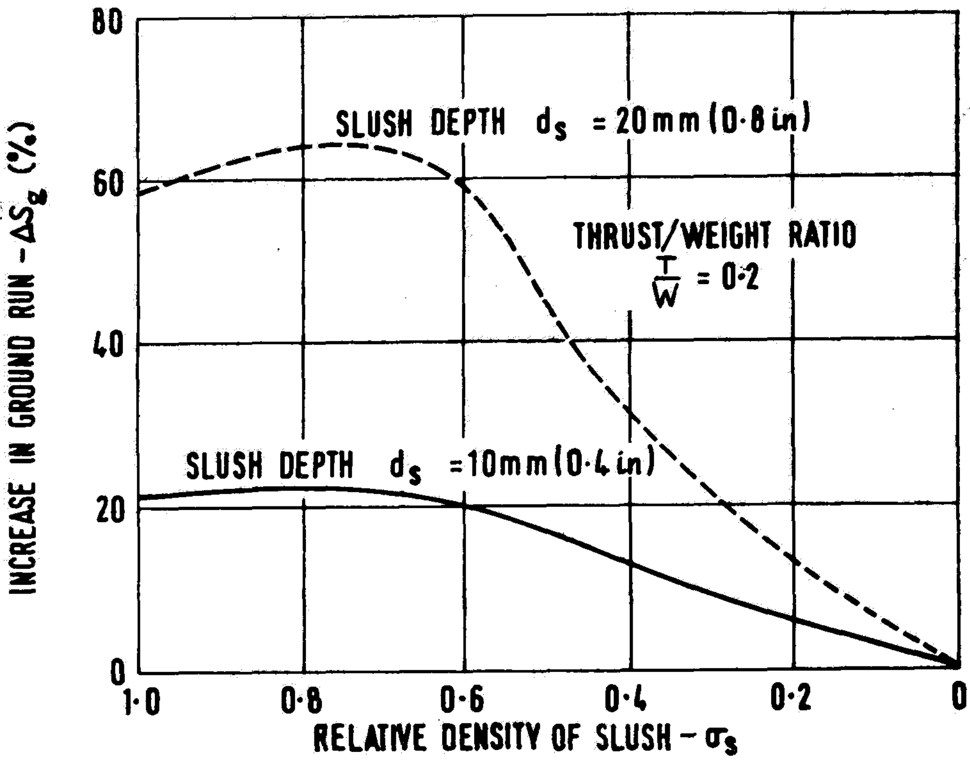
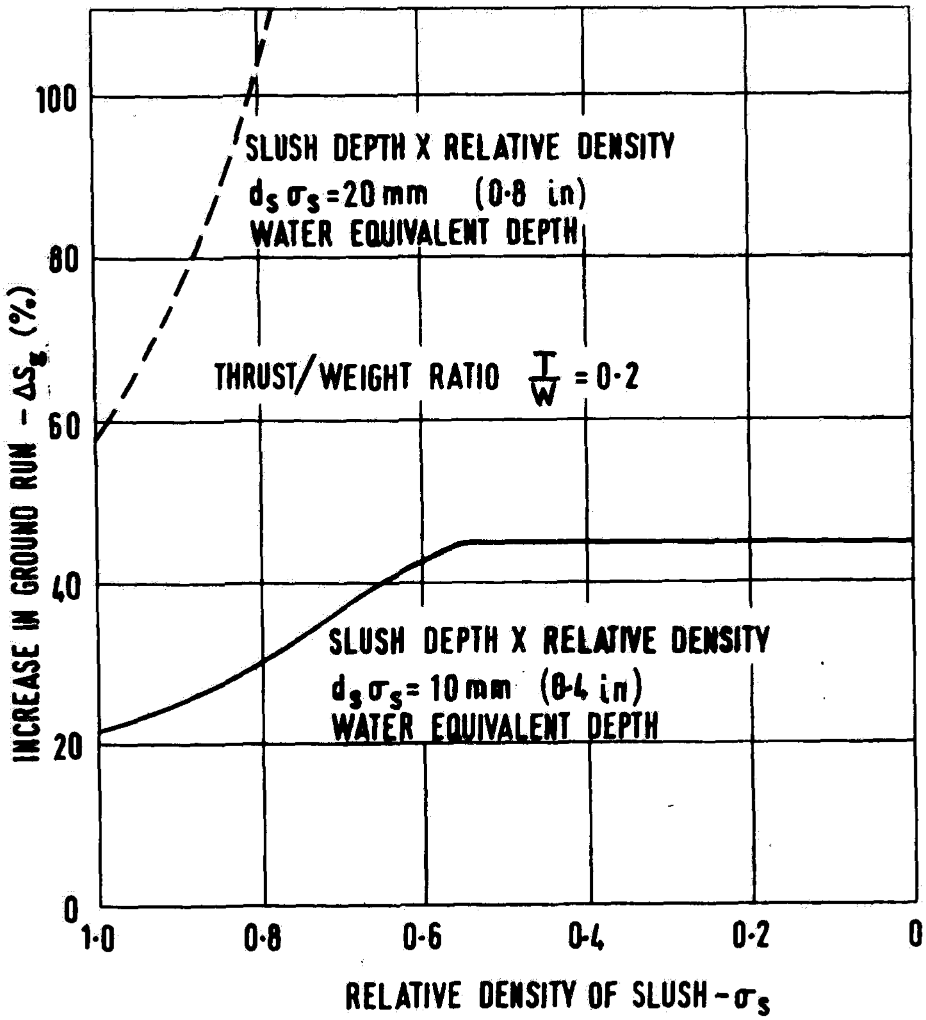


FIGURE 5B




The examples of the variation of performance penalty with thrust/weight ratio, aquaplaning speed, slush depth and density given in Figs 1 to 5 inclusive are felt to be not untypical of modern jet transport aeroplanes but it is not intended that the numerical results should be applicable to any particular aeroplane nor should it be assumed that some other parameter may not be significant in particular cases.

## REFERENCES

The following reports have been selected from the wide bibliography on slush as illustrating particular aspects of the slush drag problem:


1. Horne, Walter B.; Joyner, Upshur T.; Leland, Trafford J.W.: Studies of the Retardation Force Developed on an Aircraft Tire Rolling in Slush or Water. NASA TN D-552, 1960.

2. Dreher, Robert C.; Horne, Walter B.: Ground-Run Tests with a Bogie Landing Gear in Water and Slush. NASA TN D-3515, 1966.

3. Horne, Walter B.; Leland, Trafford J.W.: Prediction of Slush Drag on Aircraft Performance. FAA & NASA Joint Technical Conference on Slush Drag and Braking Problems, 1961.

4. Howell, Wayne D.; Sommers, Daniel E.: Slush Spray Patterns and Slush Damage. FAA & NASA Joint Technical Conference on Slush Drag and Braking Problems, 1961.

5. Horne, Walter B.; Dreher, Robert C.: Phenomena of Pneumatic Tire Hydroplaning. NASA TN D-2056, 1963.

6. Maltby, R.L.; Slatter, N.V.; Illingworth, J.K.B.: Some Measurements of the Drag due to Slush on an Ambassador Aircraft. R.A.E. Tech. Note. Aero. 2968, 1964.

7. Klueg, Eugene P.: Effect of Slush on Aircraft Drag and Wheel Rotation. FAA & NASA Joint Technical Conference on Slush Drag and Braking Problems, 1961.

## APPENDIX II

### METHODS FOR MEASURING AEROPLANE BEHAVIOUR IN SLUSH

The primary function of slush testing is to assess slush drag, impingement damage and powerplant ingestion characteristics of aeroplanes.

The apparatus and techniques employed by R.A.E. in their investigations on the Ambassador and other aeroplanes are well documented and some experience has been gained by a number of manufacturers during prototype testing, covering both slush drag and ingestion problems. This experience has allowed a broad specification of desirable but not necessarily essential facilities and procedures to be drawn up as follows:

(a) Test Facility

Although satisfactory results have been obtained using troughs of only 45 m (150 feet) length, increasing aeroplane take-off speeds and the need to ensure a stabilised spray pattern suggest that a minimum trough length of 90 m (300 feet) should be provided.

In order to minimize the effort required to conduct routine trials, the ideal procedure is to set up a permanent facility to accommodate current aeroplane types on a runway not less than 3 000 m (10 000 feet) long with the slush ponds not nearer than 1 200 m (4 000 feet) from either end. A runway width of 90 m (300 feet) is desirable with the slush ponds positioned to one side of the runway to leave sufficient unobstructed width for normal flying operations.

It is, of course, necessary for the basis of the troughs to be level to a fairly high degree of accuracy; ± 1.5 mm (± 1/16 in) has been achieved using fine grain cement.

Ponds for main and nose wheels are desirable to allow the separate study of main and nose wheel effects. Ponds should be as wide as possible to minimize spray interference effects from the pond walls and to allow the maximum number of aeroplane types to use the facility.

The containment of the water or slush by flexible rubber walls of inverted 'T' section bonded to the levelled runway surface is satisfactory. Additional cross 'dams' are necessary to minimize variations in water depth due to wind.

(b) Test Media

Water allows the easiest handling and valuable testing can be carried out using this medium. Artificial slush manufactured from crushed ice, similar to that employed by NASA has been used successfully although the manpower requirement is considerably greater than for water. Ambient temperatures of around 10°C have proved most satisfactory. Higher temperatures result in too rapid melting and lower, non-freezing, temperatures resulted in non-uniform consistency during melting.

Investigations are in hand on the use of snow-making machines to provide artificial slush. This should provide a medium of more uniform consistency but results are not yet available.

(c) Instrumentation

The most satisfactory method of arriving at the drag force on the aeroplane during its passage through water or artificial slush is that first employed by NASA, namely to compare the aeroplane longitudinal acceleration before and after passing, with that during passage, through the trough. The parameters which must be recorded are aeroplane ground speed, pitch attitude and longitudinal acceleration. Measurements of pitch attitude are necessary to allow correction of longitudinal acceleration for changes in pitch attitude as the aeroplane enters and leaves the troughs. The most effective means of measuring aeroplane speed is by kine-theodolite. Longitudinal acceleration and pitch attitude are best measured by internal recording instrumentation.

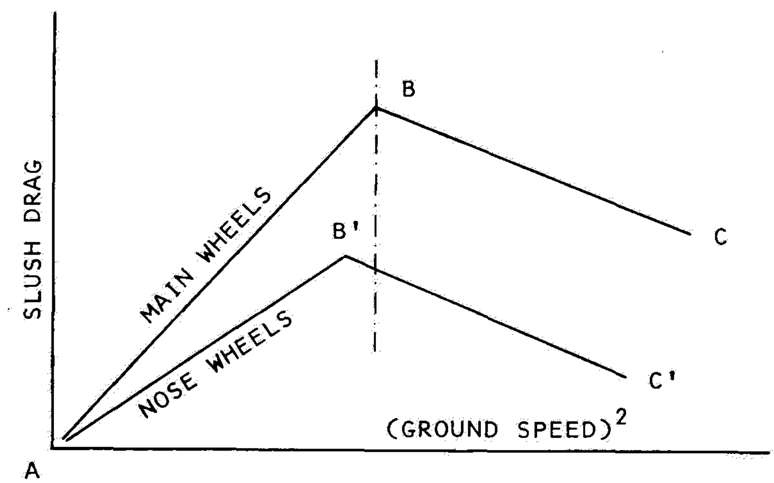
To allow a study of spray patterns, fairly generous cine-camera coverage is required. Records from the side, front and overhead have been found desirable to build up a full understanding of the spray pattern. Cameras mounted on the aeroplane have been proved less useful to date because of the view being obscured by spray. A polaroid plate camera arranged to provide three-quarter front views of the aeroplane passing through the trough has been used to provide valuable information to the test controller with the minimum of delay.

Continuous internal records of all relevant parameters associated with power plant and other vulnerable systems are desirable for ingestion tests.

(d) Test Technique

(i) Drag

NASA and R.A.E.work has suggested that, for a given aeroplane configuration and slush condition, the drag due to slush may be closely represented as follows:



Thus the establishment of the lines AB (AB') and BC (B'C') by a series of test measurements over a range of speeds provides basic data on the slush drag vs. speed relationship below and above aquaplaning speed and closely fixes the aquaplaning speed itself. Tests in a range of slush depths and densities are necessary to establish the relationship between these parameters and slush drag and aquaplaning speed.

(ii) Ingestion

Tests to study ingestion and drag effects are sometimes carried out separately since the optimum techniques for the two types of test may differ.

To ensure that an aeroplane is free from ingestion problems or alternatively to establish the conditions in which ingestion becomes unacceptable, it is frequently necessary for the aeroplane to pass through a selection of slush conditions at a range of speeds up to the maximum to be used operationally, unless a marked change in spray pattern associated with the onset of aquaplaning makes further testing unnecessary.

Ingestion problems are more usually associated with spray from the nose wheel rather than the main wheels. Auxiliary air intakes and systems sited in undercarriage bays have posed ingestion problems during past testing.

(iii) Damage

An assessment of actual and potential structural damage due to spray impingement is usually possible during drag and ingestion tests.

## REFERENCES

1. Charles M. Middlesworth; John F. Marcy; Daniel E. Sommers; Don W. Conley: Experimental Techniques. FAA & NASA Joint Technical Conference on Slush Drag and Braking Problems, 1961.

2. N.V. Slatter: R.A.E. A Testing Technique for the Effects on Aircraft of Water or Slush on Runways, Tech. Report No. 65175. 1965.

# APPENDIX III

## AIRWORTHINESS REQUIREMENTS RELATING TO OPERATIONS IN SLUSH PUBLISHED IN THE UNITED STATES AND THE UNITED KINGDOM

A. Extracts from Federal Aviation Agency Advisory Circular No. AC91-6

Subject: Water, Slush and Snow on the Runway.

"3. FAA GUIDELINES

Based on the available information, the following guidelines are basically sound:

(a) Take-offs should not be attempted when standing water, slush or wet snow greater than 12.5 mm (0.5 in) in depth covers an appreciable part of the runway.

(b) Since SR-422 series regulations are predicated on clean, dry runways, certain correction factors should be applied to the take-off data when operating in wet snow, slush or standing water in depths up to 12.5 mm (0.5 in).

(d) The operations manual of the air carrier and commercial operator or other appropriate documents for general aviation aircraft should include specific instructions for each type of turbo-jet aircraft showing the gross weight reduction and/or additional runway length required for the conditions described. These instructions should clearly outline details of the methods to be used in determining runway conditions as closely as possible to the planned departure time and this information should include the method by which the condition of the runway is determined."

Extract from Federal Aviation Regulation No. 25

"25.1091. Air Induction

(d) For turbine engine powered airplanes -

(2) The air inlet ducts must be located or protected so as to minimise the ingestion of foreign matter during take-off, landing, and taxiing."

B. Extract from British Civil Airworthiness Requirements Section D

"Chapter D2-2. Appendix

1.6.3 Where certification for take-off from precipitation-covered runways is sought, the Take-off Run Required and Take-off Distance Required appropriate to these conditions should be determined and scheduled in accordance with D2-3, 4.1.1. The data should cover a range of relative precipitation densities from 0.2 to 1.0.

*Notes.- (1) Compliance with D2-7, 3.3 and D5-5, 1.3.1 will also have to be shown.*

*(2) The Flight Manual will state whether or not take-off from precipitation-covered runways is permissible.*

*(3) Any special aeroplane handling techniques necessary to ensure compliance should still comply with D2-2, 6.4.*

*(4) It will not usually be acceptable for data obtained by means of tests in water or other high density precipitation to be extrapolated to a precipitation depth in excess of 50 mm (2 in); e.g., for depths of dry snow greater than 50 mm (2 in) direct evidence of the performance will be required.*

*(5) The data may be expressed in terms of equivalent depth of water provided that the favourable effects of aquaplaning are not assumed to occur below the aquaplaning speed for the lowest density of slush for which data are available.*

*(6) Acceptable methods for simulating precipitation-covered runways should be agreed with the Board.*

"Chapter D2-3

4.1.1 Precipitation on runways. The Take-off Run Required and Take-off Distance Required appropriate to take-off from precipitation-covered runways shall be the all-power-units-operating Take-off Run Required and the all-power-units-operating Take-off Distance Required respectively appropriate to the precipitation condition, and shall be determined in accordance with 5(a) and 6(a).

"Chapter D2-7

3.3 Precipitation on runways. Where certification for take-off from precipitation-covered runways is sought, (see D2-2, App. 1.6.3) a technique for such take-offs, compatible with D5-5, 1.3.1, shall be established. It shall be demonstrated that the technique is such that when the aeroplane is taking off in precipitation depths up to the maximum for which take-off data are to be scheduled, there is -

(a) no damage to parts of the aeroplane such as would adversely affect airworthiness, and

(b) no accumulation of precipitation on or in parts of the aeroplane which could cause immediate or subsequent hazard, e.g., loss of control or inability to change configuration, and subsequent ingestion by the power-units of hazardous quantities of accumulated slush which become detached from the aeroplane.

*Note.- Any special aeroplane handling techniques necessary to ensure compliance with this requirement should still comply with D2-2, 6.4.*

"Chapter D5-5

1.3.1 Take-off from precipitation-covered runways. Except where it is obvious, by inspection or other means, that precipitation on the runway would not enter engine intakes during the take-off run, compliance shall be shown with the requirements of (a) or (b) as appropriate.

(a) Aeroplane certificated for take-off from precipitation-covered runways. It shall be demonstrated that when the aeroplane is taking off and traverses areas of precipitation up to whichever is the greater of 19 mm (0.75 in) depth or the precipitation depth for which take-off data are to be scheduled, the power-units operate satisfactorily without unacceptable loss of power at all aeroplane speeds up to that at which the transition to climbing flight is completed and in the attitudes likely to be used in this speed range. (See also D2-2, App. 1.6.3) Compliance with this requirement may be shown either by means of complete take-offs in the specified precipitation conditions or by means of a series of demonstrations in areas of precipitation, the length of which is agreed by the Board to be sufficient both to determine the effects on aeroplane performance and on engine behaviour and response, and to establish the stabilised spray pattern.

*Note.- Any special aeroplane handling techniques necessary to ensure compliance with this requirement should still comply with D2-2, 6.4.*

(b) Aeroplane not certificated for take-off from precipitation-covered runways. It shall be demonstrated that when the aeroplane is taking off and traverses areas of precipitation up to 19 mm (0.75 in) in depth and not less than 90 m (300 feet) in length in the direction of take-off, the power-units operate satisfactorily without unacceptable loss of power at all speeds up to that at which the transition to climbing flight is completed and in all attitudes likely to be used in the specified speed range.

*Notes.- (1) The Board should be consulted where there is difficulty in meeting this requirement, in which case the Board will agree with the Applicant suitable operational limitations to ensure satisfactory operation from a runway on which there are areas of slush or water, even though the runway is nominally clear.*

*(2) An aeroplane may be accepted as complying with this requirement even if the possibility of serious power reduction is found to exist in specific circumstances; for example, where the possibility of power reduction arises only at a point from which a take-off could safely be abandoned (even in adverse braking conditions) and no unacceptable damage is caused to the power-units."*

- END -

# ICAO TECHNICAL PUBLICATIONS

*The following summary gives the status, and also describes in general terms the contents of the various series of technical publications issued by the International Civil Aviation Organization. It does not include specialized publications that do not fall specifically within one of the series, such as the* ICAO Aeronautical Chart Catalogue *or the* Meteorological Tables for International Air Navigation.

*INTERNATIONAL STANDARDS AND RECOMMENDED PRACTICES* are adopted by the Council in accordance with Articles 54, 37 and 90 of the Convention on International Civil Aviation and are designated, for convenience, as Annexes to the Convention. The uniform application by Contracting States of the specifications comprised in the International Standards is recognized as necessary for the safety or regularity of international air navigation while the uniform application of the specifications in the Recommended Practices is regarded as desirable in the interest of safety, regularity or efficiency of international air navigation. Knowledge of any differences between the national regulations or practices of a State and those established by an International Standard is essential to the safety or regularity of international air navigation. In the event of non-compliance with an International Standard, a State has, in fact, an obligation, under Article 38 of the Convention, to notify the Council of any differences. Knowledge of differences from Recommended Practices may also be important for the safety of air navigation and, although the Convention does not impose any obligation with regard thereto, the Council has invited Contracting States to notify such differences in addition to those relating to International Standards.

*PROCEDURES FOR AIR NAVIGATION SERVICES* (PANS) are approved by the Council for world-wide application. They comprise, for the most part, operating procedures regarded as not yet having attained a sufficient degree of maturity for adoption as International Standards and Recommended Practices, as well as material of a more permanent character which is considered too detailed for incorporation in an Annex, or is susceptible to frequent amendment, for which the processes of the Convention would be too cumbersome. As in the case of Recommended Practices, the Council has invited Contracting States to notify any differences between their national practices and the PANS when the knowledge of such differences is important for the safety of air navigation.

*REGIONAL SUPPLEMENTARY PROCEDURES* (SUPPS) have a status similar to that of PANS in that they are approved by the Council, but only for application in the respective regions. They are prepared in consolidated form, since certain of the procedures apply to overlapping regions or are common to two or more regions.

---

*The following publications are prepared by authority of the Secretary General in accordance with the principles and policies approved by the Council.*

*ICAO FIELD MANUALS* derive their status from the International Standards, Recommended Practices and PANS from which they are compiled. They are prepared primarily for the use of personnel engaged in operations in the field, as a service to those Contracting States who do not find it practicable, for various reasons, to prepare them for their own use.

*TECHNICAL MANUALS* provide guidance and information in amplification of the International Standards, Recommended Practices and PANS, the implementation of which they are designed to facilitate.

*AIR NAVIGATION PLANS* detail requirements for facilities and services for international air navigation in the respective ICAO Air Navigation Regions. They are prepared on the authority of the Secretary General on the basis of recommendations of regional air navigation meetings and of the Council action thereon. The plans are amended periodically to reflect changes in requirements and in the status of implementation of the recommended facilities and services.

*ICAO CIRCULARS* make available specialized information of interest to Contracting States. This includes studies on technical subjects as well as texts of Provisional Acceptable Means of Compliance.

PRICE: U.S. $0.50
(or equivalent in other currencies)