Compacted snow above OAT of -15 °C/5 °F	0 (see Note 4)		No	Yes	7.3, 7.4
Dry snow over compacted snow	More than 10 up to 130	0.2	Yes	Yes	7.2, 7.3, 7.4
Wet snow over compacted snow (see Note 3)	More than 5 up to 30	0.5	Yes	Yes	7.1, 7.3, 7.4
Ice (cold & dry)	0 (see Note 4)		No	Yes	7.3, 7.4
Slippery wet	0 (see Note 4)		No	Yes	7.3, 7.4
Specially prepared winter runway (see Note 5)	0 (see Note 4)		No	Yes	7.3.4, 7.4

Table 1

Note 1: Runways with water depths or slush depths or snow depths of 3 mm or less are considered wet, for which this AMC 25.1591 is not applicable.

Note 2: Contaminant drag may be ignored.

Note 3: For conservatism, the same landing gear displacement and impingement drag methodology is used for wet snow as for slush.

Note 4: Where depths are given as zero, it is assumed that the aeroplane is rolling on the surface of the contaminant.

Note 5: No default model is provided for specially prepared winter runways in this AMC. Such runway surfaces are specific, and their treatment may be of variable effectiveness. The competent authority of the State of operator should approve the related procedures and methods.

5.2 Other Contaminants

Table 1 lists the contaminants commonly found. It can be seen that the complete range of conditions or specific gravities has not been covered. Applicants may wish to consider other, less likely, contaminants in which case such contaminants should be defined in a manner suitable for using the resulting performance data in aeroplane operations.

6.0 Derivation of Performance Information

6.1 General Conditions

Take-off performance information for contaminated runways should be determined in accordance with the assumptions given in paragraph 7.0.

Where performance information for different contaminants are similar, the most critical may be used to represent all conditions.

This AMC does not set out to provide a complete technical analytical process but rather to indicate the elements that should be addressed. Where doubt exists with regard to the accuracy of the methodology or the penalties derived, consideration should be given to validation by the use of actual aeroplane tests or other direct experimental measurements.

6.2 Take-off on a Contaminated Runway

6.2.1 Except as modified by the effects of contaminant as derived below, performance assumptions remain unchanged from those used for a wet runway, in accordance with the agreed certification standard. These include accelerate-stop distance definition, time delays, take-off distance definition, engine failure accountability and stopping means other than by wheel brakes (but see paragraph 7.4.3).

6.2.2 Where airworthiness or operational standards permit operations on contaminated runways without engine failure accountability, or using a V_{STOP} and a V_{GO} instead of a single V_1, these performance assumptions may be retained. In this case, a simple method to derive a single V_1 and associated data consistent with the performance assumptions of paragraph 6.2.1 must also be provided in the AFM.

NOTE: V_{STOP} is the highest decision speed from which the aeroplane can stop within the accelerate-stop distance available. V_{GO} is the lowest decision speed from which a continued take-off is possible within the take-off distance available.

7.0 Effects of Contaminant

7.1 Contaminant Drag — Standing Water, Slush, Wet Snow

General advice and acceptable calculation methods are given for estimating the drag force due to fluid contaminants on runways:

Total drag		Drag due to		Drag due to airframe
due to fluid	=	fluid displacement	+	impingement of fluid
contaminant		by tyres		spray from tyres

The essence of these simple calculation methods is the provision of appropriate values of drag coefficients below, at, and above tyre aquaplaning speed, V_P (see paragraph 7.1.1):

— Paragraphs 7.1.2.a and 7.1.2.b give tyre displacement drag coefficient values for speeds below V_P.

— Paragraph 7.1.3.b.2 gives tyre equivalent displacement drag coefficient values to represent the skin friction component of impingement drag for speeds below V_P.

— Paragraph 7.1.4 gives the variation with speed, at and above V_P, of drag coefficients representing both fluid displacement and impingement.

The applicant may account for the contaminant drag for computing the deceleration segment of the accelerate-stop distance. However, if the actual contaminant depth is less than the reported value, then, using the reported value to determine the contaminant drag will result in a higher drag level than the actual one. This will lead to a conservative take-off distance and take-off run, but also to a potentially optimistic accelerate-stop distance. It is assumed that these effects will offset each other; however, the applicant may consider:

— either using 100 % of the reported contaminant depth when determining the acceleration portion, and 50 % when considering the deceleration portion; or

— using 50 % of the reported contaminant depth when determining both the acceleration portion and the stop portion of the accelerate-stop distance; this should result in a conservative computation without being unduly penalising; the applicant should ensure that using drag for 50 % of the reported contaminant depth for computing the accelerate-stop distance is conservative for the applicant's aeroplane configuration.

7.1.1 Aquaplaning Speed

An aeroplane will aquaplane at high speed on a surface that is contaminated by standing water, slush or wet snow. For the purposes of estimating the effect of aquaplaning on contaminant drag, the aquaplaning speed, V_P, is given by -

$$V_P = 9\sqrt{P}$$

where V_P is the ground speed in knots and P is the tyre pressure in lb/in^2.

To estimate the effect of aquaplaning on wheel-to-ground friction, the aquaplaning speed (V_P) that is provided above should be factored by a coefficient of 0.85.

Predictions (Reference 5) indicate that the effect of running a wheel over a low-density liquid contaminant containing air, e.g. slush, is to compress it such that it essentially acts as high-density contaminant. This means that there is essentially no increase in aquaplaning speed to be expected with such a lower density contaminant. For this reason, the aquaplaning speed given here is not a function of the density of the contaminant.

(See References 1, 5 and 10)

7.1.2 Displacement Drag

This is drag due to the wheel(s) running through the contaminant and doing work by displacing the contaminant sideways and forwards.

a. Single wheel.

The drag on the tyre is given by -

$D = C_D \frac{1}{2} \rho V^2 S$

Where ρ is the density of the contamination, S is the frontal area of the tyre in the contaminant and V is the groundspeed, in consistent units.

S = b x d where d is the depth of contamination and b is the effective tyre width at the contaminant surface and may be found from –

$$b = 2W\left[\left(\frac{\delta + d}{W}\right) - \left(\frac{\delta + d}{W}\right)^2\right]^{1/2}$$

Where W is the maximum width of the tyre and δ is the tyre deflection, which may be obtained from tyre manufacturers' load-deflection curves.

The value of C_D may be taken as 0.75 for an isolated tyre below the aquaplaning speed, V_P.

(See Reference 3)

b. Multiple wheels

A typical dual wheel undercarriage shows a drag 2.0 times the single wheel drag, including interference. For a typical four-wheel bogie layout the drag is 4 times the single wheel drag (again including interference). For a six-wheel bogie layout a reasonable conservative estimate suggests a figure of 4.2 times the single wheel drag. The drag of spray striking the landing gear structure above wheel height may also be important and should be included in the analysis for paragraph 7.1.3.b.1 but for multiple wheel bogies the factors above include centre spray impingement drag on gear structure below wheel height.

(See Reference 3)

7.1.3 Spray Impingement Drag

a. Determination of spray geometry

The sprays produced by aeroplane tyres running in a liquid contaminant such as slush or water are complex and depend on aeroplane speed, the shape and dimensions of the loaded tyre and the contaminant depth. The spray envelope should be defined, that is the height, width, shape and location of the sideways spray plumes and, in the case of a dual wheel undercarriage, the centre spray plumes. Additionally, a forward bow-wave spray will be present which may be significant in drag terms should it impinge on the aeroplane.

In order to assess the drag it is necessary to know the angles of the spray plumes so that they can be compared with the geometry of the aeroplane. The angle at which the plumes rise is generally between 10° and 20° but it varies considerably with speed and depth of precipitation and to a small extent with tyre geometry. A method for estimating the plume angles in the horizontal and vertical directions is given in References 1 and 7 and may be used in the absence of experimental evidence. This information may be used to indicate those parts of the airframe which will be struck by spray, in particular whether the nose-wheel plume will strike the main landing gear or open wheel-wells, the wing leading edges or the engine nacelles, and whether the main-wheel plumes will strike the rear fuselage or flaps.

b. Determination of the retarding forces

Following definition of the spray envelopes, the areas of contact between the spray and the airframe can be defined and hence the spray impingement drag determined. This will be in two parts, direct interaction of the spray with the aeroplane structure and skin friction.

For smaller jet aeroplanes, typically those where the wing-to-ground height is less than 2 metres (6 feet), the methods contained in this document may not be conservative. Drag estimates should be correlated with performance measurements taken, for example, during water trough tests for engine ingestion.

b.1. Drag caused by direct impact of the spray

For aeroplane designs where surface areas are exposed to direct spray impact, the resulting drag forces should be taken into account. These forces exist where a significant part of the spray flow is directed at part of the aeroplane structure at a normal or non-oblique angle. The drag, or momentum loss of the mass of fluid, so caused should be accounted for.

(See Reference 6)

b.2. Drag caused by skin friction

Reference 2 explains that the relative velocity between spray from the landing gear and wetted aeroplane components causes drag due to skin friction and provides a method for its calculation. Where more than one spray acts on the same wing or fuselage surface the skin friction forces are not cumulative and the single, higher calculated value should be used.

An alternative, simple, conservative empirical estimate of skin friction drag, which converts the skin friction drag into an equivalent displacement drag coefficient based on nose-wheel alone drag measurements, is given by

C_D spray = 8 x L x 0.0025

where C_D spray is to be applied to the total nose-wheel displacement area (b x d x number of wheels) and L is the wetted fuselage length in feet behind the point at which the top of the spray plume reaches the height of the bottom of the fuselage. This relation can also be used in the case of a main-wheel spray striking the rear fuselage. In the case of any one main wheel unit only the inner plume from the innermost leading wheel is involved so the relevant displacement area is half that of one main wheel.

7.1.4 Effect of Speed on Displacement and Impingement Drag Coefficients at and above Aquaplaning Speed (V_P)

The drag above V_P reduces to zero at lift off and one acceptable method is to reduce C_D as shown in the curve in Figure 1. This relationship applies to both displacement and spray impingement drag coefficients.

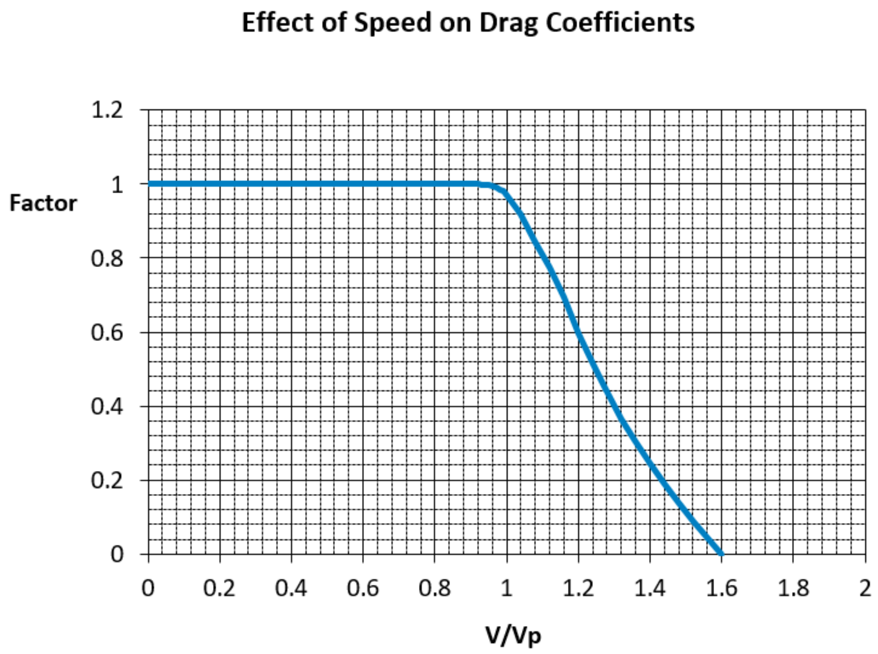

Figure 1

7.2 Contaminant Drag - Dry Snow

A basic method for calculating the drag of aeroplane tyres rolling in dry snow is given herein. The method is based on the theoretical model presented in References 8 and 9, using a specific gravity of 0.2 as provided in Table 1. Only snow of specific gravity of 0.2 is selected because it represents naturally occurring snow and results in the highest drag variation with ground speed for the range of snow specific gravities that are likely to be encountered. For other snow specific gravities, the more detailed methods of Reference 8 should be used.

7.2.1 Single Tyre Drag

The total displacement drag of a tyre rolling in dry snow is presented by the following equation:

$D = D_C + D_D$

The term D_C represents the drag due to the compression of the snow by the tyre. The term D_D represents the drag due to the displacement of the snow particles in a vertical direction.

The drag due to snow compression for a single tyre for snow with a specific gravity of 0.2 is given by:

Tyre pressure > 100 psi

$D_C = 74000\ bd$ (Newtons)

Tyre pressure $50 \leq p \leq 100$ psi

$D_C = 56000\ bd$ (Newtons)

In which:

d = snow depth in metres

b = is the tyre width at the surface in metres (see paragraph 7.1.2)

The drag due to the displacement of the snow particles in a vertical direction for a single tyre for snow with a specific gravity of 0.2 is given by:

Tyre pressure > 100 psi

$$D_D = \left(\frac{56}{R} + \frac{9}{d}\right) bd^2V_g^2 \quad \text{(Newtons)}$$

Tyre pressure $50 \leq p \leq 100$ psi

$$D_D = \left(\frac{56}{R} + \frac{8}{d}\right) bd^2V_g^2 \quad \text{(Newtons)}$$

In which:

d = snow depth in metres

b = is the tyre width at the surface in metres (see paragraph 7.1.2)

V_g = the ground speed in m/s

R = tyre radius in metres

For other snow densities D_C and D_D can be calculated using the method presented in Reference 8.

7.2.2 Multiple Wheels

The drag on dual tyre landing gears (found on both nose and main gears) is simply the drag of both single tyres added together. The interference effects between both tyres, found on dual tyre configurations running through slush or water, are not likely to be present when rolling over a snow covered surface. The drag originates from the vertical compaction of the snow layer. Although there is some deformation perpendicular to the tyre direction of motion, this deformation occurs mainly at or below the bottom of the rut and therefore does not affect the deformation in front of the adjacent tyre. Hence, interference effects can be ignored.

In the case of a bogie landing gear only the leading tyres have to be considered for the drag calculation, as explained in Reference 8. After the initial compression of the snow by the leading tyres, the snow in the rut becomes stronger and a higher pressure must be applied to compress the snow further. Therefore, the drag on the trailing tyres can be neglected and the drag on a bogie landing gear is assumed to be equal to that of a dual tyre configuration. All other multiple-tyre configurations can be treated in the same manner.

7.2.3 Spray Impingement Drag

Experiments have shown that the snow spray coming from the tyres is limited with only small amounts striking the airframe. The speed and the density of the snow spray are much lower than, for instance, that of water spray. Therefore, the drag due to snow impingement on the airframe can be neglected.

7.2.4 Total Landing Gear Drag

To obtain the total drag on the tyres due to snow, D_C and D_D for each single tyre (excluding the trailing tyres of a bogie gear) should be calculated and summed.

7.3 Braking Friction (All Contaminants)

On most contaminant surfaces the braking action of the aeroplane will be impaired. Performance data showing these effects can be based on either the minimum conservative 'default' values, given in Table 2 or test evidence and assumed values (see paragraph 7.3.2). In addition the applicant may optionally provide performance data as a function of aeroplane braking coefficient or wheel braking coefficient.

7.3.1 Default Values

To enable aeroplane performance to be calculated conservatively in the absence of any direct test evidence, default wheel-braking coefficient values as defined in Table 2 may be used. These values represent the maximum effective wheel-braking coefficient of a fully modulating anti-skid controlled braked wheel/tyre. For quasi modulating systems, the applicant should multiply the listed wheel-braking coefficient by 0.625, and for on-off systems, multiply the listed wheel-braking coefficient by 0.375. For the classification of anti-skid systems, the applicant should refer to AMC 25.109(c)(2). Aeroplanes without anti-skid systems should be addressed separately on a case-by-case basis.

Contaminant	*Default Wheel-Braking Coefficient* μ
Standing water and slush	$= -0.0632\left(\frac{V}{100}\right)^3 + 0.2683\left(\frac{V}{100}\right)^2 - 0.4321\left(\frac{V}{100}\right) + 0.3485$ where V is ground speed in knots Note: For V greater than 85 % of the aquaplaning speed (V_P), use the μ = 0.05 constant. At the discretion of the applicant, the wheel-braking coefficient as defined for runway condition codes (RWYCC) 2 in AMC 25.1592 may be applied.
Wet snow above 3 mm depth	0.16
Dry snow above 3 mm depth	0.16
Wet snow over compacted snow	0.16
Dry snow over compacted snow	0.16
Compacted snow below outside air temperature (OAT) of -15 °C	0.20
Compacted snow above OAT of -15 °C	0.16
Ice	0.07
Slippery wet	0.16

Note: Braking Force = load on braked wheel x Default Friction Value μ

Table 2

Note: For a specially prepared winter runway surface no default friction value can be given due to the diversity of conditions that will apply.

(See reference 10)

7.3.2 Other Than Default Values

In developing aeroplane braking performance using either test evidence or assumed friction values other than the default values provided in Table 2, a number of other brake related aspects should be considered. Brake efficiency should be assumed to be appropriate to the brake and anti-skid system behaviour on the contaminant under consideration or a conservative assumption can be used. It can be assumed that wheel brake torque capability and brake energy characteristics are unaffected. Where the tyre wear state significantly affects the braking performance on the contaminated surface, it should be assumed that there is 20% of the permitted wear range remaining.

Where limited test evidence is available for a model predecessor or derivative this may be used given appropriate conservative assumptions.

7.3.3 Use of Ground Friction Measurement Devices

There is not, at present, a correlation between aircraft stopping capability and ground friction measuring devices. Hence, it is not practicable at present to determine aeroplane performance on the basis of a friction index measured by ground friction devices. Notwithstanding this lack of correlation, the applicant may optionally choose to present take-off performance data as a function of an aeroplane braking coefficient or wheel braking coefficient constant with ground speed for runways contaminated with compacted snow or ice. The responsibility for relating this data to a friction index measured by a ground friction device will fall on the operator and the competent authority of the State of operator.

7.3.4 Specially prepared winter runway surfaces

At the discretion of the applicant, take-off performance data may be provided for specially prepared winter runway surfaces. This may include icy surfaces that have been treated with sand or gravel in such a way that a significant improvement of friction may be demonstrated. The applicant should apply a reasonable margin to the observed braking action in performance computations for such surfaces, and assume wheel-braking coefficients no greater than 0.20 for fully modulating anti-skid systems. For other anti-skid system types, this coefficient must be factored as described in Section 7.3.1. The competent authority of the State of aerodrome should approve appropriate procedures and methods in compliance with point ADR.OPS.B.036 of Annex IV (Part-ADR.OPS) of Regulation (EU) No 139/2014 ('Aerodromes Regulation').

7.4 Additional Considerations

7.4.1 Minimum V_1

For the purpose of take-off distance determination, it has been accepted that the minimum V_1 speed may be established using the V_{MCG} value established in accordance with CS 25.149(g). As implied in paragraph 8.1.3, this may not ensure that the lateral deviation after engine failure will not exceed 30 ft on a contaminated runway.

7.4.2 Reverse Thrust

Performance information may include credit for reverse thrust where available and controllable, as described in AMC 25.109.

8.0 Presentation of Supplementary Performance Information

8.1 General

Performance information for contaminated runways, derived in accordance with the provisions of paragraphs 5.0 to 7.0, should be accompanied by appropriate statements such as:

8.1.1 Operation on runways contaminated with water, slush, snow, ice or other contaminants implies uncertainties with regard to runway friction and contaminant drag and therefore to the achievable performance and control of the aeroplane during take-off, since the actual conditions may not completely match the assumptions on which the performance information is based. Where possible, every effort should be made to ensure that the runway surface is cleared of any significant contamination.

8.1.2 The performance information assumes any runway contaminant to be of uniform depth and density.

8.1.3 The provision of performance information for contaminated runways should not be taken as implying that ground handling characteristics on these surfaces will be as good as can be achieved on dry or wet runways, in particular following engine failure, in crosswinds or when using reverse thrust.

8.1.4 The contaminated runway performance information does not in any way replace or amend the Operating Limitations and Performance Information listed in the AFM, unless otherwise stated.

8.2 Procedures

In addition to performance information appropriate to operating on a contaminated runway, the AFM should also include recommended procedures associated with this performance information. Differences in other procedures for operation of the aeroplane on a contaminated surface should also be presented, e.g., reference to crosswinds or the use of high engine powers or derates.

8.3 Take-off Data

This should be presented either as separate data appropriate to a defined runway contaminant or as incremental data based on the AFM normal dry or wet runway information.

The landing distance must be presented either directly or with the factors required by the operating manuals, with clear explanation where appropriate.

Where data is provided for a range of contaminant depths, for example greater than 3, 6, 9, 12, 15 mm, then the AFM should clearly indicate how to define data for contaminant depths within the range of contaminant depths provided.

The AFM should provide:

— the performance data for operations on contaminated runways; and

— definitions of runway surface conditions.

The AFM should state that operations are prohibited on runways with contaminant depths greater than those for which data is provided. Instructions for the use of that data should be provided in the appropriate documentation.

Where the AFM presents data using V_{STOP} and V_{GO}, it must be stated in the AFM that use of this concept is acceptable only where operation under this standard is permitted.

9 References

Reference sources containing worked methods for the processes outlined in 7.1 to 7.3.3 are identified below:

1. ESDU Data Item 83042, December 1983, with Amendment A, May 1998, ‘Estimation of Spray Patterns Generated from the Side of Aircraft Tyres Running in Water or Slush’.

2. ESDU Data Item 98001, May 1998, ‘Estimation of Airframe Skin-Friction Drag due to Impingement of Tyre Spray’.

3. ESDU Data Item 90035*, November 1990, with Amendment A, October 1992, ‘Frictional and Retarding Forces on Aircraft Tyres, Part V: Estimation of Fluid Drag Forces’.