(iii) The aeroplane tracks essentially straight, even though runway seams, water puddles and wetter patches may not be uniformly distributed in location or extent.

3 *Determination of a specific wet runway anti-skid system efficiency*

3.1 If the applicant elects to derive the anti-skid system efficiency from flight test demonstrations, sufficient flight testing, with adequate instrumentation, must be conducted to ensure confidence in the value obtained. An anti-skid efficiency of 92% (i.e. a factor of 0·92) is considered to be the maximum efficiency on a wet runway normally achievable with fully modulating digital anti-skid systems.

3.2 A minimum of three complete stops, or equivalent segmented stops, should be conducted on a wet runway at appropriate speeds and energies to cover the critical operating modes of the anti-skid system. Since the objective of the test is to determine the efficiency of the anti-skid system, these tests will normally be conducted at energies well below the maximum brake energy condition. A sufficient range of speeds should be covered to investigate any variation of the anti-skid efficiency with speed.

3.3 The testing should be conducted on a smooth (i.e. not grooved or porous friction course) runway.

3.4 The section of the runway used for braking should be well soaked (i.e. not just damp), but not flooded. The runway test section should be wet enough to result in a number of cycles of anti-skid activity, but should not cause hydroplaning.

3.5 Before taxy and with cold tyres, the tyre pressure should be set to the highest value appropriate to the take-off weight for which approval is being sought.

3.6 The tyres and brake should not be new, but need not be in the fully worn condition. They should be in a condition considered representative of typical in-service operations.

3.7 A qualitative assessment of anti-skid system response and aeroplane controllability should be made by the test pilot(s). In particular, pilot observations should confirm that:

(i) The landing gear is free of unusual dynamics; and

(ii) The aeroplane tracks essentially straight, even though runway seams, water puddles and wetter patches may not be uniformly distributed in location or extent.

3.8 The wet runway anti-skid efficiency value should be determined as described in Paragraph 4 of this AMC. The test instrumentation and data collection should be consistent with the method used.

4 *Calculation of anti-skid system efficiency*

4.1 Paragraph 3 above provides guidance on the flight testing required to support the determination of a specific anti-skid system efficiency value. The following paragraphs describe 2 methods of calculating an efficiency value from the data recorded. These two methods, which yield equivalent results, are referred to as the torque method and the wheel slip method. Other methods may also be acceptable if they can be shown to give equivalent results.

4.2 *Torque Method*

Under the torque method, the anti-skid system efficiency is determined by comparing the energy absorbed by the brake during an actual wet runway stop to the energy that is determined by integrating, over the stopping distance, a curve defined by connecting the peaks of the instantaneous brake force curve (see figure 4). The energy absorbed by the brake during the actual wet runway stop is determined by integrating the curve of instantaneous brake force over the stopping distance.

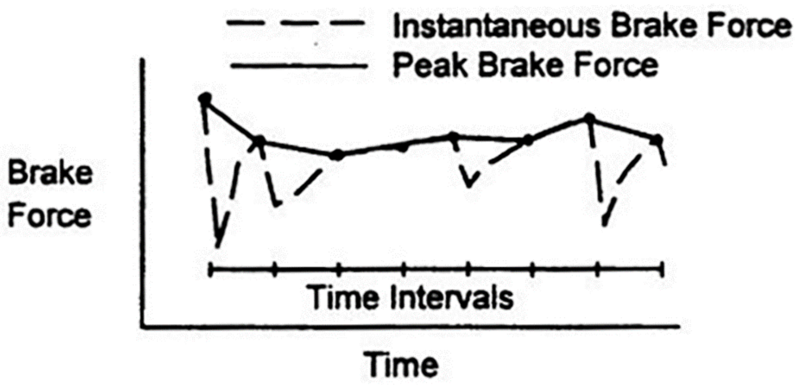

FIGURE 4. INSTANTANEOUS BRAKE FORCE AND PEAK BRAKE FORCE

Using data obtained from the wet runway stopping tests of paragraph 3, instantaneous brake force can be calculated from the following relationship:

$$F_b = \frac{(T_b + \alpha I)}{\mathrm{R}_{tyre}}$$

where:

F_b = brake force

T_b = brake torque

α = wheel acceleration

I = wheel moment of inertia; and

R_{tyre} = tyre radius

For brake installations where measuring brake torque directly is impractical, torque may be determined from other parameters (e.g. brake pressure) if a suitable correlation is available. Wheel acceleration is obtained from the first derivative of wheel speed. Instrumentation recording rates and data analysis techniques for wheel speed and torque data should be well matched to the anti-skid response characteristics to avoid introducing noise and other artifacts of the instrumentation system into the data.

Since the derivative of wheel speed is used in calculating brake force, smoothing of the wheel speed data is usually necessary to give good results. The smoothing algorithm should be carefully designed as it can affect the resulting efficiency calculation. Filtering or smoothing of the brake torque or brake force data should not normally be done. If conditioning is applied, it should be done in a conservative manner (i.e. result in a lower efficiency value) and should not misrepresent actual aeroplane/system dynamics.

Both the instantaneous brake force and the peak brake force should be integrated over the stopping distance. The anti-skid efficiency value for determining the wet runway accelerate-stop distance is the ratio of the instantaneous brake force integral to the peak brake force integral:

$$\eta = \frac{\int instantaneous\ brake\ force.ds}{\int peak\ brake\ force.ds}$$

where:

η = anti-skid efficiency; and

s = stopping distance

The stopping distance is defined as the distance travelled during the specific wet runway stopping demonstration, beginning when the full braking configuration is obtained and ending at the lowest speed at which anti-skid cycling occurs (i.e. the brakes are not torque limited), except that this speed need not be less than 19 km/h (10 kt). Any variation in the anti-skid efficiency with speed should also be investigated, which can be accomplished by determining the efficiency over segments of the total stopping distance. If significant variations are noted, this variation should be reflected in the braking force used to determine the accelerate-stop distances (either by using a variable efficiency or by using a conservative single value).

4.3 Wheel Slip Method

At brake application, the tyre begins to slip with respect to the runway surface, i.e. the wheel speed slows down with respect to the aeroplane's ground speed. As the amount of tyre slip increases, the brake force also increases until an optimal slip is reached. If the amount of slip continues to increase past the optimal slip, the braking force will decrease.

Using the wheel slip method, the anti-skid efficiency is determined by comparing the actual wheel slip measured during a wet runway stop to the optimal slip. Since the wheel slip varies significantly during the stop, sufficient wheel and ground speed data must be obtained to determine the variation of both the actual wheel slip and the optimal wheel slip over the length of the stop. A sampling rate of at least 16 samples per second for both wheel speed and ground speed has been found to yield acceptable fidelity.

For each wheel and ground speed data point, the instantaneous anti-skid efficiency value should be determined from the relationship shown in Figure 5:

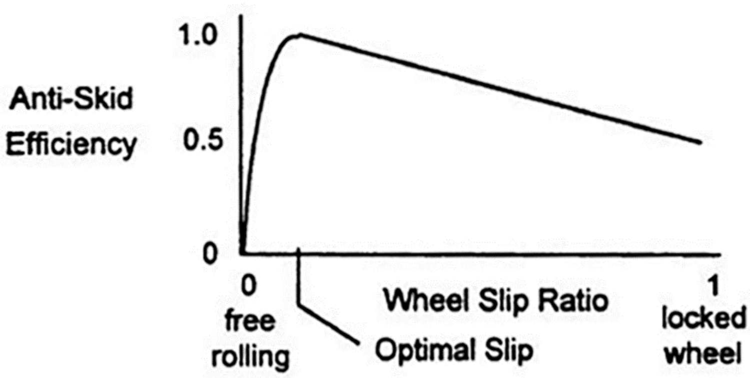

FIGURE 5. ANTI-SKID EFFICIENCY – WHEEL SLIP RELATIONSHIP

WSR = wheel slip ratio = $1 - \left(\frac{\text{wheel speed}}{\text{ground speed}}\right)$

OPS = optimal slip ratio; and

η_i = instantaneous anti-skid efficiency

To determine the overall anti-skid efficiency value for use in calculating the wet runway accelerate-stop distance, the instantaneous anti-skid efficiencies should be integrated with respect to distance and divided by the total stopping distance:

$$\eta = \frac{\int \eta_i . ds}{s}$$

where:

η = anti-skid efficiency; and

s = stopping distance

The stopping distance is defined as the distance travelled during the specific wet runway stopping demonstration, beginning when the full braking configuration is obtained and ending at the lowest speed at which anti-skid cycling occurs (i.e. the brakes are not torque limited), except that this speed need not be less than 19 km/h (10 kt). Any variation in the anti-skid efficiency with speed should also be investigated, which can be accomplished by determining the efficiency over segments of the total stopping distance. If significant variations are noted, this variation should be reflected in the braking force used to determine the accelerate-stop distances (either by using a variable efficiency or by using a conservative single value).

The applicant should provide substantiation of the optimal wheel slip value(s) used to determine the anti-skid efficiency value. An acceptable method for determining the optimal slip value(s) is to compare time history plots of the brake force and wheel slip data obtained during the wet runway stopping tests. For brake installations where measuring brake force directly is impractical, brake force may be determined from other parameters (e.g. brake pressure) if a suitable correlation is available. For those skids where wheel slip continues to increase after a reduction in the brake force, the optimal slip is the value corresponding to the brake force peak. See Figure 6 for an example and note how both the actual wheel slip and the optimal wheel slip can vary during the stop.

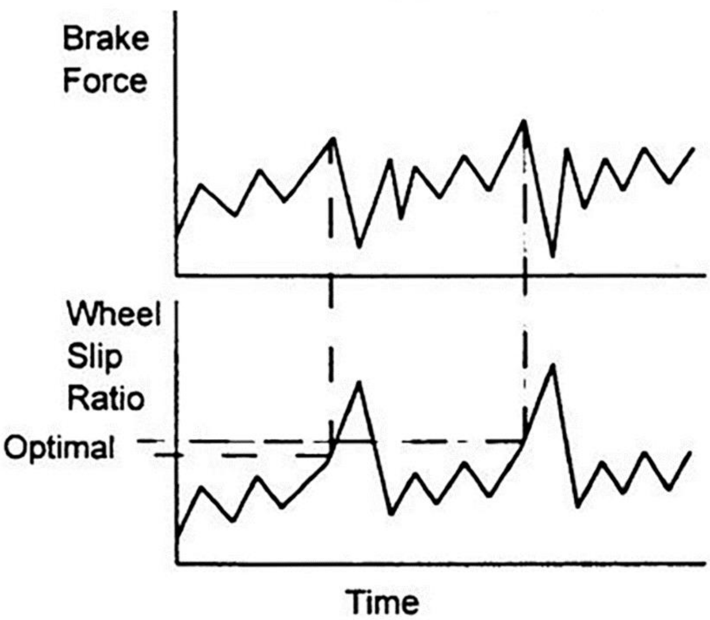

FIGURE 6. SUBSTANTIATION OF THE OPTIMAL SLIP VALUE

4.4 For dispatch with an inoperative anti-skid system (if approved), the wet runway acceleratestop distances should be based on an efficiency no higher than that allowed by CS 25.109(c)(2) for an on-off type of anti-skid system. The safety of this type of operation should be demonstrated by flight tests conducted in accordance with Paragraph 2 of this AMC.

5 *Distribution of normal load between braked and unbraked wheels*

In addition to taking into account the efficiency of the anti-skid system, CS 25.109(b)(2)(ii) also requires adjusting the braking force for the effect of the distribution of the normal load between braked and unbraked wheels at the most adverse centre of gravity position approved for take-off. The stopping force due to braking is equal to the braking coefficient multiplied by the normal load (i.e. weight) on each braked wheel. The portion of the aeroplane's weight being supported by the unbraked wheels (e.g. unbraked nose wheels) does not contribute to the stopping force generated by the brakes. This effect must be taken into account for the most adverse centre of gravity position approved for take-off, considering any centre of gravity shifts that occur due to the dynamics of the stop. The most adverse centre of gravity position is the position that results in the least load on the braked wheels.

AMC 25.109(d)(2) Accelerate-stop distance: anti-skid efficiency on grooved and porous friction course (PFC) runways.

ED Decision 2003/2/RM

Properly designed, constructed and maintained grooved and PFC runways can offer significant improvements in wet runway braking capability. A conservative level of performance credit is provided by 25.109(d) to reflect this performance improvement and to provide an incentive for installing and maintaining such surfaces.

In accordance with CS 25.105(c) and 25.109(d), applicants may optionally determine the acceleratestop distance applicable to wet grooved and PFC runways. These data would be included in the AFM in addition to the smooth runway accelerate-stop distance data. The braking coefficient for determining the accelerate-stop distance on grooved and PFC runways is defined in CS 25.109(d) as either 70% of the braking coefficient used to determine the dry runway accelerate-stop distances, or a curve based on ESDU 71026 data and derived in a manner consistent with that used for smooth runways. In either case, the brake torque limitations determined on a dry runway may not be exceeded.

Using a simple factor applied to the dry runway braking coefficient is acceptable for grooved and PFC runways because the braking coefficient's variation with speed is much lower on these types of runways. On smooth wet runways, the braking coefficient varies significantly with speed, which makes it inappropriate to apply a simple factor to the dry runway braking coefficient. For applicants who choose to determine the grooved/PFC wet runway accelerate-stop distances in a manner consistent with that used for smooth runways, CS 25.109(d)(2) provides the maximum tyre-to-ground braking coefficient applicable to grooved and PFC runways. This maximum tyre-to-ground braking coefficient must be adjusted for the anti-skid system efficiency, either by using the value specified in CS 25.109(c)(2) appropriate to the type of anti-skid system installed, or by using a specific efficiency established by the applicant. As anti-skid system performance depends on the characteristics of the runway surface, a system that has been tuned for optimum performance on a smooth surface may not achieve the same level of efficiency on a grooved or porous friction course runway, and vice versa. Consequently, if the applicant elects to establish a specific efficiency for use with grooved or PFC surfaces, anti-skid efficiency testing should be conducted on a wet runway with such a surface, in addition to testing on a smooth runway. Means other than flight testing may be acceptable, such as using the efficiency previously determined for smooth wet runways, if that efficiency is shown to be representative of, or conservative for, grooved and PFC runways. The resulting braking force for grooved/PFC wet runways must be adjusted for the effect of the distribution of the normal load between braked and unbraked wheels. This adjustment will be similar to that used for determining the braking force for smooth runways, except that the braking dynamics should be appropriate to the braking force achieved on grooved and PFC wet runways. Due to the increased braking force on grooved and PFC wet runways, an increased download on the nose wheel and corresponding reduction in the download on the main gear is expected.

AMC 25.109(f) Accelerate-stop distance: credit for reverse thrust.

ED Decision 2003/2/RM

In accordance with CS 25.109(f), reverse thrust may not be used to determine the accelerate-stop distances for a dry runway. For wet runway accelerate-stop distances, however, CS 25.109(f) allows credit for the stopping force provided by reverse thrust, if the requirements of CS 25.109(e) are met. In addition, the procedures associated with the use of reverse thrust, which CS 25.101(f) requires the applicant to provide, must meet the requirements of CS 25.101(h). The following criteria provide acceptable means of demonstrating compliance with these requirements:

1 Procedures for using reverse thrust during a rejected take-off must be developed and demonstrated. These procedures should include all of the pilot actions necessary to obtain the recommended level of reverse thrust, maintain directional control and safe engine operating characteristics, and return the reverser(s), as applicable, to either the idle or the stowed position. These procedures need not be the same as those recommended for use during a landing stop, but must not result in additional hazards, (e.g., cause a flame out or any adverse engine operating characteristics), nor may they significantly increase flightcrew workload or training needs.

2 It should be demonstrated that using reverse thrust during a rejected take-off complies with the engine operating characteristics requirements of CS 25.939(a). No adverse engine operating characteristics should be exhibited. The reverse thrust procedures may specify a speed at which the reverse thrust is to be reduced to idle in order to maintain safe engine operating characteristics.

3 The time sequence for the actions necessary to obtain the recommended level of reverse thrust should be demonstrated by flight test. The time sequence used to determine the accelerate-stop distances should reflect the most critical case relative to the time needed to deploy the thrust reversers. For example, on some aeroplanes the outboard thrust reversers are locked out if an outboard engine fails. This safety feature prevents the pilot from applying asymmetric reverse thrust on the outboard engines, but it may also delay the pilot's selection of reverse thrust on the operable reversers. In addition, if the selection of reverse thrust is the fourth or subsequent pilot action to stop the aeroplane (e.g., after manual brake application, thrust/power reduction, and spoiler deployment), a one second delay should be added to the demonstrated time to select reverse thrust. (See figure 1 of AMC 25.101(h)(3).)

4 The response times of the affected aeroplane systems to pilot inputs should be taken into account. For example, delays in system operation, such as thrust reverser interlocks that prevent the pilot from applying reverse thrust until the reverser is deployed, should be taken into account. The effects of transient response characteristics, such as reverse thrust engine spin-up, should also be included.

5 To enable a pilot of average skill to consistently obtain the recommended level of reverse thrust under typical in-service conditions, a lever position that incorporates tactile feedback (e.g., a detent or stop) should be provided. If tactile feedback is not provided, a conservative level of reverse thrust should be assumed.

6 The applicant should demonstrate that exceptional skill is not required to maintain directional control on a wet runway with a 19 km/h (ten knot) crosswind from the most adverse direction. For demonstration purposes, a wet runway may be simulated by using a castering nosewheel on a dry runway. Symmetric braking should be used during the demonstration, and both all-engines-operating and critical-engine-inoperative reverse thrust should be considered. The brakes and thrust reversers may not be modulated to maintain directional control. The reverse thrust procedures may specify a speed at which the reverse thrust is reduced to idle in order to maintain directional controllability.

7 To meet the requirements of CS 25.101(h)(2) and 25.109(e)(1) the probability of failure to provide the recommended level of reverse thrust should be no greater than 1 per 1000 selections. The effects of any system or component malfunction or failure should not create an additional hazard.

8 The number of thrust reversers used to determine the wet runway accelerate-stop distance data provided in the AFM should reflect the number of engines assumed to be operating during the rejected take-off along with any applicable system design features. The all-engines-operating accelerate-stop distances should be based on all thrust reversers operating. The one-engine-inoperative accelerate-stop distances should be based on failure of the critical engine. For example, if the outboard thrust reversers are locked out when an outboard engine fails, the one-engine-inoperative accelerate stop distances can only include reverse thrust from the inboard engine thrust reversers.

9 For the engine failure case, it should be assumed that the thrust reverser does not deploy (i.e., no reverse thrust or drag credit for deployed thrust reverser buckets on the failed engine).

10 For approval of dispatch with one or more inoperative thrust reverser(s), the associated performance information should be provided either in the Aeroplane Flight Manual or the Master Minimum Equipment List.

11 The effective stopping force provided by reverse thrust in each, or at the option of the applicant, the most critical take-off configuration, should be demonstrated by flight test. Flight test demonstrations should be conducted to substantiate the accelerate-stop distances, and should include the combined use of all the approved means for stopping the aeroplane. These demonstrations may be conducted on a dry runway.

12 For turbo-propeller powered aeroplanes, the criteria of paragraphs 1 to 11 above remain generally applicable. Additionally, the propeller of the inoperative engine should be in the position it would normally assume when an engine fails and the power lever is closed. Reverse thrust may be selected on the remaining engine(s). Unless this is achieved by a single action to retard the power lever(s) from the take-off setting without encountering a stop or lockout, it must be regarded as an additional pilot action for the purposes of assessing delay times. If this is the fourth or subsequent pilot action to stop the aeroplane, a one second delay should be added to the demonstrated time to select reverse thrust.

CS 25.111 Take-off path

ED Decision 2015/008/R

(See AMC 25.111)

(a) The take-off path extends from a standing start to a point in the take-off at which the aeroplane is 457 m (1500 ft) above the take-off surface, or at which the transition from the take-off to the en-route configuration is completed and V_{FTO} is reached, whichever point is higher. In addition –

(1) The take-off path must be based on the procedures prescribed in CS 25.101(f);

(2) The aeroplane must be accelerated on the ground to V_{EF}, at which point the critical engine must be made inoperative and remain inoperative for the rest of the take-off; and

(3) After reaching V_{EF}, the aeroplane must be accelerated to V_2.

(b) During the acceleration to speed V_2, the nose gear may be raised off the ground at a speed not less than V_R. However, landing gear retraction may not be begun until the aeroplane is airborne. (See AMC 25.111(b).)

(c) During the take-off path determination in accordance with sub-paragraphs (a) and (b) of this paragraph –

(1) The slope of the airborne part of the take-off path must be positive at each point;

(2) The aeroplane must reach V_2 before it is 11 m (35 ft) above the take-off surface and must continue at a speed as close as practical to, but not less than V_2 until it is 122 m (400 ft) above the take-off surface;

(3) At each point along the take-off path, starting at the point at which the aeroplane reaches 122 m (400 ft) above the take-off surface, the available gradient of climb may not be less than –

(i) 1·2% for two-engined aeroplanes;

(ii) 1·5% for three-engined aeroplanes; and

(iii) 1·7% for four-engined aeroplanes,

(4) The aeroplane configuration may not be changed, except for gear retraction and automatic propeller feathering, and no change in power or thrust that requires action by the pilot may be made, until the aeroplane is 122 m (400 ft) above the take-off surface, and

(5) If CS 25.105(a)(2) requires the take-off path to be determined for flight in icing conditions, the airborne part of the take-off must be based on the aeroplane drag:

(i) With the most critical of the “Take-off Ice” accretion(s) defined in Appendices C and O, as applicable, in accordance with CS 25.21(g), from a height of 11 m (35 ft) above the take-off surface up to the point where the aeroplane is 122 m (400 ft) above the take-off surface; and

(ii) With the most critical of the “Final Take-off Ice” accretion(s) defined in Appendices C and O, as applicable, in accordance with CS 25.21(g), from the point where the aeroplane is 122 m (400 ft) above the take-off surface to the end of the take-off path.

(d) The take-off path must be determined by a continuous demonstrated take-off or by synthesis from segments. If the take-off path is determined by the segmental method –

(1) The segments must be clearly defined and must relate to the distinct changes in the configuration, power or thrust, and speed;

(2) The weight of the aeroplane, the configuration, and the power or thrust must be constant throughout each segment and must correspond to the most critical condition prevailing in the segment;

(3) The flight path must be based on the aeroplane's performance without ground effect; and

(4) The take-off path data must be checked by continuous demonstrated take-offs up to the point at which the aeroplane is out of ground effect and its speed is stabilised, to ensure that the path is conservative to the continuous path.

The aeroplane is considered to be out of the ground effect when it reaches a height equal to its wing span.

(e) Not required for CS-25.

[Amdt 25/3]
[Amdt 25/16]

AMC 25.111 Take-off path

ED Decision 2003/2/RM

The height references in CS 25.111 should be interpreted as geometrical heights.

AMC 25.111(b) Take-off path

ED Decision 2003/2/RM

1 Rotation speed, V_R, is intended to be the speed at which the pilot initiates action to raise the nose gear off the ground, during the acceleration to V_2; consequently, the take-off path determination, in accordance with CS 25.111(a) and (b), should assume that pilot action to raise the nose gear off the ground will not be initiated until the speed V_R has been reached.

2 The time between lift-off and the initiation of gear retraction during take-off distance demonstrations should not be less than that necessary to establish an indicated positive rate of climb plus one second. For the purposes of flight manual expansion, the average demonstrated time delay between lift-off and initiation of gear retraction may be assumed; however, this value should not be less than 3 seconds.

CS 25.113 Take-off distance and take-off run

ED Decision 2016/010/R

(See AMC 25.113)

(a) Take-off distance on a dry runway is the greater of –

(1) The horizontal distance along the take-off path from the start of the take-off to the point at which the aeroplane is 11 m (35 ft) above the take-off surface, determined under CS 25.111 for a dry runway; or

(2) 115% of the horizontal distance along the take-off path, with all engines operating, from the start of the take-off to the point at which the aeroplane is 11 m (35 ft) above the take-off surface, as determined by a procedure consistent with CS 25.111. (See AMC 25.113(a)(2), (b)(2) and (c)(2).)

(b) Take-off distance on a wet runway is the greater of –

(1) The take-off distance on a dry runway determined in accordance with sub-paragraph (a) of this paragraph; or

(2) The horizontal distance along the take-off path from the start of the take-off to the point at which the aeroplane is 4,6 m (15 ft) above the take-off surface, achieved in a manner consistent with the achievement of V_2 before reaching 11 m (35 ft) above the take-off surface, determined under CS 25.111 for a wet runway. (See AMC 25.113(a)(2), (b)(2) and (c)(2).)

(c) If the take-off distance does not include a clearway, the take-off run is equal to the take-off distance. If the take-off distance includes a clearway –

(1) The take-off run on a dry runway is the greater of –

(i) The horizontal distance along the take-off path from the start of the takeoff to a point equidistant between the point at which V_{LOF} is reached and the point at which the aeroplane is 11 m (35 ft) above the take-off surface, as determined under CS 25.111 for a dry runway; or

(ii) 115% of the horizontal distance along the take-off path, with all engines operating, from the start of the take-off to a point equidistant between the point at which VLOF is reached and the point at which the aeroplane is 11 m (35 ft) above the take-off surface, determined by a procedure consistent with CS 25.111. (See AMC 25.113(a)(2), (b)(2) and (c)(2).)

(2) The take-off run on a wet runway is the greater of –

(i) The horizontal distance along the take-off path from the start of the takeoff to the point at which the aeroplane is 4,6 m (15 ft) above the take-off surface, achieved in a manner consistent with the achievement of V_2 before reaching 11 m (35 ft) above the take-off surface, determined under CS 25.111 for a wet runway; or

(ii) 115% of the horizontal distance along the take-off path, with all engines operating, from the start of the take-off to a point equidistant between the point at which V_{LOF} is reached and the point at which the aeroplane is 11 m (35 ft) above the take-off surface, determined by a procedure consistent with CS 25.111. (See AMC 25.113(a)(2),(b)(2) and (c)(2))

[Amdt 25/9]
[Amdt 25/18]