



Introduction

Regulatory aircraft performance is certified as a set of performance models and aircraft physical characteristics that are built and validated from flight test data. While the primary purpose of these models has always been to allow computation of aircraft performance for dispatch, the models used to determine the in-flight landing distances during approach preparation are derived from the same testing. Part of this model, affecting both the accelerate-stop computation at take-off and the landing distance computation, are the characteristics of the braking system installed on the aircraft.

This article explains which flight tests are involved in the identification of the system characteristics and how they are conducted.



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Airbus Brake Testing

Testing Method

There are several objectives for brake testing of a transport category aircraft.

The primary objective is the requirement to model and demonstrate the overall stopping performance, during rejected take-off, including the challenging Maximum Energy Rejected Take-Off (MERTO), and of course during landing.

Initially, during the early development, some fine-tuning of the braking logic may be required to optimise the system functioning and efficiency. Later in the aircraft life, subsequent modifications to braking systems or significant components (e.g. a

new carbon component or a tyre of new technology) may need further evaluation and certification. Then, there is the need to consider the possible degraded states of braking and aircraft systems that contribute to the overall aircraft deceleration (ground spoilers, reversers, etc).

To model accurately the overall aircraft stopping performance, an assembly of different performance models needs to be considered:

- A vertical loads model between the wheels during stopping, for effects of:
 - Aircraft centre of gravity position - At the most forward CG position, the non-braked nose gearwheels are

more highly loaded, the main gear braked wheels less so and therefore less overall braking effect achievable.

- Deceleration - The higher the deceleration, the stronger the load transfer from the braked main gear wheels to the non-braked nose wheels.
- An aircraft lift and drag model during the stop in the given aircraft configuration, including transients during the stop phase (e.g. ground spoilers deployment).
- An engine thrust model in forward idle and possible reverser settings, including transients (e.g. major transient in Rejected Take-Off (RTO) from engines in TOGA to forward idle or reverse thrust).

- The braking model itself with transients (e.g. brake onset with max pedal application or auto-brake initiation).

We will not explain here how vertical loads, lift and drag, and engine thrust models are built and justified. However, they are included in addition to the braking model in order to provide an accurate and validated global aircraft model. We will focus here only on the braking model development and justification.

Maximum braking performance tests are carried out in a specific and controlled manner, not to optimise the figures obtained, but to perform tests that are reproducible, as for any valid scientific experiment. This also applies to performance tests other than maximum braking, for example as validation of how auto-brake systems are performing at landing. To measure stopping distances and record deceleration very precisely, we use differential GPS, and calm wind conditions, with a typical maximum of 10 kt axial and 5 kt cross wind.

Airline pilot reaction times are defined conservatively by regulation and are added by computation into the model (except when aircraft particularities and testing demonstrate a longer test pilot reaction time).

Brake fans are an important facilitating element: they shorten cooling periods on the ground between tests. Alternatively, with an accurate assessment of energy absorbed by the braking system from the flight test installation, we can choose to cool the brakes in the air maintaining gear down, provided the performance calculation indicates sufficient energy margin when taking off with hot brakes to still allow for the possibility of a safe rejected take-off should there be a genuine test emergency that warrants such action. **It must be emphasised that this technique is a test technique only and not one recommended or allowed for “in-service use”. It requires detailed knowledge of brake energy consumption and remaining energy available.**

Rejected Take-Off (RTO) Tests

Rejected take-off performance measurements are done only on a DRY runway, with and without the use of the auto-brake system (in RTO mode) and without



Figure 1
A380 glowing brakes at stop of
Max Energy RTO on ISTRES AFB runway.

the use of thrust reverse. If done on an aircraft with a “light” flight test installation, V1 is set based upon current tower wind, and a calculation is made of the airspeed value required to give the precise ground speed needed to ensure the target energy into the brakes. On aircraft with a “heavy” or more developed flight test installation, the test pilots are provided with a dedicated speed scale display of ground speed: any wind shift will not alter the ability of the test pilot to accurately attain the target brake energy and the target V1 in ground speed.

For Rejected Take-Off (RTO) tests, the aircraft is positioned so that braking is planned to start on a runway portion not significantly contaminated by heavy rubber deposits (typical on touch-down zones). The most demanding of these tests being the Max Energy RTO (fig. 1).

As a progressive approach to this test point, we perform some so-called ‘interrupted RTOs’ in order to ensure that the braking performance in the highest speed range is correctly identified for a precise and correct V1 speed target prediction for the final Max Energy RTO certification brake test. During these “interrupted RTOs”, the pilot applies several seconds max braking from close to the max energy limited value. He then

stops braking and decelerates the aircraft using only reverse thrust, limiting the total energy absorption of the brakes to below tyre deflation values. For this test, Airbus uses the 5,000 meters (16,600 ft) runway of the ISTRES AFB, in the south of France. Obviously this special exercise requires the full length of that runway.

For the unique max energy RTO test, performed at MTOW, the aircraft demonstrates the capacity to absorb the certified max energy into the brakes. Regulatory conditions require that tyres must all be in 90% plus worn condition and, for a successful test, no intervention by the fire crews is allowed for a period of 5 minutes post RTO.

The test is typically done with auto-brake RTO mode selected and with the most critical engine cut (when there is a critical engine) at a target V1 (in ground speed): PM cuts the fuel to the critical engine whilst PF simultaneously slams the thrust levers to Idle **without selecting Reverse**. During the deceleration, the Flight Test Engineer monitors brakes function and should any brake unit fail he calls “Dead Brake”. In this case, the capacity to absorb energy by the remaining brakes is insufficient, and the PF has to disconnect the auto-brake and select max reverse, delaying braking. Hence the reason for using the longest

possible runway available to the Airbus test teams (ISTRES AFB).

If all functions correctly, the auto-brake brings the aircraft to a halt. Then, as we cannot block the ISTRES runway, we need to taxi clear before the wheel fuse plugs melt, typically 2 minutes after the stop. We come to a final halt on the pre-assigned safe parking area with minimum additional use of braking (as little brake capacity remains).

The V1 speed for thrust reduction and brake application has to be precisely calculated, as there is little margin for error. With a dedicated speed scale in ground speed, an accuracy within two tenths of a knot at a typical V1 of 160 kt plus is regularly achieved. The wheels and brakes are intentionally and effectively written off, so the Max Energy RTO is classed as a high risk test. Fire crews are pre-positioned to the side of the runway, listening on the tower frequency, but will only intervene in case of extreme necessity (engulfing fire) and only on flight test crew request: their intervention before a 5 minute period invalidates the test.

Intervention before braked wheels tyres are deflated is highly risky. In case of a wheel burst, pieces of metal of all sizes could be sent at high energy in

all directions ricocheting off gear legs and aircraft structure (it has happened). Therefore, the fire trucks are specifically configured to cool the brakes from a safe distance: hoses are set on fire truck front bumper, and cabin windshields are reinforced. Respect is rightly due to the fire crews, whose lives may be at risk should they be required to assist the flight crew in an evacuation.

At the end of the mandated 5 minutes period, with all tyres deflated, fire crews approach the aircraft and spray the gear with water, in order to rapidly cool the brakes and reduce the need for major aircraft repair beyond wheels, brakes and axles. The whole sequence is filmed for safety reasons and this film is part of the certification process as evidence of the 5 minute hold-over period.

Brake fans are never used during Max Energy RTO, as they come as an option on Airbus models. The parking brake is never set on during aircraft max energy tests to limit risk of hydraulic leaks at brake piston level, but it is demonstrated during max energy bench tests.

Finally, this test is always performed at the very end of the certification, as this minimises the risk to the certification program, since it could cause significant

airframe damage and render a critical and valuable test asset inoperable.

Should the test fail, as happened with one brake manufacturer during the A340-600 test campaign (due to a combination of detrimental factors, including a landing in extreme overweight the same morning at ISTRES AFB), then modifications to the brake and wheel assembly will be required to ensure compliance with the certification criteria. A second test will then be required with the embodied modifications.

Landings Tests

The ground distance from main gear touchdown to full stop is demonstrated by flight test only on a DRY runway. Measurements are done both with and without the use of the auto-brake system (in relevant modes) and without the use of thrust reverse (fig. 2).

Heavy rubber deposits (typical on touchdown zones) have a detrimental effect on brake performance. So, prior to a campaign of brake testing, historically, it was usual practice to clean the runway surface to get a reproducible optimum reference. This is no longer done due to the impact of a full week

Figure 2
A350 Landing performance test
on TOULOUSE DRY RWY



runway closure for rubber removal at our primary operating airport (TOULOUSE BLAGNAC). A second reason is that the rate of rubber contamination has been significantly reduced by the use of modern anti-skid systems. For braking tests, we use the normal threshold when the rubber contamination is normal. When the touchdown zone is contaminated with rubber, enough for the airport to consider a rubber removal plan as per ICAO requirements, we displace our touchdown point beyond the contaminated zone.

The touchdown rate should be on the firm side (3-4 ft/sec), to avoid any bounce and asymmetry on the main gear and in order to have an unambiguous unique touchdown point. The aircraft must be positioned and maintained on the centreline, to avoid the braked wheels running over the painted centreline, which will reduce measured performance (or, in the case of an aircraft with a braked central gear such as A340-600, to allow for the slight loss of performance from the painted centre line). Engines must be at idle at touchdown, with the throttles chopped to idle at the "RETARD" automatic call out. At touchdown, manual braking is immediately applied to maximum pedal deflection, and maintained to the full stop, or auto-brake is left to control the

aircraft deceleration. Pilot control of the de-rotation, in order to minimise load upon nose-wheel touchdown, may be needed as max brake is applied through the derotation. Once on three points, the stick then has to be released for the rest of the ground roll whilst max braking or auto-brake is maintained, in order to avoid undue credit for nose-up elevator position, which would improve performance figures.

Thrust reverse is not used, except for those tests required to validate the reverse thrust model. This is obtained from separate tests with reversers used without braking.

Validation of Performance Models for WET and CONTAMINATED Runways

All flight tests are done on a DRY smooth runway. However analytical models for WET and more slippery runways (CONTAMINATED) are developed and validated.

The reference frictions for WET or CONTAMINATED runways are defined by regulation, EASA §25.109 for WET

and EASA §25.1591 for the defined CONTAMINATED runways (Compacted Snow, Loose Dry or Wet Snow, Standing Water and Slush of more than 3 mm depth, and Ice). Differences of this regulation with TALPA ARC recommendations are minor. These reference frictions are a compilation of historical data on research aircraft. The manufacturer, with a validated wheel loads model for the useful full range of decelerations and aircraft configurations, applies these legal reference frictions to its validated wheel loads models to obtain the appropriate RTO and landing distance performance.

The only additional flight test validation required from us is the anti-skid efficiency on a WET smooth runway, up to the highest ground speed values that will be met in-service during RTO (which also covers the landing speed range). This is done through several RTO or landings in WET conditions (fig.3). They are not direct performance measurements as such, but provide the validated anti-skid efficiency value obtained from analysis. By regulation, the highest efficiency that can be claimed for a fully modulating anti-skid system is 92%. This efficiency has an effect on the certified RTO performance and on the provided landing distances on a WET runway.



Figure 3 | A380 Landing over WET runway for WET anti-skid efficiency determination

If the manufacturer is not able to perform these tests, he can opt for a conservative default anti-skid efficiency value defined by the regulation, function of the anti-skid type being used.

In-Flight Landing Distances

Airbus took the initiative to develop and use the concepts of Operational Landing Distance (OLD) and Factored Operational Landing Distance (FOLD) for aircraft landing performance assessment on arrival. This initiative was based on an industry-wide consensus, forged by the FAA mandated TALPA ARC (Take-Off and Landing Performance Assessment Aviation Rulemaking Committee), and was described in Safety first Issue 10, August 2010.

From September 2012, these more realistic landing distance performance figures have been available to Airbus operators. They are now referred to in the Airbus documentation as Landing Distance (LD) and Factored Landing Distance (FLD).

To cater for minor operational deviations, Airbus and TALPA ARC recommend a 15% factor be applied to the LD. With the resulting FLD, crews should now feel confident that the performance figures used operationally, with Airbus aircraft, are realistic for all runway conditions. This is provided correct assumptions have been made about the weather, aircraft and runway status and that there is no excessive abuse of normal approach and landing procedure.

Effective Friction (including anti-Skid Efficiency) used for Computation of RTO Distances, Dispatch and In-Flight Landing Distances

The DRY runway friction and associated ground braking distance identified in the above tests is used directly for DRY RTO computations, and through regulatory coefficients for Dispatch computations towards DRY and WET runways. It is reduced by 10% for the determination of the in-flight LD towards DRY runways (to mitigate for heavier runway contamination by rubber than on legacy test runways).

The determination of the ground distance for the RTO and In-Flight LD WET computations is not based on specific flight tests, but is computed using a reference friction defined by regulation CS/FAR25.109. This reference friction, based on a compilation of historical flight test data (fig.4), is multiplied by a demonstrated WET runway anti-skid efficiency.

The Dispatch and In-Flight LD computations towards CONTAMINATED runways is likewise based on reference frictions, which are based on a compilation of historical flight test data. These are defined in EASA AMC to CS25.1591 and adjusted, in some cases, for In-Flight Landing Distances as per the proposed TALPA ARC guidance to FAR25.125 B.

Ground roll Distance basis	RTO	Dispatch	In-Flight LD
DRY	Demonstrated DRY runway friction		Demonstrated DRY runway friction reduced by 10%
WET⁽¹⁾	WET runway friction model as per CS/FAR 25.109(c) multiplied by demonstrated WET runway anti-skid efficiency	Not defined ⁽³⁾	WET runway friction model as per CS/FAR 25.109(c) multiplied by demonstrated WET runway anti-skid efficiency
CONTAMINATED⁽²⁾	Contaminated runway friction model as per AMC to CS25.1591	Contaminated runway friction model as per AMC to CS25.1591	Friction model as per proposed TALPA ARC guidance to FAR25.125 B

Figure 4
Reference friction used for ground roll distances

- (1) The In-Flight Performance Level corresponding to WET runway is GOOD. The specific credit for ground roll distances on WET Grooved or PFC (Porous Friction Course) runways will not be discussed here.
 (2) The In-Flight Performance Levels corresponding to CONTAMINATED runways are expressed as GOOD TO MEDIUM, MEDIUM, MEDIUM TO POOR and POOR.
 (3) Dispatch landing performance on WET is derived from the Dispatch Landing Distance on DRY and thus no specific WET friction definition is provided in the regulations.

Conclusion

The primary objective of brake testing is to fulfil the requirement to model and demonstrate the aircraft's overall stopping performance during rejected take-offs as well as landings.

This entails the determination, on a DRY runway, of the maximum capabilities of the braking system through a series of tests like the Max Energy RTO assessment and landing performance evaluation.

A combination of these flight tests and of analytical models derived from the compilation of historical flight test data, is utilized to calculate the braking performance on DRY, WET and CONTAMINATED runways for RTO, Dispatch as well as In-Flight Landing Distances determination.

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A350 XWB
*A350 XWB over
the Pyrénées*

Safety first, #17 January 2014. Safety first is published by Airbus S.A.S. - 1, rond point Maurice Bellonte - 31707 Blagnac Cedex/France. Editor: Yannick Malinge, Chief Product Safety Officer, Nils Fayaud, Director Product Safety Information. Concept Design by Airbus Multi Media Support Ref. 20132304. Computer Graphic by Quat'coul. Copyright: GS 420.0045 Issue 17. Photos by Airbus, Teledyne Controls, ExM Company, master image. Printed in France by Airbus Print Centre.

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