FAA Aviation Rulemaking Advisory Committee

FTHWG Topic 30
Controllability During Low Speed OEI RTO

Recommendation Report
May 2018

Table of Contents

Executive Summary

In January 2010 there was a serious incident in Sweden in which a jet transport airplane veered-off after a low speed engine failure prompted a rejected takeoff on a runway contaminated with ice.

The Swedish investigation report pointed to technical as well as operational issues contributing to the incident. The technical issues were focused on engine maintenance practices. Among the operational issues the investigation revealed the runway was contaminated, despite being reported to the crew as good, with some patches of ice. Also on the operational aspects the investigation report cites the lack of specific certification requirements for aircraft maneuverability in the event of a sudden loss of engine thrust during the initial stage of the takeoff sequence and the lack of mandatory requirements for training regarding how to handle a sudden loss of engine thrust during the initial stage of the takeoff.

In order to address the operational safety issues raised by this incident investigation the Flight Test Harmonization Working Group recommends the FAA to introduce a specific dry runway low speed RTO controllability demonstration to Advisory Circular AC 25-7C.

Part 25 Subpart B Guidance:

- Introduce low speed RTO controllability demonstration by flight test or simulation on a dry runway

In addition, the FTHWG recommends the FAA to coordinate with a group of experts in the areas of Operations, Flight Crew Training and Cockpit Controls/Ergonomics – and their respective HWG – to implement regulation language and/or guidance language containing further mitigation for low speed OEI RTO on slippery runways in the areas introduced below.

Operations and Procedures:

- Do not takeoff if the runway surface is contaminated with wet ice
- Consider using lower thrust settings if shown to be safe
- Consider loading the aircraft in the medium to forward CG range
- Adjust pedal position properly, so that full rudder and full differential brakes can be applied simultaneously in the same sense
- Include/update information on Operating and/or Training Manuals

Flight Crew Training:

- Introduce specific ground training for low speed OEI RTO including slippery runways
    - Raise awareness of flight crews for the potential controllability issue
    - Emphasize training for quick reactions
    - Introduce training for use of differential brakes (one full brake pedal input)
    - Introduce recommendation for proper pedal adjustment before takeoff
    - Include/update information on Operating and/or Training Manuals
- Introduce dedicated simulator task with low speed OEI RTO on slippery runways
    - Revise the academic syllabus and simulator training sessions to include an event focused on the particular challenges of a low speed RTO due to engine failure
    - Revise FAA's AFS (Flight Standards) takeoff safety training aid

Cockpit Ergonomics:

- Include additional guidance for 25.777 to ensure simultaneous full rudder and full differential braking (in the same sense) can be achieved by crew of different statures

Background

Serious incident on 16 of January 2010 to aircraft EP-IBB at Stockholm/Arlanda Airport, Stockholm county, Sweden – reference RL 2012:21e – is the Swedish Accident Investigation Authority (SHK) final report for the aforementioned veer-off incident.

The incident occurred in connection with a commercial air transport with a large, wing mounted twin engine turbojet departing from Stockholm, Sweden to Tehran, Iran. Following are direct quotes from the report Summary section on page 7:

> "(…) Following normal preparations, the aircraft was taxied out to runway 19R for take-off.
>
> The runway conditions were reported as good, with some patches of ice along the runway. The investigation has however revealed that the runway was contaminated and likely had coefficients of friction which fell short of the reported values.
>
> After taxiing out, the crew began routine take-off procedures by increasing engine thrust during acceleration on the runway. After just over 10 seconds, one or more of the edges in a repaired section of the engine – the diffuser aft air seal – separated, thereby triggering a sequence which led to a sudden engine failure.
>
> No warning messages were announced in the cockpit at the time of the failure; the pilots only noticed the engine failure through a muffled bang at the same time as the aircraft began to veer to the left. The initial veer, immediately after the engine seizure, was a result of the nose wheel being unable to gain sufficient force against the contaminated surface to counteract the moment which arose when the right engine – for a duration of approximately 1.5 seconds – supplied full thrust at the same time as the left engine rapidly lost thrust. The highest speed registered during the sequence was 59 knots (110 km/h).
>
> Despite the co-pilot's reactions – retarding the thrust levers after just over a second, at the same time as steering and opposite rudder were applied – the veer could not be corrected and the aircraft ran off the runway, mainly caused by the forces from the moment in combination with the slippery surface. The chances of stopping the continued veer were probably reduced by the fact that the pilots did not apply any differential braking in the opposite direction.
>
> The investigation also showed that the pilots' braking was unintentionally asymmetrical, with a higher brake pressure on the "wrong side", i.e., in the direction in which the aircraft ran off the runway. Even if this fact may have affected the aircraft's movement pattern, such an impact has, however, not been possible to determine with any reasonable degree of certainty. It is, nevertheless, noteworthy that analyzed data from the FDR show that the recorded brake angles (asymmetric braking) were not accompanied or followed by any corresponding change in the rate of heading change.
>
> There are no specific certification requirements for aircraft design organization to show that the aircraft is manoeuvrable in the event of a sudden loss of engine thrust during the initial stage of the take-off sequence. There are also no mandatory requirements for training regarding how to handle sudden losses of engine thrust during the initial stage of the take-off sequence for pilots in training or recurrent training for this class of aircraft.(…)"

Despite the SHK final report statements above disregarding the contribution of the adverse asymmetrical braking to the outcome of the incident, the French BEA (Bureau d'Enquêtes et d'Analyses) expressed a different opinion documented in Appendix 6 as comments to the draft report (reference N° 00772/BEA/INV):

> "The BEA does not totally support the draft report. The most important is that SHK rules out the influence of asymmetric braking action on the veer off. We consider that the crew actions on the brakes have contributed to the movement of the aircraft to the left as well as the asymmetric thrust. Then, because of the contaminated pavement and the low speed, the use of tiller and rudder could not prevent the aircraft from exiting the runway.(…)"

The SHK report continues on Summary/Technical on pages 7 and 8 describing also the technical aspects relevant to the investigation, i.e., the findings related to the engine failure mode and its probable cause linked to the repair of the diffuser aft air seal.

Page 23, sections 1.2, 1.3 and 1.4 show there were no injuries to passengers or crew members as a consequence of the incident. There was limited damage to the aircraft and minor damage to the ground surface beside the runway.

On page 104 (also on page 8) the incident report concludes on the identified causal factors:

"<u>Operational</u>

- Deficiencies in the certification process for large aircraft with wing-mounted engines with regard to requirements for yaw stability in the event of sudden loss of engine power in the speed range below V_{MCG}.
- Deficiencies in the pilot training with regard to training for sudden losses of engine thrust in the speed range below V_{MCG}.

<u>Technical</u>

- Deficiencies in the approval and follow-up of the Dabbler TIG Weld repair on the engine's diffuser aft air seal."

Page 105 (also page 9) contains the recommendations from the Swedish Accident Investigation Authority:

"ICAO is recommended to:

- Take measures in order for authorities that issue certification directives – the FAA and EASA – to adopt the safety requirements issued by ICAO in Annex 8 concerning safety in large aircraft, so that these are applied during the entire take-off sequence of a flight. (RL 2012: 21 R1).

The FAA is recommended to:

- Investigate, in consultation with EASA, the prerequisites for introducing requirements concerning yaw stability in large aircraft in the event of sudden loss of engine thrust below V_{MCG} under the anticipated operating conditions. (RL 2012: 21 R2).
- Review and revise processes and permissions issued for the Dabber TIG Weld repair method regarding concerned parts in engines that have FAA type certification. (RL 2012: 21 R3).
- Improve processes to expedite safety of flight considerations in granting export licenses and waivers so that political sanctions do not unnecessarily delay civil aviation safety investigations concerning aircraft – or parts thereof – which are manufactured in the USA. (RL 2012: 21 R4).

EASA is recommended to:

- Investigate, in consultation with the FAA, the prerequisites for introducing requirements concerning yaw stability in large aircraft in the event of sudden loss of engine thrust below V_{MCG} under the anticipated operating conditions. (RL 2012: 21 R5).
- Ensure that initial and recurrent pilot training includes mandatory rejected takeoff exercises that cover events of a sudden loss of engine thrust below V_{MCG}. (RL 2012: 21 R6)."

During the course of the ARAC Flight Test Harmonization Working Group Phase 3 the driving need for the Topic 30 activities was to study and address the following recommendations:

- RL 2012: 21 R2
- RL 2012: 21 R5
- RL 2012: 21 R6

A. What is the underlying safety issue addressed by the FAA CFR / EASA CS?

Existing paragraphs 25.143(a) and (b) assess the general aspects of controllability and maneuverability of transport airplane designs during all phases of flight and during transitions from one phase to another, including the sudden failure of the critical engine.

However, the 2010 incident in Sweden uncovered a potential safety issue associated with the particular cases of one engine inoperative rejected takeoffs at such low speeds that the aerodynamic control surfaces are ineffective to counteract large thrust asymmetry yawing moments; and in combination with slippery/contaminated runway surfaces the nose wheel steering and main brakes have also reduced effectiveness.

B. What is the task ?

To recommend harmonized means of addressing the Swedish Accident Investigation Authority safety recommendation regarding engine out rejected tekoffs at speeds below V_{MCG} including slippery runways. Recommendations include specific Part 25 certification demonstrations, training, procedures, cockpit controls and operational practices.

See also Attachment 30A - Topic 30 Work Plan

C. Why is this task needed ?

In January 2010 there was a serious incident in Sweden with a jet transport airplane on a runway contaminated with ice (reference Swedish incident report RL 2012:21e Serious incident on 16 of January 2010 to aircraft EP-IBB at Stockholm/Arlanda Airport, Stockholm county, Sweden). The airplane veered-off at approximately 60kts after one of the engines failed during a takeoff run. Despite the pilot having promptly applied rudder in the correct sense he also unintentionally applied differential braking in the wrong sense (failed engine instead of live engine). According to the SHK final report, this adverse asymmetrical braking did not contribute to the veer-off, although the final report also contains evidence of the BEA disagreement with this conclusion.

The final report for this investigation states:

> "There are no specific certification requirements for aircraft design organization to show that the aircraft is maneuverable in the event of a sudden loss of engine thrust during the initial stage of the take-off sequence. There are also no mandatory requirements for training regarding how to handle sudden losses of engine thrust during the initial stage of the take-off sequence for pilots in training or recurrent training for this class of aircraft."

Existing paragraphs 25.143(a) and (b) assess the general aspects of controllability and maneuverability of transport airplane designs during all phases of flight and during transitions from one phase to another, including the sudden failure of the critical engine §25.143(b)(1).

However, guidance to §25.143(b)(1) provide no specific means of compliance addressing this issue. And neither operational or training regulations or guidance specifically address controllability during low speed OEI RTO, in particular when combined with slippery runway conditions or other relevant environmental conditions.

Recommendations RL 2012: 21 R2, RL 2012: 21 R5 and RL 2012: 21 R6 from the incident report address those issues related to the FTHWG activities and specifically call for the FAA and EASA to act.

See also Attachment 30A - Topic 30 Work Plan, and the Swedish Accident Investigation Authority (SHK) final report reference RL 2012:21e – Serious incident on 16 of January 2010 to aircraft EP-IBB at Stockholm/Arlanda Airport, Stockholm county, Sweden.

D. Who has worked the task ?

The Flight Test Harmonization Working Group, during Phase 3 activities, has worked the task. Participants in this FTHWG task included:

Airframe Manufacturers:
Airbus, Boeing, Bombardier, Dassault, Embraer, Gulfstream and Textron

Airworthiness Authorities:
FAA, EASA, TCCA and ANAC (CAAI and JCAB as observers)

Operators:
Norwegian (as an observer)

Labor Union:
ALPA

E. Any relation with other topics?

FTHWG Phase 2 Topic 10 – Runway Excursion Hazard Classification – discusses the severity of runway excursions, both longitudinal and lateral, as a function of the excursion speed. Topic 10 report presents actual fleet in-service accident/incident data from several OEM's describing the consequences of runway excursions for different speed ranges.

Some relevant aspects of the ICAO guidelines for runway construction and safety areas are also discussed in Topic 10.

Topic 10 also briefly discusses the practical challenges of modeling and validating the side forces acting on the tires on a wet runway for simulation purposes (for failures that induce yawing moments or failures combined with high crosswind values).

FTHWG Phase 2 Topic 14 – Crosswind and Tailwind – discusses the challenges of modeling and validating the use of simulators (even with pilot-in-the-loop) for handling qualities assessment under high crosswind scenarios. The use of simulation and analysis to derive guidance for operations combining crosswind and different runway conditions was also discussed.

FTHWG Phase 2 and 3 Topic 9 – Wet Runway Stopping Performance – discusses the challenges of predicting the wheel braking coefficients for a given wet runway, including states of degraded braking action and slippery/contaminated surfaces.

Historical Information

A. What are the current regulatory and guidance material in CS-25 and FAR 25?

This topic is basically related to controllability during a rejected takeoff. Therefore the only applicable regulations are:

- Paragraphs 25.143(a) and (b), which assess the general aspects of controllability and maneuverability of transport airplane designs during all phases of flight and during transitions from one phase to another, including the sudden failure of the critical engine.
- The applicable guidance for the paragraphs above is in AC 25-7C and CS-25 Book 2.

Nevertheless, this subject is also loosely related to:

- Paragraph 25.149(e), which defines V_{MCG} as the minimum control speed on the ground, the calibrated airspeed during the takeoff run at which, when the critical engine is suddenly made inoperative, it is possible to maintain control of the airplane using the rudder control alone (without the use of nosewheel steering), as limited by 150 pounds of force, and the lateral control to the extent of keeping the wings level to enable the takeoff to be safely continued using normal piloting skill.

- Paragraph 25.1309, which addresses equipment, systems and installations, including systems failure hazard analyses related to longitudinal and lateral runway excursions (discussed in detail during Phase 2 Topic 10 activities).

- CS 25.1591 (EASA only), which defines performance criteria for operations with different contaminated runway surface conditions. Guidance for this paragraph also refers to potential controllability issues, in particular when using thrust reversers.

- AC 25-31 (FAA only), which defines criteria for operational assessment of takeoff data, including contaminated runway conditions.

- AC 25-13 and AMC 25-13, which present guidance for use of derate and reduced thrust on takeoff.

- Paragraph 25.901(c), which defines failure conditions that need to be assessed for powerplant installations.

In addition, during the course of the FTHWG discussions around this topic it was noted that the following Part 25 regulation, although outside the FTHWG expertise, is relevant for this topic:

- Paragraph 25.777(a) and (c), which regulate the location and arrangement of the cockpit controls with respect to inadvertent operation, full and unrestricted movement.

B. What, if any, are the differences in the existing regulatory and guidance material CS 25 and FAR 25?

From the list of regulations discussed in section A above, one substantial difference between the FAA and EASA is §25.1591 (Performance Information for Operations with Contaminated Runway Surface Conditions) and its respective guidance AMC 25.1591, which are only present as regulatory material in the EASA CS-25.

The FAA has recently issued AC 25-31 to address this subject. However the FAA document contains only operational guidance; it does not constitute a certification regulation.

The difference between the EASA and FAA approaches to this matter however is not directly linked with controllability during low speed OEI RTO, as it deals only with the performance aspects of operations on contaminated surfaces (CS 25.1591 and AC 25-31 contain standard braking coefficients for different types of contaminants).

Paragraph 25.901(c) is substantially different between the FAA and EASA. The EASA regulation points to §25.1309 whereas the FAA has its own dedicated requirement.

AC 25-13 and AMC 25-13 have small differences, such as the maximum allowable reduced thrust that can be used.

C. What are the existing CRIs/IPs (SC and MoC)?

There is a generic CRI dealing with thrust reverser performance credit during RTO on wet and contaminated runways and landing on contaminated runways. The CRI is not specific about controllability during low speed OEI RTO, but it requires engine out ground control demonstrations with application of thrust reverser(s) on the remaining engine(s) if OEI thrust reverser credit is sought in those conditions. The CRI specifies that the controllability demonstrations should be representative of a slippery runway in combination with a moderate crosswind component.

There are also CRI’s and IP’s dealing with paragraph 25.901(c) for single failures and probable combination of failures.

D. What, if any, are the differences in the Special Conditions (CRIs/IPs) (SC and MoC) and what do these differences result in?

Not applicable.

Consensus

Initial Simulation Study

Since the potential safety issue being addressed by this topic derives from an incident event with a particular scenario (aircraft type, runway conditions, etc.), the group decided to conduct an initial study with a series of standardized RTO simulation cases. The objectives of this study were:

- To better understand the scope of the potential safety issue with low speed OEI RTO, including slippery runways and other environmental factors such as crosswind.
- To examine the physics involved in this maneuver and obtain the order of magnitude of the effects of individual parameters in the outcome of the RTO's.
- To understand how different types of designs are affected by those parameters.
- To try and identify potential procedural and/or operational practices that could help reduce the lateral deviations in case of low speed OEI RTO.

The different OEM's participating in the simulation exercise made it possible to obtain results for a variety of Part 25 designs, such as:

- Large transport twin jets, with wing mounted engines
- Medium twin jets, with wing mounted engines
- Regional twin jets, with wing mounted engines
- Regional twin jets, with fuselage mounted engines
- Long range business twin jets, with fuselage mounted engines
- Long range business three engine jets, with fuselage mounted engines
- Midsize business twin jets, with fuselage mounted engines

In total there were 20 simulation runs for each aircraft model. The following parameters were fixed for all cases:

- Sea level altitude
- ISA temperature
- Flaps/slats set to the most deflected positions approved for takeoff
- Longitudinal and transverse runway slope set to zero
- Pilot actions after delay times simulated as step input

The following variations in parameters were studied in different simulation runs:

- Mid weight and MTOW
- Aft CG and forward CG
- Initial thrust set to Maximum available takeoff thrust and 10% derate thrust
- Engine failure at 40, 60 and 80 knots
- One second delay and half a second delay between engine failure and pilot reaction to start rudder pedal (including any associated nose wheel steering inputs) and thrust lever input
- One and a half second delay and one second delay between engine failure and pilot reaction to start differential braking
- Full symmetrical brakes and full differential brake (one full brake pedal input in the good sense)
- Live engine(s) set to idle thrust and max reverse thrust
- Crosswind values of 0, 10 and 20 knots
- Nose wheel steering normal and free to caster (simulating a slippery runway)
- Braking friction and cornering coefficients emulating dry, wet, compacted snow and icy runway surfaces

The table below summarizes the 20 different simulation cases:

Simulation Case	Altitude	OAT	Thrust	TO Flaps/Slats Position	Runway slope (longitudinal and traverse)	Weight	CG	OEI Failure Speed	Reaction Time (rudder pedal input)	Reaction Time (thrust levers to idle)	Reaction Time (differential braking in the good sense)	Reaction Time (thrust levers to max reverse in the remaining engines)	Crosswind (from the engine out side)	Nose Wheel Steering Status	Braking Friction Coefficient	Cornering Coefficient (for lateral forces on the tyres)
1	SL	ISA	Max TO	Most deflected	Zero	Mid	Aft limit	60 kts	OEI + 1s	OEI + 1s	OEI + 1.5s	N/A	0 kts	Free to caster	Your Dry model	Your Dry model
2	SL	ISA	Max TO	Most deflected	Zero	Mid	Fwd limit	60 kts	OEI + 1s	OEI + 1s	OEI + 1.5s	N/A	0 kts	Free to caster	Your Dry model	Your Dry model
3	SL	ISA	Max TO	Most deflected	Zero	MTOW	Aft limit	60 kts	OEI + 1s	OEI + 1s	OEI + 1.5s	N/A	0 kts	Free to caster	Your Dry model	Your Dry model
4	SL	ISA	Max TO	Most deflected	Zero	Mid	Aft limit	60 kts	OEI + 1s	OEI + 1s	OEI + 1.5s	N/A	10 kts	Free to caster	Your Dry model	Your Dry model
5	SL	ISA	Max TO	Most deflected	Zero	Mid	Aft limit	60 kts	OEI + 1s	OEI + 1s	OEI + 1.5s	N/A	20 kts	Free to caster	Your Dry model	Your Dry model
6	SL	ISA	Max TO	Most deflected	Zero	Mid	Aft limit	80 kts	OEI + 1s	OEI + 1s	OEI + 1.5s	N/A	0 kts	Free to caster	Your Dry model	Your Dry model
7	SL	ISA	Max TO	Most deflected	Zero	Mid	Aft limit	80 kts	OEI + 1s	OEI + 1s	OEI + 1.5s	N/A	10 kts	Free to caster	Your Dry model	Your Dry model
8	SL	ISA	Max TO	Most deflected	Zero	Mid	Aft limit	60 kts	OEI + 1s	OEI + 1s	OEI + 1.5s	N/A	0 kts	Normal	Half the Dry	Half the Dry
9	SL	ISA	Max TO	Most deflected	Zero	Mid	Aft limit	60 kts	OEI + 1s	OEI + 1s	OEI + 1.5s	N/A	0 kts	Normal	0.2	0.25
10	SL	ISA	Max TO	Most deflected	Zero	Mid	Aft limit	60 kts	OEI + 1s	OEI + 1s	OEI + 1.5s	N/A	0 kts	Normal	0.05	0.15
11	SL	ISA	Max TO	Most deflected	Zero	Mid	Aft limit	60 kts	OEI + 1s	OEI + 1s	OEI + 1.5s	N/A	10 kts	Normal	Half the Dry	Half the Dry
12	SL	ISA	Max TO	Most deflected	Zero	Mid	Aft limit	60 kts	OEI + 1s	OEI + 1s	OEI + 1.5s	N/A	20 kts	Normal	Half the Dry	Half the Dry
13	SL	ISA	Max TO	Most deflected	Zero	Mid	Aft limit	40 kts	OEI + 1s	OEI + 1s	OEI + 1.5s	N/A	0 kts	Free to caster	Your Dry model	Your Dry model
14	SL	ISA	Max TO	Most deflected	Zero	Mid	Aft limit	60 kts	OEI + 1s	OEI + 1s	OEI + 1.5s	N/A	0 kts	Normal	Your Dry model	Your Dry model
15	SL	ISA	Max TO	Most deflected	Zero	Mid	Aft limit	60 kts	OEI + 1s	OEI + 1s	OEI + 1.5s	OEI + 2s	0 kts	Normal	Half the Dry	Half the Dry
16	SL	ISA	Max TO	Most deflected	Zero	Mid	Aft limit	60 kts	OEI + 1s	OEI + 1s	Full Symmetrical brakes	N/A	0 kts	Normal	Half the Dry	Half the Dry
17	SL	ISA	Max TO - 10%	Most deflected	Zero	Mid	Aft limit	60 kts	OEI + 1s	OEI + 1s	OEI + 1.5s	N/A	0 kts	Free to caster	Your Dry model	Your Dry model
18	SL	ISA	Max TO - 10%	Most deflected	Zero	Mid	Aft limit	60 kts	OEI + 1s	OEI + 1s	OEI + 1.5s	N/A	0 kts	Normal	0.2	0.25
19	SL	ISA	Max TO	Most deflected	Zero	Mid	Aft limit	60 kts	OEI + 0.5s	OEI + 0.5s	OEI + 1s	N/A	0 kts	Free to caster	Your Dry model	Your Dry model
20	SL	ISA	Max TO	Most deflected	Zero	Mid	Aft limit	60 kts	OEI + 0.5s	OEI + 0.5s	OEI + 1s	N/A	0 kts	Normal	0.2	0.25

For each simulation case the OEM's presented results for maximum deviation from the runway centerline and airplane longitudinal ground speed when first wheel lateral deviation is higher than half the width of the runway (if at least one wheel exited the assumed runway width). Runway width was assumed as 30 meters or 45 meters depending on the individual characteristics of the airplanes (ICAO runway code was used as a reference). The following results, observations and conclusions can be drawn from the simulation exercises:

- There were no runway excursions for any of the simulated airplanes in the forward CG case, even though the nose wheel steering was free to caster (case 2)
- There were no runway excursions for any of the simulated airplanes in the heavy weight case, even though the nose wheel steering was free to caster (case 3)
- There were no runway excursions for any of the simulated airplanes in the case of OEI at 80 knots, even though the nose wheel steering was free to caster (cases 6 and 7)
- There were no runway excursions for any of the simulated airplanes in the dry runway and normal steering case with OEI at 60 knots (case 14)
- There were no runway excursions in any case for the evaluated three engine jet with rear mounted engines, even when assessed on a 30 meters wide runway
- There were no runway excursions in any case for relatively small airplanes assessed at 45m runways
- The majority of the excursion cases in the study occurred for larger airplanes (large transport jets) assessed at 45m runways or for regional jets and long range business jets assessed at 30m runways
- There is a somewhat linear trend between the crosswind value and the lateral deviation (cases 1, 4 and 5)
- OEI at 40kts results in lateral deviations equal to or larger than OEI at 60kts (cases 1and13), although it is known from Topic 10 and common sense that the consequences of veering off at 40kts tend to be less severe than at 60kts
- Use of reverse thrust has some noticeable effect on the lateral deviation for most airplanes, even with a two second delay for max reverse application (cases 8 and15)
- Use of full differential brakes instead of full symmetrical brakes (one full brake pedal instead of two) is a better course of action for all airplanes when dealing with low speed OEI RTO's (cases 8 and 16). In many cases, especially for the larger airplanes, the use of differential brakes markedly decreased the lateral deviations when compared to the full symmetrical brakes
- Disregarding any potential adverse impact on the longitudinal takeoff distances or exposure time at low speed, the use of 10% derate thrust instead of maximum takeoff thrust resulted in approximately 20% lower lateral deviations (cases 17 and 18)

- Half a second quicker reaction times on the rudder pedals, thrust levers and differential braking produced an average of more than 50% reduction in the lateral deviations.
- Some results and analyses indicate there are technical limitations in the way these simulations were modeled, meaning some of the results may not be reliable. The identified issues include:
  - There is no existing industry standard or data for cornering coefficient values or modeling for higher tire slip angles associated with slippery or contaminated runways. The data provided should be appropriate for trends but the accuracy is unable to be validated. Note that this concern is applicable for the engineering analysis data provided as well as for the training devices. The training devices ground models are typically proprietary to the simulator manufacturers and not provided by the OEM's.
  - Utilizing a friction coefficient of half of the dry values is arbitrary and subject to variability in the cornering friction values of the dry runways.
  - The crosswind effects were introduced as a step increase on the slippery runways when nose gear steering was not available. Without nose gear steering or differential braking and no airspeed for rudder effectiveness, there was no means to keep the airplane on the runway centerline.

Discussing the Prerequisites for Introducing Subpart B Controllability Criteria for Low Speed OEI RTO Under All Anticipated Operating Conditions

In accordance with the Swedish incident investigation report the FAA and EASA are recommended to investigate, in consultation with each other, "the prerequisites for introducing requirements concerning yaw stability in large aircraft in the event of sudden loss of engine thrust below V_{MCG} under the anticipated operating conditions."

The Flight Test Harmonization Working Group – comprising the FAA and EASA as well other Airworthiness Authorities, Airframe Manufacturers, Operators and Labor Union – has debated about different prerequisites for introducing a new requirement on low speed OEI RTO under all anticipated operating conditions, including aspects such as feasibility, practicality, technical limitations, effectiveness, impact on aircraft design, impact on aircraft limitations, impact for the operators and, of course, impact on safety.

A straightforward approach would be to establish a set of controllability performance criteria for different conditions, for instance a regulation that would impose a maximum allowable deviation from runway centerline during an RTO as a function of a combination of runway friction coefficient or type of contaminant, different values of crosswind components and engine failure speeds. The OEM's would then design their airplanes alongside those criteria and the resulting airframe would expectedly be able to cope with low speed OEI RTO at any foreseeable operating conditions with somewhat limited lateral deviations. It is assumed the aircraft would also be tested against the criteria, either by flight tests or simulations.

The first problem with that rationale is that it implies the OEM's have feasible and practical technical solutions to be implemented in the designs to counteract the effects of low speed OEI RTO's in all conditions. The FTHWG has discussed the kinds of systems and physical design features that could be more or less helpful in these cases. In general terms the design feature would need to either actuate the control surfaces or the differential brakes or nose wheel steering or reduce the thrust asymmetry (or a combination thereof) quicker than the human pilot (automatic feature).

While automatic rudder command for thrust asymmetry compensation is a reality in some designs, it is far from sufficient to address the low speed range where the control surfaces are not effective or less effective. While auto-brakes are also a common feature in most modern transport designs, slippery runway conditions also limit its effectiveness. Also, the most effective type of auto-brake for this scenario would be one that automatically detects the engine failure and commands full differential braking (only in the low speed range). This would be a novel feature and was only mentioned hypothetically in the FTHWG brainstorm session.

Similarly, the group is aware of Automatic Takeoff Thrust Control System implementations (ATTCS), features that automatically change the thrust from the remaining live engine(s) in case one engine fails, but these kind of features do not command idle thrust, let alone reverse thrust. There are implementations, however, capable of commanding an engine shut down to cope with Uncontrollable High Thrust type failures (UHT). But especially when considering the probable outcome of a low speed veer off (low speed veer offs have occurred with typically minor consequences), the incorrect behavior of an automatic engine shut down system seems to introduce more safety concerns than it tries to address.

Other current implementations have the FADEC automatically limiting the maximum thrust and commanding a gradual thrust increase at the beginning of the takeoff run to improve ground control on aircraft with under wing mounted engines. However, with proper training, pilots are already capable of manually achieving the same effect. It is worth noting that this kind of implementation generates a trade-off between longitudinal takeoff distance (for high speed accelerate-stop performance or accelerate-go performance) and lateral deviation in case of low speed OEI RTO. It also represents a trade-off between the outcome of a low speed OEI RTO and the exposure time at the low speed range where this failure could be critical.

It seems inappropriate with the current technology to mandate the implementation of systems such as those exemplified above (or to otherwise introduce controllability regulations that would inevitably lead to those systems). They would unduly increase the cost and complexity of new Part 25 aircraft and introduce additional sources of failures and combinations of failures. The balance between the potential benefit and the unintended consequences is under par given the unlikely combination of low speed engine failure, low weight, aft CG, crosswind and low friction runway conditions.

Airplane designs with three rear mounted engines have in general a lower thrust asymmetry in the OEI case and as a consequence are less prone to the hazard associated with low speed OEI RTO at any foreseeable conditions (as shown by one example in our simulation study). Nevertheless, the group feels that mandating such airplane configurations with the sole purpose of addressing the low speed RTO issue would be yet another example of unbalanced cost/complexity to benefit.

In summary, currently there are no practical *design features* available that would eliminate the potential safety issue for any foreseeable operating condition, for Part 25 airplanes of any size, configuration, takeoff thrust or number of engines. Therefore, this kind of regulation would not meet an important prerequisite for new regulations: to improve safety by inducing a meaningful change in the way airplanes are designed.

From the Part 25 certification perspective a remaining option would be to use a Subpart B controllability criteria for low speed OEI RTO to establish airplane *limitations* in the AFM. The group recognizes that, from the safety perspective alone, this could be beneficial. However, at this point it is important to note:

- The FTHWG is indeed recommending harmonization in the sense of prohibiting takeoff on very low friction surfaces such as wet ice. This will be further discussed in this report. But this recommendation is universal, i.e., it is not attached to specific Subpart B criteria;
- According to the Swedish incident report the TC holder for the aircraft involved in the incident did have a recommendation in place not to operate under 0.05 friction coefficient. While the report states the pilots had been informed the runway was good, with some patches of ice, the investigation revealed that the runway was contaminated and likely had coefficients of friction which fell short of the reported values. This inconsistency, however, was not reported as part of the contributing factors for the incident;
- Consultation with operators, both in Europe and North America, as well as insight from the Canadian TCCA, made it clear that operations in contaminated runway conditions are common, especially during winter operations. Therefore, introducing AFM limitations for takeoff on other kinds of contaminant (other than wet ice) without a careful examination of the frequency and relevance of such operations could result in a considerable impact for those operators and a corresponding burden

to the affected communities. From that perspective, this kind of regulation could be inappropriate as to another prerequisite: to have an adequate cost-benefit balance.

Yet another issue with the approach of establishing Part 25 criteria to deal with this particular issue is the available means of compliance. Different FTHWG topics have dealt with the technical and practical challenges of properly modeling some environmental conditions for flight simulator purposes or flight testing those conditions. The final report for Topic 10 – Runway Excursion Hazard Classification – briefly discusses the practical challenges of modeling and validating the side forces acting on the tires on a wet runway for simulation purposes (for failures that induce yawing moments or failures combining high crosswind values on wet runways). The final report for Topic 9 – Wet Runway Stopping Performance – discusses the logistical and practical challenges of representing realistic effect of heavy rain or standing water on runways for flight test purposes. Finally, Topic 14 – Crosswind and Tailwind – discussed two correlated aspects in great length: 1) The logistical challenges of obtaining the target environmental conditions in the course of a flight test program (it is worth noting that target environmental conditions for crosswind demonstrations usually mean high crosswind and dry runway, whereas for the present topic it would mean different combinations of runway conditions and wind and, for test safety, adequate runway width to provide margin beyond expected lateral deviation; 2) The technical challenges of modeling and validating the use of simulators (even with pilot-in-the-loop) for handling qualities assessment under high crosswind scenarios.

Other examples of the technical challenges of simulating dynamic combinations of environmental conditions on ground were found during the initial simulation exercises discussed in the previous section of the present report. Similar complications are described in the Swedish SHK incident report, section 1.16a.4 on pages 50 and 51. Therefore, it appears to be impractical to introduce a new Subpart B regulation with clear acceptable means of compliance to completely address this issue for any foreseeable combinations of runway conditions (including contaminated runway conditions) and environmental conditions (including different levels of crosswind).

A Way Forward to Improve Safety

After reviewing the available information, including the incident report, the results from the initial simulation study, accounts and best practices from affected Part 25 operators, OEM's Operating and/or Training Manuals recommended practices and existing training practices, the majority of the FTHWG members agreed that the best way forward to address the safety issue of low speed OEI RTO is to introduce guidance to §25.143(b)(1) specifying a new Part 25 standard RTO demonstration by flight test or simulation on dry runway and – in addition – to produce combined recommendations in the areas of Operations and Procedures, Flight Crew Training and Cockpit Controls to mitigate the potential hazards associated with slippery runways.

The FTHWG has achieved full consensus on this topic. See general comments below.

General Comments	FTHWG Response to Comments
Dassault remark on proposed addition of a new guidance for evaluation of the effect of a low speed engine failure on a dry runway: This new evaluation might be useful for possible new aircraft with very powerful underwing engines but for aircraft fitted with fuselage mounted engines it does not seem very relevant since the lateral deviation following this type of event is low or very low. In consequence Dassault will abstain on this specific subject.	The group's initial simulation study showed at least one aircraft model with fuselage mounted engines and noticeable lateral deviations (even in the dry runway case with nose wheel steering engaged). The particular model in question has a very high thrust to weight ratio. The FTHWG understands the proposed demonstration creates an upper bound to the low speed OEI thrust asymmetry of future aircraft, regardless of the configuration. The FTHWG also believes the proposed demonstration

	would not be overly onerous to the OEM since it could be done by conservative offline analysis/simulation.
ALPA's note: Many group discussions have occurred specifically with respect to the topic of using a de-rate takeoff as a method to increase lateral stability at low speeds on contaminated runways. Through these conversations some group members have attempted to investigate whether de-rate takeoffs are permitted by various operators, as well as whether the technique is employed in practice. Although these methods of sampling were not conducted in an official or scientific research capacity, the group is confident in the information received. As such, it has been determined that many operators do not have the ability to conduct de-rate takeoffs, some use the assumed temperature model only on non-contaminated runways, and a few operators used de-rate for takeoff on contaminated runways. It has been shown through simulation that a reduced thrust (assumed temperature or de-rate) may assist with maintaining lateral directional control on contaminated runways should a low speed rejected takeoff be conducted with asymmetric thrust. ALPA's concerns with promoting the use of a reduced thrust takeoff on a contaminated runway are two-fold: the widespread variation in actual runway contamination reports, especially during active weather, and the longer takeoff roll exposure with reduced thrust that can further expose the aircraft to impact ice, slush, and foreign object debris during takeoff. The uniformity of contamination reports is inconsistent from airport to airport. During some weather events, it is possible that only a narrow portion of the runway in use has been treated or plowed, which may lead to outboard engines and aircraft surfaces exposed to additional contamination. Rather than dissenting to the potential use of reduced thrust takeoffs, ALPA would prefer this option be further studied where a comparison of the safety improvements versus the other inherit risks be conducted prior to agreeing with a modification of the Advisory Circular.	The FTHWG acknowledges ALPA's comment and clarifies that this group is not directly proposing changes to the operating regulations and guidance in regards to the use of reduced thrust on contaminated runways. Nevertheless, after recognizing the *potential* benefit of using reduced thrust on contaminated runways (at least from the point of view of directional control and engine out controllability) the group recommends the FAA – in coordination with a group of experts in the area of Operations – to further study this subject and to analyze all its positive and negative aspects.
Airbus comment: Airbus understands the original intent of demonstrating the ability to apply full differential braking when rudder pedals are fully deflected (Attachment 30E) but highlights at the same time that on a slippery runway, the braking efficiency will be limited by the anti-skid system before the full braking.	The FTHWG acknowledges the Airbus comment and clarifies that the proposal in Attachment 30E could be beneficial at least on dry and wet runway conditions where braking efficiency is still high.

Recommendation

The Flight Test Harmonization Working Group recommends the FAA to introduce a specific dry runway low speed RTO controllability demonstration to Advisory Circular AC 25-7C.

Part 25 Subpart B Guidance:

- Introduce low speed RTO controllability demonstration by flight test or simulation on a dry runway

In addition, the FTHWG recommends the FAA to coordinate with a group experts in the areas of Operations, Flight Crew Training and Cockpit Controls/Ergonomics – and their respective HWG – to implement regulation language and/or guidance language containing further mitigation for low speed RTO on slippery runways in the areas introduced below.

Operations and Procedures:

- Do not takeoff if the runway surface is contaminated with wet ice
- Consider using lower thrust settings if shown to be safe
- Consider loading the aircraft in the medium to forward CG range
- Adjust pedal position properly, so that full rudder and full differential brakes can be applied simultaneously in the same sense
- Include/update information on Operating and/or Training Manuals

Flight Crew Training:

- Introduce specific ground training for low speed OEI RTO including slippery runways
    - Raise awareness of flight crews for the potential controllability issue
    - Emphasize training for quick reactions
    - Introduce training for use of differential brakes (one full brake pedal input)
    - Introduce recommendation for proper pedal adjustment before takeoff
    - Include/update information on Operating and/or Training Manuals
- Introduce dedicated simulator task with low speed OEI RTO on slippery runways
    - Revise the academic syllabus and simulator training sessions to include an event focused on the particular challenges of a low speed RTO due to engine failure
    - Revise FAA's AFS (Flight Standards) takeoff safety training aid

Cockpit Ergonomics:

- Include additional guidance for §25.777 to ensure simultaneous full rudder and full differential braking (in the same sense) can be achieved by crew of different statures

Attachments 30B through 30E contain the FTHWG rationale supporting and detailing each of the recommendations above and explaining the expected safety improvement.

A. Rulemaking

1. What is the proposed action?

It is recommended that the FAA introduce guidance to §25.143(b)(1) specifying a new Part 25 standard RTO demonstration by flight test or simulation on dry runway. In addition, the FAA should coordinate with a group experts in the areas of Operations, Flight Crew Training and Cockpit Controls/Ergonomics – and their respective HWG – to introduce regulation language and/or guidance language to address the potential safety issues associated with controllability during low speed OEI RTO on slippery runways.

2. What should the harmonized standard be?

The group considers the existing regulation §25.143 to be sufficient to address the safety issue and recommends the FAA to introduce new guidance to this regulation (specifically to §25.143(b)(1); see Attachment B). As for the other mitigation means to address the potential hazards associated with slippery runways, the FTHWG is not proposing specific regulatory or guidance language (see Attachments 30C thru 30E for details). The FAA should coordinate the final language with other HWG, including specialists in the areas of operations, training and cockpit controls.

3. How does this proposed standard address the underlying safety issue?

The introduction of a low speed OEI RTO demonstration by flight test or simulation as proposed in Attachment 30B will present clear criteria to assess this particular scenario. To date, OEM's only indirectly address this topic, for instance via V_{MCG} or crosswind tests (albeit generally at higher speeds). This new criteria will provide an upper limit to future airplanes in regards to the designed OEI thrust asymmetry at low speeds (maximum engine thrust and geometry of engine installation) and/or lead to improvements in low speed directional control on ground (e.g. nose wheel steering and differential braking). The new criteria will otherwise compel airplane manufacturers who introduce configurations with thrust asymmetry considerably beyond current levels to include new compensating features (such as those discussed in the Consensus session).

The FTHWG has also provided recommendations for further consideration by the FAA and experts in the areas of Operations, Flight Crew Training and Cockpit Controls/Ergonomics in Attachments 30C thru 30E to further mitigate the underlying safety issues as follows:

Operational recommendations raise awareness to the flight crew about the potential controllability issues associated with low speed OEI RTO, especially on contaminated runways. The recommendations include limiting a known critical condition associated with wet ice. Use of lower thrust settings and loading at a more forward CG improve the initial conditions in case of low speed OEI RTO and therefore reduce the lateral deviation for any runway condition. Safety is also improved by universally recommending the crew to properly adjust the rudder and brake pedals to facilitate simultaneous application of full differential brakes and full rudder in the same sense.

Training recommendations will also raise awareness to the flight crew about the potential controllability issues associated with low speed OEI RTO. Safety is improved by presenting the pilots with a specific procedure (differential brakes) which is shown in our study to substantially reduce the lateral deviation of the aircraft in low speed OEI RTO's. Ground training would also emphasize the need for proper pedal adjustment and quick reactions in the event of OEI during takeoff. Ground training would be complemented by a dedicated simulator task to expose the flight crew to this specific scenario. The revision of the FAA Takeoff Safety Training Aid would also improve safety by highlighting this potential safety issue to a broader audience.

Cockpit Controls/Ergonomics recommendations would improve safety by ensuring new Part 25 aircraft cockpits are designed to assure that the recommended operational procedures related to this issue can be promptly accomplished by crew of different stature.

4. Relative to the current FAR, does the proposed standard increase, decrease, or maintain the same level of safety? Explain.

The FTHWG is not proposing specific regulatory language. Nevertheless, the FTHWG recommendations contained in Attachment 30B increase the level of safety by providing clear criteria for future airplane design in regards to the specific hazards associated with low speed OEI RTO. As discussed in section 3 above, these criteria would introduce an upper limit to the amount of engine out thrust asymmetry and/or drive improvements on low speed controllability on ground.

5. Relative to current industry practice, does the proposed standard increase, decrease, or maintain the same level of safety? Explain.

The FTHWG is not proposing specific regulatory language. Nevertheless, the FTHWG recommendations contained in Attachments 30B thru 30E increase the level of safety. While current airplane designs in terms of maximum OEI thrust asymmetry at low speeds, geometry of engine installation and ground control systems (such as nose wheel steering, tiller installations and brakes) would not necessarily be different (had Attachment B guidance be available in previous interactions of AC 25-7) it would have raised awareness for this specific hazard so it could be assessed with a standard demonstration. Conversely, while some OEM’s already provide operational recommendations (prohibition of takeoff on wet ice, rudder pedal adjustment, use of differential braking, etc.) this information is not universally provided nor are the flight crews trained for this specific purpose.

6. Who would be affected by the proposed change?

OEM’s (new demonstration by flight test or simulation, operational/training manuals, training syllabus and cockpit controls), training companies/partners and operators.

7. Does the proposed standard affect other HWG’s and what is the result of any consultation with other HWGs?

The FTHWG is recommending the FAA to formally consult with Operations, Training/Simulator and Flight/Cockpit Controls Working Groups to properly develop and introduce guidelines described in Attachments C thru E. The group has not directly consulted with these other working groups but Subject Matter Experts in those areas (from the OEM's and the FAA) were consulted and generally supported the proposals. The group also consulted several operators to understand their current practices regarding the use of reduced thrust on contaminated runways. As summarized in ALPA's general comment, the result of this consultation was that many operators do not have the ability to conduct de-rate takeoffs, some use the assumed temperature model for reduced thrust only on non-contaminated runways, and a few operators used de-rate for takeoff on contaminated runways. The FTHWG concluded that more in-depth consultation and study will be needed to help validate or discard an universal recommendation for use of reduced thrust on contaminated runways, taking into consideration all positive and negative consequences, for example, the trade between directional control and takeoff longitudinal distances.

B. Advisory Material

1. Is existing FAA advisory material adequate? If not, what advisory material should be adopted?

In regards to Part 25 Subpart B the existing FAA advisory material is not adequate because it lacks any specific assessment of controllability during low speed OEI RTO. The proposal in Attachment B should be adopted.

Attachments C thru E contain additional proposals that will require coordination with other working groups and SME's outside the scope and expertise of the FTHWG. This future work could eventually affect other FAA regulations and advisory material.

2. To ensure harmonization, what current advisory material (e.g., ACJ, AMJ, AC, policy letters) needs to be included in the rule text or preamble?

For harmonization purposes, it is recommended that ANAC, EASA and TCCA guidance material be revised to reflect the proposed FAA AC change.

Economics

A. What is the cost impact of complying with the proposed standard (it may be necessary to get FAA Economist support to answer this one)?

To address the proposed Part 25 Subpart B guidance the applicant needs to perform either a flight test or a simulation demonstration that is not currently included in most certification programs. However, the demonstration outlined in Attachment 30B is technically simple and straightforward and it does not seem to this group to impose a considerable cost burden. The additional guidance intended for operations/training manuals associated with the general operational proposals of Attachment 30C and the proposal for clarification related to cockpit controls in Attachment E are also considered to be a minimal cost impact.

The initial simulation study performed by the FTHWG for this topic (dry runway case, with engine failure at 60kts, mid weight, aft CG, no crosswind and nose wheel steering operating normally) indicates that current industry standards in terms of aircraft design are adequate to pass the proposed demonstration. As such, the FTHWG considers the economic impact would be minimal for future aircraft designs similar to the current ones.

The FTHWG is not proposing in this report the final standards in terms of training and simulator task introduced in Attachment 30D, but simply recommending the FAA to coordinate that activity with a group of experts on training and simulators. The FTHWG understands that if the outcome of that future activity includes recurring training, the potential cost impact to the operators could be substantial. If, on the other hand, the outcome of that future activity is an initial training task only, the cost impact would probably be lower.

B. Does the HWG want to review the draft NPRM prior to publication in the Federal Register?

Yes, please.

ICAO Standards

How does the proposed standard compare to the current ICAO standard?

The ICAO Annex 8 specifies under 2.3.2 Controllability:

> “2.3.2.1 The aeroplane shall be controllable and manoeuvrable under all anticipated operating conditions, and it shall be possible to make smooth transitions from one flight condition to another (e.g. turns, sideslips, changes of engine power or thrust, changes of aeroplane configurations) without requiring exceptional skill, alertness or strength on the part of the pilot even in the event of failure of any engine. A technique for safely controlling the aeroplane shall be established for <u>all stages of flight and aeroplane configurations for which performance is scheduled</u>.
>
> Note.— This Standard is intended, among other things, to relate to operation in conditions of no appreciable atmospheric turbulence and also to ensure that there is no undue deterioration of the flying qualities in turbulent air.

> 2.3.2.2 Controllability on the ground (or water). The aeroplane shall be controllable on the ground (or on the water) during taxiing, take-off and landing under the anticipated operating conditions.
>
> 2.3.2.3 Controllability during take-off. The aeroplane shall be controllable in the event of sudden failure of the critical engine at any point in the take-off, when the aeroplane is handled in the manner associated with the scheduling of take-off paths and accelerate-stop distances."

The scheduling of performance is in paragraph 2.2.7. This says that the scheduling of performance shall account for:

> "mass, altitude, wind, and gradient of the surface for landplanes (…)" and for "(…) any other operational variables for which the aeroplane is to be certificated".

Surface friction condition is not specifically addressed. Note that FAA approved airplanes do not necessarily have approved (certificated) scheduled performance data for contaminated runways. It could be interpreted that 2.3.2.1 and 2.3.2.3 are not applicable on contaminated runways for airplanes certified by the FAA.

At any rate, the engine failure point is assumed to be:

> "(…) not nearer to the start of the takeoff than that assumed when determining the takeoff path (…)".

This suggests that engine failure below V_{MCG} is not to be considered.

In conclusion, current ICAO Annex 8 does not address the particular issue of low speed OEI RTO at any foreseeable condition.

Attachment 30A: Topic 30 Work Plan

Work Plan – Controllability During Low Speed OEI RTO

1. What is the task?

To recommend harmonized means of addressing the Swedish Accident Investigation Authority safety recommendation regarding engine out rejected tekoffs at speeds below VMCG including slippery runways. It may also include Training, Procedures and Operational recommendations.

2. Who will work the task?

The Flight Test Harmonization Working Group (FTHWG) will have primary responsibility for this task. Consultation with flight operations SME's or direct contact with the operators community may be needed.

3. Why is this task needed? (Background information)

In January 2010 there was a serious incident in Sweden with a jet transport airplane in a runway contaminated with ice (see reference below). The airplane veered-off at approximately 60kts after one of the engines failed during a takeoff run. Despite the pilot having promptly applied rudder in the correct sense he also accidentally applied differential braking in the wrong sense (failed engine instead of live engine). Nevertheless the investigation did not find evidence (with a reasonable degree of certainty) that the braking input had any contribution to the veer-off.

The Swedish investigation concluded that one of the factors that contributed to the incident was:
"Deficiencies in the certification process for large aircraft with wing mounted engines with regard to requirements for yaw stability in the event of sudden loss of engine power in the speed range below VMCG."

And the final report for this investigation also recommended the FAA to:
"Investigate, in consultation with EASA, the prerequisites for introducing requirements concerning yaw stability in large aircraft in the event of sudden loss of engine thrust below VMCG under the anticipated operating conditions. (RL 2012: 21 R2)."

4. References (existing regulatory and guidance material, including special conditions, CRIs, etc.)

Swedish incident report RL 2012:21e Serious incident on 16 of January 2010 to aircraft EP-IBB at Stockholm/Arlanda Airport, Stockholm county, Sweden.

This topic is basically related to controllability during a rejected takeoff. Therefore the only applicable regulations are §25.143(a) and (b) (Controllability). However, this subject is also loosely related to §25.149(e) (VMCG), EASA CS-25 §25.1591 (Contaminated Runway) and 25.1309, FTHWG Topic 10 runway excursion following system failure.

5. Working method

It is envisioned that 3-4 one day face-to-face meetings will be needed to facilitate the discussion needed to complete this task. Telecons and electronic correspondence will be used to the maximum extent possible.

6. Preliminary schedule (How long?)

Recommendations to Transport Airplanes and Engines Subcommittee within 12 months of the initiation of work on these tasks.

7. Regulations/guidance affected

14 CFR Part 25 regulations §25.143
AC 25-7C (p.57)

8. Additional information

Extract from the incident report:

“ (…) After taxiing out, the crew began routine take-off procedures by increasing engine thrust during acceleration on the runway. After just over 10 seconds, one or more of the edges in a repaired section of the engine – the diffuser aft air seal – separated, thereby triggering a sequence which led to a sudden engine failure.

No warning messages were announced in the cockpit at the time of the failure; the pilots only noticed the engine failure through a muffled bang at the same time as the aircraft began to veer to the left. The initial veer, immediately after the engine seizure, was a result of the nose wheel being unable to gain sufficient force against the contaminated surface to counteract the moment which arose when the right engine – for a duration of approximately 1.5 seconds – supplied full thrust at the same time as the left engine rapidly lost thrust. The highest speed registered during the sequence was 59 knots (110 km/h).

Despite the co-pilot’s reactions – retarding the thrust levers after just over a second, at the same time as steering and opposite rudder were applied – the veer could not be corrected and the aircraft ran off the runway, mainly caused by the forces from the moment in combination with the slippery surface. The chances of stopping the continued veer were probably reduced by the fact that the pilots did not apply any differential braking in the opposite direction.

The investigation also showed that the pilots’ braking was unintentionally asymmetrical, with a higher brake pressure on the “wrong side”, i.e., in the direction in which the aircraft ran off the runway. Even if this fact may have affected the aircraft’s movement pattern, such an impact has, however, not been possible to determine with any reasonable degree of certainty. It is, nevertheless, noteworthy that analyzed data from the FDR show that the recorded brake angles (asymmetric braking) were not accompanied or followed by any corresponding change in the rate of heading change.

There are no specific certification requirements for aircraft design organization to show that the aircraft is maneuverable in the event of a sudden loss of engine thrust during the initial stage of the take-off sequence. There are also no mandatory requirements for training regarding how to handle sudden losses of engine thrust during the initial stage of the take-off sequence for pilots in training or recurrent training for this class of aircraft. (…)”

Attachment 30B: Proposed change to Controllability After Engine Failure Guidance

The Flight Test Harmonization Working Group recommends the FAA to implement the changes below (marked in blue) to the guidance for §25.143(b)(1) in AC 25-7C, Section 3. Controllability and Maneuverability, paragraph c. Controllability Following Engine Failure. The group recommends similar guidance language to be adopted also by the other airworthiness authorities.

The numerical criteria proposed in paragraph (k) below were loosely based on the ICAO Annex 14 criteria for runway design. The final numbers on Figure 20-1 were checked against the initial simulation study (case 14) with consideration given to typical runway width for very large transport airplanes. The proposal also substitutes the discrete criteria used by ICAO with a continuous range of lateral deviation as a function of wing span.

Paragraph 20. General – §25.143.

c. Controllability Following Engine Failure. Section 25.143(b)(1) requires the airplane to be controllable following the sudden failure of the critical engine. To show compliance with this requirement in flight, the demonstrations described in paragraphs (1) and (2), below, should be made with engine failure (simulated by fuel cuts) occurring during straight, wings level flight. To allow for likely in-service delays in initiating recovery action, no action should be taken to recover control for two seconds following pilot recognition of engine failure. The recovery action should not necessitate movement of the engine, propeller, or trim controls, and should not result in excessive control forces. Additionally, the airplane will be considered to have reached an unacceptable attitude if the bank angle exceeds 45 degrees during the recovery. These tests may be conducted using throttle slams to idle, with actual fuel cuts repeated only for those tests found to be critical. Also, the demonstrations described in paragraph (3), below, should be made in order to assess the airplane controllability on ground during rejected takeoffs following engine failure at low speeds.

(1) At each takeoff flap setting at the initial all-engine climb speed (e.g., V_2 + 10 knots) with:

(a) All engines operating at maximum takeoff power or thrust prior to failure of the critical engine;

(b) All propeller controls (if applicable) in the takeoff position;

(c) The landing gear retracted; and

(d) The airplane trimmed at the prescribed initial flight condition.

(2) With the wing flaps retracted at a speed of 1.23 V_{SR} with:

(a) All engines operating at maximum continuous power or thrust prior to failure of the critical engine;

(b) All propeller controls in the en route position;

(c) The landing gear retracted; and

(d) The airplane trimmed at the prescribed initial flight condition.

(3) The applicant should demonstrate – by flight test or simulation – the airplane is controllable during a low speed rejected takeoff maneuver following an engine failure. The following guidance applies:

(a) The demonstrations should be made at each takeoff flap setting or, at the option of the applicant, at the most critical flap setting for the maneuver;

(b) The airplane should be configured with aft CG and mid weight. Mid weight should be proposed by the applicant based on a typical light takeoff weight range: a weight mid-range between Minimum Operating Weight and Maximum Takeoff Weight is considered a reasonable default value;

(c) A dry, smooth and zero slope runway should be used. Testing should not be conducted on runways with excessive crowning (i.e., cross-runway slope) unless the effects of such crowning are determined to be conservative;

(d) Wind conditions may be nominally calm. Crosswind components from the critical side (the side that maximizes the airplane lateral deviation during the RTO) are permitted;

(e) All aircraft systems, such as flight control surfaces, brakes and nose wheel steering, should be functioning normally throughout the maneuver, except as affected by the failure of the critical engine;

(f) The testing should be made from an initial condition with all engines set to maximum available takeoff power or thrust;

(g) The critical engine should be suddenly made inoperative (actual fuel cut; or throttle chop to idle with additional substantiation/analysis) at different speeds between brakes release and V_{MCG} or, at the option of the applicant, at the critical speed for lateral deviation during an OEI RTO;

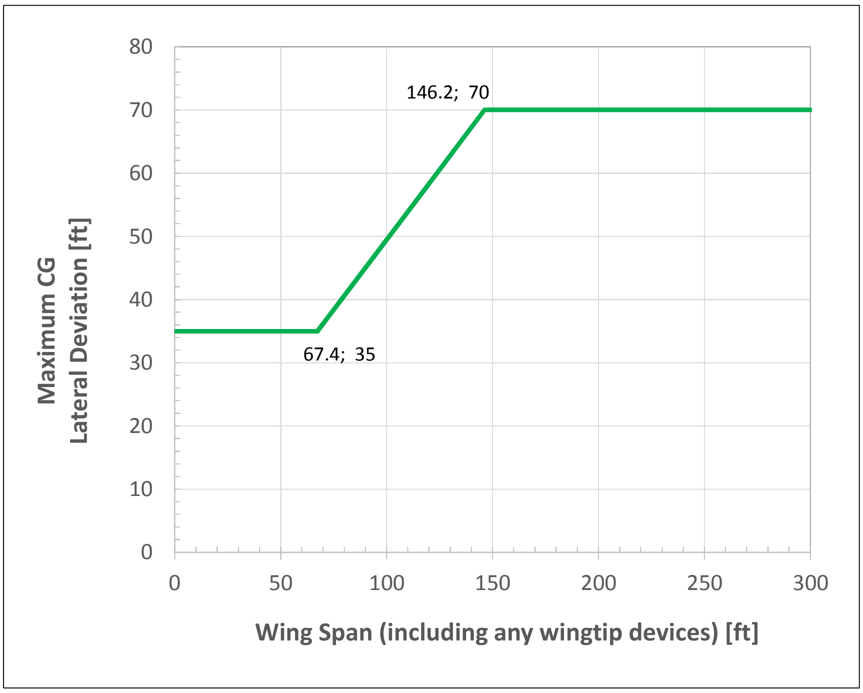
(h) Following one engine failure the pilot should abort the takeoff using the applicant's recommended procedures. The use of nose wheel steering/tiller command and/or differential brakes is permitted;

(i) The RTO maneuver should not require exceptional pilot skills, alertness or strength. If the applicant elects to demonstrate these maneuvers using offline simulation tools (as opposed to pilot-in-the-loop simulations) care should be taken to properly represent the pilots' recognition and reaction times. One acceptable approach is to consider the pilot's actions on the rudder pedals at no less than 0.5 second after the engine failure; thrust levers no less than 1 second after the engine failure; and brakes (and tiller if applicable) no less than 1.5 second after the engine failure;

(j) If compliance is demonstrated by simulation, the level of fidelity of this simulation should be commensurate to the proximity to the criticality of the test results, i.e. high fidelity simulation is only required when the lateral deviation is close to the limit defined in (k) below;

(k) During the demonstrations and until the aircraft comes to a full stop its center of gravity should not laterally deviate from the pre-engine-cut projected ground track by more than the distance specified in the chart below:

Figure 20-1. Low Speed OEI RTO lateral deviation criteria



Attachment 30C: Operational Recommendations

Operations and Procedures:

- Do not takeoff if the runway surface is contaminated with wet ice

  This recommendation is already expressed in other sources. For example, AC 150/5200-28F (Notices to Airmen (NOTAMS) for Airport Operators) prohibits operations when the Runway Condition Assessment Matrix (RCAM) indicates a code of "0". Code "0" represents wet ice, slush over ice, water over compacted snow, and dry snow or wet snow over ice, where braking deceleration is minimal to non-existent for the wheel braking effort applied OR directional control is uncertain.

  Since this recommendation is already widely accepted and used, an explicit statement in the Operating and/or Training Manuals would be an appropriate emphasis.

- Add guidance highlighting that pedal position should be properly adjusted, so that full rudder and full differential brakes can be applied simultaneously in the same sense.

  This recommendation highlights the fact that directional control on a slippery runway, in the event of an engine failure, relies heavily on differential braking at low speeds, in addition to rudder control pedal inputs.

  Since this may not be widely recognized, additional guidance in the Operating and/or Training Manuals is recommended.

- Use of lower takeoff thrust settings

  Use of lower thrust (e.g. via the assumed/flex temperature reduced thrust method or de-rate) will decrease the asymmetric thrust and associated yawing moment upon engine failure. This will reduce the lateral deviation from runway centerline during either an RTO or continued takeoff above V_1. For takeoff on wet or contaminated runways, consideration should be given to runway conditions, crosswind magnitude, and runway length and width when selecting the level of takeoff thrust to balance the risks associated with runway departure following an engine failure during the takeoff roll. Since this may not be widely recognized, additional guidance in the Operating and/or Training Manuals is recommended.

  During the simulation exercises the FTHWG confirmed that the use of lower thrust settings is indeed beneficial in case of low speed OEI RTO. Nevertheless, the group recognizes there are some aspects of this operation that need more in-depth study and formal consultation with a larger group of operators and operations specialists before making this a universal recommendation. For example, there is a trade-off between lateral deviation in case of engine failure at low speeds and longitudinal takeoff distances in case of engine failure at or above V_1. Also, there may be inconsistences between the actual runway conditions and runway status reports when the runway is contaminated. The presence of loose contaminants (e.g. greater than 3 mm of water, snow, or slush) and the different techniques used to decontaminate runways may also impose additional operational variability when trying to correlate the actual runway state with dispatch figures based on standard calculation models and assumptions.

- Consider loading in the medium to forward CG (center of gravity) range

  Increased loading on the nose landing gear improves control effectiveness of the nosewheel steering. For takeoff on runways contaminated with standing water, snow, slush, or ice, the airplane should be loaded to a more forward CG, if possible/practical.

Since this may not be widely known, additional guidance in the Operating and/or Training Manuals is recommended. If practical, a bias towards forward CG position would enhance ground directional controllability on slippery and contaminated runways.

Example of explanatory material:

<u>Proposed Operating and/or Training Manuals Material</u>
Before takeoff roll, the pilot should position their body and feet to be able to utilize both rudder pedals and differential braking to counter a sudden thrust asymmetry if an engine fails below V_1.

If an engine failure is detected at low speeds, immediate reduction in thrust must be managed on the remaining engine as rudder effectiveness is significantly reduced. Rudder pedal and differential braking should be utilized as necessary to conduct the RTO with emphasis on utilizing differential braking for contaminated runways. Differential braking effectiveness may be limited by any potential runway contamination, but it can still provide a significant contribution to helping keep the airplane on the runway. The brakes can generate a restoring moment based on the moment arm between the gear and the airplane centerline that is aided by the significant airplane weight on the main gear.

Use of derated takeoff thrust will decrease the asymmetric thrust and associated yawing moment upon engine failure. This will reduce the lateral deviation from runway centerline during either an RTO or continued takeoff above V_1. For takeoff on wet or contaminated runways, consideration should be given to runway conditions, crosswind magnitude, and runway length and width when selecting the level of takeoff thrust to balance the risks associated with runway departure following an engine failure during the takeoff roll.

Increased loading on the nose landing gear improves control effectiveness of the nosewheel steering. For takeoff on runways contaminated with standing water, snow, slush, or ice, the airplane should be loaded to a more forward CG, if possible.

Example of more explicit guidance material (best practice, but not mandatory):

- Takeoff is prohibited if the runway surface is contaminated with wet ice (runway condition code equals zero).

Runway Condition	***Maximum Reported Braking Action***	***Specify Takeoff Limitation or recommendation, if any***	***Specify derate recommendation, if sufficient TOFL is available***
Dry	6 - DRY	None	Derate or Reduced thrust (FLEX), as appropriate
Wet	5 – GOOD	None	Derate or Reduced thrust (FLEX, as appropriate
Compacted Snow	4 – GOOD to MEDIUM	15 kt maximum crosswind	Derate recommended, FLEX prohibited
More than 3 mm of Dry or Wet Snow	3 – MEDIUM	10 kt maximum crosswind	Derate optional, FLEX prohibited

More than 3 mm of Standing Water or Slush	2 – MEDIUM to POOR	5 kt maximum crosswind	Derate optional, FLEX prohibited
Ice (Cold and Dry)	1 – POOR	Takeoff prohibited with any crosswind	Derate recommended, FLEX prohibited

Attachment 30D: Training Recommendations

A. Add a simulator training demonstration event to introduce low speed OEI RTOs

Current test standards require that the cause for the decision to reject needs to be presented so that the first action to reject the takeoff may be made by V_1 speed for transport category airplanes. Even though this tends to be the most critical scenario for rejected takeoffs, it does not address the challenge of maintaining runway alignment with high asymmetrical thrust in the low speed regimes (around 50kts), where there may not be sufficient authority from the primary flight controls.

B. Revise the Takeoff Safety Training Aid and AC 120-62 to address the specific challenges of low speed RTOs

It is recommended that the Takeoff Safety Training Aid and related AC 120-62 be revised to explicitly address the concern over the lack of control authority in low speed regimes, especially on slippery runways.

The TOSTA currently uses a low speed RTO (V_1-20 knots) exercise as the first event on a practical training session containing 8 recommended events. The goal seems to be familiarization with the procedure mechanics, readying the pilots for the upcoming V_1 events. In this sense, the low speed RTO recommended by the training aid feels more like a warm-up exercise than a proper challenging condition. The document does not explicitly address the fact that, in regards to a high asymmetrical thrust and low controls authority combination (due to low airspeed), a low speed RTO is a critical event, especially on slippery runways.

A revision of the recommended academic syllabus and simulator training sessions to include an event focused on the particular challenges of a low speed RTO due to engine failure with Maximum Takeoff Thrust or Power (including lack of primary flight controls authority, importance of differential brakes and proper pedal position stature adjustment, influence of slippery runways, etc) would increase awareness of these aspects and improve safety. Publication of an InFO is also encouraged to raise awareness of the issue and the revision of the TOSTA and associated AC.

Attachment 30E: Cockpit Controls Recommendations

While some of the OEM's and authorities already interpret §25.777 as requiring full differential brakes and full rudder in the same sense be adequately commanded by crew of different statures, this interpretation is not universal. Conversely, a certification demonstration of such cockpit controls capability is not necessarily performed by all OEM's nor it is enforced by all airworthiness agencies. Adding a harmonized clarification to the §25.777 guidance would therefore improve safety. The Flight Test Harmonization Working Group recommends the FAA to consult with the Flight Controls Harmonization Working Group to derive guidance language to that effect.

The following proposal was not discussed with the FCHWG and, since it is outside the scope and expertise of the FTHWG, it should be taken solely as an example of what this group believes would be beneficial to improve safety in the low speed OEI RTO conditions.

Add paragraph 63 to AC 25-7 (currently "reserved" in AC 25-7C) which states:

63. Cockpit Controls – § 25.777.

a. Explanation. 25.777 contains requirements for cockpit controls, which include a number of system and flight control aspects. In order to assure full use of all available controls in the event of an engine failure, including on takeoff and including engine failure at low speeds, the control movement of the rudder pedals and brakes should be evaluated.

b. Procedures. Use of controls (typically rudder pedals and brakes) should be evaluated by pilots across the range of statures required by 25.777(c) during foreseeable normal and failure conditions. This should include engine failure below V_{MCG}. This evaluation is ideally done in a conforming simulator but may be performed statically in a conforming cockpit. The aim of the evaluation is to ensure that the pilot is always able to apply full rudder and maximum brake pressure on the same side simultaneously (e.g. full right rudder with maximum right brake pressure and vice versa). The pilot should, in each condition, also be able to continue to apply brake pressure on the opposite side.