Wet Runway, Physics, Certification, Application

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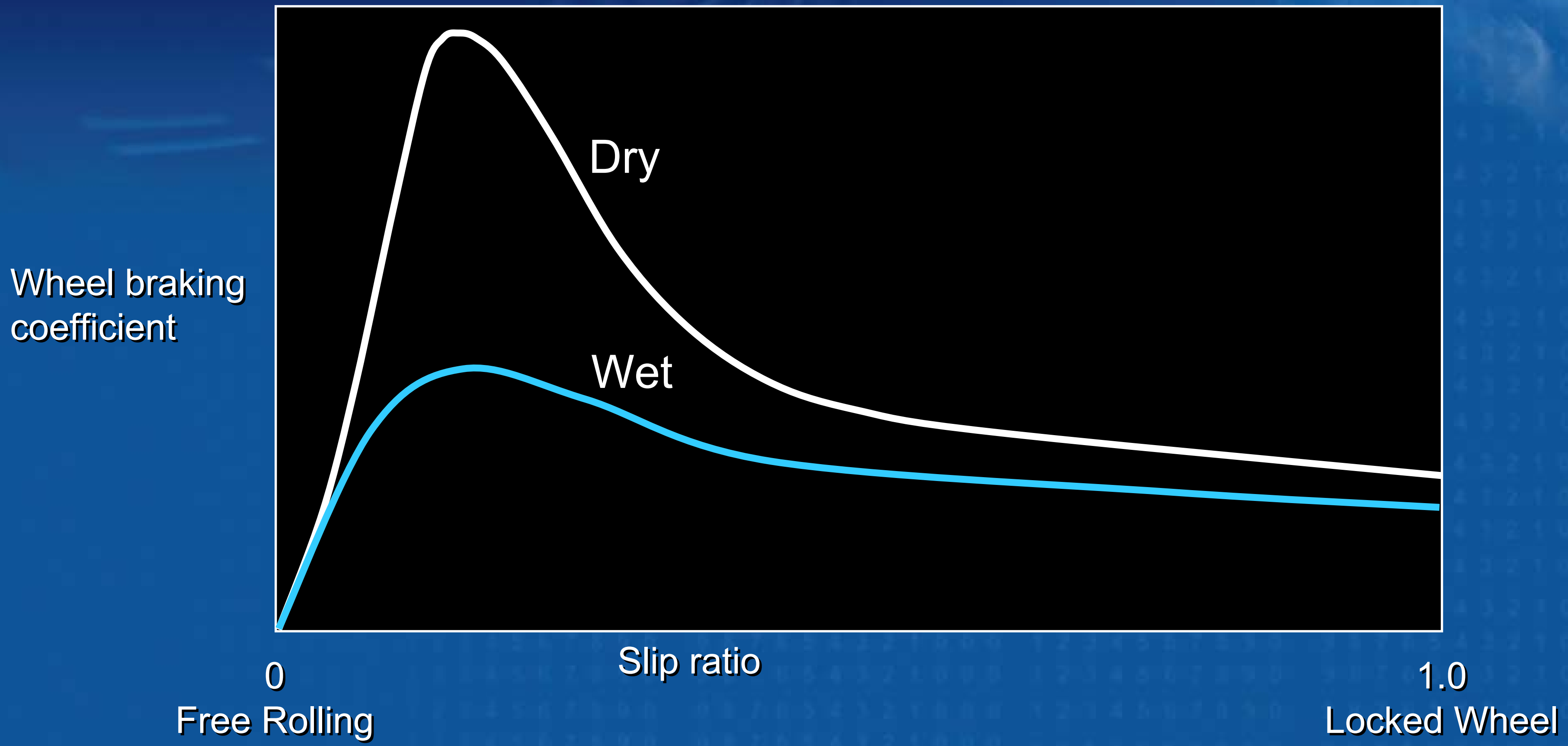
Introduction

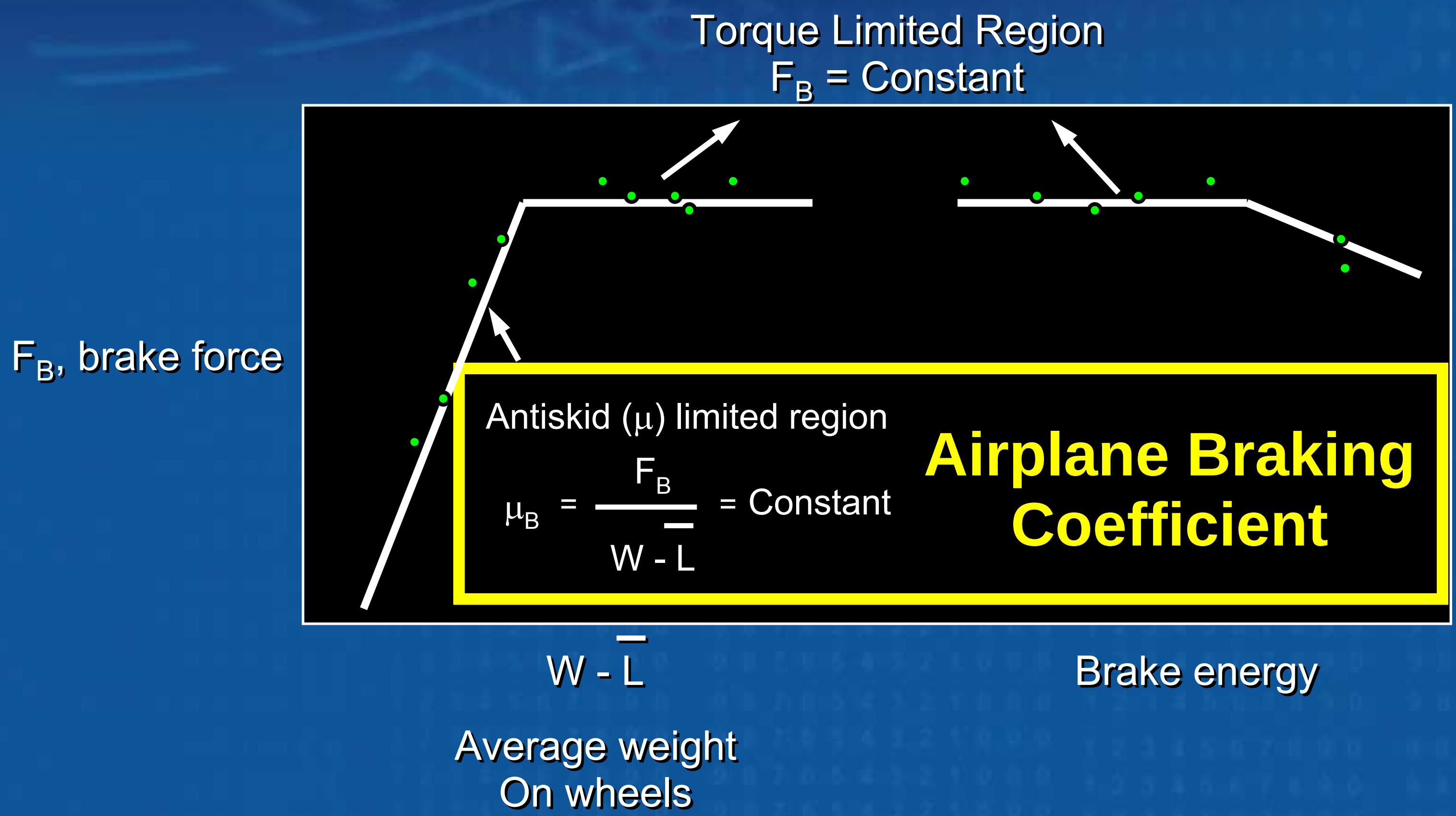
- Physics
- Regulations
- Data basis and assumptions
- Special considerations
  - Clearway considerations
  - Skid-resistant
  - Reverser inoperative
  - Antiskid inoperative

Fundamental Wheel/Tire Braking



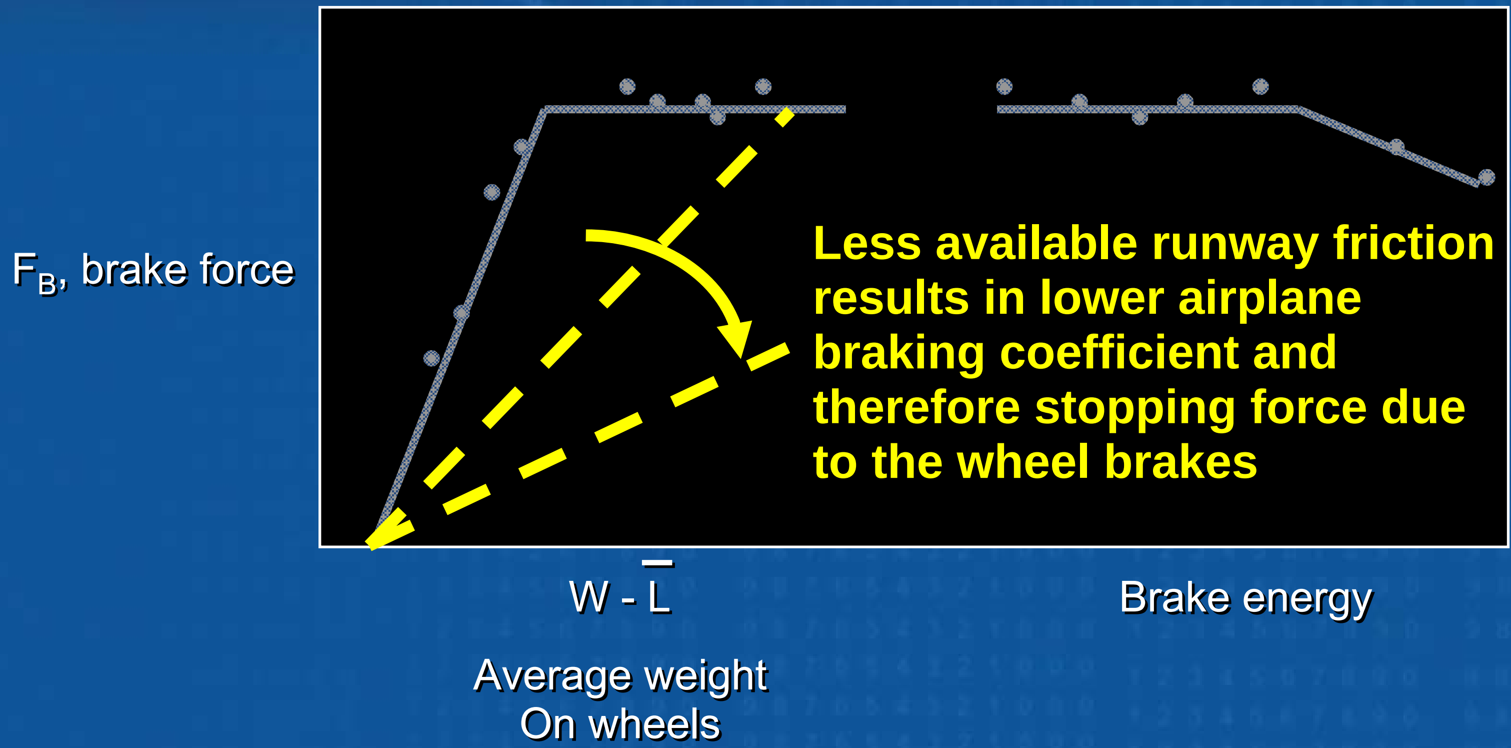
Aircraft Braking Considerations

Dry runway performance - Maximum manual wheel braking



Friction Limited Braking

Dry runway performance - Maximum manual wheel braking



Runway Friction and Runway Texture or How Slippery Is Wet

Macrotexture, Microtexture

- ***Microtexture refers to the fine scale roughness*** *contributed by small individual aggregate particles on pavement surfaces which are not readily discernible to the eye but are apparent to the touch, i.e., the feel of fine sandpaper*
- ***Macrotexture refers to visible roughness*** *of the pavement surface as a whole*
- ***Microtexture*** *provides frictional properties for aircraft operating at* ***low speeds***
- ***Macrotexture*** *provides frictional properties for aircraft operating at* ***high speeds***

Reference FAA AC 150 5320-12

Runway Friction and Runway Texture or How Slippery Is Wet

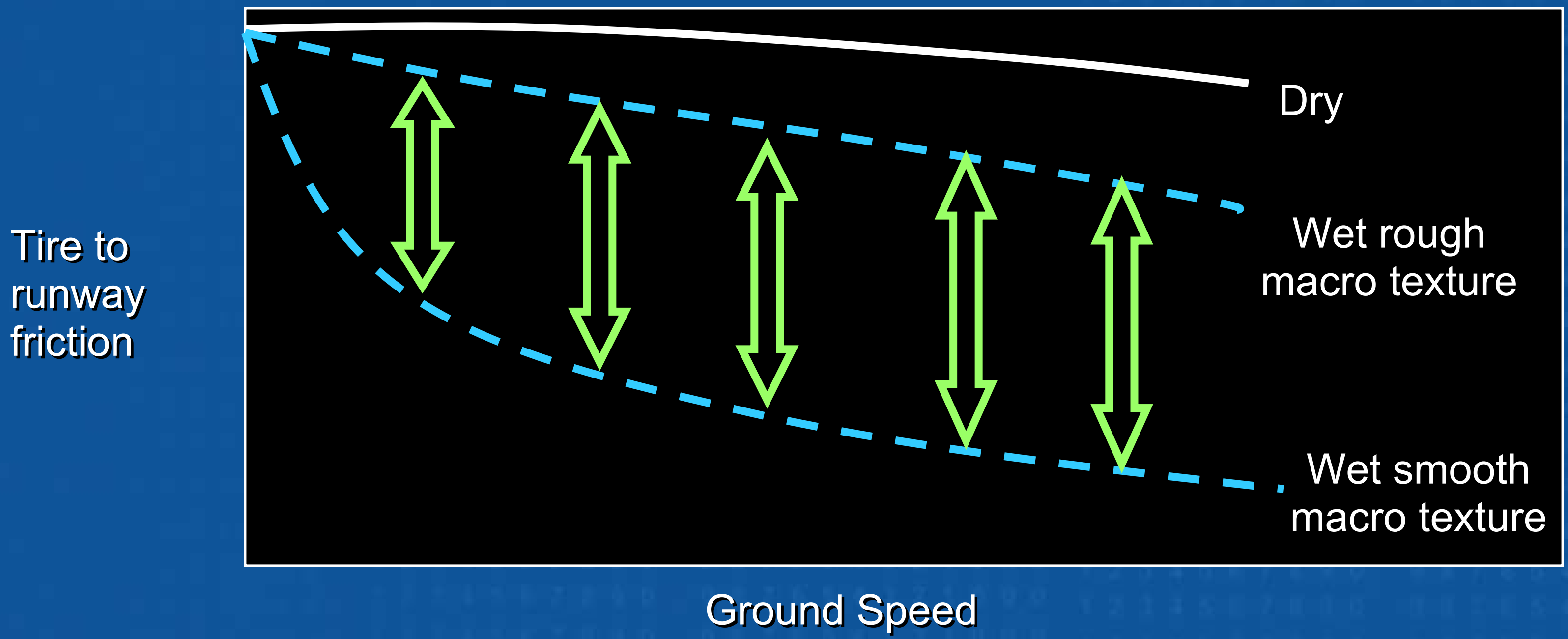
Macrotexture, Microtexture

- *The primary function of macrotexture is to provide paths for water to escape from beneath the aircraft tires*
  - *This drainage property becomes more important as the aircraft speed increases, tire tread depth decreases, and water depth increases. All three of these factors contribute to hydroplaning.*
- *Good microtexture provides a degree of "sharpness" necessary for the tire to break through the residual water film that remains after the bulk water has run off*
- *Both properties (macro/microtexture) are essential in providing skid-resistant pavement surfaces*

Reference FAA AC 150 5320-12

Runway Macrotexture Effect on Wet Runway Friction

- *As macrotexture affects the high speed tire braking characteristics, it is of most interest when looking at runway characteristics for friction when wet*
- *Simply put, a rough macrotexture surface will be capable of a greater tire to ground friction when wet than a smoother macrotexture surface*



Effect of Runway Surface On Airplane Wheel Braking Performance

NASA testing published in Technical Paper 2917, "Evaluation of Two Transport Aircraft and Several Ground Test Vehicle Friction Measurements Obtained for Various Runway Surface Types and Conditions"

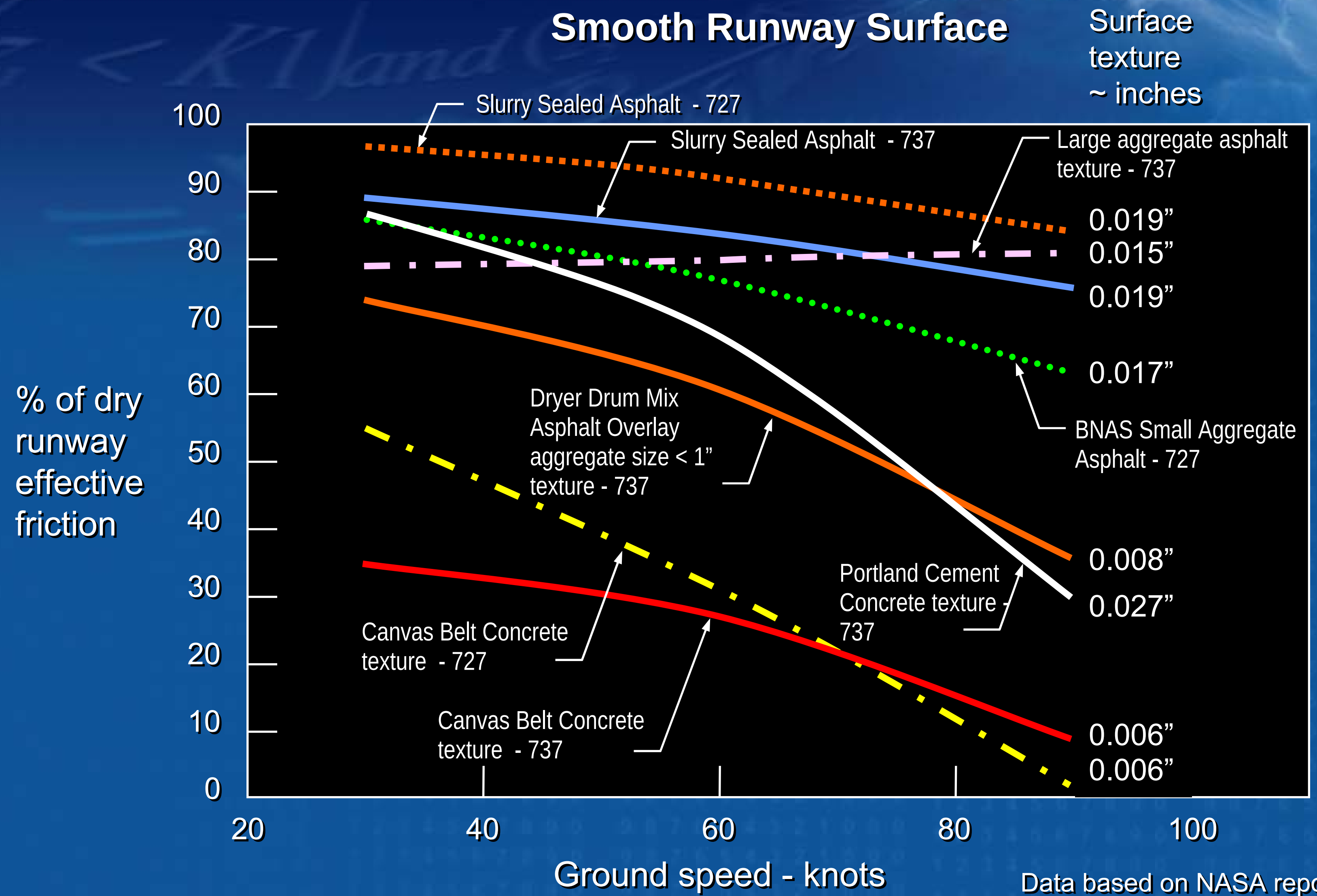
- Dry
- Wet, smooth
- "Damp"
- Wet, skid-resistant

Effect of Runway Surface On Airplane Wheel Braking Performance

NASA testing published in Technical Paper 2917, "Evaluation of Two Transport Aircraft and Several Ground Test Vehicle Friction Measurements Obtained for Various Runway Surface Types and Conditions"

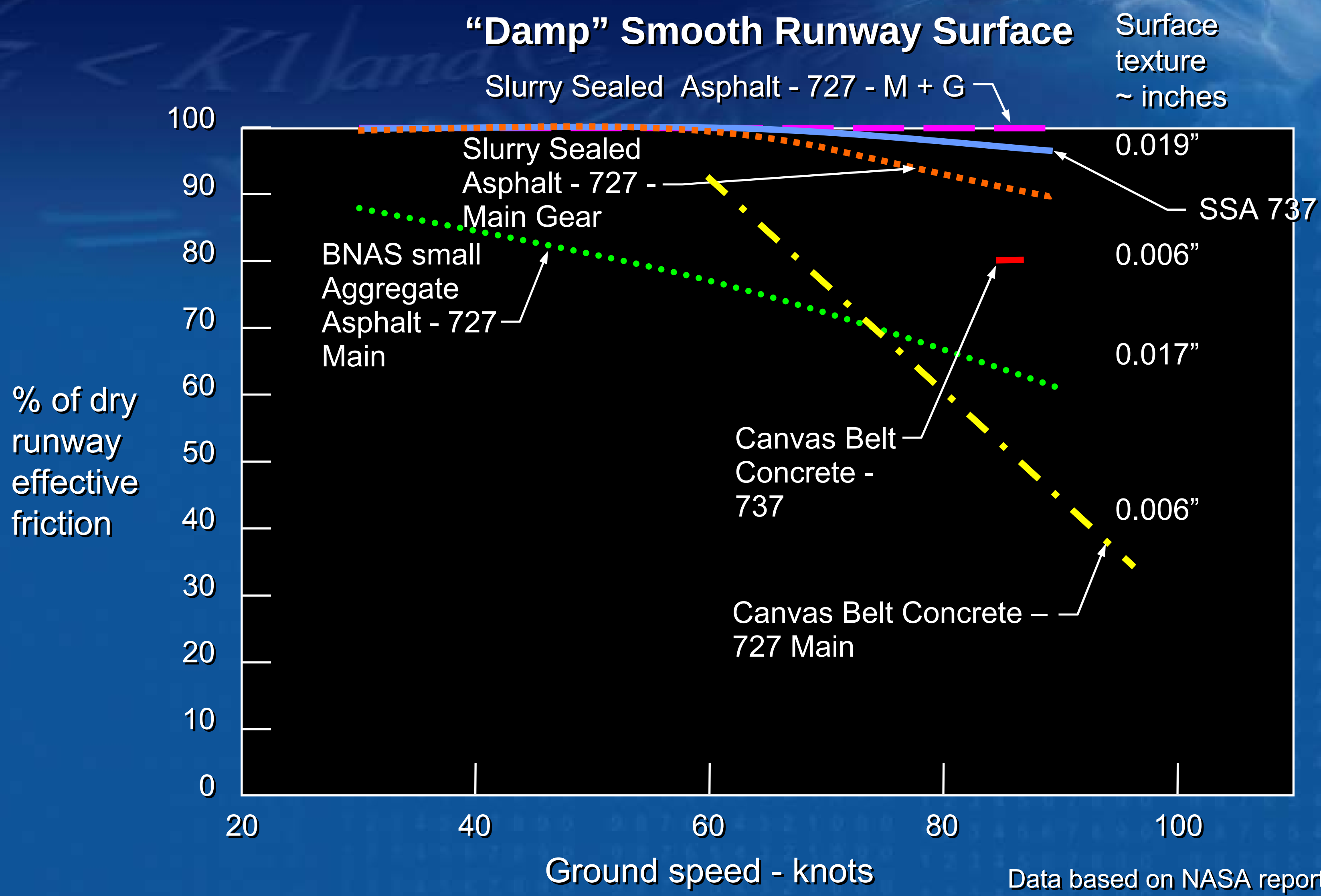
Test Site	Test Surface	Macrotexture Depth, in.
NASA Wallops Flight Facility	Slurry Sealed Asphalt (SSA)	0.019
NASA Wallops Flight Facility	Canvas Belt Finished Concrete	0.006
NASA Wallops Flight Facility	Large Aggregate Asphalt	0.015
Langley AFB	Portland Cement Concrete	0.027
Brunswick Naval Air Station – BNAS	Small Aggregate Asphalt	0.017
FAA Technical Center	Dryer Drum Mix Asphalt Overlay	0.008

Effect of Wet Runway Surface on Airplane Wheel Braking



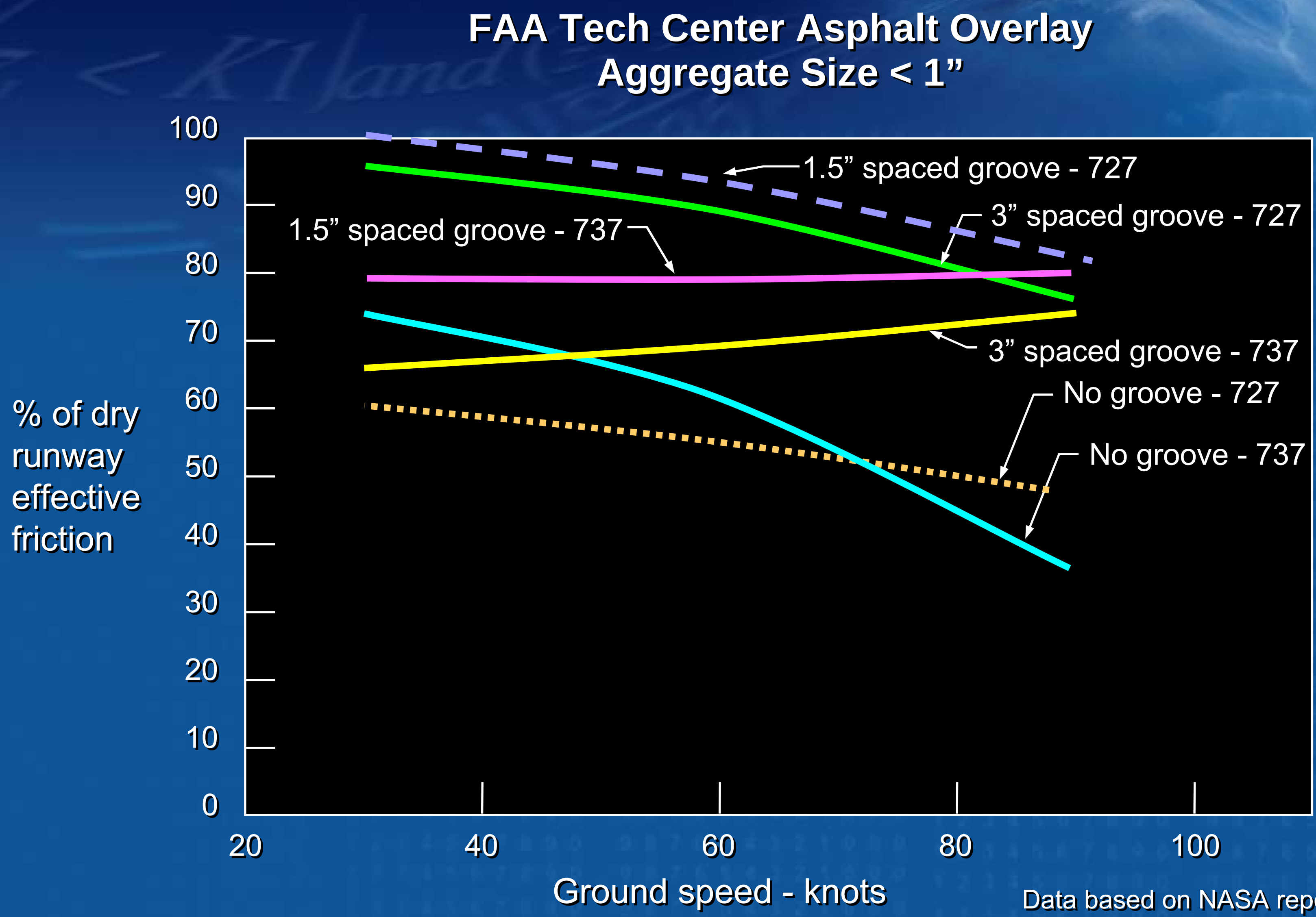
Data based on NASA report TP2 917

Effect of Damp Runway Surface on Airplane Wheel Braking



Data based on NASA report TP2 917

Effect of Wet Grooved Runway Surface on Airplane Wheel Braking



Data based on NASA report TP2 917

Effect of Wet Grooved Runway Surface on Airplane Wheel Braking

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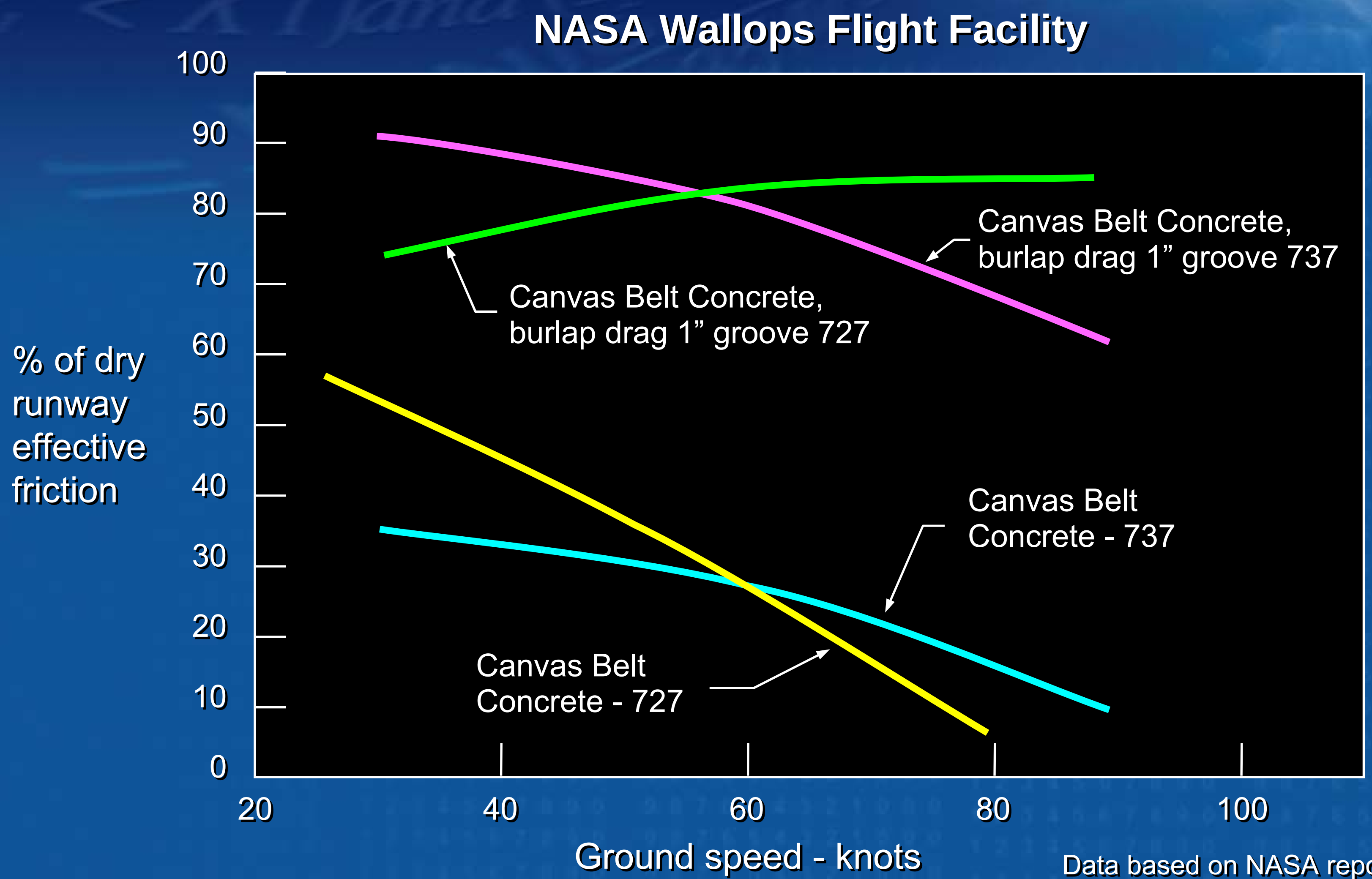


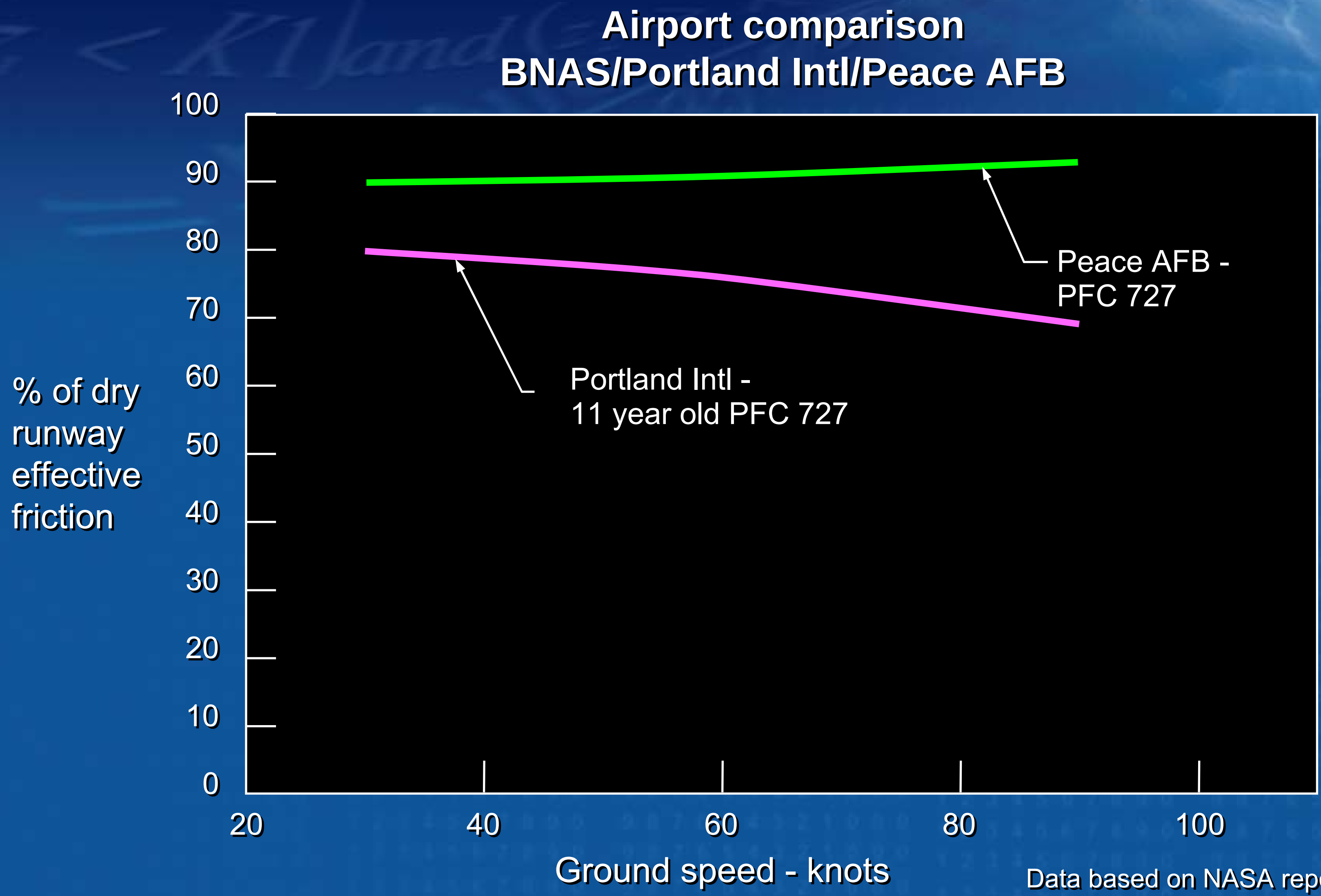
Data based on NASA report TP2 917

FAAGrooved Runway Specification

FAA AC 150/5320-12C, "Measurement, Construction, and Maintenance of Skid-Resistant Airport Pavement Surfaces," specifies that the FAA standard groove configuration is:

- 1/4 in (6 mm) in depth,
- 1/4 in (6 mm) in width
- 1 1/2 in (38 mm) in spacing

Effect of Wet PFC Runway Surface on Airplane Wheel Braking



Data based on NASA report TP2 917

Summary of TP 2917 Information

- Wet runway
  - Smooth (lower) macrotexture surface creates less friction than a rough surface
  - Pavement material makes a significant difference in the available friction on a wet surface
- Wet Grooved or PFC treatment of runways
  - Improved the wet runway friction capability
  - Not the same capability as a dry runway
  - Improvement is dependant on runway material (PFC) and groove spacing
- “Damp” runway
  - Friction was reduced compared to dry
  - Friction may be better than wet
  - Subjective term

Boeing Historical Wet Runway Testing

Support of UK CAA Certifications

Airplane	Antiskid (μ) limited airplane braking coefficient, % (approximate)*
707-300C landing data	50
727-200 landing: • Main and nose brakes • Main brakes only	 50 50
737-200 ADV • Mark III A/S • Goodyear A/S	 60 45
747-100	55
*Dry runway compared with a wet, smooth runway. Based on flight tests for UK CAA.	

- Later UK CAA certifications used ½ the dry
- Recommendation to use performance labeled Good (0.2 airplane braking coefficient) for wet runway for operational data

Airplanes Not FAA Certified for Wet Runway Takeoff Accountability

- 707, 727, 737-100/-200/Adv/-300/-400/-500, 747-100/-200/-300/-400 757-200, 767-200/-300/-200ER/-300ER, 777-2/300, DC-9/-10, MD-80/-90/-11
- Wet runway performance is in UK CAA and JAA AFMs were appropriate
- Operational data is provided in QRH and FPPM and operational computer programs, weight reductions and V_1 adjustments (not applicable for Douglas aircraft)
- JAR-OPS 1
  - Essentially the same as operational data
  - Douglas aircraft data created as required, different methods of accounting for wet runway braking

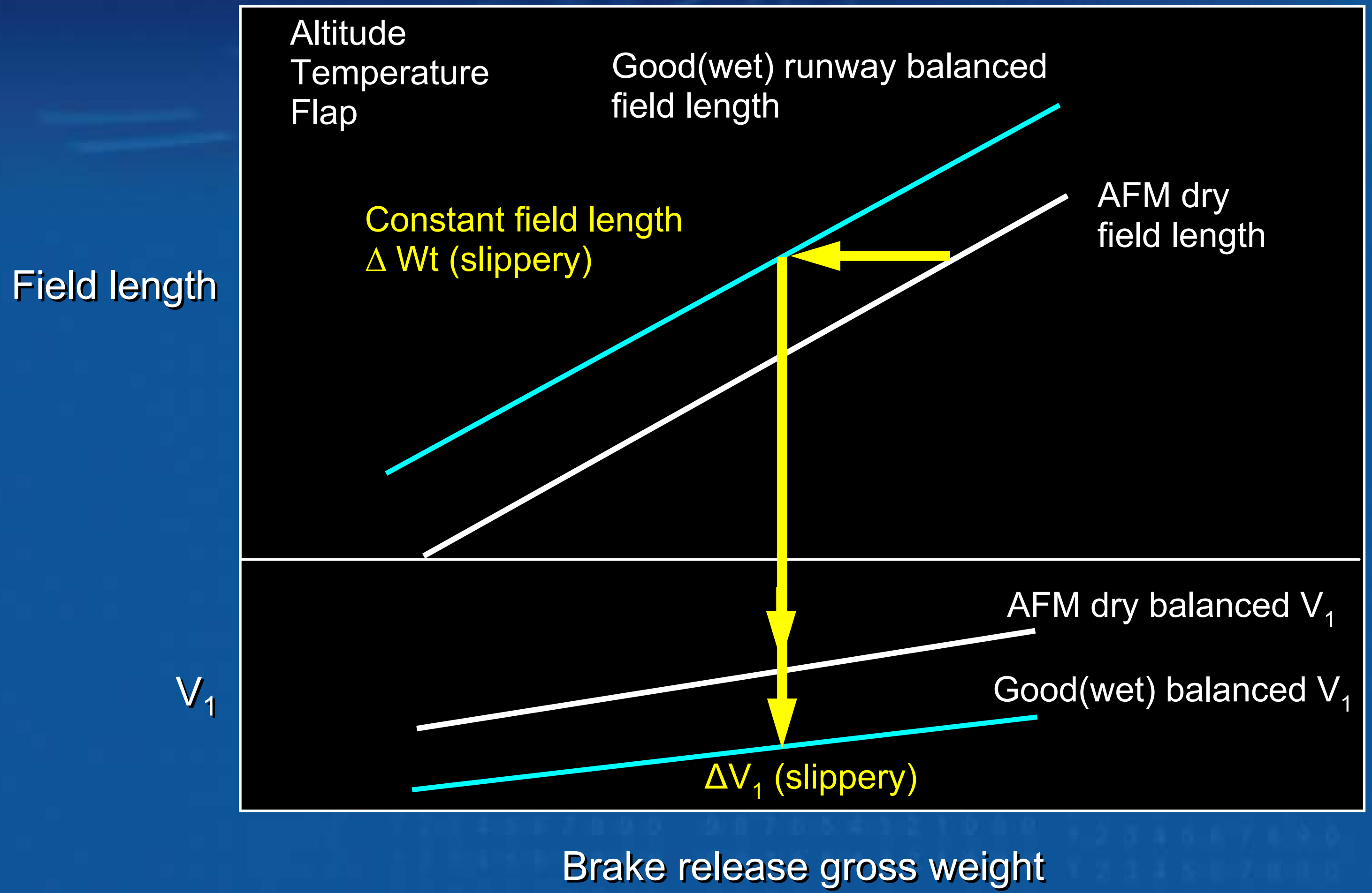
Wet Runway Performance Considerations

Performance assumptions are changed for wet runway takeoff calculations

- Reduced runway friction capability taken into account
  - UK CAA certification
    - Test data or ½ dry airplane antiskid (μ) limited airplane braking coefficient
  - QRH, FPPM data labeled reported braking action of “Good” recommended for wet runway accountability
    - Airplane braking coefficient (μ_B) = 0.20
- 15 foot screen height
  - Engine inoperative accelerate-go calculation
  - Results in V_1 reduction when re-balancing
- Reverse thrust credit accelerate-stop calculation
  - Controllability and re-ingestion issues considered

QRH and FPPM Weight and V_1 Adjustments

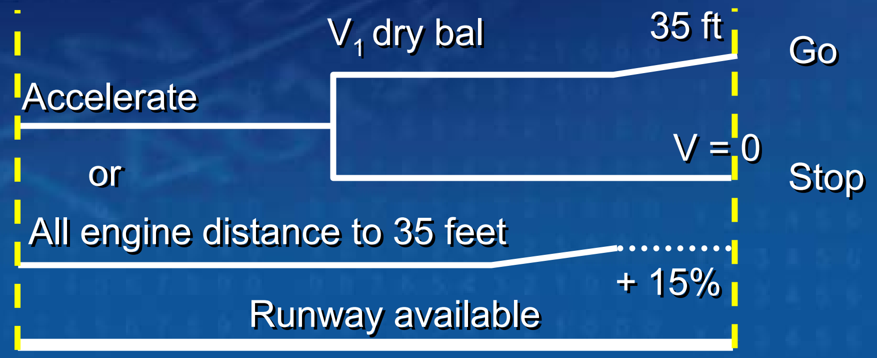
Equal distance concept



Equal Distance Concept

AFM dry field length limit weight with AFM dry balanced V_1 speed

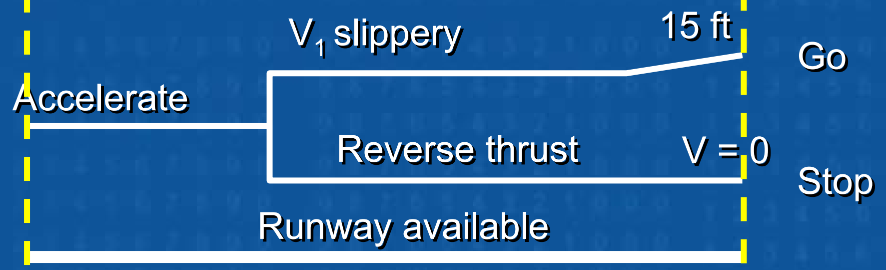
AFM dry field length limited weight*



*Note: “Most” airplanes are balanced field length limited

OM/FPPM determined Good(wet) field length limit weight
Good(wet) balanced V_1 speed

Good(wet) balanced field length limited weight

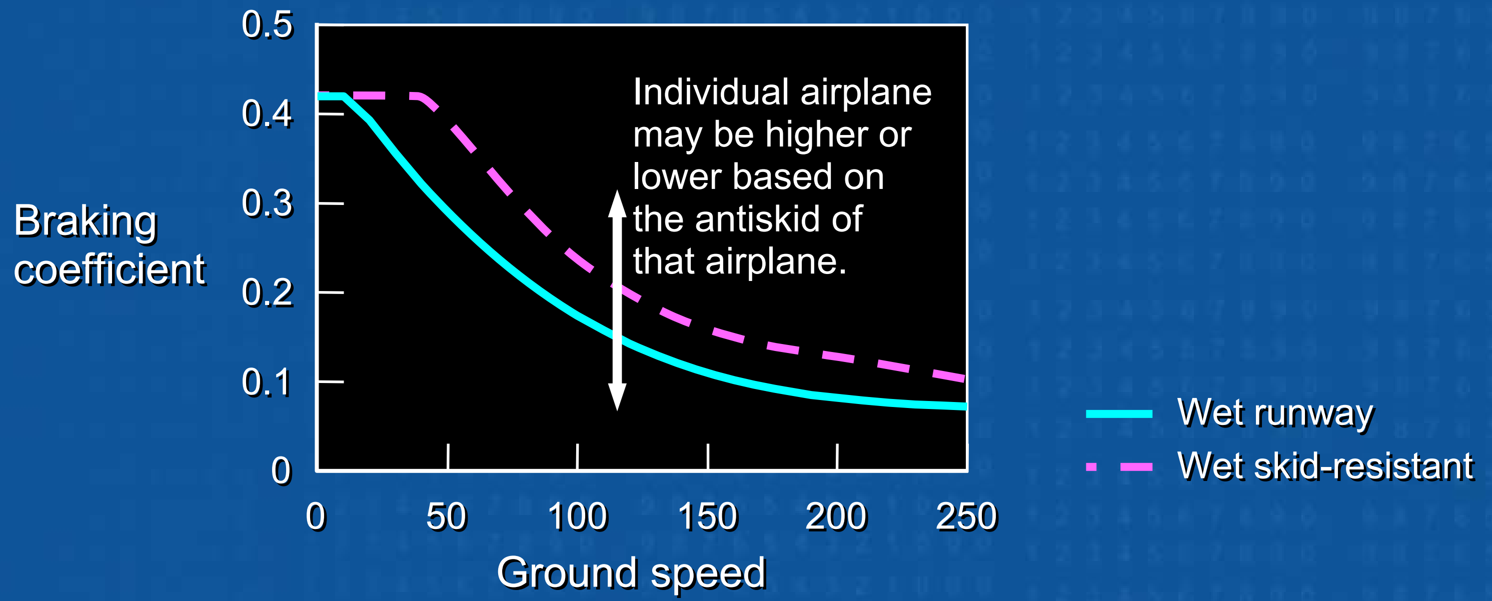


Airplanes With Wet Runway Performance In the FAA AFM — Amendment 25-92

- 737-600/-700/-800/900, 757-300, 767-400, 777-200LR/-300ER, 717
- Covers skid-resistant performance
  - Runway must be built and maintained to requirements of AC 150/5320-12C
- Same data in JAA AFM

Current Certification Requirements Amendment 25-92

- Amendment 25-92 of the FARs required inclusion of wet runway takeoff performance in the AFM
- Provided a method to account for wet runway wheel braking capability that was based on ESDU 71026
  – Both smooth and skid-resistant surfaces are addressed
- Method documented in the FAR's and AC 25-7



Runway Construction

Runway surface type	Runway surface treatment	Approximate number
Asphalt, approximately 3,640 runways	Grooved	500
	PFC	110
	Other friction treatment	15
	No data available or no special treatment listed	2,980
Concrete, approximately 1,040 runways	Grooved	170
	No data available or no special treatment listed	870

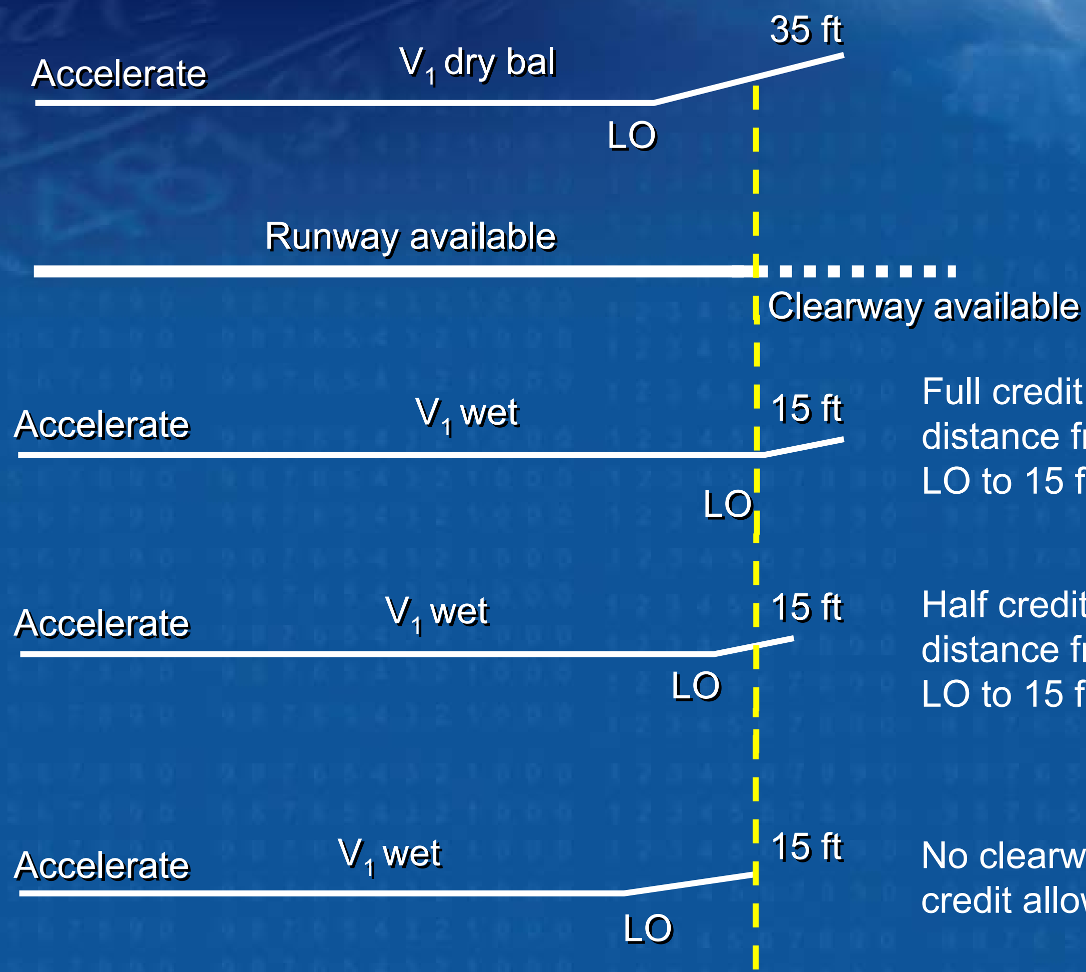
Data from Boeing Airport Information Retrieval System

- Information from databases may tell surface type and treatment
- Typically there isn't information provided on standards to which the runway was constructed and is maintained

Special Wet Runway Performance Questions

- Is clearway allowed on a wet runway?
- Can a reverser be inoperative on a wet runway?
- Can an antiskid be inoperative on a wet runway?

Maximum Clearway Available for Wet Runway Regulatory Accountability



Dry runway AFM clearway credit available

UK CAA wet runway and 747-400 JAA AFM clearway credit available — Full credit for distance from LO to 15 feet

777-200 JAA wet runway AFM clearway credit available — Half credit for distance from LO to 15 feet

Current FAA(Amend. 25-92)/JAA wet runway AFM clearway credit available — No clearway credit allowed

Clearway and Wet Runway for Airplanes Without AFM Wet Runway Coverage

- FAA AFMs or operational information do not address wet runway performance therefore clearway not addressed
- JAR-OPS 1 does not discuss clearway and wet runway but does instruct that the provisions of AMJ25X1591 or it's equivalent should be used
  - AMJ25X1591
    - b. The **take-off distance on a wet runway** is the greater of the following:
      - i. The horizontal distance along the take-off path from the start of the take-off to the point at which the **aeroplane is 15ft above the take-off surface, ……..**
    - c. The **take-off run on a wet runway** is the greater of the following:
      - i. The horizontal distance along the take-off path from the start of the take-off **to a point at which VLOF is reached**, as determined under JAR 25.111 and assuming that the critical engine fails at VEF …….
  - Current NPA to revise AMJ25X1591 removes this language with deference to JAR 25 regulations

Clearway and Wet Runway Boeing Operational Software

- Boeing Operational Software – BTOPS/BTM databases follow regulatory guidelines where they are addressed
  - Amend. 25-92, UK CAA, 747-400 and 777-200 JAR certification
- BTOPS databases provide data for slippery runway
  - Clearway is ***not*** allowed in the calculation
  - Data based on OM/FPPM/PEM weight reductions and V_1 adjustments
  - Data created based on equal distance concept and balanced field length considerations
- MTOPS
  - Clearway is ***not*** allowed in the calculation

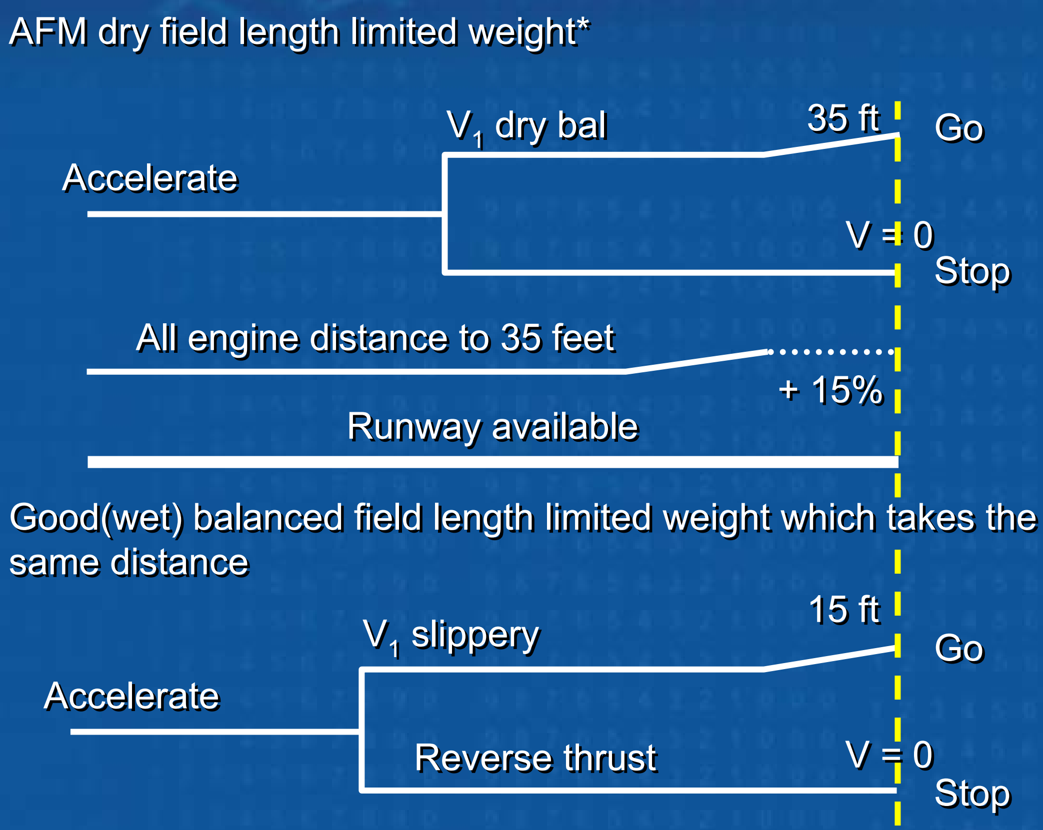
Operational Practice — Clearway and Wet Runway for Airplanes Without AFM Wet Runway Coverage

Question: The dry runway analysis is based on clearway. Can the slippery runway adjustments be applied to this data?

Following example will show the effect of this accounting

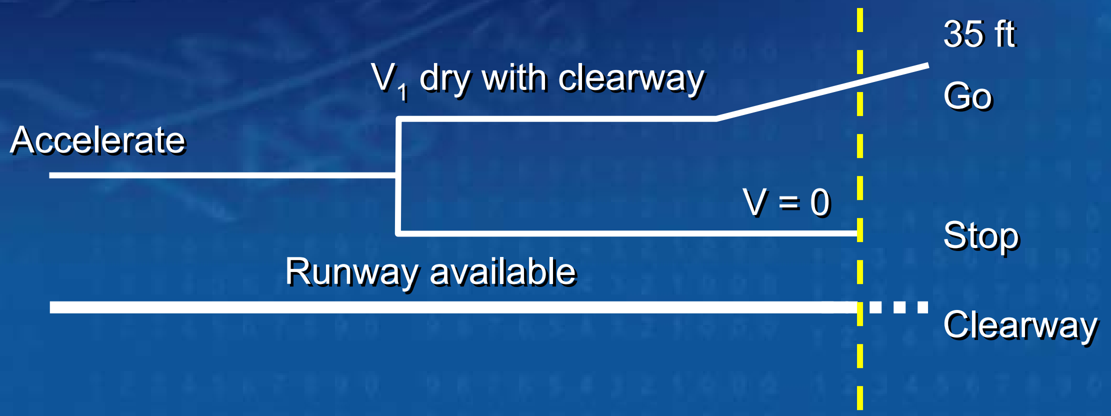
First, remember the weight reductions and V_1 adjustments are based on an equal distance concept

- Dry runway weight with dry runway V_1 takes the same distance as
- Slippery(Good(wet)) with slippery V_1 after weight and V_1 adjustments are applied



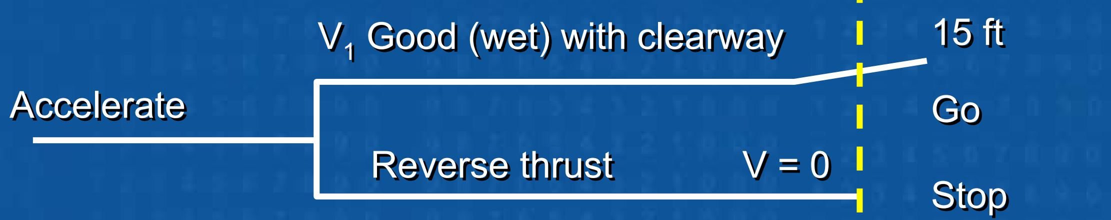
Consider Dry Runway Distance With Credit for Clearway

Baseline AFM field length limited—dry runway with clearway



Now apply weight and V_1 adjustments to get slippery-good(wet) performance

Slippery runway—FPPM-OM performance applied to AFM field length limited with clearway.



Example of Calculation, Dry Weight With Clearway Adjusted for Slippery-Good(Wet)

Temperature, ºC	Dry field length limited weight, kg	V_1, KIAS	Takeoff run, ft	Distance to 35 ft, ft	Accelerate–stop distance, ft	1.15 AE distance, ft
15	73,400	137	6,500	7,240	6,500	6,170
30	71,600	135	6,500	7,240	6,500	6,147
Example at sea level with 6,500 ft of runway and maximum allowable clearway available.						

Dry field length limited weight, kg	Weight reduction, Good(wet), kg	Good(wet) slippery field length limited weight, kg
73,400	1,300	72,100
71,600	1,300	70,300

Example of Calculation, Dry Weight With Clearway Adjusted for Slippery-Good(Wet)

Temperature, ºC	Good(wet) slippery field length limited weight, kg	V_1, adjusted for slippery and clearway – QRH based KIAS	Distance to 15 ft following EF, ft	Distance to LO following EF, ft	Runway available, ft
15	72,100	129	7,123	6,126	6,500
30	70,300	127	7,112	6,127	6,500

- This method results with 15 feet beyond the end of the runway
  - May or may not be an issue depending on airline policy and operating regulatory requirements
  - Does not effect performance unless at/near field length limited weight
  - BTOPS/MTOPS ignore clearway if **slippery** is chosen and direct calculation of Good(wet) runway weight limit is done

Reverser Inoperative and Wet Runway

- Amendment 25-92 inclusion of wet runway takeoff performance caused creation of a new proviso in MMEL
  - AFM performance credit for reverse thrust for wet runway takeoff
  - New proviso only applicable for Amend 25-92 certified performance
- Most non-Amend 25-92 airplanes have performance available in operational computer programs, FCOM and FPPM

U.S. DEPARTMENT OF TRANSPORTATION

FEDERAL AVIATION ADMINISTRATION — MASTER MINIMUM EQUIPMENT LIST

AIRCRAFT:	REVISION NO : 47	PAGE:
B-737	DATE: 06/03/2005	78-1

SYSTEM & SEQUENCE NUMBER	ITEM	1.	2. NUMBER INSTALLED	3. NUMBER REQUIRED FOR DISPATCH	4. REMARKS OR EXCEPTIONS
78 - ENGINE EXHAUST					
1.	Thrust Reverser Systems				
	1) (-100/-200)	C	2	1	(M)(O) One may be inoperative provided thrust reverser is deactivated and secured closed.
		C	2	1	(M)(O) One may be inoperative provided: a) Thrust reverser guide carriage is verified to be in the over-center (forward thrust) position, and b) The Override System is armed only after landing. NOTE: Relief also applies to airplanes modified by STC SA5730NM or ST00131SE.
	2) (-300/-400/-500)	C	2	1	(M)(O) One may be inoperative provided thrust reverser is locked in the forward thrust position.
	3) (-600/-700/-800/ -900)	C	2	1	(M)(O) One may be inoperative provided: a) Thrust reverser is locked in the forward thrust b) Appropriate performance adjustments are applied.

Wet Runway and Antiskid Inoperative

- Prior to Amend. 25-92 wet runway takeoff and antiskid inoperative performance had not been addressed in the FAA AFM or MMEL.
- The new certification standard raised the visibility of this type operation
- Initial 737NG AFM was released with this operation prohibited.
- In 2002, the FAA published a policy letter (PL) which specifically addressed takeoffs on wet runways with antiskid inoperative.
  - **FAA PL-113 dated 20 December, 2002**

PL-113, Wet Runway Takeoff With Antiskid Inoperative

FOEBs may continue to grant relief….

- The runway is grooved or has a PFC surface
- All reversers are operative
- Approved performance data is available
- Operator training programs include antiskid inoperative braking procedures

PL-113, Wet Runway Takeoff With Antiskid Inoperative

- 737NG – Boeing performed flight test
  - AFM-DPI alternate performance
  - Must be specifically called out in the AFM
- Pre Amend. 25-92 airplanes
  - Not addressed by FAA AFM or MMEL
  - No performance data specifically supplied
  - Recent studies indicate the use of the braking action “poor” data would be conservative
    - Apply “poor” weight and V_1 adjustments to the dry runway antiskid operative field/obstacle limited weight to obtain wet runway anti-skid inoperative takeoff performance

Wet Runway Takeoff With Antiskid Inoperative – Flight Crew Issues

- Additional pilot education and training
  - Stopping sequence change with antiskid inoperative
    - With antiskid inoperative the last step in the RTO procedure in brake application
  - Light brake application through out the maneuver

Summary

- Runway surface can have a significant effect on an airplanes stopping performance on a wet runway
  - Macrotexture, treatment (grooved, PFC)
- Certification standards for wet runway takeoff have changed over the years
  - Current certification standard, includes wet runway takeoff performance in AFM
  - 15 foot screen height, reverse thrust credit
  - Clearway accountability
- Other items
  - Wet Skid-resistant
  - Reverser inoperative
  - Antiskid inoperative