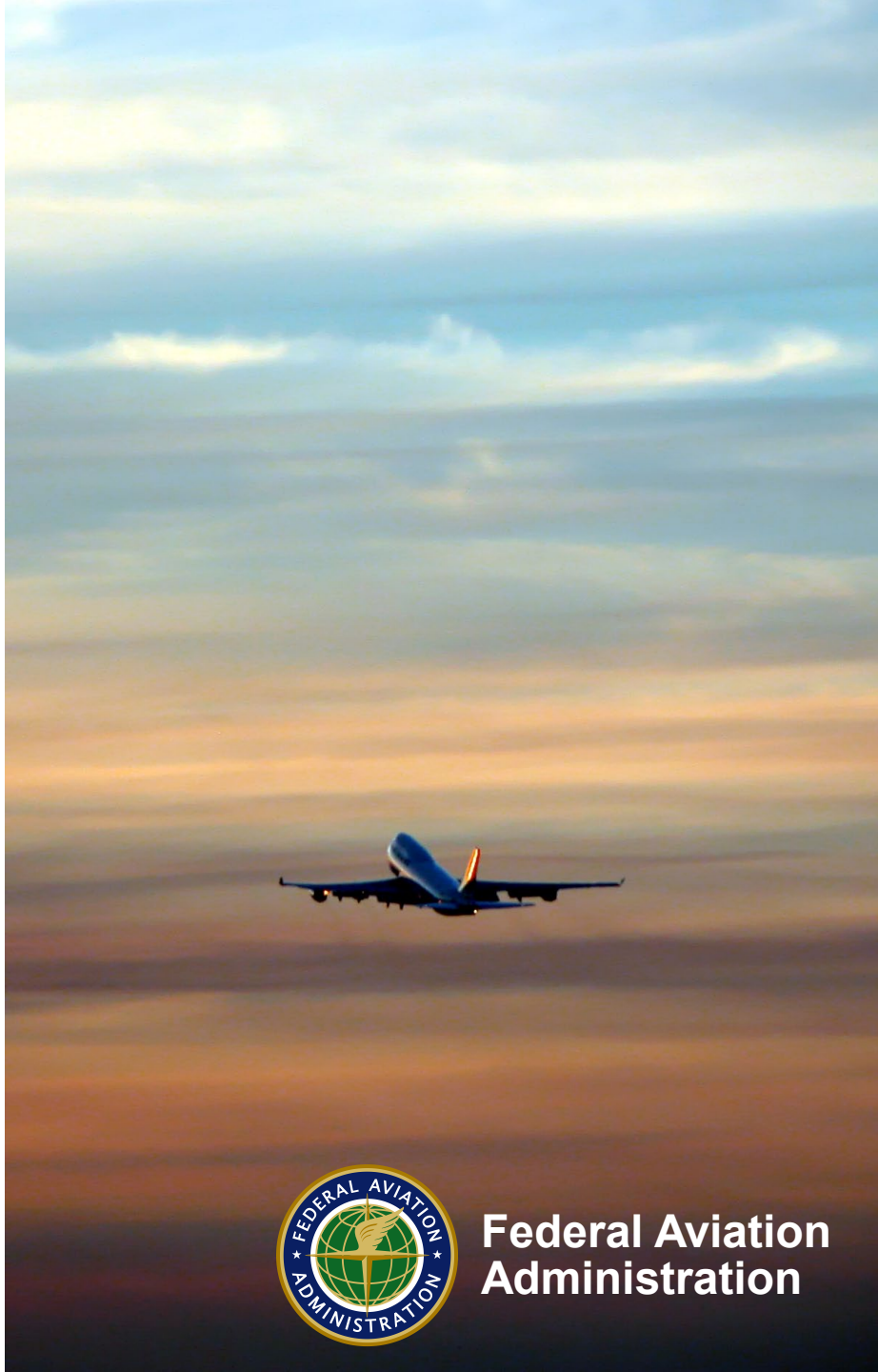
Degraded Runway Wheel Braking Research and Testing

SAS REDAC Brief

FAA William J. Hughes Technical Center

20 August 2019



Outline

1. Current State of the Industry
2. Big Picture
3. Gaps/Recommendations
4. Data Example

State of the Industry

- **Aircraft performance currently uses models of wet and contaminated runway wheel braking which have been called into question**
  - These wheel braking models used in FAA regulations and Advisory Circulars have been questioned by:
    - NTSB – multiple safety recommendations including research
      - Develop the technology to outfit transport-category airplanes with equipment and procedures to routinely calculate, record, and convey the airplane braking ability
      - NTSB encourages the FAA to perform flight tests on representative domestic and international runways which support turbine-powered airplane operations in order to validate the wet-ungrooved and wet-grooved wheel braking coefficient models in Sections 25.109(c) and (d).

State of the Industry

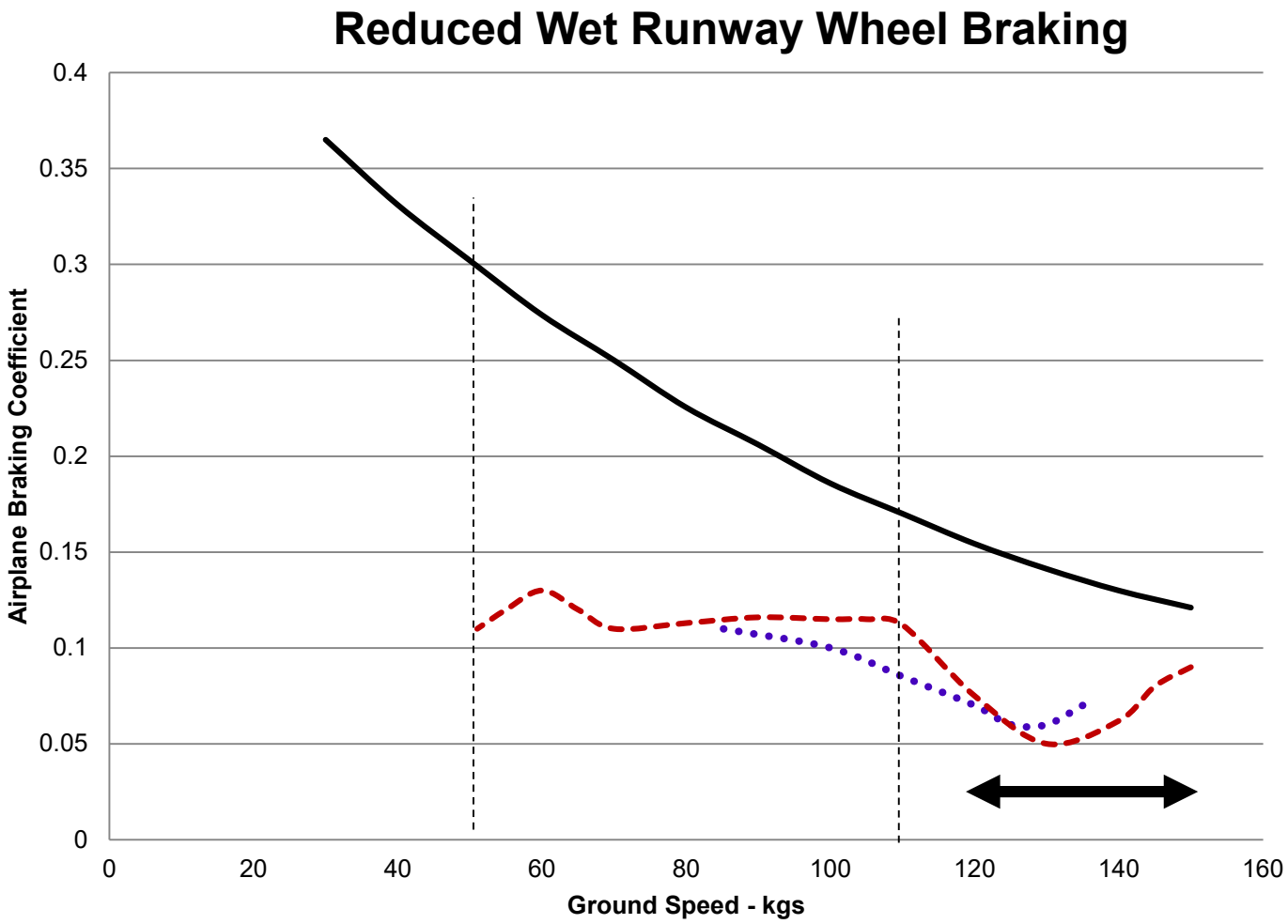
- **Flight Test Harmonization Working Group (FTHWG) recommendation**
  - Work on a method to quantitatively identify runway conditions leading to poor performing wheel braking on wet runways and use this information to identify poor performing wet runways.
- **Industry consensus on contaminated runways and Continuous Friction Measuring Equipment (CFME)**
  - Have not shown correlation with airplane on contaminated runways.
  - CFMEs are typically not available at the runways which have reduced wet runway wheel braking capability

Approach and Flare		Speed		Stopping Devices					Runway Condition		
				Speed Brake	Thrust Reversers						
Approach	% RWY Used During Flare	T/D Airspeed wrt to Vref	Tailwind	Speed Brake	# of Engines Deployed at T/R	Delayed deployment	T/R Sleeves Stowed Early	Redeploy T/R after Stow	Runway Condition	Braking Action**	Runway Available
		kts	kts			seconds	feet				feet
			>10						Ice	Poor	
									Ice	Meduim	
									Snow	Poor	
									Snow	Poor	
			>10			>10			Snow	Poor	<6500
									Snow	Poor	
Unstable	>40%	>10					x		Snow	Medium-Poor	
			>5						Snow	Medium-Poor	<7500
			>5						Snow	Medium	<6500
						>5		yes	Snow ?	Medium-Poor	<6500
	>33%		>5						stdg water	Poor	
Unstable	>40%	>10	>5	Delayed		>5	x		Wet	Medium	
	>40%		>10						Wet	Medium	
							x	yes	Wet	Medium	
		>10	>10				x		Wet	Medium	<7500
		>10	>10				x	yes	Wet	Medium	<7500
				Delayed		>20			Wet	Medium	<6500
Unstable	>50%	>10							Wet	Good	
	>50%	>10	>10						Wet	Good	<7500
						Little/No Rev Thrust			Wet	Good	
Unstable				Delayed	N-1	>10			Wet / Ice/Wet Ice	Poor	
	>33%						x	yes	Wet ?	Poor	<7500
					N-1				Wet ?	Poor	<7500
	>40%		>5							Poor	
Unstable	>50%									Good	
	>40%									Good	<7500
Unstable	>50%				0						
Unstable	>50%		>5				x				
Unstable	>50%	>10					x	yes			

- **16 of these 30 accidents/incidents had a contributor of less than expected braking for the conditions present**
- **This is a pre-existing condition**
- **What can be done to identify this lower than expected braking prior to the final approach**

Reference: Boeing presentation "Understanding Wet Runway Overruns", Flight Safety Foundation Conference, Dublin, Ireland - 2012

Example of Issues



Reference:
Data taken from Indonesian and Jamaican Incident Reports and are based on fairing of Boeing analysis

FAR 25.109 braking level
Kingston 737-800 overrun
737-900ER PKU overrun

REDAC Recommendations/FAA Actions

- **In 2016 REDAC sub-committee on airports requested formation of a technical working group**
  - Review FAA research on aircraft braking friction and make recommendations regarding the direction of future efforts.

- **Airport Technology R&D formed a technical working group in February 2017**
  - Evaluate FAA aircraft braking friction research.

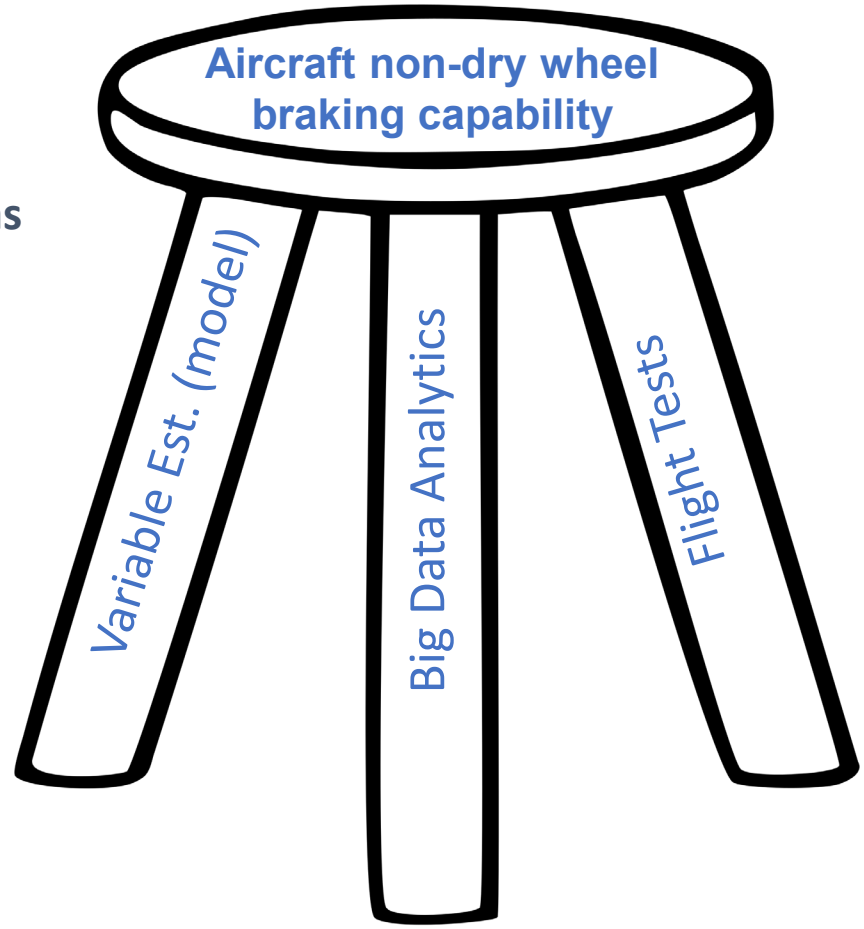
- **Technical working group included representation from the FAA, academia, aircraft braking system manufacturers, and others who are developing runway braking friction assessment technologies.**

REDAC Recommendations/FAA Actions (Continued)

- Technical working group developed a **White Paper** recommending elements of future FAA aircraft braking friction research including obtaining of a test aircraft and runway to conduct controlled-condition flight testing
- In 2018 REDAC sub-committee on Aircraft Safety (SAS) requested that the FAA **develop a plan to explore data reduction methods and provide the REDAC with an updated research approach including the overall roadmap and strategic plan.**
- Technical Working Group met June 6-7, 2019 at MIT in Cambridge, MA to develop parameters for incorporating **data reduction methods into the White Paper**.
- Modified White Paper was completed in July 2019.

The Big Picture

- **Under what conditions will an aircraft experience less wheel braking potential (as related to "mu") compared to what is predicted by current models?**
  - Wet/water/snow
  - Critical depths
  - Surface macro-/micro-texture
  - Temperature
  - Ground speed
  - Etc.
- **The problem is complex – there're many variables which are difficult to acquire, measure, or control**
- **The research team believes that multiple, complementary studies are required to address this problem**



White Paper Identified Gaps

Problems - Gaps

Validation and refinement of TALPA/GRF runway classification model: non-dry runway cond.

Relationship between aircraft braking and observable factors require a more capable and accurate predictive model than current FAA and industry modeling provide.

Wet Runway Specific

Specific FAA model of braking performance on a wet runway has been questioned at a significant level by NTSB and other industry entities.

There is a need to identify the mechanisms behind the anomalies in the current model and how they can be identified.

Mapping TALPA/GRF standards to measured braking performance

Method is in work with an ASTM standard to recommend this mapping. However, there currently isn't "truth data" to use as a basis for this mapping

White Paper Identified Gaps/Recommendations

Problems - Gaps

Non-Dry Runway Cond.	Wet Runway Specific	Mapping TALPA/GRF standards to measured braking performance

Recommendations

Analysis of operational aircraft recorded braking performance	Controlled-Condition Flight Testing	International Standards Development

White Paper Identified Gaps/Recommendations

Recommendation

Analysis of operational aircraft recorded braking performance

It is hypothesized that both clusters and branches of relationships exist between aircraft wheel braking data and exogenous features. Training a machine learning model to extract the relationships between contributing features and resultant degraded braking performance should extract these relationships.

- Gather and relate datausing established machine learning methods and links between databases
  - **Potential data usage**
    - NOTAM-FICON
    - Aircraft friction-limited braking
    - Aircraft raw parameters
    - Airport maintenance records
    - Weather data
      - ASOS
      - Weather radar
    - ADS-B
  - **Potential outcome**
    - Identifying observables that indicate wheel braking deficiencies
      - Quantifiable weather
        - Rain/snow rates/intensities
      - Runway construction/maintenance practices/standards
      - Reported depth of loose contaminants
      - Aircraft touchdown speed/runway length/FICON
      - Specific weather radar signatures
    - **Expect relationships that aren't currently identified**
    - **Expect relationships that are currently identified but not quantified**

White Paper Identified Gaps/Recommendations

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- **Expect relationships that aren't currently identified**
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- **Initial team has been identified**
- **Discussions have started**

White Paper Identified Gaps/Recommendations

Recommendation

Controlled-Condition Flight Testing

There is a need for a detailed study of the phenomena taking place where a runway starts to display properties that result in abnormally degraded aircraft wheel braking. Large scale database analysis and big data studies using exogenic sources may result in the development of predictive statistical models that could be used to more accurately estimate expected degraded wheel braking based on near real-time information on runway conditions. **However, the actual mechanism behind such a degraded braking anomaly is best determined by a detailed flight test program where variables of interest, including those which can only be obtained in controlled testing such as micro-/macro-texture, slope, water depth, etc. can be accurately measured and controlled.**

- **Needed resources**
  - **Access to an instrumented aircraft representative of a modern transport**
  - **Ability to control runway surface condition**
    - **Type and depth of water/contaminant**
  - **Runways which meet and do not meet FAA airport standards**
    - **Friction standards**
    - **Macro-texture, grooving, etc.**
  - **Potential airports are KACY and KWAL, Air Force/Naval facilities**
  - **Low utilized civilian airports which have appropriate weather conditions**

- **Potential Outcome**
  - Significant improvement on the contribution of specific runway traits to reduced wheel braking from currently expected values
  - Improved techniques to improve friction during winter operation
  - Improved ability to predict when an individual runway might go from acceptable to unacceptable in active precipitation conditions
    - Moderate to heavy snow
    - Moderate to heavy to extreme rain rates
    - Treated compact snow/ice

White Paper Identified Gaps/Recommendations

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- For wet runway, initial tests have been identified and prelim work is being performed.
- Request for Information has been released to the industry
- Responses due 23rd Aug.
- One received so far

White Paper Identified Gaps/Recommendations

Recommendation

International Standards Development

ASTM/SAPOE – ESDU Modeling of Wet Runway physics

The working group members should support participation in the SAPOE/ASTM standards effort for the collection and reporting of friction-limited aircraft braking information and as related to this a wet runway specific standard as being created by ESDU and used by FAR 25.109 and TALPA ARC ACs 25-31 and 25-32.

- **ASTM/SAPOE Effort**
  - Mapping of measured operational performance to TALPA braking levels in AC 25-32.
  - Current weakness is lack of truth information to prove accuracy of different systems.
- **Wet Runway –** current FAA model appears to have significant shortfalls. There are new wet runway models which show promise in accounting for runway traits
  - Macro-/micro-texture
  - Water depth due to drainage issues and heavy rain
- **Potential Outcome**
  - Consistency of measured operational wheel braking from system to system and with manufacturer provided performance data
  - Significant improvement on predicting when individual runways go from acceptable to unacceptable in active precipitation conditions
    - Moderate to heavy snow
    - Moderate to heavy to extreme rain rates
  - Improvement in prediction of when operator should be warned as to poor braking

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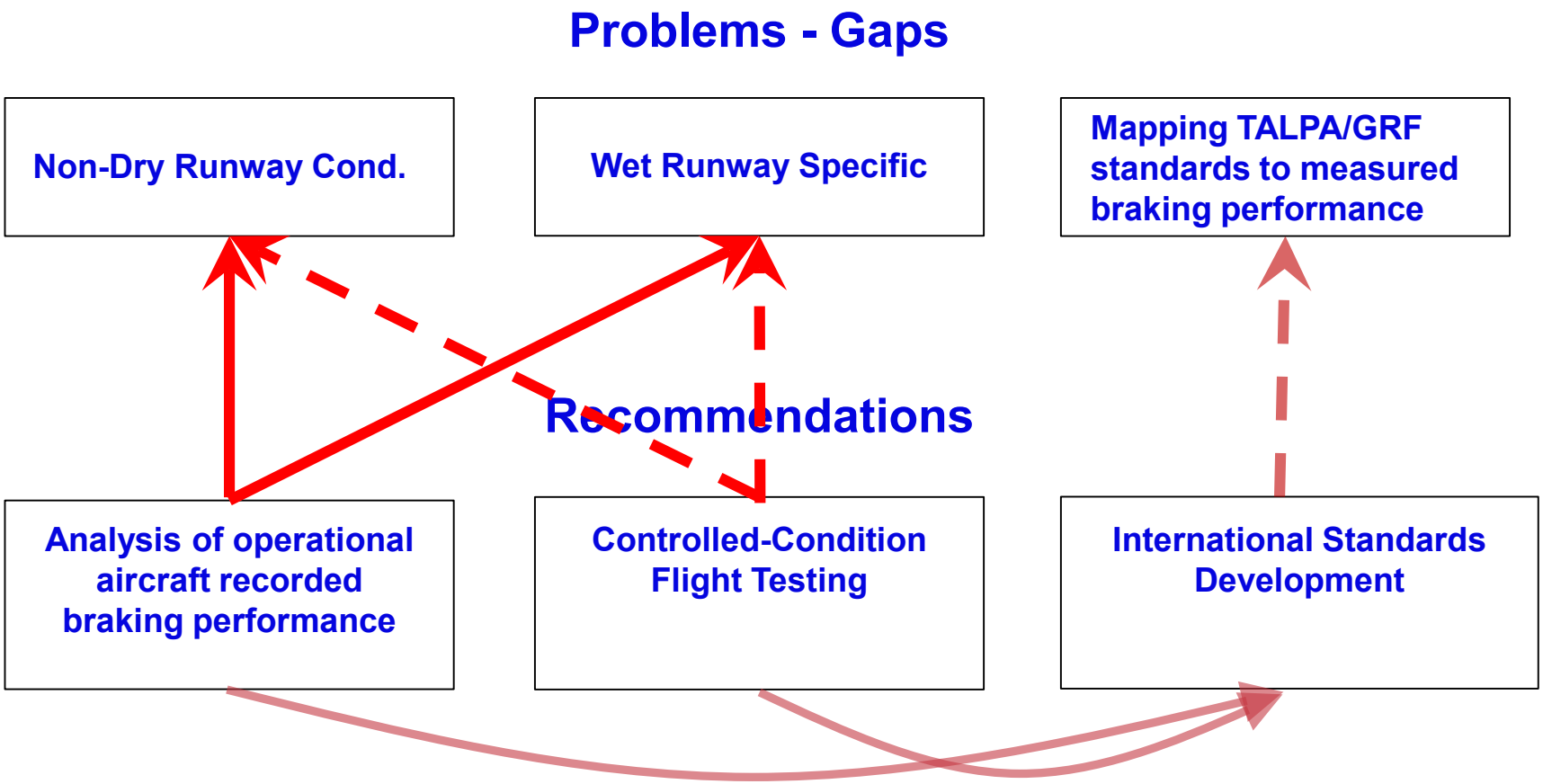
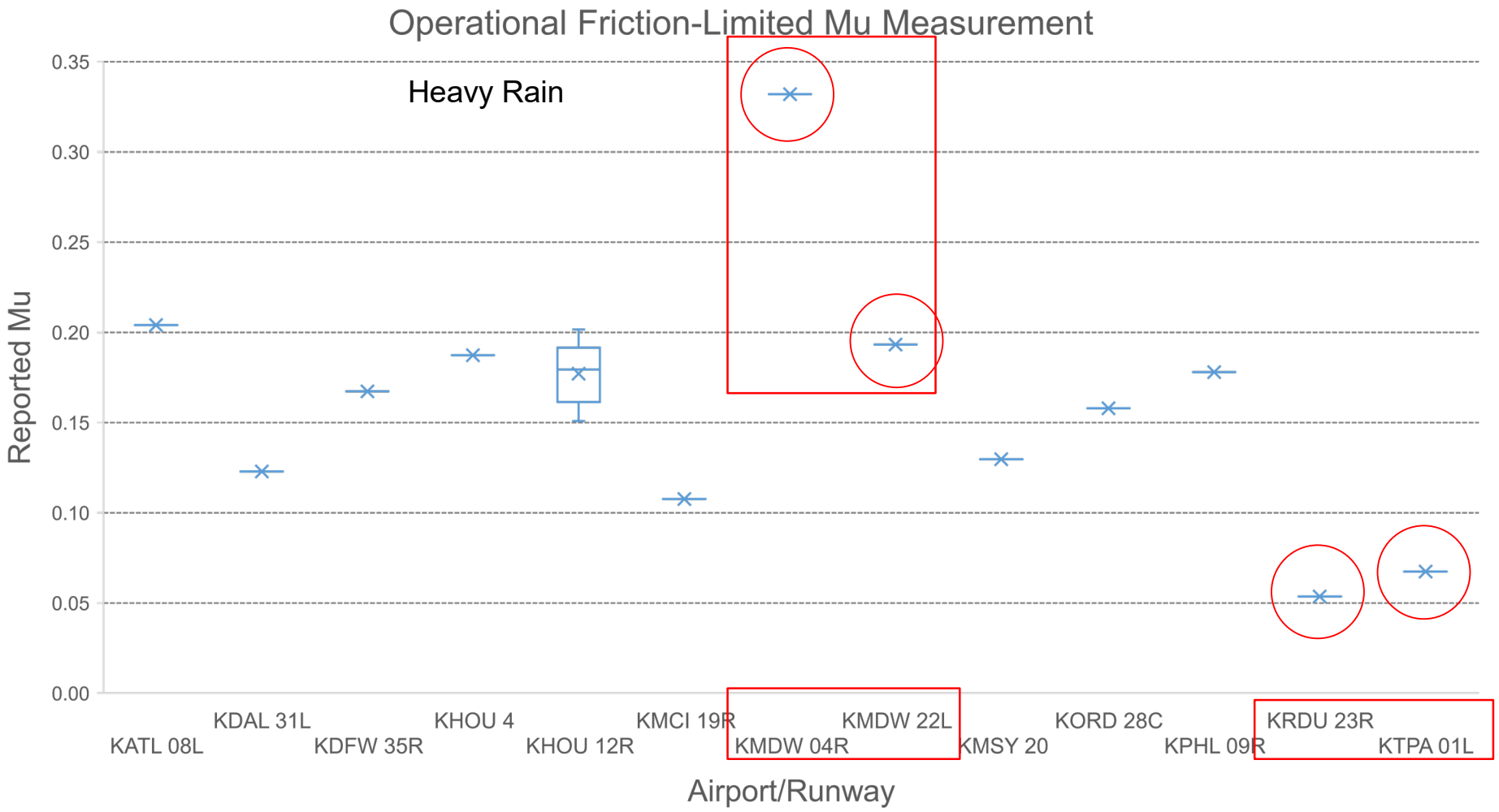
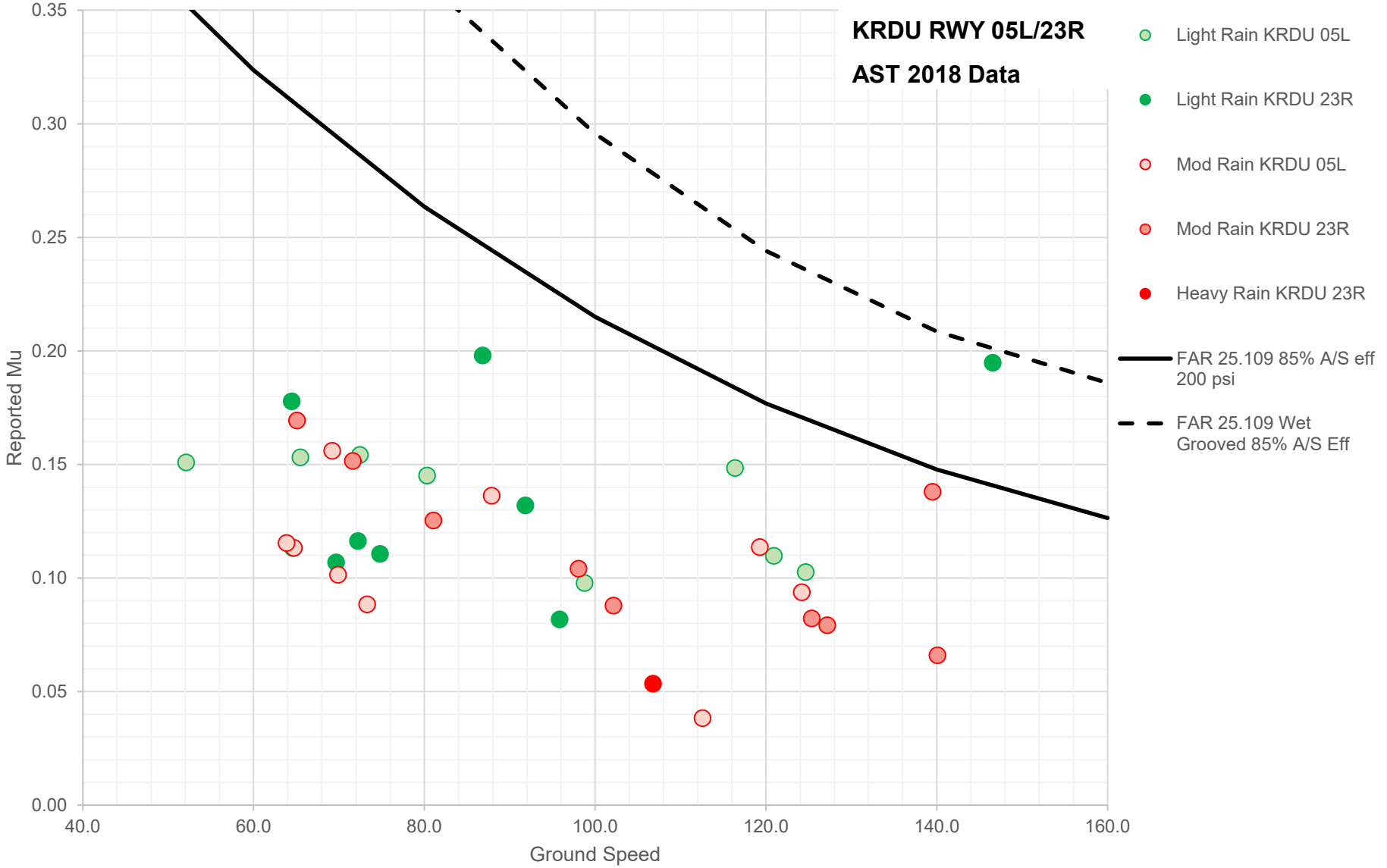
- **ASTM / SAPOE Group have been working for a year+**
- **Standard on terminology released**
- **Standard on methods of mapping measuring and mapping operational performance in work**
- **Wet runway specific – ESDU modeling will be evaluated based on first tests, way forward will be determined after that.**

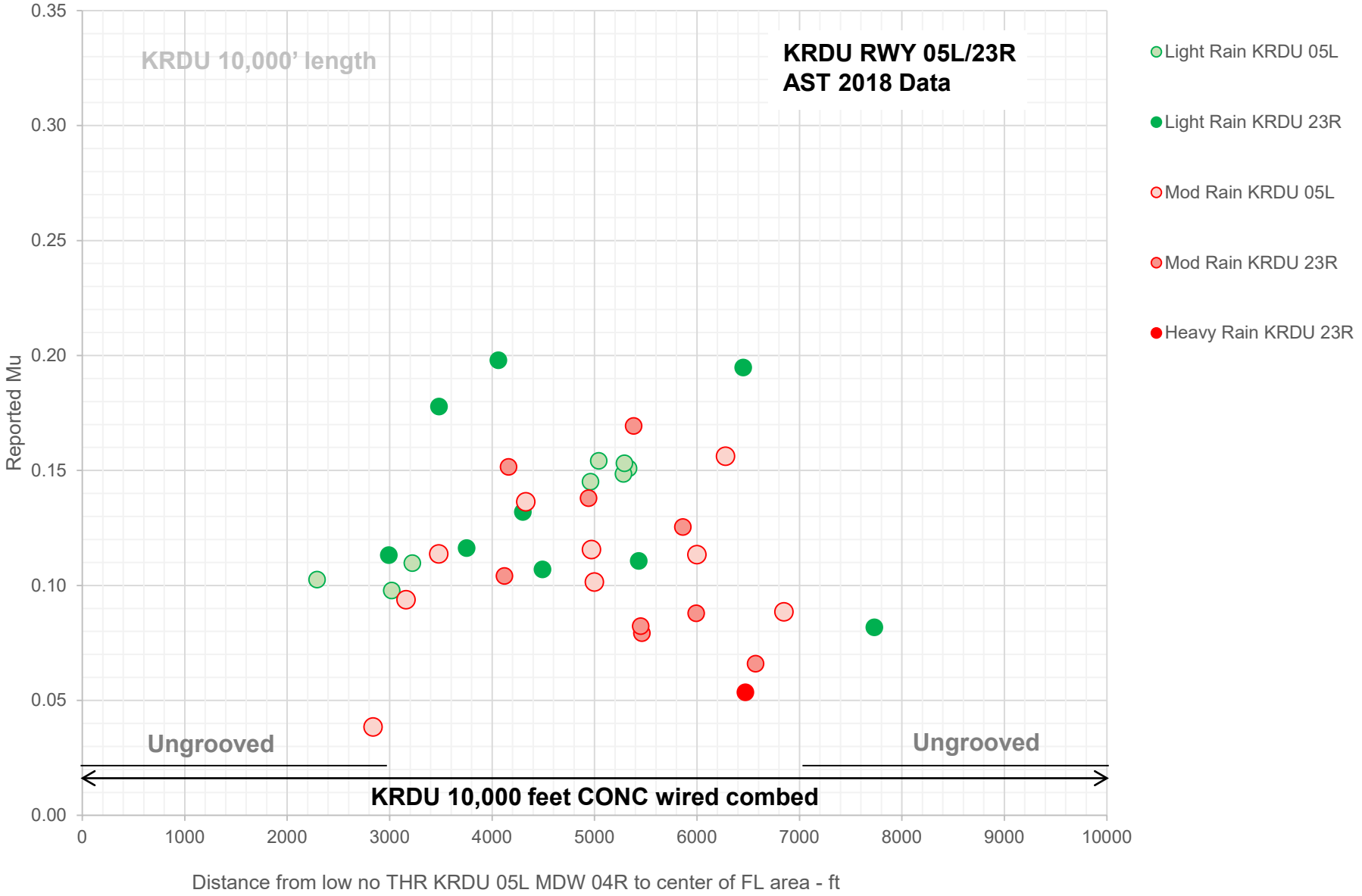
White Paper Identified Gaps/Recommendations

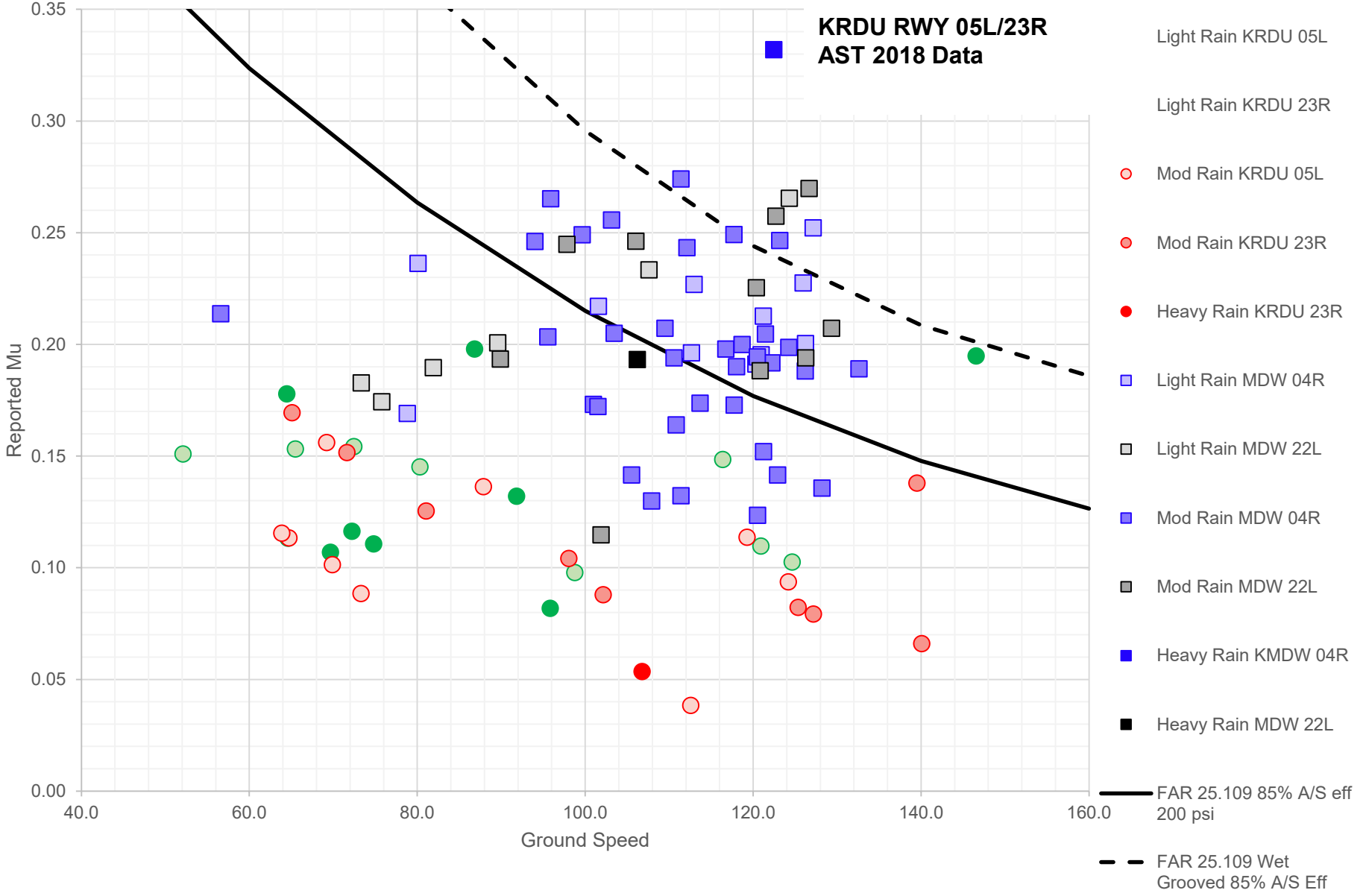


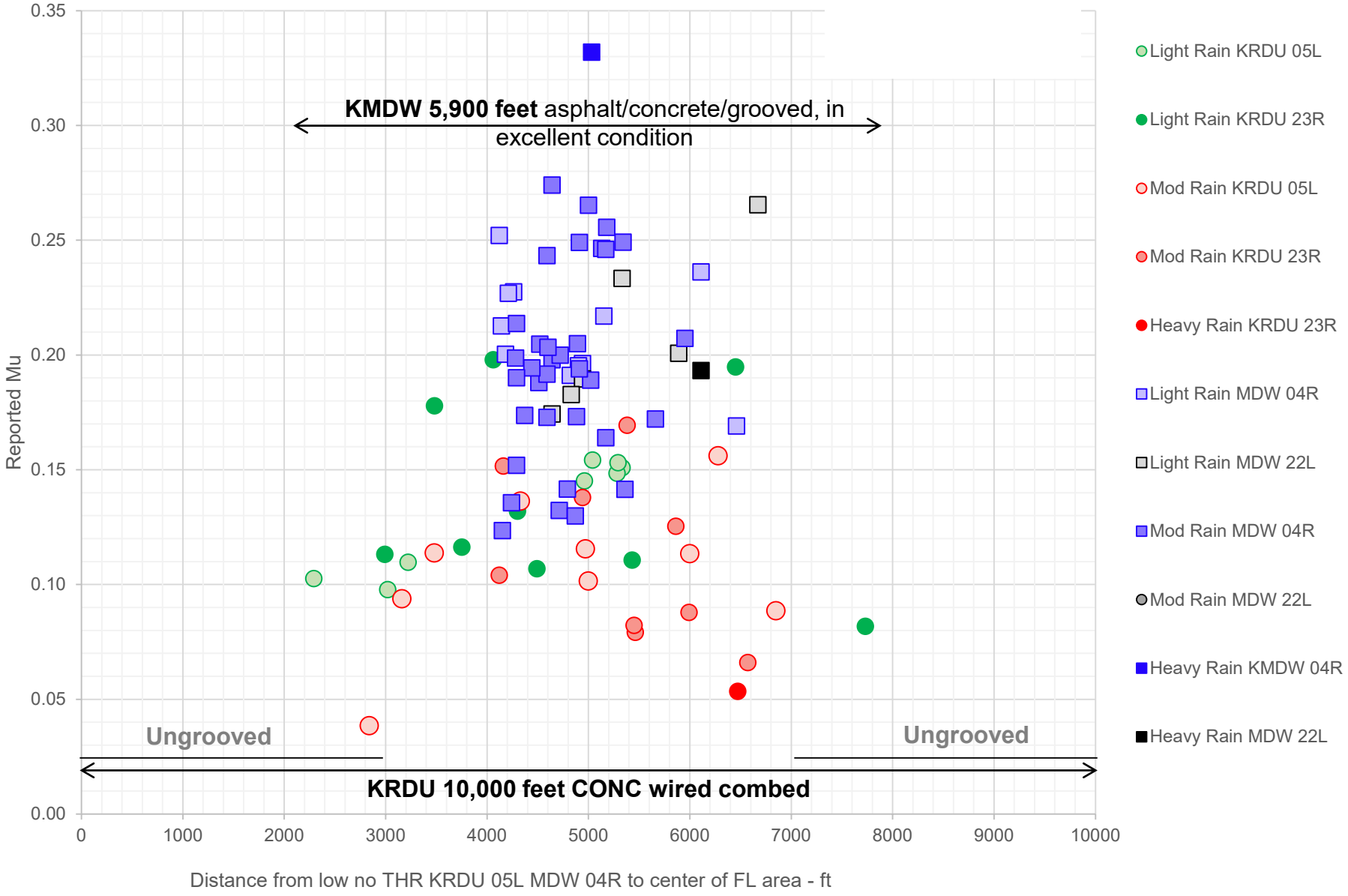
Discussion or Example Data?


Operational Friction-Limited Mu Measurement
Heavy Rain
Reported Mu
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
KATL 08L
KDAL 31L
KDFW 35R
KHOU 4
KHOU 12R
KMCI 19R
KMDW 04R
KMDW 22L
KMSY 20
KORD 28C
KPHL 09R
KRDU 23R
KTPA 01L
Airport/Runway


KRDU RWY 05L/23R
AST 2018 Data
Light Rain KRDU 05L
Light Rain KRDU 23R
Mod Rain KRDU 05L
Mod Rain KRDU 23R
Heavy Rain KRDU 23R
FAR 25.109 85% A/S eff 200 psi
FAR 25.109 Wet Grooved 85% A/S Eff
Reported Mu
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
40.0
60.0
80.0
100.0
120.0
140.0
160.0
Ground Speed

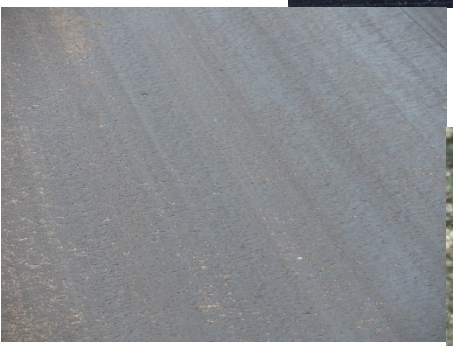

KRDU 10,000' length
KRDU RWY 05L/23R
AST 2018 Data
Light Rain KRDU 05L
Light Rain KRDU 23R
Mod Rain KRDU 05L
Mod Rain KRDU 23R
Heavy Rain KRDU 23R
Reported Mu
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Ungrooved
Ungrooved
KRDU 10,000 feet CONC wired combed
Distance from low no THR KRDU 05L MDW 04R to center of FL area - ft


KRDU RWY 05L/23R
AST 2018 Data
Reported Mu
Ground Speed
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
40.0
60.0
80.0
100.0
120.0
140.0
160.0
Light Rain KRDU 05L
Light Rain KRDU 23R
Mod Rain KRDU 05L
Mod Rain KRDU 23R
Heavy Rain KRDU 23R
Light Rain MDW 04R
Light Rain MDW 22L
Mod Rain MDW 04R
Mod Rain MDW 22L
Heavy Rain KMDW 04R
Heavy Rain MDW 22L
FAR 25.109 85% A/S eff 200 psi
FAR 25.109 Wet Grooved 85% A/S Eff

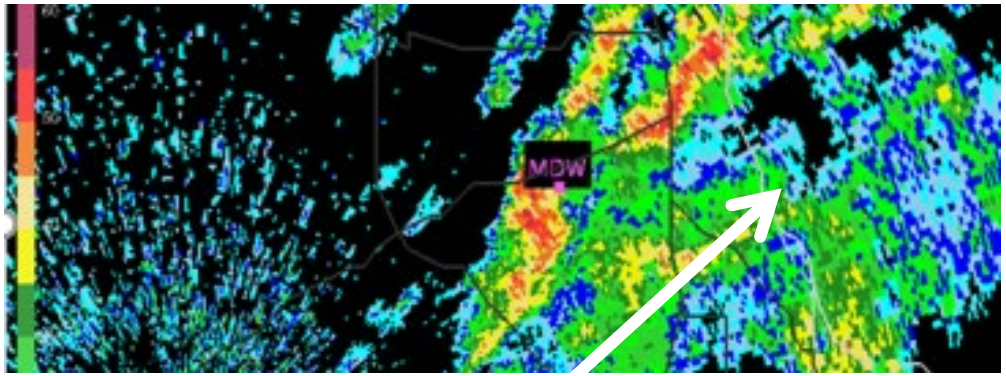

KMDW 5,900 feet asphalt/concrete/grooved, in excellent condition
Ungrooved
Ungrooved
KRDU 10,000 feet CONC wired combed
Reported Mu
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Distance from low no THR KRDU 05L MDW 04R to center of FL area - ft
Light Rain KRDU 05L
Light Rain KRDU 23R
Mod Rain KRDU 05L
Mod Rain KRDU 23R
Heavy Rain KRDU 23R
Light Rain MDW 04R
Light Rain MDW 22L
Mod Rain MDW 04R
Mod Rain MDW 22L
Heavy Rain KMDW 04R
Heavy Rain MDW 22L

- **What you do and don't know from previous data**
  - Rain Rate – do know general classification: -RA, RA, +RA
    - Don't know exact amount
      - Heavy is any thing above 7.6 mm/hr
        - » Could be 95 mm/hr (Toronto overrun)
        - » Could be 8 mm/hr
      - Moderate rain
        - » Could be 7 mm/hr
        - » Could be 3 mm/hr
  - Runway properties – Both concrete [one grooved, one wire combed]
    - Cross slope either % or runway profile [crowned or one direction]
    - Wind/Crosswind
    - Macro-texture
    - Micro-texture
    - Friction measurements
    - Age of runway, where in rubber removal cycle, local condition in the wheel tracks, etc.

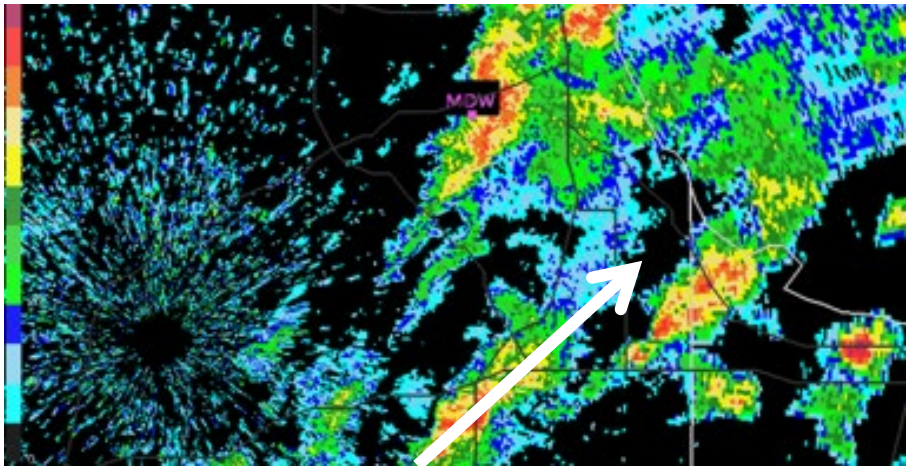
Questions/Comments



- 4.5 minutes - time of landing resulting in overrun:
- Rain rate ~ 10-15 mm/hr



Time of landing resulting in overrun
Rain rate ~ 10 mm/hr



Between the two images rain spiked to 20 to 30 mm/hr